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REAL PROPERTY OPERATION AND MAINTENANCE

MAINTENANCE AND OPERATION OF WATER SUPPLY, TREATMENT, AND DISTRIBUTION SYSTEMS

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DEPARTMENTS OF THE AIR FORCE, THE ARMY, AND THE NAVY

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MAINTENANCE AND OPERATION OF WATER SUPPLY, TREATMENT, AND DISTRIBUTION SYSTEMS

This publication provides technical guidance for operating and maintaining water supplies, treatment plants, storage facilities, and distribution systems at military installations. It covers water sources, pumping stations, unit operations of water treatment, safe drinking water act requirements, laboratory sampling and testing, recordkeeping requirements, corrosion control in water distribution systems, swimming pool operations, safety and health, and general maintenance. It applies to all personnel responsible for operating and maintaining fixed base water plants and systems.

The use of a name of any specific commercial product, commodity, or service in this publication does not imply endorsement by the military services.

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Chapter 1

INTRODUCTION

Section A—General Information

1-1. Command Responsibility. Operating and maintaining water treatment facilities and appurtenant equipment are a command responsibility. They are considered maintenance-of-installation functions.

1-2. Personnel Standards:

a. General Information. Using manpower in water treatment facilities effectively is important at all times for efficiency and economy, and is essential during periods of national emergency.

b. Number of Personnel Required. Military water treatment facilities vary so greatly in design, arrangement, and complexity, that establishing the number of personnel needed cannot be determined solely by installation population or water usage. During periods of peak demand, when additional personnel are needed, shifts should be scheduled so that they overlap, thus avoiding hiring additional personnel.

c. Operator Certification. Most states have statutes that require water treatment plant operators to be properly trained and certified. The Safe Drinking Water Act (SDWA) of 1974 (Public Law 93-523) requires all water treatment plants in states that have primary enforcement responsibility to comply with state statutes regarding water quality standards, operator training, and operator certification.

d. Training Needs. After an operator is certified, continual training is essential to maintain high standards of service, ensure efficient operation, and keep personnel informed of all current technical developments.

(1) All personnel must be made aware that the health and safety of those residing at the installation depend on their conscientious execution of their duties.

(2) Short courses or water treatment conferences should be attended periodically by all personnel who are involved in operating the installation's water treatment facilities. Such short courses and conferences are sponsored by state health departments, university extension programs, community colleges, and the American Water Works Association (AWWA). In addition, local training programs can be held on the installation with supervisory personnel conducting the training.

Section B—Elements of Water Supply System

1-3. General Information. Water supply systems of military installations must meet the qualitative and quantitative needs for both domestic use and fire protection.

a. Domestic uses of water include drinking, cooking, washing, bathing, sewage disposal, cleaning equipment, swimming pools, air-conditioning, and watering lawns.

b. The potential requirement of water for fighting fire is a critical factor in the overall planning of water shortage and distribution systems. The size and specific nature of the installation to be protected determine the quantity of water required for fire protection.

1-4. Water Supply Sources:

a. General Information. The potential sources of water for military installations (see figure 1-1) are deep wells, shallow wells, rivers, natural lakes, and reservoirs. Rain catchment and desalination are also potential water supply sources for specific installations. No two water sources are alike. Even those with the same origin may produce water of varying quality at different times. Each of these various water sources must be treated in a different way to achieve quality potable water.

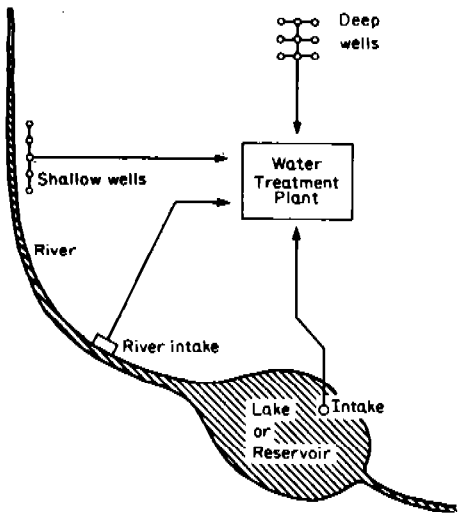


Figure 1-1. Common Military Water Sources.

b. Purchases Supplies. The best way to provide potable water at certain military installations is to buy it from a nearby municipality or private water company. However, the military installation often installs and maintains their own distribution and storage system that is directly connected into the water mains of the commercial source.

c. Ground Water Supplies:

(1) Source. Most ground water used for water supplies comes from rain or snow. The earth's water cycle, (see figure 3-1) depends on many events.

(a) The amount of water depends on several factors. Some of it is lost by direct evaporation or is used by plant life, later to be released to the atmosphere as water vapor. Some flows away as surface runoff. The remaining precipitation sinks deeply into the soil to become ground water reservoirs that supplies water to wells.

(b) Geological formations or strata from which ground water can be obtained are called aquifers. To be an aquifer, a geological formation must contain pores or spaces that can hold water and allow the water to move through them towards wells and springs.

(2) Occurrence and Character. In most parts of the world, potable water can be obtained by digging or drilling into the ground. In certain geographical locations, shallow holes only a few feet deep will produce water, while in other areas, it is necessary to drill over a mile to reach water-bearing formations. The chemical, physical, and bacteriological characteristics also varies greatly from place to place. Ground water quality is largely dictated by geological formations and contamination of aquifers. If these characteristics are such that they make the water unfit for potable use, it can almost always be treated with chemicals (if economics permit) to make it safe. However, the quantity of ground water at a particular place can not be changed. Often ground water can be found, but not enough to meet specific needs.

d. Surface Water Supplies:

(1) Source. The water found in lakes, rivers, and streams is referred to as surface water.

(2) Role of Surface Water in Domestic Use. Surface waters are a major source of domestic water. This is especially true for very large water demands because the cost of adequate ground water increases rapidly as the demand increases. Surface waters are also used when the ground water quality is unsuited for the use intended. The choice between using ground versus surface water is often determined by which costs less to produce a water of acceptable quality. In general, surface water supplies require more extensive treatment than ground waters.

(3) Types of Surface Water Sources. There are three major sources of surface water available for domestic water supplies:

(a) Continually flowing river sources can be used without reservoirs, if sufficient flow is available to meet the maximum demand of the installation.

(b) Streams and rivers not meeting the maximum demand require the construction of a reservoir to store water.

(c) Natural lakes also serve as reservoirs for domestic water supply.

e. Rain Catchment:

(1) General. Rainwater is used only in extreme cases as the source for domestic water supply and is generally confined to:

(a) Semiarid regions that are devoid of adequate ground water or surface-water supplies.

(b) Geographical areas devoid of surface water where the ground water is extremely hard or contaminated and treatment of the water required costs too much.

(2) Collection. The normal practice is to collect rainwater in concrete catchment devices located on the ground and to save the small amount that may be caught running off various buildings. The water flows by gravity through gutters and downspouts into underground storage tanks. Rainwater collected is proportional to the receiving area and the amount of precipitation. During dry seasons of the year some of the precipitation is lost through evaporation.

f. Desalination:

(1) Need for Desalination. Desalination of seawater is used too in areas where there is not enough surface-water, ground water, or rainwater, but where seawater or brackish water is found. Under these circumstances, costs become secondary.

(2) Availability of Seawater or Brackish Water. There are approximately 320,000,000 cubic miles of seawater and large amounts of inland saline water on the earth. The problem of obtaining freshwater from brackish water or seawater is essentially economics rather than technology. There are several methods of converting seawater to freshwater discussed in chapter 6, section J.

1-5. Pumping Facilities:

a. General Information. There are many different types of water pumping facilities. These facilities vary depending on their specific use.

b. Well Pumps. Well pumps include all types of pumps used to get water from wells and may discharge directly to a distribution system, to storage, or to a treatment plant.

c. Low-Lift Stations. Low-lift stations pump water from a surface supply to the intake of a nonpressure treatment plant.

d. High-Lift Stations. High-lift pump stations pump from gravity storage or other nonpressurized sources directly into the distribution system or through a pressure treatment plant. High-lift stations can be used in three different types of systems as demonstrated in figures 1-2 through 1-4.

e. Booster Stations:

(1) Booster pumping stations are generally installed to increase the pressure in a pipeline or in a specific zone in a distribution system to help meet peak demands (such as fire demands) and to supply water to elevated storage. Booster pumping stations are very suitable for a distribution system located in hilly topography where there are two or more pressure zones, or in the peripheral area of an overextended or overloaded distribution system.

(2) Booster pumping stations are very often automatically or remotely controlled from the main pumping station or the water treatment plant facilities. A variety of pump types may be used for booster service; but because most booster stations are located away from the main pumping station, the booster pumps should be electrically driven centrifugal pumps.

1-6. Water Treatment Facilities:

a. System Variations. Water treatment facilities vary from ground water supply chlorination to very sophisticated plants that use coagulation, sedimentation, activated carbon, lime-soda softening, filtration, fluoridation, and chlorination. This section gives a general introduction to water treatment processes and their applications.

b. Aeration. Aeration can be either a natural or mechanical process for increasing the contact between water and air.

(1) Water from deep lakes or reservoirs in the late summer and winter seasons, cistern water, water from deep wells, and distilled water may have an unpleasant or flat taste due to the low dissolved oxygen content. Aeration increases the dissolved oxygen content of such water

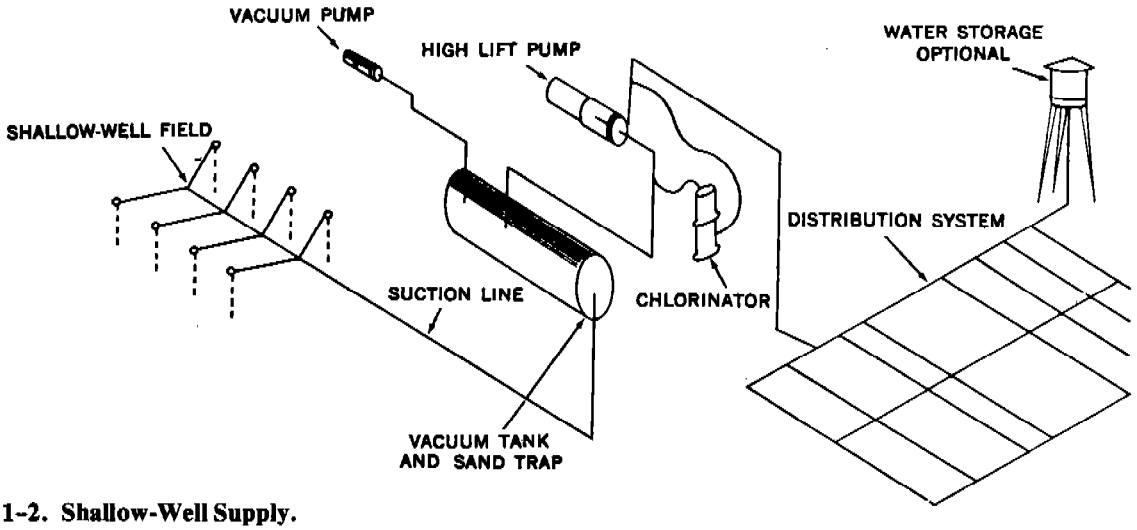


Figure 1-2. Shallow-Well Supply.

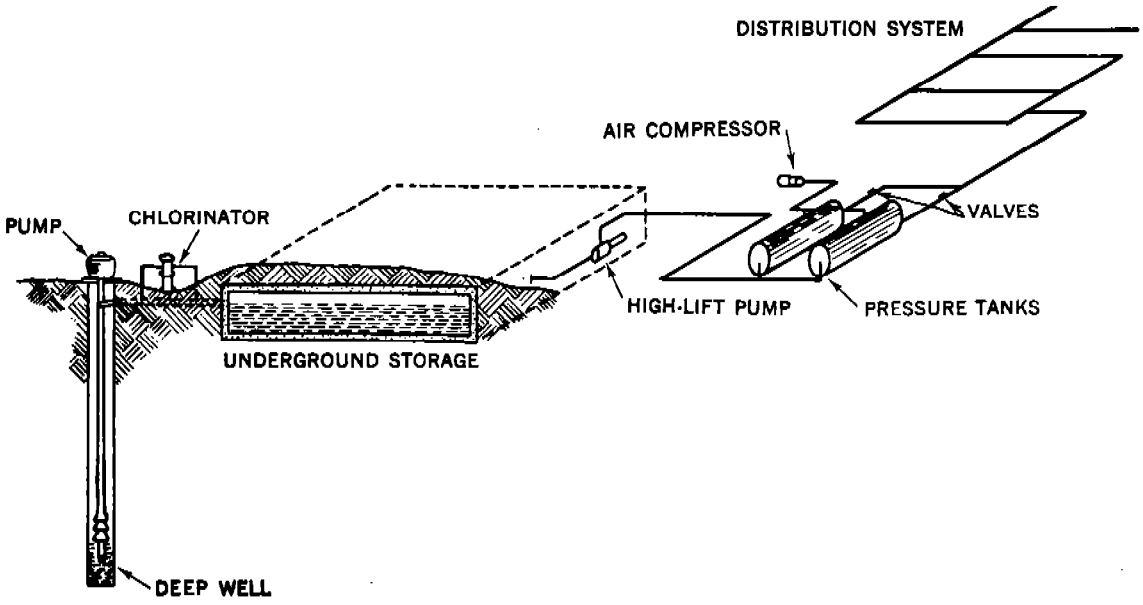


Figure 1-3. Deep-Well Supply.

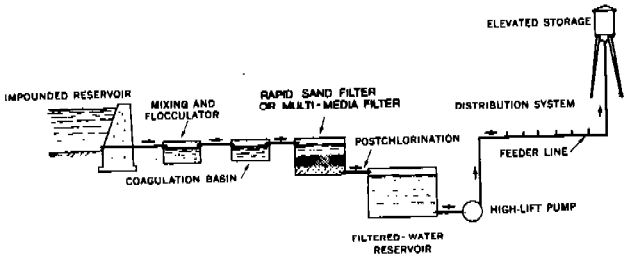


Figure 1-4. Treated Surface Supply.

and greatly improves its taste. However, the addition of oxygen makes the water more corrosive.

(2) Aeration aids in the treatment of water that has dissolved iron, because the oxygen oxidizes the iron to insoluble forms that can be chemically or physically removed. Aeration can also be used to remove volatile synthetic organic chemical compounds.

c. Carbon Adsorption. Activated carbon, available in powdered and granular forms, has large surface area per unit weight. Organic materials are attracted to the surface of the activated carbon. These materials are primarily used for taste and odor control and removal of volatile synthetic organic chemical compounds.

d. Coagulation, Flocculation, and Sedimentation. In raw water supplies heavy particles suspended in water tend to settle out quickly, but small lighter particles settle out very slowly, if at all. Coagulation and flocculation is the process of adding specific chemicals (coagulants) to the raw water. This brings the small nonsettleable particles together into larger, heavier masses of solid material, which consequently can be more easily removed by sedimentation.

(1) The first step in the coagulation process is to feed one or more chemicals into the raw water. Mechanical mixing is necessary to make sure that all chemicals are rapidly and evenly distributed throughout the water being treated. During the mixing process, and shortly afterwards, certain chemical reactions occur. Some of the reaction products are insoluble and precipitate from solution as solid particles. The term coagulation is used to refer specifically to these chemical reactions.

(2) The next step in the process, flocculation, is the gentle agitation of the treated water for a given period of time. During flocculation small floc particles collide with each other and other suspended particles in the water. These collisions cause the floc particles and suspended particles to stick together and grow into large particals which settle out.

(3) Sedimentation generally follows the process of flocculation. Sedimentation is the removal of floc from the treated water by gravity in basins specifically designed for this purpose.

e. Softening. Both surface and ground waters contain various amounts of dissolved minerals including calcium and magnesium compounds which are the primary cause of water hardness. When the water hardness is too high, it causes various problems (ranging from large soap demands for bathing and laundering to deposition of calcium and magnesium in water pipes and mains). Hardness in water may be greatly reduced by a chemical treatment process called softening.

(1) There are two general types of water hardness. The type present dictates the method of softening needed to remove the hardness. One type is carbonate hardness due to the bicarbonates of calcium and magnesium; the other type is noncarbonate hardness due to the presence of salts of calcium and magnesium such as chloride and sulfates, (excluding bicarbonates).

(2) Two major softening methods are chemical precipitation and ion exchange. Most large water treatment facilities use the chemical precipitation method for softening; smaller water treatment facilities and some industrial processes are most likely to use ion exchange.

(3) Lime or lime and soda ash is added to soften hard waters by chemical precipitation. The lime reacts with the calcium bicarbonate and magnesium bicarbonate to form insoluble calcium carbonate and magnesium hydroxide which precipitates out of solution. Noncarbonate hardness is removed by adding soda ash for calcium and soda ash plus lime for magnesium.

(4) Softening by ion exchange involves removing calcium and magnesium ions from water by exchanging them with other ions like sodium. Because calcium, magnesium, and sodium ions have a positive charge, they are all cations. Removal of calcium by sodium cation exchange continues only as long as there are sodium cations on the exchange medium. When all of the sodium has been replaced by calcium and magnesium, the softening capacity of the unit is lost and it is necessary to regenerate the exchange medium. Regeneration is done by passing a strong solution of sodium chloride (salt) through the exchange medium to replace the calcium and magnesium with sodium.

f. Filtration. When raw water supplies are passed through sand or other filtering media, suspended and colloidal matter are almost completely removed, chemical constituents are changed, and the number of bacteria in the water is reduced. These changes in water quality can be explained on the basis of four actions: mechanical straining, sedimentation and adsorption, electrostatic attraction, and to some degree, biological changes.

(1) Large particles of matter are removed by mechanical straining at the surface of the sand. Other particles are removed in the filtration bed at or near points of contact between sand grains.

(2) Sedimentation, adsorption, and electrostatic attraction between particles remove some small particles of suspended matter and bacteria. Small cavities among the sand grains act as miniature sedimentation chambers in which the earth's gravity, gravitational attraction between particles, and electrostatic charges from other particles cause suspended particles to settle out on the walls of these small cavities.

(3) A small percentage of suspended materials may be removed during sand filtration by biological degradation. Slow-rate sand filters are better for this type removal than other types of sand filters.

(4) Most filters use either sand or anthracite as a medium for filtration. The water is brought through the filter by either gravity or pressure. The two basic types of gravity filters are slow and rapid-rate filters. Pressure filters use either sand or diatomaceous earth as a filter media and are usually limited to smaller water treatment facilities.

g. Iron and Manganese Removal Processes. Iron and manganese may be found in water supplies as soluble or insoluble compounds. Both iron and manganese appear more frequently in well-water supplies than in surface-water supplies. The soluble iron and manganese compounds are found in water supplies were dissolved oxygen is absent

or in very low concentrations.

(1) Water low in dissolved oxygen converts iron and manganese in the insoluble (oxidized) state into the soluble (reduced) state. In the soluble state, iron and manganese are colorless in the concentrations generally found in water supplies. When iron and manganese come in contact with air or chemical oxidizers they are converted to the insoluble state. In concentrations as low as 0.3 mg/l these compounds discolor water and even stain clothes and fixtures.

(2) There are four basic methods for removing or sequestering iron or manganese in a water supply:

(a) Oxidation. Aeration may be followed by sedimentation and filtration or in some cases by filtration alone. Chlorine or other strong oxidants may be used to replace air as the oxidizing agent.

(b) Lime and Lime-Soda Softening. This process precipitates iron in an insoluble form for removal by sedimentation and filtration.

(c) Ion Exchange. Both iron and manganese compounds in a soluble state may be reduced to acceptable limits by ion exchange water softening.

(d) Iron Retention. Soluble iron compounds may be stabilized or sequestered by adding polyphosphates or organic sequestering agents.

h. Demineralization. Demineralization is the complete hydrogen ion exchange for all cations (positive charged) and complete hydroxyl ion exchange for all anions (negative charge). Demineralization can be used for treating water for specific industrial processes, laboratory uses, and small water treatment facilities.

i. Fluorides. Statistics show that fluorides in public water supplies can reduce cavities in children and young adults. Depending on the temperature, a concentration of 0.7 to 1.2 mg/l of fluoride in the final water supply has been found to be an effective dosage. Fluoride ions, naturally or artificially present in drinking water, are absorbed into the bone structure of the body, including the tooth enamel. Excess fluoride content causes tooth mottling and pitting of tooth enamel and possible loss of teeth. Fluorides should be controlled by addition of fluoride ions by dry- or solution-feed equipment or by defluoridation if the natural fluoride level is too high.

j. Disinfection:

(1) Public water supplies are disinfected to kill pathogenic (disease-producing) organisms and thus prevent waterborne disease. The disinfection of public water supplies is not a substitute for other forms of treatment that may be needed. The disinfection process requires sensitive feeding equipment that needs close monitoring by skilled water treatment plant operators to avoid breakdown and incorrect dosages.

(2) Disinfection may be done by chlorination, ozonation, ultraviolet radiation, boiling, bromination, and iodination.

k. Use of Proprietary Compounds. Commercial firms frequently offer under trade names ready-made mixtures of chemicals for water treatment. At best, they may consist of one or more of the well known chemicals commonly used for water treatment, and may contain the appropriate chemicals for the particular water being treated. However, these compounds are fixed chemical mixtures and there is no way to adjust the proportion of individual chemicals to maintain the desired concentrations of each. In addition, the compounds usually are much more expensive than the chemicals bought individually by their generic name. Some compounds contain chemicals that are not suitable for the particular water being treated; sometimes, they contain chemicals that actually damage equipment. Other compounds are composed of chemicals that have virtually no effect. Operators should never use any chemicals without knowing its specifications, physical properties, and application.

l. Deposit and Corrosion Control. Corrosion control techniques include cathodic protection and protective coatings. These methods are external to the water treatment process, whereas chemical treatment methods are a part of the process itself. Chemicals such as phosphates and silicates are added to the water to control deposits and corrosion. The pH, hardness, and alkalinity of the final treated water must be in proper relationship to prevent corrosion or scale deposition in the distribution system.

1–7. Distribution and Storage Systems:

a. General Information. A distribution system is a network of pipes (including necessary valves, hydrants, and distribution reservoirs) that carry water from the point where it is obtained, stored, or treated to the points where it is used. The system must deliver enough water to meet the normal maximum demand at all points of use. All the pipes should be large enough to allow for reasonable growth of the system and normal reduction in capacities due to aging. The distribution system must also deliver sufficient water to provide the required fire flows at all points within the distribution system. Because fire flows are always the greatest demand, the amount of water required for fighting fires usually controls the pipe sizes in the system.

b. Mains and Piping. The mains and piping of a water treatment facility are usually divided into the following four groups:

(1) Arterial mains, supply distribution mains, and storage tanks.

(2) Distribution mains are the pipelines that make up the distribution system, including any arterial mains from which service lines take their supply.

(3) Service lines connect individual building plumbing to distribution mains.

(4) Supply lines connect the source of supply to the water treatment facilities. In a strict sense, these are not a part of the water distribution system, because untreated water is never allowed to enter the distribution system itself. Often, such lines are termed transmission lines.

c. Storage Tanks. Public water supplies are stored to equalize the daily pumping rates; to equalize the supply and demand of potable supplies; and, to provide ample water supplies for emergencies such as firefighting or accidental breakdowns. Storage tanks are divided into the following classifications:

(1) Elevated storage tanks store water at elevations (towers or high ground) approximating that of the normal hydraulic gradelines.

(2) Ground storage tanks store water at or near ground level. Ground storage requires a pumping station to transfer water from the ground level tanks directly into the distribution system or elevated storage.

(3) Pneumatic storage tanks are pressurized tanks, at or near ground level, which are partially filled with compressed air to keep pressure in the distribution system.

(4) Emergency reservoirs are small ground storage tanks which are filled from the distribution system and located in strategic areas for firefighting if the water supply system fails.

d. Valves and Hydrants. Valves and hydrants are integral pieces of equipment that must be installed in a distribution system. Typical valves and hydrants used are:

(1) Gate valves in arterial mains and distribution grids for isolating sections of the system for repair.

(2) Pressure-reducing valves on service connections to prevent excessive pressure in installation areas of relatively low elevation.

(3) Check and backflow-prevention valves in distribution systems to prevent reversal of flow.

(4) Curb stops to isolate service connections.

(5) Fire hydrants, standard type for normal street use and flush type (pit-mounted) for airfield apron use.

e. Reservoirs. Water storage reservoirs are used with water treatment facilities to impound water, store water, equalize flow rates, and to equalize pressures in the distribution system. Reservoirs used to store water are termed storage reservoirs. Those used to equalize flow rates are called equalizing reservoirs. Reservoirs used to equalize pressure on a distribution system are known as distribution reservoirs.

Section C—Reports and Records

1-8. General Information. It is important to set up a workable records and reports system. This requires careful planning, close supervision, and persistent effort if maximum benefits are to be gained.

a. All personnel responsible for operating a water supply system must have an adequate knowledge of the system and all its parts. They must know what to expect in the way of fire-flow demands in various areas, and how to meet those demands. They should know why the failure of any part a system or its equipment affects other parts of the system. Reports and records provide the basis for such knowledge of the system.

b. Operating personnel must also be familiar with manufacturer's catalogs, brochures, and instruction manuals for all installed equipment. Shop drawings provide detailed, specific information about the actual equipment the operator must work with each day and should be used with maintenance manuals to get the most efficient operation, maintenance, and repair of plant systems.

c. Water supply personnel must also be familiar with all local command directives.

1-9. Daily Logs. Daily logs of plant operation are extremely valuable in preparing monthy operating reports that are required for internal review, regulatory agency review, and in maintaining efficient operation. Analysis of such records reveals the need for any necessary changes in operation of the water treatment facility. Record-keeping requirements to comply with the SDWA are in applicable service component regulations (see paragraph 1-19). These regulations are compatible with requirements in EPA regulations.

1-10. Monthly and Yearly Operating Reports:

a. Each installation's water treatment facility prepares a monthly report compiled from daily operation data reports. Monthly reports permit technical review of current performance and comparison of performance over a long period. Accumulated monthly reports show variations due to changes of seasons, methods of operation, and installation population. A review of monthly reports can also show whether design of the system needs modification to fit certain conditions.

b. Forms used for preparing the monthly operating record are as follows:

(1) AF Form 1461, Water Utility Operating Log, NAVFAC Form 11340/2, Potable Water Treatment Plant Operating Record, or DA Form 4141, Water General, is the basic operating record which must be completed at each installation.

(2) AF Form 1460, Water Utility Operating Log (Supplemental), NAVFAC Form 11330/6, Potable Water Supply and Distribution Operating Records, or DA Form 4374, Water Supplementary, is used with the forms mentioned in (1) above at installations that have treatment in addition to disinfection, fluoridation, or treatment for scale and corrosion control.

c. The yearly operating report must be easy to read, factual, informative, and comprehensive. Statistics are required, but should be kept to a minimum. The data presented in each yearly report may be continued indefinitely to permit comparisons with other annual performances.

1-11. Maps and Records:

a. General Information. Rapid adjustment of waterflows to meet emergency fire-flow needs is an important phase of water treatment operation, but speed is impossible without good maps and records to show locations of controlling valves. Repairs and extensions to underground portions of the system are difficult and time consuming without accurate maps. Drawings of well construction are needed for maintenance and control of production. Therefore, as-built maps and drawings must be prepared for all new construction. Any errors found in existing maps should be corrected at once.

b. Symbols. The symbols shown in figure 1-5 have been universally adopted to ensure uniform, easily interpreted distribution maps. Personnel preparing distribution maps must follow these symbols exactly.

c. General Water Utility Map:

(1) The general water utility map is a diagram of the

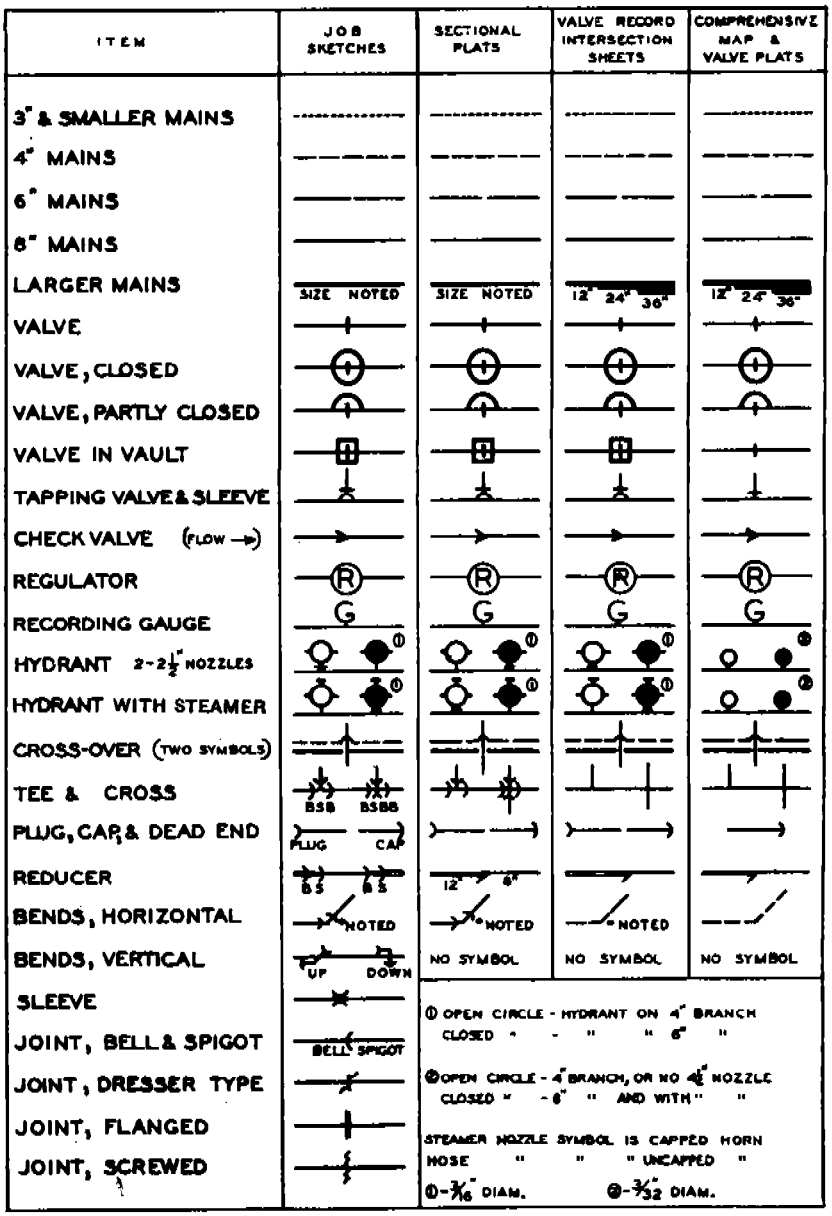


Figure 1-5. Water Distribution Symbols.

entire water supply system. It can be prepared by tracing the outlines and essential information from an installation map. The scale should not be smaller than 1 = 5,000. For small installations a scale as large as 1 = 2,000 may be practical.

(2) The map should include the street names, sizes of mains, fire hydrants, valves, sectional plat limit lines, orientation arrow, scale, and date last corrected. Mains are shown by different types of lines and line widths to show relative sizes and make relative carrying capacity easy to see. The map should clearly show areas that are adequately piped, those that do not have the proper size mains, and those where improvements are needed (such as short extensions to eliminate dead ends). Detailed street, road, and building lines are not included on the map; however, where such lines help identify locations, they may be drawn lightly. A section of a general water utility map is shown in figure 8-1.

d. Detailed Utility Map:

(1) A detailed utility map is a consolidated map of all utility systems on the installation. Because it clearly indicates the relative locations of all systems, it helps maintenance personnel avoid damaging one under ground system when working on another. The scale for the map should be from 1 = 500 to 1 = 1,000. At a congested intersection, inserts at a larger scale may be needed to show all data clearly.

(2) Information needed to make the map complete includes plat designation or number, adjacent plat numbers, street names, mains and main sizes, materials of mains, year each main was installed, valves and valve number, fire hydrants and fire hydrant numbers, building numbers, measurements to service lines, distance from main to curb stop, date last corrected, orientation arrow, and scale.

e. Gate Valve and Hydrant Record. A master print should be prepared for each valve and hydrant, giving in-

formation on valve and hydrant location; direction and number of turns to fully open gate valve; size of valve and hydrant; date installed; and manufacturer and model number. Enough copies of each print should be made to provide a full set of gate valve and hydrant records for all key distribution system personnel. Air Force personnel use AF Form 995, Gate Valve/Hydrant Record, to record this information.

f. Hydrant Record. Manufacturer's data for each type of hydrant should be obtained, filed, and referenced by hydrant number. The information should be maintained and updated as required.

g. Pumping Station Diagram. A schematic diagram for each pumping station should be provided showing all major piping and control valves in bold lines, as well as indications of source of supply, direction of flow and point of discharge piping, and the purpose and identifying number of each valve. Mount the diagram on the pumping station wall as guidance for operators and, in emergencies, for personnel not familiar with the layout.

h. Structural Plans. Keep copies of structural plans of treatment plants, pumping stations, reservoirs, elevated tanks, and meter and valve vaults available for immediate use.

i. Well Records. Well records show decreases in yield or increases in drawdown, and help to show the cause. Well records should be completed when the well is built and the records brought up-to-date when the well is tested. All well data are kept on file and used for reference when well repairs are made or when other wells are constructed in the area. Use prescribed forms for recording general well data, as well as pumping test results. Air Force personnel use AF Form 996, Well Data, to record this information.

j. Record Files. Maintain and file record plans and drawings according to military procedures so they will be convenient and accessible for other water treatment personnel.

1-12. Stock Control. Sufficient types and quantities of materials and stock should be kept on hand to ensure practical, economical, and continuous service.

a. Expendable Stock. Stock levels for expendable items used at a fairly uniform rate (such as pump packing, treatment chemicals, and laboratory reagents) are based on maintenance experience and operating reports. However, levels may be modified for reasons of economy. Thus, savings can sometimes result if treatment chemicals are bought in large lots.

b. Standby Items. Seldom used materials needed to safeguard health, ensure uninterrupted operation of installation facilities, or prevent destruction or property are classed as standby items. Typical examples are chlorinator parts like a spare flowmeter, auxiliary chlorine valves, and cylinder connections. Materials to be stocked as standby items are held to a minimum, based on a detailed study of the water supply system. The following should be considered in setting up stocks of standby items:

(1) Noncritical immediately available from nearby installations, municipalities, or supply houses are not stocked. Critical parts should be stocked.

(2) Much repair work at pumping stations and treatment plants can be anticipated and parts for these repairs secured when needed.

(3) Only major sizes of pipe and fittings are stocked in large amounts.

(4) If the plant has several similar units, parts that are interchangeable need not be stocked for each unit.

(5) As soon as an item is drawn from standby stock, a replacement is ordered.

c. Supply of Material. Stock levels must be watched closely and essential materials ordered far enough in advance to ensure continuous service. Supervisors must be familiar with normal and alternate sources of supply and the time each source usually needs to make delivery. They must follow up orders and help supply personnel find alternate supply sources if delivery is delayed. Supplies will be obtained according to normal supply procedures.

1-13. Cost Accounting:

a. Cost accounting is to determine the actual cost of specific features of operation and maintenance, provide a unit of work measurement called base data, and to provide a basis of cost comparison called unit cost (cost divided by base data).

b. Waterworks supervisors are responsible for making sure that their labor and materials costs are charged to the proper waterworks accounts. They must be thoroughly familiar with the account description and help accounting personnel properly apply these accounts to the installation waterworks system. They are responsible for providing the base data. When these data are in terms of gallons of water produced or consumed they must agree with operating reports. Data, in terms of fixed quantities such as linear feet of mains and services, must be corrected when alterations or additions are made to the system.

c. Waterworks cost data enable supervisors to find where savings can be made. Analysis of cost data point out deficiencies in preventive maintenance procedures, indicate need for changes in operating methods, show results of improved operation and maintenance, and form justification for self-amortizing improvements to the system. Plotting the monthly waterworks costs and budget allowances gives a continuous picture of efficiency and shows variations caused by season, population served, and other factors.

Section D—Emergency Protective Measures

1-14. Emergency Requirements:

a. As defined in the American Waterworks Association Manual—M19 on emergency planning, "A disaster is an event, natural or man-made (sic), which is concentrated in time and space, and which causes a community or a specific subdivision of a community to suffer danger or disruption of normal functions." Natural disasters include earthquakes, hurricanes, tornadoes, and floods; disasters made by people are events such as riots, strikes, and bomb blasts.

b. Health and fire protection are so dependent on a safe, adequate water supply that measures for protection of the system and plans for emergency operation are basic responsibilities of the water treatment facility supervisor. The supervisor is also responsible for making sure that operating and maintenance personnel are fully trained in these protective emergency measures. Emergency water supply operations must be well planned. The plan must be kept current, establish standard operating procedures for alerting water supply personnel, and clearly explain the duties of each individual.

1-15. Emergency Planning Procedures:

a. General Information:

(1) The first task is to determine through command channels what type of disaster is most likely to affect your facility, and plan accordingly.

(2) The goal of the plan is to provide for the earliest possible restoration of water service to essential activities in a prescribed order, and at the same time provide for sufficient water to meet minimum health and sanitation requirements.

(3) Personnel must be trained in specific functions and duties; they must know where to report and what to do. Emergency crews should be organized and trained to work as a complete unit. While volunteers may be of some help in emergencies, they should not be relied on to perform principal waterworks duties. Personnel who are responsible for operating water supplies and equipment must have adequate knowledge of:

(a) The physical plant, including characteristics, size, capacity, location, operation, and maintenance.

(b) Current inspection status of pumps, motors, engines, chlorinators, indicating devices, controls, valves, water sources, storage and distribution facilities, fire hydrants, and connections.

(c) Availability of water and effect of fire flow drain on the supply system; alternate and emergency methods for obtaining supply; and effect of failure of each unit of equipment on other components of the system.

(4) The plan must be coordinated with other interested services and agencies (such as the medical, fire prevention, transportation, and supply services). The probability of water contamination must be anticipated. Emergency procedures that deal with contamination and disinfection must be developed in conjunction with medical personnel.

(5) Accurate and complete distribution system, sectional, and valve location maps must be prepared and kept current. A schematic diagram of all plumbing station layouts, piping, and equipment must be posted for operating reference.

(6) Arrangements must be made to provide additional transportation service for hauling personnel, equipment, and materials during emergencies.

b. Supply Sources. The following are minimal procedures to follow during an emergency to protect the installation's raw water.

(1) Select auxiliary supply sources that are adequate. Set up a procedure for connecting them into the system in an emergency and disconnecting them as soon as the emergency is over.

(2) Provide protection against flood damage by sandbagging or the construction of temporary earth levees.

(3) Check the possibility of contamination or pollution caused by domestic or industrial wastes entering the source of supply and take steps either to eliminate such hazard or provide for adequate treatment.

(4) Check for improper well construction (such as pumps or motors in a subsurface pit) or inadequate sealing against pollution, and correct unsafe conditions.

(5) Test purchased water supplies periodically to make sure that they are adequately chlorinated.

c. Pumping Plants. Provide standby power for the pumping plant using internal combustion engines that can be put into immediate service when needed. As an expedient, a salvaged vehicle engine or the power-takeoff pulley on a tractor can be belt-connected to the pump.

d. Treatment Plants. Procedures outlined below are essential to execute an emergency water treatment program.

(1) Make a study of the treatment plant and operating procedures to determine points that would be critical in an emergency. Thus, plant capacity may be limited by a single unit. Providing a standby unit of that type may facilitate emergency operation. Inadequate treatment due to damage to certain units can usually be offset by increasing the chemical dosage, producing safe water at the cost of lowered efficiency.

(2) Provide and maintain standby or portable chlorinators in working condition for emergency chlorination.

(3) Keep an emergency supply of hypochlorite on hand.

(4) Protect intake and suction lines in the plant against entrance of foreign objects that might plug the lines or damage equipment.

(5) Set up a procedure for chlorinating auxiliary water sources.

(6) Check chlorine residuals in the distribution system frequently and adjust plant dosages as needed. Residuals above normal requirements may be justified in an emergency.

(7) Chlorinate all equipment when it is first installed and after repairs.

e. Distribution System. The distribution system should be handled in the following way when planning and executing emergency procedures.

(1) Check the distribution system and supply lines carefully to see whether they can supply critical areas with enough water to fight fires, despite power or main failure at any point. Make plans for providing temporary duplicate supply facilities at critical points.

(2) Check into adding valves in the system to localize areas that would be affected by failure of a single main.

(3) Carry adequate stocks of essential repair parts. To keep repair stocks at a minimum, carry standard-size valves and sleeves. Stock reducers to adapt standard-size fittings to all piping in the system.

(4) Check with neighboring installations and munici-

palities on the availability of manpower, materials, and equipment that can be borrowed in an emergency.

(5) Inspect all valves, hydrants, pressure regulators, and other equipment, and consider increasing inspection frequency for critical points. Make immediate repairs where needed. Valves and hydrants are essential parts of the system and must be tested periodically and kept in good working order.

(6) Maintain complete and accurate maps and records. Make sure that copies of maps and records used by maintenance and operating personnel are not made available to unauthorized persons.

(7) Check carefully for improper connections that are health hazards. These include cross connections between the water system and any unsafe or unapproved systems; direct connections with the sewage system; and direct connections with dishwashing equipment, hospital sterilizers, or urinals.

(8) Make leak and flow surveys at periodic intervals to determine system efficiency. Data should be sufficiently complete to determine additional changes and improvements required for emergency conditions.

f. Repair Tools and Equipment. Adequate supplies of repair tools, shoring, bracing, and emergency equipment such as floodlights and small air compressors are essential. If the necessary tools and equipment are not on hand or available from the supply sources on the installation, check on procuring them from neighboring installations or communities.

Section E—Command and Technical Inspections

1-16. Installation Command Inspections. Installation engineers should make sure that formal or informal inspections or spot checks of the water plants and systems are made to determine their general condition and the efficiency of personnel. These inspections should be thorough enough to reveal major faults, neglect, and carelessness.

1-17. Installation Technical Inspections:

a. Purpose of Technical Inspections. The installation civil engineer is responsible for technical inspections that should include inspection of the physical condition of the plants and systems, the quality of water produced, the effectiveness of the preventive maintenance program, and the need for additional training of operation and maintenance personnel. Such inspections should be made by technically qualified personnel.

b. Scope of Technical Inspection. Technical inspections should be made of all major functional structures and items of equipment or portions of systems selected at random. They are usually made without prior notice, except when maintenance schedules or conditions require disassembly of equipment or draining of tanks. Technical inspections include:

(1) Checking preventive maintenance forms to make sure scheduled inspections and preventive maintenance services have been completed.

(2) Determining whether all required shop-type maintenance noted on the operator's preventive maintenance record has been completed.

(3) Noting fequency of shop-type maintenance repair.

(4) Inspecting individual units (use scheduled inspection items in this manual as a guide).

(5) Checking loading and operating conditions carefully (give consideration to possible need for revision of maintenance service and inspection schedules to fit local conditions where shop-type maintenance or repair requirements have been abnormal.)

Section F—The Safe Drinking Water Act (SDWA)

1-18. Drinking Water Regulations. The Safe Drinking Water Act (SDWA) (Public Law 93-523) directs the EPA to promulgate national primary and secondary drinking water regulations. Primary drinking water regulations, published as Title 40, Code of Federal Regulations (CFR) Part 141 (40 CFR 141), include federally enforceable maximum contamination levels (MCL) for protection of health plus monitoring, record-keeping and reporting requirements. Secondary regulations, published as Title 41, Code of Federal Regulations (CFR) Part 143 (41 CFR 143), contain MCLs that primarily affect aesthetic qualities relating to the public acceptance of drinking water. Secondary regulations are not federally enforceable.

1-19. Applicability of EPA Regulations. The EPA regulations apply to all public water systems. Most water systems at military installations fall under the regulatory definition of "public." Guidance for these EPA regulations are in the following military regulations.

a. Air Force Regulation 161-44 (AFR 161-44), Management of the Drinking Water Surveillance Program.

b. Naval Facilities Instruction 11330.14A (NAVFAC) INST 11330.14A), Safe Drinking Water at Navy Installations.

c. Army Technical Bulletin, Medical, 576 (TMB 576), Sanitary Control and Surveillance of Water Supplies at Fixed Installations.

Section G—Water Conservation

1-20. General Information. Water wastage indicates poor discipline. It creates an unnecessary economic burden and may cause a serious drain on water resources. A water supply system cannot be operated efficiently unless water consumption is controlled continuously, to reduce the amount of waste to a minimum. During a critical water shortage (from inadequate rainfall, depleted ground sources, or a sharp rise in population etc.), the importance of conservation is readily apparent. Rigid emergency controls are essential at such times to provide water for basic personal needs, essential installation operations, and for fire protection, however, conservation is needed on a full-time basis, not on an emergency basis, to perform the installation mission effectively.

1-21. Water Conservation Practices:

a. Faucets and Fixtures. Ask each using organization to continuously inspect these fixtures for leaks. Establish a

requirement to report all leaking fixtures to the civil engineer. If appropriate, establish a requirement to use flexible roller bearing washers and rubber ball valves in faucets, to decrease leaks and the need for maintenance.

b. Urinals. Use self-closing valves or flushometers. Do not permit the use of continuously flowing urinals.

c. Showers. Replace all shower heads that have an unrestricted flow with shower heads that permit only a 3 to 5 gallons per minute (gpm) flow.

d. Aircraft and Vehicle Washing. Use deadman control valves so that the hose stream will shut off automatically when it is released. The minimum size of hose nozzle should be used. If possible, schedule washing hours to off-peak consumption periods.

e. Irrigation. The occupants of family housing should be instructed in the proper methods of irrigation. In addition, the hours of irrigation should be set so that water will not be used or wasted during peak periods of consumption; irrigation should be limited generally to late evening and early morning hours.

f. Waste-Water Treatment. Make sure that potable water is not used in settling tank sprays and washing down purposes at waste-water treatment plants; plant effluents should be used for this purpose.

g. Swimming Pools. Equip pools with filtering systems so that they do not have to be drained and refilled during the swimming seasons. Control the use of water so that only the minimum amount necessary to meet and maintain sanitary requirements is used. Do not permit increased use of water to dilute excessive chlorine residuals.

h. Water Mains. The promiscuous flushing of water mains is prohibited, except where necessary to reduce tastes and odors, or when required for cleaning purposes. Flushing to maintain acceptable chlorine residuals is permitted only when there have been nonpotable samples of water.

i. Fire Hydrants. An annual test of fire hydrants is required. This should be conducted with full flow from the open butt, and the flow test should continue only until a clear water flow is attained.

j. Pumps. If feasible, water supply and wastewater pumps should be operated during off-peak electrical demands. The proper use of water storage facilities provides more flexibility in the schedule for operating water service pumps.

1-22. Water Conservation Devices:

a. Leak Detection. There should be a systematic inspection of water distribution systems, storage tanks, and other facilities at regular intervals, so that leakage may be eliminated as quickly as possible. The distribution system should be surveyed regularly with leak detection equipment, and particularly when there is an unaccountable increase in water consumption. If the installation lacks the capability to make such a survey, it should arrange to have it done under contract, by a commercial firm that specializes in this work.

b. Pressure Reducing Valves. Because excessive water pressure causes more waste, valves or regulators should be installed to reduce and regulate the flow of water to suitable pressures.

c. Automatic Shut-off Valves. Many items of equipment that use water for cooling are not equipped with water conservation devices (for example, air compressors, small air conditioners, and refrigeration units commonly lack such devices). If water conservation devices (like evaporative condensers and cooling towers, etc.) are not economical or feasible on these equipment items, automatic control and shut-off valves must be provided in the water supply line to shut off the water when the equipment is not operating.

d. Air-Cooled Condensers. Air-cooled condensers are rapidly replacing water-cooled condensers in air conditioning and refrigeration systems. Air-cooled condensers for refrigerant gases, which are practical in most climates, must be used in place of water-cooled condensers, if possible, at military installations.

e. Evaporative Condensers or Cooling Towers. Approximately 95 percent of the cooling water used in air conditioning, refrigeration, and air compressor equipment can be conserved by recirculating it through evaporative condensers, cooling towers, and similar conservation devices. Air-cooled condensers should be used for air conditioning or refrigeration systems when it is practical. If this is not feasible, evaporative condensers or cooling towers should be used on any air conditioning or refrigeration system whose capacity exceeds 3 tons.

f. Spray Ponds. The same principles and applications are recommended here as discussed above, for the evaporative condensers and cooling towers. Spray ponds may be especially suited for the recirculation of cooling waters used for purposes such as aircraft engine testing.

g. Plating Shop Devices. Considerable quantities of water are often wasted in plating shops because of improper rinsing procedures and lack of devices to conserve the rinse water. Rinse facilities should not run continuously, but only when plating parts are passing through tanks. Plating shops should use the following devices when it is economically feasible:

(1) Counter-current rinsing.
(2) Fog sprays.
(3) Drip racks for drag-out reduction.
(4) Uniformity in racking.
(5) Save rinse tanks.
(6) Drip rinse tanks.
(7) Air blow-off for drag-out reduction.
(8) Conductivity control of rinse water discharge with automatic solenoid valves.

h. Swimming Pool Filtration Systems. Swimming pools of the "fill and draw" or "flow through" type are not approved for military installations. Only circulating pools that have continuous filtration and disinfection are approved for construction and continuous operation. Noncirculating type pools should not be used until they have been modified to meet the standards of pools approved for use on militay installations. The civil engineer must coordinate with the installation surgeon on water used for swimming pools so that only the volume of water needed

to meet sanitary requirements is used. Pools should not be drained and refilled during the swimming season, unless the installation surgeon so directs.

i. Boiler Water Concentrators (Flash Tanks). Because the boiler water concentrators tends to save water, chemicals and fuel, they are encouraged for steam boiler blowdown systems when the following conditions exist:

(1) Makeup water exceeds 100 parts per million as calcium carbonate ($CaCO_3$).

(2) There is no pretreatment of makeup water.

(3) Boilers are in excess of 100 horsepower.

(4) Boilers have continuous blowdown equipment.

1-23. Control of Water Use:

a. Domestic Use. The consumption of water to meet personal needs is termed "domestic use." Domestic uses include the water for kitchens, baths, rest rooms, laundries, private car washing, etc.

b. Conservation of Water for Domestic Use. These rules will yield substantial savings:

(1) Do not operate washing machines without a full load of laundry.

(2) Water lawns only as required.

(3) Do not operate dishwashers without a full load of dinnerware.

(4) Turn off garbage disposals and water when grinding has stopped.

(5) Do not use softened water for irrigation or car washing.

(6) Repair all leaking faucets without delay. A leaky faucet can waste more than 500 gallons of water a day.

(7) Do not irrigate gardens or lawns improperly. All family housing occupants should be given detailed instructions on the correct method of irrigation; these instructions should be included in the Family Housing Brochure.

(8) Postpone as many water uses as possible until nonpeak use periods to conserve both water and electricity.

c. Promoting the Conservation of Water for Domestic Use. A continuous campaign (in installation newspapers, bulletins, brochures, etc.) is necessary to keep people alert and interested in conservation. The best approach to domestic users is usually through advertising media, women's clubs, executive clubs, etc. Domestic users, in particular, should be constantly reminded of the need to conserve water.

d. Metering. Temporary metering should be provided periodically for housing units and the tenant sent a "dummy" billing of what the bill for domestic water and sewage service would be if he or she was a private homeowner. An aggressive program of this sort can identify the worst offenders and inspire competition among families to be the "best conservationists."

e. Industrial Uses of Water. Industrial water use includes aircraft and motor vehicle washing, boiler water, cooling water, engine testing, plating, overhaul shops, etc. Although the supervisor is responsible for encouraging conservation in these functions, civil engineering personnel should observe these users periodically and see whether the correct conservation measures are actually being carried out. If they find wasteful practices or methods, they should report these officially to the management of the offending shop, and recommend action to correct the deficiencies. Violations should be brought to the attention of the installation commander, if the deficiencies are not corrected within a reasonable time.

f. Temporary Metering. At regular intervals, there should be temporary metering of water consumed for industrial use, to compile data that can be used in evaluating the degree of conservation being practiced.

g. Irrigation Uses. Irrigation often imposes high demand for water. At some southwestern installations, the highest requirement for water is for irrigation. Because of this, the greatest waste of water is also through irrigation. To prevent such waste, irrigation methods must be monitored closely. The base landscape and the base master plan should emphasize the use of drought-tolerant plants. Maximum use of treated sewage effluent for irrigation should be implemented where possible.

h. Special Uses. Water needed in maintaining the installation but not classified under other uses is termed "special use." This includes street washing, firefighting, leakage, system losses, swimming pools, and others. The amount of water consumed in "special uses" is relatively small in comparison with other uses, but can be wasted if it is not properly controlled. Consequently, the civil engineers and supervisors must also exercise strict supervision of these special uses.

i. Reuse of Cooling Water. Water used to cool equipment (for example generators, air compressors, air conditioners, computers, engine testing, etc.) should be recirculated as much as possible. If this is not possible, it should be reused to irrigate lawns, wash streets, or as makeup water in plating shops or boiler plants, or in some other useful way.

j. Reuse of Wastewater Plants Effluents. These effluents may be suitable for irrigation and industrial use under certain conditions and the use of effluent can result in conservation of potable water. At least 85 percent of the 5-day biochemical oxygen demand (B.O.D.) should be removed, and the effluent should be chlorinated, however, before effluents are suitable for irrigation. This use of wastewater effluents is subject to approval by higher technical authority. This procedure must also be approved by the Director of Base Medical Services.

k. Reuse of Industrial Waste Treatment Plant Effluents. Some elements in these effluents may be toxic to plants, may damage soils, or may inhibit the osmotic action of the soil solution. Water that has too much of such critical elements (for example sodium bicarbonate, boron, and heavy metals) should be controlled carefully, to avoid damage to soil or turf grass. A valuable guide on the quality of industrial wastewater that is suitable for reuse in irrigation is published by the American Society for Testing Materials, 1916 Race Street, Philadelphia, Pennsylvania (see Special Bulletin No. 273, entitled "Effect of Industrial Wastes on Water for Irrigation Use," by L. V. Wilcox; published in 1959).

Chapter 2

WATER SUPPLY REQUIREMENTS

Section A—General Information

2-1. Water System Objectives. An installation water system must at all times meet the qualitative and quantitative needs for domestic use and fire protection. The amount of water available for an installation's use is determined by both the quantity and quality of raw water sources.

2-2. Units and Conversion Factors:

a. Quantity. The amount of water flowing in a river, pumped from a well, treated, stored, and consumed is measured quantitatively and then affixed with the proper units of measurement. Units of measurement can be converted to other units by applying conversion factors.

(1) In the United States, flow in a river or stream is usually measured in cubic feet per second (cfs). This unit of measurement is the rate of discharge that represents 1 cubic foot of water passing by a given point during a 1 second interval; this is equivalent to 7.48 gallons per second (gps) or 448.8 gallons per minute (gpm) or 646,315 gallons per day (gpd).

(2) Pumps used throughout the treatment process are rated quantitatively by the gpm they have the capacity to pump. For conversions of units, 1 gpm is equal to 0.00223 cfs or 1,440 gpd. Pumps impart energy to the water to move or lift it to another location. Pressure imparted to the water by pumping is measured in pounds per square inch (psi) or feet of head. One psi is equal to 2.31 feet of head as water.

(3) The total amount of water treated or pumped to storage at a given installation is usually measured and referred to as million gallons per day (mgd) or fractions of it. One mgd is equal to 1.547 cfs or 694.4 gpm.

(4) The rate of water use is a function of the installation's population and industrial uses served by the water system. Water uses are often expressed as gallons per capita per day (gpcd). GPCD may be an average daily rate or it may represent a peak daily rate. It is determined by taking the total average or peak daily water demand (usually for a given year) and dividing it by the population served.

(5) In designing processes and storage tanks, cubic feet (ft^3) is the unit of quantitative measurement. One ft^3 of water is equal to 7.48 gallons.

(6) In measuring concentrations of substances and microorganisms in water supplies, a metric volume of water (the liter) is used. A subunit of liter is a milliliter (ml). There are 1,000 ml in a liter. One liter is equal to 0.2642 gallons.

(7) The quantity of radioactive material that produces 2.22 nuclear transformations per minute is called a picocurie (pCi). Another unit quantity measurement or radiation is the rem. A rem is the unit of dose equivalent from ionizing radiation to the total body or any internal organ or organ system. A millirem (mrem) is 1/1000 of a rem. A dose equivalent is the product of the absorbed dose from ionizing radiation and such factors that account for differences in biological effectiveness due to the type of radiation and its distribution in the body as specified by the International Commission on Radiological Units and Measurements (ICRUM).

(8) Tables with these and other rates of flow, volume, capacity, and pressure equivalents are given in attachment 3.

b. Quality. Pure waters, without dissolved or suspended substances, are not found in nature. Various units of concentration are used to express the amount of a substance present in water supplies. These units of concentration are used to describe the quality of the water.

(1) The term "parts per million" (ppm) is a weight-to-weight ratio that is used to express the various chemical constituents of water. It tells how many grams, pounds, etc., of a constituent in each million grams, pounds, etc., of water.

(2) When waters contain a number of pollutants, the usage of ppm is not exactly correct because the specific gravity of the water has been changed by pollutants. This discrepancy has led to using the metric term "Milligrams per liter" (mg/l). A milligram equals 1/1000 of a gram. Milligrams per liter is a weight-volume relationship. Because 1 liter of pure water weighs 1,000 grams, 1 mg/l is equivalent to 1 ppm in most cases encountered in water treatment. In water treatment and water quality assessment, the term "mg/l" offers a convenient basis for calculation of doses and pollutants. To convert mg/l into pounds/million gallons, a factor of 8.34 is multiplied times the mg/l of a given constituent or pollutant.

(3) Concentrations of chemicals in water are sometimes expressed as percentage solutions. For low percentage solutions, each percentage equals approximately 10,000 mg/l concentration. For example, a 2 percent solution of a chemical would contain approximately 20,000 milligrams of the chemical per liter of water.

(4) Grains per gallon (gpg) is an older unit of measurement used to denote the hardness of water as calcium carbonate. One gpg is equivalent to 17.12 mg/l.

(5) Microorganisms found in water supplies, both bacteria and algae, can be counted to assess a particular source's quality. Bacteria are incubated from water supplies and then expressed as the number of total bacteria per 100 ml of water. Depending on the degree of quality that is being examined (that is raw water versus finished), the specific types of common bacteria associated with water (for example, fecal coliforms, fecal streptococci) can be expressed as the number of this specific bacterium per 100 ml of water. Algae are counted in water supplies under a microscope and expressed as the number of algal cells per ml of water. Again, specific species of algae may be identified and expressed as the number of a given species per ml.

(6) The color present in water, be it true or apparent, is important from an aesthetic standpoint. Color is measured by visual comparison of the sample with platinum-co-

balt standards. One unit of color is that produced by 1 mg/l platinum in the form of the chloroplatinate ion.

(7) Taste and odors that may be imparted to water are useful tests to check the quality of raw and finished water. A variety of qualitative descriptions of odors have been compiled (for example, damp earth, free chlorine, damp cellars, etc.), and are described in Standard Methods for the Examination of Water and Wastewater. There are also threshold measurements of odors. The threshold odor (TO) number is defined as the ratio by which the odor-bearing water has to be diluted with distilled odor-free water for the odor to be just detectable by the odor test.

(8) Turbidity units (TU) are used to express the turbidity in water. Turbidity is the presence of fine suspended matter such as clay, silt, microorganisms, etc., in the water; hence, this measurement is also a valuable tool in assessing the quality of raw and finished water. It must be understood that turbidity is the expression of the optical property of a sample that causes light to be scattered or absorbed rather than transmitted to the analyst's eye. The TU readings are used as qualitative comparisons with low TU readings indicating less turbidity and generally better water quality, than water with higher readings.

Section B—Quantity Requirements

2-3. Factors Affecting Water Use:

a. Climatic Conditions. Rates of water use are influenced by climatic conditions. A definite correlation exists throughout the world between the amount of rainfall and water use. During periods of hot, dry weather, a large quantity of water is used for watering lawns, gardens, and cooling purposes. Also, regions that are subjected to extremely cold weather often report high water use from water drafts used to prevent water pipes from freezing. The effect of rainfall on water use is demonstrated in table 2-1.

b. Water Pressure. The rate of water use increases proportionally with the water pressure in the distribution system. This increase in use is due to increased leakage and increased volumes of flow through fixture units per unit of time. Studies have demonstrated that water-use rate can increase 30 percent for a 20 psi increase in line pressure.

c. Cost of Water. There is a natural tendency for consumers to conserve water when rates are high. As might be expected, the lower the rate the greater the water use or waste.

d. Conservation Measures. Potable water should be conserved for reasons of supply and economics. A discussion on water conservation is covered in chapter 1, section G.

2-4. Water-Use Quantity:

a. Domestic (Residential) Use. Domestic or residential water-use rates are continually fluctuating. Some of these fluctuations are demonstrated in table 2-2. Water usage changes from hour-to-hour, day-to-day, and season-to-season. The averages are approximately 25 percent greater than the annual daily average.

(1) Residential communities, in general, show two daily peaks; one between 7 am and 1 pm, and the other between 5 and 9 pm. During the summer months, the late afternoon or evening demand is the greatest due to lawn and garden watering.

(2) Most residential water supplies have their lowest daily demand on Sunday, and the minimum hourly rate during the early morning hours of Monday morning. The peak hourly demand for the week is generally seen during Monday afternoons.

b. Other Water Uses:

(1) Most moderate to larger installations are required to serve a variety of miscellaneous water users (barracks, guesthouses, office buildings, shopping areas, etc.), along with residential and industrial demands. To adequately supply all water requirements, it is important to know the magnitude and occurrence of peak flows. In general, it can be stated that these miscellaneous water users do not significantly affect peak installation demands. In many cases, peak hours for many of the miscellaneous users tend to coincide with the secondary residential peak periods.

(2) Industrial water usage varies greatly from installation to installation. Most installations have laundry facilities, but few have manufacturing facilities that consume a large percentage of the daily water use. Each installation must evaluate the effect of industrial uses on its water system. Such things are seasonal quantity variations, peak demands, and water quality requirements of the industrial user may alter normal supply and treatment operations.

c. Fire Protection. Firefighting demands must be considered when operating any water treatment facility and distribution system. Annual volumes of water required for fire protection are usually small, but during periods of emergency, demand may be exceedingly large and consequently govern the operation of the entire treatment facilities, especially the distribution system.

Section C—Quality Requirements

2-5. Statement of Meaning:

a. Chemical Characteristics. Water is a universal solvent. Ground, surface, and rainwater supplies come into contact with many chemical materials (both from the natural and created environments) which to some degree are soluble in water. As a consequence, all water supplies contain many extraneous chemical compounds. Surface water supplies tend to contain a greater variety of chemicals, which alters the quality of the water, than rainwater or ground water. A great many of the chemicals dissolved in water cause no real problems except from a nuisance or

Table 2-1. Effect of Rainfall on Water Use.

Rainfall (inches/year)	Water Use, gpcd	
	All Purposes	Domestic Purposes
Less than 15	210	92
15 - 25	156	55
25 - 35	143	57
35 - 45	139	42
Over 45	119	64

Table 2-2. Variations in Rates of Demands for Water.

Condition	Pumpage Observed in Five Cities: Character of City: Residential	Industrial	Residential	Residential	Industrial	Design Recommendations % Annual Average: Period of Time	Less Than 100,000 Population: Max	Min	More Than 100,000 Population: Max	Min
Population, thousands	37.4	100.4	110.5	307	320	Month	120-150	75-90	110-130	80-90
Avg pumpage, gpcd	99	96	63	57	137	Day	150-250	50-75	125-175	60-80
Max day, % avg day	138	182	196	175	160	Hr	300-400	25-50	200-300	50-75
Max hr:										
% max day	158	205	222	172	165					
% avg day	218	384	440	305	262					
Storage to equalize hourly peaks:										
Gal per capita	24	33	31	14	50					
% max day	18	19	25	14	23					
Reduced pumpage peak by storage:										
Gal per capita	80	184	154	73	140					
% max day	37	51	55	42	39					

aesthetic standpoint. There are, however, certain chemicals, both inorganic and organic, in raw water supplies that are toxic and pose a threat to human health. Specific kinds of toxic chemicals are discussed in paragraph 2-6a.

b. Physical Characteristics. Along with the chemical characteristics that influence water quality, there are also physical influences. There are five major physical factors that influence water quality: odor, taste, turbidity, color, and temperature. These factors are discussed in more detail in paragraph 2-7a.

c. Biological Characteristics:

(1) The ability of water supplies to spread massive epidemics is a matter of public record. In the early years of the 20th century, typhoid fever and other diseases spread by human fecal material were the most common cause of death. Modern disinfection practices have almost entirely eliminated waterborne disease outbreaks.

(2) The biological agents responsible for waterborne disease or toxicity are bacteria, viruses, certain species of algae, and protozoa.

(a) The principal diseases of human contracted by drinking infected water are bacillary and amebic dysentery, typhoid fever, and cholera. Typhoid fever is caused by drinking water containing the bacterium salmonella typhosa. Cholera is contracted from infected water supplies containing the bacterium vibrio comma. Bacillary dysentery is an acute bacterial disease of the gastrointestinal tract contracted by drinking water containing either shigella dysenteriae, shigella flexneri, shigella boydii, or shigella sonnei.

(b) Amebic dysentery has similar symptoms as bacillary dysentery, except amebic dysentery is caused by the presence of protozoa in water, specifically entamoeba histolytica.

(c) Certain algae (blue-green) secrete a toxic material through their cell wall. In large enough concentrations, these algae may produce illness in humans and animals drinking the contaminated water.

(d) Radioactive materials may contaminate the water supply from natural background radiation (radioactive geological formations), nuclear testing, and from industrial use of radioactivity. Radioactive compounds contain atoms of matter that are unstable and emit an energetic particle, a pulse of energy, or both. This process is known as radioactive decay. The various forms of radiation are referred to as alpha and beta particles, and gamma rays. The penetrating powers of the alpha and beta particles and gamma rays increase in the order listed. The harm of such materials occurs when they are ingested or touched, at which time they penetrate living cells and cause harmful chemical reactions to occur in the cell. The effects of radiation on human beings are harmful, and unneccessary exposure to radiation should be avoided.

2-6. Characteristics of Health Significance:

a. Chemical:

(1) Inorganics:

(a) National Interim Primary Drinking Water Regulations (40 CFR 141) lists those constituents on which the EPA has placed maximum contaminant levels to protect human health. They are also included in the military service regulations identified in paragraph 1-19. The ra-

tionale behind establishing each of these maximum contaminant levels is as follows:

1. Arsenic. Arsenic has an adverse effect on human beings and there is a lack of adequate data pertaining to treating arsenic toxicity. Arsenic occurs commonly in nature, can exhibit both acute and chronic toxicity to humans and is believed to be a cancer-causing agent.

2. Barium. Barium can cause adverse physiological effects, and there are no data on effectiveness of treatment. Barium ingestion can seriously affect the heart, blood vessels, and nerves.

3. Cadmium. Cadmium ingestion can cause adverse physiological effects, and there is not adequate information on effective treatment. Cadmium is an element of high toxicity that is associated with many pathological changes, including renal arterial hypertension.

4. Lead. Lead is toxic to humans, and there is limited information on effective treatment. Lead compounds, when ingested, manifest their toxicity through various neurological lesions.

5. Mercury. Mercury levels were set on the basis of their adverse physiological effects. Standard water treatment methods have little affect on removing mercury at low levels. Mercury and its various compounds upon ingestion destroy enzymes and consequently hinder cellular metabolism.

6. Nitrate. Interim standards have been placed on nitrate due to the adverse physiological effects on infants and the lack of defined treatment. Nitrite ingested by infants is converted to nitrite. The nitrate ion combines with hemoglobin to form methemoglobin which produces an oxygen deficiency, resulting in a condition characterized as "blue babies."

7. Selenium. Regulation levels are stringent because standard treatment processes have little effect on removing selenium at low levels. There is also a lack of data regarding the toxic effects of selenium on humans when ingested.

8. Silver. The silver standard was set to protect people from cosmetic problems. Low levels of silver can cause a permanent grey discoloration of skin, eyes, and mucous membranes.

9. Fluoride. Excessive levels of fluoride result in mottling of dental enamel and minor changes in bone density. The physiological effect of fluoride has been shown to be temperature-dependent since it relates to the quantity of water consumed at varying air temperatures. A temperature scale was used to establish contaminant levels of fluoride because there is a small margin between beneficial levels and levels causing mottling and other effects.

10. Chromium. The limit for chromium was based on the known toxicity of the hexavalent form. The MCL is for total chromium.

(b) Several other inorganic chemicals have health significance, but were not included in those inorganic chemicals for which maximum contaminant levels were established. Some of these chemicals include:

1. Cyanide. Cyanide in water usually results from industrial spills or accidents. Chlorination reduces the toxicity of cyanide, but in high enough concentrations, cyanide can have toxic effects of humans.

2. Sodium. Sodium has an adverse effect on certain persons suffering from cardiovascular diseases. The exact level at which sodium in a water supply results in adverse health effects varies from person-to-person, so to establish a maximum level is difficult. However, the EPA does require that sodium levels be monitored and reported to the state.

3. Sulfate. High levels of sulfate in drinking water may have laxative effects on people unaccustomed to a high-sulfate water source.

(2) Organics. The National Interim Primary Drinking Water Regulations (40 CFR 141) also detail maximum contaminant levels set by the EPA for organic chemicals. Refer to the military service regulations in paragraph 1-19 for a list of these maximum contaminant levels.

(a) Endrin, lindane, methoxychlor, and toxaphene are members of a group of pesticides referred to as chlorinated hydrocarbons. It is well documented in scientific literature that chlorinated hydrocarbons are extremely toxic to all types of animal life including human. When these compounds are ingested, the residue is deposited in the fatty tissue of the body and slowly released to the nervous system, where the toxicity is manifested. Also, some chlorinated hydrocarbons are believed to be cancer-causing agents.

(b) The compounds 2, 4-D and 2, 4, 5-TP are chlorophenoxy herbicides. Because of possible toxicological effects of these compounds and inadequate data regarding chlorophenoxy herbicides removal by standard water treatment methods, the EPA has set rather stringent levels on them.

(c) Trihalomethanes (THM) are organic compounds, formed by the interaction of natural organics found in water with chlorine-based disinfectants. One of the compounds formed, chloroform, has been shown to be a carcinogen (cancer-causing) in rodents (mice and rats) at high dose levels. Because its metabolic pattern in animals is qualitatively similar to that in humans, it is suspected of being a human carcinogen. Epidemiological studies also suggest a human risk. Although documentation of their toxicity is not so well known, other THMs may be suspect of posing similar risks. Because the treatment process that can reduce drinking water levels of chloroform have about the same effectiveness in reducing levels of the other THMs, the proposed drinking water regulation is addressed to these substances as well.

(d) Volatile synthetic organic chemicals (VOC), such as trichloroethylene, can present significant health risks to humans. They may be found in both surface and ground water supplies as the result of accidental discharge or improper disposal of fuels, solvents, and other industrial hydrocarbon compounds. EPA MCLs for VOCs are in the extremely low parts per billion range because of their high toxicity and, in some cases, suspect carcinogenicity.

b. Biological:

(1) Bacterial Disease. Water is definitely a potential vehicle for the bacteria responsible for specific human en-

teric (of the intestine) diseases; specifically cholera, typhoid, and bacillary dysentery. Any water supply that has been polluted with human or animal wastes, and not properly treated before consumption, must be considered a possible source of disease and infection. With the advent of disinfection, waterborne diseases caused by bacteria have become an insignificant contribution to total illness and death.

(2) Viral Diseases. Various viruses infect the gastrointestinal tracts of both humans and warm-blooded animals, and are excreted in the diseased human's or animal's fecal material. The enteric viruses (which are known to be excreted in relatively large numbers in feces) are those of the enterovirus group, the adenoviruses, reoviruses, and the virus or viruses associated with infectious hepatitis. There may be other viruses associated with human excretions, but not usually in large numbers. It must be kept in mind that viruses are not a normal inhabitant of the human or animal intestinal tract; they are only excreted by infected individuals or animals. Therefore, when sanitary wastewater or agricultural runoff contains virus contaminated water supplies, there is a public health reason for concern, because most viruses are more resistant to conventional water treatment processes than bacteria.

(3) Standard Plate Count. A bacterial examination of water should include the count of total colonies of bacteria developing from measured portions (1 ml) of the water being tested, which have been planted on a suitable culture media and incubated for 48 hours at 20 degree centigrade (°C), or for 24 hours at 35°C. The test, known as the standard plate count, is of significance when used for comparative purposes under known or controlled conditions.

(4) The Coliform Indicator. The bacterial examination of drinking water should always include a quantitative estimation of total organisms of the coliform group, which are indicative of fecal contamination. Organisms (bacteria) that are indicative of or associated with fecal material are good indicators of the presence of potential pathogens from sewage. The coliform group of bacteria associated with fecal material are more resistant than disease-causing bacteria, and their presence is easy to determine. Therefore, they make a good indicator organism of the potental presence of disease-causing bacteria.

(a) The total coliform group consists of bacteria from soil and plants, as well as bacteria found predominantly in the feces of humans and warm-blooded animals. The group includes all of the aerobic and facultative anaerobic, gram-negative, nonspore-forming, rod-shaped bacteria that ferment lactose with gas formation within 48 hours at 35°C. This is the presumptive coliform test that can be confirmed and completed by carrying the test further as outlined in Standard Methods for the Examination of Water and Wastewater.

(b) A more rapid method for detecting specific bacteria is the membrane filter technique. A special membrane that removes bacteria from water filtered through it is available for water quality analysis. By incubation of the filter membrane on special media, it is possible to make coliform determinations in 18 to 24 hours, rather than the 3 to 4 days required by the conventional completed and confirmed test procedures. Isolating salmonella typhosa and other organisms by cultivation on a selected medium is also possible.

(c) Fecal coliforms are escherichia (E.) coli that occur in the intestinal tract of humans and warm-blooded animals. E. coli are rarely, if ever, found outside the intestines, except where pollution by human or animal feces has occurred. The fecal coliform tests may also be conducted, using either the multiple-tube fermentation technique or the membrane filter technique. The test serves as a quantitative measure of contamination and has greatest application in the study of stream pollution, raw water sources, sewage treatment plants, and the quality of bathing waters.

(d) The analysis for total coliforms would indicate the presence of feces of human and warm-blooded animals, as well as coliforms associated with vegetation, soils, joint and valve packing materials, slimes, swimming pool ropes, pump leathers, sewage, storm-water drainage, surface-water runoff, surface waters, or others. Therefore, this test is less specific than the fecal coliform test.

(e) The presence of any of the coliform organisms in finished drinking water is a danger sign; it must be carefully interpreted in the light of a sanitary or epidemiological survey and eliminated at once. Intestinal diseases may result from sources other than drinking water, but the sanitary or epidemiological survey helps to make sure that the water supply is not the source of the disease-causing organisms. It should also be recognized that a negative coliform test gives no assurance that viruses such as infectious hepatitis are absent. The results of a bacterial examination shows the quality of the water only at the time of sampling and must be interpreted in the light of the sanitary survey.

c. Radiological. The effects of radiation on human beings are viewed as harmful, and any unnecessary intake of radioactive material in water should be avoided. Development of the nuclear industry, the use of radioactive materials in medicine, and nuclear weapons testing have caused an increase of radioactivity in the environment. Radiological standards for drinking water are listed in the military service regulation identified in paragraph 1-19.

(1) Above average levels of radium 226 generally occur only in specific areas. Certain ground waters have naturally occurring radium 226, and there is a possibility of pollution from industrial discharges. The principal source of strontium 90 thus far has been fallout due to weapons testing. The increased use and wide variety of radionuclides require continued surveillance by regulatory authorities.

(2) The removal of radioactive materials from either surface waters or ground water starts before the water enters the water treatment facility. In surface water, the physical process of sedimentation reduces particulate activity. The extent of this reduction depends on the stream turbulence and size of the particles. Many silts have ion-exchange capabilities and this treatment process can reduce the level of soluble activity. Biological process may be effective in reducing the radiochemical concentration, and some forms of algae have been known to accumulate

radiophosphorus. These benefits by natural processes are only temporary because the radioactivity is merely stored in bottom sediments, plants, and animals in the stream and not removed. During periods of increased turbulence, the bottom sediments are resuspended and plants and animals die, returning their contained radioactivity to the stream.

(3) Percolating ground water usually undergoes some natural treatment. Filtration is effective on particulate substances and some ion-exchange probably takes place with soluble material. Many minerals have good ion-exchange properties, especially some of the clays. The actual degree of decontamination obtained depends on the chemical and physical properties of the radioactive material and the geology of the area.

(4) The radiological quality of water is further improved by conventional treatment processes. Radioactive materials are retained in sludges, filter backwash water, and ion-exchange resin. These radioactive materials removed in water residue treatment require special handling.

2-7. Characteristics of Aesthetic Significance:

a. Physical Characteristics:

(1) Taste and Odor. Tastes and odor in water supplies are usually imparted to the water from organic matter, living organisms, and dissolved gases, none of which pose a threat to human health. Domestic consumers, however, desire a palatable water that is free from any noxious tastes and odors. Tastes and odors not only destroy aesthetic quality, but cause people to doubt the sanitary quality.

(2) Turbidity. Turbidity is caused by suspended and colloidal material in water. In excess of 1 TU, turbidity is visible to the naked eye and raises questions as to the cause of the turbidity; for example, bacterial growth, faulty treatment process, or contamination.

(3) Color. Color in water results from the raw water supplies coming in contact with organic debris such as leaves, conifer needles, and wood in all stages of decomposition. Tannin, humic acid, and humates from the decomposition of lignin are considered to be the principal color bodies. Color bodies in water pose no real threat to human health, but instead render the water undesirable from an aesthetic standpoint. Tannins tend to impart a yellow-brown color to water which consumers identify with urine and human waste.

(4) Temperature. Water for drinking is more palatable and aesthetically pleasing if the temperature is approximately 60° Fahrenheit (F). Water warmer than this is not pleasing to the consumer. Also, cooler water tends to mask any taste and odors that might be present.

b. Chemical Characteristics:

(1) Iron and Manganese. Both iron and manganese compounds that are dissolved in water supplies in concentrations as low as 0.3 to 0.5 mg/l stain bathroom fixtures and laundry. Iron bacteria are very common in well water. These organisms are responsible for metallic tasting water, plugged water pipes, and stringy or fluffy growths in water. Obviously, when present, both iron and manganese pose a real aesthetic problem in water supplies.

(2) Taste-Producing Minerals and Organics. Many of the aesthetically undesirable tastes in water supplies stem from the minerals and organic materials the water has been in contact. Chloride or sulfate ions associated with sodium, calcium, or magnesium create a variety of tastes. Phenols and many other aromatic hydrocarbons that are present in raw water supplies impart a medicinal or chemical taste to finished water that is very undesirable to consumers.

c. Biological Characteristics:

(1) Algae and Diatoms. In raw water supply, algae are recognized as being one of the primary causes of tastes and odors. It is evident from research that algae are involved, either directly or indirectly, in establishing conditions that lead to taste and odor production of specific distinctive tastes and odors. A larger number of others are associated with tastes and odors that vary in type according to local conditions. Certain diatoms, blue-green algae, and pigmented flagellates are the principal offenders, but green algae, including desmids, may also be involved. Thirty-nine species have been selected as representative of the more important taste and odor algae.

(2) Nematodes. Nematodes are small, round worms, many of which are aquatic. Well water rich in organics or improperly treated surface water could conceivably contain such creatures. Such contaminated water is both unpalatable and aesthetically unpleasant.

(3) Iron Bacteria. Crenothrix and lepothrix are two common species of iron bacteria often found in well water. Both species are reddish-brown, gelatinous, stringy masses that grow in dark, oxygen-free environments. Both their undesirable physical appearance and the taste they impart to water readily render the water supply aesthetically undesirable. Both species of bacteria pose no threat to human health.

2-8. Quality Improvement. The EPA has set drinking water standards for the various characteristics of drinking water that were described above. These standards are divided into two parts. The primary standards (40 CFR 141) set maximum allowable limits that are not to be exceeded. The characteristics covered by these primary standards are known to be harmful to humans if taken in sufficient quantities. The secondary standards (41 CFR 143) are recommended standards only and are based primarily on aesthetic considerations. The various characteristics covered by the primary and secondary drinking water standards along with effective treatment methods for their removal are listed in tables 2-3 and 2-4.

Table 2-3. Most Effective Treatment Methods—Primary Standards.

Contaminant	Treatment	Chapter/ Section
Inorganic		
Arsenic (As^{+3})	Oxidize to +5 valence for treatment	
Arsenic (As^{+5})	Coagulation with alum or ferric sulfate; Lime softening; Ion-exchange (anion and activated alumina); Granular activate carbon (G.A.C.).	6C, 6D, 6E
Barium	Lime softening; Ion-exchange (cation).	6E
Cadmium	Coagulation with ferric sulfate; Lime softening; Ion-exchange (cation).	6D, 6E
Chromium (Cr^{+3})	Coagulation with alum or ferrous sulfate; Lime softening; Ion-exchange (cation).	6D, 6E
Chromium (Cr^{+6})	Coagulation with ferric sulfate; Lime softening; Ion-exchange (anion)	6D, 6E.
Fluoride	Lime softening; Ion-exchange (activated alumina); G.A.C.	6C, 6D, 6E
Lead	Settling and filtration; coagulation with alum or ferric sulfate; Lime softening.	6D, 6E, 6F
Mercury		
Organic	Coagulation with ferric sulfate; G.A.C.	6D, 6C
Inorganic	Ion-exchange (cation).	
Nitrate	Ion-exchange (cation).	
Selenium (Se^{+4})	Coagulation with ferric sulfate; Ion-exchange (cation); Reverse osmosis.	6D
Selenium (Se^{+6})	Ion-exchange (cation); Reverse osmosis.	
Silver	Coagulation with alum or ferric sulfate; Lime softening	6D, 6E
Organic	Activated carbon.	6C
Endrin	Activated carbon.	6C
Lindane	Activated carbon.	6C
Methoxychlor	Activated carbon.	6C
2, 4D	Activated carbon.	6C
2, 4, STP	Activated carbon.	6C
THMs	Aeration; Activated carbon.	6C
VOCs	G.A.C.	6C
Turbidity	Aeration; Settling and filtration; Coagulation with alum or ferric sulfate; Lime softening.	
Microbiology	Disinfection.	6H
Radionuclides		
Alpha emitter	Lime softening; Ion-exchange; Reverse osmosis	6E
Beta & photon emitters	Lime softening; Ion-exchange; Reverse osmosis	6E

Table 2-4. Most Effective Treatment Methods—Secondary Standards.

Contaminant	Treatment	Chapter/ Section
Chloride	Ion-exchange; Reverse osmosis; Distillation.	
Color	Aeration; Settling and filtration; Coagulation with alum or ferric sulfate; Activated carbon.	6A, 6C
Copper	Ion-exchange.	
Corrosivity	Depends on pH, TDS, alkalinity, D.O., etc.	
Foaming agents	Activated carbon.	
Hydrogen Sulfide	Aeration; Chemical oxidation	6A
Iron	Aeration; Settling and filtration; Coagulation with alum or ferric sulfate; Lime softening: Ion-exchange (cation).	6A, 6B 6D, 6F
Manganese	Same as iron.	6B
Odor	Aeration; Activated carbon.	6A, 6C
pH	Increase by alkalies and decrease by acids.	

Table 2-4. Continued.

Contaminant	Treatment	Chapter/ Section
Sulfate	Lime softening; Demineralization.	6E
Total dissolved solids	Ion-exchange; Demineralization; Lime softening.	6F
Zinc	Lime softening; Ion-exchange.	6E

Chapter 3

SOURCES AND DEVELOPMENT OF WATER SUPPLIES

Section A—General Information

3-1. The Hydrologic Cycle. Earth water's occurrence, distribution, and circulation is a function of the hydrologic cycle which consists of precipitation, consequent runoff, infiltration, storage, evaporation, transpiration, and reprecipitation (figure 3-1). The oceans (covering about three-quarters of the earth's surface and containing about 97 percent of the earth's water) provide water to the atmosphere by evaporation. Some of this water precipitates on the land and becomes the source of essentially all freshwater supplies. A portion of the precipitation evaporates, a portion runs overland to lakes or streams, and a portion infiltrates into the ground. Gravitational forces eventually draw the water back to the oceans. Gravitational forces also influence the flow of water over and through the land, establishing an interrelationship between ground and surface water. Ground water can emerge at the surface to supplement direct runoff.

3-2. Water Availability:

a. Geographical Variability. Water occurs in the air, on the surface, and underground. Water supplies are developed from surface and underground supplies. The amount of water available at a given location depends on current and past rain or snow and supplies of surface and ground water from other areas. The flow is governed by many factors that affect the quantity and quality of water. In many areas, precipitation is so minimal that water is extremely scarce. In other areas, precipitation is so great that flooding frequently occurs.

b. Quantity Problems. Water supply development includes finding or modifying a source of water that can yield enough to meet the needs of the users. Water trapped in snowfields of the Arctic and rainfall in the tropics can be used for water supplies. Seawater can be converted to freshwater and wells can be constructed to tap ground water sources. Reservoirs, lakes, and suitable streams can be used as water supplies. Considerable work and cost may be involved to get quantities of freshwater sufficient for even small water supplies in water-poor areas. In water-rich areas, considerable effort may be required to convert the water to a quality suitable for use. The overall problem in water supply development is to examine alternative water sources, their quality and quantity, and the costs of producing a finished water of desired quantity and quality to serve the needs of a location without adversely affecting other locations.

c. Quality Problems. Large quantities of water are available in the sea. The high salt content prohibits direct use. The high cost of converting the water to freshwater and of transporting converted water inland to a point of use has restricted its use. Streams, lakes, and reservoirs are used by many areas for water supplies. The quality is affected by natural and pollution made by people so that elaborate treatment facilities are often needed to produce quality water for users. Large quantities of water are available in the ground. As the water passes through the ground, it often dissolves various minerals from the earth so that treatment to provide quality water is again necessary. The focus of this manual is on operating and maintaining water supply works to provide high quality water of sufficient quantity to meet user needs.

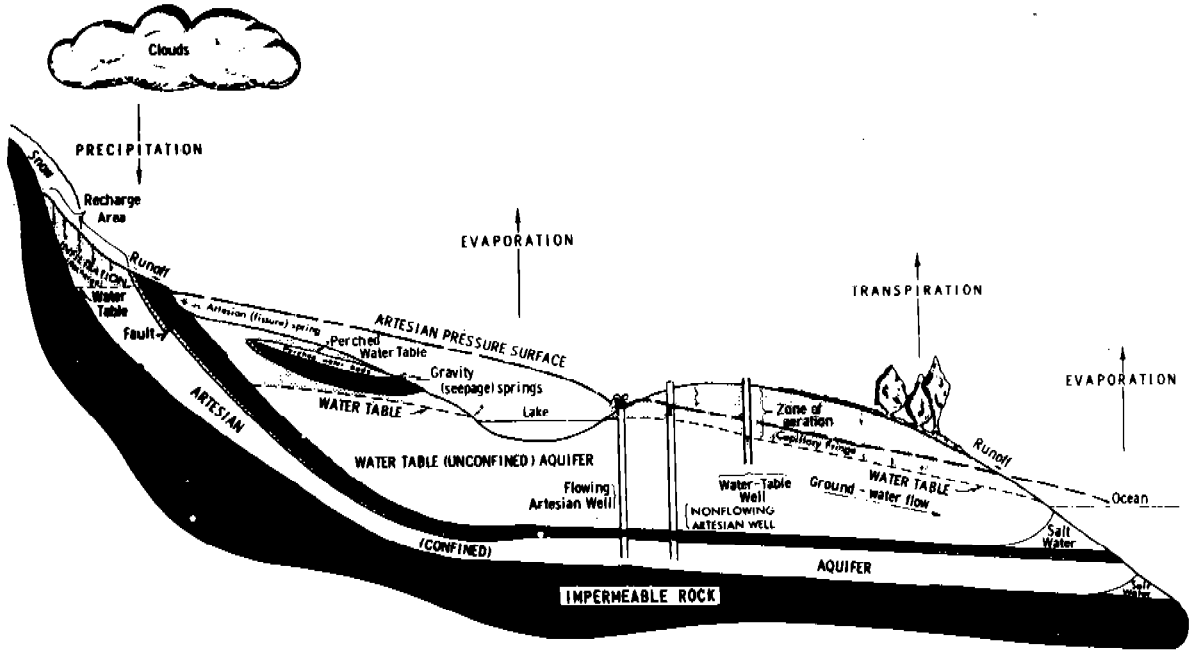


Figure 3-1. The Hydrologic Cycle.

Section B—Ground Water Supplies

3-3. General Information:

a. Water Occurrence. Water occuring below the water table that is available to feed springs, flow into streams, and supply wells is called ground water. Variations in surface elevation, precipitation, surface and subsurface materials, and other factors cause the water table to fluctuate. These factors determine the amount of ground water that can be made available as a water supply. The quality of ground water available at a given location is relatively fixed. The depth to ground water varies considerably from location to location, and will often vary at the same location with the season and cumulative rainfall history. The rate at which ground water may be removed from a given location depends on the kinds of subsurface materials and the rate at which the water is supplied to the aquifer or aquifers serving that location. About 95 percent of the freshwater available in the United States is ground water. About 80 percent of water supply sources are ground water, although less than 25 percent of the total freshwater used is from ground water supplies.

b. Source and Movement. Almost all ground water originates from precipitation. The portion of precipitation that does not either evaporate or run off the ground surface enters the soil. Some is trapped as soil moisture, some is used by plants, and the remainder continues downward through the soil until a layer of rock or other impervious material is encountered. The water then flows in the general downhill direction of the impervious layer. The layer of soil, sand, gravel, or broken rock through which the water flows is called the aquifer. The rate of movement is slow, depending on the resistance offered by the materials of the aquifer. Gravity and the pressure of additional ground water keep the water moving until the surface of the ground dips down or until the aquifer rises so that the water table is higher than the ground. The water than flows into either a lake or stream or trickles out of the ground as a spring. The water can again evaporate, be used by plants, or infiltrate to become ground water again.

c. General Characteristics. As the water passes through various underground soil formations, some of the objectionable material accumulated on the surface is either effectively filtered out or removed by other natural means. The same water chemically reacts with the material it passes through, leaching or extracting mineral constituents. The quality of ground water at a given location is usually consistent. The quality at different locations varies markedly.

(1) Overall, ground water is usually free of pathogenic organisms and usually clear. It has a constant chemical composition and a temperature that is nearly constant.

(2) Other advantages of ground water supplies are that they are less affected by droughts, are more difficult to biologically or radiologically contaminate, and are available in many areas.

(3) The quantity of water that can be made available and excessive mineral content are the two main constraints on universal use of ground water. High concentrations of minerals such as calcium and magnesium (which cause hardness) and iron can be practically removed from ground waters. High concentrations of minerals such as sulfates and chlorides cannot be removed easily and usually require that an alternative water supply be developed.

(4) Where ground water is found at different depths in the same locale, deeper aquifers offer more protection against contamination and drought than shallow aquifers. Bacteria, chloride, and nitrates are seldom found in ground water supplies. Their presence indicates pollution of the ground water supply.

(5) Ground water temperatures are usually constant, being equal to the mean annual surface temperature at the 100-foot depth and increasing 1.8°F for each 100 feet below that point. Increases or decreases in temperature can also indicate deterioration of quality.

3-4. Types of Wells:

a. Classification. A well is a hole or shaft made in the ground permitting ground water to be pumped to the surface. Wells can be classified according to the method of construction, the depth, the type of aquifer penetrated, or the type of intake used to draw water from an aquifer. All wells penetrate either a gravity or pressure aquifer. Also, wells are often classified as either shallow or deep wells.

(1) Gravity Wells. A gravity well receives water from a water table aquifer. Water table aquifers receive most of their water from local vertical percolation. The water level in a nonpumping well in a water table aquifer represents the water table.

(2) Pressure Wells. A pressure well receives water from an artesian aquifer. An artesian aquifer is one that is overlain by a layer of material that inhibits vertical water movement. Artesian aquifers receive most of their water from the lateral movements of ground water from a distant surface recharge area. The water level in a nonpumping well in an artesian aquifer rises to an elevation (piezometric level) above the top of the aquifer. This may or may not be above the ground level. The same aquifer may be considered artesian at one point and water table at another location (figure 3-2).

(3) Shallow Wells. Although there is no exact dividing line between a shallow and deep well, wells less than 100 feet in depth are usually classified as shallow wells. They may be one of three types: dug, bored, or driven.

(a) Dug Wells. This type of well (figure 3-3) consists of vertical holes excavated through top soil until the water table aquifer is encountered. These wells are best where the water table is high, because excavation is generally conducted with picks and shovels or a power digger. Dug wells vary from 3 to 20 feet in diameter and are usually 10 to 50 feet deep. The water supply is usually less than 100 gallons per minute (gpm) from such wells. Brick, rough stone, or vitrified tile are sometimes used to line the wells, although concrete makes the most watertight lining. Even with poured concrete linings, however, sanitation of dug wells is a prime concern.

(b) Bored Wells. This type of well is similar to the dug well, but may be extended deeper into the water-bearing formation. Well holes are dug by hand or power

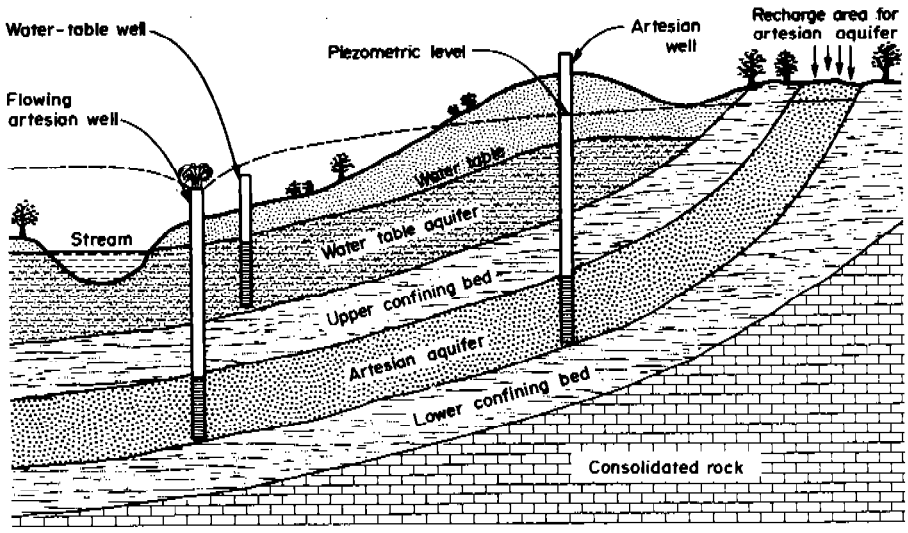


Figure 3-2. Subsurface and Ground Water Phase of the Hydrologic Cycle.

augers. Augers are best applied in sticky clay formations that will not cave in. Augers are not very effective in rocky formations. Hand augers can be used for 6- to 8-inch diameter holes up to 50 feet deep. Power augers can be used for holes up to 36 inches in diameter and to depths of 100 feet. Bored wells may be cased with concrete pipe, vitrified tile, or steel casing. The well may be completed by installing a well screen or perforated casing in the water-bearing sand or gravel layer. Small quantities of water are typically available from these wells.

(c) Driven Wells. This type of well can be used where ground water is within about 25 feet or less of the ground surface and where driving does not encounter rock or boulders. A driven well consists of a drive point (figure 3-4) on a pipe driven into the ground. The pipe and drive point serve as the well screen and casing for a pump. Such wells can use up to 4-inch pipe for depths to 100 feet. Only 10 to 20 gpm can be obtained from each well. Some locations use a battery of driven wells connected to a common header and pump to supply higher flows. These work best in sand and gravel formations.

(4) Deep Wells. When it is necessary to go deeper than 100 feet to reach ground water or to avoid pollution, wells must be drilled to deeper water-bearing strata. Ordinarily, drilled wells are 4 to 12 inches in diameter. Some drilled wells, however, are up to 4 feet in diameter and some are thousands of feet deep.

(a) Drilling Methods. Drilled wells are subclassified by the method used in drilling. Some methods include cable-tool or percussion, rotary, reverse rotary, and jetted.

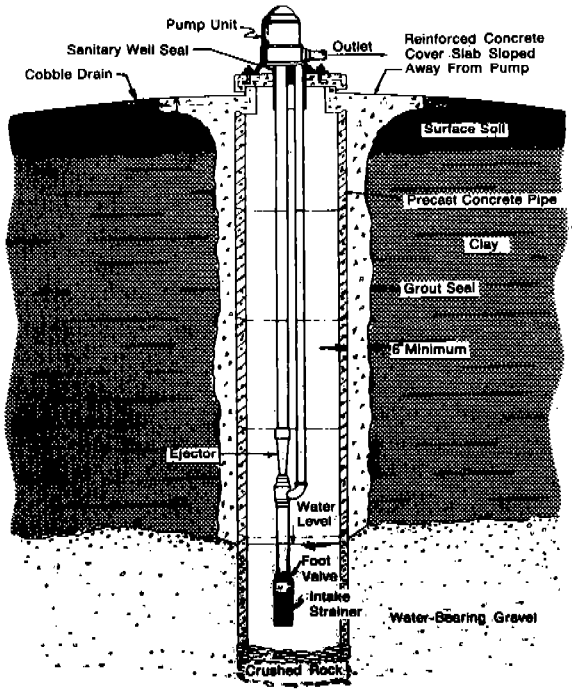


Figure 3-3. Dug Well With Two-Pipe Jet Pump Installation.

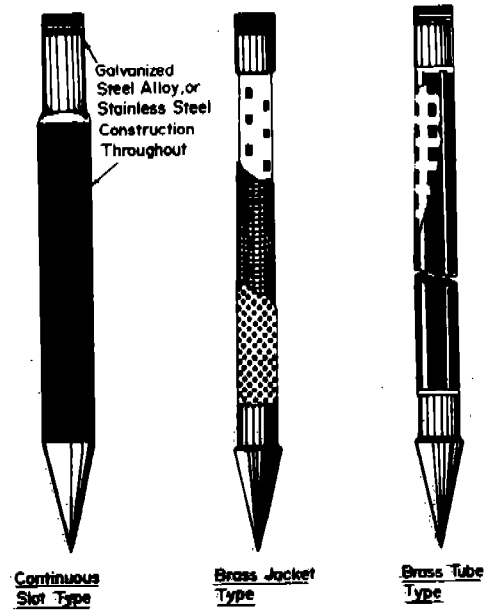


Figure 3-4. Different Kinds of Drive-Well Points.

Each is used to best drill through a given formation. Equipment to drill wells is bulky, costly, and requires trained personnel to operate.

(b) Casing and Screen. Properly sealed, metal casings can provide effective protection against the entrance of surface water and polluted ground water. If the water-bearing strata is sand and gravel, a well screen is usually placed at the well bottom.

(c) Gravel-Wall Wells. These wells use a gravel encasement of the well screen. This serves as a prestrainer to prevent sand from clogging the screen or entering the well. The gravel-well usually has more capacity than wells that have straining screens only.

b. Other Types of Ground Water Development. In addition to water extracted from holes or shafts, ground water may be obtained from springs, infiltration galleries, and Ranney wells.

(1) Springs. Springs are points at which ground water comes to the surface naturally. They are supplied from either water table aquifers or artesian aquifers where rock crevices allow water to escape to the surface. Water table springs are not reliable sources of water since the amount available fluctuates with the rise and fall of the water table and is subject to contamination from the surface. Rock springs may yield more consistent quantities of water, but the rock crevices cannot be relied on to filter out pollutants that may be in the aquifer or in the rock "out-crop." Spring water is collected in structures designed to exclude all water except spring water (figure 3-5). Covers, screens, collection pipes, and central collection basins are standard features that should receive the attention of operation personnel.

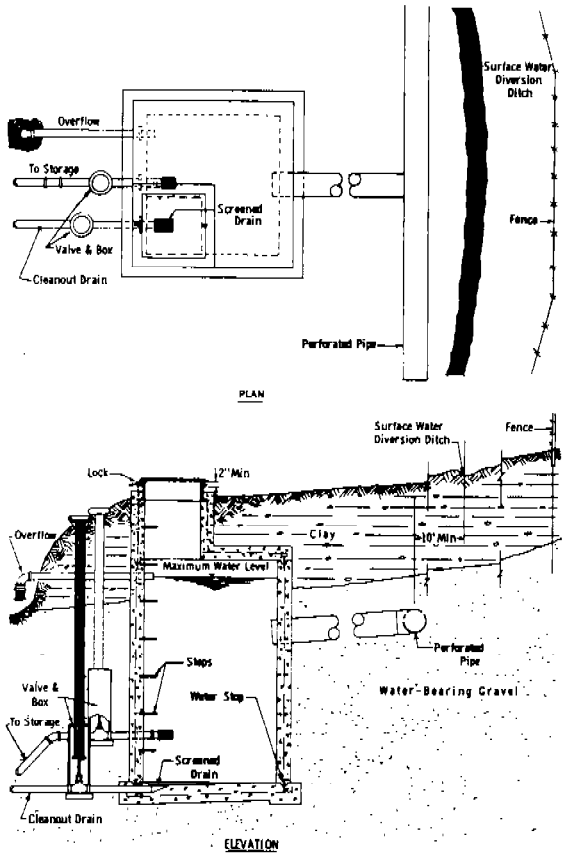


Figure 3-5. Properly Constructed Spring.

(2) Infiltration Galleries. An infiltration gallery is an open trench or a tunnel cut into an aquifer to intercept ground water. The trench is filled with a porous media. It is similar in principle to a well, except it is horizontal (figure 3-6). Galleries are generally located near surface or underground streams or springs. Water is pumped out in the same way as shallow wells. From 700 to 3,500 gpm per 1,000 feet of length can be obtained. Quantity and quality fluctuations and construction difficulties restrict the use of infiltration galleries.

(3) Ranney Wells. This type of well (figure 3-7) is constructed by sinking a reinforced concrete caisson to the aquifer level and running horizontal screened lateral pipes from the side of the caisson into the surrounding water-bearing deposits. The pipes collect the water which is then emptied into the caisson. The caisson thus serves as a clear well from which water can be pumped. Installed alongside a river with the laterals extending below the riverbed, the Ranney well allows collection of a naturally filtered water from the river.

(4) Maui Wells. This water source is a special type of infiltration gallery where fresh basal lens water is skimmed off the top of brackish ground water by use of a weir. Proper placement of the well tunnel and the weir are crucial to successful long-term operation of the well. The weir level must be set to allow removal of fresh water at a rate compatible with the recharge rate.

c. Well Development. Development work is an essential step to complete a water well. It removes fine material from the aquifer, thereby opening and enlarging passages in the water-bearing formation so the water can enter the well more frequently.

(1) Benefits of Well Development. Development benefits include:

(a) Correction of any aquifer damage or clogging that occurred during the drilling operation.

(b) Increased porosity and permeability of the formation in the vicinity of the well.

(2) Fine Particle Removal. Removal of fine particles leaves a naturally developed area of uniformly graded sand or gravel around the well screen (figure 3-8). Water can move through this area toward the well with negligible head loss, resulting in reduced drawdown.

(3) Gravel Pack. An alternate method of providing a highly permeable annular area of granular material around the well screen is to use a gravel pack. Development work must still be done after placing the gravel pack if maximum well capacity is to be attained.

(4) Methods. Development is done in a number of ways, including mechanical surging, air surging, overpumping, backwashing, explosives, chemicals, and high-velocity jetting.

d. The Well Screen. A drilled well consists of an intake structure, an enclosed casing to connect the aquifer to the surface, and the well pump, (figure 3-9). Various other

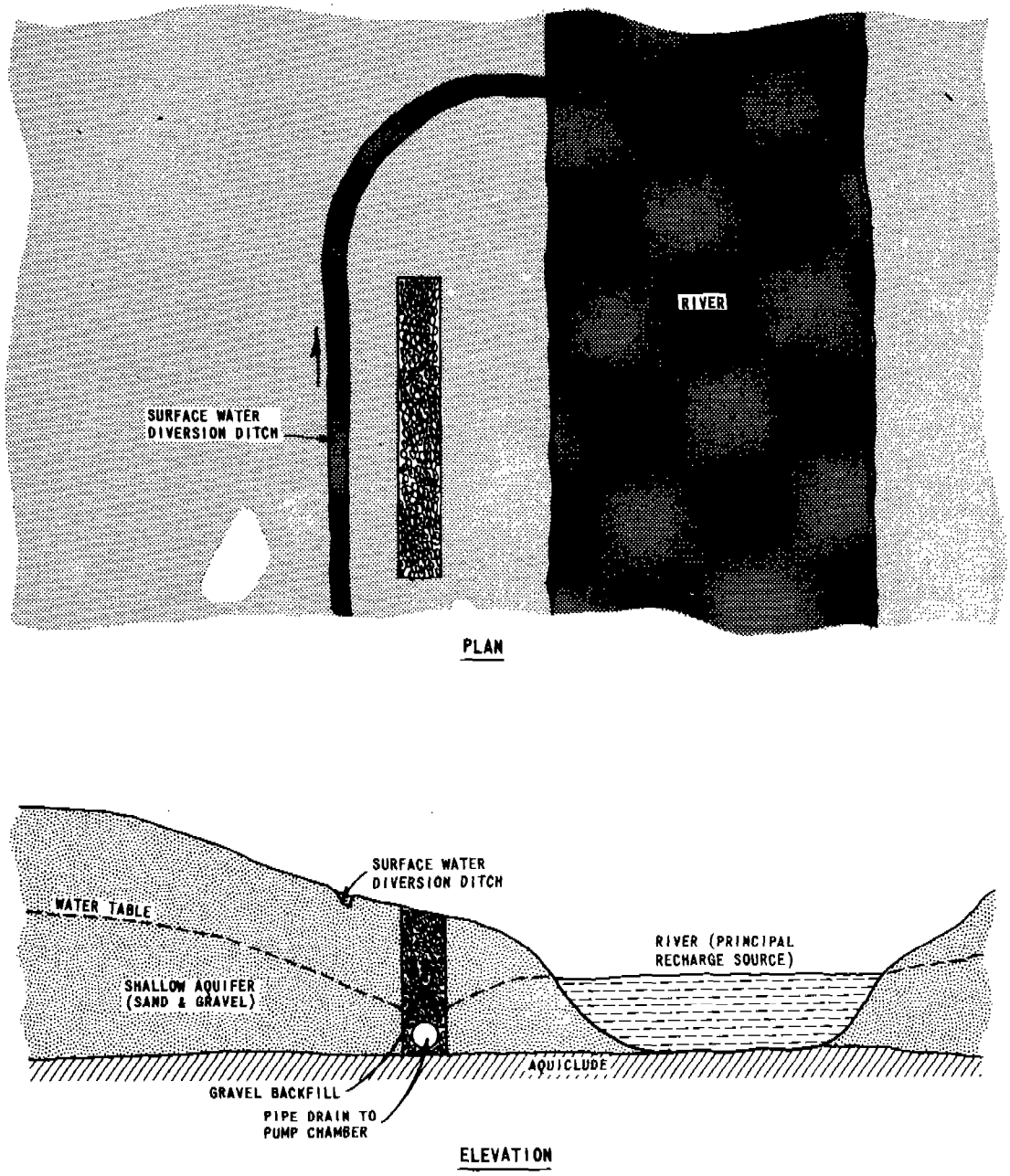


Figure 3-6. Infiltration Gallery.

construction details such as grouting, gravel packing, and hole lining are carried out for sanitation reasons or to ensure against wellhole collapse. The intake structure may have a well screen.

(1) Function. The well screen serves as the intake structure of a well. It allows the water to flow freely into the well while excluding sand or other materials.

(2) When Needed. Well screens are generally needed on all wells in sand and gravel aquifers. Screens may not be needed in limestone or creviced rock aquifers where fine particles are not likely to enter the wellhole.

(3) Types of Screens. Screens may be of reinforced wire mesh, thinly slotted sections of pipe, perforated pipe sections, or finely spaced wire wound on a structural skeleton. Types of screens and opening sizes are selected on the basis of the nature of the material in the aquifer. Screens providing a maximum percentage of open area and low entrace velocity will extend the useful life of wells. Screens usually extend through 70 to 80 percent of the depth of an artesian aquifer and the lower one-third or one-half of a water-table aquifer.

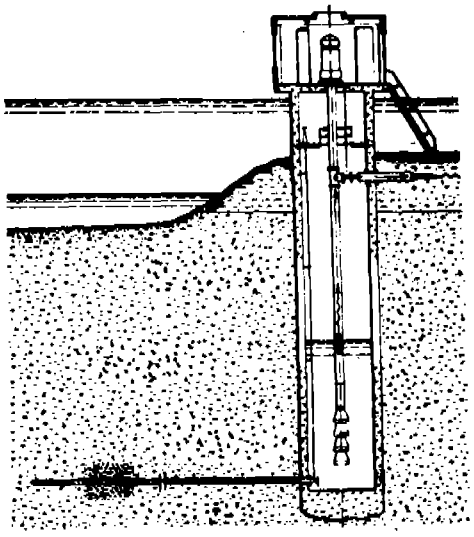
(4) The Gravel Pack. A gravel pack is a layer of gravel from 3 to 8 inches thick surrounding a well screen. Its function is to exclude fines. It is commonly used in sandstone and fine sand aquifers and in layered formations. The gravel can be placed by installing a double casing and filling the outer casing with gravel around the screen at the bottom of the inner casing. The gravel pack serves to re-

Development of the Collector

YEARS AGO some alluvial aquifers were developed by infiltration galleries, constructed by digging long trenches of limited depth parallel to a river, then placing and covering perforated pipe. However, as the quantities of water required became greater and labor costs increased, the old-fashioned infiltration galleries became economically impractical.

In the early 1930's Leo Ranney, of Northwestern University, conceived a method of developing pure water from shallow alluvial deposits, utilizing the old gallery principle, but eliminating the construction difficulties encountered under the old method, and in addition providing better development of the aquifer.

The Ranney Method consists of sinking a reinforced concrete caisson from the bottom of which screens (sometimes called laterals) are projected horizontally like the spokes of a wheel (fig. below); as much as 3000 lineal feet from a single unit is practicable. The caisson is used as a clear well from which the water can be pumped. This complete unit is patented and is known as the "Ranney-Collector."



Ranney-Collector showing superstructure, caisson and laterals.

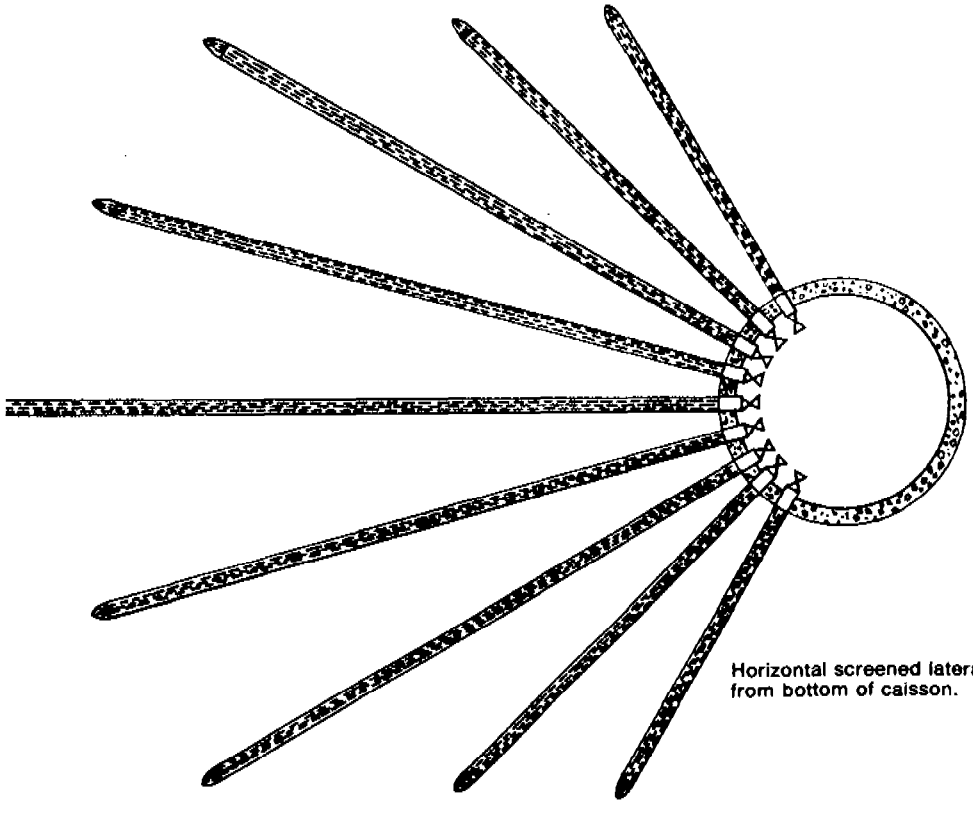


Figure 3–7. Ranney Collector Showing Superstructure, Caisson, and Laterals.

duce the velocity of water entering the well. This reduces erosion and deposition and maintains well yield for a longer period.

3–5. Capacity of Wells. The capacity of a well depends on the static water level, pumping water level, and water supplied to the aquifer supplying the well.

a. Water Levels and Drawdown. The static water level is the point at which water stands in a well when no water is being removed from the aquifer by pumping or free flow. An artesian well can have a static water level about ground surface that must be measured by pressure gages. The static water level depends on amount of water taken from the aquifer by wells and water supplied by precipitation and infiltration. If more water is removed than replaced, then the static water level or artesian pressure decreases.

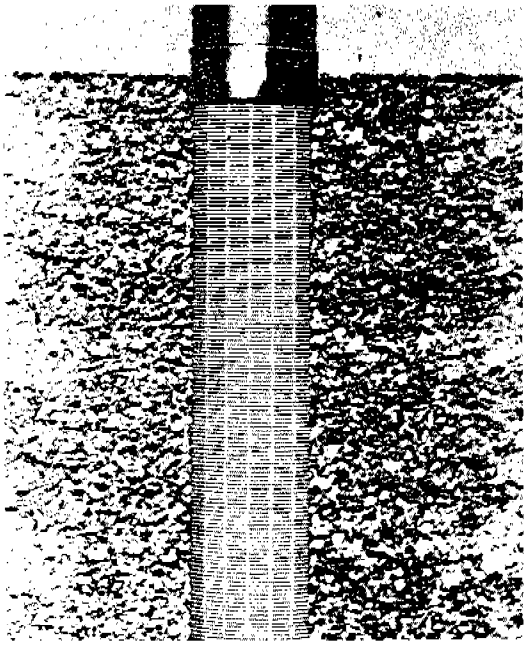


Figure 3–8. Naturally Developed Well.

As a well is pumped, the ground water is lowered in a cone of depression around the well (figure 3-10). Water level lowers to a pumping level. The drawdown in a well is the difference between static and pumping levels. It represents the head (in feet) that causes water to flow through the aquifer material toward the well at the rate at which water is being taken from the aquifer.

b. Yield. The yield of a well is simply the rate at which water can be pumped from a well. The yield can be estimated by several methods, (for example, sieve analysis of the aquifer and tests of flow characteristics). As more water is taken from an aquifer, further drawdown occurs.

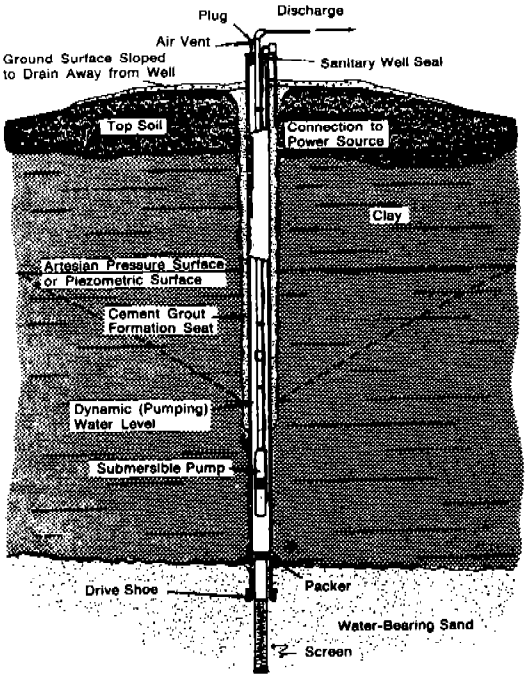


Figure 3–9. Drilled Well.

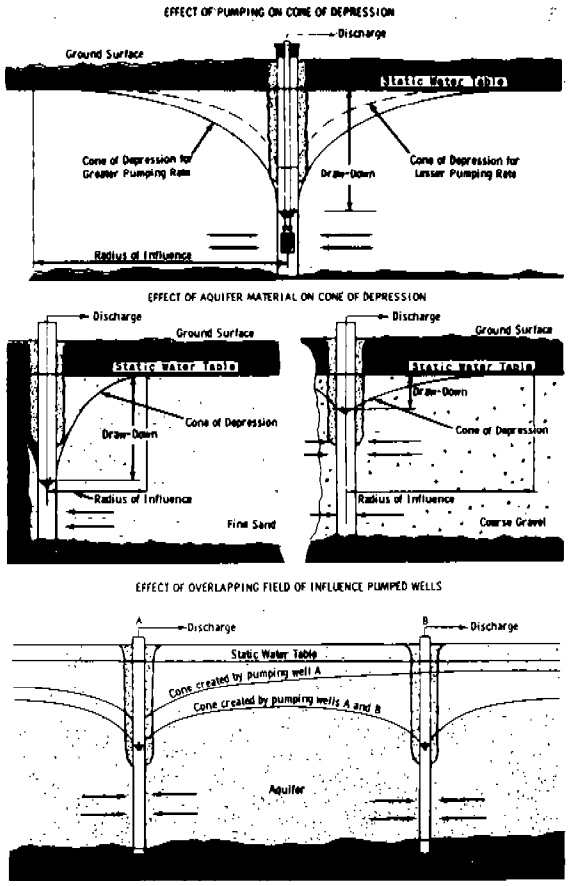


Figure 3–10. Pumping Effects on Aquifers.

c. Safe Yield. The safe yield of a well is the rate at which water can be withdrawn without exposing the well screen or the aquifer to the atmosphere. It is best to operate the well at about one-half to two-thirds of the distance down from the static level to the top of the well screen or aquifer. The safe yield from an aquifer is equal to the average annual quantity of water supplied to the aquifer by precipitation and ground-water movement.

d. Specific Capacity. This is the number of gpm pumped per foot of drawdown. If a well delivers 300 gpm with a drawdown of 15 feet, the specific capacity is 300/15 or 20 gpm per foot of drawdown. The specific capacity is not constant for all values of drawdown, but is nearly constant for wells tapping very thick aquifers or artesian aquifers. Usually the specific capacity decreases with increased drawdown. Decreasing specific capacity also reduces the safe yield from the well. Knowing the specific capacity of a well enables the operator to estimate the drawdowns that are produced at different pump settings. Comparing specific capacity measurements over a set period reveals changes in well characteristics and shows when maintenance is necessary.

e. Well Efficiency. This is the actual specific capacity of the well divided by the maximum possible specific capacity for the water-bearing formation. Properly designed, constructed, and developed wells have efficiencies as high as 80 percent. As the well is pumped, a reduction in efficiency

will indicate screen clogging or a reduction in aquifer permeability adjacent to the well intake. The latter condition occurs as the formation adjacent to the screen becomes plugged with fine material. Screen cleaning or redevelopment of the well is then required to increase the well efficiency. As the efficiency of a well decreases, the drawdown required to pump the same quantity of water from the well and the distance the water has to be lifted increases. This lower pumping level results in increased pump horsepower demand and power usage, with a resulting increase in pumping power costs.

3-6. Operation and Maintenance:

a. How To Start a New Well:

(1) Before the pump in a new well is started for the first time, several checks and operations must be performed including the following:

(a) Disinfect the well.

(b) Check alignment of the casing, pump column, and shaft on line-shaft pumps.

(c) Check the valves and piping system for proper operation and freedom from leaks. All valving should be set so that water pumped at startup is not fed into the distribution system until bacteriological quality is tested.

(d) Make plans for prelubricating the bearings on water-lubricated line-shaft pumps with settings of more than 50 feet.

(e) Inspect other details of pump and well construction including electrical and instrumentation connections.

(2) After preliminary work has been completed, the pump should be started. The pump, motor, and instrumentation should be checked at once for any evidence of malfunction.

(a) Check operation power input.

(b) Check rotation direction of motor.

(c) Observe how quickly motor comes up to operating speed and check final operation speed.

(d) Check water or oil lubrication system.

(e) Check pump, motor, and bearings for excessive heat or vibration.

(f) Refer to table 4-7 (paragraph 4-3) if the:

1. Pump fails to start.

2. Motor starts but pump is locked.

3. Pump does not deliver water.

4. Pump does not deliver designed capacity.

5. Pump uses excess power.

6. Pump vibrates.

(3) After the pump is started:

(a) Make an immediate check of pumping water level, followed periodically by additional water-level checks as shown in figure 3-11.

(b) Check for abrasive material (sand pumping) or the presence of gas within the well.

(c) Check pump pressure and flow output. Determine the corresponding pumping level in the well. Compute the field head and compare this to the pump curve from the manufacturer. The pump curve supplied by the manufacturer should be a combined curve showing a composite assembly rating for multistage pumps, rather than just showing a single bowl assembly curve as is the case for a single-stage pump.

(d) The field head may be computed by calculating the static and dynamic head losses being overcome by the pump. The total field head is equal to the friction losses in the pump column and through the pump discharge elbow to the location of the pressure gage on the pump discharge; plus the vertical distance from the pumping level in the well to the pressure gage; plus the pressure gage reading converted to feet of head.

1. For example, a pressure gage located on the discharge of a well pump indicates a pressure of 35 pounds per square inch (psi) for a discharge of 500 gpm. The corresponding pumping level in the well is 60 feet below the elevation of the pressure gage. The pump column is 8 inches in diameter and extends into the well 100 feet below the pump discharge.

2. The friction loss for 500 gpm of water through an 8-inch pipe and C = 100 is 8.1 ft/1,000 ft (from figure A3-2). The equivalent length of an 8-inch long sweep elbow is 13 feet (from figure A3-3). The friction loss through the column and discharge elbow is therefore equal to:

$$113 \text{ ft} \times \frac{8.1 \text{ ft}}{1000 \text{ ft}} = 0.9 \text{ ft}$$

3. The vertical distance from the well pumping level to the pressure gage was given as 60 feet.

4. The pressure at the pressure gage expressed as feet of head is equal to:

$$35 \text{ psi} \times \frac{2.31 \text{ ft}}{\text{psi}} = 80.9 \text{ ft}$$

5. The total field head would be equal to:

$$0.9 \text{ ft} + 60 \text{ ft} + 80.9 \text{ ft} = 141.8 \text{ ft}$$

(e) After pumping for 24 hours, collect a water sample for microbiological analysis to make sure the water is free from disease-causing organisms.

b. Balancing the Pumping Schedule. When water is pumped from a well, a depression is produced in the water table as drawdown occurs. When pumping is stopped the water again rises to the static water level (figure 3-11). The depth and lateral extent of the cone of depression depends on the pumping rate of the well. If two or more wells are located so close together that their cones of depression overlap, the wells compete with each other for the ground water, each producing less water than if operated alone (figure 3-10). Wells should be operated in rotation to equalize wear on pumping equipment. Operating wells should be as far apart as possible to keep the effect of the radius influence of the individual well's cone of depression to a minimum.

c. Pump Operation. Wells should be pumped carefully and within specified pumping rates.

(1) Excessive pumping rates may cause sand and silt to pack in and around the well screen, thus clogging the screen, or fill the voids in gravel-pack wells, thus reducing yield.

(2) When a well pump is started or stopped, a certain amount of agitation occurs in the aquifer around the well. Frequent starting and stopping may erode part of the aqui-

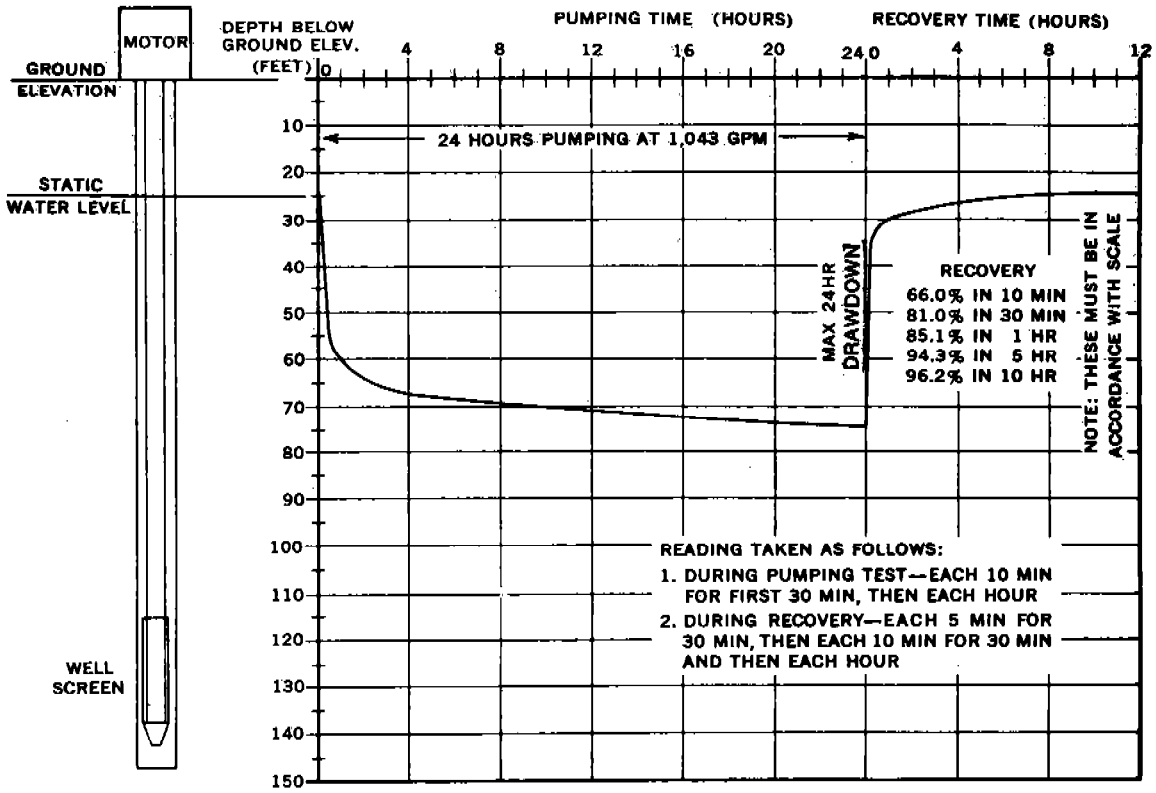


Figure 3-11. Typical Well Pumping and Recovery Test.

fer and cause clogging or cave-ins that reduce yield.

d. Measurement of Water Levels and Drawdown. To evaluate the performance of a well, it is necessary to conduct well tests. These tests include measuring the static water level, the pumping rate, the pumping levels at various times after pumping has started, and the increasing water levels after pumping has stopped. Measure the static level, pumping level, and drawdown on each well daily. If daily measurement cannot be made because of the large number of wells or difficulty in making the measurements, measure the level in each well at least twice a month at as near the same time as possible.

(1) Orifices, meters, pitot tubes, or other flow measuring devices, as described in chapter 5, are used to measure the flow rate.

(2) Water levels can be measured using the air line method, electric sounders, wetted tape, or electrical depth gages. The most common method of depth measurement is the air line method, which is described below:

(a) An air line of known length is placed (or has been permanently placed) in a well to a depth below the expected pumping level. Connect the surface end of the line to a bicycle pump and connect a pressure gage into the line so the air pressure in the line can be read. Make all joints airtight.

(b) With the well pump shut down, apply air pressure through the bicycle pump until the gage needle no longer registers any increase in pressure. The gage reading then shows the amount of pressure that was necessary to force the the standing water out of the air line. This is directly proportional to the height of water standing in the well above the bottom of the air line. Multiply the gage pressure in psi by 2.31 to determine the height in feet. Use of a gage that indicates feet of water is preferable. To determine the distance below the air gage at which the water stands in the well, subtract the calculated height of water above the bottom of the air line from the known length of the air line below the well top. This is the static level.

(c) Start the well pump and observe the air gage until the reading no longer changes, pumping in additional air to make up for any leakage. Convert this pressure reading to feet. It is the height at which water stands in the well above the bottom of the air line during pumping. Deduct this from the length of the air pipe below the well top to get the pumping level. The difference between the static level and the pumping level is the drawdown.

(d) For example, assume a length (L) of air line of 150 feet. Assume that the pressure gage reading (P_1) before starting the pump is 25 psi. Then pressure converted to feet (A) is $25 \times 2.31 = 57.7$ feet. The static water level (B) = L − A = 150 − 57.7 = 92.3 feet. Assume that the gage reading (P_2) during pumping is 18 psi. Converted to feet (C) this is $18 \times 2.31 = 41.6$ feet. The pumping level (D) = L − C = 150 − 41.6 = 108.4 feet.

(e) The drawdown is determined by any of the following methods:

1. D − B = 108.4 − 92.3 = 16.1 feet.

2. A − C = 57.7 − 41.6 = 16.1 feet

3. $P_1 - P_2 = 25 - 18 = 7$ psi; 7 psi × 2.31 = 16.1 feet.

(f) The comments made above are illustrated in figure 3-12.

(3) Maintain careful records of static level and drawdown correlated with capacity or pumping rate. This helps to anticipate difficulties in advance and provide data for proper maintenance measures. The following examples prove the value of properly maintained records:

(a) A falling static level indicates gradual lowering of the water table or reveals interference by other installation wells.

(b) An increased drawdown may show receding ground water level, interference of other wells, leaky casing or delivery pipes; clogging, scaling, or corroding of well screen; gravel area and adjacent stratum becoming packed with sand or silt, or a cave-in of water-bearing stratum.

(4) Measurements are taken periodically to develop a well chart as shown in figure 3-11. Pumping rate can be controlled to a constant rate by a valve in the discharge line. The test should start with the valve one-half to three-fourths open at the desired flow rate. Well charts are compared with prior test results to indicate changes that require attention.

e. Check for Safe Pumping Yield. The drawdown measured should be compared to the depth of the top of the well screen or artesian aquifer. To prolong the life of the well, especially a gravel-packed well, and to decrease maintenance at the proper yield, the well should be operated at a pumping rate causing only 50 percent of this maximum drawdown. If desired yield cannot be obtained at this pumping rate, it may be necessary to undertake maintenance functions to restore well yield.

f. Cleaning Well Screens. The most common cause of decreasing yield is clogging of the aquifer or well screen in the vicinity of the well bore. If the specific capacity has dropped to 60 percent of the new well value, then the well screen cleaning can improve yield. If it has dropped to 40 percent of the new well value, it is usually necessary to redevelop the well. Well screens on deep wells can be cleaned in place by using one of the methods below. Well screens can also be pulled for cleaning or to be reused.

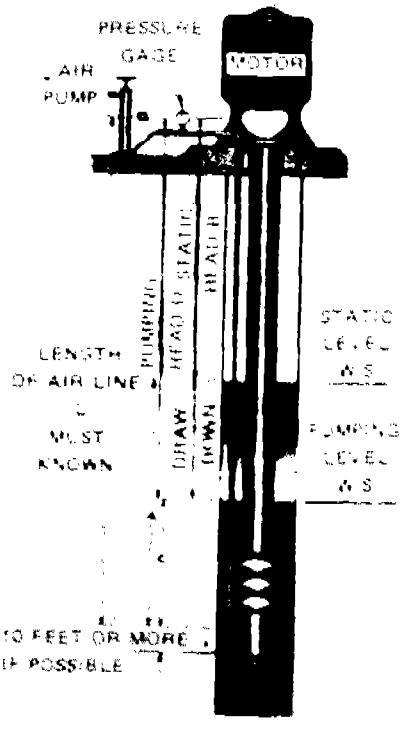


Figure 3-12. Using Air Line To Find Depth of Water Level.

(1) Acidizing. Encrustation of screens is caused principally by the deposition of calcium carbonate, or sometimes by deposition of iron oxide or calcium sulfate. It may also be caused by corrosion. Acidizing with properly inhibited muriatic acid or sulfamic acid cleans encrusted screens. Do not use uninhibited acids. The following procedures apply:

(a) Estimate the severity of encrustation from the records of changes in yield, specific capacity, drawdown, etc.

(b) Unless otherwise directed by the utility manager, base personnel should not be used for acidizing operations. Use an experienced and qualified contractor. All persons working on an acidizing project should wear proper protective clothing.

CAUTION: Before proceeding with the treatment, disconnect the well from the distribution system.

(c) Use an inhibited acid. Most frequently used for acidizing wells is muriatic acid (commercial hydrochloric acid, 27 percent concentration) purchased with, or to which has been added, an inhibitor. These inhibitors keep the attack on the metal to a minimum, but do not affect the reaction with calcium carbonate; they are proprietary compounds. The inhibitor or inhibited acid should be selected to obtain the maximum protection of the particular metal in the screen.

(d) Add the acid carefully through a hose placed in the case with its discharge end at the level of the screen. This prevents dilution of the acid and gives a concentration of about 15 percent at the screen.

(e) Usually leave the acid in the well for at least 5 hours. For quicker action, the acid may be heated, particularly if there is a flow of water past the well screen.

(f) After the acid treatment, pump the well to waste until the pH of the water returns to normal.

CAUTION: Provide for neutralization of this wastewater or other safe disposal until the water returns to normal.

(g) Sulfamic acid (do not confuse with sulfuric acid) may be used in place of muriatic acid when it is desirable to do so. Sulfamic acid is a granular solid that is safe and easy to store and handle. It may be dissolved in water at the job site to provide a strong acid solution that will do the same cleaning job as muriatic acid. Although sulfamic acid does not attack metals as rapidly as muriatic acid, inhibitors should still be used to protect the casing. To dissolve iron oxide deposits on the screens, add 50 pounds of salt (sodium chloride) for every 100 pounds of granular sulfamic acid.

(h) Reaction of the acid in the well produces carbon dioxide and hydrogen. If iron sulfide is present in the well screen, encrusted hydrogen sulfide results. Adequate ventilation must be provided in pumphouses or other confined areas when acid treatment is being used. Personnel should

avoid standing in pits or depressions adjacent to the well being treated, because carbon dioxide and hydrogen sulfide are heavier than air and settle in low areas.

(i) Do not pump wells near to the well receiving acid treatment while cleaning is in progress.

(j) In addition to cleaning the well screen in place, the acidizing treatment described above can be used to dissolve encrustations before pulling the well screen. This treatment helps loosen the well screen in the well and makes it much easier to pull.

(2) Chlorine Treatment. In addition to acid treatment, chlorine solutions may be used for cleaning well screens. Chlorine added to a clogged well may function in two ways. First, it destroys bacterial slime growths; and second, it forms weak hypochlorous acid that attacks the calcium carbonate. Follow the steps in (a) through (c) below:

(a) Prepare solutions of chlorine that produce 100 to 200 mg/l of chlorine when mixed with the water in the well (tables 3-1 and 3-2). Introduce the solution into the well in the same way as acids are introduced.

(b) Allow the well to stand for 24 hours, and then pump to waste until the chlorine residual reaches 0.1 mg/l. Surging during chlorine treatment is helpful.

(c) Three of four successive treatments with chlorine should be performed. Alternating acid treatment with chlorine treatment can be very effective. The acid treatment should be completed first, followed by chlorine treatment after most of the acid has been pumped to waste. A second series of acid and chlorine treatments can be undertaken after the initial acid and chlorine treatments have been completed.

(3) Phosphate Treatment. The glassy phosphates (sodium hexametaphosphates) act as dispersing agents on such screen-plugging materials as amorphous silicia, hydrated ferric oxide, iron carbonate, and calcium carbonate. The treatment is as follows:

(a) Dissolve 15 to 30 pounds of glassy phosphate in a minimum amount of water and add 1 pound of calcium hypochlorite for each 100 gallons of water in the well casing (under static conditions). To dissolve the phosphate, suspend the chemical in a wire basket or burlap bag—do not simply dump it in the dissolving tank or barrel. Add the solution to the well through a hose in the same way as described for acids.

(b) Allow the solution to remain for 24 to 48 hours and surge every 2 hours or so. If surging is not possible, allow the solution to stand in the well a week.

CAUTION: Treatment with glassy phosphate for more than a week may cause the well yield to decrease.

(c) After treatment, pump the well to waste for 8 hours and test the output. Repeat the treatment until the output no longer improves. Analyze the phosphate content of the well water after final treatment and pumping to make sure it has been reduced to normal background levels.

(4) Dry Ice. Compressed carbon dioxide gas, or "dry

Table 3-1. Materials Required for 100 Gallons of Chlorine Solution.

Desired Chlorine Strength	Chlorine (lb)	Dry Calcium Hypochlorite, 70% (lb)	Quarts of Bleach Per 100 Gallons of Water		
			5%	7%	10%
50 ppm	0.05	0.07	0.4	0.3	0.2
100 ppm	0.10	0.14	0.8	0.6	0.4
150 ppm	0.15	0.20	1.2	0.9	0.6
200 ppm	0.20	0.30	1.6	1.2	0.8
300 ppm	0.25	0.40	2.4	1.7	1.2
400 ppm	0.35	0.50	3.2	2.3	1.6

Table 3-2. Gallons of Water Per Foot of Depth for Various Well Diameters.

Well Diameter (inches)	Gallons of Water Per Foot of Depth	Well Diameter (inches)	Gallons of Water Per Foot of Depth
4	0.65	20	16.32
6	1.47	22	19.75
8	2.61	24	23.50
10	4.08	27	29.74
12	5.88	30	36.72
14	8.00	36	52.88
15	9.18	42	71.97
16	10.44	48	94.00
18	13.22	60	148.88

ice" has been used for well cleaning with mixed results. It works best in deep wells with high static levels. For treatment procedure, follows these steps.

(a) For wells 6 to 10 inches in diameter; use 10 to 15 pounds of dry ice for light surging and 25 to 50 pounds for heavy surging. Drop broken dry ice (pieces about 2 inches in diameter) into the well casing until enough has been added to blow the water out through the screen. There is no danger of freezing if there are 11 pounds (approximately 1.5 gallons) of water in the well casing for each pound of dry ice added.

(b) Provide a pressure gage on the well casing and seal the well to prevent loss of CO_2. When the gas is released, it expands and creates a surging action that produces backpressure and backwashing of the screens. The escape of gas through the water-bearing strata will be evident from irregular movement of the pressure gage needle. The particular conditions involved are different in practically all cases, and the exact procedure must depend largely on the judgement of the operator.

CAUTION: Dry ice may cause "burns" if handled with bare hands. Therefore, use heavy gloves or tongs. Also, since high pressure may develop in dry ice treatment, provide for control and release of excessive pressure (150 psi). The gas is suffocating, and ample ventilation must be provided.

(5) Jet Cleaning. Horizontal jet cleaning of wells is done from inside the well screen. A relatively simple jetting tool with high pressure pump, necessary hose, a string of 2-inch pipe, and an adequate water supply are the only equipment needed. The jetting tool is shown on figure 3-13. It consists of an attachment fitted with one to four horizontal nozzles (3/16, 1/4, or 3/8-inch orifices). The bottom of the tool is closed and the upper end is threaded so that it can be screwed to the lower end of the string of 2-inch pipe.

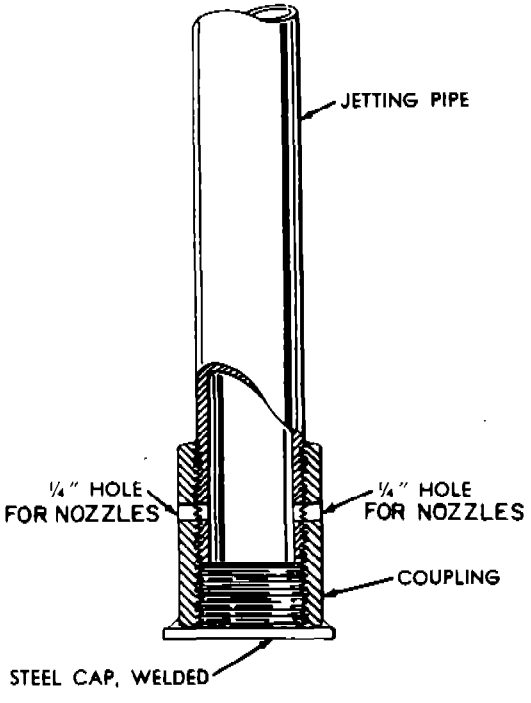


Figure 3-13. Jetting Tool for Well Screen Cleaning.

(a) Select a nozzle to match the output of the high pressure pump used and the well pump (table 3-3).

(b) Attach the string of 2-inch pipe to a hose with a swivel connection at the top.

(c) Lower the jetting tool to the screen, turn on the high pressure pump, and slowly rotate the jetting tool while it is being slowly raised and lowered. The forceful action on high-velocity jets, working out through the screen openings, breaks up the clogging material.

(d) Pump the well lightly at the same time the jetting is underway in order to remove the dislodged material. The well pump should pump out approximately 15 percent more water than is being added to the well by the jetting tool.

(6) Sonic Process. This method must be performed only by outside contractors. It consists of lowering a series of small, explosive charges on a wire into the well and detonating them by means of an electrical charge at the surface. The size of each charge depends on pipe size, thickness, grade, type, and condition. The charges are placed on a connecting wire at calculated distances and are detonated in a special, time-delay sequence. Each charge, lasting only a fraction of a second, creates an expanded gas bubble that produces a shock wave at its leading edge as it rushes down the well column. As the wave strikes the well casing, it causes strong vibrations that help loosen the clogging material. The expanding bubble also produces a surging action that helps clean the screen. This action is repeated with the detonation of each charge. Sonic processes are most effective in sandstone aquifers where clogging may only extend 1 to 2 inches into the aquifer.

CAUTION: Do not use any other method of blasting for cleaning screens.

g. Well Screen Repair. It is sometimes desirable to pull a heavily encrusted screen for cleaning. Likewise, a screen that is suspected of being damaged by corrosion should be pulled and inspected. The wire windings, bail plug, and packer should be inspected for damage on screens that have been pulled for any reason. If the screen has corroded away or been damaged, it should be replaced with a new screen or returned to the factory for repair. Generally, field repair of well screens is neither practical nor effective.

h. Surging, Backwashing, and Backblowing. These methods are used to clean the well screen and assist in cleaning the aquifer.

(1) Surging. Surging is accomplished by a different method from that used for surging a new well being developed. This operation can be accomplished by utility personnel, without pulling the pump and without expert help. Follow these steps.

(a) Disconnect the discharge of the pump and alternately start and stop the pump. This operation raises the water in the pump casing and allows it to fall again. The greater the distance to the static water level, the more effective the operation. If the water level in the well stands at a high elevation, a surge pipe may be attached to the discharge of the pump.

Table 3-3. Jetting Nozzle Discharge.

Orifice (inches)	150 psi		200 psi		250 psi	
	1 Nozzle (gpm)	2 Nozzles (gpm)	1 Nozzle (gpm)	2 Nozzles (gpm)	1 Nozzle (gpm)	2 Nozzles (gpm)
3/16	13	25	15	29	17	33
1/4	23	45	26	52	52	37
3/8	49	97	56	110	61	120

(b) Repeat the process of starting and stopping the pump at 3 to 5 minute intervals until the discharge runs clear. Water running back down the pump column just after the pump is stopped may cause the motor and impeller to turn in a reverse direction. Do not attempt to start pump during this time of reverse rotation.

(2) Backwashing and Surging. When surging alone is not sufficient, backwashing may be used. This procedure consists of allowing a large volume of water to rush down the casing. Detailed steps are:

(a) Where bypass pump connections or wash water lines are not included in the installation, remove the flap in the check valve.

(b) Open the pump discharge valve and allow a full head of water from the storage tank to rush down the well casing. If the casing fills rapidly, it is because the screen is badly clogged.

CAUTION: Before starting the backwash operation, be sure the pump and motor turn freely; otherwise the downrush of water may rotate the pump in the wrong direction and unscrew the pump shafting.

(c) Allow the backwashing to continue for 5 minutes or so then close the backwash valve, open the pump discharge valve and start the pump. Run the discharge to waste until the water is clear. Repeat the operation. Check the results by measuring the water level and yield.

(3) Backwashing and Backblowing. A combination of backwashing with water and backblowing with air may be used, if the well pump has been pulled. The compressed air increases the surging action and provides air-lift pumping that removes dislodged sand. Use experienced personnel for this operation, and follow this procedure.

(a) Remove the well pump and insert a 4-inch eductor pipe to a depth according to table 3-4. The arrangement of eductor pipe and air line is shown in figure 3-14.

Table 3-4. Eductor Submergence Required for Various Well Depths.

Depth of Well (ft)	Submergence of Eductor (%)
10-50	70-66
51-100	65-55
101-200	54-50
201-300	49-43
301-400	42-40
401-500	39-33

(b) Cap the 4-inch eduction line with a tapped pipe plug through which the air line runs. Connect the air pipe by means of air hose (or nonrigid system) to an air compressor having a minimum capacity of 110 cubic feet per minute (cfm).

(c) With the eduction valve open, build up the air pressure until the water is discharged and pressure reaches a constant value. Pump until water becomes clear.

(d) Release the air pressure, close the 4-inch dis-

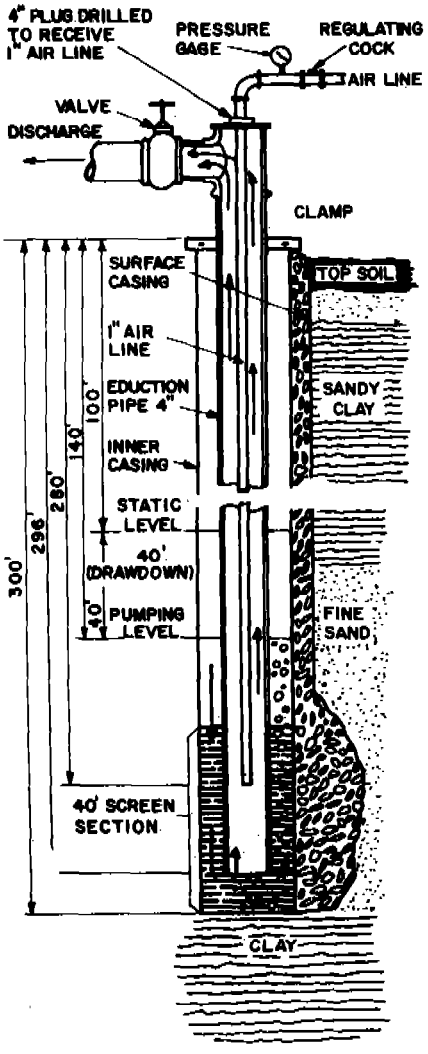


Figure 3-14. Piping Arrangement for Backwashing and Backblowing.

charge valve; apply air until static pressure is reached. At this point air escapes from the bottom of the 4-inch eduction pipe and causes both air and water to surge through the screen and create movement in the sand and gravel.

(e) Open the 4-inch valve and allow the air-lift to pump out the loosened sand and silt.

(f) When the water is clear, repeat steps (d) and (e) above. Faster results are obtained if water can be pumped into the well casing at the same time as air is being added (step (d) above).

(g) Check results after each series of operation. An increase in pumping pressure on the gage indicates increasing inflow into the well and less drawdown.

CAUTION: When starting backblowing operations, do not start at maximum rates. The gravel chamber should be full at all times to replace sand loss.

(h) For this operation, provide excess air. The desirable amounts of excess air, with 50 percent submergence, are shown in table 3-5.

i. Maintenance for Specific Well Types. In addition to the general maintenance items common to all wells, different types of wells require special care because of their particular construction or operation. Ground water supply maintenance procedures discussed in this subsection, as well as previous subsections of chapter 3, are summarized in table 3-6.

(1) Bored Wells. Casing failures and screen clogging are primary causes of failure of bored wells. High turbidity in the water may indicate that the screen should be cleaned or replaced.

(2) Dug Wells. The masonry or concrete casings are subject to cracking and joint failure allowing surface water to enter into the well. The bottoms can fill with silt and sand which must be periodically removed.

(3) Driven Wells. Driving the well point may damage the screen or seal it off. If water yield decreases, suspect screen clogging and try backwashing. If this fails, pull the point and clean or replace it with a new one.

(4) Drilled Wells. Little maintenance of casings is needed for drilled wells. Screens can clog and must be cleaned periodically. It is a major job to inspect or remove the screen.

(5) Gravel-Packed Wells. Both the gravel and screen may clog in a gravel-packed well. The gravel level needs to be maintained above the well screen by periodic gravel additions.

j. Springs. Springs are subject to surface contamination. Regular inspection of the area around the spring and the spring structure should be made to detect and guide preventive measures for contamination control. If contamination is detected, the spring should be thoroughly disinfected before being returned to service.

Table 3-5. Air Requirements for Backwashing Well Screen With Air-Lift.

Lift (ft)	Air Required (cfm/gal pumped)
100	0.5
200	0.7
400	1.0
500	1.5

k. Infiltration Galleries. In addition to silt accumulation, undermining of walls and failure of the wall structures may occur. Operating records on static level and drawdown will indicate if the yield is being maintained. Cross bracing, adding sheet piles, and adding gravel are maintenance functions that are undertaken to increase the life of the structure. Yield can sometimes be increased by driving wells in the bottom of the galleries.

l. Ranney Wells. Ranney water collectors may be subject to contamination from overlying ground pollution if they are not deep. In some locations, silt or sand may accumulate in the caisson and requires removal. If spalling of concrete walls is severe, dewatering of the collector well and guniting the surface may be required.

m. Maui Wells. Maui wells require maintenance of weirs, walkways and steps, pumps and motors, and electrical systems for lighting and ventilation. The tunnels may extend several hundred feet underground. Care must be taken to prevent contamination of the water collection system.

n. Ground Water Conservation. Subsurface water represents water in storage. Pumping from wells depletes the supply of stored water. Infiltrated water replenishes the supply. Conservation consists of balancing the pumping rate with the supply rate so that storage water is not depleted. In some areas pumping has outstripped the recharge supply and artificial recharging has emerged as a water conservation practice. Excess storm water, streamflow, or treated wastewaters are pumped or allowed to seep into the ground water.

3-7. Coastal Ground Water Supplies:

a. Saltwater Intrusion. When ground water supplies are taken from coastal areas, saltwater from the ocean may enter the aquifer. Seawater is heavier than freshwater allowing freshwater to float on top of seawater under calm conditions. Pumping from an aquifer upsets the balance and may allow saltwater to rise.

b. Effects of Pumping. Pumping lowers the water table if the pumping rate of wells in the aquifer exceeds the natural recharge to the aquifer. Frequent checks on static water level are needed to monitor aquifer levels. Pumping must be decreased or terminated if static or pumping levels are lowered.

c. Special Operating Procedures:

(1) The chloride content of water from aquifers where saltwater intrusion is possible must be checked regularly. If the chloride level is increasing, the pumping rate must be reduced. If the chloride level exceeds the allowable limit, the pump must be shut down to allow fresh-water to displace the saltwater.

(2) Artificial recharge has been used in some areas to establish a barrier against saltwater intrusion.

3-8. Well Records. Records to be maintained for wells include the well log of the original wellhole, pump design details, maintenance records, water quality analyses made on the water, well discharge meter readings, schedule of which pumps and wells are in use and for what periods of time, pumping and static levels of well capacity tests, and pump discharge pressure at various pumping rates. In addition, long-term records of rainfall and the departure from normal rainfall amounts help show if changes in the level of the water table and artesian pressure surface are due to variations in long-term rainfall patterns. Air Force personnel use AF Form 996, Well Data, and AF Form 997, Daily Well Activity Record, to record this information.

3-9. Protection of Ground Water Supplies:

a. Factors Affecting Ground Water Quality:

(1) The quality of ground water is influenced by the characteristics of the soil and the underground layers of rock, sand, and gravel through which it flows. As water flows downward, carbon dioxide, which is a waste product of bacterial activity in the soil, is dissolved and the water becomes more acid. Water is also filtered as it passes through the soil; thus it becomes clear. Acid water is soft water, but it also has the capability of readily dissolving other soluble minerals that it contacts as it flows through the ground. Limestone (calcium carbonate) is easily carried into solution by an acid water and, in the process, changes the water from soft to hard.

(2) Sources of surface or underground pollution may affect the quality of ground water. In limestone regions where there are many cracks, crevices, and caverns, pollution from surface streams or drainage is particularly hazardous to underground supplies. Such pollution may be carried many miles, contaminating wells or springs. Lagooning of industrial or municipal wastes and injection of sewage effluent should be prohibited in such regions. Underground discharges of wastes from cesspools or spetic tanks may also create a hazard to a ground supply.

b. The Sanitary Survey. Wells, springs, and infiltration galleries are vulnerable to contamination from surface water. Cesspools, privies, septic tanks, sewer lines, tile drains, and unsealed abandoned wells can provide direct connections to underground aquifers. The sanitary survey is undertaken twice a year to identify and correct conditions in the vicinity of the well or aquifer that can cause its waters to be contaminated.

c. Protection Against Surface Contamination:

(1) Locate a well or spring on high ground, if feasible, and as far as possible from the nearest pond, lagoon, privy, or barnyard.

(2) If natural drainage away from a well is not available, grade the surface (within 50 feet) to drain away from the supply. In the case of springs, provide a diversion ditch and curbing to prevent surface contamination and to protect against flooding.

(3) Provide a fence to keep livestock at least 500 feet away.

(4) Provide a watertight concrete slab that slopes away from the well and which extends at least 18 inches beyond the casing or curbing.

(5) The annular space outside the casing should be filled with watertight cement grout or puddled clay from the surface to the depth necessary to prevent entry of contaminated water. When a water-bearing formation that has poor quality water is penetrated, the formations should be sealed to prevent infiltration of the poor quality water into the well or aquifer.

(6) Extend the well casing at least 6 inches above floor slab level and at least 1 inch into the pump base to prevent flooding. Keep the casing and top of the well head sealed at all times. Extend the casing downward to 10 feet below the water table if possible, but at least 10 feet below the ground surface.

(7) For a well pumphouse, provide a floor drain and conduct drainage at least 30 feet away from the well to a gravel pocket. Do not connect this drain to a sanitary or storm sewer.

(8) Repair defective well linings.

(9) Screen well vents to prevent entry of insects, rodents, or dirt. The well vent prevents a partial vacuum inside the well casing as the pump lowers the water level in the well. Therefore, the vent must not become clogged.

(10) Maintain water tightness in all well structures and keep well works in good repair.

(11) Seal all test borings and abandoned wells with puddled clay or concrete to prevent surface contamination from reaching the ground water supply. This may not be practicable if the well is located in a region of fissured limestone where pollution can travel great distances. How a ground water supply may be contaminated by surface pollution through a fissured limestone formation is illustrated in figure 3-15.

d. Protection Against Underground Contamination:

(1) Locate wells at a sufficient distance from latrines, septic tanks, subsurface drainage fields, and polluted bodies of water to prevent contamination. This distance depends on local conditions such as direction of movement of underground waters, tightness of soil, and rate of pumping. Wells may be located within 50 feet of cast-iron sewers with caulked joints. A ground water source in fractured ground or rock cannot be considered safe.

(2) Disinfection of all supplies from springs and infiltration galleries is required to make sure that the water is safe for human consumption. Control of pollution that may enter the catchment areas of such waters is uncertain and difficult. Practice of watershed inspection and sanitation is required, but does not eliminate the need for disinfection.

(3) Although full protective measures may be taken to prevent contamination of wells, pollution detection is difficult and pollution from undetected sources may enter the supply. Therefore, all well-water supplies must be disinfected. Grossly polluted wells should be abandoned. If bacteriological and chemical tests consistently reveal contamination in the untreated well water, a special study should be made to determine causes of the pollution.

e. Protection Against Contamination Through Improper Operation. To guard against pollution through improp-

er operation of well supplies:

(1) Always prime the pump with potable water.

(2) Disinfect the pump and drop pipe before installation and after any repair as they are lowered into the well. NOTE: Give particular attention to the disinfection of the pump packing. Difficulty is sometimes experienced in ridding this particular area of bacteria.

(3) Keep drain from the pump base open and free so that any leakage will be carried away from the source.

f. Disinfection of Wells. Major pollution of aquifers may take years to overcome. Minor pollution may be overcome by the normal operating procedure of chlorination. Disinfection (as a maintenance procedure) may be applied to wells, springs, infiltration galleries, and Ranney collectors. Deep wells must be disinfected after original development; each time the pump is removed; each time the screen is cleaned by surging methods; and whenever regular bacteriological analyses indicate contamination is present. Disinfection can best be done by preparing a stock chlorine solution that, when mixed with 100 gallons of water in the well, provides a dosage of 100 mg/l. The stock solutions described below have a volume of 2 quarts. Two quarts of the stock solution are required for each 100 gallons of water in the well.

(1) How to Prepare Stock Solution. Calcium hypochlorite (65 percent available chlorine) or sodium hypochlorite (liquid household bleach containing 5.25 percent available chlorine) can be used to make the stock solution.

Table 3-6. Maintenance Procedures for Ground-Water Supplies.

Inspection	Action	Frequency[1,2]
Operating record review	Ascertain changes in conditions since previous inspection and take necessary action.	SA
Sanitary conditions	Dig ditches to carry away standing water within 50 ft. of well, spring or infiltration gallery.	SA
Pollution sources	Fence area to keep livestock at least 50 ft. distant from well, spring, etc.	SA
	Remove cesspools, privies, septic tanks, etc.; cover area with hypochlorite; fill any open excavations resulting from removal.	SA
Wells, springs, infiltration galleries, silt, etc.	Remove accumulations if more than 1 ft. deep.	V
Concrete; cracks in housing; Other watertight structures of wells, springs, infiltration galleries and Ranney wells.	Repair as necessary by making surface structure watertight.	Q
	Shore up infiltration gallery wall structures.	Q
Operating records and evidence of contamination.	Disinfect wells, springs, infiltration galleries, etc., when indicated.	V
Well output loss and condition of well screen.	Clean well streen by approved method.	V
Well equipment (well apron, top of casing, well pits); cracks and possible leakage.	Repair as necessary to make all items watertight.	SA
Well vents	Clean, repair or replace if torn or clogged.	M
Water use for equipment operation.	Make certain water for bearing lubrication and pump priming are from a safe supply, and that cooling water for engines and compressors is not returned to water system.	SA
Air intakes on compressors	Screen air intake if necessary; clean and replace air filters; blow down air storage tanks to remove accumulated oil.	M
Bored wells; casing failure	If water is turbid, the screen is defective; remove and replace.	V
Dug wells; silt accumulation and wall failure.	Clean as necessary; repair cracked walls; increase capacity if necessary by driving horizontal collector pipes.	Q
Driven well; decrease in water yield and screen clogging.	Try backwashing, or pull the point and clean or replace.	M
Gravel-packed wells; silt clogging of screen and gravel pack; check gravel level.	Clean as necessary; add new gravel as required to keep the level at proper elevation.	M

[1]M-Monthly; Q-Quarterly; SA-Semiannually; V-Variable, as conditions may indicate.

[2]The frequencies shown are suggested frequencies which may be modified by local command, as individual installation conditions warrant.

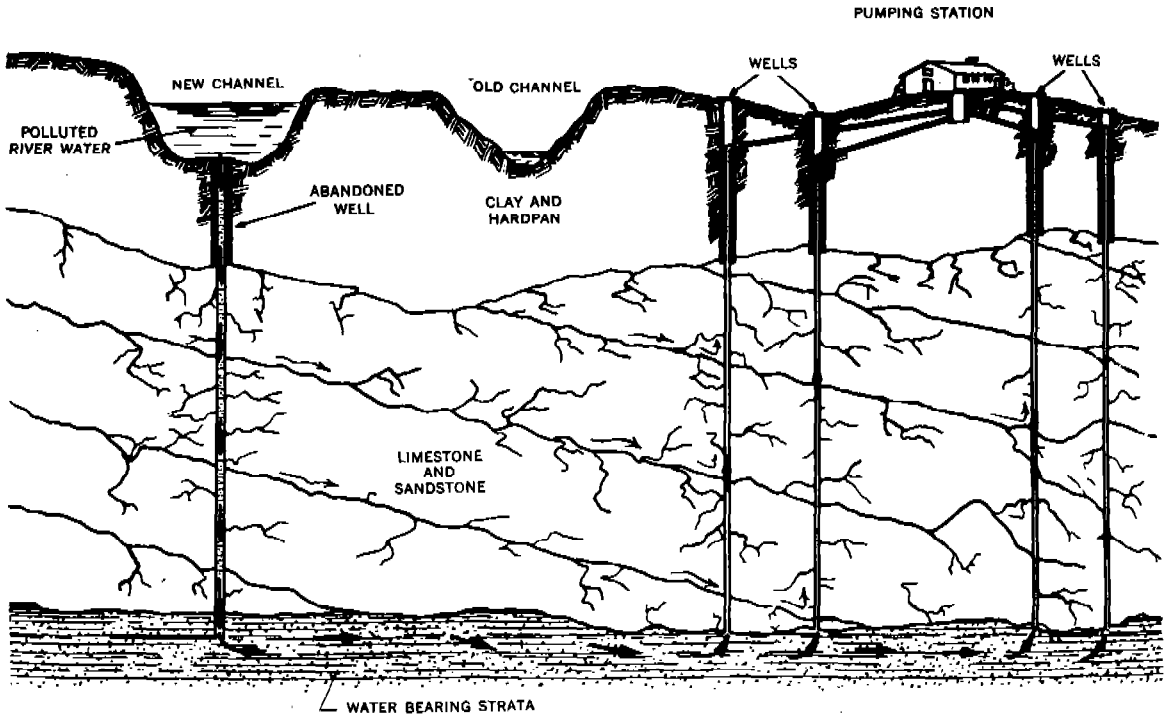


Figure 3–15. Wells Polluted by Flow From an Abandoned Well Through Fissured Rock.

(a) Calcium Hypochlorite. Two ounces of granular high test calcium hypochlorite may be added to a small quantity of water and stirred to a smooth watery paste free of lumps. This mixture is then added to enough water to make up a 2-quart solution. The solution should be stirred for 10 to 15 minutes before allowing the inert ingredients to settle. The clear liquid with the chlorine should be used and the inert ingredients discarded. The solution should be prepared in clean crockery, glass, or rubberlined containers. Metal containers will be corroded by the strong chlorine solution.

(b) Sodium Hypochlorite. One quart of common liquid household bleach can be diluted with one quart of water to give a stock solution that can be used for disinfecting 100 gallons of well water.

(2) Drilled, Driven, and Bored Wells. Calculate the quantity of water in the well based on the depth of water and the contents of the well in gallons per foot (table 3–2). Introduce 2 quarts of stock solution for each 100 gallons of water in the well. The stock solution should be poured directly into the well through a clean hose that is being alternately raised and lowered in the well water. Operate the pump until a distinct odor of chlorine can be detected in the water discharged. Allow the well to stand for 24 hours, and then pump to waste until the chlorine residual drops to an acceptable level. Surging during chlorine treatment is helpful. Obtain samples for bacteriological analysis and determine potability before putting well in service.

(3) Dug Wells. After the casing or lining has been completed, use a stiff brush or broom to wash the interior wall of the casing or lining with a strong solution (100 mg/l) of chlorine. Calculate the quantity of water in the well and follow the procedure for disinfection described above for drilled, driven, or bored wells.

(4) Springs. Spring encasements should be disinfected by a procedure similar to that described for dug wells. If the water pressure is not sufficient to raise the water to the top of the encasement, it may be possible to shut off the flow from the spring and keep the chlorine solution in the spring for 24 hours. If the flow cannot be shut off completely, disinfection should be continued for as long as practicable. Stock chlorine solution can be used as the disinfecting agent and bacteriological testing should be completed before returning the spring to use.

(5) Infiltration Galleries and Ranney Collectors. Add sufficient hypochlorite compounds to ensure a free residual chlorine concentration in the gallery of 50 to 100 mg/l, allow to stand for 24 hours and then pump to the storm sewer system until the residual chlorine content drops to an acceptable level.

g. Abandonment of Wells. Wells may be abandoned because of lowered water table, plugged screens, corroded casings that allow soil to enter the well, or objectionable sand pumping. The following procedures apply:

(1) For deep wells and driven wells, the casing should be pulled and the hole filled with concrete. The top of the well should be securely capped to prevent any person or animal from falling into the well. The well cap also helps prevent contamination of the aquifer.

(2) Dug wells and springs, when abandoned, should be filled as a safety measure.

Section C—Surface Water Supplies

3–10. General Information:

a. Occurrence and Movement. The portion of rain or

melting snow that becomes surface water is called runoff. Gravity and the geology and topography of the earth completely control the movement of this water. In some areas where fresh water is extremely scarce, rainfall is collected directly in a controlled catchment area. In most cases, however, the rainfall runs off the land into a stream or lake. The land area from which surface runoff drains into a stream or lake is called the watershed of the stream or lake.

b. General Characteristics. Rainfall is free from most impurities as it starts its fall from the clouds. It is low in mineral content, near neutral pH, and therefore "soft." As it falls through the atmosphere, it absorbs gases and airborne dusts. The pH decreases and the rain becomes acidic. As the rainfall hits and flows from the earth's surface, it comes in contact with material which it dissolves or suspends. Even though the water from a controlled catchment area has not been allowed to come in contact with all the contaminants that affect water flowing into most streams or lakes, filtration and disinfection are generally required to ensure potability. Much of the water in a stream or lake has flowed over open fields, agricultural areas, and urban areas. Generally, sewage from industries and cities are discharged to surface waters. The end result is a water supply that is highly variable in flow and quality. Surface water is usually lower in mineral content than ground water but almost always contains suspended material such as silt, algae, and other organic material that makes the water turbid. Surface water is much easier to obtain than ground water, but usually requires more extensive treatment than ground waters to make it acceptable as a water supply. Structures can be constructed to store surface water for use.

3-11. Rainwater Catchment:

a. Controlled Catchments. In areas where deep well or surface waters are not available for a potable water supply, rainwater catchment is one method of providing fresh water. Rainfall is collected after flowing from a defined surface area. The area may be a roof or a paved ground surface. The collected water is stored in tanks, filtered and disinfected before being pumped to the distribution system. Losses of water due to evaporation and infiltration on asphalt or concrete covered ground is slight. Approximately 90 percent of the rainfall landing on the catchment area is collected for treatment. Ground surface catchments should be fenced to prevent unauthorized entrance by either human or animal. An intercepting drainage ditch around the upper edge of the area and a raised curb around the surface helps to prevent mixing of undesirable surface drainage with the controlled runoff. "Bermuda roofs" or similar structures and cisterns are common in some areas as collection and storage structures.

b. Water Quality Characteristics:

(1) The rainwater has a low mineral content, so it is soft. It also is generally corrosive in nature and attacks unlined metal piping.

(2) Those catchment areas located near the shoreline on islands in the ocean are subject to mineral deposition from ocean vapors and sprays carried by the wind. The mineral content of runoff from ocean shoreline catchment areas increases as the length of time between rainfall events increases. The rainfall dissolves the minerals deposited on the catchment area and transports them to the treatment system. Most treatment systems for these waters are not designed to remove dissolved minerals. At times, the chloride ion concentration in the runoff may increase beyond the 250 mg/l level recommended in EPA guidelines. During these periods, it may be necessary to dilute the treated water with distilled water from backup seawater distillation units to get good quality water with no mineral taste.

c. Maintenance of Rainwater Catchment Systems. The catchment area itself should be inspected regularly to make sure that the drainage ditch and curbing surrounding the area are in good repair. The paved concrete or asphalt surface should be checked for cracking and suitable patching procedures used to repair any cracks or breaks. Most ocean island installations have backup equipment for desalting seawater during times of drought. This backup equipment must be kept in good repair and properly maintained so that it will operate properly during periods of rainfall shortage. Piping systems should be inspected regularly for corrosion.

3-12. Dams and Reservoirs:

a. Reservoirs Functions. The two basic functions of an impounding reservoir are to impound water for beneficial use and to retard flood flows. Beneficial uses may be for power generation, recreation, or water supply. Reservoirs made by humans are frequently constructed to serve more than one function. Lakes that are natural reservoirs can also serve many functions.

b. Types of Dams. Dams are the structures that are built to form reservoirs. Depending on the size, structural conditions, and intended length of use, dams may be built of masonry, concrete, earth, wood, steel, or a combination of these.

c. The Parts of an Impounding Reservoir for Water Supply:

(1) Spillway:

(a) A spillway structure can control the water level in a reservoir and the rate of discharge from a reservoir, depending on its design. It serves to permit water to flow from the reservoir without overflowing the dam, thus preventing damage to the structure.

(b) A spillway can be controlled or uncontrolled. Most small dams have uncontrolled spillways in which the water level in the reservoir is fixed by the height of the spillway crest. Controlled spillways have crest gates to allow adjustment of the reservoir water level. These gates can be simple flashboards or steel gates of complex design and operation.

(2) Outlet Structure. The major volume of water in a reservoir is below the spillway crest. Outlet works are structures constructed so that this water can be drawn from the reservoir for use. A sluiceway is a pipe or tunnel that serves to pass water through the dam to the stream be-

low. The sluiceway can be operated to lower the reservoir surface below the spillway crest.

(3) Intake Structures:

(a) Location. An intake structure is located in the reservoir at the end of the water supply line. It permits the withdrawal of water from the reservoir without damaging or clogging the supply line.

(b) Types. Intake structures can vary from simple blocks that support the supply line above the reservoir bottom to elaborate towers that can be operated to withdraw water from various levels in the reservoir by opening various intake parts. Screens and valves are a part of the intake structures that control entry of debris and water to the supply conduit.

(c) Screens. When necessary, intakes are equipped with removable screens to keep fish and debris out of the pipeline. A platform above the water provides access for servicing and cleaning of the screen. Intake screens should be cleaned at regular intervals determined by local experience.

1. Intake Screens. Intake screens are usually divided into two general classes: coarse and fine. When the water treatment process includes filtration, fine screens are not usually used. It is more economical (in most cases) to remove fine material in the water treatment processes and to provide only coarse screens for the removal of large materials that may clog or injure pipelines, valves, and equipment. Coarse bar screens are most commonly used. They usually have a series of parallel bars set in the flow channel either vertically or at an angle of about 60° to the horizontal.

2. Coarse Screens. This type of screen is generally a bar screen or rack, usually consisting of parallel bars or grids placed over the intake pipe or ports of the intake structure or in the flow channel. Screens with parallel bars are much more satisfactory than the grid type, because it is difficult to clean the latter. Openings between the bars of coarse screens are usually 1 to 3 inches, and the velocity through the screen should not exceed 30 feet per minute (fpm), and preferably much less. When a considerable amount of material may be caught on bar screens, they are often equipped with mechanical rakes or its removal. However, except in larger installations, the operators usually clean the bar screens by hand.

3. Fine Screens. Fine screens usually are constructed of wire or cloth mesh with varying sizes of openings, depending on local conditions. Fine screens are usually installed in tandem to permit cleaning without interrupting the screening operation. The mesh is held in frames that, in smaller installations, are removed and cleaned manually. For larger installations, mechanized traveling screens or revolving screens may be provided.

4. Mechanized Screens. This type of screen usually is operated intermittently with the starting and stopping controlled by the loss of head that results from clogging of the screen. Fine screens apply particularly to water supplies where refuse is finely divided. Clogging material can be removed from screens by brushes or sprays. It can be removed from the spray water by dewatering screw, flight conveyor, or a liquid vibrating screen.

5. Traveling Screens. This type of screen is an endless belt type in which the sections are linked together to form the belt. They are usually equipped with sprays for automatic cleaning.

6. Rotating Screens. The two types of revolving fine screens are the drum and disc types.

a. Revolving Drum. This type of screen rotates on a horizontal axis with the flow entering the inside of the drum and passing through the mesh. The solids are retained on the mesh cloth inside the drum and flushed to a screenings trough inside the drum by water spray.

b. Disc Screens. A disc screen is a revolving spoked hoop with 6 to 60 mesh screen cloth covering the area within the hoop. The screen rotates on a horizontal axis with the flow passing through the cloth parallel to the axis. The solids are retained on the cloth, elevated as the disc revolves, and flushed from the cloth by water sprays into a screening trough.

d. Effects of Impoundments on Water Quality. When water enters an impoundment, it either evaporates, seeps through the reservoir bottom or dam, or flows through the spillway, outlet structure, or an intake. The quality of water in the reservoir depends on a number of factors.

(1) Turbidity. A reservoir offers a settling place for the sediment load of a river. The turbidity decreases as water flows through the reservoir. The deposit of settled material reduces the effective storage volume of the reservoir, but does aid in providing water of higher quality for water supplies. Temperature and chemical stratification can occur in deep reservoirs. In the spring and fall, destratification can occur that results in an intermixing of the waters in the reservoir. Turbidity and chemical quality can be adversely affected during these conditions.

(2) Algae. Algae are tiny, single-celled plants that grow in water. Abundant growth can occur if nutrients and sunlight are present. The clarified water occurring in the reservoir lets in light, enhancing algae growth. As algae grow and decay, they affect the water quality throughout the reservoir. Algae are undesirable chiefly because they impart taste and odor to the water, make the water turbid and unsightly, and clog filters of a water treatment plant.

(3) Bacteria Levels. Because of settlement and natural degradation, bacteria levels usually decrease as water is stored in reservoirs.

(4) Color. Color in a reservoir may be either true or apparent color. True color is caused by material in solution or colloidal condition and is generally from decaying vegetation. Apparent color is generally caused by turbidity. Both forms of color can vary with the season of the year and conditions in the reservoir, but in general may be reduced by impoundment. Apparent color associated with turbidity is directly affected by the amount of erosion and rainfall frequency in the watershed, as well as algae blooms during certain times of the year. The original construction of the reservoir and subsequent maintenance affect the quantities of vegetation that are available to decompose and form true color. True color is bleached by sunlight and varies with depth.

e. Reservoir and Dam Operation and Maintenance. Surface water supply maintenance procedures are summarized in table 3-7.

(1) Watershed Sanitation, Surveillance, and Control. The quality of water depends on the quality of water in the feeding stream. Various sources of pollution are possible. Operating functions consist of surveying the watershed to locate possible contamination sources and to control those sources as much as practicable. Total ownership of the watershed is seldom possible, so agreements with others may be necessary to ensure a quality source.

(2) Reservoir:

(a) Silting. Reservoirs are designed with a siltation basin that may account for half or more of the total volume of the reservoir for silt accumulation over the design lifetime of the reservoir. Silt can be removed by dredging. The extent of silting can be determined by comparing the reservoir volume with the initial reservoir contour or prior sounding surveys. The information can be used to calculate the storage capacities available for various water levels in the reservoir.

(b) Algae Control. Algae growth can be controlled using algicidal chemicals and the alteration of environmental conditions (such as the reduction of light intensity). The latter apply usually only in small storage basins and tanks. Standard chemicals for controlling algae include copper sulfate, chlorine, potassium permanganate, and activated carbon.

1. Copper Sulfate. In soft waters 1 mg/l of copper sulfate (8.34 pounds per million gallons of water) destroys most algae. Large dosages are needed in hard water because some of the copper is precipitated by the alkalinity in water. Effective hard water dosage may be from 1 to 4.5 mg/l, depending on the alkalinity of the water. Because copper sulfate kills fish, its use is limited. Approximate concentrations that kill common varieties of fish and limiting safe dosages are in table 3-8 (in mg/l and pounds of copper sulfate per million gallons of soft water). Fatal concentrations are higher in hard waters. Copper sulfate treatment is most effective if started early in the season, before heavy algae concentrations have formed. The treatment is repeated when algae growths reappear.

a. Solution Feed. If copper sulfate can be applied by solution feeders to the water entering the reservoir, continuous application of lower concentrations can

Table 3-7. Maintenance Procedures for Surface-Water Supplies.

Inspection	Action	Frequency[1,2]
Watershed area	Make certain facilities are in working order for sewage disposal, and garbage and trash removal; repair facilities as necessary; remove debris.	Q
Recreational facilities on watershed.	Clean and repair facilities as necessary	M
Reservoir mosquito control	Remove vegetation in shallow water; vary water level a few inches.	Every 10-days (summer only)
Reservoir algae	Report algae blooms to operating staff	W (summer only)
Reservoir capacity loss	Dredge when necessary	A
Reservoir sides and bottom	Remove extraneous debris and vegetation from sides and bottom, if exposed; grade sides to prevent erosion.	W
Dams; leakage and exposed surface conditions.	Concrete and masonry dams: repair upstream face first, then downstream face.	M
	Earth and rockfill dams: sod or gravel slopes; keep riprap on upstream face even and in good condition; repair leaks by excavating and backfilling.	W
Ice conditions on concrete dam.	Where ice formations exist, break ice to a few feet upstream.	D (winter)
Dam spillway conditions	If blocked, remove trash, debris or ice	D
Dam gates	Lubricate gates and appurtenances	M
Intake structures to ascertain cracks and determine silt deposits; ice conditions.	Repair cracks; remove silt deposits; take action to prevent ice clogging.	W
Intake screens	Remove any material not removable by regular operation procedures.	W

[1]D-Daily; W-Weekly; M-Monthly; Q-Quarterly; A-Annually; as conditions may indicate.

[2]The frequencies shown are suggested frequencies which may be modified by local command, as individual installation conditions warrant.

Table 3-8. Approximate Toxic and Safe Copper Sulfate Dosages for Various Fish Species.

	Toxic Concentrations mg/l	Limiting Safe Dosage	
		mg/l	lb/Million Gal
Trout	1.2	0.14	1.17
Catfish	2.5	0.40	3.34
Suckers	2.5	0.33	2.75
Carp	2.5	0.33	2.75
Pickerel	3.5	0.40	3.34
Black Bass	17.0	2.00	16.68
Perch	6.0	0.67	5.59

be used instead of intermittent treatment. This usually results in the most efficient control of algae growths.

b. Bag Feed. The simplest, though not the best, method of applying copper sulfate is to tie a bag of copper sulfate crystals to a boat and cover the reservoir in a definite zigzag pattern.

c. Spray Feed. In reservoirs needing frequent treatment, the best method is to spray the copper sulfate solution of crystals on the water's surface from a spray unit mounted in a boat. Apply the copper sulfate evenly to avoid overdosing shallow areas.

CAUTION: Copper sulfate is toxic; care should be taken to avoid contact with the spray.

2. Chlorine. Chlorine compounds should be applied in dosages that result in a 0.2 to 1.0 mg/l free chlorine residual. High test hypochlorites are generally used as the chlorine source, due to their transportability and ease of applying. The effectiveness of chlorine for algae control is rapidly lost in the presence of sunlight and organic matter. It is difficult, therefore, to maintain chlorine concentrations in open reservoirs.

3. Potassium Permanganate. Dosages of 0.4 to 4.0 mg/l kill algae while also helping to oxidize odor-causing compounds in the reservoir. Potassium permanganate can be applied by methods similar to those for applying copper sulfate.

4. Activated Carbon. Because algae grows only in sunlight, they can be eliminated by preventing light from entering the water. This is the principle behind the activated carbon method of algae control. As a rule, carbon dosages of 6 to 20 pounds per million gallons of water place enough carbon in suspension to absorb all light. The carbon also removes tastes and odors in the water. This method is used only for relatively small basins or tanks. The use of activated carbon in large reservoirs is impractical.

5. Other Methods. Other methods that have been used on small reservoirs for algae control include physical intermixing to prevent stratification and using biological agents (viruses) to selectively attack algae. These methods should be examined as alternatives.

(c) Reservoir Sides and Bottoms. When the sides of a reservoir become exposed because of the lowered water level, they should be inspected. Extraneous debris and vegetation should be removed. The same operation applies to the bottom if it becomes exposed. Sides should be graded to prevent erosion.

(d) Sanitation:

1. Recreational Use of Reservoirs. Recreational use of impounding reservoirs used as a source of water supply must be prohibited or strictly controlled in line with specific orders from higher authority.

2. Mosquito Control. Pest and malarial mosquitoes breed in standing water. If precautions are not taken during the summer months, a great amount of breeding may take place in the reservoir. Mosquito larvae attach themselves to vegetation just at the waterline so they can breathe. Therefore, eliminating vegetation greatly reduces the problem. In addition, varying the water level in the reservoir is very effective. If the larvae are thus immersed or left high and dry, they will die. Varying the water level up or down several inches is sufficient. Since the larval stage lasts 10 days, one such variation each 10 days during the breeding season is sufficient. Introduction of mosquito fish of the genus Gambasia or Fundulus may be considered for mosquito larvae control.

(3) Intakes. The intake is an important part of the water supply system. Unless it is properly designed, maintained, and operated, it can readily be the cause of a partial or complete shutdown of the entire system, often causing difficult and expensive work to return it to operation.

(a) Operation. Intakes are fitted with gates at various depths, or have an adjustable suction pipe attached to a floating raft so that water can be taken from the reservoir or lake at different levels. Water may be drawn from or near the surface when the deeper water has a bad taste or odor because of decomposing organic matter. The intermediate depth is used when microorganisms are prevalent near the surface. The lower depth can provide cooler water in the summer. Experience will tell the operator the water intake depth that yields the best water. Intake stoppage may, in most cases, be cleared by backflushing the intake conduit or pipeline. When danger of such stoppage exists, facilities should be available at all times for backflushing the intake. Damage by surface ice can be prevented by using an intake located below the ice level and by placing lake intakes beyond the iceline of the lake. The intake structure, however, must be able to withstand the pressure of the ice. If ice freezes around an intake and cannot be removed by scraping or other manual means, it may be removed by pumping water out of the intake (reverse flushing). If necessary, steam can be piped into the water to raise the temperature sufficiently.

(b) Maintenance. Maintenance operations on intakes in rivers, lakes, and impounded reservoirs are concerned with the structures and their appurtenances.

1. Periodic inspections must be made for cracks or structural defects.

2. The depth of the suction well should be measured to determine the accumulation of silt and sand. These accumulations should be dredged as necessary.

3. When ice conditions endanger the structure or clog the intake opening, protective measures are necessary.

Log booms should be installed or compressed air bubbled into the water at critical points to prevent freezing.

4. Remove any material on screens that is not removable by ordinary operations. Lubricate and repair any accessory equipment to movable screens.

(4) Dams:

(a) Concrete and Masonry Dams. Dams should be inspected periodically.

1. Leaks or seepage indicate cracks that can be repaired with cement mortar or grout. The upstream side should be sealed first so that water is not trapped in the dam.

2. If ice formations exist, break the ice along the dam to a distance of a few feet upstream to protect the dam against ice-thrust.

3. At each inspection, gates and appurtenance equipment should be lubricated as necessary.

(b) Earthfill and Rockfill Dams. Properly constructed earth dams provide a means of keeping water from entering the earth, and provide a means for any water that is not retained to travel to the downstream face of the dam without building up internal pressure.

1. Dams should be inspected and a proper appearance maintained with all slopes sodded or graveled. Riprap on the upstream face should be kept even and in good condition.

2. If leaks or seepage are evident from inspection, the turbidity of the seeping water indicates the importance of the condition. Clear water indicates no loss of soil and no increase in size of the leak. Turbid water indicates a worsening of conditions, and the more turbid the water, the more urgent the need for repair. Seepage at or under the toe of the dam indicates a dangerous condition. Such seepage can result in failure. If seepage is observed, it should be reported to a higher authority at once. Minor leaks should be repaired immediately by excavating to a moderate depth on the upstream face and sealing with puddled clay rammed into place. Serious leaks require that the dam be cut down from the tip and filled with good material. The new fill should be bonded into the original material and compacted as for a new dam. When seepage is detected at the toe of the dam, new layers of earth should be added to the downstream face in the same manner as is done for new dams.

(5) Spillways:

(a) Keep spillways free of trash and debris, since blocking of spillways may cause overtopping of the dam and possible failure by erosion. Earthfill dams invariably fail if they are overtopped. A log boom stretched across the reservoir about 30 feet ahead of the spillway helps keep it clear. Spillway flashboards are not used in cases where the dam is subject to flash flooding.

(b) Inspect and lubricate gates and similar apparatus as required.

Chapter 4

PUMPS AND PUMPING STATIONS

Section A—Information on Pumps

4-1. General Information:

a. Pumping Requirements:

(1) A pump is a mechanical device to add energy to a fluid to create fluid flow. Pumps of various types may be required for moving liquids or semiliquids in a water supply system. Pumping requirements include:

(a) Pumping water from a well to storage or treatment facilities.

(b) Pumping water from a surface supply to treatment facilities.

(c) Feeding various chemicals during treatment.

(d) Moving water through treatment facilities.

(e) Moving water through distribution systems.

(f) Boosting pressures in distribution systems.

(g) Pumping waste sludges to treatment or storage facilities.

(2) Standby or emergency pumps ordinarily are needed for operation during breakdowns, power outages, or to meet fire demands.

b. Comprehensive Information. The descriptive information presented in the following subparagraphs contains material to familiarize the operator with the wide variety of pumping equipment available for a water-supply system. References listed in attachment 4 provide additional information that concerns designing and applying pumping equipment. It is necessary for the operator to supplement the descriptive, operating, and maintenance information presented from the individual manufacturer's manuals. The wide variety of pumping equipment available and the variability in similar types of pumping equipment makes supplemental information necessary.

4-2. Pump Description:

a. Classification. Pumps may be classified according to use (service) or design (operating principle).

(1) Use. According to use, pumps may be classified as shown in table 4-1.

(2) Design. According to design, there are three major pump classes used in water supply systems; velocity, displacement, and air-lift.

(a) Velocity pumps include ejector and centrifugal types. Centrifugal types may be classified as volute, axial-flow diffuser, mixed-flow, vertical-turbine, and regenerative-turbine pumps.

(b) Displacement pumps include rotary and reciprocating pumps. Rotary-displacement pumps include gear, lobe, and progressive-cavity pumps. Reciprocating displacement pumps include diaphragm, piston, and plunger pumps.

(c) Air-lift is a method of raising water with compressed air.

(d) Characteristics of pumps discussed above are in tables 4-2 and 4-3.

b. Centrifugal-Type Pumps:

(1) General Description. A centrifugal pump consists of a set of rotating vanes (impeller) enclosed within a housing or casing. The impeller imparts energy to a fluid by centrifugal force. In operation, the pump discharge pressure (head) is produced from velocity imparted to the liquid and not from any impact or displacement.

(2) Types. Terms most commonly applied to centrifugal-type pumps used with water-supply systems include: volute, diffuser, vertical-turbine, axial-flow (propeller), mixed-flow, and regenerative-turbine.

(3) Common Uses. Centrifugal pumps are the type most commonly used in water-supply systems. They are well adapted to most drives and to a wide variety of operating conditions.

c. Volute-Centrifugal Pumps:

(1) General Description. A volute-centrifugal pump consists primarily of a rotating impeller, an impeller casing, and a flow-receiving chamber (volute). As shown in figure 4-1, the cross-sectional area of the volute increases toward the point of discharge. A horizontal split-case, double-suction volute centrifugal pump is shown in figure 4-2.

(2) Operating Principal. Water enters the impeller

Table 4-1. Pump Classification by Use (Service).

Use (Service)	Function of Service
Boiler feed	To pump water into steam boilers.
Booster	To increase distribution system pressure or supply elevated storage systems.
Chemical feed	To add chemical solutions to treatment processes.
Cooling	To circulate water through heat exchangers or pump water to cooling towers.
Fire	To supply the pressure and volume necessary for firefighting.
High-lift	To discharge water under pressure to the distribution system.
Low-lift	To raise water from source to treatment system.
Sampling	To pump water from sampling source to sample collection point.
Sludge	To pump waste sludge to treatment or disposal facilities.
Sump	To raise water from collection sumps to disposal or treatment facilities.
Well	To raise water from shallow or deep wells and discharge to treatment or distribution systems.

Table 4-2. Comparison of Pump Characteristics.

	Centrifugal		Rotary	Reciprocating	
	Volute	Axial Flow and Turbine		Double Acting Power	Direct Acting Steam
Flow	Even	Even	Even	Pulsating	Pulsating
Effect of Increasing Head					
Capacity	Decrease	Decrease	None	None	Decrease
Power requirement	Decrease	Increase	Increase	Increase	Increase
Effect of Decreasing Head					
Capacity	Increase	Increase	None	None	Slight Increase
Power requirement	Increase	Decrease	Decrease	Decrease	Decrease
Effect of Shutting Discharge Valve					
Pressure	Increase 15 to 30 Percent	Considerable Increase	Pressure Increases With Destructive Effect If No Relief Valve Used		Increase
Power requirement	Decrease 50 to 60 Percent	Increase	Increase to Destruction		Increase

center (eye) and is thrown outward by centrifugal force at high velocity. The velocity head (kinetic energy) is gradually reduced with an accompanying increase in pressure head (potential energy). The pressure head developed primarily depends on the speed of impeller rotation and the impeller diameter. Quantity pumped depends mostly on impeller width and water passage size. For a given pump, as the total operating head increases, capacity decreases until pressure reaches a point that no water is pumped (shutoff head). Power requirement is minimum at shutoff head, and increases as head is reduced and volume pumped increases. If two or more pumps are connected in parallel and feed a common main, their combined capacity is less than the sum of their single capacities, because of the increased resistance in the header main with increased discharge. If they are connected in series, capacity is the same as that of the smallest pump, but the total discharge pressure developed is the sum of the discharge heads of all pumps.

(3) Uses. Volute-centrifugal pumps are suitable for clean water only. They are used for general service and fire pumping. Maximum capacity and discharge head are approximately 40,000 gallons per minute (gpm) and 500 feet, respectively. They are not suitable for operation under high-suction lifts; suction lift should not exceed 15 feet. Multistage volute pumps are used for high-discharge pressures.

Table 4-3. Comparison of Pump Discharge and Head.

Pump Type	Maximum Capacity (gpm)	Maximum Discharge Head (ft)
Air-lift	3,000	700
Centrifugal		
Axial-flow (propeller)	200,000+	50
Diffuser	700	1,000
Mixed-flow	250,000+	100
Regenerative turbine	100	600
Vertical turbine	30,000	>1,500
Volute	40,000	500
Ejector (jet)	50	150
Progressive cavity (helical rotor)	1,200	2,300
Reciprocating displacement		
Diaphragm	300	800
Piston	300	800
Plunger	300	800
Rotary displacement	55	1,000

d. Diffuser (Turbine)-Centrifugal Pumps:

(1) General Description. The major components of a diffuser-centrifugal pump include a rotating impeller, impeller casing, stationary diffusion vanes, and flow-

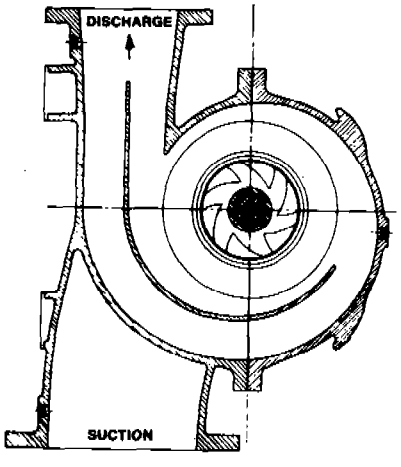


Figure 4-1. Cross-Section Diagram of Volute-Centrifugal Pump.

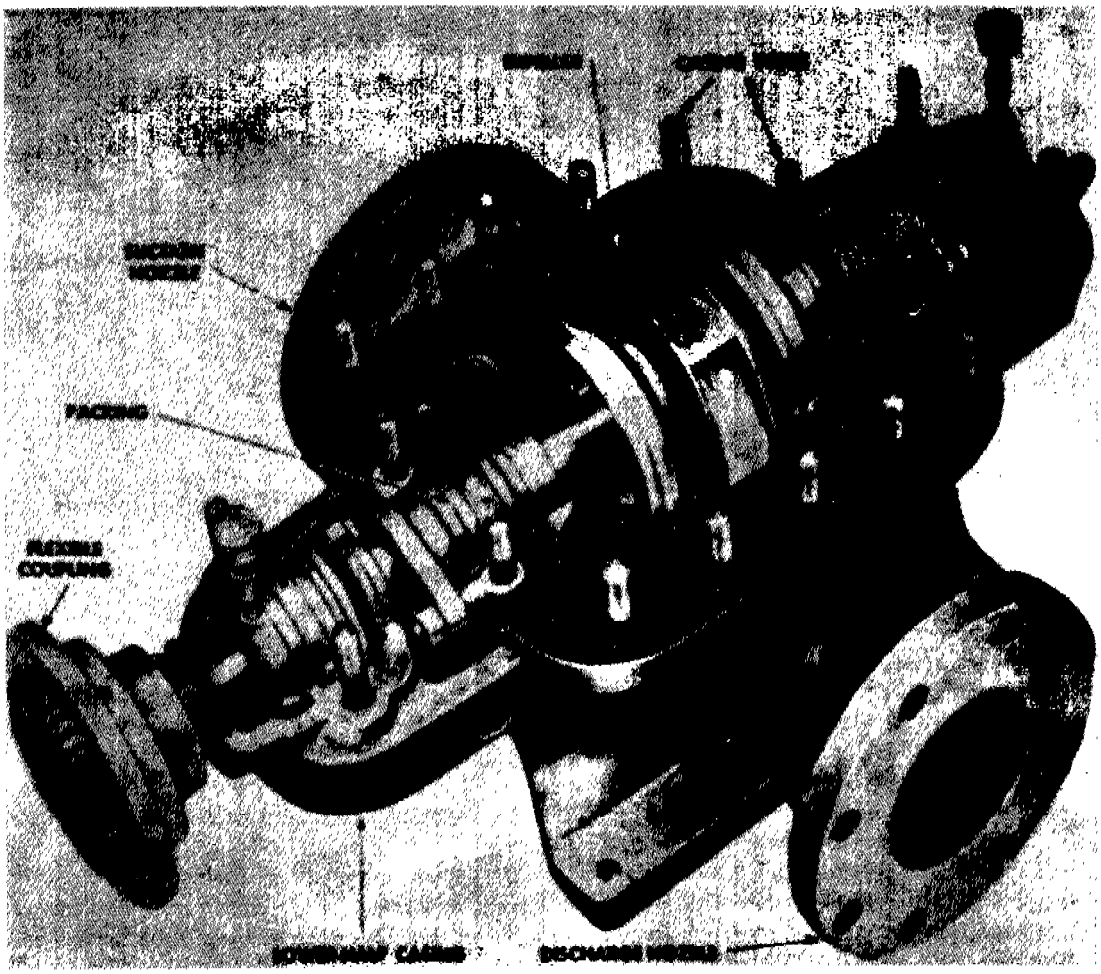


Figure 4-2. Horizontal Split-Case Double-Suction Volute Centrifugal Pump.

receiving chamber. As shown in figure 4-3, the cross-sectional area of a flow-receiving chamber is constant.

(2) Operating Principle. As with the volute pump, water enters the eye of the impeller and is thrown outward by centrifugal force at a high velocity. The velocity head is converted to pressure head as the water passes through the diffusion vanes. The diffusion vanes provide most efficient conversion of velocity head to pressure head at the rated pump speed.

(3) Uses. Diffuser-centrifugal pumps are used for clean water service only. Capacity and pressure head usually do not exceed 700 gpm and 1,000 feet, respectively. The most common use is boiler feed pumps.

e. Axial-Flow Pumps:

(1) General Description. Axial-flow pumps, also known as propeller or screw pumps, consist of a rotating impeller resembling the propeller of a ship, a cylindrical casing, and a slightly expanding annular discharge passage. A vertical axial-flow pump with screw-type impeller is shown in figure 4-4.

(2) Operating Principles. Water enters the casing and is pushed forward by the screw action of the vanes. The liquid flow is parallel to the axis of the pump. Diffusion vanes are used in the pump discharge port to eliminate swirl produced by the rotating element. Relatively small increases in total system head cause large reductions in discharge. The power required may be at a maximum at shut-off head, decreasing as head decreases and discharge increases. Discharge head varies with speed and vane pitch; capacity varies with propeller and inlet diameter. Greater head is obtained with pumps that have several propellers in series. Inlet water level must be above the propeller; the axial-flow pump does not operate satisfactorily with suction lift.

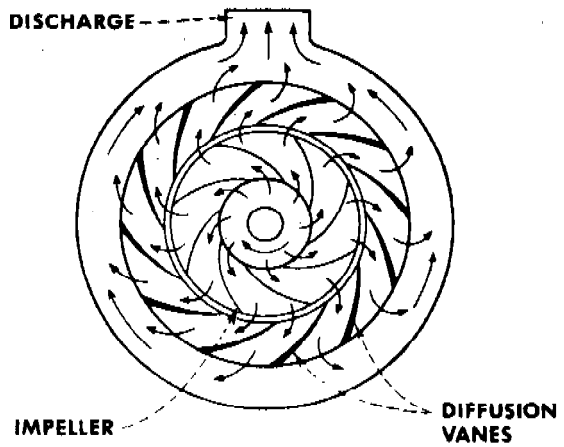


Figure 4-3. Cross-Section Diagram of Diffuser Pump.

(3) Uses. Axial-flow pumps are suited only for a very low head (less than 50 feet), high-capacity service (up to 200,000 gpm). Their principal use is for pumping surface water supply to treatment, industrial irrigation, and storm-water pumping.

f. Mixed-Flow Pumps:

(1) General Description. Liquid discharge is a combination of both radial and axial discharge into either volute-type casings or expanding discharge pipes. A cross-sectional diagram of a mixed-flow pump is shown in figure 4-5.

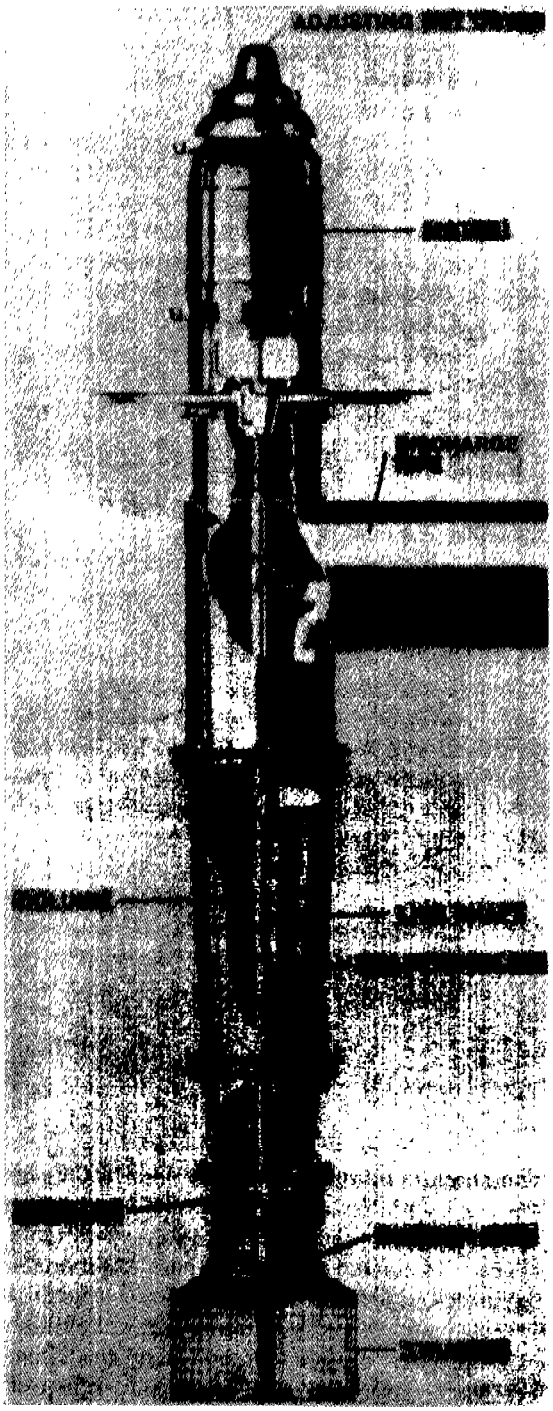


Figure 4-4. Vertical Axial-Flow Pump With Screw-Type Impeller.

(2) Operating Principles. In mixed-flow pumps, pressure head is developed by a combination of screw action and centrifugal force. The power requirement near shutoff head is greater than at rated flow.

(3) Uses. Mixed-flow pumps are not self-priming, but are useful for moving liquids with solids. They are best suited for high capacity (up to 250,000 gpm), low head (100 feet maximum) service, such as raw water intake.

g. Vertical-Turbine (Turbine Well) Pumps:

(1) General Description. Vertical-turbine pumps have been called "deep well pumps," "turbine well pumps," and "borehole pumps." They are small diameter multi-stage diffuser or mixed-flow centrifugal pumps.

(a) Because the well diameter limits impeller diameter and hence limits the head produced in a single stage, multiple stages are provided to create the head and capacity desired. The discharge casing, pump housing, and inlet screen are supported from a base at the ground surface. Weight of rotating parts is usually carried by the thrust bearing in the pump head. Pump and intermediate bearings may be either oil or water lubricated. From a sanitary viewpoint, water lubrication of pump bearings in any well is preferable. Contaminated lubricating oil has been responsible in some cases for contaminating well water. A water lubricated vertical-turbine pump is shown in figure 4-6.

(b) Vertical-turbine pumps may also be of the submersible type, with a watertight electric drive motor below water immediately above the pump bowls. Electric power is supplied through waterproof conductors. The pump and submersible motor hang on the discharge pipe.

(c) As a rule, the maximum horsepower requirement for vertical-turbine pumps occurs when operating at shutoff head or at the peak efficiency point.

(2) Uses. Vertical-turbine pumps are used in deep wells of 4 inches diameter and larger. They also may be used as booster pumps. These pumps are used for service requiring capacities as high as 30,000 gpm and pressure heads exceeding 1,500 feet.

h. Regenerative-Turbine Pumps:

(1) General Description. Regenerative-turbine pumps are also called turbulence, peripheral, and vortex pumps. These pumps do not operate solely on the centrifugal prin-

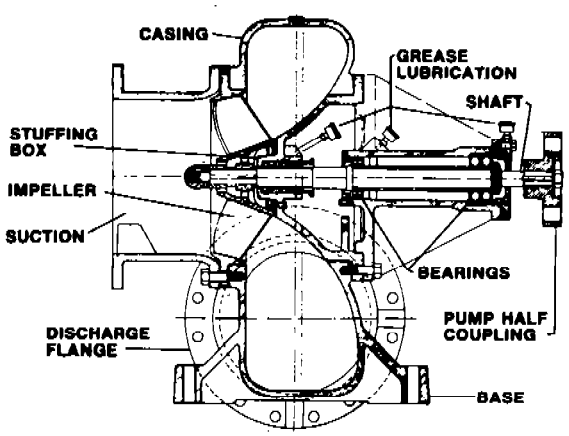


Figure 4-5. Cross-Section Diagram of Mixed-Flow Pump.

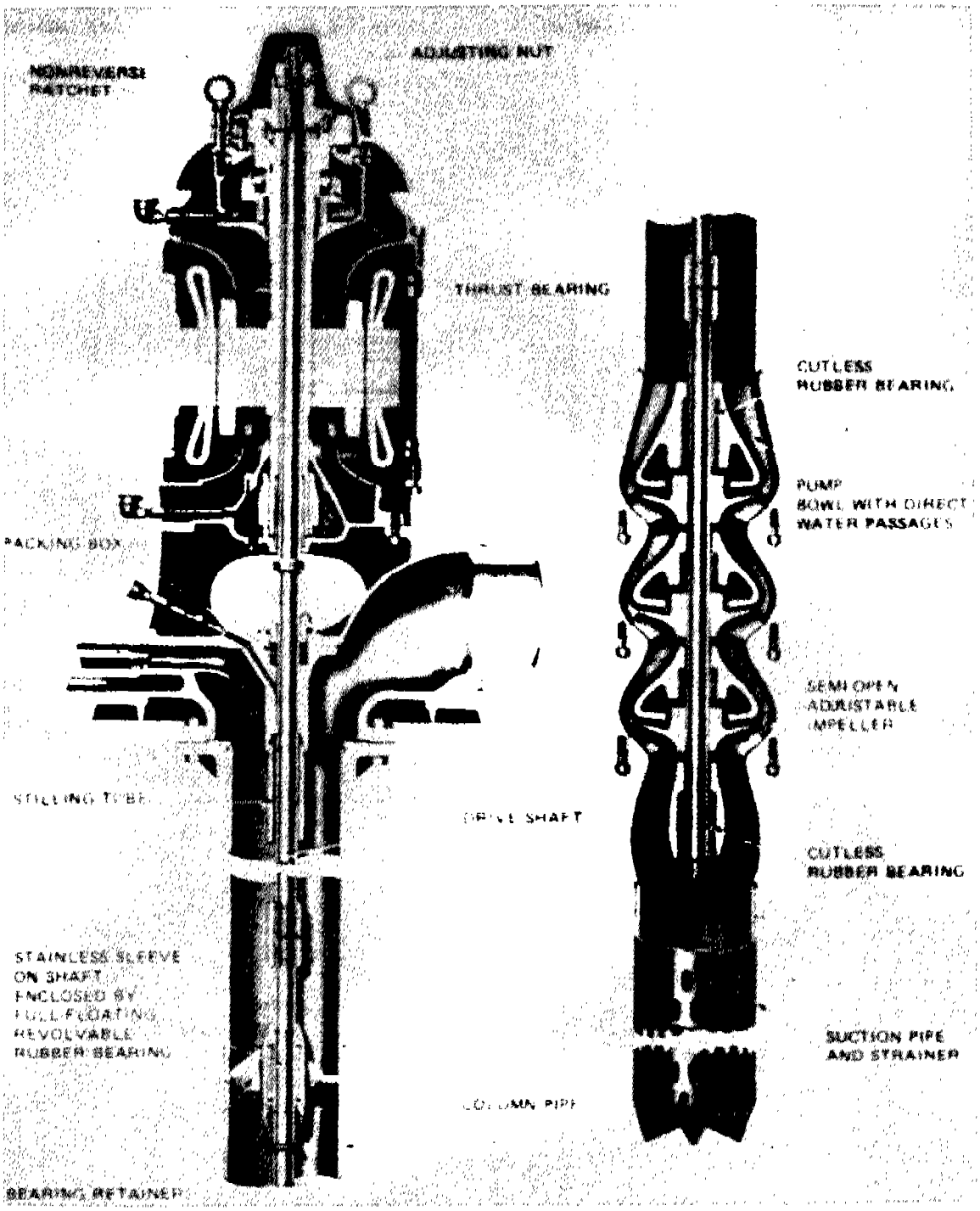


Figure 4-6. Water-Lubricated Vertical-Turbine Pump.

ciple. The liquid does not discharge freely from the impeller blade tips; rather, it is recirculated to a lower point before leaving the impeller. They have a disc-shaped rotating impeller with many small radial vanes near the edge. The inside of the casing is channeled around the impeller vanes, providing water passage from suction port to discharge port. An exploded view of a regenerative-turbine pump is shown in figure 4-7.

(2) Operating Principles:

(a) The flow in a regenerative-turbine and a volute-centrifugal pump is compared in figure 4-8. In the regenerative-turbine pump, water enters the suction port and is repeatedly picked up by the impeller vanes, driven into the channel, and recirculated onto the vanes. Additional energy is imparted to the water each time it is engaged by the impeller vanes and pressure increases continually during passage of the water from the suction to the discharge port. Therefore, readings taken at gages 1 through 4 in figure 4-8 show uniformly increasing pressures. In the volute pump, water enters the eye of the impeller, is forced into

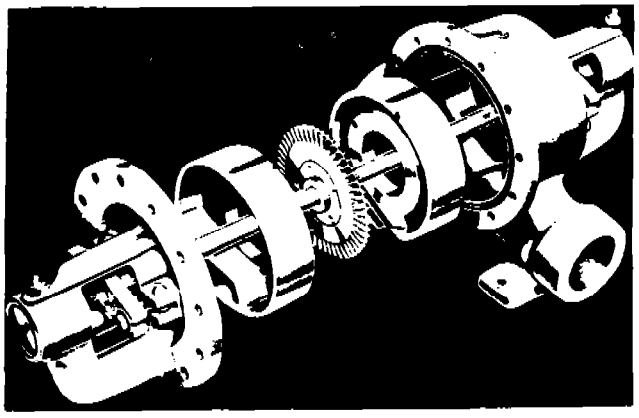


Figure 4-7. Impeller and Housing of Regenerative-Turbine Pump.

the volute passage by centrifugal force, and then passes to the discharge of the pump. Since the water goes through this cycle but once, readings taken from gages 1A through 4A in figure 4-8 show a constant pressure.

(b) The horsepower requirement increases as the head is increased in a regenerative turbine pump.

(c) A pressure-relief valve in the pump discharge line is required to prevent overloading the motor when discharging against a closed valve or restricted pipe.

(3) Uses. Regenerative-turbine pumps are not suitable for handling corrosive or abrasive liquids. Capacities and pressure heads are usually less than 100 gpm and 600 feet, respectively. They are used mainly for general-purpose high-head, low-capacity service.

i. Air-Lift Pumps:

(1) General Description. Air lift is a method of raising water by compressed air.

(2) Operating Principles. When air in fine bubbles is introduced into a column of water, such as in a well casing, the air-water mixture in the column is lighter than water outside the column. Therefore, the heavier water outside will force the lighter mixture up and out of the well casing. If the U-tube shown in figure 4-9 is filled with water, the water stands at height H in both legs of the tube. When compressed air is introduced as shown, a mixture of air and water is formed on one leg. The solid column of water H weighs more than the air-water column P, forcing it over the top of the U-tube.

(3) Uses. Air-lift pumps are occasionally used for a group of wells discharging to ground storage where the air-lift pumps may be served by a single compressor installation. Lower efficiency is offset by lack of maintenance problems, especially in crooked wells and those producing sand. They are particularly adapted for emergency deep-well pumping, using a portable air compressor for power. Air-lift pumps cannot be used for direct pumping to a distribution system or for horizontal transmission of water. The added oxygen in air-lifted supplies tends to make the water more corrosive.

j. Ejector (Jet Pumps):

(1) General Description. An ejector pump consists of a centrifugal-type single impeller pump (located above-ground) and a stationary ejector (located in the water). The ejector assembly is made up of a nozzle within a tube which tapers down to a narrow throat opening at the tip of the nozzle.

(2) Operating Principles. The pump rotates at high speed, throwing water from the volute or housing through the discharge line. Part of this water is bypassed back to the ejector assembly through a small pressure line. It goes first to the pressure chamber and is then forced through the nozzle into the narrow throat of the tube. Its high

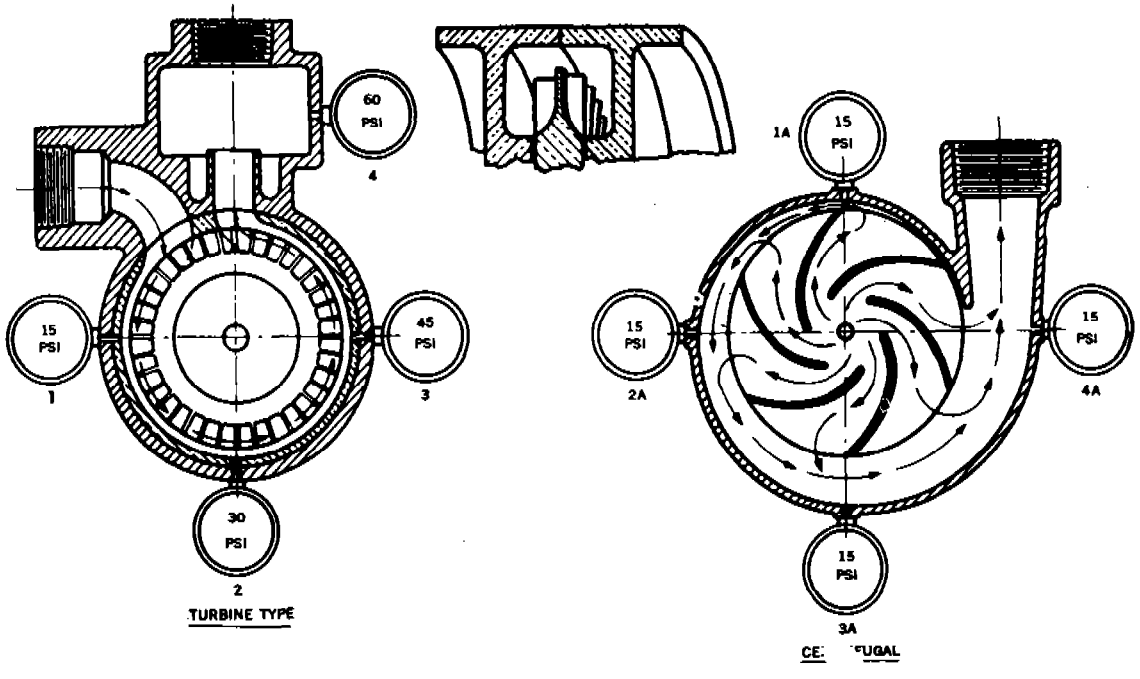


Figure 4-8. Comparison of Regenerative-Turbine and Volute-Centrifugal Pumps.

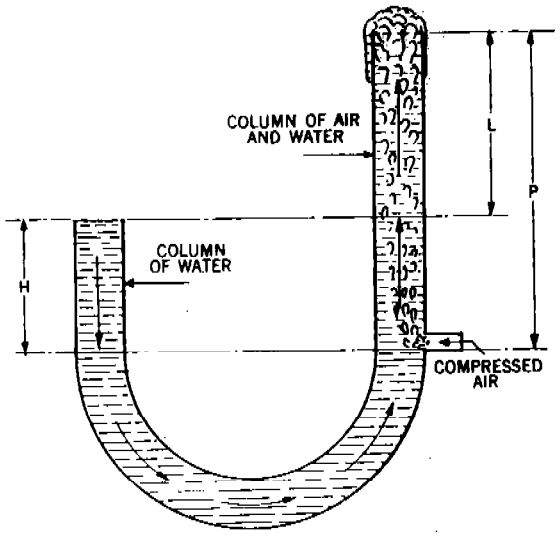


Figure 4-9. Principle of Air-Lift.

velocity as it leaves the tube creates a reduced pressure that causes water to enter from the source and rise in the pump suction pipe. The pump suction then lifts the water from this point, completing the pump cycle. A suction pipe with a foot valve is always installed at the bottom to make the unit self-priming after it is first started.

(3) Uses. Ejector well pumps are suitable for small wells within limited ranges of depth. Because there are no moving parts in the well, they can be installed away from or directly over a well as shown on figures 4-10 and 4-11. Other uses include pumps for small pressure systems and small capacity, low-lift services.

k. Helical-Rotor (Progressive-Cavity) Pumps:

(1) General Description. The pumping element, shown in figure 4-12, consists of a main body or stator and a rotor, both helical in form. The helixes are really worm threads, the stator having a double thread and the rotor a corresponding single thread.

(2) Operating Principles. The pump is a positive-displacement type. The rotor turns with an eccentric rolling motion within the stationary double helix, squeezing the water ahead of the rolling action with minimum turbulence. Required head determines the length and pitch of the rotor.

(3) Uses. Vertical high-lift helical-rotor pumps are used for small deep wells, 4 to 6 inches in diameter. Capacities range for 28 to 47 gpm. Helical-rotor pumps are made in several lengths, the longer elements developing greater pressure. Horizontal helical-rotor pumps can be used for pumping chemical water treatment sludges (capacities are available up to 1,200 gpm) and have been used to pump dry powdered activated carbon.

l. Rotary-Displacement Pumps:

(1) General Description. A rotary-displacement pump is a displacement pump that has a stationary casing with one or more rotating elements. Four of the many types, all with the same general principle of operation, are shown in figure 4-13. The helical-rotor pump (see k above) is a special form of rotary pump.

(2) Principle of Operation. The internal and idler

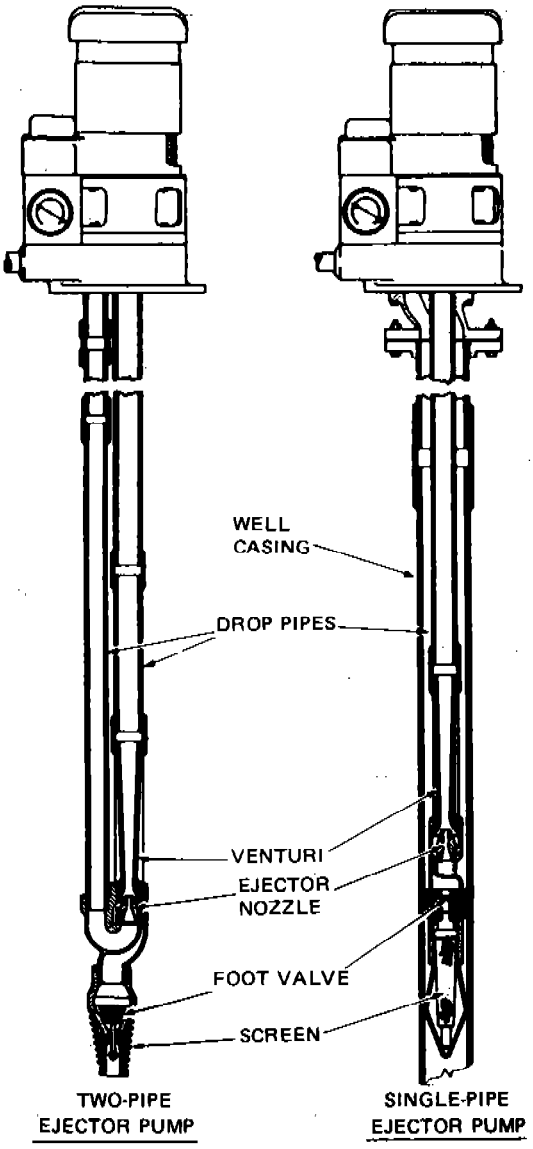


Figure 4-10. Ejector Pump Installed Over Well.

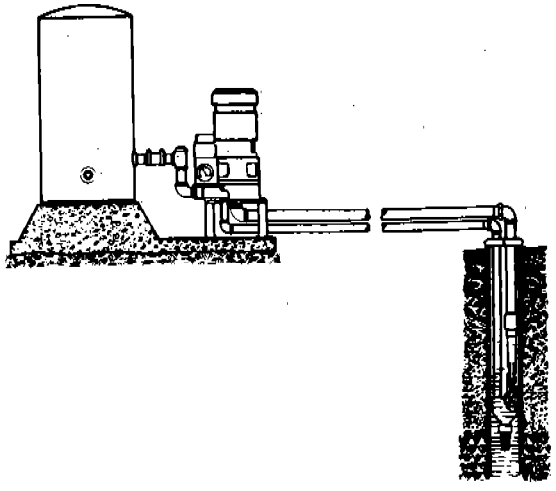


Figure 4-11. Ejector Pump Installed Away From Well.

gears are shown in figure 4-13. As viewed, these rotate counterclockwise separating at the suction port on the left and meshing at the discharge port at the top. For the Type 1 pump at position 1, the rotor and idler form a barrier between ports. At position 2, the idler and rotor separate, creating a space to be filled with liquid. At position 3, the spaces between rotor and idler are completely filled. At position 4, the rotor and idler come together, forcing the liquid out through the discharge opening. The other three types shown on the figure operate similarly to form pockets between the teeth, vanes, or lobes at the suction side. When the pump rotates, water is carried to the discharge side.

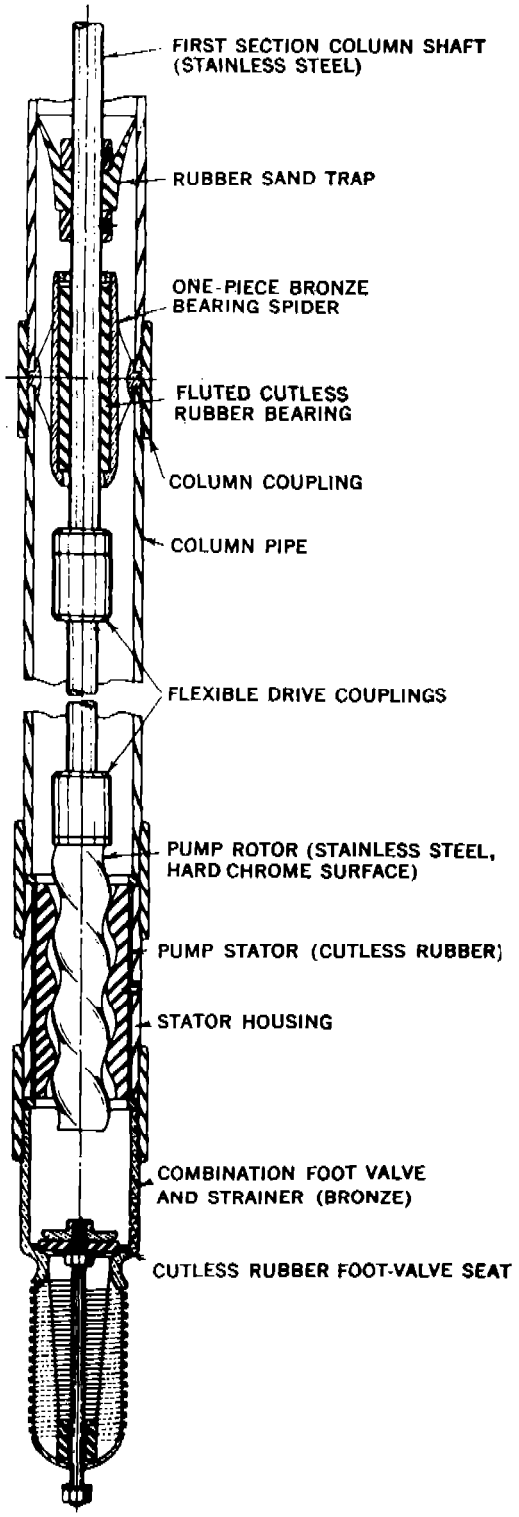


Figure 4-12. Vertical Helical-Rotary High-Lift Pump.

(3) Uses. Rotary pumps are used in waterworks for priming larger pumps and for limited special applications. They are adapted to low-capacity, high-suction duty, when air or vapor cause difficulty with other types.

m. Reciprocating-Displacement Pumps:

(1) General Description. Three types of reciprocating-displacement pumps include diaphragm, piston, and plunger pumps. These pumps use the positive action of a solid element moving in alternate directions. Check valves are necessary on the suction and discharge. A diaphragm pump uses a flexible diaphragm as the moving unit. Piston and plunger pumps both use a piston-type element as the moving unit. A reciprocating well pump and the cross section of a reciprocating sludge pump are shown in figures 4-14 and 4-15, respectively.

(2) Uses. Reciprocating-displacement pumps are used primarily for well, chemical feed, and sludge services.

4-3. Pump Operation:

a. Prestart Operations. Before operating any pump it is necessary for the operator to make certain checks and perform certain operations. These checks and operations, which vary for different pump types and pump applications, include pump prime, valving, lubrication, and other items.

b. Centrifugal Pumps:

(1) Prestart Operations:

(a) Valving:

1. Open valve in the cooling liquid supply to the bearings, if the bearings are liquid cooled.

2. Open valve in the flushing water supply to the stuffing boxes, if so equipped.

3. Open valve in the sealing liquid supply to the stuffing boxes or mechanical seals, if so equipped.

4. Open or close the discharge valves according to the manufacturer's manual.

(b) Check Rotor Freeness. Before starting, check rotor to see that it is free. It should be possible to turn the rotor by hand. If not, do not start the pump until the difficulty is corrected.

(c) Priming. Centrifugal-type pumps must be primed before starting. They will not pump water unless air in the pump and suction piping is replaced with water. In addition, the rotating element may seize due to lack of lubrication. Prime centrifugal pumps by one of the following methods, depending on operating conditons:

1. Positive Suction Head. With a positive suction head (suction under pressure), use the following prime sequence:

a. Open all suction valves to allow water to enter the suction pipe and pump casing.

b. Open all vents located on the highest point of the pump casing to allow trapped air to be released.

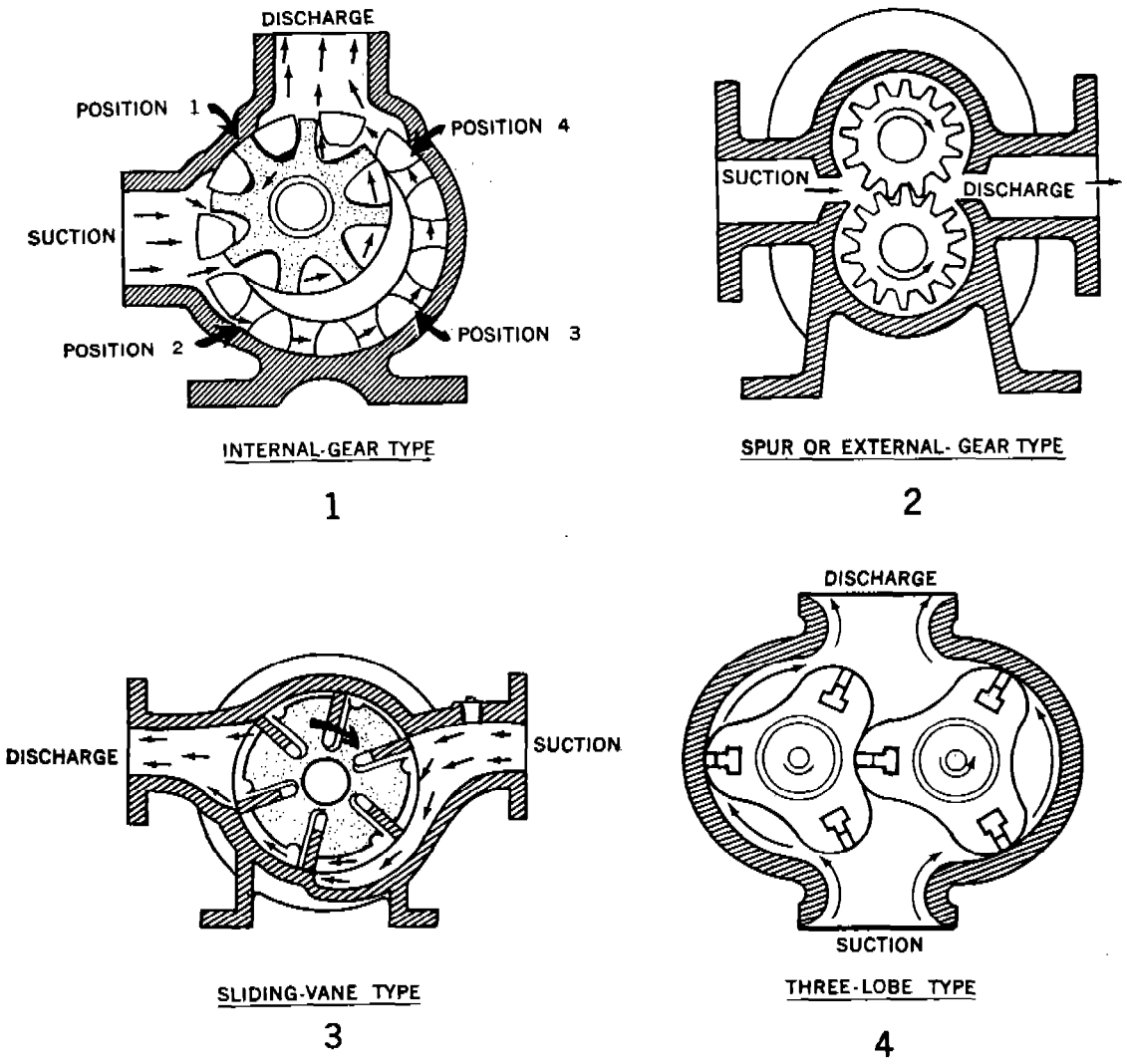


Figure 4-13. Several Types of Rotary-Displacement Pumps.

NOTE: The pump is properly primed when water flows from all open vents in a steady stream.

2. Negative Suction Head (Suction Lift). There are two priming methods available for negative suction head conditions:

a. Vacuum Pump or Ejection Method. When steam, high-pressure water, or compressed air is available, prime the pump by attaching an ejector to the highest point in the pump casing for evacuating the air from the suction piping and casing. A vacuum may be substituted for the above equipment. Start the ejector or vacuum pump to exhaust the air from the pump casing and suction pipe. When water discharges from the ejector or vacuum pump, start the centrifugal pump, but continue priming until the centrifugal pump has reached operating speed.

b. Priming a Pump with a Foot Valve. A foot valve should be used at the lowest point on the suction pipe. The foot valve retains water in the suction pipe and pump casing after the pump has been initially primed. To prime, open the suction valve, if one is installed. Open vent valves at highest points on the pump casing. Fill the pump and suction line from an independent water supply. Allow to fill until a steady stream flows from the vent valves.

(2) How to Start the Pump:

(a) Always start the pump according to the manufacturer's manual.

(b) For pumps started with discharge valves closed, open valves slowly after pump approaches operating speed. Do not operate the pump with a closed discharge valve.

(c) Observe a leakage from the stuffing boxes and adjust the sealing liquid valve for proper flow to ensure packing lubrication. Allow "run-in" (paragraph 4-4a(3)(c)7) before tightening new packing.

(d) Check the general mechanical operation of the pump and driver.

(3) Operating Requirements. Operators must learn to recognize the normal sounds and conditions of a properly run pump and to investigate any change in the sound or operating condition at once. As a matter of routine, operators should make the inspections listed below during regular tours of duty:

(a) Check bearing temperature and lubrication. Where petroleum-based lubricants are used, follow the

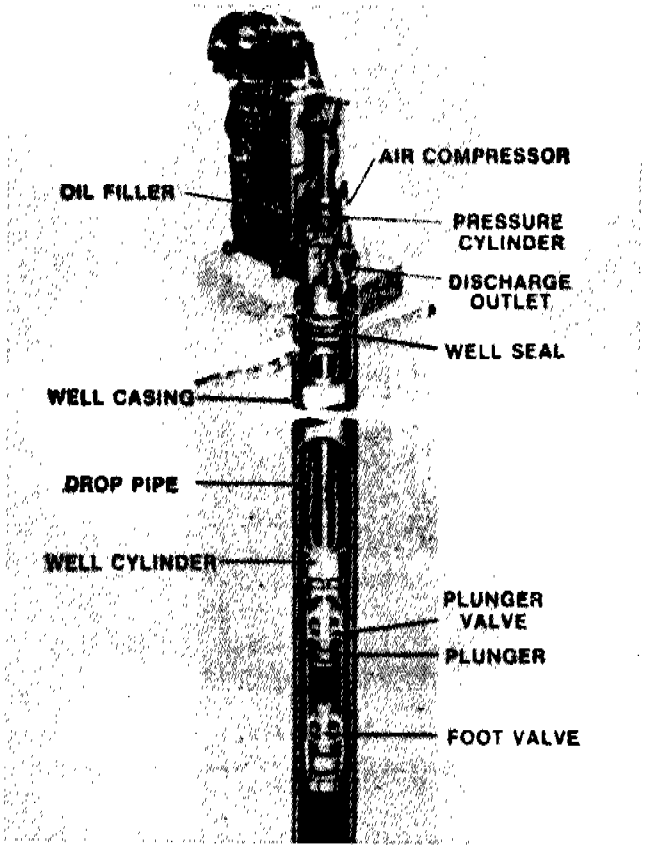


Figure 4-14. Reciprocating Well Pump, Single-Stroke, Single-Acting Cylinder.

manufacturer's manual and never overlubricate.

(b) Listen to the sounds of the pump and, if abnormal, investigate the cause.

(c) Check the suction and discharge readings and compare with "normal" valves.

(d) Make sure valves are set as required.

(e) Check shaft packing.

(f) Check discharge rate.

(g) Check driving equipment (paragraph 4-5).

(4) Troubleshooting Operating Problems. Symptoms and possible causes of operating difficulties are listed in table 4-4.

(5) Cavitation Problems:

(a) Cavitation is one of the most serious operational problems with centrifugal pumps. Cavitation may be defined as the formation of cavities in the liquid usually in contact with the back surface of an impeller vane. As the cavity moves along the underside of the vane toward the outer circumference of the impeller, the pressure in the surrounding liquid increases. The cavity that collapses against the impeller in a cavitating pump will reveal deep pitting and general erosion on the underside of the vanes some distance from the impeller inlet.

(b) Cavitation in a centrifugal pump may be caused by any of the following:

1. The impeller vane is traveling at higher revolutions per minutes (RPM) than the liquid.

2. Restricted suction.

NOTE: Never throttle the suction of a centrifugal pump.

3. The required net positive suction head (NPSH) is equal to or greater than the available NPSH.

4. The specific speed is too high for the best design conditions.

5. The liquid temperature is too high for the suction conditons.

(c) Operating the pump with too great a suction lift or insufficient submergence of the suction inlet are conditions that typically cause cavitation. Cavitation develops more easily when normal pump operating conditions have been exceeded. Noise, vibration, impeller erosion, and reduction in total head and efficiency result from cavitation.

(6) How to Stop the Pump:

(a) As a rule, there is a check valve in the discharge line close to the pump. In such cases, the pump can be shut down by stopping the driver according to the manufacturer's manual.

(b) All valves except the check valve should then be closed in the following order: discharge, suction, pump cooling water supply, and other connections leading to the pump or system.

(c) In some instances, however, the use of a check valve is not feasible because the sudden closing of the valve under high discharge pressure might create pressure surges or water hammer. In such cases, the discharge valve should be closed slowly to eliminate the possibility of water hammer.

c. Air-Lift Pumps:

(1) Operating Procedures. The principal precaution in operating the air-lift pump is to make sure that the correct volume of air is used. The volume of air should be the minimum required to produce a continuous flow. Lesser amounts cause discharge in spurts. Greater amounts cause more discharge at lower efficiency. If air is increased still further, discharge is reduced. The compressor output should be adjusted accordingly.

(2) Troubleshooting Operating Problems. The most common operating difficulties and their most probable causes are in table 4-5.

d. Ejector (Jet) Pumps:

(1) General Information. Ejector pumps use a centrifugal pump in the system. Therefore, all operating rules and troubleshooting checks that apply to centrifugal pumps apply to ejector pumps.

(2) Starting and Operating. Start the pump and set the hand valve until the proper amount of back pressure is achieved to complete the operating cycle. Do not change adjustment after the pump is operating; the pump operates automatically.

(3) Operating Problems. In case of a decrease in pump discharge, check troubleshooting items pertaining to the centrifugal pump. It is also advisable to check on the possibility of deposits in the ejector nozzle or throat, as well as checking submergence of the nozzle.

e. Helical-Rotor Well Pumps:

(1) General Information. This type of pump has a unique design and is not subject to the same problems as centrifugal pumps. Operate according to the manufactur-

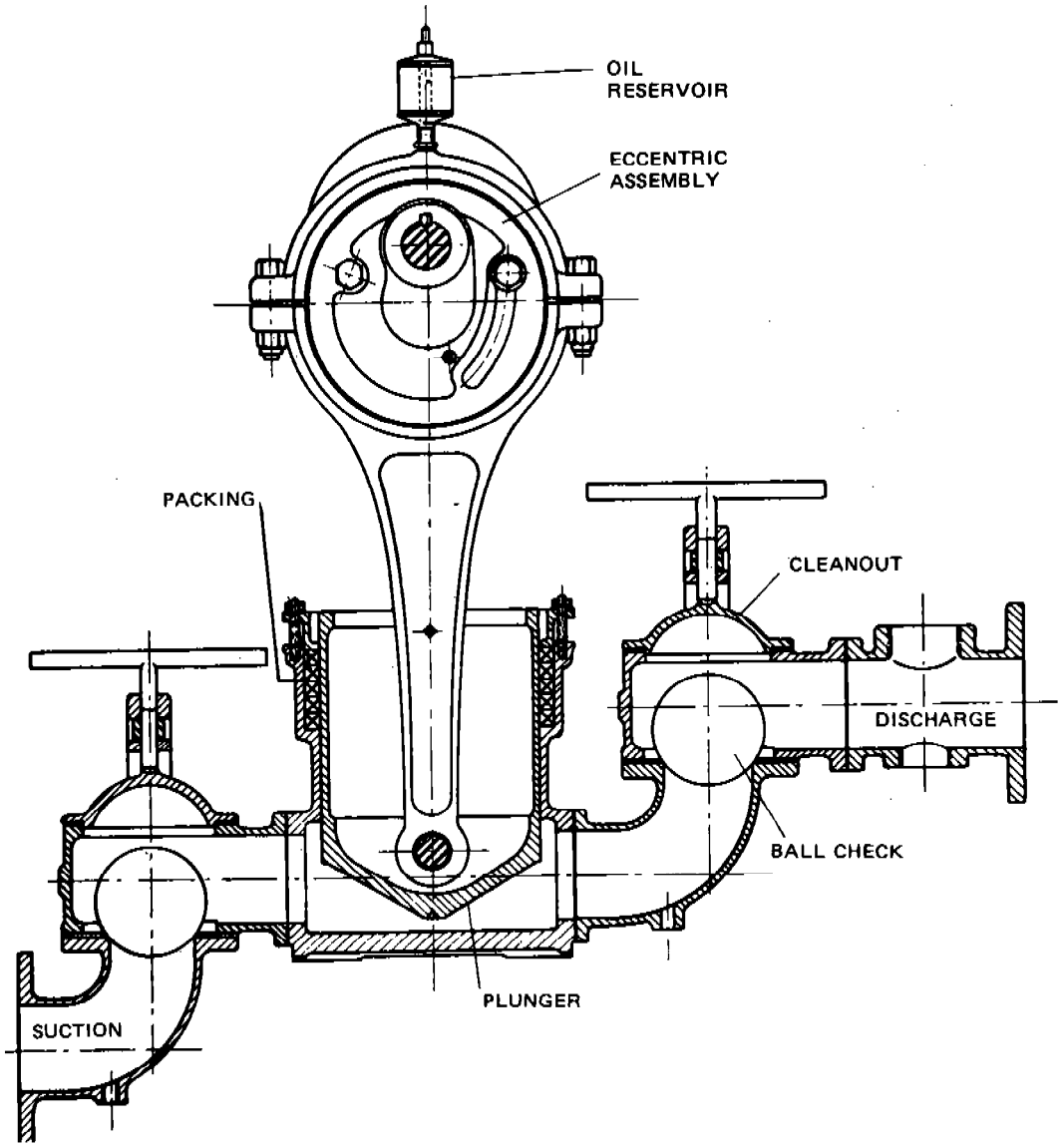


Figure 4–15. Cross-Section Diagram of Reciprocating Sludge Pump.

er's manual.

(2) Troubleshooting Operating Problems. Operating problems encountered with helical-rotor well pumps and their possible causes are in table 4–6.

f. Rotary- and Reciprocating-Displacement Pumps:

(1) Prestart. Rotary- and reciprocating-displacement pumps do not usually require priming. However, when priming is necessary, follow priming procedures for centrifugal pumps.

(2) Starting and Operating. Always start and operate rotary- and reciprocating-displacement pumps with both suction and discharge valves open to prevent motor overload and pump damage.

(3) Operating Precautions:

(a) Rotary- and reciprocating-displacement pumps depend on clearances for efficiency. Keep grit or other abrasive material out of the liquid being pumped to prevent excessive wear and rapid loss of efficiency and self-priming ability.

(b) A pressure-relief valve that discharges back to the suction side of the pump is usually provided on the outlet piping. Adjust this valve for a relief pressure that does not overload the motor. Make sure the check valves seat properly at normal pressures; otherwise, loss of efficiency and priming ability result.

(c) Use table 4–4 with the manufacturer's manuals to develop a checklist for the particular rotary- or reciprocating-displacement pump being used.

g. Well Pump Operating Problems. A troubleshooting checklist for vertical-turbine well pumps is in table 4–7.

4–4. Pump Maintenance:

a. General Information:

(1) Record Files. Maintenance records should be kept for each pump and drive assembly. The method used is prescribed by local command, but should contain entries for routine maintenance (lubrication, equipment checks, etc.), as well as scheduled overhauls and nonscheduled re-

Table 4-4. Troubleshooting Checklist for Centrifugal Pumps.

Symptom	Possible Cause
Pump does not deliver water.	Pump not primed.
	Pump or suction pipe not completely filled with water.
	Suction lift too high.
	Air pocket in suction line.
	Inlet of suction pipe insufficiently submerged.
	Suction valve not open or partially open.
	Discharge valve not open.
	Speed too low.
	Wrong direction of rotation.
	Total head of system higher than design head of pump.
	Parallel operation of pumps unsuitable for such operation.
	Foreign matter in impeller.
Insufficient capacity delivered.	Pump or suction pipe not completely filled with water.
	Suction lift too high.
	Excessive amount of air or gas in water.
	Air pocket in suction line.
	Air leaks into suction line.
	Air leaks into pump through stuffing boxes.
	Foot valve too small.
	Foot valve partially clogged.
	Inlet of suction pipe insufficiently submerged.
	Suction valve only partially open.
	Discharge valve only partially open.
	Speed too low.
	Total head of system higher than design head of pump.
	Parallel operation of pumps unsuitable for such operation.
	Foreign matter in impeller.
	Wearing rings worn.
	Impeller damaged.
	Casing gasket defective permitting internal leakage.
Insufficient pressure developed.	Excessive amount of air or gas in water.
	Speed too low.
	Wrong direction of rotation.
	Total head of system higher than design head of pump.
	Parallel operation of pumps unsuitable for such operation.
	Wearing rings worn.
	Impeller damaged.
	Casing gasket defective permitting internal leakage.
Pump loses prime after starting.	Pump or suction pipe not completely filled with water.
	Suction lift too high.
	Excessive amount of air or gas in water.
	Air pocket in suction line.
	Air leaks into suction line.
	Air leaks into pump through stuffing boxes.
	Inlet of suction pipe insufficiently submerged.
	Water-seal pipe plugged.
	Seal cage improperly located in stuffing box, preventing sealing fluid from entering space to form the seal.
Pump requires excessive power.	Speed too high.
	Wrong direction of rotation.
	Total head of system higher than design head of pump.
	Total head of system lower than pump design head.
	Foreign matter in impeller.
	Misalignment.
	Shaft bent.
	Rotating part rubbing on stationary part.
	Wearing rings worn.
	Packing improperly installed.
	Incorrect type of packing for operating conditions.
	Gland too tight resulting in no flow of liquid to lubricate packing.
Stuffing box leaks excessively.	Seal cage improperly located in stuffing box, preventing sealing fluid entering space to form the seal.
	Misalignment.
	Shaft bent.
	Shaft or shaft sleeves worn or scored at the packing.
	Packing improperly installed.
	Incorrect type of packing for operating conditions.
	Shaft running off center because of worn bearings or misalignment.
	Rotor out of balance resulting in vibration.

pairs. A description of the work done, the date, and the name of the person doing the work are minimum entries.

(2) Lubrication:

(a) Lubricant types are listed in chapter 11.

(b) General Rules. Manufacturer's manuals cover lubrication frequency for special cases, but the following generally apply.

1. Caution. Totally enclosed equipment and equipment that is insufficiently guarded should not be lubricated while the equipment is in motion.

2. Lubrication Identification. To avoid errors, establish a marking system to make sure that the proper lubricant is used. Make sure the same product symbol and identifying color are marked on lubricant containers, lu-

Table 4-4. Continued.

Symptom	Possible Cause
Packing has short life.	Gland too tight resulting in no flow of liquid to lubricate packing. Excessive clearance at bottom of stuffing box between shaft and casing, causing packing to be forced into pump interior. Dirt or grit in sealing liquid, leading to scoring of shaft or shaft sleeve. Water-seal pipe plugged. Seal cage improperly located in stuffing box, preventing sealing fluid from entering space to form the seal. Misalignment. Shaft bent. Bearings worn. Shaft or shaft sleeves worn or scored at the packing. Packing improperly installed. Incorrect type of packing for operating conditions. Shaft running off center because of worn bearings or misalignment. Rotor out of balance resulting in vibration.
Pump vibrates or is noisy.	Gland too tight resulting in no flow of liquid to lubricate packing. Failure to provide cooling liquid to watercooled stuffing boxes. Excessive clearance at bottom of stuffing box between shaft and casing, causing packing to be forced into pump interior. Dirt or grit in sealing liquid, leading to scoring of shaft or shaft sleeve. Pump or suction pipe not completely filled with water. Suction lift too high. Foot valve too small. Foot valve partially clogged. Inlet of suction pipe insufficiently submerged. Operation at very low capacity. Foreign matter in impeller. Misalignment.
Bearings have short life.	Foundations not rigid. Shaft bent. Rotating part rubbing on stationary part. Bearings worn. Impeller damaged. Shaft running off center because of worn bearings or misalignment. Rotor out of balance resulting in vibration. Dirt or grit in sealing liquid, leading to scoring of shaft or shaft sleeve. Excessive grease or oil in antifriction-bearing housing, or lack of cooling, causing excessive bearing temperature. Lack of lubrication. Improper installation of antifriction bearings (damage during assembly, incorrect assembly of stacked bearings, use of unmatched bearings as a pair, etc.). Dirt getting into bearings. Rusting of bearings because of water getting into housing. Excessive cooling of watercooled bearing resulting in condensation in the bearing housing of moisture from the atmosphere. Misalignment. Shaft bent. Rotating part rubbing on stationary part. Bearings worn. Shaft running off center because of worn bearings or misalignment. Rotor out of balance resulting in vibration. Excessive thrust caused by a mechanical failure inside the pump or by the failure of the hydraulic balancing device, if any. Excessive grease or oil in antifriction-bearing housing or lack of cooling, causing excessive bearing temperature. Lack of lubrication.

bricant applicators, and locations near lubrication points.

3. Overlubrication. Use care to never overlubricate. Overlubrication causes antifriction bearings to overheat and may damage the grease seals. Overlubrication may also damage electric motor windings.

4. Greasing. The fewer the types of grease used, the fewer grease guns required and the less likelihood of improper grease being used. For simplified operation, the same type of grease gun fitting should be provided at all points using the same type of grease.

(3) Packing. Selection of packing is usually done in accordance with the manufacturer's recommendations or assistance.

(a) Packing Types. For pumping water, packing

Table 4-4. Continued.

Symptom	Possible Cause
Pump overheats and seizes.	Improper installation of anti-friction bearings (damage during assembly, incorrect assembly of stacked bearings, use of unmatched bearings as a pair, etc.). Dirt getting into bearings. Rusting of bearings because of water getting into housing. Excessive cooling of water-cooled bearing resulting in condensation in the bearing housing of moisture from the temperature. Pump not primed. Operation at very low capacity. Parallel operation of pumps unsuitable for such operation. Misalignment. Rotating part rubbing on stationary part. Bearings worn. Shaft running off center because of worn bearings or misalignment. Rotor out of balance resulting in vibration. Excessive thrust caused by a mechanical failure inside the pump or by the failure of the hydraulic balancing device, if any. Lack of lubrication.

types include nonreinforced woven or braided cotton asbestos, semimetallic plastic, or a combination of the two.

(b) Packing Selection. If the manufacturer's assistance is required for the selection of packing, detailed information must be supplied to the manufacturer on the following items:

1. Description of liquid handled, including percentage concentration, temperature, and impurities.

2. Amount of abrasive present.

3. Stuffing box dimensions (depth of box, outside diameter, and shaft or sleeve diameter); also, stuffing box pressure and temperature.

4. Shaft speeds.

5. Sealing cage (lantern gland) location and width.

6. Shaft or seal material and hardness.

(c) Packing the Stuffing Box. The stuffing box should be inspected twice a year for free movement of the stuffing box glands, and the gland bolts and nuts oiled. The operator should check for excessive leakage that cannot be reduced by gland adjustment and should follow procedures in *1.* through *7.* below:

1. Remove the Old Packing. Before adding new packing to the stuffing box, be sure that all old packing has been removed and that the box is clean. If a seal cage exists in the box, make sure that it is located opposite the sealing liquid inlet, in this manner. Measure the depth of box and sealing liquid inlet tap, then place enough rings of packing in the bottom of the box so that when the packing is compressed, the seal cage will be in its proper position. Make sure that the packing ring joints are staggered.

2. Add New Packing. Use the packing recommended by the manufacturer. Do not try to pack a pump by renewing only the last three or four rings. Cut the packing so that the joints are square after the packing is bent around the shaft. Packing should be cut about $\frac{1}{16}$-inch longer than measured to be sure that the outside diameter of the ring hugs the stuffing box wall rather than the sleeve. Use care in cutting the rings. Except as detailed in the following paragraphs, use the follower gland and a few convenient equal-length spacers to compress each ring firmly into place before inserting the next ring. Stagger the joints, and make sure that the lantern ring is centered under the water-supply connection. After the last piece of packing has been placed, tighten the follower gland nuts until fingertight.

3. Woven and Braided Packing. For woven or braided packing, dip each ring of packing in oil before adding it to the suffing box. This type of packing does not have to be added one ring at a time. Fill box half full, then draw rings up snug by taking up on the packing sleeves and

Table 4-5. Troubleshooting Checklist for Air-Lift Pumps.

Symptom	Cause of Trouble	Remedy
Flow does not start.	Inadequate compressor pressure. Leaking air line.	Check and repair as necessary.
Air blows through eduction pipe without water flow.	Bottom of eduction line or foot piece plugged or restricted with debris.	Close discharge valve and backblow. Vibrate by tapping; remove line and clean.
Compressor pressure builds up with no flow.	Obstruction in air line or foot piece.	Check for obstruction.
	Closed valve in air line.	Check valving.
Well pumps in spurts.	Well not receiving sufficient air.	Check for closed or clogged valves in air line or inadequate compressor delivery.
Water level lowered to point where submergence is too low to pump at capacity with the air available.	Water flow into well is insufficient.	Check capacity records to determine whether well needs cleaning or backblowing.

Table 4-6. Troubleshooting Checklist for Helical-Rotor Well Pumps.

Symptom	Possible Cause
No water is delivered.	Broken or disconnected shaft.
	Excessive discharge head.
	Plugged or nonsubmerged suction strainer.
Pump does not deliver rated capacity.	Speed too low.
	Drawdown excessive.
	Strainer partially plugged.
	Mechanical defect.
Pressure is too low.	Discharge head too high.
	Speed too low.
	Pressure relief valve set too low.
	Mechanical defect.
Pump stops after starting to operate.	Bent column shaft.
	Clogged suction strainer.
	Pump binding in well.

gland. Release the follower, add the remainder of the packing, and draw up snug, then back off the gland until fingertight.

4. Plastic and Metallic Packing. Plastic and metallic packing must be compressed individually. Dip each ring in oil, insert in stuffing box, and draw up tight by split packing rings and gland. Handturn the shaft a few times to gloss the packing. Always use metallic or jacketed rings next to the bottom of the box, bushings, seal cages, or glands, because nonjacketed plastic rings squeeze under the clearances at these locations.

5. Combustion-Type Packing. When combustion-type packing is used, follow the instructions supplied with the packing.

6. Lantern Ring. If a lantern ring is used, be sure it is positioned correctly, and if grease sealing is used, be sure the lantern ring is filled with grease before the remaining rings are put in place.

7. New Packing. New packing has to be "run-in." Start the pump with the stuffing box gland quite loose. Allow the pump to run 10 to 15 minutes.

a. Gradually tighten the stuffing box gland until leakage is reduced to a constant drip.

b. Packing that is too tight in the box causes undue friction, creates heat, glazes the packing, and may score the shaft sleeves. Packing must remain soft and pliable.

c. Drip leakage is necessary to ensure proper lubrication throughout the packing box.

(d) Packing-Gland Assembly. At weekly intervals, the packing-gland assembly should be inspected. If the stuffing box leaks too much, the gland should be tightened; if this action does not alleviate the condition, the packing should be removed and the shaft sleeve inspected.

(4) Sealing Water Systems. The operator should use the following procedures:

(a) Make the daily checks listed in table 4-8. If the leakage cannot be adjusted properly, repack the stuffing box according to (3)(c) above.

(b) Each year, disassemble the sealing water lines and valves to make sure that the water passages are open.

(5) Rotary Seals. If a pump has seals that do not have the conventional follower and pliable, replaceable packing, consult manufacturer's manual.

(6) Shafts and Shaft Sleeves. Each year, when the pump is dismantled, examine the shaft carefully at the impeller hub, under the shaft sleeves, and at the bearings.

(a) Shafts. The shaft may be damaged by rusting or pitting caused by leakage along the shaft at the impeller or shaft sleeves.

1. Antifriction bearings improperly fitted to the pump shaft cause the inner race to rotate on the pump shaft, and result in damage to the shaft.

2. Excessive thermal stresses or corrosion may loosen the impeller on the shaft and subject the keyway to shock.

3. A shaft that is bent or distorted should be replaced. After the shaft has been replaced, check it for possible runout (maximum allowable, 0.002 inches).

(b) Shaft Sleeves. Shaft sleeves should be inspected each year. They are subject to wear and may require replacement, depending on the severity of service. When the sleeve has become appreciably worn, it is not possible to adjust the packing to prevent leakage. Under these conditions, the sleeve should be replaced; otherwise, excessively grooved or scored sleeves will pare and score new packing as soon as it is inserted into the stuffing box.

(7) Wearing or Sealing Rings. Each year, the operator should inspect the wearing or sealing rings that seal the discharge water from suction water in rotating pumps. These are not perfect seals and do allow some leakage. This leakage should not be allowed to become excessive because of worn rings, or the pump efficiency will be impaired. Three types of wearing rings are shown in figure 4-16.

(a) Proper wearing ring clearance is very important. In the straight-type wearing ring (figure 4-16(1)), which is the most common type, the diametrical clearance need not be less than 0.025 inch and should not be greater than 0.050 inch.

(b) In the L-shaped type (figure 4-16(2)), clearance

Table 4-7. Troubleshooting Checklist for Vertical-Turbine Well Pumps.

Symptom	Cause of Trouble	Remedy
Pump does not deliver water.	Pump not primed.	Check for proper pump submergence. Vent well to atmosphere to eliminate vacuum at pump suction.
	Discharge head too high.	Check for closed discharge valves or stuck check valves.
	Pump parts failure.	Check for broken shaft, broken bowl assembly, loose impellers, and loose column-pipe joints.
	Wrong direction of rotation.	Check for switched power leads.
	Speed too low.	Check power supply voltage and frequency; bearing friction; impeller corrosion and obstruction.
	Suction clogged.	Backwash or use chemical treatment to clean.
	Operating water level low.	Check static level and drawdown. Lower pump; clean screen; decrease pumping rate.
Insufficient capacity delivered.	Impeller wear.	Check for metal loss at tips of impeller vane; excessive clearance at wearing rings on fully-enclosed impellers; excessive clearance at bottom of vanes on semi-open impellers.
	Leaks.	Check for leaks at flanged or threaded joints, gaskets, and packings; holes in bowls, column pipe, or pump head.
	Low speed.	Check power supply voltage and frequency; excessive bearing friction; impeller corrosion or obstruction.
	Low water level in well.	Check well vent; pump inlet for turbulence, vortexing, or eddies; well screen for sand, rust, or biological growth.
	Faulty instruments.	Correct instrument readings.
Pump requires excessive power.	Impeller rub.	Check adjustment of impeller height.
	Wrong lubricant.	Compare manufacturer's instructions with lubricant being used.
	Misalignment.	Check for tight bearings; pump and casing vibration.
	Packing too tight.	Check for proper leakage to provide shaft lubrication.
	Pump selection wrong.	Check capacity rating, etc.
	Wrong direction of rotation.	Check power leads.
	Excessive speed.	Check power frequency and voltage; check gear ratios.
Pump fails to start.	Bearing friction.	Check tube tension nut for tightness; bent shaft; proper anchoring; check oil.
	Corrosion products or biological growth.	Check particularly on out-of-service pumps. Where necessary flush with acid, chlorine, and/or hexametaphosphate.
	Fuses burned out.	Check voltages on phases of motor terminals.
	Impeller locked.	Check for sand; raise or lower impeller; backwash. Pull pump if necessary. Also check impeller adjustment; raise impeller to allow shaft to stretch for hydraulic thrust.
	Faulty driver.	Disconnect from pump and check starting.
	Power not available.	Check circuit breaker, fuse, and starter.
	Overload relay trip.	Reset.
	Trash in casing.	Check; if necessary, pull pump and clean.
	Low voltage.	Check.
	Well cave-in.	Check; pull pump; repair well.
Excessive vibration.	Air entering pump.	Check on overpumping and water level drawdown; check leaks in well vent.
	Bearing trouble.	Check for sand in water; check lubricant (oil and grease) for proper grade.
	Rough operation.	Check disconnected motor; check for sand in impeller or bowl; check for wear in rotating parts.

in the space parallel to the shaft should be the same as for the straight-type. The clearance of the space at the right angle to the shaft is governed by the end-play tolerances in the bearing.

(c) For specification information on the L-shape and labyrinth-type rings, consult the manufacturer's manual.

(8) How Bearings Are Maintained. Bearing maintenance procedures depend on the type of bearing.

(a) Antifriction Bearings. Make a monthly check of the bearing temperature with a thermometer. Antifriction bearings that are running hot probably have too much lubricant.

1. If the lubricant change (according to table 4-8) does not prevent overheating, disassemble and inspect the bearing. If nothing is detected wrong, check the pump and motor alignment.

2. When performing the quarterly lubrication change, check the clearances. The clearance allowed is 0.002 inch, plus 0.001 inch for each inch (or fraction of an

Table 4-8. Lubrication Schedule for Centrifugal-Type Pumps.

Lubrication Point	Frequency	Action Required
Antifriction bearing	Monthly	Check temperature (with thermometer); if running hot, bearing is probably overlubricated; remove excess lubricant.
	Quarterly	Drain lubricant; flush lubricant wells and bearings with kerosene; add clean fresh lubricant.
Ball-thrust bearing	Monthly	Add fresh grease to grease cups, but do not attempt to keep grease from coming out around the collar seal.
	Quarterly	Change the grease in the grease cup if the pump operates more than 50 times a day; otherwise, change annually.
Bearing housing	Daily	Check oil level in oil housing; do not add oil with pump running; remove oil vent plug when adding oil.
	Quarterly	Open housing; flush with kerosene; add clean fresh lubricant.
Enclosed shaft-type bearing	Weekly	Check oil cup; add lubricant as necessary.
Grease-sealed packing gland	Daily	Check spring loaded grease cup; refill as necessary; adjust spring tension to maintain grease discharge through packing at approximately 1 ounce per day.
Guide bearing	Monthly	Add grease through fittings provided.
Sealing water system	Daily	Check packing gland assembly; adjust packing if excessive leakage for water seals, allow 60 drops per minute with pump running.
	Semiannually	Check stuffing box for free movement of gland.
Hand oiler	Each shift	According to Table 4-9.
Solenoid oiler	Daily	Check that leads are connected; check needle valve for clogging; adjust for 2 to 4 drops per minute; refill container as necessary.
Sleeve bearing	Monthly	Check bearing temperature; if too hot, add lubricant.
	Quarterly	Drain lubricant; wash wells and bearing with kerosene.
Universal joint coupling	Semiannually	Lubricate couplings and slip splines with fresh grease.

inch) of the shaft-journal diameter.

3. Each year, when the pump is dismantled, check on the condition of the bearings and the bearing race and replace, as necessary.

a. The preferred method in general use for mounting a bearing on a pump shaft is to heat the bearing to expand the inner race and shrink it on the shaft. The bearings is heated in an oil bath or electric oven to a uniform temperature of 200° to 250°F. When heated, it should be quickly mounted on the shaft.

b. An alternate method uses force exerted by an arbor press or hammer blows.

c. In forcing a bearing onto a shaft, care should be taken that the race is never cocked during the operation. The bearing position on the shaft should be pressed firmly against the shaft shoulder. It should be checked with a feeler gage.

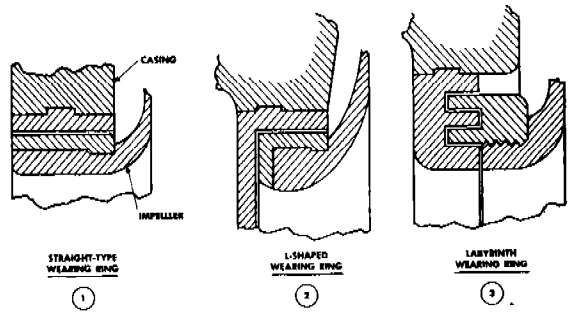


Figure 4-16. Types of Wearing (Sealing) Ring.

(b) Sleeve Bearings. Make a monthly check of the bearing temperature with a thermometer. Sleeve bearings that are running hot probably need lubricant.

1. If the lubrication change specified in table 4-8 does not remedy overheating, disassemble and inspect the bearing. If the bearing is in good condition, check the pump and motor alignmemt.

2. During the quarterly lubrication change, check the clearances. The normal clearance allowed in these bearings in 0.002 inch plus 0.001 inch for each inch (or fraction of an inch) of shaft-journal diameter. Make sure that the oil rings are free to turn with the shaft. Repair or replace oil rings when necessary.

3. Each year, when the pump is dismantled, check on the condition of the bearings and the bearing race and replace, as necessary. Sleeve bearings are usually of the split type and easily removed and installed. Rotation of the bearing is prevented by a pin in the top half of the bearing housing.

(9) Impeller. Each year, the rotating element should be removed and inspected thoroughly for wear (see (12)(b) below for dismantling procedures).

(a) Any deposits or scaling should be removed.

(b) The operator should check for erosion and cavitation effects. Cavitation causes severe pitting and a spongy appearance in the metal.

(c) If cavitation effects are severe, some changes may be necessary in pump design or use. The matter should be reported to the supervisor.

(10) Casing Procedures. The waterways must be kept clean and clear of rust. When the unit is dismantled, clean and paint the waterway with a suitable paint that will adhere firmly to the metal. A routine program of cleaning and repainting is desirable to prevent complete erosion of the protective coat before replacement.

(11) Pump Shutdown. When a pump is shutdown for an extended period, or for overhaul inspection and maintenance, the following procedures apply:

(a) Shut off all valves on suction discharge, waterseal, and priming lines. Drain pump completely by removing vent and drain plugs until the water has runoff. This operation protects against corrosion, sedimentation, and freezing.

(b) Disconnect the switch to the motor and remove the fuses.

(c) Drain the bearing-housing, and refill with fresh grease, or purge all the old grease if the shutdown is to be followed by an inactive period. If an overhaul is scheduled, do not refill the oil or grease receptacles until the pump is reassembled.

(12) Overhaul Procedures:

(a) Frequency. The frequency of complete overhaul depends on the hours of operation of the pump, the severity of service conditions, the material of construction of the pump, and the care the pump receives during its operation. If the pump is not in continuous operation, it is not necessary to open the pump for inspection unless there is definite evidence that the capacity has fallen off excessively, or if there is an indication of trouble inside the pump or in the bearings. Pumps in relatively continuous operation should be dismantled on an annual basis.

(b) Dismantling and Reassembling. Because pump designs and construction vary from model to model, and from one manufacturer to another, there is no set of specific procedures for dismantling and reassembling. The rules in *1* through *4* below are basic, but for detailed procedures consult the manufacturer's manual.

1. Exercise extreme care in the dismantling operation to prevent damage to internal parts of the pump. For convenience in reassembly, lay out all parts in the order that they are removed. Protect all machined faces against metal-to-metal contact and corrosion. Do not remove ball bearings unless absolutely necessary.

2. While the pump is dismantled, examine the foot valve and check valve to make sure that they are seating and functioning properly.

3. To assemble the pump, reverse the dismantling procedure. Follow the manufacturer's manual explicitly.

4. Check the pump and motor alignment after reassembly.

b. Centrifugal-Type Pump:

(1) General Information. The following paragraphs describe general maintenance procedures apply to all types of horizontal and vertical centrifugal pumps. Details of procedures that apply to specifically to volute, diffuser, regenerative-turbine, split-case, and multistage design should be obtained by consulting the manufacturer's manuals. A cutaway diagram of a two-stage centrifugal pump is shown in figure 4-17. This figure shows many of the items discussed in the following paragraphs.

(2) Lubrication. The general lubrication items listed in a(2) above and chapter 11 pertain to this section. A general lubrication schedule for centrifugal-type pumps is presented in table 4-8. When hand oilers are used to lubricate the shaft bearings, the settings should be checked daily and adjusted according to table 4-9.

c. Rotary-Displacement Pumps:

(1) General Maintenance. There are numerous types of rotary displacement pumps and, therefore, it is not possible to set up detailed maintenance procedures that apply to all types. Individual maintenance procedures must be set according to the manufacturer's manuals. Use the manual to set up procedures similar to those presented for a centrifugal-type pump.

(2) Overhaul Procedures. At annual intervals, disassemble the pumps and clean both exterior and interior surfaces.

(a) Check clearances for tolerances listed in the manufacturer's manual.

(b) Check the packing assembly, and repack as needed.

(c) Check the bearings and the alignment of the pump and motor.

(d) Check all items included in the checklist previously determined from the manufacturer's manual and the listings for centrifugal-type pumps.

(e) Paint exterior surfaces and interior surfaces subject to rust with a suitable underwater paint or effective protective coating.

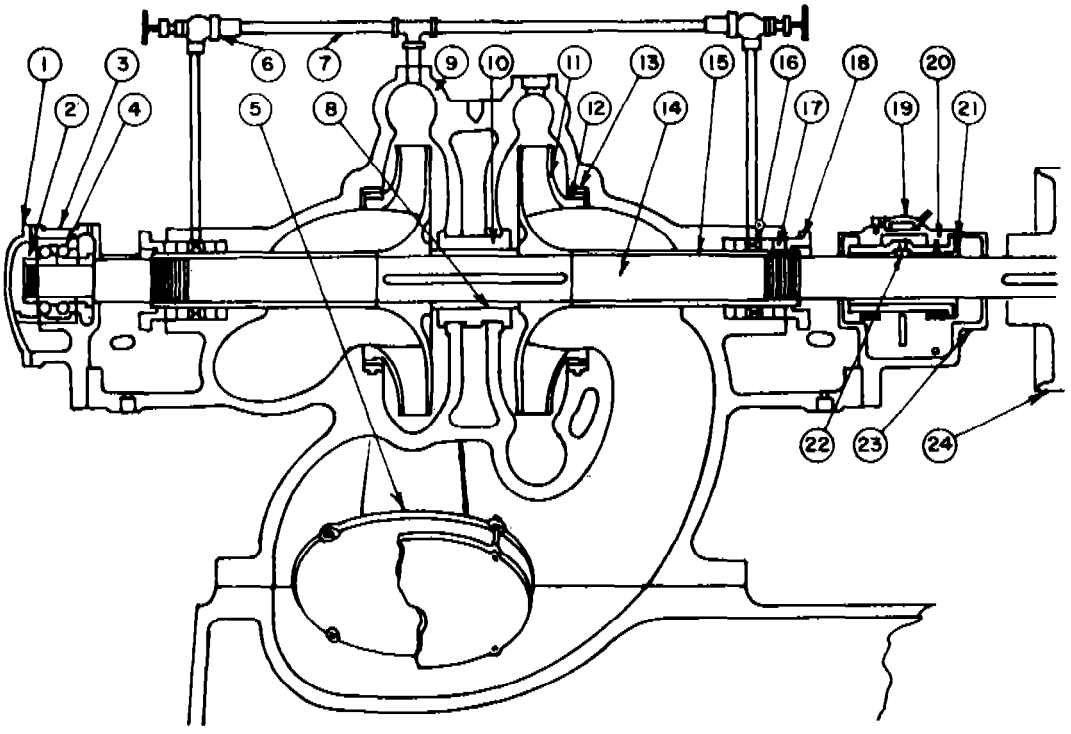
d. Reciprocating-Displacement Pumps:

(1) General Information. As explained in paragraph 4-2m, there are three types of reciprocating pumps: plunger, piston, and diaphragm. The manufacturer's manual should be consulted for each individual pump.

(2) Check Delivery. The delivery of piston and plunger pumps must be determined each year. The decrease in percent delivery from the volumetric displacement per pump stroke is termed "slippage." Excessive slippage indicates the need for maintenance and possible repair.

(a) Volumetric Displacement. Compute the volumetric displacement by multiplying the piston or plunger area by the length of stroke. Make proper allowance for double-action pumps.

(b) Calculate Delivery. Calculate the percent delivery from a comparison of the measured delivery per stroke and the computed volumetric displacement per stroke. If delivery is less than 90 percent of the volumetric displacement, check the valves, pistons, and packing for leakage.



1. SHAFT SLEEVE
2. RETURN GUIDE BUSHING
3. SUCTION COVER
4. BALL BEARING
5. THRUST PLATE
6. WATER-SEAL PIPING
7. SET COLLAR
8. SPACER SLEEVE
9. CASING
10. BALANCING DISK
11. RUNNER
12. RETURN GUIDE
13. WEARING RING
14. SHAFT
15. SHAFT SLEEVE
16. WATER-SEAL RING
17. PACKING
18. GLANDS
19. OIL-HOLE COVERS
20. BEARING HOUSING
21. BABBITTED SHELL
22. OILING RING
23. BEARING HOUSING
24. PUMP HALF COUPLING

Figure 4-17. Cross-Section Diagram of Two-Stage Centrifugal Pump.

Make any necessary replacements to maintain the desired efficiency.

(3) Inspect Pump. Dismantle the pump and inspect thoroughly each year according to the following:

(a) Remove and examine all valves, valve seats, and springs. Reface valves and valve seats as necessary and replace worn or defective parts.

(b) Remove all old packing and repack.

(c) Check the pump and driver alignment.

(d) Check the plunger or rod for scoring or grooving.

Table 4-9. Hand Oiler Adjustment.

Pump Operation Schedule (times per day)	Pump Running Time (minutes)	Oiler Rate
Maximum of 2	Not over 5*	1 drop/15 min
3 to 12	Not over 5*	1 drop/4 min
12 to 50	Not over 5*	1 drop/2 min
More than 50		2 to 4 drops/min

*Pump running times in excess of 5 minutes will require increased oiling rates.

(e) Clean the interior and exterior surfaces. Paint the interior with suitable underwater paint or protective coating. Paint the exterior.

e. Sludge Pumps:

(1) General Maintenance Procedures. Two types of sludge pumps, reciprocating and progressive-cavity, are presented in this section. Centrifugal-type sludge pumps should be maintained according to the procedures previously presented for centrifugal-type pumps. The procedures listed should be modified to conform to the individual manufacturer's manuals.

(2) Lubrication. A lubrication chart should be formulated using table 4-8 and the manufacturer's manual.

(3) Reciprocating-Sludge Pumps:

(a) Packing Procedures:

1. Daily, or more frequently if necessary, check the sight-feed oil cup, if one is provided for lubrication between the plunger and the stuffing box. Add a squirt of oil around the plunger as often as necessary.

2. At varying intervals, renew the packing when no takeup is left on the packing-gland bolts.

a. Remove the old packing, clean the cylinder and piston walls. Place new packing in the cylinder and tamp each ring into place. Be sure that the packing ring

joints are staggered.

b. To break the packing, run the pump for a few minutes with the sludge line closed and the valve covers open.

c. Turn down the gland nuts, no more than is necessary, to keep sludge from getting past the packing. Be sure all packing-gland nuts are tightened uniformly. When chevron-type packing is used, make sure that the nuts holding the packing gland are only fingertight to prevent ruining the packing and scoring the plunger.

3. Check the packing-gland adjustment each week to make sure that the gland is just tight enough to keep sludge from leaking through the gland, making sure that the piston walls are not being scored. Before a pump is operated, especially after it has been standing idle, loosen all nuts on the packing gland.

(b) Bearings and Gear Transmission:

1. Daily (or once per shift), lubricate the bearings and the gear transmissions with a grease gun. If the pump runs continuously, grease more often than once a shift.

2. Check the gear transmission each month and keep it filled to the proper level with the proper oil. Open the drain to eliminate accumulated moisture.

3. Change the oil every 3 months to prevent sludging.

(c) Shear Pins. Make a check each week of the shear-pin adjustment. Set the eccentric by placing a proper shear pin through the proper hole in eccentric flanges to give the required stroke. Tighten the hexagonal nuts on the eccentric flanges just enough to take the spring out of the lock washers.

1. If shear-pin failures occur, check for a solid object lodged under the piston, a clogged discharge line, or a stuck or wedged valve.

2. When a shear pin fails, the eccentric moves to the neutral position and prevents damage to the pump. Remove the cause of failure and insert a new shear pin.

(d) Ball Valves. Replace all valve balls that are worn small enough to jam into the valve chamber every 3 months. A decrease in diameter of ½ inch is sufficient to cause this difficulty. Check the valve chamber gaskets and replace them when necessary.

(e) Eccentric. Each year, remove the brass shims from the eccentric strap to take up the babbitt bearing. After removing the shims, operate the pump for 1 hour and check the eccentric to be sure it is not running hot.

(4) Progressive-Cavity Sludge Pumps. Where screw-type sludge pumps are used, the maintenance procedures are as follows:

(a) Seals. Daily, when grease seals are used instead of water seals, check the grease pressure in the seals.

(b) Bearings. Lubricate the sludge pump through the grease connections on the bearing housing each week. Flush out the bearing housing each year, then refill with new grease.

(c) Packing Glands. Check the packing glands for leakage each week.

1. For water seals, allow about 60 drops of leakage per minute when the pump is running.

2. If leakage is high, tighten the two gland nuts evenly a few turns, but do not draw the glands too tight. After adjusting the gland, turn the shaft by hand to make sure that it turns freely.

f. Well Pumps. Well-pump types are centrifugal pumps, reciprocating (piston or plunger) pumps, air-lift pumps, and ejector pumps.

(1) Centrifugal Well Pumps. The turbine well pump is the most widely used type of well pump. The maintenance items listed for centrifugal-type pumps and the manufacturer's manual should be used to develop maintenance charts for turbine well pumps. In addition, the following items should be observed:

(a) Types of Lubrication:

1. Oil-Lubricated Pump and Bearings. Make sure that oil tubing and lubricators are filled each day. Check solenoid oilers for proper operation and see that they are filled. Check oil level in sight lubricator for underwater bearings. Make sure that the oil feed is at an average rate of 3 to 4 drops per minutes.

2. Water-Lubricated Pump and Bearings. This type of design requires lubrication with clear water. Daily, make sure that the prelubrication tank is full when the pump is in use.

a. When filling the tank by pump, be sure to close the tank-filling valve when the tank is full. Open lubrication valve to allow water to reach the bearings before the pump is started.

b. If the bearings are lubricated from main pressure, close the lubricating valve after the pump is started.

c. If the pump operates automatically, with a lubrication-delayed solenoid valve, allow one minute before checking lubricating valve for proper operation. Check solenoid valve and packing.

d. Check the prelubrication control on pumps that have safety controls to prevent starting before lubrication water is turned on. Make sure that this water flows to bearings when the equipment is supposed to function.

e. Check the time-delay relay for proper functioning, and compare with the manufacturer's recommendation.

f. Clean and lubricate the guides and linkages.

(b) Impeller Adjustment. Check the impeller for maximum efficiency setting and adjust if necessary every 3 months. On hollow-shaft motors, the adjustment nut is on the top of the motor. Consult the manufacturer's manual for the detailed adjustment procedure.

(c) Impeller Fitting. When the pump is pulled for inspection, note signs of pitting or wear on the impellers.

1. Cavitation. If pitting occurs in the lower stages, it may be due to cavitation.

2. Sand Erosion. Sand in the water causes the impellers to erode. If sand is the cause of difficulty, refer to chapter 3, section B. Where the erosion effect is appreciable, repair or replace impellers that are not likely to last until the next inspection.

3. Check Clearances. Repair or replace impel-

lers, as necessary, to maintain the close clearance required for pump efficiency. See the manufacturer's manual regarding pump clearances and efficiencies.

(d) Bowls and Waterways. When the pump is pulled for inspection, the bowls and water passage should be inspected for pitting, wear, and corrosion.

(e) Overhaul Procedures:

1. Frequency. As with the centrifugal pumps, the frequency of complete overhaul depends on the hours of operation, severity of operation, etc. Generally, however, a pump in continuous operation should be pulled for inspection and overhaul on an annual basis. The work of overhaul should be done under experienced supervision and in strict accordance with the manufacturer's manual. The pump should be overhauled if any of the following conditions exist, regardless of scheduled frequency of maintenance:

a. The pump shaft does not turn freely because parts below the pump head are binding.

b. The pump shows excessive vibration.

c. Performance test shows a decrease of 25 percent in capacity under normal head and speed conditions.

2. Clearances. When a pump is pulled, check the diametrical clearance of each bearing ring to make sure it is between 0.025 and 0.050 inch. Allow a maximum diametrical clearance of 0.025 inch on oil-lubricated bearings. Acceptable clearances for water-lubricated cutless rubber bearings are listed in table 4-10.

3. Dismantling and Reassembly. Follow the same procedures listed for centrifugal-type pumps.

4. Alignment. Check the pump and motor alignment each year.

5. Painting. Annually, or when the pump is pulled, paint all iron parts with a good grade of underwater paint or effective protective coating on the exterior of the pump and, if possible, on the interior parts subject to rust. Apply the paint only to surfaces that are clean and dry. Do not paint data plate.

(2) Reciprocating Well Pumps:

(a) General Information. The manufacturer's manual should be used to develop checklists for each reciprocating well pump.

(b) Check Delivery. The pump output should be measured twice a year for a known number of strokes. Delivery per stroke should be at least 90 percent of the volumetric displacement of the pump (plunger area times stroke length). When the pump delivery drops to 50 percent or less, or when the pump delivery is between 50 and 90 percent but less than the installed water requirements, the pump should be removed from the well and the valves and cup leathers checked. Before removing the pump, consult the manufacturer's method for picking up the foot valve and for additional maintenance procedures.

Table 4-10. Diametrical Clearance of Water-Lubricated Cutless-Rubber Bearings.

Conditions	Shaft Diameter (inches)	
	Up to 1½	1½ to 4
Clearance when new (inch).	0.020 to 0.032	0.040 to 0.050
Maximum clearance allowable (inch).	0.040	0.070

(c) Overhaul Procedures. The pump jack should be inspected for wear each year. Replace worn bearings and parts. Check the packing assembly and repack as necessary. If the pump delivery is satisfactory, do not overhaul the pump parts in the well. Paint the exterior of the pump as necessary.

(3) Air-Lift Pumps. The manufacturer's manual should be consulted for repair of the air compressor and as a supplement to maintenance procedures described below:

(a) The following operations and inspections are to be performed each day:

1. Lubricate the compressor according to the manufacturer's instructions.

2. Blow down the air-receiving tank.

3. Check the relief valve on the receiving tank, or in the air line between the valve and the compressor. Repair, if not operating properly.

4. Make sure that the cooling water is ample for cooling the cylinder jacket and has been properly treated for corrosion control.

(b) The following operations and inspections must be performed each week.

1. Examine the compressor for oil pumping, if oil appears in the sample.

2. Check the filters for air intake and replace, if necessary.

3. Check for air contamination in the air-lift. Because well water can become contaminated by air, make sure that there are no cross-connections in the air system by which contaminated water may enter the well.

4. Check the well water for presence of oil from compressed air by looking for oil film on surface of the water sample.

(4) Ejector Pumps:

(a) Centrifugal Pump. The centrifugal pump portion of the system should be maintained according to (1) above.

(b) Ejector Assembly. Each year, or as directed by the utilities manager, remove the ejector, the foot valve, and the screen from the well. Examine all parts for wear and corrosion and repair or replace any defective parts. Paint the exterior of the pump and, if practical, paint interior iron with a good grade of underwater paint or effective protective coating. Do not paint data plate.

Section B—Pump-Driving Equipment

4-5. Driving Equipment Description, Operation, and Maintenance:

a. General Information. Pumps are devices for transmitting energy from a mechanical source to a fluid, usually water. The mechanical source of energy is referred to as

the driver. The driver is coupled to the pump with some type of drive connection.

(1) The driver is usually one of three types:

(a) Electric motor.

(b) Gasoline or diesel engine.

(c) Steam turbine (not discussed in this regulation).

(2) The drive connection is usually of the following types:

(a) Shaft.

(b) Gear.

(c) Belt.

(d) Chain.

(3) The information in the following paragraphs is of a general nature. The operator should consult the manufacturer's manual to determine specific operating and maintenance requirements for the driving equipment in use. In addition, various installation support groups are responsible for certain aspects of the driving equipment. For example, the electrical shop is responsible for electric motor repair.

b. Electric Motors:

(1) General Information. Electric motors are the most common drive used in military water systems. Sizes range from fractional horsepower to high horsepower units.

(2) Routine Operation. To properly maintain an electric motor, the operator must recognize the normal sounds and conditions of a properly running motor. Any change in the sound or operating condition detected during the regular inspection should be investigated. Routine operating checks are listed below:

(a) Motor Condition:

1. Keep motor free from dirt or moisture.

2. Keep operating space free from articles that may obstruct air circulation.

3. Check bearing for oil leakage.

(b) Unusual Conditions. Report any of the following to the plant superintendent for correction by the electrical shop:

1. Unusual noises in operation.

2. Motor failing to start or to come up to speed in a normal manner.

3. Motor or bearings that feel or smell hot.

4. Continuous or excessive sparking at commutator.

5. Blackened commutator.

6. Sparking at brushes.

7. Fine dust under couplings that have rubber buffers or pins.

8. Smoke, charred insulation, or solder whiskers extending from armature.

9. Excessive hum.

10. Regular clicking.

11. Rapid knocking.

12. Chattering brush.

13. Vibration.

14. Hot commutator.

(3) Maintenance:

(a) Lubrication. The operator is responsible for proper electric motor lubrication. To determine the correct lubricant, see chapter 11. Bearing lubrication frequency is listed in table 4-8.

1. Check oil level in sleeve bearing and replenish as needed. See that the oil ring operates freely.

2. Check grease in ball or roller bearings and replenish when necessary.

(b) Additional Responsibilities. As a rule, the electrical shop is responsible for routine maintenance of electrical motors. Under some circumstances, the responsibility for cleaning and servicing antifriction bearings may be delegated to the operator. When this occurs, the necessary procedures will be provided.

c. Gasoline and Diesel Engines:

(1) General Information. Gasoline and diesel engines are commonly used for emergency, standby, and portable pumping units.

(2) Operation Checks. The operator is usually responsible for performing operating checks. The following paragraphs contain checklists of common items to be checked when operating gasoline and diesel engines. These checklists should be used as general guides only, with specific details being obtained from each manufacturer's manual.

(a) Weekly Checks. All emergency and standby units should be operated 15 minutes each week, under normal operating conditions if practical, to ensure unit readiness.

(b) Prestart Operations. Check:

1. For tampering.

2. Fire extinguisher.

3. Fuel, oil, and water levels.

4. Accessories and drives.

5. For leaks.

6. Battery for cracks and leaks.

7. Air breather.

(c) Starting and Warmup. Check:

1. Choke or primer operation.

2. Engine warmup.

3. Oil gage or indicator light.

4. Instruments:

a. Ammeter.

b. Tachometer.

c. Fuel gage.

d. Voltmeter.

e. Temperature gage.

(d) Service During Operation. Check:

1. Clutch.

2. Transmission.

3. Engine and controls.

4. Instruments.

(e) Service After Operation. Check:

1. Fuel, oil, and water.

2. Instruments.

3. Battery and voltmeter.

4. Accessories and belts.

5. Electrical wiring.

6. Air cleaner and breather caps.

7. Fuel filters.

8. Engine controls.

9. For leaks.

10. Gear oil levels.

(f) Additional Services. Perform any additional checks and services that may be required by the manufacturer's manual.

(3) Routine Maintenance. The operator is responsible for routine maintenance such as maintaining proper oil, water, and fuel levels; cleaning breathers; and keeping the units clean. Fuel, oil, and water additive types, if required, should be determined from the manufacturer's manuals and local conditions. Mechanical-type maintenance is the responsibility of the motor pool.

d. Belt Drives:

(1) General Information. There are two types of belts used for belt drivers; V belts and flat belts. Maintaining proper tension and alignment of belt drives ensures long life of belts and sheaves. Incorrect alignment causes poor operation and excessive belt wear. Inadequate tension reduces the belt grip and causes high belt loads, snapping, and unusual wear. Keep belts and sheaves clean and free of oil, which causes belts to deteriorate.

(2) Routine Maintenance:

(a) Installing Belts. Before installing belts, replace worn or damaged sheaves, then slack off on adjustments. Do not try to force belts into position; never use a screwdriver or similar-type lever to get belts onto sheaves. Check multiple belts for matching size and length. After belts are installed, adjust tension; recheck tension after 8 hours of operation.

(b) Replacing Belts. Replace belts as soon as they become frayed, worn, or cracked.

NOTE: Never replace one V belt on a multiple belt. Replace the complete set with a set of matching belts.

(c) Check Tension. Belt tension should be checked each week and adjusted, as required, to prevent slipping and to prevent excessive wear on the belts.

(d) Check Alignment. Check alignment with a straight edge or string, and make the necessary corrections to keep the pulleys in line.

e. Chain Drives:

(1) General Information. Chain drives may be designed for slow, medium, or high speeds.

(2) Routine Maintenance:

(a) Check Operation. Check general operating conditions during regular tours of duty.

(b) Check Chain Slack. The correct amount of slack is essential for proper chain-drive operation. Unlike belts, chains should not be tight around the sprocket. When chains are tight, working parts carry a much heavier load than necessary. Too much slack is also harmful. A properly installed chain has a slight sag or looseness on the return run. All drive chains should have a tightener installed.

(c) Check Alignment. If sprockets are not in line or if shafts are not parallel, excessive sprocket and chain wear results. To check alignment, remove chain and place a straight edge against sides of the sprocket where no wear has occurred. Replace sprockets and chain if excessively worn.

(d) Lubrication. Lubrication depends on the drive speeds. Refer to the manufacturer's manual and chapter 11 for lubricant types.

1. Slow-Speed Drives. Because slow-speed drives are not usually enclosed, adequate lubrication is difficult. Heavy oil applied to the outside of the chain seldom reaches the working parts; in addition, the oil catches dirt and grit and becomes abrasive. Soak exposed-type chains in a recommended lubricant to restore lubricating film. Remove excess lubricant by hanging chains up to drain. Do not lubricate chains on elevators, conveyers, or feeders that handle dirty, gritty material. Dust and grit combine with lubricants to form a cutting compound which reduces chain life. Do not lubricate underwater chains which operate in contact with considerable grit. If water is clean, lubricate with the recommended lubricant with a brush while chain is running.

2. Medium-Speed Drives. Continuously lubricate medium-speed drives with a drip or sight-feed oiler. The lubricant type depends on temperature conditions.

3. High-Speed Drives. High-speed drives should be completely enclosed in an oil-type case and the oil maintained at proper level. Oil type depends on temperature conditions. Drain the oil and refill the case to the proper level according to manufacturer's recommendations.

(e) Clean and Inspect:

1. On enclosed types, flush chain and enclosure with kerosene. On exposed types, remove chain and soak and wash in kerosene. Clean sprockets, install chain, and adjust tension.

2. Note and correct abnormal conditions before serious damage results. Do not put a new chain on old sprockets. Always replace old sprockets when replacing a chain. Old, out-of-pitch sprockets cause as much chain wear in a few hours time as years of normal operation.

(f) Troubleshooting. A troubleshooting chart for chain drives is in table 4-11.

f. Right-Angle Gear Drives:

(1) General Information. Operating and maintenance procedures for right-angle gear drives should follow manufacturer's recommendations.

(2) Check Lubricant Flow. Immediately after starting a right angle gear drive, remove inspection plate and check for proper flow of lubricant. If there is no flow, stop motion and check for mechanical defect. If no mechanical defect is found, it may be necessary to change lubricant or drain and warm the old lubricant. Temperature or service conditions may require changing lubricant type.

(3) Drain and Change Lubricant. To avoid detrimental effects of possible water-oil emulsion, refill with fresh recommended lubricant about every 500 hours of operation. Lubricant depends on prevailing air temperatures and manufacturer's recommendations.

g. Variable-Speed Drives:

(1) General Information. Variable-speed drives are commonly used in water systems. Designs vary considerably from manufacturer to manufacturer. Therefore, the manufacturer's manual should be consulted to determine operating and maintenance requirements. Items common to most variable-speed drives are listed in (2) below.

Table 4-11. Troubleshooting Chart for Chain Drives.

Symptom	Cause of Trouble	Remedy
Broken pins or rollers.	Shock leads or chain speed too high for pitch.	If speed-pitch relation is cause, use chain of shorter pitch.
Chain climbs sprockets.	Poor fit or severe overload	If sprockets fit poorly, renew; make sure tightener is installed in drive chain.
Chain clings to sprockets.	Possibly incorrect or worn sprockets or heavy tacky lubricants.	Renew or reverse sprockets, or change to proper lubricant.
Chain gets stiff	Poor alignment or excessive overload.	Correct alignment and eliminate overload.
Chain whips	Too long centers; or high pulsating loads.	Correct either condition.
Noise	Misalignment; improper slack, loose bolts.	Correct alignment; adjust slack; tighten bolts; reverse or renew worn chain.
Wear on chain side walls or sides of teeth.	Misalignment	Remove chain and correct alignment.

(2) Operation and Maintenance:

(a) Check for Normal Operation. The drive should be observed each shift and any abnormal conditions noted.

(b) Clean Discs. Remove grease, acid, and water from disc face and thoroughly dry. Use clear solvents that leave no residue.

(c) Check Speed-Change Mechanisms. Shift drive through entire speed range to make sure that shafts and bearings are lubricated and discs move freely in a lateral direction on shafts.

(d) Check V Belt. Make sure the belt runs level and true. If one side rides high, a disc is sticking on the shaft because of insufficient lubrication or wrong lubricant. In that case, stop drive, remove V belt, and clean disc and shaft thoroughly with kerosene until disc moves freely.

(e) Lubrication. Be sure to apply lubricant at all force-feed lubrication fittings and grease cup fittings. Refer to chapter 11 and manufacturer's manual for proper lubricants.

1. Once every 10 to 14 days, use two or three strokes of grease through force-feed fittings at the end of the shifting screw and variable shaft to lubricate bearings of movable discs. Shift drive from one extreme speed to the other to attain thorough distribution of lubricant over disc-hub bearings.

2. Every 60 days, add two or three shots of grease through force-feed fittings which lubricate frame bearings on variable-speed shaft.

3. Every 60 days, add 2 or 3 cups of grease to grease cup which lubricates thrust bearings on constant-speed shaft.

4. Every 60 days, use two or three strokes of grease through force-feed fittings on motor-frame bearings. Do not use hard grease or grease that has graphite.

5. Check reducer oil level every 30 days and add oil when necessary. Drain and replace oil according to manufacturer's recommendations.

(f) Removing Unit From Service. If drive is not to be operated for 30 days or more, shift unit to minimum speed, which places springs on variable-speed shaft on minimum tension and relieves the belt of excessive pressure and tension.

h. Couplings:

(1) General Information. Unless couplings between the driving and driven elements of a pump or any other piece of equipment are kept in proper alignment, breaking or excessive wear occurs in the coupling, the driving machinery, or the driver. Worn or broken couplings, burned-out bearings, sprung or broken shafts, and excessively worn or ruined gears are some of the damages caused by misalignment. To prevent outages and the expense of installing replacement parts, check the alignment of the equipment before damage occurs.

(2) Check Coupling Alignment. Excessive bearing and motor temperatures caused by overload, noticeable vibration, or by unusual noises may all be warnings of misalignment. Realign when necessary, using a straight edge and thickness-gage or wedge. To ensure satisfactory operation, level up to within 0.005 inch:

(a) Remove coupling pins.

(b) Rigidly tighten any driven equipment to its base; slightly tighten bolts holding driver to its base.

(c) To correct horizontal and vertical alignment, shift or shim driver to bring coupling halves into position so no light can be seen under a straight edge layed across them. Lay straight edge in at quarter points of circumference, holding a light back of straight edge to help ensure accuracy.

(d) Check for angular misalignment with a thickness or feeler gage inserted at the same four places to make sure that the space between coupling halves is equal at all points.

(e) If proper alignment has been secured, coupling pins can be put in place easily (using only finger pressure). Never hammer pins into place.

(f) If equipment is still misaligned, repeat procedure.

(3) Lubrication. Use lubrication procedures and lubricants recommended by the manufacturer and those in chapter 11.

Section C—Pumping Stations

4-6. Pumping Station Description. A pumping station consists of combinations of pumps, pipes, valves, gages, meters, controls, drivers, drives, and housing facilities used for pumping water from one location to another. Pumping station complexity can range from relatively simple manually operated, single-pump boosters to complex, automatically controlled multipump installations with auxiliary standby power and pumps.

4-7. Pumping Station Operation:

a. General Information. The operator of a pumping station must be familiar with the function of the particular pumping station and know how to:

(1) Operate and maintain the pumps and drives.

(2) Maintain required waterflow and pressures through the portion of the system affected by the station.

(3) Operate standby equipment on a routine basis without interrupting station service.

(4) Maintain fire flow when needed.

b. Information Required for Operation. The operator must be familiar with all equipment and accessories, the piping layout, the location of valves and other items of station layout, and the function of the particular pumping station. Efficient operation of pumps and pumping stations requires that information about equipment and the plant be readily available, and that information on normal and emergency operation and on maintenance be kept at or near the station.

(1) Detailed Utility Map. Required information includes a detailed utility map.

(2) Pump Information. Maintenance records, pump records and characteristic curves, station plans and design data, as-built drawings, manufacturer's instructions, repair parts lists, guarantees, and maintenance manuals are also required information. For each pumping station a chart should be furnished showing capacity at average discharge head of each pump when operating alone, or in combination with others. If operations reveal significant variations from expected performance, the operator should report these variations to higher authority at once.

(3) Distribution System Information. The operator should know the direction of flow in the distribution system. He or she must keep the system balanced at all times, maintaining specified pressure ranges in each of its parts. It is particularly important that storage tanks be kept adequately filled. It is essential that the operator be familar with the changes required to alter pressures or flows in any section of the distribution system.

c. Records. A daily pumping station activity record, showing what pumps were operated, the amount of water supplied, and other pertinent information must be maintained on a form prescribed by local command. Air Force personnel use AF Form 998, Daily Pumping Station Activity Record Water, to record this information.

d. Controls:

(1) Manual Controls. At stations with manual controls, operators start and stop pumps as the demand changes, open and close valves as required, and maintain close observation of indicating and recording devices and the functioning of drives and drivers.

(2) Automatic Controls. Automatic controls for operating pumping stations eliminate the need for constant attendance of an operator, and in some cases provide closer control of operations. For details of automatic controls, see chapter 5.

e. Standby Pumps and Drivers. Standby pumps and drivers must be fully operative at all times to meet fire flow demands and to replace out-of-service equipment when necessary. They should be run at least once a week, or at intervals established by local command. They should be inspected and serviced regularly, receiving the same attention as regularly operated equipment.

f. Housekeeping Requirements. Because plant efficiency depends on cleanliness, keep the machinery and surroundings clean and orderly.

g. Fire Pumping. Providing maximum waterflow to fight fires is one of the most important functions of the pumping station.

(1) Fire Notification. Unless the principal pumping station is staffed at all times, arrangements must be made for competent personnel to be at the pumping station during fires. Telephone service is provided so that the fire chief can communicate readily with the pumping station. A fire station attendant must notify the pumping station operator of all fires that require increased waterflow.

(2) Pump Operation. When an alarm is given, the necessary pump or pumps should be started as soon as possible and pumping maintained to keep storage tanks as nearly full as possible. Pumps and drivers should be run at full-rated speed, even if the demand for water is small, until the operator is directed to shutdown.

4-8. Pumping Station Maintenance:

a. General Information. Proper maintenance is required to make sure that the pumping station performs its function under normal and emergency operations.

(1) A log of all inspection and maintenance actions must be kept on file detailing work done, date of work, and name of person performing the work.

(2) Maintenance of pumps, drives, and driving equipment is covered in paragraphs 4-4 and 4-5.

b. Building Inspection. Building interiors and exteriors should be inspected each spring for signs of structural damage or weakening. Check wooden structures for timber splitting, dry rot, and termites. Concrete structures should be inspected for signs of spalling, exposed reinforcing, and concrete deterioration. Notify the utility superintendent if signs of structural deterioration are found. The structure is painted by the paint shop personnel.

c. Pump Controls:

(1) Manual Control. Since this type of control consists of manual starting and stopping, and opening and closing valves, the maintenance procedures are limited to the devices used.

(a) Valves. See chapter 9 for maintenance procedures.

(b) Electrical Switches. Check all switches twice a

year to make sure they do not bind or arc. Clean, repair, or renew them as necessary.

(c) Instruments. See chapter 5.

(2) Automatic Controls. Automatic controls are described in chapter 5. Each week, observe the control operation through one complete cycle. If the system includes an air-water pressure tank, check the water level in the tank to make sure it is not waterlogged. If it is waterlogged, drain it partially to restore the air cushion. Maintenance procedures for water level, pressure, and flow sensors are covered in chapter 5.

d. Piping. Each year, or as often as necessary, paint all piping; use a gloss paint that resists moisture condensation. Repaint the pipes in the same color as previously established. If stencilled labels are used to identify the pipe, be sure the labels are restencilled. If color coding or stencil identification was not established previously, one or the other method of pipe identification should be adopted.

e. Standby Equipment. Standby pumps and driving equipment must be inspected and serviced regularly. Maintenance schedules and procedures for standby equipment are the same as those for regular equipment, except that overhaul scheduling is variable. Overhaul procedures should be followed about every third year, or more often if the equipment is used frequently. Standby electrical power may be provided by using dual electric feeds or gasoline or diesel motor-operated generators. The electrical shop is responsible for checking and maintaining electrical switching devices, but the operator should simulate the loss of electrical power to make sure that the standby electrical source functions properly. The simulation frequency is established by local command.

f. Valves Maintenance. Maintenance procedures for all types of valves are in chapter 9. In addition, the following procedures are pertinent to pumping station valves:

(1) Every 3 months, check the operation of all valves, particularly those that usually remain in either an opened or a closed position.

(2) Every 3 months, check the packing glands for leaks. Take up the gland by turning down the nuts by one or two turns. If leaking continues, repack the valve stem.

(3) Each year, or as often as necessary, paint the cast iron valves, and make sure that all identification tags or plates are in place. When such identification does not exist, tags or identification plates should be installed. Do not paint identification tags or plates.

(4) When operation of the valve appears to indicate internal trouble, dismantle the valve and repair as necessary.

g. Housekeeping. Housekeeping is generally a part of operation, but when maintenance procedures are carried out, the maintenance personnel must leave the equipment and surroundings in a clean condition.

Chapter 5

METERS AND CONTROLS

Section A—Functions and Types

5-1. General Information. Many indicating and recording devices are used in water supply and distribution systems to provide information essential to system performance. This information may be fed into the base monitoring and control system. The information provided usually consists of demand, rate of flow, total volume, liquid level, and pressure. In addition, readings of temperature, humidity, weight, electric power consumption, gas concentration, chemical concentration, and time are required for various stages of process control. This information is used by operating and management personnel to:

a. Determine capacity of pumping and treatment facilities.

b. Provide records of supply, production, and consumption.

c. Furnish basis for determining costs and efficiency of operation.

d. Alert operators to possible malfunctions of equipment, leaks, etc.

e. Provide information needed to determine adjustment in flow, pressure, chemical feed, and other parameters.

f. Input the necessary information into control apparatus for the automatic operation of the water supply system equipment used in maintaining proper pressures, effective treatment processes, and desired output (for example, pumps, valves, and chemical feeders).

5-2. Equipment Types. Water system monitoring and control equipment ranges from simple, direct-reading meters and gages to complex, automatic-control systems. Each has basic elements consisting of one or more of the following:

a. Sensor.
b. Transmitter.
c. Indicator.
d. Recorder.
e. Controller.

Section B—Sensor Description

5-3. General Information. A sensor is that part of a meter, gage, controller, or device that is actuated by the material monitored (that is, moving water actuates the sensor in a water meter). Sensors are commonly referred to as primary elements.

5-4. Sensor Types:

a. Flow Sensors. Flow sensors used in water treatment systems operate on one of the following principles:

(1) Velocity-Head Relationship. This type includes the Venturi tube, flow nozzle, orifice, and pitot tube used in pipes that carry flow under pressure. As water flows through a restriction in a pipe, velocity increases in direct proportion to the decrease in cross-sectional area. The energy used to accelerate the flow causes a corresponding drop in pressure at the point of restriction. Thus, the differential pressure between the two taps is a measure of increase in velocity head. These devices are illustrated in figure 5-1. Each of these devices produces a pressure change that can be detected by one of the sensors discussed in c below.

(2) Velocity Relationship. This type includes propeller and turbine meters used principally in closed pipes. Portable propeller meters are also used to determine the velocity of flow in open streams and rivers.

(3) Volumetric Relationship. The volumetric sensor most commonly used is the nutating-disc meter. Another form of volumetric measurement for flow rate determination involves monitoring water level changes in a container of known size as water is discharged into or drawn from the container.

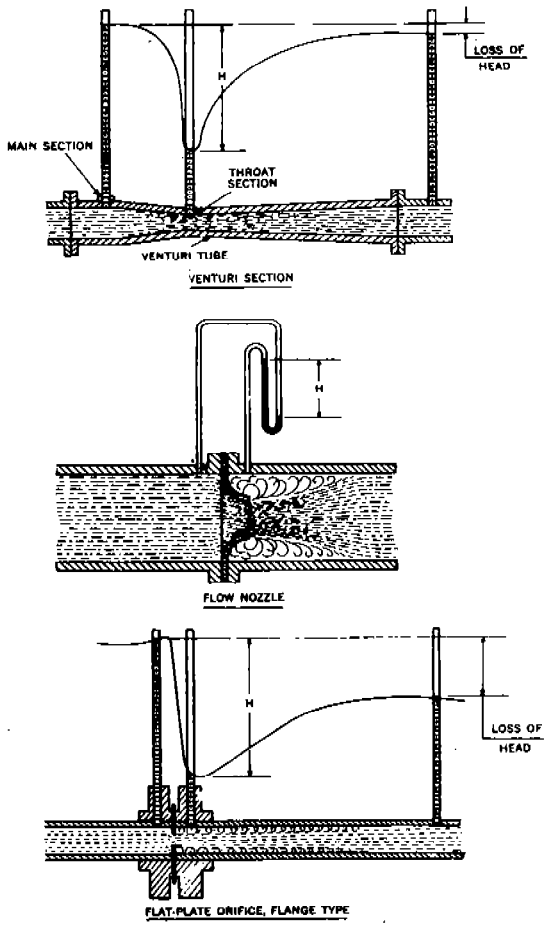


Figure 5-1. Changes in Pressure (H) and Permanent Loss of Head in Venturi, Flow Nozzle, and Orifice.

(4) Head-Area Relationship. This type of sensor includes weirs (figure 5-2) and flumes used in open channels, and orifices and nozzles with free discharge to the atmosphere. As a rule, the water level in weirs and flumes is detected with one of the level sensors discussed in d below. Free-discharging orifices and nozzles produce pressure changes detected by either pressure or velocity sensors.

b. Velocity Sensors. As presented in a(2) above, propeller and turbine meters are used to detect the velocity of water movement. The velocity is proportional to the rate of fluid flow.

c. Pressure Sensors. As a rule, pressure (head) sensors used in water supply systems are explained in (1) through (3) below.

(1) The Bourdon gage is a curved tube of elliptical cross section. A change in pressure within the tube will cause the curvature of the tube to change.

(2) A piezometer column is a tube in which liquid can freely rise. It is used for measuring moderate liquid pressures.

(3) A manometer (either simple or differential) is a U-tube containing a fluid with a density different from that of the fluid being monitored.

d. Level Sensors. Liquid level control is of primary importance in a water supply system for maintaining the liquid level within a tank or other vessel between upper and lower operating limits. Four basic level sensors are used in water supply systems.

(1) Visual. This simple method of level sensing includes dipsticks, hook gages, and gage glasses.

(2) Floats. These common devices are buoyant spheres or discs that sit on the liquid surface.

(3) Probes. Probes may be actuated by capacitance, resistance, ultrasonic waves, heat, mechanical contact (vibrating leaf and rotating paddle), and light refraction.

(4) Pressure. Differential pressure units include pressure switches, closed tube units, and bubblers. Hydrostatic units measure the pressure exerted by a column of liquid with either a diaphragm gage or a direct-connected pressure gage.

Section C—Instrumentation

5-5. General Information. To be useful, the primary signal from a sensing element must be translated into a usable form. "Readout" is used by an operator to determine necessary process adjustments and by supervisors to determine costs, operating trends, need for system additions, etc. With automatic control, the primary signal is translated into a command signal that causes a control system to function.

5-6. Transmitters. A transmitter is that part of a meter, gage, recorder, controller, or other device that transforms and transmits the primary signal from the sensor to indicating, recording, or controlling devices. The primary signal is transmitted through a mechanical linkage or by hydraulic, pneumatic, magnetic, or electrical impulses.

5-7. Indicating and Recording Instruments:

a. General Information. Indicating and recording instruments range from direct-reading gages to complex instruments that receive more than one type of information from various sensing devices and interpret these data for control purposes.

b. Direct-Reading Gages. A direct-reading gage is an indicating instrument used to give an immediate reading of a particular variable (that is, pressure, flow, water level, etc.). The scale is graduated in units according to the particular variable being measured (such as pounds per square inch for pressure or gallons per minute for flow rate). Direct-reading gages are often used to supply information that the operator may use to manually control a piece of equipment or process. Information from a gage is used to determine whether to maintain, increase, or decrease flow;

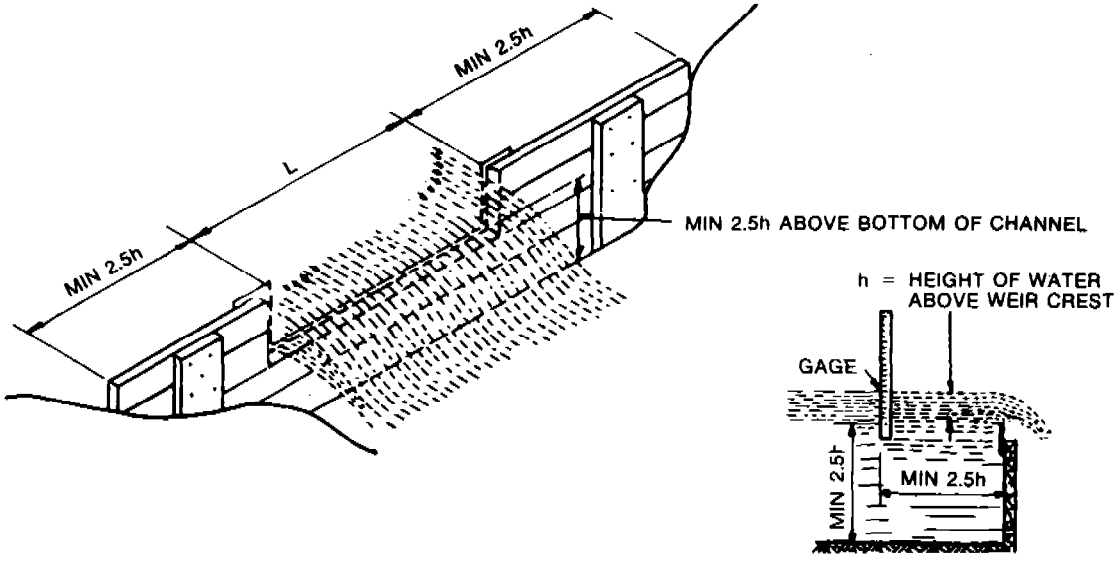


Figure 5-2. Rectangular Weir.

open or shut certain valves; alter pump operation; or adjust chemical feed.

c. Recording Instruments:

(1) Types. There are two basic types of recorders-continuous and event. A continuous recorder indicates quantities at the present and for historical times, i.e, water pressure. An event recorder indicates an on- and off-event, i.e., an engine hour recorder. The pointer of an indicating instrument may be supplied with a pen or stylus arranged to travel over a paper chart that is in continuous motion. There are three principal types of recording instruments:

(a) Circular chart.

(b) Strip or roll chart which is continuously unwound from a roll.

(c) Strip chart mounted on a drum.

(2) Chart Speed. The speed of the chart may be constant or variable. Constant chart speed is usually governed by a clock, in which case the item being recorded is plotted against time. Variable chart speed may be controlled by the instantaneous rate of some parameter such as flow, in which case the item being recorded is plotted against the parameter controlling the chart speed.

(3) Recorder Mechanism. In most circular-chart instruments the position of the pen is controlled by a mechanical linkage.

(a) Types of Records. Recorders may make either single or multiple records. In circular-chart instruments this is done by using as many indicators and pens recording on the same chart as there are records. A roll-chart instrument using an electrical indicating mechanism often has one indicator that switches consecutively to a series of detecting or sensing devices. The switch is operated at proper intervals by a clock.

(b) Line Distinguishing. In order that the records may be distinguished, points are marked in different colors, by various combinations of dots and dashes, or by a number corresponding to each of the several detecting devices. Rotating print wheels, carbon paper, or movable ribbons carrying several colors are used in this distinguishing process.

(4) Pens and Styluses. Single record recorders with mechanical indicating devices use capillary pens that have a reservoir for ink, and terminating in a point that is held against the chart. Pens are made of glass, monel metal, or some other corrosion-resistant material. For recorder movements with little power, or for very rapid fluctuations, a stylus is more generally used. For continuous contact, the charts may be coated with wax or finely divided carbon. In intermittent contact (depressor bar) instruments, the stylus prints through a piece of carbon paper or a typewriter ribbon.

(5) Charts. Circular charts are marked with concentric circles representing values of the variable, and radical arcs representing time. Circular-chart records are for 24 hours or 7 days, and in diameters from 6 to 12 inches. Roll charts are made in lengths up to 90 feet and widths to 12 inches. Lengthwise lines are provided for values of the variable, and crosslines for time. Chart speeds in standard strip-chart instruments vary from 1/2 to 6 inches per hour, with extremes of from 1 inch a day to 12 inches per minute.

(6) Clocks. Clocks may be either spring-driven or the synchronous electric type, when alternating current is available. The clock furnishes the power to rotate the chart.

(7) Operation. It is the operator's responsibility to make sure that:

(a) Each recorder has the proper chart, and reserve supplies are available.

(b) Marking mechanisms are functioning properly.

(c) Recorders using ink have an adequate ink supply in the reservoir, and a reserve supply available.

(d) Spring-driven recorders are wound according to the manufacturer's recommendations.

(e) Charts are changed at specified times.

(f) When a chart is removed from a recorder, it is clearly marked with the date, instrument number, and data measured.

(g) The chart is filed for future reference for the period of time designated by the local command.

5-8. Automatic Controls. Automatic control systems are used to control the operation of equipment and processes. They use an automatic feedback system that senses the condition or character of the final product and adjusts the process operation and components to produce the desired product. In waterworks, there are few completely automatic control systems with feedback features. The most common are applied to the control of the water level in elevated tanks, the flow in distribution systems or through filters, the pressure in the mains, and treatment plant operation. The operator should be familiar with all automatic controls and should observe their operation at regular intervals established by the local command. Because of the wide variety of automatic controls now in use, it is possible here to give only a general description of the methods involved. Operators should consult the manufacturer's instructions for complete details for each particular piece of equipment.

a. Controlling Agents. The controlling agent may be the rising and falling of water in a filter or water tank, the pressure in a water main, the rate of flow in a main, a clock or timing device, conductivity, pH, or turbidity.

(1) Water Level. When water level fluctuation is the controlling agent, there are several devices that may be used.

(a) Float-Operated Switch. A float may be used as a sensing device that actuates a switch when it rises to a given point, and activates another switch when it falls to a lower point. The switches close or open contacts, thereby closing or opening circuits in the control apparatus.

(b) Probes. Two electrodes may be suspended at two elevations, so that when the water reaches the upper one it causes a relay to be energized, and when the water falls below the lower electrode it causes another delay to be energized.

(c) Float-Operated Valve. A float may operate a valve (or its pilot valve) directly, being connected to it by a lever or cord passing over a pulley.

(d) Pressure Sensor. Instead of a float, the pressure in a pipe connected to a tank or reservoir may be used as the sensing device.

(e) Bubble Pipe. A bubble control may be used for starting and stopping pumps. In operation, a compressor forces just enough air through a tube immersed in the tank to ensure a continuous escape of bubbles. As the level of the measured liquid changes, a diaphragm shows a corresponding change in back pressure in the tube, and actuates a switch.

(2) Pressure. In pressure control, the sensing device is a diaphragm (in some cases bellows or piston), acted on by the pressure or a pressure differential exerted by the water. The pressure is counteracted by a weight or spring so adjusted that when the pressure exceeds that for which it is set, the diaphragm moves and actuates a pump, valve, or other device. As a rule, this type of control may be used for closed valves that may be opened automatically when the pressure on one side falls below a certain level (as in valves separating high and low service districts).

(3) Other Controlling Agents. A clock may be used to start a pump or open a valve at a given time, by setting a pin with which the clock hand makes contact. The pump can be stopped or the valve closed at another given time. At some installations, photoelectric relays have been installed that sound an alarm or operate a pilot valve when the turbidity exceeds a certain limit, permitting automatic increase of the coagulant feed.

b. Control of Valves. Gate valves and butterfly valves used in automatic control are ordinarily operated by either air cylinders, hydraulic cylinders, or electric motors.

c. Standpipe Level Control. The water level in standpipes is generally controlled through automatic altitude valves, float valves, or pressure valves, coupled with pump operation. Sometimes the control may be through a combination of pressure and flow.

d. Flow Control. Flow into or out of systems is usually controlled by pump operation or valving coupled with a flow-measuring device, and much the same control equipment as for standpipe level control.

e. Pressure Control. Pressure in systems is a function of pump operation related to flow or use of the water, and can be controlled by the feedback of pressure to control pump operations.

f. Treatment Plant Control. In water treatment plants, control systems are usually applied to chemical feeder operation, filter rate, and filter backwash.

(1) Chemical Feeder Control. Chlorination and neutralization may be controlled in a fully automatic system that involves a sensing device (glass electrode or potentiometer), transmission system (electrical), and motor controllers subject to the signal.

(2) Filter Rate Control. Control of the filter rate may be automatic through rate controllers or, in some cases, by a turbidimeter connected with the valving system.

(3) Filter Backwash Control. Automatic backwash control systems use electrical switches and contacts, loss-of-head gages, turbidity controls, time-cycle control, pilot valves, and other valves.

g. Supervisory Control. Control systems involving start-stop rate control, valve opening and closing, and remote monitoring are available in supervisory control systems, and are used particularly for controlling the scattered pumping stations and well field operations. In addition to the normal components of control systems, supervisory control includes a scanning and remote monitoring and telemetering system. These units are usually mounted as module packs that can be removed and returned to the factory for servicing.

Section D—Water Metering

5-9. General Information. Water meters are used throughout water supply systems. The types of meters available and meter functions are numerous. Most meters consist of the three elements discussed in previous sections: a sensor, a transmitter; and an indicator, recorder or integrator. The sensor of a water meter is commonly referred to as the primary element. The indicator, recorder, and integrator are commonly referred to as secondary elements. The signal transmitted from the sensor may actuate an indicator, recorder, integrator, or control device.

5-10. Meter Types:

a. Disc Meter. This type of meter (figure 5-3) is used chiefly for services supplied through pipes less than 1-1/2 inches in diameter, although they are made in sizes up to 6 inches. Disc meters have a measuring chamber of definite volume in which a disc is actuated by the passage of water. Each disc cycle motion marks the discharge of the contents of the measuring chamber. By means of gearing, the motion of the disc is translated into units of water volume on the register dial.

b. Turbine Meter. This type of meter (figure 5-4) is used on large service lines and in metering supply sources. The turbine wheel revolves with a speed proportional to water velocity. These meters have a high flow capacity with low loss of head. They are not accurate in low-velocity waterflows.

c. Propeller Meter. This type of meter (figure 5-5) is used to determine velocities of flow in a main or branch

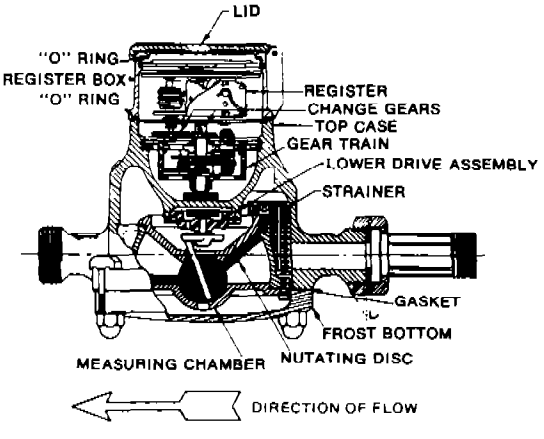


Figure 5-3. Magnetic-Drive Disc Meter.

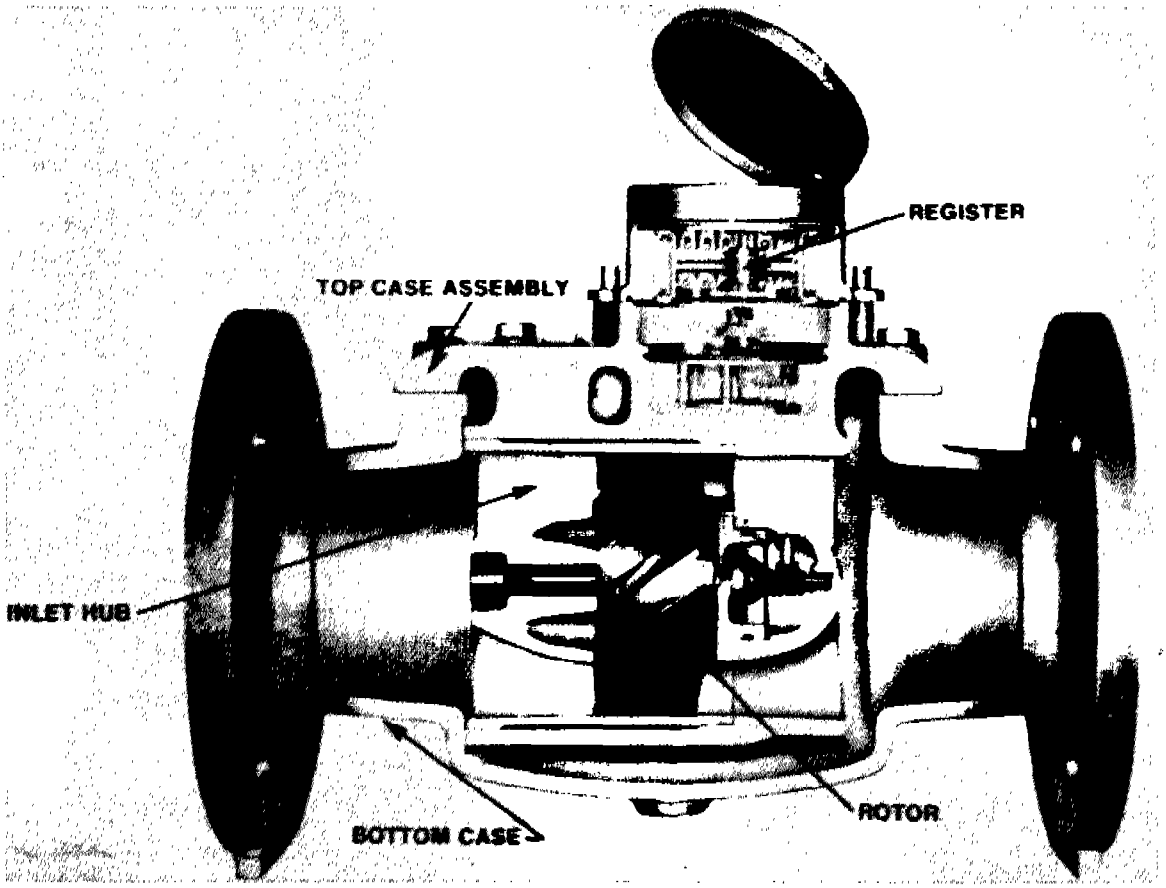


Figure 5-4. Turbine Meter.

line. These meters use a propeller which is placed inside the pipe and is revolved by the water flowing past it. The rate of revolution of the propeller is proportional to the velocity of flow.

Figure 5-5. Propeller Meter.

d. Proportional Meter. In this type of meter (figure 5-6) a portion of the total flow is diverted through a bypass meter to be measured. The gears of the measuring bypass meter are adjusted to indicate on the register dial the total amount of water passing through the entire unit. Proportional meters are inaccurate during low flows and should not be used where a low rate demand is likely. It operates with a low loss of head and and its capacity is limited only by the pipe size. It is principally used as a fire-line meter, or in other settings with sustained high flows.

e. *Compound* Meter. The compound meter (figure 5-7), as its name implies, is a combination of a disc meter and a turbine meter. It is designed to make use of the features of each in situations where neither one nor the other will make an accurate measurement of the full range of flows demanded. It is assembled in such a fashion that small rates of flow are registered only by the small displacement (disc) meter. The small flows are prevented from passing through the turbine meter by a check valve that is weighted to keep it seated until a rate of flow is reached that is above the low rate of which the turbine meter is inaccurate, but below the maximum capacity of the disc meter. When that rate of flow (predetermined by the manufacturer) is reached, the loss of head across the disc meter is sufficient to cause the check valve to open, admitting flow through the turbine meter.

f. Magnetic-Drive Meter. Disc, turbine, and piston me-

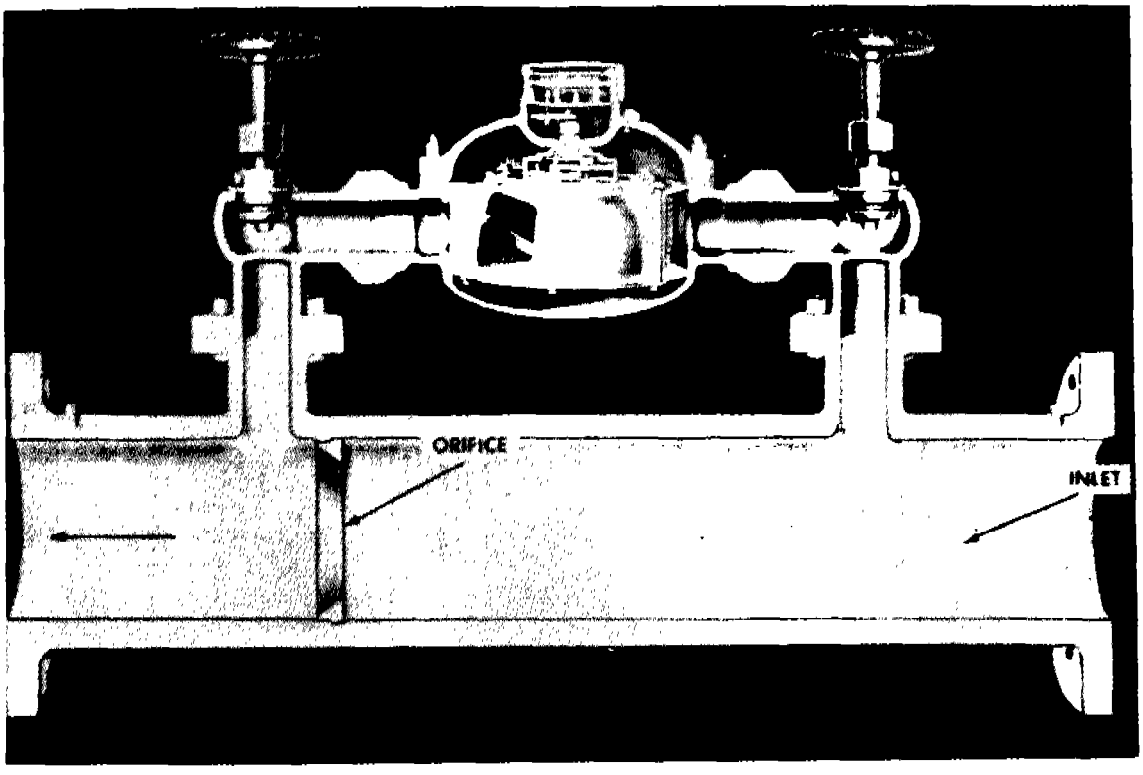


Figure 5-6. Proportional Meter.

ters are manufactured with magnetic drives. This allows the register assembly to be sealed from the water being measured and any substances in the water.

g. Magnetic-Flow Meter. A magnetic-flow meter measures the electrical characteristics of flowing water. There are no protruding parts or restrictions in the throat (figure 5-8).

5-11. Meter Accessories. Remote indicating, recording, and controlling accessory equipment is frequently installed for the above meters. For operating instructions for specific equipment, consult the manufacturer's instructions.

5-12. How to Read Meters. Water is measured in terms of flow rate (volume passing in a unit of time) or total volume. Commonly used flow rate and volume units and their equivalents are found in attachment 3. In reading a meter, the operator should first determine whether it is measuring the water volume in cubic feet or in gallons. Two general types of meter dials are the straight-reading type and the circular-reading type.

a. Straight-Reading Dial. The straight-reading dial (figure 5-9) may be read in the same way as mileage in an automobile. When the meter register has one or more fixed zeros, always be sure to read these fixed zeros in addition to the other numerals. The dial in figure 5-9 reads 321,650 gallons.

b. Circular-Reading Dial. In the circular-reading dial (figure 5-10), when a hand on any scale is between two numbers, the lower number is read. If the hand seems exactly on any figure, check the hand on the next lower scale. If that hand is on the left side of zero, read the figure on which the hand lies; otherwise read the next lower figure. The dial on figure 5-10 reads 96,872 cubic feet.

c. Obtaining Current Reading. As the registers are never reset while the meters are in service, the amounts recorded for any given period must be determined by subtraction. To obtain the volume of water that passed through the meter since the previous reading, simply subtract the previously recorded reading from the present reading. It must be remembered that the maximum amount that can be indicated on the usual line meter before it turns to all zeros and starts all over again is 99,999 cubic feet, or 999,999 gallons. Thus, to get a current measurement when the reading is lower than the last previous one, add 100,000 to the present reading on a cubic feet meter, or 1,000,000 to the present reading on a gallon meter. The small denomination scale, giving fractions of one cubic foot or 10 gallons, is used for testing purposes only and is disregarded in the regular reading.

5-13. Weirs and Related Installations:

a. Weirs. Weirs (figure 5-2) are used to measure flow in channels or streams. A weir consists of a bulkhead or dam across the channel or stream, and a sharp level crest or specially shaped notch mounted on the crest. The volume or flow over the weir varies with the length of the crest or shape and size of the notch, and with the elevation of the water surface above the crest or the bottom of the notch. Because both the head and the cross-sectional area of flow over the weir vary with the flow, it is a head-area meter. Weirs are easily built and give fairly accurate measurement

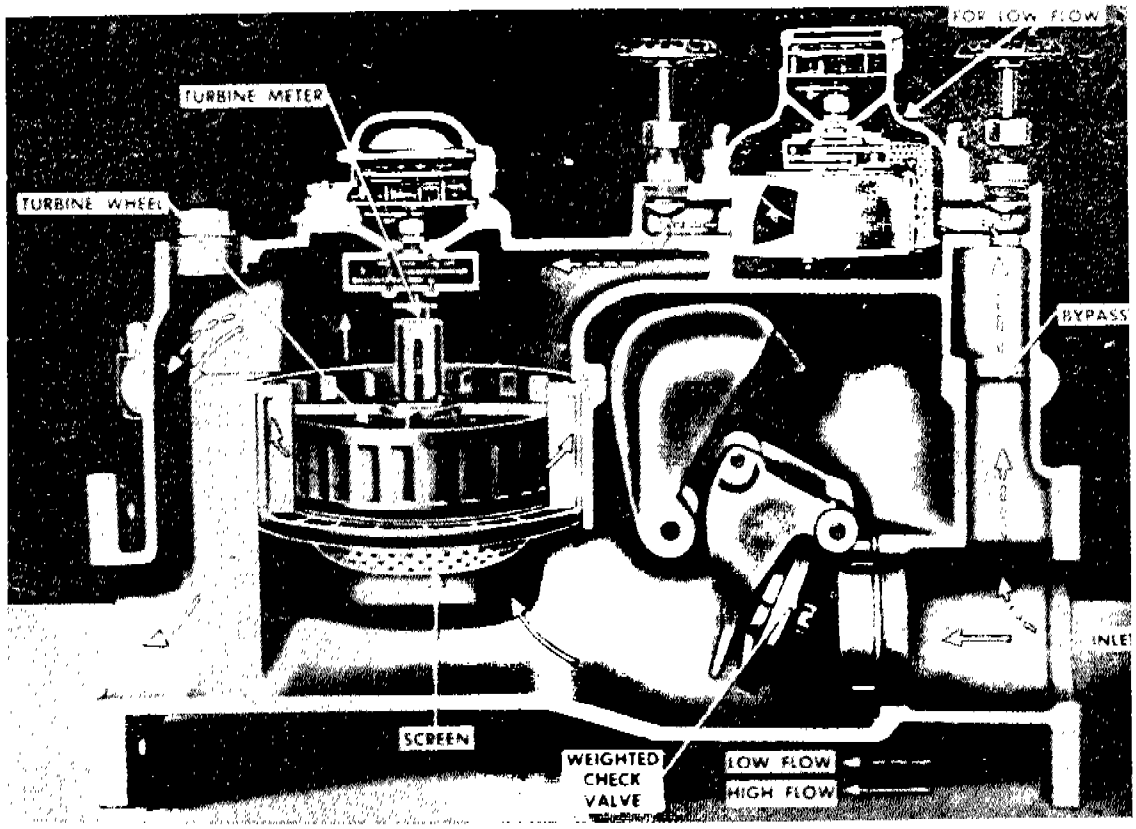


Figure 5-7. Compound Meter.

if properly installed. The more common types of weirs are the rectangular and V-notch weir.

(1) Rectangular Weir. Rectangular weirs are suitable for flows over 150 to 200 gpm. The crest should be a sharply beveled metal plate.

(2) V-Notch Weir. The V-notch weir is preferred for flows less than 1,000 gpm and is particularly suitable for very low flows.

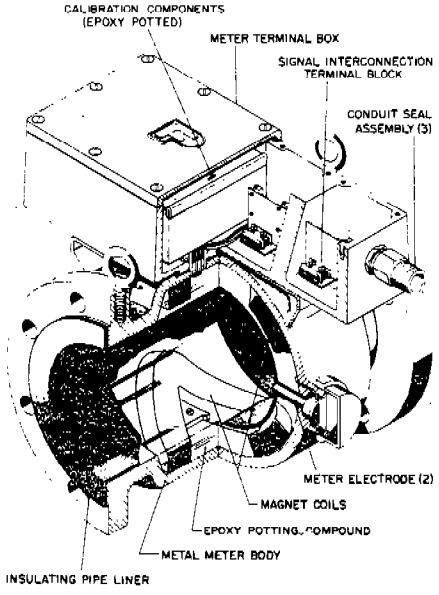


Figure 5-8. Magnetic-Flow Meter.

b. Parshall Flume. A special type of measuring flume developed for determining the discharge in open channels is the Parshall flume (figure 5-11). This flume has an open and constricted channel in which the difference in liquid elevation above and below the contraction can be accurately translated into the rate of flow. The liquid level is usually indicated and recorded by the same type of equipment that is used with weirs. The Parshall flume has several advantages over weirs. It is self-cleaning, can handle a wide variation of flow, does not require as great a head loss, and is particularly useful where the available head is limited.

5-14. Temporary Metering Methods. It is often necessary to determine the capacity of pumps that are not equipped with meters. In these cases, the temporary methods described below can be used. During metering by these methods, normal pressure must be maintained on the pump, by throttling if necessary.

a. Storage Tank Displacement. If an elevated or ground storage tank (whose volume is known or can be determined) is available and can be taken out of service, the simplest method is to pump to the storage tank, measuring the rise in elevation for a given period. This rise can be converted into gpm by the following simple calculation.

$$\text{gpm} = \frac{\textit{rise in inches} \times \text{gallons per inch}}{\text{minutes}}$$

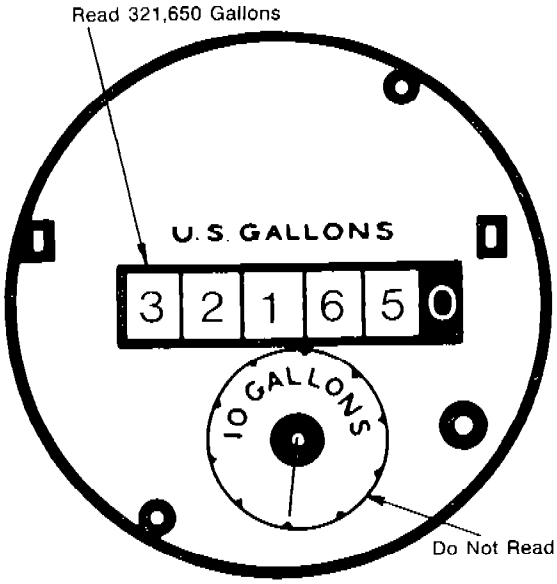


Figure 5-9. Straight-Reading Meter Dial.

b. Pitot Tube. One type of pitot tube equipment uses a set of two tubes which measure the velocity head causing flow through a pipe of given cross section. Two pressure readings are taken, as illustrated in figure 5-12. One reading is taken from a tap flush with the wall, and the other from a connection pointing upstream to catch the impact of the current. The flush tap indicates static head, and the bent tube indicates the impact head. The differential between these two is the velocity head of the waterflow. The velocity of flow can be calculated from the velocity head measurement. Knowing the velocity of the waterflow and the cross-sectional area of the pipe, the flow rate can be calculated.

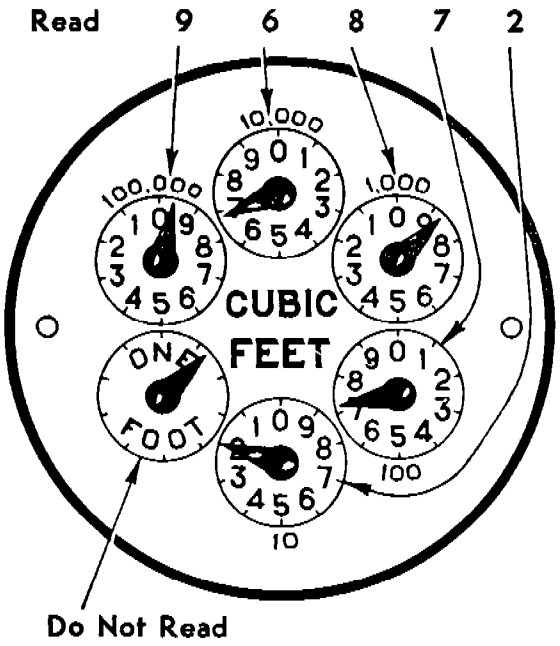


Figure 5-10. Circular-Reading Meter Dial.

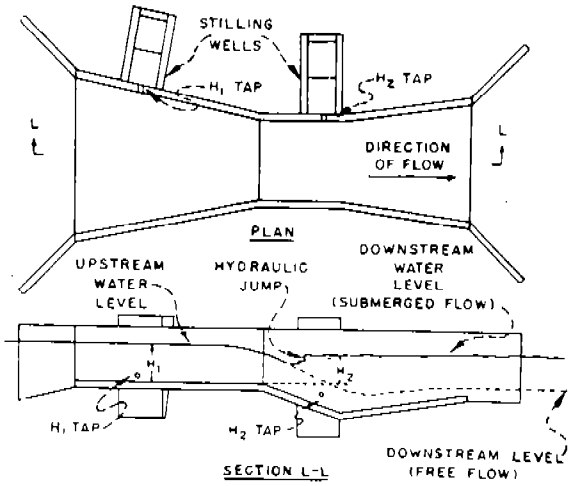


Figure 5-11. Plan and Section of Parshall Flume.

(1) Example of Calculation. The pitot velocity head, h, measured at the center of a pipe with an inside diameter, D, of 8.00 inches was 0.60 feet of water. The pitot coefficient, c, for the pitot tube used in the measurement is 0.80.

(a) The velocity at the center of the pipe, V_C, equals:

$$V_C = c\sqrt{2gh}$$

where g, the acceleration due to gravity, equals 32.16 ft/sec^2.

$$V_C = 0.80\sqrt{2(32.16)(0.60)} = 4.97 \text{ ft/sec}$$

(b) The average velocity, V_A, of the waterflow in the pipe can be assumed to be approximately 85 percent of the velocity measured at the center of the pipe.

$$V_A = 0.85\, V_C = (0.85)(4.97) = 4.22 \text{ ft/sec}$$

(c) The flow in ft^3/sec (Q) is calculated by multiplying the cross-sectional area of the pipe in square feet (A) times V_A or:

$$Q = V_A A$$

$$Q = 4.22 \times \frac{(3.14)(8.00/12)^2}{4} = 1.48 \text{ ft}^3/\text{sec} = 660 \text{ gpm}$$

(2) Pitot Traverse. To attain more accuracy than possible with just one velocity head measurement, a pitot "traverse" is conducted in which the velocity head is measured at several points across the interior of the pipe. These measurements take into account the differences in velocity at the pipe sidewalls and in the pipe center. The calculation of waterflow based on these many measurements is quite laborious and is often done graphically or with the aid of a computer.

c. Orifice Discharge. A simple orifice meter for testing discharge from small well pumps and hydrants is shown in figure 5-13. Flow is proportional to the pressure reading.

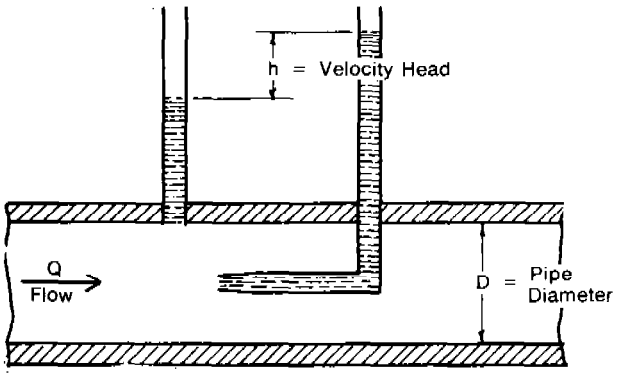


Figure 5-12. Pitot Tube Installation.

Section E—Maintenance Procedures

5-15. General Information:

a. Basic Factors in Maintenance. The success of maintenance procedures is based on knowledge of the construction, operation, and adjustment of the equipment; availability of the necessary special tools; and stored spare parts and special instructions from manufacturers. For the special knowledge necessary, maintenance personnel should consult the manufacturer's instructions. Special tools and spare parts should be carefully labeled and kept in a specific place. When spare parts are installed, replacements for them should be ordered at once.

b. Components. Meters and control systems consist of three component parts—the sensing element (or primary measuring device), transmission systems, and receivers or terminal equipment. The latter, often termed secondary instruments, includes indicators (gages), recorders, totalizers, or combination of all three. Automatic control systems consist of equipment that converts a sensed variable at the primary unit into a command for control of operating equipment (pumps, feeders, etc.) or process operation.

c. Maintenance Schedules. The design and intricacy of meters, instrumentation, and automatic control systems depend on the function to be performed and the manufacturer's particular equipment. Because there are many manufacturers of meters, instruments, and automatic controls, it is not possible to list specific maintenance procedures that apply to all units. The procedures here are basic and the minimum required for the most common types of units. When developing maintenance schedules, personnel should relate the procedures given here to specific directions issued by manufacturers.

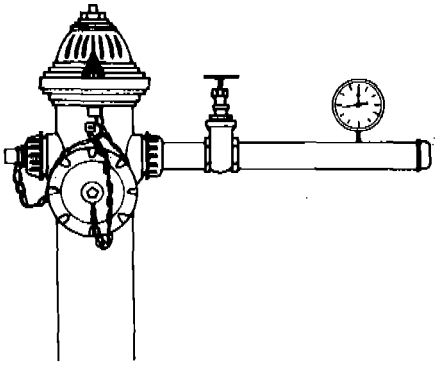


Figure 5-13. Simple Orifice Meter.

d. Inspection and Maintenance Records. A log must be kept of all inspection and maintenance actions. A particularly useful record system is a card file for each piece of equipment. This card should show the type of equipment, the manufacturer's serial number, the date installed, the location, and the frequency of scheduled maintenance. If these cards are arranged chronologically, each card will come to the attention of maintenance personnel at the proper time for the inspection to be made.

5-16. Sensor Maintenance:

a. Flow Sensors. Sensor maintenance for specific water meters is included in paragraph 5-19. Sensors operating on a velocity-differential head relationship include ventri-type devices, orifice plates, pitot tubes, and flow tubes. Maintenance procedures for these devices are given in table 5-1.

b. Pressure Sensors. The most common devices in this classification are the diaphragm, the Bourdon tube, and the manometer. Maintenance procedures for these devices are also found in table 5-1.

c. Level Sensors. Included in this classification are the float, bubble pipe, electrical probe, and diaphragm. Maintenance procedures for floats, bubble pipes, and electrical probes are given in table 5-1. The diaphragm is actually a pressure-measuring device, and maintenance procedures for diaphragm pressure sensors are as described in table 5-1.

5-17. Transmission System Maintenance:

a. General Information. From the sensing device, which measures the variable, there must be a way for transmitting this discrete information to the instruments which indicate, record, or totalize it. The transmission system may be mechanical, hydraulic, pneumatic, or electrical; and each system consists of two components—the transmitter and the transmission link. Maintenance procedures for transmission systems are summarized in table 5-2.

b. Mechanical Transmission System. Mechanical transmission is by direct mechanical linkage, cable, chain, or rod. Such mechanisms require quarterly inspections to make sure that pulleys and drums, or links, are lubricated, and that cables or rods are not corroded or dirty. Clean, lubricate, and adjust the system when necessary.

c. Hydraulic Transmission System. This type of transmission includes both direct pressure transmission, and oil or other substance as the transmission fluid. In differential pressure transmission, pressure pipes are run directly from the differential head producer to the mercury wells of the secondary instrument. The pressure lines should be checked twice a year to make sure that they are open and not restricted in any way. Correct undesirable conditions. Where fluids other than water are used, maintenance procedures should be according to the manufacturer's instructions.

Table 5-1. Maintenance Procedures for Flow, Pressure, and Level Sensors.

Inspection	Action	Frequency[1,2]
Flow sensors		
Venturi-type devices		
Annular chamber	Flush and clean annular chamber, throat and inlet; purge trapped air from chamber and connecting piping; flush piezometer pressure taps.	Q
Exterior	Clean and paint as necessary.	A
Interior	Check interior for corrosion; dismantle, clean and restore smoothness of interior surfaces, as necessary; for flanged joints, check possible intrusion of gasket into interior; replace if necessary.	A
Orifice plates	Remove plate, dress off roughness; flush sediment traps.	A
Pitot tube	On permanent installations, check tips and clean.	Q
Flow tube	Check instrument taps; flush if necessary.	Q
Pressure sensors		
Diaphragm	Disassemble and check for condition and leaks; also, clean, adjust, repair, or renew as necessary; check calibration.	A
Bourdon tube	Check calibration, clean and adjust as necessary.	A
Manometer	Clean tubes and gage unit as necessary.	SA
	Check mercury level and add mercury if necessary; clean or replace mercury if necessary.	A or V
Level sensors		
Floats	Check for bent rod, binding or other damage; correct undesirable conditions; apply light oil to moving parts; check alarm system.	M
Bubble pipe	Check air discharge pipe for freeness; check air compressor system; clean, repair, or renew worn parts as necessary.	Q
Probes	Check contacts, wiring, and electrical connections; repair as necessary.	Q
	Check probe surfaces; check calibration; clean, repair, or renew as necessary.	SA

[1]W-Weekly; M-Monthly; Q-Quarterly; SA-Semiannually; A-Annually; V-Variable, as conditions may indicate.

[2]The frequencies shown are suggested frequencies which may be modified by local command, as individual installation conditions warrant.

d. Pneumatic Transmission System. In this type of system, air pressure (between 3 and 15 psi) is the medium of transmission.

(1) Transmitter. The transmitter contains a specifically calibrated cam, positioned by a diaphragm or mercury float well, that responds to changes in the measured variable. This cam operates and controls a bleeder valve system and bellows unit to produce an output pressure directly proportional to the measured variable. Maintenance procedures include the following:

(a) Each day, flush the liquid side of the air-relay units, and drain the air sides. If the amount of water drained is large, remove the cover and examine the diaphragm for punctures or cracks. Use care not to bend the needle-valve stem when replacing the diaphragm. Check the air-input orifice, and clean and remove any foreign matter. Blow out the moisture traps. See the manufacturer's instructions for details of cleaning the metering orifice and nozzle.

(b) When necessary, disassemble and repair or renew parts. Be sure to follow the manufacturer's instructions.

(2) Transmission Link. Transmission of the output signal is through a small pipe to the secondary unit. Check the connecting tubing twice a year to make sure that there are no dents, crimps, or other difficulties. Also check nozzle system for leaks.

e. Electrical Transmission System. One example of this type of transmission system is the time-duration-impulse system, for which maintenance procedures are described below. (For other systems, consult the manufacturer's instructions.)

(1) Transmitter. In this system, the transmitter contains a cam, a synchronous motor, and a magnetically operated mercury switch. The electrical output signal (which is proportional to the measured variable) is transmitted to the receiver converter, which is a counterpart of the transmission. Maintenance procedures include the following.

(a) Monthly, service the transmitter. Check the length of signal interval at various points throughout the instrument's range. Follow the manufacturer's instructions for methods of correcting errors.

(b) Every 3 months, check the mercury switch and magnet. With the transmitter trip-arm riding on the cam, make sure that the magnet is far enough away from the mercury switch so there is no pull on the switch. With the transmitter arm off the cam, make sure that the magnet pulls the movable electrode and is entirely clear of the mercury globule; there should be no electrical contact. Adjust as necessary according to the manufacturer's instructions

(c) Every 6 months, remove the cam oil-trough, discard the oil, wipe the trough clean, and refill it with spe-

cial oil, as directed by the manufacturer's instructions. As the cam revolves, it will carry oil to the drive gears and cam bearing.

(2) Transmission Link. The signal may be transmitted over private wire (alternating or direct current), over telephone circuits, or over multiservice wires. Check and repair wires when necessary.

5-18. Indicator, Register, and Recorder Maintenance:

a. General Information. Secondary instruments are classified as indicators or gages (momentary indication of discrete information), recorders (chart record of information by time), and registers or totalizers (also termed integrators) that express the total quantity of measured variable from start to current time. There are many styles and designs of each basic type, and there are various combinations of these types. Therefore, no detailed maintenance procedure can be given to cover all types, designs, and combinations. Maintenance procedures depend not only on the type of receiver (indicator, recorder, or register), but also on the type of transmission system used. Maintenance personnel must study the manufacturer's instructions for detailed procedures, in addition to the following basic recommended procedures. Maintenance procedures for indicators, registers, and recorders are summarized in table 5-3.

b. Indicators. Indicators have a calibrated dial or band, and a pointer to show conditions to the observer.

(1) All Transmission Types. For indicators using any type of transmission system, the following procedures apply:

(a) Clean the cover and the glass of indicator gages twice a year.

(b) Check the instrument for zero setting and for calibration throughout its range each year. See the manufacturer's instructions. For level indicators, use baseline data for comparison; for the flow indicator, check against volumetric displacement; for pressure indicator, use a dead-weight tester. In all cases, if the error is more than ± 3 percent, reset the hand or adjust the level motion as necessary.

(2) Mechanical Transmission System. For indicators using a mechanical linkage transmission system, inspect and service the receiver on a quarterly schedule the same way as for the transmitter.

(3) Hydraulic Transmission System:

(a) Where direct water pressure transmission is used, the following procedures apply:

1. Vent air from the mercury wells on a weekly basis, unless it is determined that less frequent venting is sufficient.

2. Inspect the pulley shaft, chain, cam, and stuffing box each week, and other functional parts as prescribed by the manufacturer's instructions.

3. Inspect the pressure mercury wells each year. If the mercury has blown over, check the mercury level and replace lost mercury according to the manufacturer's instructions. Use virgin or triple-distilled mercury (as directed by the manufacturer), or clean and replace the mercury when necessary.

CAUTION: Mercury fumes are poisonous. Use caution when handling mercury and avoid spills.

Table 5-2. Maintenance Procedures for Transmission Systems.

Inspection	Action	Frequency[1,2]
Mechanical	Direct links—make certain pulleys, drums, cable, etc., work freely and are not corroded; clean, lubricate and adjust.	Q
Hydraulic	Pressure links—blow down pressure lines, make certain there are no restrictions; correct adverse conditions.	SA
Pneumatic		
Transmitter	Flush liquid side of air-relay units; clean; if necessary check diaphragm; check air-input orifice, clean, blow out moisture traps.	D
	Disassemble, repair or renew as necessary	V
Link	Check connecting tubing for condition; check nozzle system for leaks.	SA
Electrical		
Transmitter	Service transmitter; check signal interval length over instrument range.	M
	Check mercury switch and magnet; adjust as necessary.	Q
	Remove old lubricant, add new	SA
Link	Check wires whenever necessary	V

[1]D-Daily; M-Monthly; Q-Quarterly; SA-Semiannually; V-Variable, as conditions may indicate.

[2]The frequencies shown are suggested frequencies which may be modified by local command, as individual installation conditions warrant.

Table 5-3. Maintenance Procedures for Indicators, Registers, and Recorders.

Inspection	Action	Frequency[1,2]
Indicators	Clean cover and glass of gages	SA
	Check zero setting and calibration	A
Mechanical transmission.	Inspect and service as for transmitter	Q
Hydraulic transmission	Vent air from mercury wells; check pulley shaft, chain, cam, stuffing box and other parts.	W
	Check mercury wells; add new mercury if necessary; clean or replace mercury if necessary.	A
Pneumatic transmission	Service on same schedule and in same manner as transmitter	
Electrical transmission	Service generally on same schedule as transmitter	
	Clean unit, especially dials	SA
	Check operation, adjust and repair as necessary	A
Recorders	Clean pen; check ink flow; check cam cycle and pulley freedom.	2W
	Check zero position; adjust and lubricate	Q
	Check contact points, armature, clutch, clutch cups, etc.; clean, adjust, repair, or renew parts.	SA
	Renew modular unit if necessary	V
	Renew illumination lamp as necessary	V
Totalizers	Inspect, clean, adjust or repair on same schedule as recorders	
Combination	Check, clean, adjust or repair on same schedule as individual components	

[1]D-Daily; M-Monthly; Q-Quarterly; SA-Semiannually; V-Variable, as conditions may indicate.
[2]The frequencies shown are suggested frequencies which may be modified by local command, as individual installation conditions warrant.

(b) When other hydraulic fluids are used, consult the manufacturer's instructions.

(4) Pneumatic Transmission System. In an indicator that uses a pneumatic transmission system, the receiver mechanism is a counterpart of the transmitter mechanism and should be serviced on the same schedule and in the same way as the transmitter mechanism.

(5) Electrical Transmission System. In an indicator that uses an electrical transmission system of the time-impulse-duration type, the receiver instrument contains all of the fundamental elements of the transmitter unit and, in addition, a magnet and clutch mechanism and, of course, the indicator dial and pointer. Do not tamper with the internal mechanism. Where the mechanism has been permanently lubricated, do not add oil (see manufacturer's instructions).

(a) Generally, the receiver should be serviced in the same way and on the same schedule as the transmitter.

(b) The unit, including the white dials, should be cleaned twice a year.

(c) Each year the operator should check the operation, and adjust, repair, or renew parts as necessary, and then only according to the manufacturer's instructions.

c. Recorders. Recording instruments have all of the fundamental elements of an indicator unit and, in addition, contain a clock mechanism (spring or electrical), a chart, and a marking pen. Charts may be either circular or strip, and are changed on schedule by operating personnel. Maintenance procedures depend on the type of transmission system employed, as well as on the design and other factors. Consult the manufacturer's instructions for detailed procedures. General maintenance procedures are as follows:

(1) Every 2 weeks, clean the chart-marking pen according to the manufacturer's instructions; and, after cleaning, check the ink flow. Also, inspect the cam cycle and the pulley freedom.

(2) Every 3 months, check the pen or indicator zero positions, and adjust according to the manufacturer's instructions. Lubricate the unit according to manufacturer's instructions, but do not add oil to the parts that are permanently lubricated, or to electric clocks.

(3) Twice a year, or more often if necessary, examine the points of the contacts and clean or burnish them as necessary. Also, check the armature, clutch cups, and other parts. Clean, adjust, repair, or renew them when necessary, according to the manufacturer's instructions.

(4) When receivers are of the design that uses a modular unit or power-supply modules, refer to the manufacturer's instructions for a troubleshooting guide and service

the mechanism, or remove and renew it according to those instructions.

(5) When necessary, replace the illumination lamp.

d. Totalizers or Registers. This type of receiver is similar in internal components to recorders. In addition, it contains an integrator mechanism that converts transmitted signals into a sum of the total quantity of material that has moved past the point of measurement from the beginning of the measured period to the time of observation. This total appears on a numerical register similar to an automobile odometer. Clean, service, and adjust registers according to the manufacturer's instructions on the same general schedule as recorders.

e. Combination Totalizer Indicator-Recorder. There are various combinations, designs, and styles of instruments in this classification. There are also devices that sum totals from various individual totalizers, or show ratios of one flow to another. In general, the maintenance procedures and schedules are a combination of the procedures for the individual units above. Develop a maintenance schedule according to the manufacturer's instructions.

5-19. Water Meter Maintenance:

a. Volume Meters. The following procedures apply to volume-type (disc and piston) meters used as service meters, and for sizes up to 6 inches:

(1) Each month, make sure that the meter is operating properly. If its operation is noisy, remove and examine the parts, and repair or renew when necessary. Check the dial face for cleanliness, and clean the glass dial cover when necessary.

(2) Each year, make sure that the meter has not been moved from a horizontal position.

(3) Each year, 1 month before the freezing season begins, inspect and clean the meter housing or pit, and make sure the meter is protected against possible freezing.

(4) Check the meter each year for damage by hot water backing up from an improperly operated water heater.

(5) At variable periods, clean and inspect the meter for worn parts; change gears and other parts when necessary.

(a) A schedule for cleaning and repairing meters is necessary at each activity, and should be based on experience with the meters used in the system and the costs attributable to meterings. A large volume of water registered in a relatively short time may cause more deterioration of the meter than a small volume registered over a longer period.

(b) Disassemble the meter according to the manufacturer's instructions. Remove sediment; check the interior for corrosion or wear; replace the gears if they are worn; replace the disc or the piston when necessary; and clean and brighten the exterior by wire brushing, sand or shot blast, or acid dip.

CAUTION: Use acid dip according to the manufacturer's instructions and safety procedures.

b. Velocity-Type Meters. Maintenance procedures for velocity-type meters (turbine and propeller types) are:

(1) Check the operation of the meter each month. If the operation is noisy, remove and examine the parts, and repair or replace when necessary. Clean the meter dial face and the glass cover when necessary.

(2) Clean the meter pit twice a year. Remove any water.

(3) Clean and paint the exterior of the meter each year if necessary.

c. Proportional Meters. Except for annual external painting, the only maintenance required is inspecting the bypass meter and its parts on a variable schedule, the same as for volume meters.

d. Compound Meters. The component for measuring large flows is generally a velocity-type meter, and the component for measuring small flows is generally a disc, piston, or nutating-disc type. Therefore, maintenance for the large-flow component should follow procedures for velocity-type meters, and maintenance for the small-flow component is the same as those for house-service (volume) meters.

e. Meter Maintenance. Maintenance procedures for water meters are summarized in table 5-4.

5-20. Weir and Flume Maintenance:

a. General Information. All types of head-area meters are used for open-flow measurement, and their proper operation depends on the absence of any kind of interference at the discharge opening. Maintenance procedures for weirs and flumes are summarized in table 5-5.

b. Weirs. Weirs, either rectangular or V-notch, require the following maintenance procedures:

(1) Daily, check the weir edge to make sure it is clean and free of algae growths and other interfering material.

(2) If a weir is installed in a flume and is equipped with a breather pipe, at monthly intervals make sure that the breather pipe is open and, particularly in winter, that frost does not block the opening.

(3) Each year, on horizontal weirs, drain the weir and make sure that the water breaks evenly over the entire weir length. Check the weir edge for scale formation or corrosion. Dress any rough spots, and make sure that the weir edge is level. On V-notch weirs, check the knife edge to be sure it is smooth and free from scale or corrosion. Clean and dress as necessary.

c. Parshall Flume:

(1) Monthly, make sure that interfering substances do not appear in the throat section. Clean, as necessary, and remove algae growths. If algae growth is a problem, paint with an algacidal coating.

(2) Quarterly, clean the stilling well and the float well. Clean the float, as necessary, and make sure that the connecting pipe is free of silt.

5-21. Miscellaneous Maintenance:

a. Electrical Quantities Measurement. Included in this class of devices are the voltmeter, ammeter, and wattmeter used with electrical power; and devices such as the glass electrode (for pH determination), dropping mercury elec-

Table 5-4. Maintenance Procedures for Water Meters.

Inspection	Action	Frequency[1,2]
Volume meters	Check operation; check for noise	M
	Check mounting and alinement	A
Velocity-type meters	Check operation; check for noise	M
Meter pit	Clean, remove water before freezing season	SA
Exterior	Paint as necessary	A
Interior	Check for worn parts; repair or replace as necessary.	V
Proportional meters	Check on same program as velocity meters	V
Compound meters	Check large-flow component on same schedule as velocity-type meters	M
	Check small-flow component on same schedule as volume meters	V
Magnetic flow meters	Check electrical connections	A
Meter pit	Check, clean, remove water to protect against freezing.	A (Fall)
Measuring unit	Check for possible hot water damage	A
Unit parts	Check for worn parts, repair or replace as necessary; clean and brighten.	V

[1]D-Daily; M-Monthly; Q-Quarterly; SA-Semiannually; V-Variable, as conditions may indicate.

[2]The frequencies shown are suggested frequencies which may be modified by local command, as individual installation conditions warrant.

trode (for dissolved oxygen determination), amperometric chlorine meter; and other voltage, current, and resistance devices used in process control.

(1) All devices in this category should be kept clean and free of dust. Regular monthly or quarterly cleaning should be performed. The instrument setting should be at the zero reading and adjusted when necessary.

(2) For the most part, all of these devices are of intricate construction and should be subjected to maintenance procedures strictly according to the manufacturer's instructions, or returned to the factory when adjustments or repairs are required.

b. Temperature Movement. Temperature may be measured by a mercury or an alcohol thermometer, or by thermocouples. The only maintenance required is to clean the equipment at least quarterly.

Table 5-5. Maintenance Procedures for Weirs and Flumes.

Inspection	Action	Frequency[1,2]
Weirs	Check weir edge to make certain it is clean	D
	Check and open breather pipe, if any	M
	Drain weir to check evenness of water break-over; check for tuberculation or corrosion; dress-off rough spots.	A
Parshall flume	Check throat section to be sure it is clean and free of growths.	M
	Clean stilling well and connecting pipe	Q

[1]D-Daily; M-Monthly; Q-Quarterly; SA-Semiannually; V-Variable, as conditions may indicate.

[2]The frequencies shown are suggested frequencies which may be modified by local command, as individual installation conditions warrant.

Chapter 6

WATER TREATMENT

Section A—Aeration Treatment

6-1. General Information. Aeration is used in water treatment for oxidizing iron and for increasing or decreasing concentrations of dissolved gases (carbon dioxide, oxygen, hydrogen sulfide, methane, mercaptans, and volatile organics).

a. Iron and Manganese Oxidation. Dissolved iron and manganese can cause tastes and odors, stains on bathroom fixtures, fouling of ion-exchange water softeners, and growths of iron bacteria in water mains. Aeration readily oxidizes iron to a state that forms a precipitate that is readily removed by filtration. Manganese is not oxidized as readily by aeration, but chemical oxidation is enhanced by prior oxidation of iron by aeration.

b. Carbon Dioxide Control. Concentrations of dissolved carbon dioxide (CO_2) may be increased or decreased by aeration, depending on whether the initial carbon dioxide concentration of the water is higher or lower than normal.

(1) Carbon Dioxide Removal. Removal of high concentrations of carbon dioxide by aeration reduces the quantity of lime required for carbon dioxide neutralization in lime-soda water softening. When the initial carbon dioxide content of the water is approximately 10 mg/l or less, however, it may be more economical to use lime neutralization to remove the carbon dioxide. Removal of high concentrations of carbon dioxide also reduces the corrosiveness of the water. The carbon dioxide content of the water cannot be reduced to zero by aerators that expose water to the atmosphere, because carbon dioxide is present in the air. The minimum water concentration of carbon dioxide attainable by aeration is about 5 mg/l (ppm) for normal water temperatures and atmospheric conditions.

(2) Carbon Dioxide Addition. Carbon dioxide can be added to water by an aeration process using carbon dioxide from flue gas or carbon dioxide generators. Water softened by the lime-soda process can be stabilized by adding carbon dioxide before filtration, thereby reducing precipitation of calcium carbonate on filter sand grains and in the distribution system. Removal of hydrogen sulfide from water can be enhanced by lowering the hydrogen ion concentration (pH) by carbon dioxide addition.

c. Oxygen Addition. Aeration increases the dissolved oxygen (DO) concentration of water, eliminating the "flat" taste, as well as providing the oxidizing agent for iron oxidation.

d. Hydrogen Sulfide, Methane, Mercaptans, Trihalomethanes (THMs) and Volatile Synthetic Organic Chemicals (VOCs) Removal. Some corrosive and taste and odor causing compounds resulting from industrial waste or the natural decomposition of organic matter in water supplies are volatile and may be removed to a certain extent by aeration processes. Hydrogen sulfide creates a chlorine demand, resulting in increased use of chlorine if not removed by aeration or other processes.

e. Limitations. Aeration does not usually result in complete taste and odor removal, often due to the limited volatility of odor-causing substances. In addition, the odorous gases removed from the water by aeration may contaminate the air, resulting in complaints. As mentioned above, manganese is not readily removed by aeration alone. Oxygen dissolved in the water may cause corrosiveness in some cases. Finally, aerators do not disinfect water and must be followed by filtration or chlorination or both.

6-2. Principle of Operation. The basic principle behind aeration is that molecules of dissolved gas readily move between gas and liquid phases and that these materials will move from a supersaturated to an undersaturated media. This is done by increased mixing and exposure of as much as possible of the water surface to the air. Aeration for removal of carbon dioxide, hydrogen sulfide, and other volatile materials is more effective in warm waters than in cold. Low pH values favor removal of carbon dioxide and hydrogen sulfide.

6-3. Aerator Types. The types of aerators commonly used in water treatment include the following:

a. Cascade or Step. This type of aerator usually consists of a concrete-stepped structure, often with obstructions to create turbulence as the water flows down the steps. Carbon dioxide removals of 20 to 45 percent by cascade aerators have been reported.

b. Tray or Splash Pan. Tray aerators consist of a series of slotted or wire mesh bottom trays. Each tray has a coarse media (such as coke or stones) over which the water is distributed and allowed to trickle down to a collection basin at the bottom (figure 6-1).

c. Spray Nozzle. Spray-type aerators have nozzles through which water is forced into the air in the manner of a fountain. Generally, spray aerators will remove more than 70 percent of dissolved carbon dioxide. A variation of this type deaerator is the countercurrent packed-bed air-stripping column. In this treatment, which shows the most

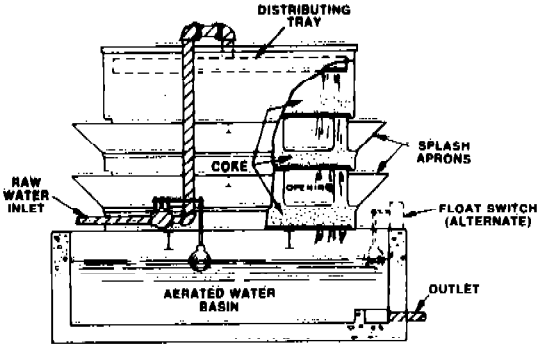


Figure 6-1. Coke Tray Aerator.

promise for removal of VOCs, untreated water is introduced at the top and flows downward by gravity. Air enters the bottom of the column and moves upward through a forced or induced draft. A synthetic packing material fills a majority of the column volume to provide an increased surface area over which transfer of contaminates from liquid to the gas phase may occur.

d. Diffused Air. Diffused air aerators have a submerged system of air diffusers (perforated pipes, porous plate, or tubes). Compressed air is forced through the diffusers producing air bubbles that provide gas transfer surfaces and act as mixing mechanisms as the bubbles rise to the water surface. Unlike the cascade, tray, and spray nozzle aerators, there is very little hydraulic head loss with this type of aerator.

e. Off-the-Shelf-Equipment. In addition to the general types of aerators previously described, there are certain patented types (such as jet, turbine, etc.) that can be purchased from equipment suppliers. These types will not be described here; specific information regarding design and operation should be obtained from the suppliers.

6-4. Operational Problems. Commonly encountered problems in operating aeration equipment include freezing, biological growth, scale deposits and corrosion, ventilation, and nesting of birds and insects:

a. Freezing. Cascade, tray, and spray aerators can be adversely affected by freezing during extended periods of severe cold. To prevent this, aerators may be housed or otherwise enclosed.

b. Biological Growth. The growth of algae and slime bacteria can be particularly troublesome to cascade and tray aerators. Algae can be a particular problem for aerators located outdoors in direct sunlight. Treatment with copper sulfate or chlorine solutions may be required.

c. Scale Deposits and Corrosion. Oxidized iron may precipitate out and cause scaling in some cases. Due to the corrosive nature of the gases (such as hydrogen sulfide) being removed from the water, housings for aerators should be corrosion resistant.

d. Ventilation. Housed aerators must be properly ventilated to prevent the accumulation of toxic and explosive gases (such as methane, and hydrogen sulfide) and to increase process efficiency. Mechanical ventilation may be warranted.

e. Birds and Insects. Screens, traps, etc., should be used to prevent birds and insects from nesting in aerators and aerator enclosures.

6-5. Laboratory Control Tests. Laboratory control tests should be run on the water before and after aeration to determine if removals or additions are adequate. Recommended tests include carbon dioxide, dissolved oxygen, hydrogen sulfide, total iron, total manganese, threshold odor (TO) number, as well as pH.

6-6. Aeration Equipment Maintenance. The following maintenance checklist is composed of items specific to aeration equipment that should be evaluated in addition to the normal general maintenance practices. Maintenance frequencies for aeration equipment are compiled in table 6-1. In specific instances, aerator manufacturer's instructions regarding maintenance should be followed.

a. Waterfall Aerators (Cascade or Step, and Tray or Splash Pan):

(1) Daily, inspect the aerator surfaces for algae or other growths; precipitated iron oxide; and, for nonuniformity of water distribution and staining. Clean when necessary. Treat with copper sulfate or hypochlorite solution to destroy growths.

(2) Clean and repair tray aerators twice a year, removing the trays as necessary. Inspect the coke tray aerators for biological growths and coke deterioration. Replace the coke if the cleaning is not effective. Repair the screens and enclosures if necessary.

(3) Repair or replace the surfaces on cascades or step aerators annually, if necessary.

b. Diffuser Aerators. Diffuser aerators may be either porous medium design or injection nozzles.

(1) Porous Ceramic Diffusers—Plate or Tube. This type of equipment is maintained as follows:

(a) When nonuniform distribution of air is discovered (or clogging that impairs operation), empty the tank, inspect and clean diffusers if necessary.

(b) Every 6 months, drain the aeration tank and inspect the diffusers for joint leaks, broken diffusers, and clogging. Porous ceramic diffusers may suffer clogging of either the water side or the air side (underside).

1. Water Side (Porous Plate Diffusers). Use oxidizing acids to clean organic growths from plate surface.

NOTE: Chlorine gas introduced into the air line at intervals between inspections helps hold down organic growths. Removable plates should be soaked in 50 percent nitric acid. Plates grouted in place cannot be treated with nitric acid; use chromic acid (made by adding 1 gram of sodium dichromate to 50 ml of sulfuric acid). Pour approximately 2 fluid ounces on each plate on 2 succeeding days.

CAUTION: These acids must be handled carefully. Particularly, do not pour water into sulfuric or chromic acid, as it will explode and splatter the acid over the person handling it. Such acid will cause severe burns to the skin and clothes. Acid treatment should be done only on the approval of the plant superintendent and under the supervision of a chemist or other qualified personnel.

2. Air Side (Porous Plate Diffusers). If clogging is caused by iron oxide particles from pipes, treat this condition with a 30 percent solution of hydrochloric acid. If clogging is by soot, oil, or dust from improperly filtered air, remove the diffusers and burn off the extraneous material in a furnance.

3. Porous Ceramic Tubes. Tubes may be removed and cleaned by soaking in acids or by burning, as described above for porous plate diffusers.

(2) Porous Saran-Wound Tube Diffusers. These diffusers should be inspected and cleaned twice a year as necessary. This material cannot be subjected to strong acid or heat. It must be scrubbed with a brush and detergent.

Table 6-1. Maintenance Procedures for Aeration Equipment.

Inspection	Action	Frequency[1,2]
Waterfall type aerators (cascade).	Inspect aerator surfaces; remove algae; clean.	D
Waterfall type aerators (tray).	Clean and repair trays; clean coke or replace.	SA
Waterfall type aerators (cascade).	Repair or replace surfaces as necessary.	A
Injection aerators.		
Porous ceramic plate or tube.	Check discharge pressure; if clogging is evident, dewater tank, clean diffusers.	V
Porous ceramic plate or tube.	Drain aeration tank, check for joint leaks, broken diffusers, clogging.	SA
Water side of ceramic diffusers.	Clean with acid, in place, or remove and soak in acid.	SA
Air side of ceramic diffusers.	If plates are clogged by iron oxide, treat with HCl; if clogged by soot, oil, etc., remove diffusers and burn.	SA
Saran wound diffusers.	Clean by scrubbing with soap or detergent.	SA
Nozzles.	Clean nozzles inside and out.	SA
Spray nozzle aerators.		
Nozzles.	Check for clogging; clean, remove if necessary to clean.	W
Manifolds.	Remove caps and clean out sediment; check pipe supports, repair, as necessary; paint as necessary.	Q
Spray fence.	Paint.	A
Blowers and accessory equipment.		
Compressor or blower.	Lubricate, check output pressure for indications of clogging.	D
Air filters.	Clean, repair or replace.	W
Compressor or blower.	Open, inspect, clean, repair and paint exterior surfaces.	A

[1]D-Daily; W-Weekly; Q-Quarterly; SA-Semiannually; A-Annually; V-Variable, as conditions may indicate.

[2]The frequencies shown are suggested frequencies which may be modified by local command as individual installation conditions warrant.

(3) Injection Nozzles. Injection nozzles should be inspected and cleaned twice a year as necessary. Diffuser nozzles on header lines may become clogged from deposition inside, from iron oxide particles, or on the outside from organic growths. Clogging from the inside may necessitate removing of the individual nozzles for cleaning. Chlorine gas injection into the air line header between inspections holds down organic growths. At inspection periods, if growths are present, scrub them off with a brush and detergent solution to which hypochlorite has been added.

c. Spray Nozzle Aerators. The following procedures apply to this type of equipment:

(1) At weekly intervals, check the nozzles for clogging, and clean when necessary. Remove the nozzles only when necessary. Do not use a pipe wrench for this purpose. Check for inadequate spread.

(2) Quarterly, check air line manifolds, remove caps, and clean out sediment; check for joint leaks. Check pipe supports, replace or repair, and paint as necessary.

(3) If spray fences exist, repair and paint on an annual schedule.

d. Blowers and Accessory Equipment. Where injection aeration is used, adopt the following procedures:

(1) Lubricate the blower or compressor each day according to the manufacturer's instructions. Check output pressures.

(2) Inspect the air filters each week; clean, repair, or replace them as necessary.

(3) Open the blower or compressor each year and inspect for internal erosion or deterioration; repair as necessary. Paint exterior surfaces.

6-7. Maintaining Records. Records of the results of influent and effluent analytical tests, regular inspection, and periodic cleaning and repairs should be conscientiously maintained. These records serve as a long-term means of evaluating treatment efficiency, maintenance requirements, and equipment performance.

Section B—Iron and Manganese

6-8. General Information. Iron and manganese are often found in surface and ground waters. When present in excess of acceptable concentrations (0.3 mg/l and, 0.05 mg/l, respectively), iron and manganese can cause significant problems in water treatment and usage.

a. Sources of Iron and Manganese in Water. Natural geologic formations often contain iron and manganese compounds in rocks and soils. Iron and manganese may be dissolved from these natural formations by acidic water, such as mine drainage, waters high in carbon dioxide (caused by bacterial decomposition of organic matter), or waters subject to anaerobic conditions (swaps, anaerobic bottoms of eutrophic lakes, etc.). Iron and manganese may also be present in complex combination with organic matter and are referred to as organically bound iron or manganese. A third common source of iron in water systems is the corrosion of pumps or piping.

b. Problems Caused by Iron and Manganese:

(1) The most common complaint resulting from the presence of iron and manganese in water is that of discolored water from the red (iron) and black (manganese) precipitates which stain plumbing fixtures and laundry.

(2) Iron and manganese in concentrations greater than 2 to 3 mg/l give tastes to the water.

(3) The presence of iron encourages the growth of iron bacteria in water distribution systems. The iron bacteria may produce corrosion, tastes, and odors. In addition, the bacteria can reduce the carrying capacity of pipelines, clog meters and valves, and cause severe consumer complaints as a result of periodic sloughing of bacterial growths.

(4) Precipitates of iron and manganese may cause problems with water softening ion exchange units by clogging or coating the exchange resin, resulting in reduced ion exchange capacity.

c. Recommended Concentrations. To prevent the above-mentioned problems, iron and manganese concentrations should not exceed 0.3 mg/l and 0.05 mg/l., respectively. In addition, the combined iron and manganese concentration should not exceed 0.3 mg/l.

6-9. Preventive Measures. If concentrations of iron and manganese are in excess of those recommended, measures should be taken to prevent or eliminate the problems outlined above. It should be determined whether the source of the problem is supply or corrosion.

a. Collect several samples from the water supply source over a period of several hours. Analyze all samples for iron and manganese. Compare values with treated water being pumped to consumers. This allows evaluation of treatment effectiveness. Treated water concentrations should not exceed the recommended levels above.

b. If corrosion of the well casing, screen, or pump is the source of the iron, samples collected after the pump is first started will have higher levels than found in samples collected after the pump has run for a few hours.

c. If corrosion of the distribution system is responsible for iron problems, samples collected at the edge of the distribution system will have higher levels than those collected near the water source.

d. If iron and manganese are derived from the water supply, the water treatment processes outlined in paragraphs 6-10 and 6-11 should be initiated. If the iron concentrations are the result of corrosion of the well, pumps, or distribution system, appropriate corrosion control methods outlined in chapter 7 should be performed.

6-10. Treatment Measures. Iron is found in water in two oxidation levels, as bivalent ferrous iron (Fe^{+2}) and as a trivalent ferric (Fe^{+3}) form. In most ground waters, the iron present is almost always in the ferrous (Fe^{+2}) form, which is highly soluble. Ferrous iron is quite readily oxidized to the ferric form when it is exposed to air or oxygen. Ferric iron is almost totally insoluble in the pH range 6 to 8 and readily precipitates as a ferric hydroxide [$Fe(OH)_3$]. Manganese is also found in water in two oxidation states. They are bivalent (Mn^{+2}) and tetravalent (Mn^{+4}) oxidation levels. Manganese is not readily oxidized to the tetravalent form as iron is to the trivalent form, and removal procedures are more difficult. The following treatment processes apply for the removing of soluble iron and manganese. Special treatment methods for removing organically bound iron and manganese are in paragraph 6-11.

a. Oxidation, Precipitation, and Filtration. A variety of water treatment processes are available for converting soluble iron and manganese in the reduced ferrous (Fe^{+2}) and manganous (Mn^{+2}) states to insoluble ferric hydroxide [$Fe(OH)_3$], ferrous carbonate ($FeCO_3$), and manganese dioxide (MnO_2) by a combination of mechanical and chemical oxidation processes. The insoluble iron and manganese precipitates may be subsequently removed by settling and filtration.

(1) Aeration, Detention, and Filtration. Aeration removes carbon dioxide and raises the pH of the water containing soluble iron and manganese. Aeration may result in the precipitation of ferrous iron as ferrous carbonate in hard alkaline waters as the bicarbonate ion is converted to the carbonate ion by the rise in pH. Iron also precipitates as ferric hydroxide as the iron is oxidized from the ferrous to the ferric state. In cases where carbon dioxide removal does not raise the pH to an adequate level, chemicals (generally lime, soda ash, or caustic soda) may be added to attain a pH that enhances oxidation of the iron and manganese. The oxidation of manganese by aeration alone, however, is too slow to be feasible, and must be supplemented by chemical oxidation using potassium permanganate or chlorine compounds. Chemical oxidation with chlorine compounds may cause the formation of trihalomethanes. Trihalomethanes are contaminants that are considered harmful if found in high concentrations. These contaminants are regulated by law and must not be greater than a specified concentration. (See sections L and M of this chapter for more information.) Filtration, sometimes preceded by a short period of settling in a detention basin, removes iron and manganese precipitates.

(2) Chemical Oxidation Followed by Filtration. Soluble iron and manganese may be chemically oxidized to in-

soluble ferric hydroxide and manganese dioxide by adding potassium permanganate ($KMnO_4$), chlorine (Cl_2), or chlorine dioxide (ClO_2). Theoretical quantities of chemicals required for oxidation of iron and manganese are in table 6-2. Oxidation with permanganate is much faster than with chlorine; however, over dosing with permanganate can result in a carryover of a pink (permanganate) color. Oxidation of manganese with chlorine or chlorine dioxide requires a high pH (8.0 to 9.0), while oxidation with potassium permanganate occurs rapidly over a broad pH range (6.5 and up). Oxidation of manganese with any of the three chemicals is more effective as the pH increases. The precipitates formed may be removed by conventional filtration processes, although ferric hydroxide created by chemical oxidation is more difficult to filter than the ferrous carbonate precipitate. To keep the amount of oxidizing chemical used to a minimum and to improve insoluble ferric compound filterability, chemical oxidation of manganese is often preceded by an aeration process for oxidation of iron.

(3) Calcined Magnesite—Diatomaceous Earth Filtration. Calcined magnesite (MgO) may be fed in combination with diatomaceous earth into a rapid-mix tank providing 5 to 10 minutes of contact. If manganese is to be removed, potassium permanganate must also be added as an oxidizing agent. Finally, the mixture is filtered through a diatomaceous earth filter to remove the precipitated iron and manganese oxides.

b. Ion Exchange:

(1) Conventional Ion Exchange. Using ion exchange for removing iron and manganese is generally limited to very small systems in which the iron and manganese concentrations are less than 0.5 mg/l. It is more common to remove iron and manganese by aeration, chemical oxidation, and filtration before ion-exchange softening. Conventional water softening cation exchange zeolites remove dissolved iron and manganese, although problems may occur with clogged pores and fouled exchange media due to accumulations of iron and manganese precipitates. It is important to avoid aerating the water before ion-exchange treatment in systems that do not remove the iron and manganese before zeolite softening. Soluble, ferrous iron is fairly readily removed from zeolite by regeneration; however, oxidized ferric iron is extremely difficult to remove. If any oxidized iron precipitates accumulate on the zeolite due to insufficient backwash or (if due to improper regeneration) the ferrous iron is not removed and becomes oxidized to ferric iron, the ion-exchange capacity of the zeolite will be decreased steadily, eventually requiring replacement of the zeolite.

(2) Manganese Zeolite Ion Exchange. For certain applications where it is necessary to remove practically all iron and manganese, the manganese zeolite method may be used. This process consists of filtration through a bed of crushed anthracite or other coarse filtration media overlying a natural zeolite ("greensand") ion-exchange media. Oxidation of iron and manganese is initiated by continuous feeding 1 to 4 percent potassium permanganate solution before filtration. The oxidized iron and manganese precipitates are then filtered out by the crushed anthracite and zeolite media. The accumulations of oxidized iron and manganese deposited on the exchange media have an absorptive capacity for unoxidized iron and manganese. Thus, iron and manganese that were not oxidized by the permanganate are removed by the accumulated iron and manganese oxides and by the ion-exchange capacity of the zeolite. As additional iron and manganese precipitates build up in the filter bed, and as the absorptive capacity of the accumulated oxidation products is exhausted, the filter and ion-exchange beds must be backwashed with a potassium permanganate solution.

c. Stabilization With Polyphosphates. Polyphosphates (such as sodium hexametaphosphate) have been found to be effective in sequestering, or "tieing-up" iron and manganese when the iron and manganese concentration is less than 1 mg/l. The polyphosphates should be added before aeration or chlorination processes at a dosage of approximately 4 mg/l of sodium hexametaphosphate for each mg/l of iron and manganese. The polyphosphate does not prevent oxidation of iron and manganese but does tend to hold them in solution. Thus, the sequestered oxides or ions pass through the distribution system without precipitating, which results in visible problems. The phosphorous in the polyphosphate sequestering agent may help stimulate bacterial growths in distribution systems. It is important, therefore, to maintain adequate chlorine residuals in the distribution system to prevent bacterial slime growths.

d. Lime or Lime-Soda Ash Softening. Iron and manganese are effectively removed by conventional lime or lime-soda ash water softening processes because of the high pH values. When only part of the total flow is softened, the by-passed stream may need to be treated for iron and manganese removal by other means.

Table 6-2. Theoretical Chemical Requirements for Chemical Oxidation of Iron and Manganese.

Chemical	Theoretical Quantity Required to Oxidize 1 mg/l Iron	Theoretical Quantity Required to Oxidize 1 mg/l Manganese
Chlorine (Cl_2)	0.66 mg/l	1.30 mg/l
Chlorine Dioxide (ClO_2)	1.20 mg/l	2.45 mg/l
Potassium Permanganate ($KMnO_4$)	0.94 mg/l	1.95 mg/l

6-11. Special Treatment. Special treatment processes are required for some surface waters with organically bound iron and manganese. The iron and manganese organic water complexes are generally not soluble but are highly stable, colloidal dispersions. In some cases, oxidation may be inhibited by the presence of organic matter, requiring long-

er aeration periods or higher dosages of oxidizing chemicals. Oxidation alone usually does not result in the removal of iron and manganese complexes as insoluble precipitates. Treatment consists of an initial step to oxidize the iron and manganese followed by a chemical coagulation and filtration step to remove the oxidized metal or organic matter complexes. A typical treatment scheme may include the following:

a. Upward adjustment of pH with sodium hydroxide or lime to make the subsequent oxidation of iron and manganese easier.

b. Oxidation mechanically by aeration or chemically by adding chlorine or permanganate, using aeration detention times or chemical dosages sufficient to oxidize the organic matter in addition to iron and manganese.

c. Chemical coagulation of oxidized iron and manganese as well as colloidal dispersions of metal and organic matter with lime, alum, or iron salts.

d. Sedimentation to remove the readily settleable coagulated material.

e. Filtration to remove the remainder of the coagulated precipitates and metal and organic matter complexes.

6-12. Operational Problems. Operational problems often experienced with iron and manganese removal systems include growths of iron bacteria, cemented filter sand due to inadequate backwash, cation-exchange beds fouled by deposits of oxidized iron and manganese, and aerators clogged with iron deposits.

a. Growths of iron bacteria should be controlled by continuous chlorination. If growths do occur, they may be treated by shock dosages of chlorine (50 to 100 mg/l) for several hours followed by a thorough flushing. More than one shock may be necessary.

b. Accumulated iron and manganese deposits on filter sand, certain cation-exchange resins, or aerators may be removed in some cases by applying reducing agents such as sodium hydrosulfite or hydrochloric (muriatic) acid. It should be noted that some naturally occuring zeolites may not be cleaned with acid solutions because pH conditions below 7.0 may cause serious physical deterioration of the exchange media. Experienced commercial firms may be contracted to perform the cleaning services.

NOTE: The best solution, by far, is to eliminate these problems before they become serious.

6-13. Laboratory Control Tests. Important laboratory control tests should be performed to evaluate treatment effectiveness, including pH, iron, manganese, and concentrations of chlorine, potassium permanganate, or other oxidants used.

a. Hydrogen-ion Concentration (pH). The effectiveness of oxidation of iron and manganese by aeration and chemical addition depends on the pH of the water.

b. Iron and Manganese. Iron and manganese concentrations must be measured before treatment to determine the need for and degree of treatment required. Iron and manganese concentrations are measured after treatment to assess the effectiveness of the treatment processes and the suitability of the water for public distribution.

c. Chlorine, Potassium Permanganate, and Other Oxidants. Control of dosage of chlorine, potassium permanganate, and other oxidants being used is necessary to ensure adequate treatment. Overdosing wastes money and, in case of potassium permanganate, may result in a carryover of a pink color to the distribution system.

6-14. Residue Characteristics. Waste products generated by iron and manganese removal processes included hydrated ferric and manganic oxides and spent brine from the regeneration of zeolite ion-exchangers. The volume of the precipitated iron and manganese solids is relatively small. The precipitated iron and manganese is usually removed from the water by filtration, and thus becomes a component of the filter backwash. Likewise, soluble iron and manganese removed in zeolite ion-exchange units become part of the spent brine.

6-15. Requirements for Records. Operating records should be kept up-to-date reporting the results of laboratory control tests, as well as operating conditions, problems encountered, chemical usage, and other pertinent information.

Section C—Taste and Odor Control

6-16. General Information. Because the average consumer judges water quality by its taste and clarity, water treatment plant operators must effectively control taste and odor problems, in addition to turbidity.

a. Causes of the Problem. In general, tastes and odors in surface waters are the result of algae or bacterial growths or pollution; in ground water, the causes are usually dissolved gases, metals, or other minerals.

(1) Surface Waters. Algae are usually the main cause of taste and order problems; bacteria and other microorganisms may be significant in some instances. Decomposing organic matter from either natural sources (weeds, grasses, and leaves) or from human sources (sewage, detergents, etc.) may cause tastes and odors in water supplies. Contamination by industrial wastes (such as sulfites from paper mills, cannery wastes, oils, phenols, and metals) may produce characteristic tastes and odors. Agricultural chemicals may enter water supplies by overland runoff, resulting in tastes and odors. Chlorine odors may be the result of chlorine residual alone, although usually the cause is a chemical combination of chlorine with organic compounds.

(2) Ground Waters. Dissolved gases (such as methane and hydrogen sulfide) are the result of decomposing organic matter. These gases are corrosive or explosive, in addition to odor causing. Iron and manganese are dissolved metals commonly found in ground waters that result in adverse tastes and odors, in addition to having other disagreeable characteristics. High concentrations of sulfates and chlorides can also cause adverse tastes.

b. Preventive Treatment in Surface Waters. Control of sewage and industrial waste discharges into surface waters and proper land use methods (to control the entrance of

decomposable matter or pesticides into water sources) can be effective in preventing tastes and odors. Controlling the growth and multiplication of algae in the water does much to prevent tastes and odors from occurring in reservoirs. Although supplemental algae control may be required, reduced amount of organic and inorganic nutrients (primarily nitrogen and phosphorus) can prevent continued algae growths. The proper construction of reservoirs and impoundments can help prevents tastes and odor problems by controlling algae growth and the entrance of pollutants.

c. Corrective Treatment. Dissolved gases may be removed by aeration (section A). Iron and manganese may be effectively oxidized and removed by aeration or chemical oxidation processes (section B). Dissolved organics may be removed by either oxidation (aeration or chemical addition) or adsorption on powdered or granular activated carbon. Minerals such as chlorides and sulfates can be removed by ion exchange, electrodialysis, and reverse osmosis processes. These processes are generally quite expensive and therefore are usually not used.

6-17. Reservoir Algae Control. Methods of controlling algae, which are commonly used, involve adding biocidal or oxidizing chemicals (such as copper sulfate, chlorine compounds, and potassium permanganate). Adding powdered activated carbon to adsorb of dissolved organic compounds can also have the effect of controlling algae development by means of eliminating the direct sunlight required for algae growth. However, activated carbon usage generally apply only in small tanks or basins. Chemical dosages and feeding methods for reservoir algae control are discussed in paragraph 3-12e(2)(b).

6-18. Activated Carbon Treatment for Organics Removal. Activated carbon is a charcoal-like material that has been "activated" to greatly increase its surface area per unit of weight. In activated carbon adsorption, materials are attracted to and accumulated on the surface of the activated carbon. It is essentially a surface phenomena; the greater the surface area of the adsorbent, the greater its adsorptive power. In addition to taste, odor, and color removal, both powdered and granular activated carbon can effectively remove endrin, lindane, Toxaphene, 2, 4, 5-TP, Silvex, 2,4-D, methoxychlor, and trihalomethanes. Granular activated carbon also removes arsenic (valence 5), fluoride, mercury, and VOC compounds.

a. Powdered Carbon:

(1) General Information. The powdered form of activated carbon is best applied as a batch process where low or infrequent usage is required. Powdered activated carbon is used for adsorption only and not as a filter media. The powder is extremely fine, and potential dust and explosion problems exist unless proper safety precautions are followed. American Water Works Association (AWWA) Standard B600 lists requirements for powdered activated carbon.

(2) Carbon Dosage. Because of the differences in waters, no general rule can be given for powdered activated carbon dosage or contact time. The dosage and point of application for each plant must be determined experimentally. The dosage for a given water treatment plant may vary significantly throughout the year. Carbon dosages of about 3 mg/l should remove most tastes and odors. However, if the tastes and odors are caused by pollution from industrial wastes, the dose may have to be increased to 8 to 10 mg/l, or even 20 mg/l at times. When odors develop suddenly, feed an excess dose until the odors are under control. A laboratory method of determining powdered activated carbon dosage may be performed as follows:

(a) Secure several gallons of the odor-bearing water (in a clean odor-free container) at a point just ahead of the point of carbon application.

(b) Get a representative sample from material in stock that will be used for plant operations. Prepare a stock carbon suspension by adding 1 gram of the carbon to exactly 1 liter of odor-free water. Each milliliter of the stock suspension, when added to 1 liter of the odorous water, is equivalent to a dosage of 1 mg/l. The suspension should be agitated each time a sample is to be withdrawn and should be freshly prepared each day.

(c) Place 1-liter samples of the odor-bearing water in each of five clean and odor-free containers. The containers should be suitable for use with a laboratory stirring machine.

(d) Agitate each of the five samples in the stirring mechanism at a rate of about 100 revolutions per minute (rpm). Add stock carbon solution sufficient to give varying dosages in four of the five containers. Typical dosages, based on the threshold odor (TO) of the untreated sample, are in table 6-3. The fifth sample is retained as a blank. The samples should be stirred for a length of time equivalent to the carbon detention period in the plant.

Table 6-3. Determination of Proper Carbon Dosage for Different Odor Concentrations.

Threshold Odor of Untreated Sample	Carbon Dosage, mg/l				
	Container 1	Container 2	Container 3	Container 4	Container 5
10-20	None	2	4	8	16
20-40	None	4	8	16	32
40-80	None	8	16	32	64
Over 80	None	10	20	40	80

(e) Filter the samples through a Buchner funnel containing about ½-inch depth of very fine glass wool that has been thoroughly washed with odor-free water. Discard the first 200 ml of the filtered samples and retain the remainder of the samples for odor testing. Numerical comparison can be made with the TO test described in the latest edition of Standard Methods for the Examination of Water and Wastewater.

(f) The required carbon dosage based on the laboratory test usually results in a higher dosage estimation than required for plant operation. The plant dosage should be set at about three-fourths of the laboratory dosage and reduced gradually until the minimum dosage required for palatability is reached.

(3) Method of Application:

(a) Dry Feed:

1. As a rule, powdered activated carbon is fed into the water by dry feeders similar to those used for coagulants. Because activated carbon is so finely powdered, it must be handled more carefully than coagulants to guard against spreading carbon dust and causing fires or explosions. In addition, motors, lighting fixtures, and switches must be explosion-proof.

2. If dry carbon were dry-fed into the water, it would float to the surface for a long period of time. Therefore, to ensure better mixing, the carbon is first wetted thoroughly, usually by agitating it with the feedwater in a small tank. The agitating agent may be a paddle wheel, a strong spray, or a swirling action obtained by introducing the feedwater at a tangent to the side of the tank. Most carbon dry feeders have a mixing chamber or hopper in which the carbon is wetted by the swirling action of the water.

3. Dusting often results when the bags with the powdered activated carbon are dumped into the feed hopper. The following procedures help reduce the dust:

a. Open the carbon bag only at the location where it is to be emptied.

b. Cut under the seam at the top of the bag with a knife.

c. Allow the carbon to flow slowly out of the bag and don't allow it to fall a great distance. Cutting a hole in the opposite end of the bag prevents a vacuum from developing within the bag and permits the carbon to discharge easily.

d. Empty carbon bags should not be shaken because shaking causes dust and results in very little carbon being saved.

e. Store the empty bags in a nearby drum or barrel until they may be disposed.

4. The dry powdered activated carbon may be shipped in bulk by rail or truck, as well as in bags. The rail cars or bulk trucks are usually unloaded by gravity or pneumatically and the carbon is stored in bins before being passed to the dry feed machines. Pressure or vacuum pneumatic conveying systems can be supplemented by screw conveyors, bucket elevators, or special dry carbon pumps.

(b) Slurry Feed. To help offset dusting problems associated with feeding dry powdered activated carbon, slurries may be produced by wetting the carbon as soon after delivery as possible.

1. The slurry can be formed by emptying bags into a slurry tank at small installations and by wetting bulk deliveries at larger installations. The concentration of carbon in the slurry is generally 1 pound per gallon of slurry. Because the carbon tends to settle out of the slurry, agitators are required in the slurry storage tank. The agitators also aid in wetting the dry carbon as it is first introduced into the tank. Air spargers are sometimes used in the slurry storage tank to provide auxiliary agitation if carbon has settled. Dust collectors are required on vents where the incoming deliver of carbon displaces air in the tank.

2. Pumps and piping for handling the carbon slurry must be corrosion resistant. Rubber-coated or 316 stainless steel is generally used. The most widely used method of metering the feed of the activated carbon slurry is by a rotating dipper feeder (section I).

3. The following laboratory procedure may be used to determine the concentration of carbon in the slurry:

a. Use a 10 ml pipette to transfer 10 ml of the slurry into a tared aluminum foil dish.

b. Dry the sample in a 284°F oven or under an infrared lamp. About 45 minutes are required for drying.

c. Cool the dish and sample in a desiccator before weighing.

d. Subtract the weight of the dish from the total weight. The weight of the carbon, in grams, divided by 1.2 gives the carbon concentration in pounds per gallons of slurry.

(4) Points of Application. Activated carbon may be applied at one or more points in the treatment process. The point of application must allow for proper distribution of the carbon throughout the entire water stream and should allow a contact time of at least 15 minutes. Carbon may be added at the following points:

(a) Raw Water. Carbon added at this point usually has a long contact time and may prove satisfactory in plants where adequate dispersion of the carbon is possible. The carbon particles aid coagulation by providing nuclei for the formation of floc.

(b) Rapid-Mix Basin. Carbon added at the rapid-mix basin enables the operator to more easily judge the physical appearance of the coagulation floc and, thus, aids in the control of the coagulation process. The floc also carries down most of the carbon during sedimentation. This is helpful during periods of high carbon dosages, because the length of filter runs is not adversely affected. The settled carbon continues to adsorb products of sludge decomposition, thus preventing formation of secondary tastes and odors.

(c) Before Filtration. Carbon applied just before filtration is not removed during coagulation and flocculation and its affect continues during the filtration process. The carbon that accumulates in the filter helps remove tastes and odors. When a filter is returned to service after backwashing, it is a good practice to add a small batch of carbon to the filter influent.

(d) Split Feed. When part of the dosage is applied in the mixing basin and the balance just ahead of the filters, it is referred to as "split feed." Proportions of the dosage at these points depend on the water being treated. This method combines the advantages of both feed methods.

(e) Chlorine. Chlorine frequently alters the intensity of odors. If chlorine makes the odor harder to remove, carbon feed should precede chlorination; if chlorine makes the odor less difficult to remove, carbon application should follow chlorination.

b. Granular Carbon. The granular form of activated carbon is much cleaner and easier to handle than powdered carbon. Granular carbon is packed into beds or columns through which the water flows, thus providing both adsorption and filtration. This is usually a continuous process, most efficiently applied when there is a fairly constant need for taste and odor control. When the adsorptive capacity of the carbon has been exhausted, granular carbon must be replaced or regenerated, depending on which is the most economical alternative. For larger activated carbon users, regeneration becomes economically attractive. Activated carbon is regenerated in a furnace at 1500° to 1700°F in a controlled atmosphere that volatilizes and oxidizes the absorbed impurities. About 5 to 10 percent of the carbon is lost during each regeneration cycle, and the adsorptive capacity of the carbon is slightly reduced during each regeneration. Because the carbon bed also acts as a filtration device, accumulated solids must be backwashed from the beds in order to prevent clogging. AWWA Standard B604 lists requirements for granular activated carbon.

6-19. Corrective Treatment With Oxidizing Chemicals:

a. Chlorination. Taste and odor reduction may be done, in many cases, by using chlorine. The method of chlorine treatment and point of chlorine application resulting in the greatest benefit vary from plant to plant. Further information on the chlorine treatment methods discussed below is found in section H. Chlorination may cause the formation of trihalomethanes. These substances are contaminants that are considered harmful if found in high concentrations. These contaminants are regulated by law and must not be greater than a specified concentration (see sections L and M for more information).

(1) Combined Residual Chlorination. In this method of treatment, chlorine combines with natural ammonia in the water or added ammonia to form chloramines (combined chlorine residual) (see paragraph 6-69). The chlorine combines with ammonia, reducing the formation of compounds of chlorine with phenols, cresols, or tannins. These latter compounds, if formed, result in significant tastes and odors in the water supply. An ammonia nitrogen to chlorine ratio of 1 to 5 has been found satisfactory for combined residual chlorination. Combined residuals are not as effective when used as disinfecting agents as free chlorine residuals, but are more persistent, lasting longer in the distribution system.

(2) Free Residual (Breakpoint) Chlorination. Breakpoint chlorination is the application of enough chlorine to oxidize ammonia, other organic compounds, and inorganic reducing agents in the water. This results in a chlorine residual that is predominantly hypochlorous acid. This method of chlorine treatment attempts to "burn up" taste and odor producing organic compounds. Approximately 10 mg/l of chlorine is required to oxidize every 1 mg/l of ammonia in the water, in addition to the chlorine required to oxidize organic compounds and inorganic reducing agents. Determination of breakpoint depends on time, as well as chlorine concentration. Because the breakpoint reaction is time dependent, chlorine is generally applied at the inlet of the treatment plant to keep contact time to a maximum. Breakpoint chlorine dosages may vary widely in the same surface water source due to variations in runoff, streamflow, temperature, etc. Breakpoint chlorination may also result in producing nitrogen trichloride that may cause severe odors. Aeration is effective in removing this gas, but should be used after sedimentation and before filtration. It is not considered good practice to aerate filtered water because it exposes the water to possible atmospheric contamination.

(3) Superchlorination-Dechlorination. Even with breakpoint chlorination, some organic material may remain in the water and be available for formation of tastes and odors. Superchlorination is the application of chlorine in much greater dosages than required for breakpoint in order to speed up the decomposition of organic material. Superchlorination is generally practiced at a lake outlet or plant outlet in order to maximize chlorine concentration and contact time. Dechlorination of the resulting high chlorine residuals is accomplished by aeration, activated carbon adsorption, or addition of sulfur dioxide. Dosage requirements may vary widely.

b. Chlorine Dioxide. Chlorine dioxide (ClO_2) is a heavy reddish-yellow gas which is a very active oxidizing agent and is particularly effective for taste and odor control following ammonia destruction using chlorine gas. Chlorine dioxide is a specialized form of treatment and is not generally used continuously. Chlorine dioxide may be used when it proves more effective in removing certain odors than chlorine alone.

c. Potassium Permanganate. Potassium permanganate ($KMnO_4$) is a useful oxidizing agent that can be used as an algicide or to oxidize manganese in addition to taste and odor control. It is usually added to the raw water entering the plant at a dosage that gives a pink coloration about two-thirds of the way across the primary sedimentation basin or clarifier. Potassium permanganate dosages usually range from 0.5 to 5 mg/l. Excess dosages of potassium permanganate may result in a carry over of pink water due to residual potassium permanganate. The addition of permanganate to water does not intensify odors, as may be the case with chlorine.

d. Ozone. Ozone (O_3) is generated by passing air through a special electrical discharge. Oxygen in the air is changed to ozone. The ozone is produced at the point of use in an "ozonator." The ozone is bubbled into the water being treated at normal dosages ranging from 8 to 50 pounds of ozone per million gallons of water. The ozone

oxidizes taste and odor producing organic compounds, leaving no aftertaste.

6-20. Removal in Other Treatment Processes. Aeration is only effective in removing highly volatile or easily oxidized substances, such as hydrogen sulfide. Conventional coagulation-filtration water treatment plant operations can remove some taste and odor causing materials. Some materials, particularly colloids, are removed along with turbidity. The chemical addition and pH adjustment of the coagulation process may also cause a chemical reaction with the taste and odor causing materials, thereby removing or modifying the taste or odor causing characteristics. If odor is increased after rapid sand filtration, individual filters should be checked for organic growths or other problems.

6-21. Taste and Odor Control Equipment Maintenance. For information on maintaining equipment, refer to other sections of this publication as noted below:

a. Dry chemical feeders, paragraph 6-80.

b. Solution chemical feeders, paragraphs 6-76 and 6-80.

c. Dust collecting equipment, paragraph 6-80.

6-22. Laboratory Control Tests. Laboratory control tests for taste and odor control should be performed before and after treatment. For information regarding test procedures, see section M of this chapter. The most important parameters in controlling taste and odor are threshold odor number and taste. Ammonia, phenol, chlorine, and possibly iron and manganese, or any oxidizing chemicals added to the water should also be monitored to establish the sources of taste and odor, as well as to evaluate the efficiency of treatment.

6-23. Operating Records. A conscientious program of recording laboratory control test results, operating conditions, and chemical usage is essential to evaluate operations effectively.

Section D—Coagulation, Flocculation, and Sedimentation

6-24. General Information. Impurities present in raw water are in suspended, colloidal, and dissolved forms. The impurities are dissolved organic and inorganic substances, microscopic organisms, and various suspended inorganic materials. Suspensions are usually defined as solid particles large enough to be removed by plain sedimentation. The finely divided colloidal material must first be destabilized and brought together (coagulated) to form small particles. The small particles are gently stirred to form larger particles in a process called flocculation. The large particles may then be removed by ordinary sedimentation and filtration procedures. Colloidal material is the most difficult to remove from raw water. Processes that remove colloids from water also remove suspensions.

a. Properties of Colloids:

(1) Size. Colloids do not readily settle out of solution due to their extremely small size (approximately 0.0001 to 1.0 microns) and their large surface area in relationship to their weight.

(2) Electrical Charge. Most colloids found in water exhibit a negative charge. Because like charged particles repel, colloidal material will not join together to form suspended particles unless the particles' electrical charge is reduced or neutralized.

b. Organic Color. Color removal deserves special consideration due to is special colloidal properties.

(1) Cause of Organic Colors. Organic color is primarily caused by the decomposition of natural organic matter, although oxidized, metallic ions (such as iron) may also produce color.

(2) Size. Color associated colloidal particles are the smallest of the turbidity causing particles. They generally have diameters of about 0.003 microns, as compared to clays with a typical diameter of 1.0 micron.

(3) Charge. Color particles are negatively charged, with the strength of charge depending on pH. The charge is an integral part of the molecule, rather than merely adsorbed on the surface as with clays.

(4) Removal. The mechanism of color removal is thought to be the direct formation of an insoluble chemical compound with the metallic coagulant, rather than charge neutralization usually associated with turbidity removal. Color removal is affected by pH and should be carried out under acid conditions (pH 4 to 6). Raising the pH for other processes before removing color may cause color fixation to take place. This makes subsequent color removal (even at optimum pH) much more difficult.

c. Role in Heavy Metal Removal. As was shown in tables 2-3 and 2-4, coagulation, flocculation, and sedimentation can be very effective in removing arsenic (valence +5), cadmium, chromium, lead, inorganic mercury, selenium (valence +4), silver, and iron. Some of these are removed as a side benefit of the color or turbidity removal process. However, efficient removal of some of these might require process modifications such as changes in coagulant type, dose, or pH levels as determined by jar tests or pilot plant testing.

6-25. Principles of Coagulation, Flocculation, and Sedimentation:

a. Coagulation:

(1) Destabilization. In coagulation, a chemical is dispersed throughout the raw water to neutralize and destabilize particle charges on the colloids. Destabilized colloidal particles adhere to each other on particle-to-particle contact.

(2) Mixing. Because many colloidal particles are present in the water, charge neutralization among all particles requires immediate and even dispersion of the chemical coagulant. The destabilization reactions occur very rapidly. Incomplete or slow mixing results in wasted chemical and uneven flocculation. This mixing is usually carried out in a rapid-mix basin.

b. Flocculation:

(1) Mechanism of Floc Formulation. Once colloidal destabilization has occurred, random particle motion

causes particle collision, resulting in formation of a larger particle or floc. This naturally occuring process is relatively slow. A flocculation basin is used to provide slow mechanical stirring to speed interparticle contact and resultant floc formation.

(2) Particle Agglomeration. Neutralized particles stick together forming floc masses. The gentle mixing by the flocculation equipment causes floc mass collisions, resulting in the formation of ever-growing floc masses in a process termed agglomeration.

(3) Bacteria Enmeshment. Bacteria particles are also neutralized (but not physically deactivated) and become enmeshed in the floc particles during normal particle agglomeration. The enmeshed bacteria must be removed from the water as the floc settles.

(4) Particle Size and Weight. As particle agglomeration continues, particle size and weight increase to a point where the larger floc can be removed by gravity in a sedimentation basin or in filters following the sedimentation process.

c. Sedimentation. Sedimentation is the physical separation of solids from water by gravity. A large particle size and weight increase the rate and efficiency of the sedimentation process. Suspended solids are easily removed by sedimentation. Flocculated particles also settle once they reach the proper size and weight.

6-26. Factors Influencing Coagulation:

a. Hydrogen-ion Concentration (pH) Range. Each coagulant chemical has an optimum pH range in which good coagulation and flocculation occur in the shortest time with a given coagulent dosage. The type of colloid existing in the particular water also affects the pH range for efficient coagulation. In some cases, it may be necessary to use chemicals to adjust the pH of the water to obtain optimum coagulation and flocculation. Trial and error testing is the only sure method to determine the most efficient coagulant and pH range for the particular water being treated.

b. Type of Turbidity To Be Coagulated. The type of turbidity plays a role in determining requirements for optimum pH and coagulant dosage. The following generalizations can be made.

(1) Turbidity caused by clay concentrations requires a minimum of coagulant to provide an enmeshing mass of floc.

(2) As turbidity increases, additional coagulant dosage is generally required, although the dosage of coagulant does not increase in direct proportion to the increase in turbidity. Highly turbid waters require relatively lower coagulant dosages than low turbidity waters due to the higher probability of particle collisions.

(3) The organic matter typically adsorbed on clays in natural stream water does not significantly increase coagulant demand.

(4) Organic colloids caused by sewage and industrial wastes are more difficult to coagulate because of extensive chemical reaction that occur between the coagulant and the colloidal organic matter.

c. Type of Coagulant. Many types of coagulants are available to the water plant operator. Although the most commonly used coagulant is alum, iron salts and sodium aluminate are used, depending on the pH. Recently polyelectrolytes, with a variety of weights and charges, have become increasingly popular coagulants. Typical coagulants used in water treatment, along with their advantages and disadvantages, are discussed in paragraph 6-27.

d. Physical Factors. As temperatures decrease, the water viscosity increases. The rate of floc settlement decreases as the water viscosity increases, resulting in general loss of coagulation and flocculation efficiency. The temperature effect can be overcome by adding more chemical coagulant, weighting the floc by recirculation of settled coagulant sludge, operating the coagulation process at the optimum pH for the particular coagulant being used, or by adding a coagulant aid such as activated silica, polyelectrolytes, or clay.

e. Number of Particles of "Nuclei" Present. Although coagulation and floc formation can occur in the complete absence of solid suspended particles, the presence of suspended particles does serve to increase the rate of flocculation, density of floc, and settling velocities. In low turbidity waters, settled sludge from previously treated water is sometimes added to incoming water to provide the suspended particles, increase the efficiency of the coagulation process, and reduce the amount of fresh coagulant being added to the water.

f. Mixing. Two stages of mixing are generally used in the water plant.

(1) The first stage is frequently called flash mixing and is a very rapid and highly turbulent agitation that uniformly disperses the coagulant and promotes coagulant contact with turbidity particles. Flash mixing is usually maintained for 30 to 60 seconds before second stage mixing begins.

(2) The second stage is one of floc formation and growth, commonly termed flocculation, and is promoted through gentle stirring and thus increases the formation and density of floc. Flocculation times of 30 to 60 minutes are generally adequate to produce floc that settles in a reasonable time.

6-27. Coagulants Chemicals. The chemical properties of the following coagulant chemicals are presented in table 6-19.

a. Aluminum Sulfate:

(1) When aluminum sulfate (filter alum) is added to a water containing alkalinity in the form of calcium and magnesium bicarbonate, the theoretical reaction is as follows:

$$Al_2(SO_4)_3 \cdot 14H_2O + 3Ca(HCO_3)_2 = 3CaSO_4 + 2A1(OH)_3 + 6CO_2 + 14H_2O$$

Aluminum Sulfate	+	Calcium Bicarbonate	=	Calcium Sulfate	+	Aluminum Hydroxide Precipitate	+	Carbon Dioxide	+	Water

$$Al_2(SO_4)_3 \cdot 14H_2O + 3Mg(HCO_3)_2 = 3MgSO_4 + 2Al(OH)_3 + 6CO_2 + 14H_2O$$

Aluminum Sulfate	+ Magnesium Bicarbonate	= Magnesium Sulfate	+ Aluminum Hydroxide Precipitate	+ Carbon Dioxide	+ Water

(2) When water does not contain sufficient natural alkalinity to react with alum, an alkali such a hydrated lime, $Ca(OH)_2$, is added (0.39 mg/l of 95 percent hydrated lime as $Ca(OH)_2$ will maintain the alkalinity decreased by addition of 1 mg/l of alum). The theoretical reaction is:

$$Al_2(SO_4)_3 \cdot 14H_2O + 3Ca(OH)_2 = 3CaSO_4 + 2Al(OH)_3 + 14H_2O$$

Aluminum Sulfate	+ Calcium Hydroxide	= Calcium Sulfate	+ Aluminum Hydroxide Precipitate	+ Water

(3) When soda ash, Na_2CO_3, is used with alum to supply the necessary alkalinity, 0.54 mg/l are needed to maintain the alkalinity decreased by the addition of 1 mg/l of alum. The reaction is:

$$Al_2(SO_4)_3 \cdot 14H_2O + 3Na_2CO_3 = 3Na_2SO_4 + 2Al(OH)_3 + 3CO_2 + 14H_2O$$

Aluminum Sulfate	+ Sodium Carbonate	= Sodium Sulfate	+ Aluminum Hydroxide Precipitate	+ Carbon Dioxide	+ Water

(4) When alum is added to water containing sufficient natural alkalinity for its reaction:

(a) The aluminum added precipitates out as aluminum hydroxide.

(b) The carbonate or temporary hardness, caused by the calcium or magnesium bicarbonate, is reduced.

(c) The noncarbonate or permanent hardness, caused by the calcium or magnesium sulfate, is increased.

(d) Carbon dioxide is produced, which is undesirable since it is corrosive to metals.

(5) When lime is added with alum, the results are practically the same as with alum alone, except that no residual carbon dioxide remains.

(6) The addition of soda ash with alum has the advantage of not increasing the hardness, although the corrosiveness is increased to some extent.

(7) It is advantageous to use alum alone when possible, because it greatly simplifies the control of the treatment process. It does not intensity any color that may be present in the water and may actually reduce color already present to some extent. Ordinarily, the resulting increase in hardness and corrosiveness is of little consequence. The minimum dosage should never be less than 5.0 mg/l, even with relatively clear water, because smaller dosages do not produce the concentration of aluminum hydroxide necessary for precipitation.

b. Liquid Alum. Liquid alum is a concentrated solution of alum in water that is sometimes lower in price than dry alum. Liquid alum is convenient to transport, handle, store, and feed. All chemical reactions occuring with dry aluminum sulfate alum occur with liquid alum.

c. Sodium Aluminate. Sodium aluminate supplies alkali as well as aluminum ion and is generally used with alum. Sodium aluminate is also used for coagulation in lime-softening plants. The chemical reactions are:

$$Ca(HCO_3)_2 + 2NaAlO_2 = CaAl_2O_4 + 2NaHCO_3$$

Calcium Bicarbonate	+ Sodium Aluminate	= Calcium Aluminate Precipitate	+ Sodium Bicarbonate

$$Ca(OH)_2 + 2NaAlO_2 = CaAl_2O_4 + 2NaOH$$

Calcium Hydroxide	+ Sodium Aluminate	= Calcium Aluminate Precipitate	+ Sodium Hydroxide

d. Ferrous Sulfate. Ferrous sulfate ($FeSO_4$), commonly called copperas, reacts with natural alkalinity in the water or with alkalinity created by lime addition. The chemical reactions are:

$$FeSO_4 + Ca(OH)_2 = Fe(OH)_2 + CaSO_4$$

Ferrous Sulfate	+ Calcium Hydroxide	= Ferrous Hydroxide	+ Calcium Sulfate

$$4Fe(OH)_2 + O_2 + 2H_2O = 4Fe(OH)_3$$

Ferrous Hydroxide	+ Oxygen	+ Water	= Ferric Hydroxide Precipitate

Oxidation of ferrous hydroxide, $Fe(OH)_2$, to the ferric hydroxide, $Fe(OH)_3$, which is precipitated, occurs quickest at a pH of 9.0 to 11.0. When ferrous sulfate is used as a coagulant:

(1) pH between 9.0 and 11.0 is necessary to complete the reaction quickly.

(2) Natural alkalinity of waters is generally insufficient to complete the reactions. Lime must be added in a dosage of about 0.27 mg/l of 95 percent hydrated lime for each 1 mg/l of ferrous sulfate.

e. Ferric Sulfate and Ferric Chloride. Although infrequently used in water treatment, ferric chloride ($FeCl_3$) is available as a liquid, a crystal, or anhydrous. It is corrosive in the liquid state and when the crystalline or anhydrous forms come in contact with moisture. Ferric sulfate ($Fe_2(SO_4)_3$) is available as a commercial coagulant and has the advantage of being less corrosive than ferric chloride. Ferric sulfate is commonly used for color removal at low pH and for iron and manganese removal at high pH values. The chemical reactions for ferric chloride and ferric sulfate are:

$$2FeCl_3 + 3Ca(HCO_3)_2 = 2Fe(OH)_3 + 3CaCl_2 + 6CO_2$$

Ferric Chloride	+ Calcium Bicarbonate	= Ferric Hydroxide Precipitate	+ Calcium Chloride	+ Carbon Dioxide

$$2FeCl_3 + 3Ca(OH)_2 = 2Fe(OH)_3 + 3CaCl_2$$

Ferric Chloride	+ Calcium Hydroxide	= Ferric Hydroxide Precipitate	+ Calcium Chloride

$$Fe_2(SO_4)_3 + 3Ca(HCO_3)_2 = 2Fe(OH)_3 + 3CaSO_4 + 6CO_2$$

Ferric Sulfate	+ Calcium Bicarbonate	= Ferric Hydroxide Precipitate	+ Calcium Sulfate	+ Carbon Dioxide

$$Fe_2(SO_4)_3 + 3Ca(OH)_2 = 2Fe(OH)_3 + 3CaSO_4$$

Ferric Sulfate	+ Calcium Hydroxide	= Ferric Hydroxide Precipitate	+ Calcium Sulfate

When ferric salts are used:

(1) In reacting with bicarbonate, carbon dioxide is formed as in the case with alum.

(2) Ferric sulfate is less corrosive than ferric chloride.

(3) Ferric floc is heavier than alum floc and settles more readily. It is also more completely precipitated over a wider pH range.

(4) Ferric floc does not redissolve at high pH when lime is used for corrosion control.

(5) Ferric floc forms more rapidly in cold water than alum floc.

(6) Ferric coagulants are more effective in color removal in waters with pH values of 4.0 to 6.0 and in iron and manganese bearing waters when used with lime to produce a pH value of 9.0 to 9.6.

f. Chlorinated Copperas. Chlorinated copperas is formed by the interaction of ferrous sulfate and chlorine. The chemical reaction is:

$$6FeSO_4 \cdot 7H_2O + 3Cl_2 = 2Fe_2(SO_4)_3 + 2FeCl_3 + 7H_2O$$

Ferrous Sulfate (Copperas)	+ Chlorine =	Ferric Sulfate	+ Ferric Chloride	+ Water

Theoretically, one part of chlorine reacts with 7.8 parts of ferrous sulfate; but in practice an excess of chlorine is added to ensure complete reaction and for disinfection. When chlorinated copperas is used as a coagulant:

(1) The field of usefulness is practically the same as that of ferric sulfate and ferric chloride except that copperas is more easily added.

(2) Copperas is oxidized by chlorine over the entire pH range of natural waters to form ferric chloride and ferric sulfate.

(3) It is useful when disinfection is desired and can be used with prechlorination.

g. Polycationic Coagulants. Cationic (positively charged) polyelectrolytes can often be used without adding metal coagulants to perform the coagulation treatment step because their positive nature destabilizes negative turbidity particles. However, if used with coagulants, the polycationic compounds can reduce alum requirements and reduce interferences in the coagulation and flocculation of living organisms such as algae and bacteria.

h. Specialized Coagulants:

(1) Activated alum contains inert insoluble material that aids coagulation. It reacts chemically the same as regular filter alum and is of particular advantage in filter plant operation where water with a usually very low turbidity is being treated. The additional insoluble matter aids in clarification by weighting the floc.

(2) Black alum, or alum containing activated carbon, likewise reacts chemically the same as alum and is an advantage where taste and odor are problems. It is not recommended for general use because it is usually more economical to add the two chemicals separately in the proportions needed.

6-28. Coagulant and Flocculant Aids:

a. Oxidants. Occasionally in water treatment, organic materials inhibit the coagulation process. Chemicals such as chlorine, chlorine dioxide, ozone, and potassium permanganate can oxidize these interfering materials and are usually added before coagulation.

b. Adsorbents and Weighting Agents:

(1) Clay. Bentonite clay has been used successfully with a coagulant for treating waters high in color and low in turbidity and mineral content. Clay addition increases the mass of light settling floc produced by iron and aluminum coagulants and adsorbs organic compounds to a certain degree. The precise dosage of clay needed for any water should be determined by appropriate trial and error testing, although dosages are often in the range of 10 to 50 mg/l.

(2) Powdered Silica, Limestone, and Activated Carbon. These three chemicals are also used as weighting agents although somewhat less frequently than clay materials. Limestone and activated carbon, in particular, possess the additional advantage of increased alkalinity and high adsorptive capacity, respectively.

c. Activated Silica:

(1) Normal Usage and Dosage. As a rule, activated silica is used with aluminum coagulants in a dosage between 7 and 11 percent of the alum dosage (expressed as milligrams per liter (mg/l) of SiO_2). Activated silica is produced by neutralizing a concentrated sodium silicate solution with acid and allowing the mixture to age for about 10 minutes.

(2) Beneficial Effects. Activated silica can increase the rate of coagulation, reduce the coagulant dosage required, and extend the pH range for optimum coagulant dosage. Activated silica can produce larger, faster settling, toughened floc that filters or settles more efficiently. Activated silica allows more efficient coagulation at low temperatures, improves color removal, improves high turbidity water flocculation, and reduces the colloidal matter passing through filters.

(3) Possible Disadvantages. It requires precise control to prepare an activated silica solution. Exceptionally large floc may be produced that leaves a high turbidity in the finished water and significantly shorten filter runs by clogging the filter surface. Overdosage of activated silica can inhibit floc formation.

d. Polyelectrolytes:

(1) Characteristics. Polyelectrolytes are manufactured synthetically as a high molecular weight, colloidal size molecule. The molecule can be manufactured to meet varying specific requirements. Synthetic polyelectrolytes are available in anionic (negatively charged), cationic (positively charged), or nonionic (neutral) forms. The anionic and nonionic forms are generally used as flocculant aids, while cationic forms are generally used as primary coagulants or coagulant aids.

(2) Polyelectrolyte Feed:

(a) In dry and concentrated liquid form, polyelectrolytes are reasonably stable and can be stored approximately 1 year. In feed solution form, however, shelf life is only about 24 hours.

(b) Polyelectrolyte makeup water should be high quality.

(c) Polyelectrolytes are difficult to put in solution, and package feeders are often supplied by the polyelectrolyte manufacturer to feed their particular chemical.

(d) Polyelectrolyte solution strengths are usually 1.0 percent or less since more concentrated solutions can start to solidify causing clogging of feeding devices and valves.

(3) Beneficial Effects. Polyelectrolytes produce a very large and dense floc that can significantly increase particle settling rate. The floc produced is often stronger and more easily removed by filtration equipment. Polyelectrolyte coagulant and flocculant aids are less easily influenced by water pH, alkalinity, hardness, and turbidity than are some other aids. Polyelectrolytes are easier to prepare, use, and store than activated silica.

(4) Precautions. Overdosage of polyelectrolytes can hinder flocculation. Precise dosages of polyelectrolytes with metallic coagulants can be determined only by trial and error testing procedures. Only those polyelectrolytes specifically approved by the US Environmental Protection Agency (EPA) as acceptable for use in potable water treatment should be used in military installations.

6-29. Chemical Dosages. Many factors influence the coagulation of raw waters which, in turn, influence the type and the amount of chemicals required. It is necessary to know which chemicals produce the most satisfactory results and are the most economical, and to determine the exact dosage required. This can be done only through trial and error, either by jar tests or by full-scale trial runs in the plant. It is usually more efficient to make jar tests than to experiment in the treatment plant.

a. Laboratory Control Tests. The following laboratory tests are essential for control of the coagulation and flocculation processes:

(1) Turbidity. Turbidity determination is perhaps the single most important control test performed in the coagulation, flocculation, and sedimentation process. Turbidity tests should be performed on the raw water and final filtered water to determine the overall turbidity removal effectiveness.

(a) Once chemical dosages are determined, raw water turbidity tests will probably be performed only as frequently as the raw water quality varies. River waters require more frequent analysis than lake waters, especially during the spring where snow thawing and runoff dramatically increase the silt load in rapidly moving rivers. Well waters are not usually turbid.

(b) Turbidity analysis should be conducted on treated effluent water. An increase in effluent turbidity indicates process control problems and may be related to filter breakdown, poor floc formation, or coagulant dosage variation. The effluent turbidity test, more than any other test, directly indicates the effectiveness of the colloid removal processes.

(2) Residual Aluminum or Iron. Residual aluminum or iron control tests should be performed occasionally in the filter effluent if these chemicals are used for coagulation. The appearance of aluminum or iron residuals indicates treatment inefficiency that may be due to filter breakthrough, coagulant overdosage, or other factors that should be corrected at once to maintain treatment economy.

(3) pH Values. Depending on the raw water source, pH values can vary during different times of the year. Raw water pH influences the proper selection of coagulant. Filter effluent pH is one of the parameters needed to determine if the water is corrosive or depositing and allow the proper pH adjustment procedures.

(4) Alkalinity Analysis. Raw water alkalinity should be evaluated almost as frequently as filter effluent turbidity to make sure that sufficient alkalinity is present in the raw water to react with the coagulant to begin floc formation. Effluent alkalinity should be measured occasionally (along with other calcium carbonate stability index parameters) to determine the corrosive or depositing tendencies of the treated water.

(5) Color. Raw water color should be analyzed to note any dramatic color changes and to take the proper corrective actions (for example, pH adjustment, coagulant dosage change, etc). Color usually increases during spring runoff and again in the fall for surface supplies.

b. Chemical Selection. The kind of chemical or chemicals suitable for coagulating the particular raw water can be determined by using the results of the control tests mentioned above, jar tests, plant control tests, and by using the data shown in table 6-4. Although table 6-4 is theoretically correct, these values may be found to be misleading when applied to some waters. The chemical content of some water has a considerable influence on the optimum pH range for the various coagulants. For example, coagulation with ferrous sulfate is usually best accomplished at relatively high pH values in the alkaline zone. With soft, colored waters, ferric coagulants may sometimes be used with considerable success at low pH values of 4.0 or less. Due to this variation in the optimum pH range of coagulants caused by the individual characteristics of the raw water, the coagulant dosage and the optimum zone for floc formation should be determined by jar tests rather than just replying on table 6-4. In determining the optimum dosage of coagulant by jar tests, the amount selected should be the least amount required for satisfactory flocculation within the time available for flocculation in the particular treatment plant. Similarly, the quantity of alkali or acid required should be the least amount necessary to maintain the optimum pH value as determined by the jar test.

Table 6-4. Optimum pH Ranges for Common Coagulants.

Coagulant	pH
Aluminum sulfate	5.0 to 7.0
Ferrous sulfate	9.5 and above
Chlorinated copperas	4.0 to 6.5 and above 9.5
Ferric chloride	4.0 to 6.5 and above 9.5
Ferric sulfate	4.0 to 10.0

c. Dosage Determination. The proper coagulant dosage can be determined by trial and error testing. The jar test is the most common method used for determining proper dosage.

(1) Jar Test. The coagulant dosage must be determined or checked as often as raw water quality varies at each point. As there may be a question as to which chemicals should be used, it is often necessary to run more than one series of jar tests. Different coagulant chemicals and different pH ranges should be used in order to determine which produces the most satisfactory results at lowest cost. In many cases, seasonal or other changes in the raw water require using different chemicals at different times. Complete records of these tests should be kept to develop an experience table for future guidance.

(2) Procedure. The method to be followed for the jar test is:

(a) Prepare a standard solution of each coagulant selected for trial by adding 10 grams of the coagulant to 1 liter of distilled water.

(b) Correct the pH of a sample of raw water to within the optimum range for the coagulant being tested (only if the pH is to be adjusted to the same extent in actual plant operation). Divide raw water into six 1-liter samples.

(c) Add 0.5 ml of standard coagulant solution to one of the liter samples of raw water, 1.0 ml to second sample, 2.0 ml to third, 3.0 ml to fourth, 4.0 ml to fifth, and 5.0 ml to sixth. This gives dosage of 5, 10, 20, 30, 40, and 50 mg/l, respectively.

(d) Agitate samples in the jar test apparatus at a velocity that is about equal to that in the plant mixing chamber and for the same length of time as the plant mixing time.

(e) Keep the samples at the same temperature as water passing through the plant, using a water bath around jars if necessary.

(f) After stirring, let samples settle for 30 minutes.

(g) Siphon off a sample of the supernatant and determine turbidity by a turbidimeter.

(h) The smallest amount of coagulant (or combination of coagulants) that produces the lowest turbidity represents the optimum dosage. Multiply the coagulant dosage in mg/l ((c) above) by 8.33 to get the correct chemical feed in pounds per million gallons.

(i) Repeat for each chemical (or combination of chemicals) being tested until satisfactory result is obtained. When polyelectrolytes are used, testing ranges should cover 0.001 to 10 mg/l of polyelectrolyte dosage. Accurate records should be kept.

d. Plant Control Tests:

(1) Observation Stations. Observation stations in the flocculator and sedimentation basin are essential to enable the operator to inspect raw water treatment and note floc formation as the water progresses through these units. Unless the operator can so observe the process, he or she must rely solely on the appearance of the water leaving the sedimentation basin. The operator cannot tell from the appearance of this water whether inefficient removal is due to deficiencies in flocculation or in sedimentation.

(2) Length of Filter Runs. The length of filter runs can be important in determining the adequacy of coagulant dosage. The floc should not penetrate too deeply in the bed or residual effluent turbidity results. On the other hand, a dense floc not removed by sedimentation may coat the filter surface and cause very short filter runs.

(3) Pilot Filter. The pilot filter technique is gaining rapid acceptance as one of the most accurate plant control tests. Basically, coagulated water from the rapid mix discharge is passed through a small (usually 4.5 inches in diameter) pilot filter. The pilot filter turbidity is continuously monitored. The pilot filter does not predict length of plant filter run, optimum filter aid dosage, or the rate of plant filter head loss. The only purpose of the filter is to determine the proper coagulant dosage. Pilot filter control of coagulant dosage accurately predicts resultant turbidity produced in the full scale plant effluent. The short time lag between introducing coagulant and control test results with pilot filter operation (10 to 15 minutes) allows quick modification of coagulant dosage to produce the highly settling floc.

(4) Continuous Turbidity Analysis. A continuous reading, low range turbidimeter (figure 6-2) provides a continuous record of the quality of the filter effluent. Continuous turbidity analysis cannot be efficiently used for process modification, however, due to the time lag (1.5 to 2 hours) between coagulant dosage and filtration. The turbidity reading does reflect the efficiency of the overall treatment provided. It is related to the probability of escape of pathogenic organisms and aesthetic acceptability of the product by the consumer.

e. Measurement of Chemicals. When possible, provide each feeder unit with a weighing device so that amounts of chemical being fed can be checked frequently. If no weighing device is available, catch the chemical being fed in a weighing dish for a definite period, determine its weight, and calculate the rate of feed. Daily records of chemical treatment to be kept on the treatment plant daily operating log include:

(1) Pounds of each chemical fed in 24 hours.

(2) Gallons of water treated.

(3) Pounds of each chemical fed per million gallons of water treated.

(4) Milligram per liter concentration of each chemical fed.

f. Chemical Dosing Equipment. As a rule, dry feeders are used to disperse dry chemical coagulants. Polyelectrolytes are often dosed with proprietary solution feeders and metering pumps. Futher details concerning dry and solution feeders may be found in section I.

6-30. Types of Mixing:

a. Rapid Mixing:

(1) Function. The more quickly the coagulants can be uniformly mixed with water to be treated, the more rapidly and completely the chemical reactions take place. In water treatment practice, this is called rapid or flash mixing. The compartment in which this process takes place is known as

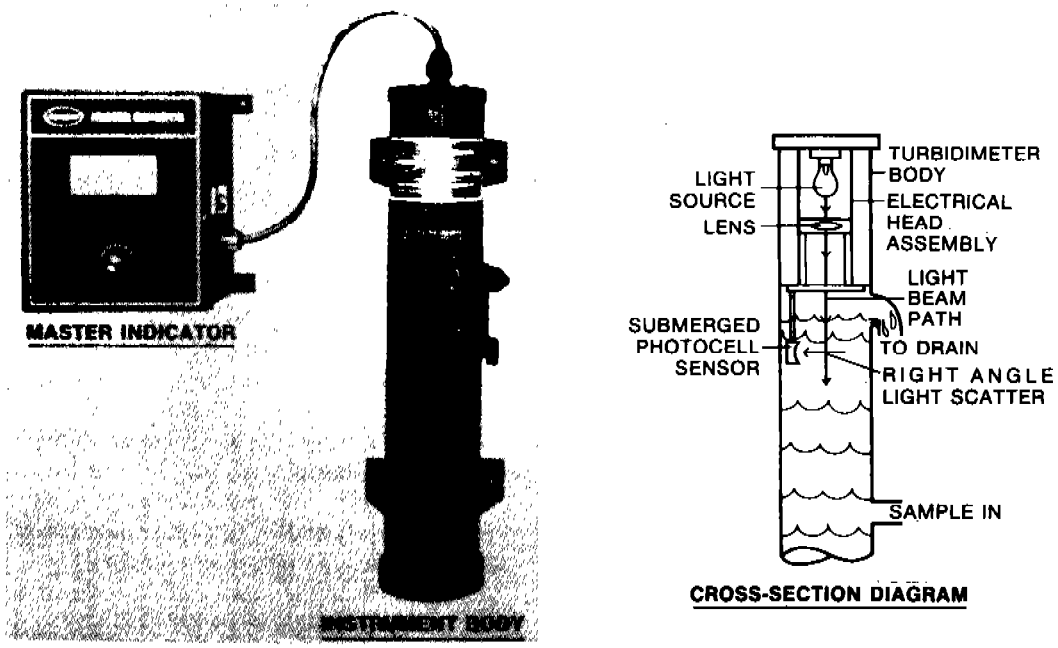


Figure 6-2. Continuous Reading, Low-Range Turbidimeter.

the rapid or flash mix basin.

(2) Equipment Types. The devices by which rapid mixing is done are known as rapid or flash mixers. These include pumps, aero-mixers, turbo-mixers, hydraulic pumps, air-agitated mixing chambers, and mechanical stirrers (figure 6-3). Some mixing also takes place in the pipes and conduits through which turbulent water flows.

b. Slow Mixing (Flocculation):

(1) Function. The purpose of flocculation, which follows adding and mixing the coagulant, is to promote the growth of the floc particle and to provide opportunity for contact between the floc and the suspended particles causing turbidity. The increased weight of the floc results not only from the increased size of the floc, but also from the adsorption of turbidity particles on the enlarged precipitate as it moves through the water. The more opportunity floc has to contact the suspended turbidity, the more efficient is the removal. Floc increases in size by gentle stirring, and contact between the floc and turbidity is promoted by allowing low enough velocities through the flocculation chambers and furnishing a long path of travel. Too much agitation breaks up the floc.

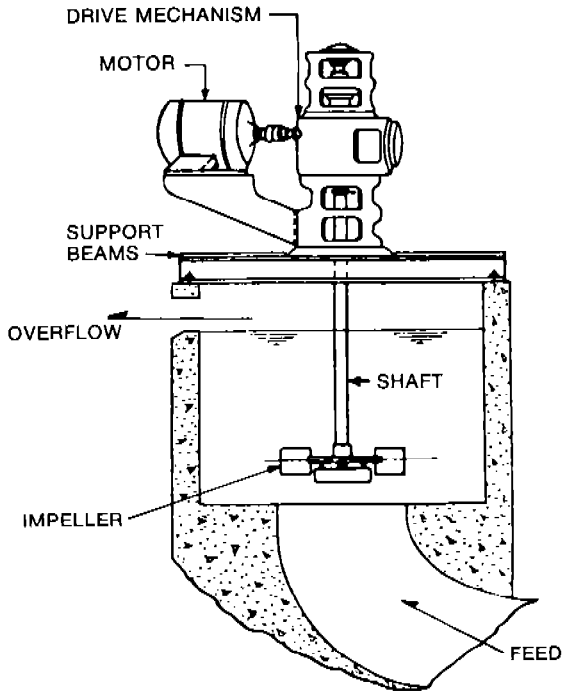


Figure 6-3. Flash Mixer.

(2) Equipment Types. While individual installations may vary, most flocculation equipment or treatment plants is of two types, baffle basins and power-driven paddles or agitators.

(a) Baffle Basins. As suggested by the name, baffle basins consist of a tank with baffle walls built in them to turn the water. The baffles may be of the "over and under" type, or the "end around" type. The passageways formed by the baffles constrict the flow so that increased velocity is set up, and in going around the baffles, the water is slowly mixed.

(b) Mechanically Stirred Basins:

1. Rotary-Type Flocculator. The rotary-type flocculator uses a paddle-like stirrer to impart a velocity to the water. The area of the paddles is usually from 10 to 25 percent of the cross-sectional area of the tank (figure 6-4). These mechanical devices are used to achieve slow or gentle stirring and to provide a long path of travel for the floc. The paddles (usually of steel or wood) are generally mounted on a steel frame revolving on a horizontal axis, with the vertical dimension of the frame being slightly less than the depth of the water. The rotating unit may be mounted so that the axis is either parallel or perpendicular

Figure 6-4. Rotary-Type Paddle Flocculators.

to the direction of the flow of water. As a rule, there are three to four units in a row, and three to four rows in a series, as may be required.

2. Walking-Beam Flocculators. The "walking-beam" type of flocculator provides the same primary functions as the rotary type, but by a different mechanism (figure 6-5). This flocculator applies the stirring action by an up-and-down motion of paddles mounted on triangular forms at the bottoms of long vertical arms.

6-31. Removal by Sedimentation:

a. Purpose of Sedimentation. Sedimentation for removing suspended solids is one of the most commonly used processes in water treatment. Plain sedimentation is used for undesirable amounts of suspended solids in relatively pure untreated water. For waters containing undesirable minerals (or other materials in solution) or finely divided and collodial materials in suspension, it is necessary to add coagulants that react to form a chemical floc. The chemical floc is then removed in a sedimentation basin. Coagulation, flocculation, and sedimentation are always followed by filtration in modern, efficient water treatment plants.

b. Fundamentals of Sedimentation:

(1) Gravity Separation. Particles heavier than water settle by gravity in a sedimentation basin. The basin is large enough to allow very slow water movement so that particles are not held in suspension, but settle to the bottom of the tank for removal (see figure 6-6).

(2) Inlet and Outlet Conditions. Correct basin design keeps the water from flowing directly from inlet to outlet and distributes the flow uniformly throughout the cross section of the basin. Inlet velocities should be low (between 0.5 and 2.0 fps) to prevent floc breakup. The outlet should collect water uniformly across the width of the basin to keep velocities low and prevent settled sludge from being carried over the outlet weir by localized high velocities. Some basins use baffles between inlet and outlet to keep short circuiting to a minimum.

(a) Outlet Weir Loading. The overflow rate on the outlet weir must be kept at a value that will not allow settled sludge to be lifted and carried over the weir. A commonly used maximum overflow rate for outlet weirs in sedimentation tanks is 20,000 gallons a day per foot of weir length, while solids contact units used as clarifiers are often limited to 14,500 gallons per day per foot of weir length.

(b) Example of Weir Loading Rate Calculation. A sedimentation basin receiving 0.5 mgd has an outlet weir length of 30 feet. The weir loading rate equals 500,000 gallons per day divided by 30 feet, or approximately 16,700 gallons per day per foot of weir length.

(3) Wind and Density Currents. Currents reduce the performance of a sedimentation basin by producing localized high velocity eddies that resuspend sludge or cause particles to travel from inlet to outlet in a shorter time than required for good settling (short circuiting). Covers over the sedimentation basin eliminate wind currents and reduce thermal variations. Baffle arrangements can also reduce the effects of currents.

(4) Velocity. A uniform horizontal velocity of from 1 to 2 fpm is desirable with lower values perferred.

(5) Detention Time. The theoretical detention time (volume of basin divided by rate of flow through the basin) should be as long as possible, with about 2 to 4 hours providing adequate settling of properly coagulated waters before filtration. The actual detention time may be estimated using dyes, confetti, and submerged floats.

(a) Dye and Confetti Detention Time Determination:

1. Dye is very helpful in indicating the existence of serious short circuiting and locating where water may be passing through the basin at a high rate. Eventually dye diffuses throughout the water in a basin and further observations are not feasible.

2. Eddie observations that result in short circuiting in sedimentation basins may also be made with con-

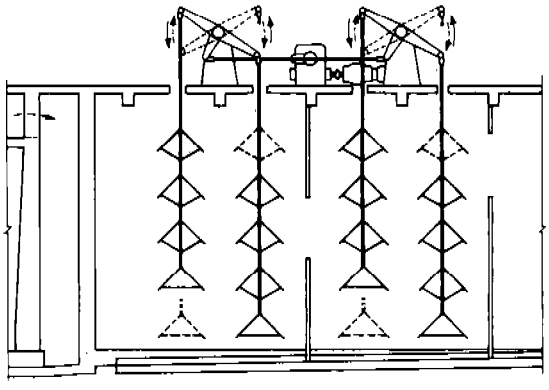


Figure 6-5. Walking-Beam Flocculator.

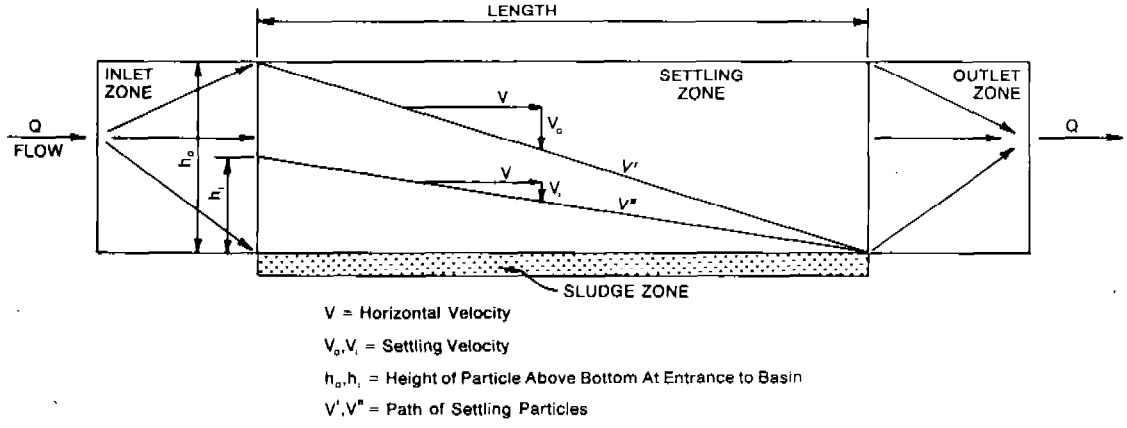


Figure 6-6. Ideal Sedimentation Basin.

fetti. A small handful of confetti is dropped into the stream of water entering a basin at intervals of 5 minutes to disclose the direction and the velocity of the currents. The three dimensional appearance of the batches of confetti also makes observation of vertical eddies possible.

(b) Submerged Float. Submerged floats with an above the water flag or target indicate the direction and rate of movement of water through a basin. The floats should have a large area to make them respond to slow velocity currents, and their depth of submergence should be as representative as possible. Floats are particularly useful in studying of large open basins or reservoirs.

c. Equipment. Sedimentation basins are constructed in several configurations.

(1) Rectangular (Horizontal Flow). Rectangular sedimentation basins consist of a rectangular tank, generally constructed of concrete, in which water is introduced at one end and drawn off over weirs at the opposite end. Sludge settling on the bottom of mechanically cleaned basins is collected by chains with wooden flights or by a traveling bridge sludge collector. Sedimentation basins for waters with a low solids content are sometimes not equipped with mechanical sludge collection equipment. These basins must be periodically drained and the sludge manually removed. The rectangular configuration provides the best protection against short circuiting.

(2) Circular (Horizontal Flow). Circular sedimentation basins also remove solids effectively, although they are generally less efficient than rectangular configurations due to short circuiting. Three common circular clarifier arrangements are shown in figure 6-7.

(3) Tube Settlers (Inclined Flow). Tube settlers consist of bundles of individual tubes of square, hexagonal, or other shapes. Typically, the tubes are installed in the sedimentation basin at a steep 60° angle to increase effective surface area for settling. As the liquid flows upward through the tubes and toward the basin overflow, solids settle along the tube sides and tumble downward into the sludge collection system as shown in figure 6-8. Tube settlers can be purchased as original equipment or bundles of tubes can be installed in upflow solids contact clarifiers or horizontal flow (circular or rectangular) sedimentation basins to improve sedimentation performance or increase the capacity of the existing sedimentation basins.

(4) Operation. The main items in operating sedimentation basins are controlling of the quantity of water flowing through the basin and the removal of sludge from the basin.

(a) Control of Flow. The quantity of water flowing through the sedimentation basin is controlled by using control valves and plant metering devices or by checking the discharge rate of the raw water pumps periodically. In cases where the raw water enters the plant by gravity flow, an orifice plate, venturi tube or other type of meter, and a control valve are used so that the flow through quantity can be accurately determined and controlled.

(b) Sludge Removal. Sludge removal can be either intermittent or continuous:

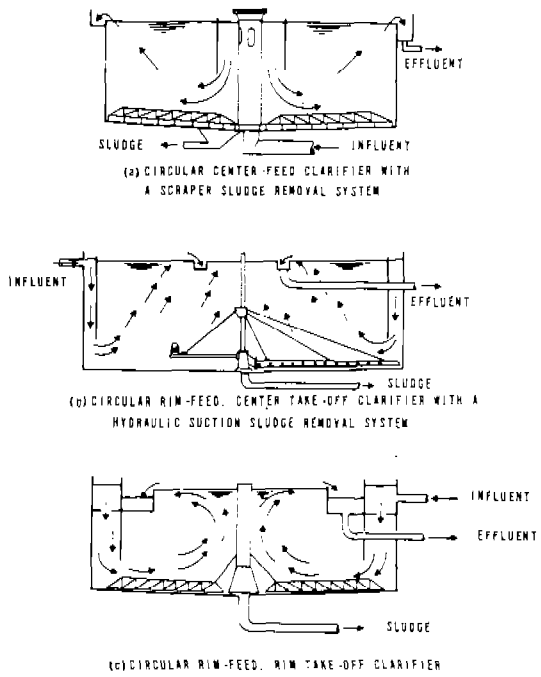


Figure 6-7. Typical Circular Clarifier Configurations.

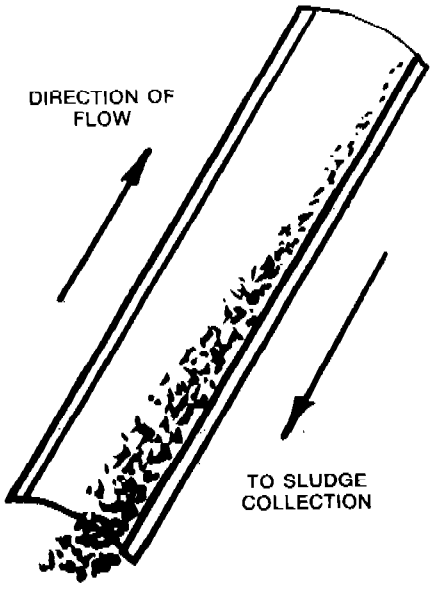


Figure 6-8. Tube Settler Flow Pattern.

1. Intermittent Removal. For sedimentation basins not equipped for continuous sludge removal, the basin is usually drained by a sump located in one corner of the tank. The remaining sludge is removed manually by either hosing to the sump or by shovel.

2. Continuous Sludge Removal. Continuous removal of sludge has been found to be more satisfactory and efficient, particularly where there is a considerable amount of sludge to be removed. The bottom of square and round sedimentation basins are usually equipped with a spiral rake that rotates and moves the sludge to the sludge drain in the center. The tank bottom is sloped toward the center to assist in moving the sludge toward the drain. For rectangular basins, scrapers are provided that are dragged along the floor of the basin, carrying the sludge to sludge hoppers located at the bottom of the inlet end of the tank. From these hoppers, the sludge is removed either by gravity or by pumping to sludge handling facilities.

d. Combination Units (Flocculation and Sedimentation):

(1) General Description. Combination units incorporate chemical mixing, flocculation, and clarification in a single tank. Although not as flexible from an operating standpoint, combination units require less space and generally have a lower construction cost than units performing similar separate functions.

(2) Upflow Clarifier. In upflow clarifiers, raw water and coagulation chemicals are introduced into a mixing chamber where they are mixed by slow moving agitator paddles. The raw water then moves downward through a sludge blanket and upward to the effluent weir. The sludge blanket serves to concentrate, trap, and settle out suspended solids particles before they are discharged over the effluent weir. The primary difference between the solids contact unit and the upflow clarifier is that the latter neither recirculates sludge nor maintains a high rate of mixing within the unit. Upflow clarifiers are rarely used for any process except clarification.

(3) Upflow Solids Contact Units. This combination unit uses high rate rapid mixing and sludge recirculation as shown in figure 6-9. The recirculated settled sludge provides additional particles that increase the probability of particle contact and forms a dense sludge blanket. The sludge blanket concentrates, traps, and settles out suspended particles and floc before they are discharged over the effluent weir. Upflow solids contact units use continuous removal of solids and are effectively used in softening as well as clarification processes.

(4) Operation:

(a) Water Rate Control. The water rate should be controlled to provide low velocities at the effluent weirs to keep solids carryover and short circuiting to a minimum.

(b) Chemical Feed. The chemicals must be accurately dosed. In solids contact units, chemicals should be added to the mixing zone in such a way that the coagulation process occurs in the presence of previously formed floc.

(c) Sludge Removal. Continuous removal of solids should be practiced for upflow solids contact units. A steady level of solids is usually maintained in the reaction zone to control the operation of the solids contact units. Sludge removal in upflow clarifiers can be on an intermittent basis. In both units, the sludge blanket levels must be kept at a minimum of 5 feet below the water surface. Sludge is removed from either unit by opening a valve at the lower extremity of the unit and withdrawing sludge by gravity or pumping.

6-32. Direct Filtration. Some raw water sources with low turbidity (15 turbidity units (TU) or less) can be filtered without going through a separate sedimentation process. Coagulation and filter aid chemicals are applied directly before the water is introduced to the filters. The filter removes the suspended solids and colloids by providing the required contact surface and detention time. The benefits of direct filtration of good quality raw waters include lower chemical requirements and less sludge to be handled.

6-33. Residue Characteristics. Aluminum hydroxide and ferric hydroxide are the primary solids produced during the coagulation, flocculation, and sedimentation process. Entrained among these hydroxide precipitates will be naturally occurring suspended sediment usually found in turbid waters. The sludge is stable (doesn't undergo active decomposition), has a pH between 6 and 8, and is primarily of inorganic composition. The solids concentration usually associated with sedimentation sludges vary between 0.1 to 2.0 percent. Hydroxides are poor filtering sludges and usually have a high bacterial count due to the organic matter present in the raw water source. Treatment and disposal methods for these residues are discussed in section K.

6-34. Coagulation, Flocculation, and Sedimentation Equipment Maintenance. Maintenance procedures for

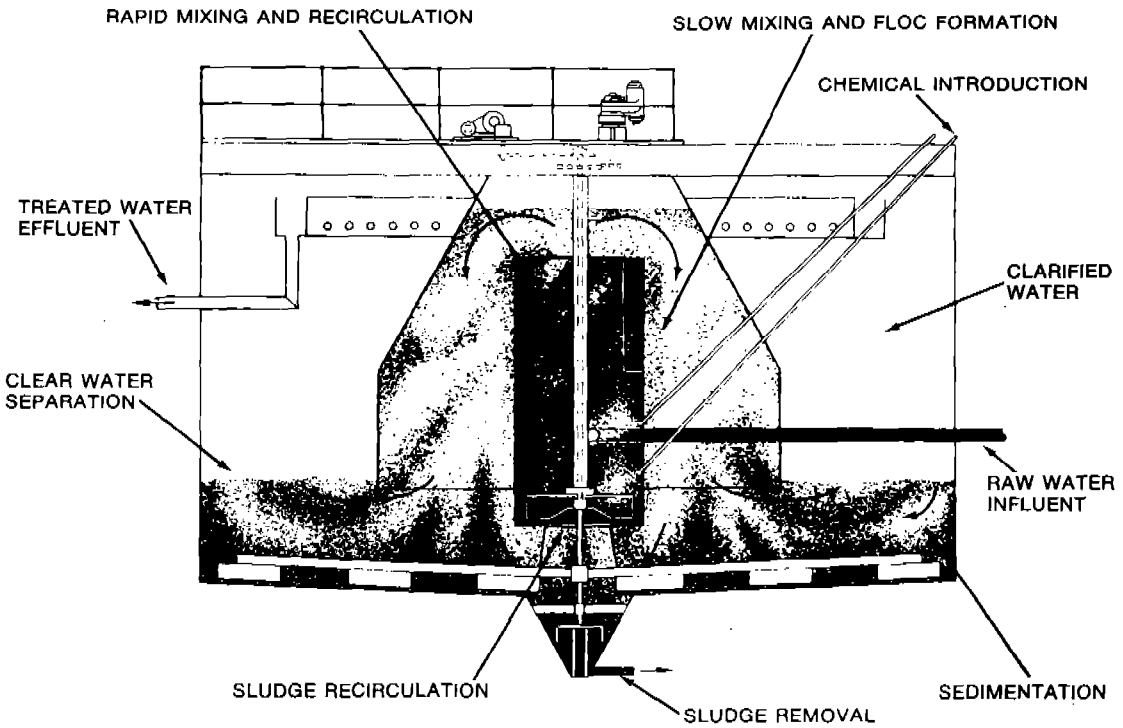


Figure 6-9. Upflow Solids—Contact Clarifier.

coagulation, flocculation, and sedimentation equipment are summarized in table 6-5.

a. Chemical Feed Equipment. Chemical feeder maintenance is discussed in section I.

b. Dust Collecting Equipment. Dust collecting equipment maintenance is discussed in section I.

c. Rapid Mix Equipment. Because rapid mix devices revolve at great speed, do not attempt to check the rotation of the mixer paddles during operation, except by visual observation. When the mixing basin is empty, the condition of the paddles, bearings, drive shaft, and motor should be checked, cleaned, lubricated, and painted as necessary.

d. Rapid Mix Basins. Mixing basins, whether baffled or mechanically stirred (rapid or flash), require attention and cleaning twice a year.

(1) After draining, wash down the walls with a hose and flush the sediment to the drain. Repair spalled spots on walls or bottom, as necessary.

(2) Check the valves or sluice gates for corrosion and ease of operation; clean and lubricate; and paint valves as necessary.

(3) After cleaning the walls and bottom of baffled mixing basins, brush the baffles and repair as necessary.

e. Flocculator Basins. The following procedures apply:

(1) During operation, check paddle rotation each month to make sure that all flocculators are operating. Lower a light pole (bamboo fishing rod) into the water until the paddles strike the pole, giving evidence of paddle operation. Inoperative paddles may be caused by broken shafts or chains.

(2) Twice a year, drain and clean the basin, walls, and floor; inspect the flocculator mechanism, the drive, bearings, gears, and other mechanical parts; and clean and lubricate. Especially check underwater bearings for silt penetration. Replace scored bearings. Paint mechanism parts, where necessary.

f. Sedimentation Basins. All types of settling basins require the same basic maintenance (such as lubrication, cleaning, flushing, and painting). Basins that incorporate proprietary mechanisms or devices must be maintained according to the manufacturer's instructions.

(1) Tank Equipment Annual Inspection:

(a) Check bolts and tighten nuts to maintain original alignments and adjustments.

(b) Check for excessive wear of moving parts, including gears.

(c) Flush and backblow sludge withdrawal line, using high pressure or compressed air.

NOTE: Do not allow waterline to be cross-connected to the drinking water supply system.

(d) Check the plows or rakes and straighten them as necessary.

(e) Check the motor condition, couplings, and service shear pins.

(f) Clean equipment and paint as necessary.

(2) Nonmechanically Cleaned Sedimentation Basins. Clean at about 3-month intervals, or when development of an odor or rising floc particles indicate development of septic sludge conditions. Basins with mechanical equipment for removing settled sludge usually clean themselves satisfactorily during normal operations. However, it may be necessary at times to drain them, and to clean the tank and mechanism with a high-pressure water hose.

(3) Lubrication Requirement. Regular lubrication is required when the basin is in continuous operation. Intermittent operation affects the lubrication schedule, making

Table 6-5. Maintenance Procedures for Coagulation, Flocculation, and Sedimentation.

Inspection	Action	Frequency[1,2]
Rapid-mix basins	Drain, wash down walls, flush sediment to waste line; repair spalled spots on walls and bottom; check valves or sluice gates, lubricate and paint as necessary.	SA
Baffled mixing chambers	Clean baffles and repair as necessary	SA
Flocculator basins	Check paddle rotation to ascertain if any flocculators are inoperative.	M
	Clean and lubricate drive, bearings, gears, and other mechanical parts; check underwater bearings for silt penetration; replace scored bearings.	SA
Rapid (or flash) mixers	Check paddles; clean bearings and drive shaft; lubricate and paint as necessary.	SA
Revolving-sludge-collector basins.	Drain tank, check submerged parts	SA
Operating parts	Lubricate	D or W
Speed reducers and oil baths.	Remove water and grit; replace oil as necessary.	W
Drive head	Lubricate—do not overlubricate	D
Worm-gear	Check oil level	W
	Drain water from housing	M
Turntable bearings	Lubricate	M
	Change oil	SA
Chains	Drain off water, add oil as necessary	M
	Change oil	SA
Annular ball bearings	Lubricate	D
Center bearings, shaft bearings, bushings, etc.	See manufacturer's instructions	V
Tank equipment	Tighten bolts and nuts; check for excessive wear; flush and backblow sludge line; check motors, couplings, and shear pins; check rakes; clean and paint equipment.	A
Conveyor-type-collector basins.	See above, and consult manufacturer's instructions.	V
Upflow or solids-contact clarifier	See manufacturer's instructions	V

[1]D-Daily; W-Weekly; M-Monthly; SA-Semiannually; A-Annually; V-Variable, as conditions may indicate.

[2]The frequencies shown are suggested frequencies which may be modified by local command, as individual installation conditions warrant.

it possible to increase the interval between lubrication periods. If operating periods are intermittent and infrequent, the mechanism must be operated briefly between operating periods, and lubricated accordingly. Devices subject to wide seasonal temperature variations must have seasonal changes in lubricant grades, especially when summer grade oils thicken at lower temperatures and reduce the flow capability. Daily or weekly lubrication of operating units is part of the operator's inspection. The choice of lubricant and its frequency of application are established by the manufacturer or by local command. The following items, where they exist in the equipment, require attention on a regular basis, as explained in the following paragraphs.

(a) The speed reducer should be inspected each week to make sure that the oil is at the proper level, is free of water and grit, and is of a suitable viscosity. If a reducer runs hot during its operation, the oil level may be too high or too low. When the reducer is out of service for extended periods, make sure that it is filled completely to prevent seals from drying out. Replace oil when necessary.

(b) The drive head should be lubricated each day, and care taken not to overlubricate.

(c) The worm gear oil should be checked at least once a week, and water drained from the housing each month.

(d) The turntable bearings should be lubricated at monthly intervals, and the oil changed twice a year.

(e) Lubrication procedures for chains depend on the design of the chain and chain guard. Inspect them each month and add oil as necessary; drain off the accumulated oil as necessary. Change the oil twice a year.

(f) Annular ball bearings and thrust bearings are

generally lubricated each day and inspected each month for condition of lubrication.

(g) Center bearings, shaft bearings, bushings, etc., are lubricated according to the manufacturer's instructions.

(4) Overload Alarm. If the equipment has an overload alarm, check it for operation. If the alarm sounds at any time, shut off the equipment, locate the source of trouble, and rectify the situation. Under no condition should the alarm switch be nullified to provide continuous operation under overload conditions. If the overload is caused by a sludge buildup leading to cut-out of the starter switch or pin shearing, the tank must then be drained and the sludge flushed out.

g. Upflow Clarifiers and Solids Contact Unit. These are all proprietary items, and must be maintained according to the manufacturer's instructions. Those devices that use rotating parts have motors and gears that require maintenance.

(1) Operator Inspection. Check for leaks in valves and piping each month. Make sure that sludge valves function properly. Also check time clock and other accessories that control sludge valve operation.

(2) Cleaning Maintenance. Drain unit, clean, and inspect wearing parts twice a year. Remove encrustation where it may interfere with operating parts; follow the manufacturer's instructions in this operation. Check chemical feedlines to make sure that they are not clogged and are in good condition.

6-35. Records Requirement. In addition to recording the quantities of chemicals fed and the quantity of water treated on the daily operating log (paragraph 6-29e), the following information should be recorded:

a. Chemical feeder set points and times of change.

b. Results of laboratory and plant control tests.

c. Quantity of sludge removed from sedimentation basins.

Section E—Softening

6-36. General Information. Waters that require a large amount of soap to produce a lather and that also produce scale in hot water pipes, heaters, and boilers where the water temperature is increased is considered hard. Water hardness varies considerably from place to place, but waters are commonly classified in terms of hardness (expressed as mg/l (ppm) calcium carbonate ($CaCO_3$)) as shown in table 6-6. Softening is the term applied to water treatment processes that remove the hardness causing constituents. A final water hardness of 80 to 100 mg/l is desirable for domestic use.

a. Need for Softening. Although water softening is not a requirement for potable water, it can usually be justified from an economic and aesthetic standpoint. Economic considerations include savings in soap and longer life of boilers, water heaters, etc., as a result of reducing scale deposition. Soft water greatly reduces skin irritations from bathing and shaving, eliminates the unsightly "bathtub ring" and is generally aesthetically pleasing for personal use. On the other hand, zero hardness water is not desirable for domestic uses, because it can be highly corrosive to pipes and containers and because some people object to the slippery, oily feeling it leaves on the skin after bathing.

Table 6-6. Hardness Classification of Water.

Hardness Expressed as $CaCO_3$	Classification
0-75 mg/l	Soft
75-150 mg/l	Moderately Hard
150-300 mg/l	Hard
>300 mg/l	Very Hard

b. Causes and Sources of Hardness:

(1) The primary cause of hardness is the divalent metallic cations of calcium (Ca^{+2}) and magnesium (Mg^{+2}). Strontium, ferrous iron, and manganous ions also cause hardness, but are usually present in such small quantities as to be negligible as compared to calcium and magnesium. These divalent cations react with soap to form precipitates and with anions already present in the water to form scale.

(2) The hardness in water comes primarily from contact with soil and rock formations. As rainwater seeps through the soil layer it picks up carbon dioxide released by bacterial action. This creates an acidic water which, on contact with limestone, dissolves the calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$) which makes up the bulk of the limestone. These enter the water as bicarbonates (HCO_3^-) and calcium and magnesium ions. The limestone also contains noncarbonate minerals and these are also dissolved, which cause other anions besides bicarbonates such as sulfates (SO_4^{-2}), chlorides (Cl^-), and silicates (SiO_3^-). The hard water is a mixture then of primary magnesium and calcium cations and a mixture of anions.

(3) Generally, high hardness waters are found in areas with a thick topsoil above a limestone strata. Soft waters are found in areas where the topsoil layer is thin and limestone formations are negligible or absent.

c. Types of Hardness. Hardness is classified in two ways. These classes are (with respect to the metallic ions and with respect to the anions associated with the metallic ions):

(1) Carbonate and Noncarbonate. Carbonate hardness is caused by dissolved calcium or magnesium carbonate and bicarbonate in the water. Carbonate hardness is hardness that is chemically equivalent to the alkalinity. Most of the alkalinity in natural waters is due to the bicarbonate and carbonate ions. Noncarbonate hardness is caused by calcium and magnesium compounds of sulfate, chloride, or silicate that are dissolved in the water. Noncarbonate hardness is equal to the total hardness minus the carbonate hardness.

(2) Total Hardness. The total hardness in the water is composed of calcium and magnesium hardness. Generally, chemical analyses are performed to determine the total

hardness and calcium hardness present in the water. It is then assumed that the magnesium hardness is equal to the total hardness minus the calcium hardness, all terms being expressed as equivalent concentrations of calcium carbonate.

		Example No. 1	2	3
Given:				
Total Hardness	(mg/l as $CaCO_3$)	300	300	300
Calcium Hardness	(mg/l as $CaCO_3$)	200	150	250
Total Alkalinity	(mg/l as $CaCO_3$)	200	300	400
Find:				
Carbonate Hardness	(mg/l as $CaCO_3$)	200	300	300
Noncarbonate Hardness	(mg/l as $CaCO_3$)	100	0	0
Magnesium Hardness	(mg/l as $CaCO_3$)	100*	150	50

* May be associated with either carbonate or noncarbonate forms.

d. Units of Expression. Hardness and alkalinity are typically expressed in terms of equivalent calcium carbonate ($CaCO_3$) concentrations. Carbon dioxide is generally expressed as mg/l CO_2.

(1) Equivalent Calcium Carbonate. The concentration of an element or compound as equivalent calcium carbonate is defined as the mg/l concentration of the element or compound times the ratio of the equivalent weight of calcium carbonate to the equivalent weight of the element or compound. The equivalent weight of a compound is calculated by dividing the molecular weight of the compound by the valence of the cation in the compound.

(2) Example. Express a 45 mg/l concentration of $MgSO_4$ as equivalent $CaCO_3$.

(a) $CaCO_3$ has a molecular weight of 100, and calcium has a valence of +2 in this compound, so the equivalent weight of $CaCO_3$ = 100/2 = 50 mg/l.

(b) $MgSO_4$ has a molecular weight of 120.4, and magnesium has a valence of +2 in this compound, so the equivalent weight of $MgSO_4$ = 120.4/2 = 60.2 mg/l.

(c) The concentration of $MgSO_4$ as equivalent $CaCO_3$ = 45 mg/l x 50/60.2 = 37.4 mg/l.

e. Method of Softening. The softening of domestic water supplies is done either by chemical precipitation or ion-exchange processes:

(1) Lime-Soda Ash Process (Chemical Precipitation). The lime-soda ash process is the most common process of softening by precipitation. Lime and soda ash are added to raw water, and the softening reaction occurs during mixing and flocculation; the precipitated calcium and magnesium compounds are removed during sedimentation. Calcium precipitates as calcium carbonate and magnesium as magnesium hydroxide ($Mg(OH)_2$). An additional step, called recarbonation, is frequently provided within the process to lower the pH and stabilize the treated water and reduce deposition of calcium carbonate in filters and piping. Filtration must follow chemical precipitation softening processes to remove the floc carryover from the softeners. The minimum theoretical hardness of the treated water is 30 mg/l or greater, due to the inherent solubilities of magnesium and calcium compounds. This chemical precipitation process is economically practiced at large water treatment plants. Lime softening can effectively remove arsenic (valence +5), barium, cadmium, chromium (valence +3), fluoride, lead, silver, turbidity, radionuclides, manganese, and zinc. Some dosage of pH adjustment may be needed for most effective removal.

(2) Ion Exchange. The ion exchange process exchanges sodium and sometimes hydrogen for the hardness producing calcium and magnesium ions as the water is passed through a bed of cation exchange media (such as sodium zeolite). Water containing zero hardness can be produced with ion exchange process. The relatively greater expense involved with the ion exchange process limits is suitability to small municipal water plants, private home use, industrial applications, and areas treating waters with very high noncarbonate hardness. As shown in tables 2-3 and 2-4, certain types of ion exchange medium can remove arsenic (valence +5), barium, cadmium, chromium, fluoride, nitrate, selenium, radionuclides, copper, iron, manganese, sulfates, and zinc.

CAUTION: The addition of sodium to the water supply during the softening process can be hazardous to persons with hypertension or on low- or no-sodium diets.

6-37. Lime-Soda Ash Process of Water Softening:

a. Chemicals:

(1) Quicklime (Calcium Oxide) (CaO):

(a) Quicklime is a product of burned limestone and consists primarily of calcium and magnesium oxides. Quicklime is available with various degrees of impurities in various forms ranging from large lumps to fine pulverized granules. Calcium oxide is available in purities of approximately 88 or 90 percent by weight. Quicklime is slaked (hydrated) and is then usually diluted to form milk-of-lime for water application. In the slaking chamber, a controlled amount of water is added to quicklime (as chemically shown below) to create a liquid suspension called slaked lime (calcium hydroxide) whose consistency varies with the slaking process employed (f(1) below):

$$CaO + H_2O = Ca(OH)_2 + Heat$$
Quicklime + Water = Slaked Lime + Heat

(b) Contact with quicklime may cause skin burns or other inflammatory injuries. Protective clothing, gloves, goggles, respirators, and face shields should be provided to persons handling lime materials. Lime burns heal very slowly and immediate treatment is mandatory to avoid prolonged discomfort.

(2) Hydrated Lime (Calcium Hydroxide ($Ca(OH_2)$)). Hydrated lime (slaked lime) is a very fine powder resulting from the addition of precise amounts of water to quicklime. The available calcium oxide content of hydrated lime is approximately 68 percent by weight due to dilution with the makeup water. Hydrated lime does not need further slaking. It is usually diluted with makeup water to form milk-of-lime which is then added to the water to be treated.

(3) Soda Ash (Sodium Carbonate (Na_2CO_3)). Soda ash is a grayish-white powder with a purity of 98 percent or

better. It is noncorrosive and may be stored in ordinary steel or concrete bins. Conventional dry feeders may feed this chemical with the resulting solution transmitted through conventional pipelines or troughs. The hazards are those of any chemical dust, and protective clothing devices (such as gloves, respirators, and goggles) should be provided. Soda ash can be shipped in bulk, bags, or barrels.

(4) Caustic Soda (Sodium Hydroxide (NaOH)). Caustic soda is sometimes used instead of soda ash in the lime-soda process. The caustic soda precipitates carbonate hardness and reacts to form soda ash that precipitates the noncarbonate hardness. Caustic soda may not only be used in place of soda ash but actually as a substitute for part of the lime requirement of the raw water. The economics of using the more expensive caustic soda as a replacement for the soda ash depend on the raw water mineral content and relative costs for each treatment chemical. A 50 percent liquid solution of caustic soda is generally used in water treatment to facilitate handling and feeding. Because concentrated caustic soda has a pH of approximately 13, appropriate safety measures should be followed.

(5) Carbon Dioxide (CO_2). Carbon dioxide (CO_2) is often used to lower the pH between softening stages and to stabilize the treated water to prevent deposition of calcium carbonate.

(a) Carbon dioxide is available as a compressed gas, a solid (dry ice), or as a solution in water (carbonic acid). Carbon dioxide is usually used as a gas. The liquid carbon dioxide is generally stored in large tanks before being vaporized. The gaseous carbon dioxide is then bubbled into the water to be treated by using diffusers or is fed in solution form with the use of vacuum operated feeders quite similar to modern chlorinators.

(b) Some water treatment plants with softening facilities prefer the economics of generating carbon dioxide on site by burning fuel.

(c) Carbon dioxide forms carbonic acid in a moist environment and should be handled with corrosion resistant materials.

(6) Sodium Aluminate ($Na_2Al_2O_4$). Sodium aluminate is not a softening chemical, but its use as a coagulant in place of alum may significantly reduce lime and soda ash requirements for softening. Less lime is needed because alum tends to decrease the pH, while sodium aluminate raises the pH.

b. Chemical Reactions. The following chemical reactions take place in a typical water that contains both carbonate and noncarbonate hardness as well as free carbon dioxide.

(1) Free Carbon Dioxide (Lime Addition). Although carbon dioxide is not a hardness constituent, it must be neutralized before the other reactions can proceed. In certain waters with higher carbon dioxide concentrations, it may be more economical to remove carbon dioxide by aeration before softening. Free carbon dioxide reacts with slaked lime to form a calcium carbonate precipitate according to the following equation:

$$CO_2 + Ca(OH)_2 = CaCO_3 + H_2O$$

Carbon Dioxide + Slaked Lime = Calcium Carbonate Precipitate + Water

(2) Calcium Carbonate Hardness (Lime Addition). All calcium associated with alkalinity (generally in the form of bicarbonate (HCO_3) ions) is carbonate hardness and is removed through direct use of lime according to the following equation:

$$(Ca^{++} + 2HCO_3^-) + Ca(OH)_2 = 2CaCO_3 + 2H_2O$$

Calcium Bicarbonate + Slaked Lime = Calcium Carbonate Precipitate + Water

(3) Magnesium Carbonate Hardness (Lime Addition):

(a) All magnesium associated with alkalinity (generally in the form of bicarbonate ions) is termed magnesium carbonate hardness and can be removed through the direct use of lime according to the following equation:

$$(Mg^{++} + 2HCO_3^-) + 2Ca(OH)_2 = Mg(OH)_2 + 2CaCO_3 + 2H_2O$$

Magnesium Bicarbonate + Slaked Lime = Magnesium Hydroxide Precipitate + Calcium Carbonate Precipitate + Water

(b) Note that twice as much lime is needed for removal of magnesium carbonate hardness as for calcium carbonate hardness.

(4) Calcium Noncarbonate Hardness (Soda Ash Addition). When calcium is associated with sulfate, chloride, or silicate ions, it is termed calcium noncarbonate hardness and can be removed only through the use of soda ash (Na_2CO_3) according to the following equation:

$$(Ca^{++} + SO_4^=) + Na_2CO_3 = CaCO_3 + (2NA^+ + SO_4^=)$$

Calcium Sulfate or Chloride, etc. + Soda Ash = Calcium Carbonate Precipitate + Sodium Sulfate or Chloride, etc.

(5) Magnesium Noncarbonate Hardness (Lime and Soda Ash Addition). All magnesium associated with sulfate, chloride, or nitrate ions is termed magnesium noncarbonate hardness and can be removed only by adding both lime and soda ash according to the following equations:

$$MG^{++} + SO_4^=) + Ca(OH)_2 = Mg(OH)_2 + (Ca^{++} + SO_4^=)$$

Magnesium Sulfate or Chloride, etc. + Slaked Lime = Magnesium Hydroxide Precipitate + Calcium Sulfate or Chloride, etc.

$$(Ca^{++} + SO_4^=) + Na_2CO_3 = CaCO_3 + (2Na^+ + SO_4^=)$$

Calcium Sulfate or Chloride, etc. + Soda Ash = Calcium Carbonate Precipitate + Sodium Sulfate or Chloride, etc.

NOTE: The first equation shows the removal of magnesium noncarbonate hardness by lime, but the water is not softened since calcium noncarbonate hardness is merely substituted for the magnesium noncarbonate hardness.

The second equation illustrates the removal of the calcium noncarbonate formed in the first equation.

(6) Recarbonation. Depending on the softening process variation, the treated water usually has a pH of 10 or more and tends to deposit hard calcium carbonate scale on filter sand, distribution piping, and private home piping. Recarbonation is typically practiced to reduce the pH of the treated water to approximately 8 to prevent further calcium carbonate precipitation and to neutralize and precipitate excess calcium hydroxide after the first stage of treatment of high magnesium waters. General equations to determine carbon dioxide requirements for stabilization of softened waters are given in d(3) below.

(a) After selective calcium carbonate removal in low magnesium waters, the treated water is supersaturated with calcium carbonate and has a pH of 10.2 to 10.6. Carbon dioxide combines with the unprecipitated carbonate ion to form soluble bicarbonate as shown in the following equation:

$$(Ca^{++} + CO_3^{=}) + CO_2 + H_2O = (Ca^{++} + 2HCO_3^{-})$$

Calcium Carbonate in Solution	+	Carbon Dioxide	+	Water	+	Calcium Bicarbonate in Solution

NOTE: Sufficient carbon dioxide should be added to reduce the pH to 8.4 to 8.6.

(b) When magnesium removal is required, excess lime must be added to raise the pH above 11 to precipitate magnesium hydroxide (Mg(OH)2). In this case, carbon dioxide must be added to neutralize the excess hydroxide ions in addition to the carbon dioxide needed to convert the carbonate ion to bicarbonate. Calcium carbonate forms at a pH of 9.5 or above, as shown in the following first equation. As addition carbon dioxide is added, the pH is further decreased and redissolves the calcium carbonate to form calcium bicarbonate, as shown in the second equation below. The second step is used to lower the pH to 8.4 to 8.6:

$$(Ca^{++} + 2(OH)^{-}) + CO_2 = CaCO_3 + H_2O$$

Calcium Hydroxide in Solution	+	Carbon Dioxide	=	Calcium Carbonate Precipitate	+	Water

$$CaCO_3 + H_2O + CO_2 = Ca^{++} + 2(HCO3)^{-}$$

Calcium Carbonate Precipitate	+	Water	+	Carbon Dioxide	=	Calcium Bicarbonate in Solution

NOTE: In two stage excess lime softening, carbon dioxide is often added between the stages to lower the pH to about 9.5. The excess lime precipitates as calcium carbonate in the second stage. In single stage excess lime treatment, enough carbon dioxide is added to drop the pH to 8.4 to 8.6 and redissolve the calcium carbonate as shown in the reactions above.

(7) General Observations:

(a) Calcium is always removed as calcium carbonate. The optimum pH for calcium carbonate precipitation is 10.2 to 10.6, depending on temperature.

(b) Magnesium is always removed as magnesium hydroxide. The optimum removal occurs at pH 11.0 or higher. Some excess lime (greater than that needed for the chemical precipitation reactions) is needed to raise the pH to this level.

(c) Magnesium hardness should be kept below 40 mg/l to keep scaling in hot water tanks and boilers to a minimum.

(d) Soda ash is required for noncarbonate hardness removal. Because soda ash is much more expensive than lime, the least amount of noncarbonate hardness should be removed for maximum economy.

(e) Water that is totally free of hardness cannot be produced by the lime-soda ash method of water softening because of the solubility of magnesium hydroxide and calcium carbonate. In addition, both magnesium hydroxide and calcium carbonate tend to form supersaturated solutions. It is also impractical to allow sufficient detention times that allow reactions to proceed to equilibrium, or that allow complete settling of the precipitates. Therefore, waters softened by the lime-soda ash process usually have hardnesses from 50 to 80 mg/l.

c. Process Variations:

(1) Single Stage with Recarbonation (Calcium Hardness Removal Only). Quite often, this process is preceded by aeration to remove free carbon dioxide, thereby reducing lime requirements. Next, lime is combined with raw water in a rapid mix chamber, resulting in a pH of 10.2 to 10.6. Soda ash is added in the rapid mix changer if removal of noncarbonate hardness is required. The water is then gently mixed for 40 to 60 minutes to allow small indiscrete particles to agglomerate. The heavier agglomerated particles are then introduced to a sedimentation basin for 2 to 3 hours, where most of the precipitates and suspended solids are removed. The lime treated water, with some particles still in suspension, is passed into another chamber where carbon dioxide is added to adjust the pH to 8.4 to 8.6 and reduce the water's scale forming tendencies. The final step in the single stage process involves the use of sand or multimedia filtration to capture remaining suspended solids and produce a sparkling, clear effluent. If the treated water is nonrecarbonated or phosphated (paragraph 7-21) before filtration, the water would deposit a calcium carbonate scale on the filter media. Scale buildup causes the filtration process to become progressively inefficient and eventually will require replacement of the filter media. A typical plant arrangement for single stage softening with recarbonation is shown in figure 6-10.

(2) Two Stage with Recarbonation (Calcium and Magnesium Hardness Removal). This process may also use aeration to remove carbon dioxide. Addition to 50 mg/l or more of excess lime in the first stage raises the pH to 11.0 or higher for optimum magnesium removal. Following first stage treatment, carbon dioxide is added to reduce the pH to the optimum value for calcium removal (10.2 to 10.6). Soda ash is added in the second stage, if necessary, to remove calcium and magnesium noncarbonate hardness. The softened water is recarbonated to a pH of about 8.2 to 8.6 for scale and corrosion control. In some cases,

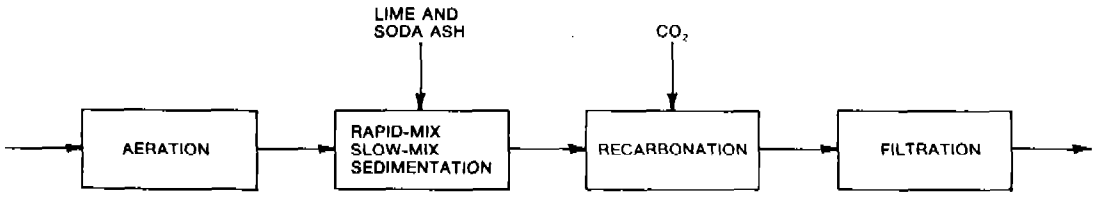


Figure 6-10. Typical Plant Arrangement for Single-Stage Softening With Recarbonation.

phosphate addition may also be practiced to control scale and corrosion. Filtration to remove residual suspended solids follows second stage recarbonation. A typical plant arrangement for two stage softening with recarbonation is shown in figure 6-11.

(3) Split Treatment. After aeration, the flow is split, with one portion receiving excess lime treatment for magnesium removal. This softened water is then combined with bypassed water which lowers the pH to a desirable level for calcium removal in the second stage. In the second stage, soda ash (if needed for noncarbonate hardness removal) is added to the combination of split flows in typical mixing and sedimentation chambers, followed by recarbonation to control deposition. Polishing is accomplished on the final filter. Split treatment can be successfully practiced for certain combinations of calcium and magnesium hardness. It offers savings in chemical costs because it reduces lime requirements and usually eliminates the need for recarbonation between the first and second stage softening steps. A typical plant arrangement for split treatment softening is shown in figure 6-12.

d. Dosage Determination:

(1) Calculating Lime and Soda Ash Dosage. An analysis must be conducted to determine the carbon dioxide, alkalinity, and calcium and magnesium hardness in the water in order to calculate lime and soda ash requirements for softening. There are many ways for calculating chemical dosages. The following methods are simple; they give correct results for most hardwaters. The carbon dioxide content in the equations below are expressed as mg/l of carbon dioxide, while alkalinities and hardness are expressed in terms of mg/l of equivalent calcium carbonate ($CaCO_3$) (paragraph 6-36d).

(a) To calculate lime requirements for carbonate hardness and magnesium removal, use the following formula: Pounds of 100 percent quicklime (CaO) per million gallons of raw water = (10.6 × mg/l CO_2) + (4.7 × mg/l alkalinity) + (4.7 × mg/l magnesium hardness) + 292; where 292 is the pounds of excess lime required to raise the pH to greater than 11 (based on the addition of 35 mg/l of excess lime for pH adjustment) for optimum magnesium removal. If magnesium removal is not required, this should not be used.

(b) To calculate soda ash requirements for noncarbonate hardness removal, use the following formula: Pounds of 100 percent soda ash (Na_2CO_3) per million gallons of raw water = 8.8 x (mg/l noncarbonate hardness −y); when y is the mg/l of noncarbonate hardness to be left in the treated water (usually about 50 mg/l as $CaCO_3$). NOTE: These formulas are based on pure chemical compounds. The results from the first formula should be divided by the percentage CaO present in the lime used and multiplied by 100. If the exact analysis of quicklime is unknown, the results may be divided by 0.88, and, for hydrated lime, by 0.68. Commercial soda ash in the second equation need not be corrected for purity because it is usually 99 to 100 percent pure.

(2) Dosage Test. It is well to check the calculations for lime and soda ash requirements by actually adding the calculated dosage to small measured quantities of the water to be treated and analyzing the treated water. The following procedures are found convenient:

(a) Prepare a standard lime suspension by adding 10 grams of slaked or hydrated lime, $Ca(OH)_2$, to 1 liter of distilled water. If quicklime is used, mix it thoroughly with just enough water to make a boiling solution, then dilute to 1 liter. A standard solution of soda ash is prepared the same way. The addition of 1 ml of the standard solution to 1 liter of water gives a dosage of 10 mg/l.

(b) Place 1 liter of water to be treated in a beaker or jar and add the calculated quantities of lime suspension and soda ash solution needed to soften it. Stir gently for 30 minutes and allow to settle until the liquid becomes fairly clear (usually 10 to 15 minutes).

(c) Siphon off about one-half of the clear solution and filter through filter paper.

(d) Analyze the filtrate for alkalinity and hardness using standard laboratory test procedures.

(e) Determine whether the extent of softening agrees with that expected from the chemical dosage used, considering the residual solubilities of calcium carbonate ($CaCO_3$) and magnesium hydroxide ($Mg(OH)_2$) and other factors discussed in b(7)(e) above.

(3) Calculating Carbon Dioxide Dosage. The quantity of gas required for recarbonation varies with the quantity of water treated, the amounts of carbonate and hydroxide

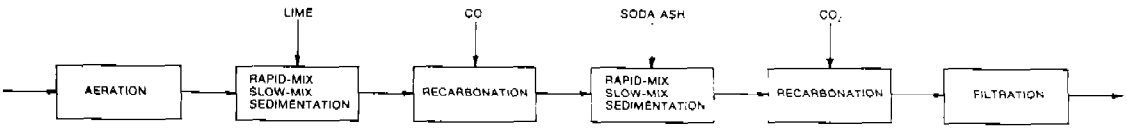


Figure 6-11. Typical Plant Arrangement for Two-Stage Softening With Recarbonation.

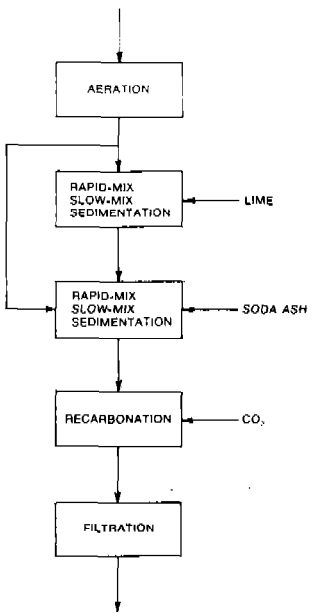


Figure 6-12. Typical Plant Arrangement for Split-Treatment Softening.

alkalinity in the water, and the degree to which recarbonation is to be performed. Approximate dosage can be calculated from the following equation, which depends on the phenolphthalein alkalinity (P-Alk) of the water. The equation will yield the maximum carbon dioxide required to convert all alkalinity to bicarbonate ion:

$$Q = 7.2 \times (P\text{-}Alk)$$

where:

Q = amount of carbon dioxide in pounds per million gallons.

P-Alk = Phenolphthalein alkalinity (the alkalinity measured to the phenolphthalein end point at pH 8.3 and corresponding to the hydroxide plus one-half of the normal carbonates in aqueous suspension).

Field adjustment is necessary to supply proper amounts of carbon dioxide since normal practice allows some carbonate ions to remain in solution. The carbonate alkalinity left in solution provides a slight protective deposit on pipe interiors. Carbon dioxide dosages required to lower the pH after first stage softening will be less than calculated by the above method and will generally be chemically equal to the excess lime added in the first stage.

e. Chemical Storage:

(1) Since soda ash is noncorrosive and relatively safe to handle, it may be stored in containers like barrels or drums without additional undue precautions.

(2) Although quicklime and hydrated lime are not corrosive, extreme care must be taken to keep the storage units watertight and airtight. The chemical storage room should be well ventilated and the containers stored off the ground or in steel watertight storage silos. Quicklime is especially susceptible to humid air and water. Moisture causes the lime to hydrate, thereby releasing heat, and possibly causing a fire or a ruptured container. All flammable material should be kept away from quicklime storage areas due to the heat generated by the accidental slaking of lime. Quicklime deteriorates very quickly in storage. Under good storage conditions, it may last as long as 6 months, but generally should not be stored over 3 months. Hydrated lime, on the other hand, can be stored dry for up to 1 year without resulting in serious chemical deterioration. Hydrated lime has a tendency to air slake and absorb carbon dioxide.

(3) For softening purposes, carbon dioxide may be generated on-site or stored as a bulk purchased liquid. The chief storage hazard is the danger of suffocation if carbon dioxide is released in a room. On-site generation of carbon dioxide by fuel burning may also produce dangerous carbon monoxide gas.

f. Chemical Feeding:

(1) Lime Slaking Equipment:

(a) Paste Type. The paste type of lime slaker (figure 6-13) combines quicklime with water in a paddle agitated compartment to form a paste at near boiling temperature. A gravimetric feeder typically controls the amount of lime discharged into the slaking compartment with a water to lime ration of 2:1 or 2.5:1. The paste oozes over a weir and is sprayed with water. The water spray dilutes the lime to form milk-of-lime and separates heavier grit particles. The milk-of-lime is discharged by a conveyor-elevator system.

(b) Retention Type. The retention type of lime slaker (not shown) uses a higher water to lime ratio (4:1 or 5:1) and a correspondingly cooler slaking temperature and longer contact time. Rotating paddles sweep the accumulated grit out of the active slaking compartment. The water introduced into the slaking compartment is usually warmed by some form of heat exchanger to optimize slaking efficiency.

(2) Dry Chemical Feeders. See section I for further information.

(3) Solution Feeders. See section I for further information.

(4) Recarbonation:

(a) In some plants, carbon dioxide is produced by burning wood, coal, coke, fuel oil, or gas. The burned gas is blown to a diffuser system in the recarbonation chamber.

(b) A more recent method of burning fuel to produce carbon dioxide is an underwater burner. This method burns fuels such as propane with excess air near the bottom of the recarbonation chamber.

(c) Liquid carbon dioxide is purchased in bulk and stored in large pressure tanks. The liquid carbon dioxide is vaporized by evaporators and fed by a diffusion system or by chlorinator-like solution feeders.

g. Process Equipment:

(1) Flocculation and Sedimentation Equipment. Rapid mix equipment, flocculators, and sedimentation basins are discussed in section D.

(2) Upflow Solids Contact Units. All combination flocculation and sedimentation units, except the spiractor, are covered in section D. The spiractor unit, as shown in figure 6-14, is limited to softening operations.

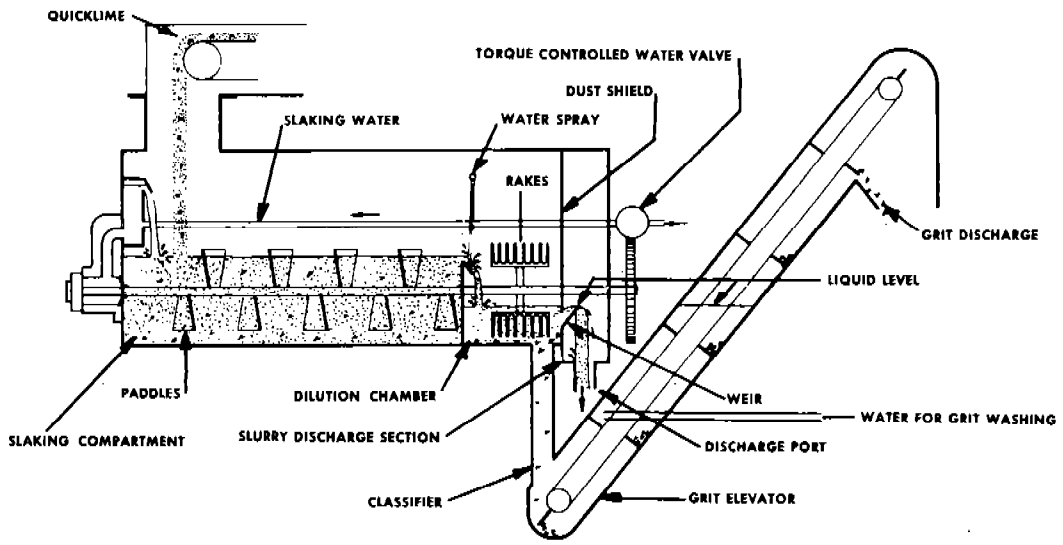


Figure 6-13. Paste-Type Lime Slaker.

(a) The spiractor consists of an inverted conical tank in which the lime soda softening reactions take place in the presence of a suspended bed of fine sand that acts as a catalyst. In operation, the tank is slightly more than half filled with 0.1 to 0.2 millimeter granular sand. Hard water and chemicals enter the bottom of the cone tangentially and close to each other so that they mix immediately as the treated stream of water rises through the granular bed with a swirling motion. The upward velocity keeps the granular material in suspension. As the water rises, velocity decreases to a point where material is no longer in suspension. The contact time, 8 to 10 minutes, is enough to complete softening reactions. Softened water is drawn off from the top of the cone. The precipitated hardness particles attach themselves to the sand granules in the unit. However, the bulk level in the unit is kept down to the desired point by withdrawing the largest particles from the bottom. New catalyst material must be added periodically. It can be produced by regrinding and screening the discharged material. The softened water is usually filtered through a sand filter to remove remaining turbidity.

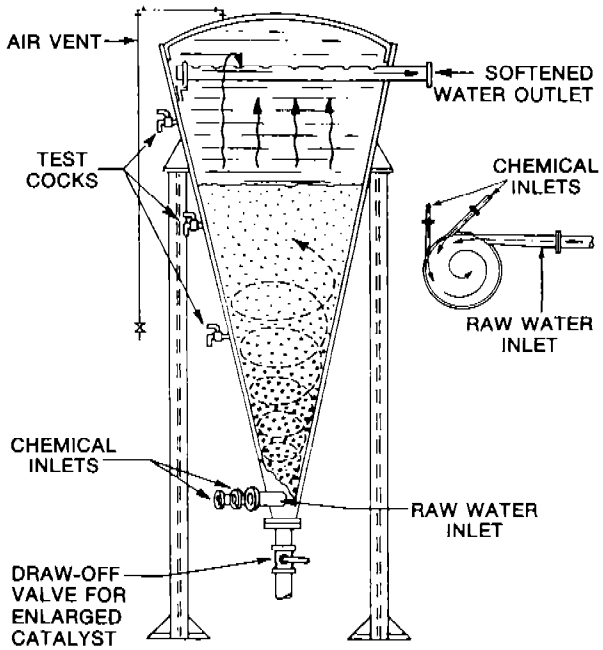


Figure 6-14. Spiractor Precipitator.

(b) Care should be taken to keep the pH low enough to prevent the formation of magnesium hydroxide precipitate. The precipitate does not adhere very well to the sand particles and will leave the spiractor unit, resulting in large solids loadings on the subsequent filter.

(c) Advantages of the spiractor equipment are its small size, low installation cost, rapid treatment, and lack of moving parts and pumping equipment. In addition, the precipitated hardness is withdrawn as sand-like granules, which are much easier to get rid of than the watery slime from the normal lime-soda process. The unit is most effective when hardness is predominately calcium, there is less than 17 mg/l magnesium hardness (expressed as calcium carbonate), water temperature is about 50 °F, and turbidity is less than 5 turbidity units (TU).

(3) Chemical Feeders. Chemical feeders are discussed in section I.

(4) Filtration Equipment. Filters and appurtenances are discussed in section F.

(5) Sludge Removal Equipment. Continuous mechanical sludge removal equipment is used to remove chemical softening precipitates from sedimentation basins. A standard sedimentation basin with scraper boards (as discussed in section D) is commonly used.

h. Characteristics of Residues From Lime-Soda Softening. The residues from lime-soda softening are generally either calcium carbonate ($CaCO_3$) or magnesium hydroxide ($Mg(OH)_2$). Calcium carbonate sludges are generally dense, stable, inert, and relatively pure materials that dry well. The solids of the sludge vary between 2 per-

cent and 30 percent, although 5 is considered typical. The pH is usually very high, in the range of 11.0. Relatively pure calcium carbonate sludge can be easily dewatered to solids contents up to 40 percent or 50 percent. Magnesium hydroxide sluge, on the other hand, is a soupy, gelatinous material that is difficult to handle and very difficult to dewater. The pH characteristics are similar to pure calcium carbonate sludges. Treatment and disposal methods for these residues are discussed in section K.

i. Equipment Maintenance:

(1) Chemical Feeder Maintenance. Dry chemical and solution feeder maintenance is covered in section I.

(2) Lime Slakers. Continuous lime slakers are part of a chemical feed system where quicklime is used for water softening. The following maintenance procedures must be used on this equipment:

(a) Inspection. Each day clean dust removal and vapor removal equipment each shift, and make sure that dust and moisture do not reach the chemical feeding mechanism and cause caking or corrosion. Remove clinkers or grit not removed by regular operations.

(b) Cleaning Maintenance. Each week when the slaker is out of service, clean grit out of each compartment. Wipe off the outside of the slaker with an oily rag. (The thin film of oil prevents the adherence of moisture or lime solution and thus protects paint.) Clean the vapor removal system and check the mechanism for proper functioning. Clean all appurtenances.

(c) Inspection and Repair. Each month check agitators, stirrers, and heat exchangers; replace any impellers on baffles in front of the heat exchanger that show appreciable wear. Inspect and repair, or replace as necessary, all wiring defects or metal deteriorations. Tighten bolts, eliminate vibration, tighten belts, and paint where necessary. Every 1,000 to 1,500 hours, lubricate with grease (do not use oil) the support bearing-drive.

(d) Overhaul. Lime slakers should be overhauled each year. Drain and clean the slaker and dust removal system. Check the slaker bottom and sides for wear and repair as necessary. Paint the exterior and inside top edges of the slaker lids to protect from corrosion. Check for leaks and scale in the heat exchanger. Clean thermometers and check their accuracy. Clean and lubricate all bearings. Repair controls, floats, piping, screens, valves, and vapor removal equipment. Paint all equipment where necessary.

(3) Flocculation and Sedimentation Equipment Maintenance. Mixer, flocculator, and sedimentation basin maintenance is discussed in section D.

(4) Solids-Contact Clarifiers. Solids-contact clarifier maintenance is discussed in section D.

(5) Recarbonation Equipment:

(a) Maintenance of combustion units depends on the equipment used, fuel impurities, effectiveness of scrubber and drier, and materials of construction. Consult the manufacturer's instructions for maintenance of the compressor or blower.

1. Operator Inspection. Each day check burners, compressor, gages, and traps, and adjust equipment to ensure top-level operation.

2. Drier, Scrubber, and Traps. Each month check material in the drier and replace as necessary. Adjust spray and clean out connecting piping; clean gas traps.

3. Corrosion Inspection. Every 6 months inspect all equipment for internal and external corrosion. Repair as necessary, and paint equipment or use protective coatings.

(b) Maintenance of solution feeders and evaporator units will follow the procedures outlined in section H for vacuum operated solution feed chlorinators and liquid chlorine evaporators.

(6) Filter Equipment. Filter maintenance is discussed in section F.

6-38. Ion-Exchange Water Softening:

a. General Information. Many natural and synthetic materials have the ability to exchange cations. Naturally occurring sodium aluminosilicates (zeolites) were the first exchange materials used in water softening, but these have been largely replaced by synthetic organic-exchange resins with much higher exchange capacities. In an ion exchange unit, water softened by passing it through an exchange material where the calcium and magnesium ions are exchanged for some other cation, usually sodium. This cation-exchange process is reversible by a process called regeneration when the exchange media is exposed to a high concentration of the original cation, such as sodium.

b. Factors Affecting Applicability:

(1) Iron, Manganese, and Aluminum Contamination of Exchange Resin:

(a) Iron, in its unoxidized ferrous form, is removed from solution during the ion-exchange process. The unoxidized iron may be removed during the normal backwash cycle. Iron which is oxidized in the exchange materials by dissolved oxygen or chlorine cannot be removed by normal regeneration techniques. The oxidized iron reduces the capacity of the exchange material.

(b) Iron that is oxidized before ion-exchange softening must be allowed to precipitate before reaching the exchange material. Any unprecipitated, oxidized iron will be filtered out by the exchange material, resulting in the reduction of exchange capacity and making regeneration more difficult. Oxidized manganese and aluminum carryover from alum coagulation causes similar difficulties in operation of ion-exchange units.

(c) Normal sodium chloride regeneration does not remove iron, manganese, or aluminum to any appreciable degree, and more exotic methods must be used to affect their removal. If iron, manganese, or aluminum becomes a problem in ion-exchange operation, consult the manufacturer to determine the best removal method for the particular installation.

(2) Turbidity. The ion-exchange softening method is not designed to serve as a filter for removal of suspended solids. Turbidity in water coats the resin particles and reduces the efficiency of the exchange unit. Depending on the degree of turbidity in the raw water, special methods may be required to backwash this material and restore original ion-exchange efficiency. The most practical ap-

proach is to remove turbidity before the ion-exchange.

(3) Oxidizing Agents. Chlorine is the most common oxidizing agent used in water treatment. Depending on the particular resin used, the introduction of chlorine ahead of the ion-exchange unit can swell the resin, cause the ion-exchanging sites to be broken, and reduce the efficiency of the unit. The manufacturer should be consulted concerning the physical limitations for the particular exchange media begin used.

(4) Temperature. Temperatures up to 212°*F* have been applied to synthetic resins without appreciable ill effects. Individual manufacturers should be consulted concerning their exchange resins.

(5) Hydrogen-ion Concentration (pH). Polystyrene resins show no serious limitation on pH of raw water, although pH extremes seriously limit natural zeolite performance.

c. Process Equipment. A typical ion-exchange water-softening unit comprised of softening chamber and salt regeneration equipment is shown in figure 6-15.

(1) Downflow Pressure Type of Exchanger. Most ion-exchange water softeners are of the downflow pressure type where raw water is fed through the top, passed through the exchange media, and withdrawn through the bottom.

(a) Shell Elements. The pressure shell containing the exchange media and associated appurtenances is usually constructed of galvanized steel or lined with plastic to resist the corrosiveness of the regenerating solutions. The shells may be in a vertical or horizontal configuration. Vertical configurations require less space and are the commonly selected arrangement.

(b) Underdrain System. At the bottom of the softener shell is an underdrain system that collects softened water, distributes backwash water, and collects brine and rinse water during regeneration to ensure maximum useful capacity of the zeolite resin.

(c) Gravel Arrangement. Gravel is placed between the zeolite medium and the underdrain to support the ion-exchange material and evenly distribute flows through the material. Gravel is placed in several layers, with the coarse material on the bottom and the finest toward the top. The gravel size depends on the underdrain configuration.

(d) Ion-Exchange Bed. The ion-exchange bed is placed on the supporting gravel and during backwash redistributes itself according to particle size, with the largest closest to the gravel and the finest on top of the bed. Similar to a rapid sand filter, a freeboard space must be maintained between the top of the exchange media during backwashing. The range of bed depth generally used is 20 to 60 inches.

(e) Service-Water Inlet and Wash-Water Collector. One single inlet-outlet serves the double function of distributing the raw water to the bed and collecting the dirty water during backwashing before regeneration. The location of this inlet-outlet is near the upper part of the vessel as shown on figure 6-15. Engineering design is used to evenly distribute raw water over the softening surface and to prevent surface disruption from localized eddies and currents.

(f) Brine-Inlet System. The brine distributor is placed immediately over the softener bed so that brine contacts all parts of the softener surface and penetrates into the bed. Brine is supplied by the wet-salt storage tanks. Occasional monitoring of the spent brine-discharge concentration serves as a check on the efficiency of the regeneration step.

(2) Brine and Wet-Salt Storage Tanks. Depending on the size of installation, the brine and wet-salt storage tanks may take several different forms.

(a) In small installations, a brine tank serves as both a salt and concentrated brine storage tank. During regeneration, freshwater is introduced at the top of the tank while brine is withdrawn from the bottom. Excess undissolved salt in the tank ensures a saturated solution of brine. The saturated brine solution is often diluted to a lower strength before it is applied to the exchange media.

(b) In larger installations, the salt is dissolved in a separate wet-salt storage tank and transferred to a holding tank where it is withdrawn for regeneration purposes. Typical brine feeding requires an eductor to draw solution from the holding tank where it is blended and carried into the softening unit by pressurized water.

d. Softening Capacity of Zeolites. The softening capacities of different exchange media vary. The lower capacity natural zeolite greensand (glauconite) has an exchange capacity between 2,800 and 5,000 grains per cubic foot when regenerated at a level of 0.45 pounds of salt per kilograin of hardness removed. The high capacity synthetic siliceous gel-type zeolites have capacities in the range of 8,000 to 14,000 grains per cubic foot, when regenerated with 0.4 to 0.5 pounds of salt per kilograin of hardness removed. The polystyrene ion-exchange resins have exchange capacities in the range of 28,000 grains per cubic foot, when regenerated with 0.45 pounds of salt per kilograin of hardness removed. Individual manufacturers should be consulted concerning the capacities and limitations of their ion-exchange materials. Several factors outlined below should be considered when the softening capacity of the particular exchange media is less than optimum. Among these are:

(1) Effect of Salt Dosage on Exchange Capacity. The amount of salt used for regeneration is the most important factor in determining the exchange capacity of a softener. Although low-salt dosages result in more efficient use of the brine, the quantity of brine involved in regeneration may become so small that the regeneration flow rate is lowered to the point where turbulence may not be sufficient to prevent stream-lined channeling or short-circuiting of the bed.

(2) Effect of Brine Concentration on Exchange Capacity. Each resin has an optimum concentration of regeneration brine for maximum exchange capacity. Although manufacturer's data should be followed in this matter, a concentration of 12 to 14 percent will usually provide satisfactory regeneration.

(3) Effect of Brine Contact Time on Exchange Capac-

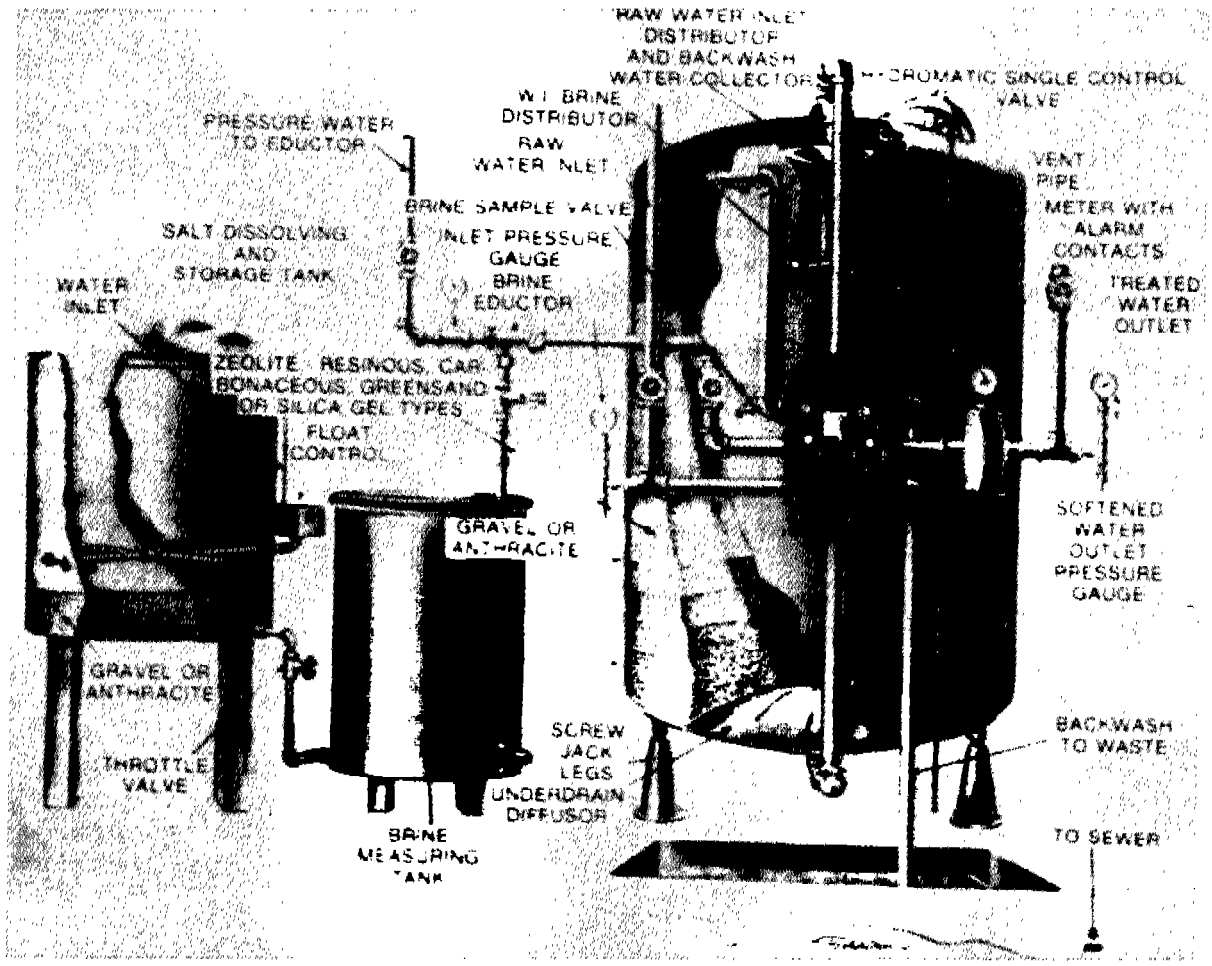


Figure 6-15. Downflow Ion-Exchange Unit for Water Softening.

ity. The brine contact time is the interval between the time the brine passes a point in the bed and the moment at which the rinse water passes the same point. A contact time between 20 and 35 minutes for a 10 to 15 percent brine solution produces good results. This contact time produces a flow rate of about 1 gpm per cubic foot of exchange material. Large flow variations either way of optimum contact time will generally reduce exchange capacity.

(4) Effect of Water Composition on Softener Performance. The chemical composition of influent raw water affects the capacity and hardness leakage of the resin. Hardness alone does not significantly affect the capacity of the resin. However, hardness and sodium together in the raw water compete for the active exchange sites on the resin. If the ratio of the sodium to hardness is low (on the order of 1:1 or less), the resin is not adversely affected. When the sodium-hardness ration approaches 2:1 or greater, the capacity of the resin deteriorates.

(5) Effect of the Service-Flow Rate on Capacity. Ion-exchange reactions are so rapid that high-service flow rates (10 gmp per cubic foot) have little affect on operating capacity of synthetic resins, although a steady flow rate of 2 to 4 gpm per cubic foot maintains a much better hydraulic flow and efficiency. Greensand and other zeolite exchange media should never be operated at high rates. Pressure drop through the exchange bed can affect efficiency, depending on the surface flow rate and temperature of the influent water. If the influent water is low in turbidity, excessive pressure drop should be of little concern.

(6) Effect of Temperature on Performance. A large water temperature change affects backwash expansion, pressure drop, and exchange capacity. Small temperature changes should not significantly affect operation.

(7) Backwash Flow Rate. The softener should be backwashed after each softening cycle to maintain the hydraulic characteristics of the ion-exchange resin. Backwash rates sufficient to expand the resin bed 50 to 75 percent should effectively remove foreign matter. Backwash rates vary with the relative densities of water and resin caused by variation in water temperatures. Seasonal temperature changes may call for an occasional adjustment of the backwash rate to prevent loss of resin or to maintain sufficient flow to keep the bed clean.

e. Operational Cycle. The manufacturer's instructions should be consulted for details of operating specific ion-exchange units. Hardness of the water is tested periodically at the outlet of each softener either manually or as part of the automatic controls. The softener is regenerated whenever the hardness test indicates 1 mg/l or more. If regeneration is delayed, hardness increases rapidly and the nor-

mal regeneration cycle should be run twice to prevent a significant decrease in quantity of water treated and time between regenerations. There are four steps in the ion-exchange softening process.

(1) Backwash. During the softening period, water flowing downward through the exchange bed leaves suspended material on the surface of the bed. As this accumulation grows, the pressure drop across the bed increases and the bed becomes more compact. Therefore, when the exchange bed becomes exhausted, it is necessary not only to regenerate it, but also to backwash it to remove the surface deposit and to ensure efficient regeneration and later operation. Backwashing consists of flowing water upward through the bed at a rate between 6 and 8 gpm per square foot, which causes the bed to expand a specified minimum amount. This permits dirt to be separated from between grains and floated off at the top. It also cleans and loosens the bed so that in the succeeding regeneration step the salt solution can properly contact all the zeolite.

(2) Regeneration. In the course of softening water, the sodium content of the ion-exchange bed is depleted and requires regeneration by passage through a common salt (sodium chloride) solution in order to restore its capacity to remove hardness from water. The sodium of the salt displaces the calcium and magnesium taken up by the bed during the softening step and restores the ion-exchange material to its original condition. The salt solution is fed into the softener above the resin bed and flows downward. The efficiency of this operation is determined by using the proper amount and strength of salt solution, distribution and rate of flow, and time of contact with the bed. The salt solution should be added slowly. For greensand, allow about 5 minutes. For other materials, follow the manufacturer's instructions (usually 15 to 20 minutes).

(3) Rinse. After regeneration, the ion-exchange bed must be rinsed to flush out the excess-salt solution. To do this, water is passed downward through the bed until all traces of salt have been thoroughly washed out. Rinse at rates recommended in the manufacturer's instructions. Ordinarily the rate is about 2 gpm per square foot of bed surface area, with about a 20 minute rinse period. Synthetic resins require a longer rinse time.

(4) Service. After the bed has been regenerated and rinsed, the softening process is resumed by passing raw water downward through the bed at the manufacturer's recommended flow rate, and into the effluent mains. This flow is continued until the bed is again exhausted. At such time, the operational cycle is repeated.

f. Computing Salt Charge for Regeneration. The amount of regenerating salt needed depends on the amount of exchange media in the bed and the softening capacity of the exchanger. Generally, good results are obtained by using about 0.45 pound of salt per 1,000 grains of hardness removed by the exchange media. The regenerating salt solution is prepared as follows:

(1) Prepare a saturated solution of sodium chloride. At 60°F, 1 gallon of saturated solution weighs about 10 pounds and contains about 25 percent salt, or 2.5 pounds. Dilute to a 10 to 15 percent solution with water from the injector that puts the salt solution into the softener.

(2) Calculate the total softening capacity. If a unit has 1,000 cubic feet of exchange media and has a capacity (in terms of $CaCO_3$ removable) of 3,000 grains per cubic foot, total softening capacity = 3,000 × 1,000 = 3,000,000 grains.

(3) If the exchange media being regenerated needs 0.5 pound of salt per 1,000 grains of hardness removed, total salt requirements = 3,000,000 × 0.5 divided by 1,000 = 1,500 pounds.

(4) Compute the gallons of salt solution containing that amount of salt. For example, a 25 percent solution contains 2.5 pounds of salt per gallon. Then, the number of gallons required = 1,500 divided by 2.5 = 600 gallons. The 600 gallons of saturated solution (25 percent) would be diluted to about 10 percent before being fed into the softener.

g. Supplementary Treatment of Ion-Exchange Softened Water. An ion-exchange softener produces water of zero hardness. Since this water does not form a protective coating on distribution piping, oxygen in the water causes rusting of exposed iron. It is therefore desirable to mix or blend the softened water with unsoftened water to get the desired degree of hardness. If the unsoftened water contains so much iron that the final mixture contains more than 0.3 mg/l, the unsoftened water should be aerated and filtered before it is mixed with the softened water. The pH of ion-exchange softened water may be adjusted to make the water less corrosive by adding a caustic silicate solution.

h. Residue Characteristics. The total quantity of brine for regeneration or ion-exchange resins varies from about 2 to 10 percent of the total water treated. The total dissolved solids may be as high as 45,000 mg/l, with a substantial chloride content. There are very few suspended solids from the process. Treatment and disposal of ion-exchange brines are discussed in section K.

i. Equipment Maintenance. Ion-exchange maintenance procedures are described in (1) through (4) below and summarized in table 6-7.

(1) Softener Unit. The softener unit itself has a steel shell (with a supporting grid in the bottom), a layer of gravel, and a layer of ion-exchange resin. The shell is equipped with openings, valves, and fittings.

(a) Shell. Each year the exterior of the shell must be cleaned and brushed with a wire brush, and then painted to protect it against corrosion.

(b) Valves and Fittings. Quarterly, fittings for distributing water and brine must be checked for possible obstructions, corrosion, and security fastness. Each individual valve must be inspected, tested for leaks, and repacked, twice a year if necessary.

(c) Ion-Exchange Medium. Quarterly, flush ion-exchange beds with chlorinated water that contains at least 2 mg/l of chlorine. Do not use water with a hardness greater than 170 mg/l, and be sure that the pH of the water is approximately neutral. Also, follow these directions.

1. Check the bed surface for dirt, fines, organic growths, and smoothness. Scrape excess foreign matter off

Table 6-7. Maintenance Procedures for Ion-Exchange Softening Units.

Inspection	Action	Frequency[1,2]
Softener unit		
Shell	Clean and wire brush; paint	A
Valves and fittings	Check for obstructions, corrosion and fastness	Q
	Check for leaks; repack if necessary	SA
Ion-exchange medium	Check bed surface for dirt, fines and organic growths; remove foreign matter and add resin to desired level.	Q
Gravel	Probe through resin to determine gravel surface; level gravel surface with rake during backwash flow; replace gravel when caked, or if resin is being lost to effluent; wash and grade gravel and place in four separate layers; use new lime-free gravel at discretion of inspector.	Q
Underdrains	Check pressure drop through underdrains; if necessary, remove manifold or plate underdrains; clean and replace.	A or V
Regeneration equipment		
Salt storage unit	Clean tank as necessary to remove dirt	V
Brine tank	Clean out dirt and insolubles; allow to dry; paint both exterior and interior surface.	SA
Ejector	Clean, disassemble, check erosion and corrosion; clear clogged piping; assemble and replace.	A
Operating conditions		
Flow rates	Check rate of flow through bed; adjust controls to optimum rate, depending on type of resin.	Q
Backwash rates	Check rate and adjust controls to optimum rate	Q
Pressure	Check difference between inlet and outlet pressures; if undesirable changes in pressure drop have occurred, seek cause and remedy.	Q
Efficiency	Compare total softening capacity with previous inspection; determine cause of decrease, if any, and remedy situation.	Q
Out-of-service softeners	Drain; keep synthetic resins damp; do not regenerate before draining.	V

[1]Q-Quarterly; SA-Semiannually; A-Annually; V-Variable, as conditions may indicate.

[2]The frequencies shown are suggested frequencies which may be modified by local command, as individual installation conditions warrant.

and replace with new resin. If the surface is not even, the grave bed underneath is not distributing the wash water evenly. The remedy includes removing the resin and gravel, and replacing both in the proper fashion.

2. Check height of ion-exchange bed surface, remove or add ion-exchange resin to maintain proper elevation. (A low elevation allows excess fines and foreign matter to accumulate on the surface of the bed; a high elevation allows resin to be washed out during backwashing.) Extra ion-exchange resin may be added through a 2- to 3-inch half coupling (with brass plug) in the upper head of the shell, or through the manhole cover plate.

3. Replace ion-exchange bed with new resin whenever the inspection indicates the need, or if the exchange capacity has decreased and cannot be restored by cleaning and special procedures recommended by the manufacturer.

(d) Gravel. Quarterly, probe through resin bed to determine the surface of the supporting gravel. The surface should be relatively even, with a maximum difference of 4 inches between high and low spots. Any indication of shifting gravel bed, caking, or other difficulties, calls for repair efforts. Uneven gravel may be raked smooth through the open manhole, during backwashing operation.

1. Gravel Removal. When gravel needs to be removed for one reason or another, new gravel may be cheaper to install than to remove, wash, and regrade old gravel. New gravel should be lime free (do not use ordinary river gravel). If old gravel is reused, screen out all resin particles. Spraying with water is the best method of removing the resin from the gravel on the screen.

2. Gravel Replacement. Replace or add new gravel in four layers. Fill the shell with water to the depth desired, then add to the coarsest grade first; level the gravel layer to fill low spots; next raise the water level to the next depth required, and add the next smaller grade. Repeat the process; then add the resin to the desired depth and classify by backwashing the bed.

(e) Underdrains. Each year, or as necessary, find out the condition of underdrains from the pressure drop across the underdrain system with a full backwash flow being discharged from the manhole. A greater pressure drop than existed at the time of installation indicates plugging underdrains; a lesser pressure drop indicates displaced or corroded nozzles. Underdrains must be inspected, removed, cleaned, painted (where necessary), and replaced every 3 years.

1. Manifold-Type Underdrains. Manifold-type underdrains must be inspected when gravel is removed. Remove several laterals at random and check for clogging. When clogging is evident, remove all laterals and clean mechanically, or by treatment with inhibited muriatic acid.

2. Plate-Type Underdrains. Plate-type underdrains must be removed, inspected, painted, and replaced every 3 years; make sure that the clearance space between the plate and lower head is the same at all points.

(2) Regeneration Equipment. With regeneration equipment, the following procedures must be used:

(a) Salt-Storage Tank. The storage tank must be cleaned at varying periods, depending on the amount of insolubles in the salt, tank size, and the salt usage. Rock salt contains more insolubles than evaporated salt. The greater the salt usage, the more frequent the cleaning is required.

(b) Brine Tank. The brine-measuring tank must be cleaned every 6 months, and both exterior and interior surfaces painted.

(c) Brine Ejector. At annual intervals. the brine ejector must be cleaned, disassembled, and checked for erosion or corrosion. Any clogging of piping must be removed before the ejector is reassembled and replaced.

(3) Operating Conditions. At quarterly intervals, the operating condition of the softener must be determined. Refer to operating records and make such tests and meter readings that are necessary to determine the following information:

(a) Flow Rate. Natural ion exchangers can operate satisfactorily at a flow rate of 5 gpm per square foot; synthetic resins at a rate of 6 to 7 gpm per square foot. Rates higher than these cause undesirable head loss through the bed and packing of the bed. Quarterly, adjust the controls of the flow rate.

(b) Backwash Rate. Rate of backwash should be 6 to 8 gpm per square foot of bed surface. Rates below this value do not clean the bed properly. Rates too high wash some of the resin out of the softener and reduce its softening capacity. Quarterly, adjust the flow rate control to produce the best backwash rate.

(c) Pressure. Quarterly, check operating records for any change in the difference between inlet and outlet pressure. Any change in head loss through the softener indicates some difficulty. A decrease in pressure drop may indicate improper valve closure or a channelized bed. An increase in pressure drop may indicate a valve not completely opened, a dirty bed, clogged gravel or a clogged underdrain system.

(d) Softening Efficiency. Quarterly, check the records to determine the softening capacity between the regeneration periods. Compare the amount of hardness removal with that when the ion-exchange resin bed was new, and calculate the efficiency based on the original capacity as 100 percent. A decrease in efficiency may be caused by a dirty bed, coated resin grains, loss of ion-exchange bed or improper regeneration (either by weak brine solution or underregeneration or overregeneration). Replace resin bed if efficiency has decreased by 25 percent and cannot be almost completely restored by cleaning and special procedures recommended by the manufacturer.

(4) Out-of-Service Softeners. If ion-exchange softeners are taken out-of-service for more than 10 hours, they must be emptied of water. Synthetic resins should be kept damp (not submerged) during standby conditions. Also, do not regenerate resins before they are taken out-of-service.

6-39. Laboratory Control Tests:

a. Lime Softening:

(1) Total Hardness. Test total hardness of raw, coagulated, settled, and filtered water once each shift. Use the standard hardness titration test.

(2) Alkalinity Test. Test for alkalinity of raw, settled, and filtered water each shift.

(3) The pH Test. Determine pH of raw, settled, and filtered water each shift.

(4) Calcium Carbonate Stability. Test calcium carbonate stability of recarbonated and filtered water daily.

(5) Carbon Dioxide, Carbonate, and Noncarbonate Hardness. Calculate carbon dioxide, carbonate, and noncarbonate hardness from total hardness, alkalinity, and pH tests daily.

b. Ion-Exchange Softening:

(1) Total Hardness. Test total hardness of raw and softened water daily.

(2) Chlorides Test. Test for chlorides by testing last wash water after each regeneration. Make occasional quantitative tests.

6-40. Keeping Records:

a. Lime-Soda Ash Softening. Records should be kept of all tests made in paragraph 6-39. In addition, the records should be kept of the:

(1) Quantities of chemicals fed daily (for example, slaked or hydrated lime, soda ash, carbon dioxide, etc.).

(2) Dosage settings on all chemical feeders and time of change to new settings.

(3) Total quantity of water softened.

(4) Total sludge removed from process each day.

(5) Operating records of unusual operating conditions, equipment breakdown, etc.

b. Ion-Exchange Softening. Records to help determine efficiency of ion-exchange softeners, discover and correct problems, and control operation include the:

(1) Raw water hardness.

(2) Soft water hardness at end of run.

(3) Backwash rate.

(4) Length of time of backwash.

(5) Length of time of salt solution injection.

(6) Strength of brine used.

(7) Depth of brine or weight of salt used during each regeneration.

(8) Rate of rinse.

(9) Length of time of rinse.

(10) Gallons softened each run.

(11) Length of time of each run.

(12) Quantity of residue disposed of.

(13) Operating records of unusual operating conditions, equipment breakdown, etc.

Section F—Filtration Processes

6-41. Objective of Filtration. Filtration processes are used to remove microorganisms and other suspended matter from the product water. In most plants, the suspended material consists of floc carryover from chemical clarification of surface waters, lime-soda ash softening, or iron and manganese removal processes. These floc particles consist primarily of chemical precipitates that have not been removed by sedimentation. The removal of these suspended solids is essential to produce the sparkling clear water required by drinking water standards.

6-42. Principles of Filtration:

a. Removal Mechanisms:

(1) It is a common misconception that filtration removes suspended solids by a simple straining process where particles too large to pass through openings in the filter media are retained on the media. Actually the mechanisms involved in removing of suspended solids by filtration are very complex. While straining is important at the filter media surface, most solids removal in deep granular filters occurs within the filter bed.

(2) Flocculation and sedimentation in the pore spaces between filter media particles is an important removal mechanism as well as adsorption of particles onto the filter media surfaces. Additional straining between media particles within the filter also contributes to overall solids removal.

(3) Proper treatment of the influent water to the filters is essential for good filter performance. If not coagulated, fine turbidity will pass through a filter. Also, if large coagulant turbidity flocs are not removed in clarifiers before filtration, they will tend to form a thick layer on top of the filter media, causing substantial resistance to flow and rapid head loss.

b. Head Loss Development. As floc particles accumulate at the influent surface and in the internal pores of the filter bed, resistance to flow is created, and loss of hydraulic head through the bed increases. The filter must be taken out of service and cleaned when the head loss exceeds a predetermined value. It should also be cleaned if the high pressure applied in order to force water through the bed shears the accumulated flocs, causing them to pass through the filter and create a turbid effluent.

c. Solids Breakthrough. Filter operation and performance are adversely affected by hydraulic surges. The higher rate of flow through the filter bed causes increased velocities between media particles, shearing the accumulated floc particles and carrying them deeper into the filter bed or all the way through the filter.

6-43. Types of Filters:

a. General Information. Filters can be classified by the media type, the flow rate, the direction of flow, the hydraulics (gravity or pressure), and the method of controlling the flow through the filter.

b. Type of Media. The most common method of classifying filters is by the type of filter medium. The two main types are granular and precoat.

(1) Granular media filters use sand or crushed anthracite coal with a graded gravel base, although granular activated carbon has also been used in a few cases.

(a) Slow sand filters have a 3- to 5-foot thick layer of sand supported on a gravel layer 6- to 12-inches thick. The filter is not backwashed, but when the head loss reaches the maximum limit, the filter is removed from service, drained, and the top layer of sand is scraped off and washed.

(b) Rapid sand filters use 18 to 30 inches of sand supported on a gravel base which in turn is supported by an underdrain system. Following backwashing, the sand is stratified in a fine-to-coarse gradation in the direction of flow through the filter.

(c) In order to get higher filtration rates with acceptable filter runs, several different types of granular media filters have been developed. Dual media filters typically have 6 to 8 inches of sand overlaid with 18 to 24 inches of anthracite. When two or more types of sand are used with the anthracite, the filter is called trimedia. Media layers are arranged in a coarse to fine gradation in direction of flow, which allows greater depths of penetration of floc particles. Dual and trimedia filter media are generally selected with specific gravities such that moderate intermixing between media layers occurs during backwashing. If the different media were in sharply stratified layers, essentially all solids removal would occur due to straining at the top surface of each layer. With intermixing, the upper zones of the fine media mix with the lower zones of the coarse media, resulting in a filter bed with more overall filtering capacity.

(2) Precoat filters consist of a permanent, coarse, screen base (septum) which is coated with materials such as diatomaceous earth, perlite, or powdered activated carbon to reduce the pore size of the septum. Diatomaceous earth is essentially the fossil skeletal remains of microscopic sized water plants call diatoms that are mined and processed to maintain a high porosity when wet. Perlite has properties similar to diatomaceous earth but is produced from siliceous rock. Because the precoat layer is only about $\frac{1}{16}$- to $\frac{1}{8}$-inch thick, the only turbidity removal mechanism is surface straining. When powdered activated carbon is used as a precoat, some adsorption of color, taste, and odor compounds may occur, although this is limited by the relatively short contact time with the carbon.

c. Flow Rate. Granular filters can also be classified in terms of flow rate. Slow sand filters were widely used in the past, but have been replaced in most plants by rapid

sand filters because of their high cost per unit of capacity and the labor required to clean them. Slow sand filters are operated at 0.05 to 0.15 gallons per minute per square foot (gpm/sq ft) of surface area, with most removal resulting from straining at the filter surface. Rapid sand filters operate at flow rates of about 2 gpm/sq ft under normal conditions and with proper pretreatment can operate at rates of 4 to 5 gpm/sq ft during peak demand periods. Removal is a combination of surface straining and other mechanisms in the top 8 inches of the filter bed. The new multimedia filters can be termed "high rate," because they typically operate in the range of 3 to 15 gpm/sq ft, with turbidity removed throughout the filter bed.

d. Flow Direction. Most granular filters are operated with the direction of flow from top to bottom through the bed. This is because most filters, particularly older sand filters, use gravity for the hydraulic driving force. Some pressure sand filters operate in an upflow mode; however, these are exceptions.

e. Hydraulics. As mentioned above, most sand filters use gravity as the hydraulic driving force. However, the height of water above the filter media is the maximum hydraulic head that can be applied to a gravity filter. If a filter can be economically operated at head losses higher than attainable by gravity, without solids breakthrough, pressure filters are often used. Pressure filters operate at the same flow rates as gravity filters, the only difference is the potential for operating at higher head loss through the filter bed. Precoat filters usually operate by pumping the water through under pressure, although some use a suction system to pull the water through the filter.

f. Flow Control. The final classification of granular filters is based on the way by which flow rate through the filter bed is controlled. As discussed previously, hydraulic surges are detrimental to filter performance and should be prevented. There are three basic operating modes: constant rate, constant pressure, and variable declining rate.

(1) Constant rate can be attained by using a flow control valve on the filter effluent. At the start of a filtration run, the media is cleaned, and flow is too fast for good filtration; therefore, the control valve is partially closed. As filtration continues and the media clogs with solids, the control valve gradually opens to maintain constant flow. The high initial and maintenance costs of the complex controls required are disadvantages of this system. Rate controllers are not necessary in new plants, and often can be circumvented in existing plants. An alternate method of constant rate filtration control in gravity filters is to build the filter cells with extra high walls and to split the flow equally between all filters. As the filter becomes clogged (causing resistance to flow) the water level above the media rises, increasing the head applied to the filter thereby maintaining a constant flow rate.

(2) In constant pressure systems, the same hydraulic head is applied to the filter throughout the filtration run. Initially, the media is clean, resistance to flow is minimal, and the resulting flow rate is high. As the media clogs, the flow rate through the filter is decreased. This method of flow control is not commonly used because of the large storage requirements during initial high flow rate period of the filter run.

(3) Variable declining rate filtration systems are designed with all filters being fed from an oversized, common header. When one filter at a time is taken out of operation for cleaning or as a filter becomes fouled, the flow backs up through the common header and is applied evenly to the remaining filters, resulting in a slight, gradual increase in flow rate through all filters in operation. The filters are provided with extra depth above the media surface to allow the water level to rise as the media becomes clogged or when more water is applied as a result of backwashing a filter. The main differences between variable declining rate filtration and constant rate filtration with equal flow splitting is the location and type of influent arrangement and the head available for filtering.

6-44. Slow Sand Filters:

a. General Description:

(1) Uses. Slow sand filters were used predominantly before the advent of modern day rapid sand filters. Some of these slow sand filters are still in use and are capable of providing good quality effluent when the raw water being filtered is low in turbidity. Generally, water having a turbidity in rage of 10 to 30 TU can be treated with slow sand filtration. Coagulation is not practiced before filtration.

(2) Filtration Mechanism. The slow sand filter uses adsorption as well as physical straining to remove turbidity and colloidal particles from the water. Solids removed are contained mainly in the upper inch of sand. Slow sand filters are operated at low hydraulic rates to prevent flushing the adsorptive layer through the filter. When fouled sand has been replaced in a slow sand filter, the filtered water must be wasted for several days until the adsorptive layer can be built up on the clean sand. To limit the quantity of water wasted, filtration is started at a very low rate and is gradually increased until the desired operating flow rate and desired water quality are achieved.

(3) Physical Arrangement. Slow sand filters are generally housed in concrete covered basins of 10 to 12 feet deep. Open jointed drain tiles are located at the bottom of the structure to collect the filtered water. The drains are covered with about 12 to 18 inches of gravel. The gravel ranges in size from ¼-inch diameter at the top of the gravel layer to 2 inches in diameter at the bottom of the gravel layer. The gravel is covered by 3 to 5 feet of sand with an effective size of about 0.25 to 0.35 millimeters.

b. Operation and Maintenance:

(1) Filtration Rate Control. The filtration rate in slow sand filters is maintained at a constant flow by controlling both influent and effluent valves. The influent is controlled so the water level over the top of the sand is always held constant. The effluent valve is opened as the filter slowly plugs. The influent and effluent valves may be controlled either manually or automatically, and is done with a rate of flow gage and water level indicator. An operational diagram of a slow sand filter is shown in figure 6-16.

(2) Filter Cleaning. It is necessary to clean the filter when the head loss reaches the maximum allowable limit.

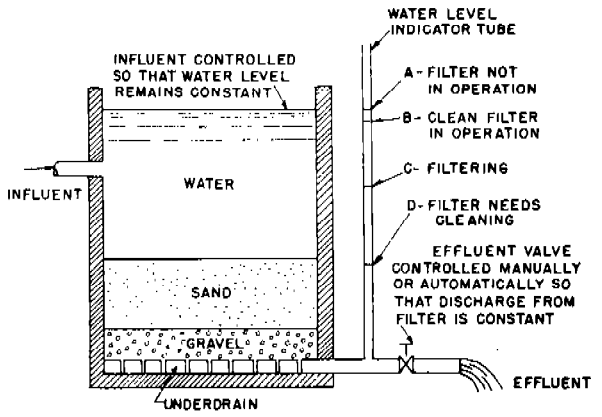


Figure 6-16. Slow Sand Filter Operational Diagram.

The time between filter cleaning is generally 1 to 6 months. The filter is emptied of water and the top inch or two of sand is manually scraped from the filter. The dirty sand is removed, washed, and stored for future use. Several cleanings are made before the sand is replaced, but it is necessary to always maintain a bed depth of at least 24 inches of sand.

NOTE: The remaining discussions of sand media filters in this section refer to rapid sand filters.

6-45. Granular Filter Media Characteristics:

a. Sand for Rapid Sand Filters. The types of sand used in filtration are silica or garnet. Garnet sand is denser and smaller than silica sand and is used as the final (bottom) layer in trimedia filters. Typical characteristics are listed in table 6-8. Filter materials are rated by particle size and uniformity. The effective particle size equals the sieve opening (in millimeters) that passes 10 percent by weight of the sand. Uniformity is measured by relating the effective size to a second characteristic, the sieve opening that passes 60 percent of the sand. The uniformity coefficient is the 60 percent value divided by the effective size (10 percent value). The smaller the uniformity coefficient, the more uniform the particle size.

(1) Common silica sand specifications for rapid sand filters 24 to 30 inches deep are: effective size 0.45 to 0.55 mm and uniformity coefficient no greater than 1.65 or less than 1.40. Coarser sand with effective sizes as high as 0.70 mm have also been effectively used. Advantages of coarse sand include easier and better backwashing.

(2) Specifications on garnet sand for trimedia filters are not available as the tri- or mixed-media filter is a patented process.

b. Anthracite Coal. Crushed anthracite coal is a more angular media with higher porosity than sand (table 6-8), and a resulting higher storage capacity for flocculated solids. The lower specific gravity (density) of the anthracite compared with sand allows the anthracite to maintain its position in the filter bed following backwashing. A typical dual media filter would contain 6 to 16 inches of sand and from 12 to 24 inches of anthracite coal. Typical anthracite coal specifications are: effective size of 0.9 to 1.0 mm and a uniformly coefficient less than 1.90.

c. Filter Gravel. Silica gravel is used for a 12- to 18-inch thick base layer to prevent the filter media from being washed out of the filter and to distribute the flow of backwash water. The gravel acts as a buffer zone, protecting the filter media from localized high velocity streams during backwash. Gravel sizes range from a maximum of 1 to 2 inches to a minimum of about $\frac{1}{16}$-inch. To prevent the gravel from being mixed with the overlying media by such high velocity streams, a layer of dense, coarse garnet sand, about 3 inches thick, can be placed between the gravel and the fine media.

d. Activated Carbon. Characteristics of granular activated carbon used for both filtration and adsorption of color, taste, and odor causing compounds should be obtained from carbon manufacturers and suppliers.

6-46. Granular Media Filter Bottoms and Underdrains. The filter bottoms and underdrains should distribute backwash water and collect filtered water in a uniform fashion to prevent excessive intermixing of filter media and gravel layers. Underdrains may be classified into the following types.

a. Porous Plate. Porous plates made of aluminum oxide provide good, uniform distribution of backwash flow. In addition, filter gravel is not needed because the holes in the plates are too small to be clogged by filter media. Brittleness of the plates and potential for clogging by calcium carbonate deposits are disadvantages of porous plates that have limited their usage.

b. Perforated Pipe Lateral. This commonly used system (figure 6-17) has several lateral pipes connected to a main header. The lateral pipes have ¼- to ½-inch diameter orifices on the underside, typically spaced 3 to 8 inches apart. The initial velocity of the backwash waterflow is thus absorbed by the filter floor and surrounding gravel.

c. Perforated Precast Block. Another commonly used underdrain is the precast vitrified clay block with 40 to 50

Table 6-8. Typical Granular Media Characteristics.

Material	Specific Gravity	Hardness (Moh Scale)	Porosity (%)	Effective Size (mm)
Crushed anthracite	1.4	3	55	0.4-1.4
Silica sand	2.65	7	42-44	0.2-1.0
Garnet sand	3.1-4.3	6.75-7.5	--	0.2-0.4
Silica gravel	2.5-2.65	7	40	1.0-50

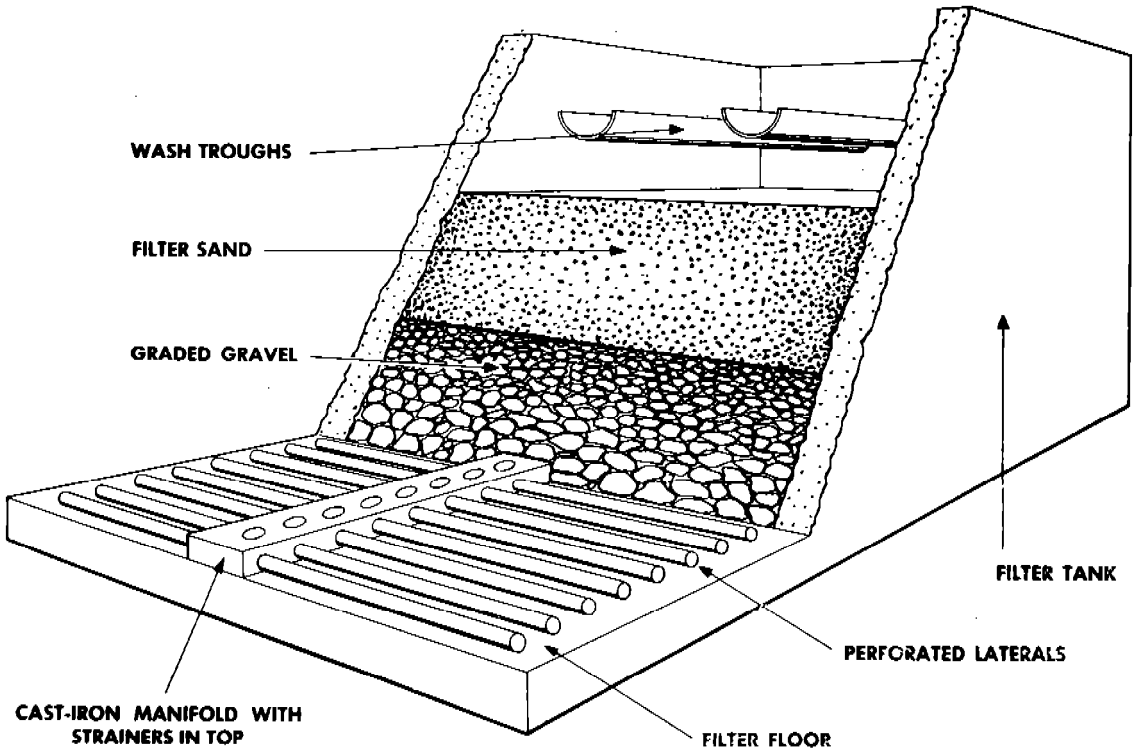


Figure 6-17. Typical Filter, Showing Relationship of Perforated Laterals.

orifices per square foot in the top. This type of underdrain is illustrated in figure 6-18.

d. False Bottom With Sphere-Filled Depressions. The third commonly used filter bottom has a false concrete bottom (22 inches above the structural bottom) with a series of cone shaped depressions. The depressions are filled with porcelain spheres which help dissipate the velocity head of the backwash waterflow.

e. Underdrain Strainers. Several manufacturers are marketing new underdrains that consist of a strainer or screen with metal or plastic supports. These underdrains attempt to eliminate the need for filter gravel. The size screen openings must be carefully selected so media does not pass through the screen.

6-47. Granular Bed Filter Operation. This discussion also applies in general to multimedia filters.

a. General Information. Influent water to a filter discharges into a baffle to dissipate the velocity head that could disturb the surface of the filter media. The flow then passes through the filter media, gravel base, and underdrains. Commonly a rate controller is located in the effluent line from the filter to maintain a constant flow rate through the filter. The bed is backwashed when the head loss through the filter bed increases above a certain level as a result of clogging of the media with removed solids, when effluent water quality fails to meet criteria, or when breakthrough of solids occurs. Backwashing is done by reversing the flow through the bed; this expands the media and shears loose the accumulated solids, which are carried away in the backwash water. Operating problems may include mud accumulation and permanent clogging of filter media, coating of media grains with various materials, improper coagulation, and backwash control. The single most common problems in filtration is unsatisfactory filter media cleaning.

b. Filter Equipment and Appurtenances:

(1) Rate Controller. The rate of flow through the filter is often limited by a throttling valve which is controlled by a head loss sensing device. A typical rate controller system is illustrated in figure 6-19. Other methods of rate control are discussed in paragraph 6-43f.

(2) Head Loss Gage. The loss of hydraulic head through a filter is measured as shown on figure 6-20. Unless solids breakthrough occurs first, the maximum allowable head loss triggers a filter backwash in many plants.

(3) Backwash Water Controller. Excessively high backwash waterflow rates could carry away some filter media along the backwash water and cause excessive intermixing of sand and gravel layers. If too low, the media may not be sufficiently expanded and cleaned of accumulated solids. For these reasons, the backwash waterflow rate is regulated by a control valve similar to that often used to control flow rate through the filter.

(4) Flow Rate Indicator. A flow rate indicator measures the rate of water production by the filter, typically by means of a venturi device connected to an indicating gage on the operating floor, although other instruments are also used. In some cases, the flow rate indicator also acts as a part of the automatic flow rate controller.

(5) Hook Gage. A multiple hook gage (figure 6-21) is a series of vertical sharp pointed rods held in a frame that may be hung on the side of the filter. The tips of the sharp pointed rods are set accurately at 2- or 3-inch spacings. It

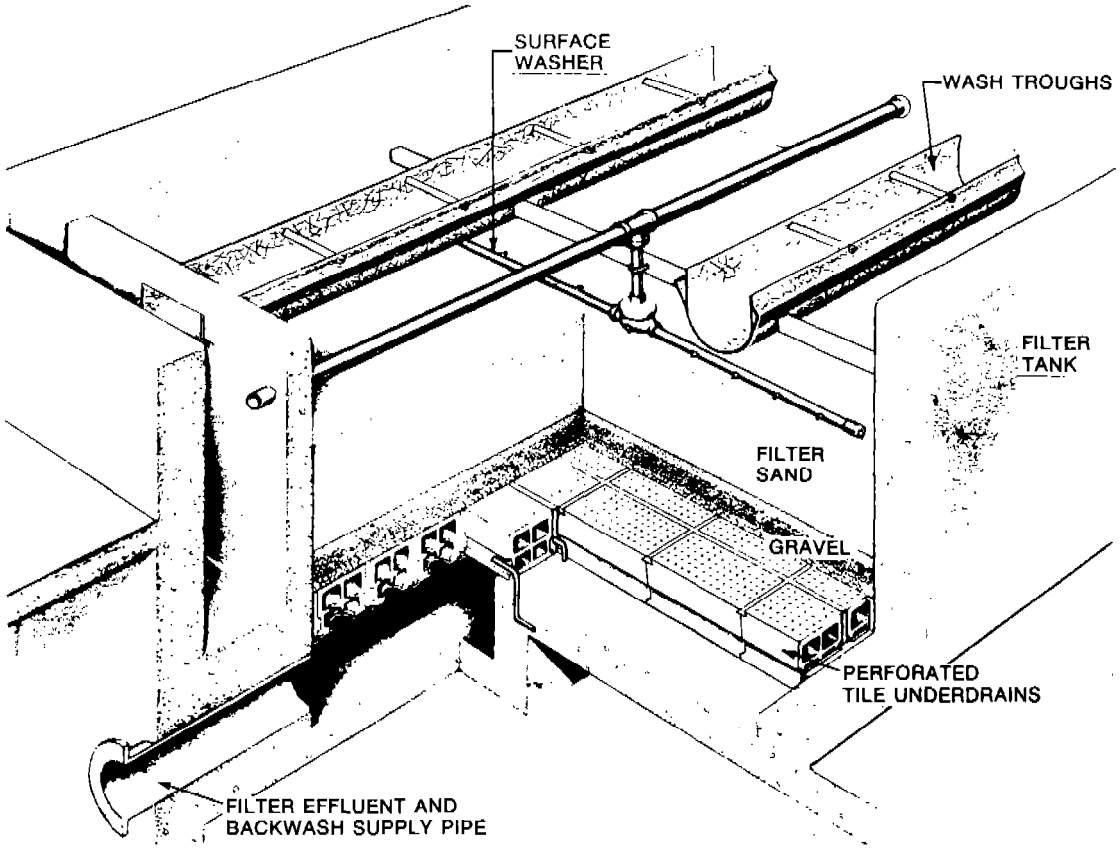


Figure 6-18. Perforated Tile Underdrain System.

can be used to check the rate of filtration or backwashing, although the primary use is for measuring backwash flow rate. The frame is hung on the side of the filter and the time required for the water level to fall or rise between the points is accurately recorded. The volume of water in the filter box between the gage points can be easily calculated, and from the time recording, the flow rate can be accurately determined.

(6) Piping and Valves. The filter piping is usually located in a pipe gallery and carries the influent, effluent, and backwash water to and from the filter. Valves and piping are so arranged that some of the piping may be used for more than one purpose. Flow rate controllers and metering units are installed in these pipelines. Valves may be operated manually, electrically, hydraulically, or pneumatically. Sampling faucets and air cocks for releasing of trapped air are usually provided. Because of expansion and contraction, at least one sleeve joint should be provided in each pipeline at each filter. The pipe gallery should be well lighted, well ventilated, and provided with a floor drain or sump pump. All piping and valves should be well painted and labeled at all times.

c. Filter Rate Control. A relatively constant, or slightly declining, filter rate must be maintained to prevent solids breakthrough. Sudden flow surges are not desirable as they may flush solids through the bed. Flow can either be controlled at the influent or effluent end of the filter as described in paragraph 6-43f. The accuracy of the rate control should be checked periodically, using a hook gage.

d. Loss of Head. The resistance to water passing through the filter bed and underdrains causes a loss of hydraulic head between the inlet and outlet of the filter. At the beginning of a filter run, suspended material collects primarily in the upper layer of the filter. This causes resistance to flow, and water pressure below the bed decreases, causing an increase in the loss of head as shown on figure 6-22. As the resistance to flow increases, accumulated floc particles penetrate deeper and deeper into the bed and head loss continues to increase until backwashing is required. The amount of head loss shortly after washing the filter varies with the type of media. The higher the rate of filtration and the finer the media, the higher the initial head loss. Higher losses of head can cause the media to become packed tightly, creating solids breakthrough and difficulty in backwashing. The head loss gage is an extremely important guide for proper operation and it should be checked periodically to make sure that its accuracy is maintained. Floats may become stuck or indicators may get out of adjustment.

6-48. Backwashing Granular Filters. After a filter has been operating for some time, turbidity and suspended solids collect on the surface and in the filter media to the extent that flow of water through the bed is limited and a significant loss of hydraulic head results. At this point solids can shear loose and break through into the effluent.

When these conditions occur, it is necessary to backwash the accumulated solids from the filter. It is common practice to backwash sand filters when head loss has reached 7 to 9 feet, although it should be backwashed sooner if effluent quality becomes unacceptable. Some plants require backwashing after 50 hours of operation, even if head loss or effluent quality is within acceptable limits. Length of filter runs vary from 12 hours to several days. One day is considered average.

a. Method of Operation. Backwashing is done by reversing the flow, forcing filtered water up through the gravel and sand. This loosens the filter media, agitating the media grains against each other and washing accumulated solids off the grain surfaces. The wash water rises into the wash troughs and flows to waste, carrying the solids with it. (See section K for a discussion of filter backwash treatment and disposal methods.) A typical procedure for backwashing a sand filter, as shown in figure 6-23, is as follows. The valves referred to are shown in the figure.

(1) Close valve A and allow the filter to continue to operate until the water level in the filter has reached a point at least 6 inches below the top of the wash water trough and at least 6 inches above the surface of the sand. Do not introduce air into the filter media by allowing the water level to fall below the surface of the sand.

(2) Close valve B. The filter is then out of operation with both influent and effluent valves closed.

(3) Open valve C and allow the water remaining in the filter gullet to drain to waste.

(4) Open valve D slowly, admitting wash water to the underdrain system. The time from start to full backwash flow rate should be a minimum of 30 seconds. This valve must not be opened too quickly as it may cause air accumulated in the bottom of the filter to be compressed and practically explode up through the filter, disturbing the arrangement of the sand and gravel. The wash water then flows upward through the sand bed, dislodging the dirt, overflowing into the wash water troughs which carry it to the filter gullet. From there it drains out through the waste piping to holding tanks before treatment or recycle. Washing should be continued for 3 to 10 minutes, until the wash water has cleared, indicating that the accumulated foreign material has been removed.

(5) Close valve D, stopping the flow of wash water to the filter.

(6) Close valve C, which shuts off the drain from the filter gullet.

(7) Open valves A and E, permitting influent water to

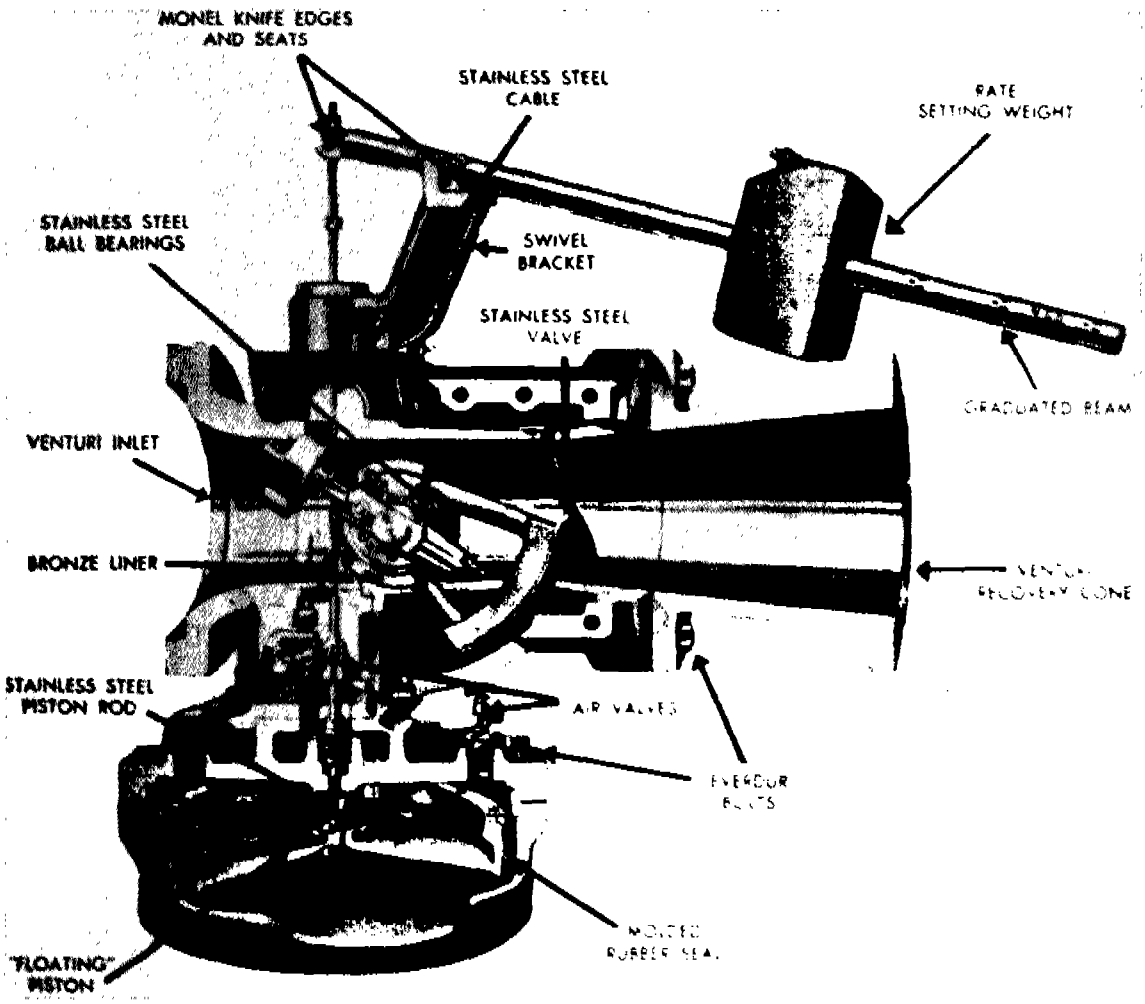


Figure 6-19. Sectional View of Rate-of-Flow Controller.

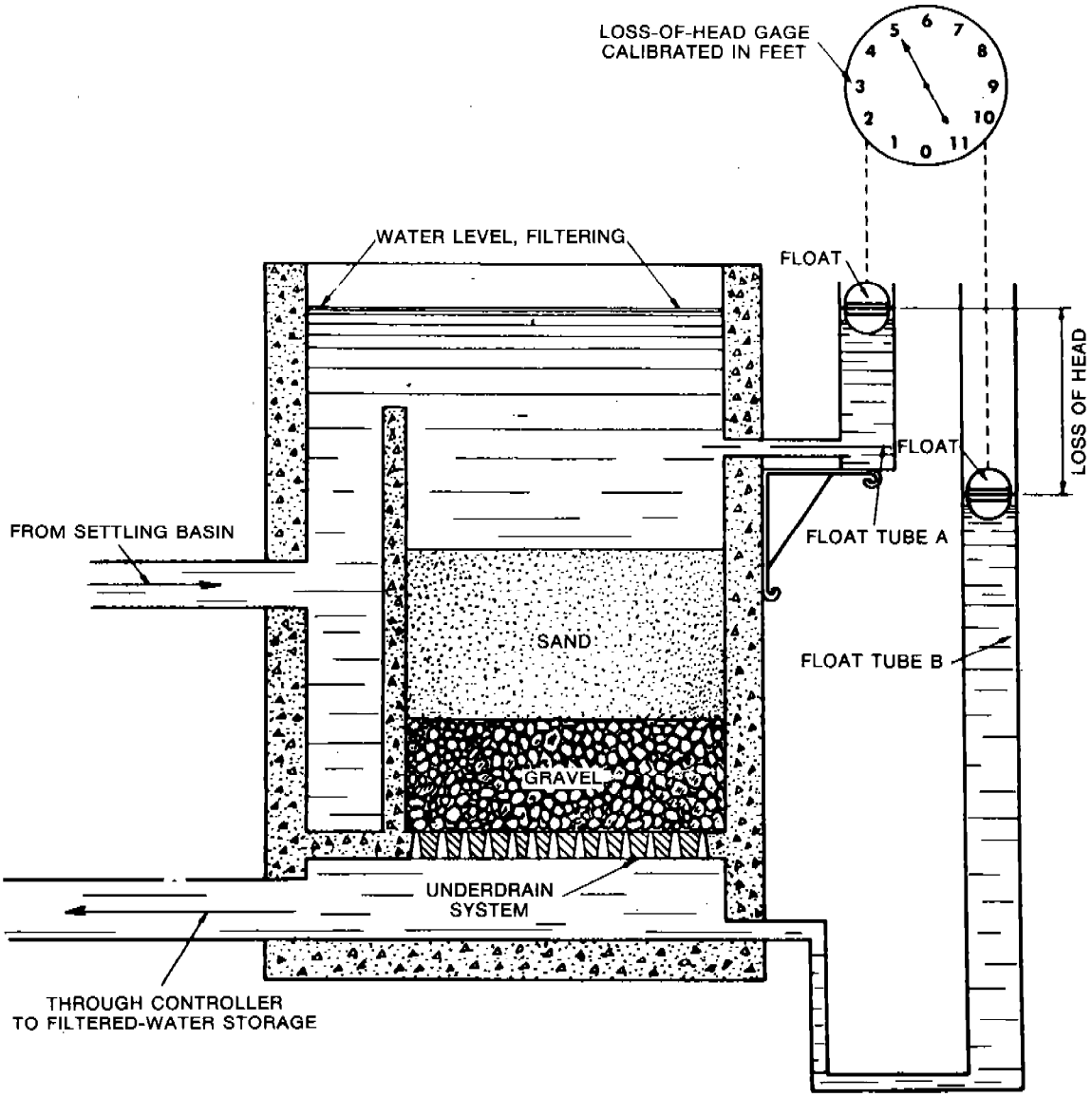


Figure 6–20. Loss-of-Head Measurement.

flow to the filter and the effluent to flow to waste. This filtering to waste should be continued for at least 2 minutes or for sufficient time to waste an amount of water equal to that contained in the filter below the level of the sand.

(8) Close valve E and open valve B, which places the filter back in normal operation, filtering water directly to the clear well.

(9) During normal filtering operation, A and B are open and C, D, and E are closed.

b. Backwash Flow Rate. The flow rate of backwash water should be sufficient for cleaning the media but not so much that loss of media results. In general, the backwash flow rate should be at least 15 gpm/sq ft, which is equivalent to a rise rate of 2 feet per minute as measured by a hook gage. Higher rates may be required for some types of filter media, but rapid sand filters typically backwash at a rise rate of about 2.0 to 2.5 feet per minute. The highest rate for each filter should be determined by actual experience at the plant. The rise rate is related to the backwash rate as illustrated in the following calculation:

$$\frac{15\ \text{gal}}{\text{min x sq ft}} \times \frac{1\ \text{cu ft}}{7.48\ \text{gal}} = \frac{2\ \text{ft}}{\text{min}}$$

(1) Media Expansion. Filter media should be expanded at least 20 to 25 percent for good cleaning action, although a 40 percent expansion is optimum in many cases. Higher expansions risk washing out some filter media along with the accumulated solids. Media cleaning may also be reduced due to less interparticle abrasion, although the bulk of the cleaning action is due to the force of the rising backwash water. Expansion can be measured by attaching cups to a pole at suitable intervals, then dipping the pole into the backwashing filter bed; the highest cup that contains sand indicates the height of bed expansion. Another method that can work at the end of the wash

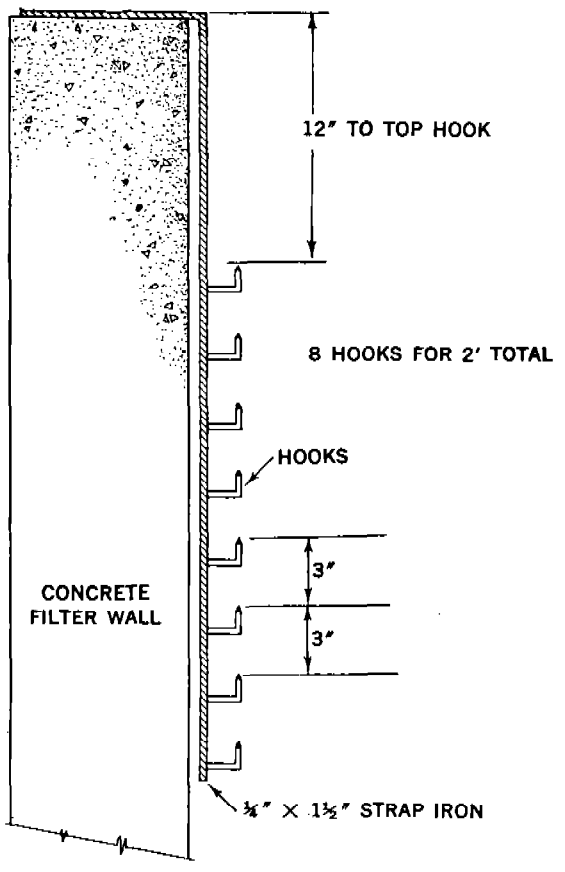


Figure 6-21. Multiple Hook Gage.

(when backwash water becomes relatively clear) is to use a hook light to show the top of the sand.

(2) Quantity and Duration of Backwash. The amount of water required for sufficient backwashing is typically 1 to 5 percent of the total amount of water filtered, with an average of 2 percent. The duration of backwash required depends on the type and size of filter media, temperature of the water, type of solids being removed, and backwash flow rate. Typical durations are 5 to 10 minutes. A rule generally applied to sand filters is 75 to 100 gallons of backwash water required per square foot of filter area.

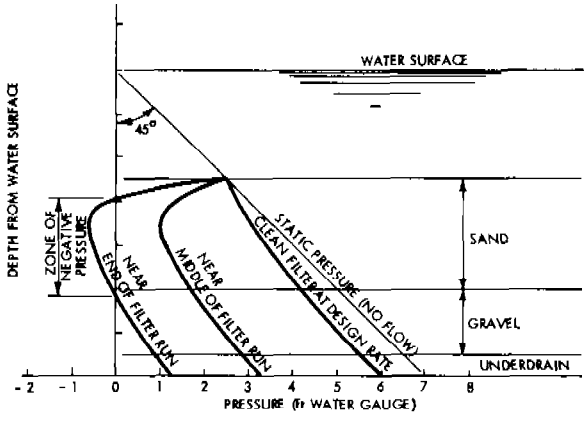


Figure 6-22. Pressure Versus Depth in a Gravity Filter at Various Times During a Filter Run.

c. Wash Water Troughs. After the backwash water flows through the filter bed removing accumulated solids, it flows into troughs which transport it from the filter to the wash water gullet or drain. The bottom of the trough should be located above the top of the expanded filter bed to prevent loss of media during backwashing. The weir edges of the troughs should be perfectly level to avoid creating hydraulic currents toward the lowest trough during backwash.

d. Filter Agitators. Simple backwashing by reversal of flow is not sufficient for adequate cleaning in some cases. Auxiliary scour using water, air, or mechanical means may be required.

(1) Water Scour or Surface Wash. Rotating or fixed high pressure water sprays can help eliminate the accumulation of solids in the filter bed. The sprays are located so that they are about 2 inches above the unexpanded filter bed during filtration but below the expanded bed surface during backwash. Water flow rates range from 0.75 to 2 gpm/sq ft at pressures of 40 to 100 psi. Water scour should be started before regular backwashing and continue almost to the end of backwashing unless clogged media becomes a problem.

(2) Air Scour. Air or air and water mixtures can be used similarly to the surface scour water alone or fed through a distributor at the media and gravel interface. Air scour should be performed before, not during, backwashing with water.

(3) Mechanical Scour. Some filters are equipped with mechanically operated rakes that scour the expanded filter bed during backwash.

e. Filter Media Cleaning. As a result of insufficient backwashing, filter media grains can become coated with algae or other biological slime, causing increased clogging problems. Even with adequate backwashing, the media may become coated with calcium carbonate precipitate. Cleaning with chlorine may kill algae or biological slime, but acid cleaning may be required to remove the encrusted slime. Acid is required to remove calcium carbonate precipitate. Before this type of filter cleaning is undertaken, higher technical authority must be consulted.

6-49. Granular Media Control. Common problems regarding the granular media and filter gravel are excessive intermixing within the filter and loss from the filter.

a. Media or Media and Gravel Intermixing. Excessive intermixing of various layers of filter media (different types and sizes of sand, coal, etc.) should not occur in a properly designed filter unless severe channeling has developed due to plugging of media, gravel, or underdrains. If it does occur, the plugging problem should be solved at once and the filter backwashed to reclassify the media. Intermixing of gravel and filter media can be the result of plugging of underdrains or gravel, excessively high backwash flow rates, or unevenly distributed backwash water. If media or gravel intermixing does occur, the filter must be removed from service, cleaned, and filled with new media and gravel. Gravel movement can be monitored by probing during backwash or while the filter is at rest. A layer of

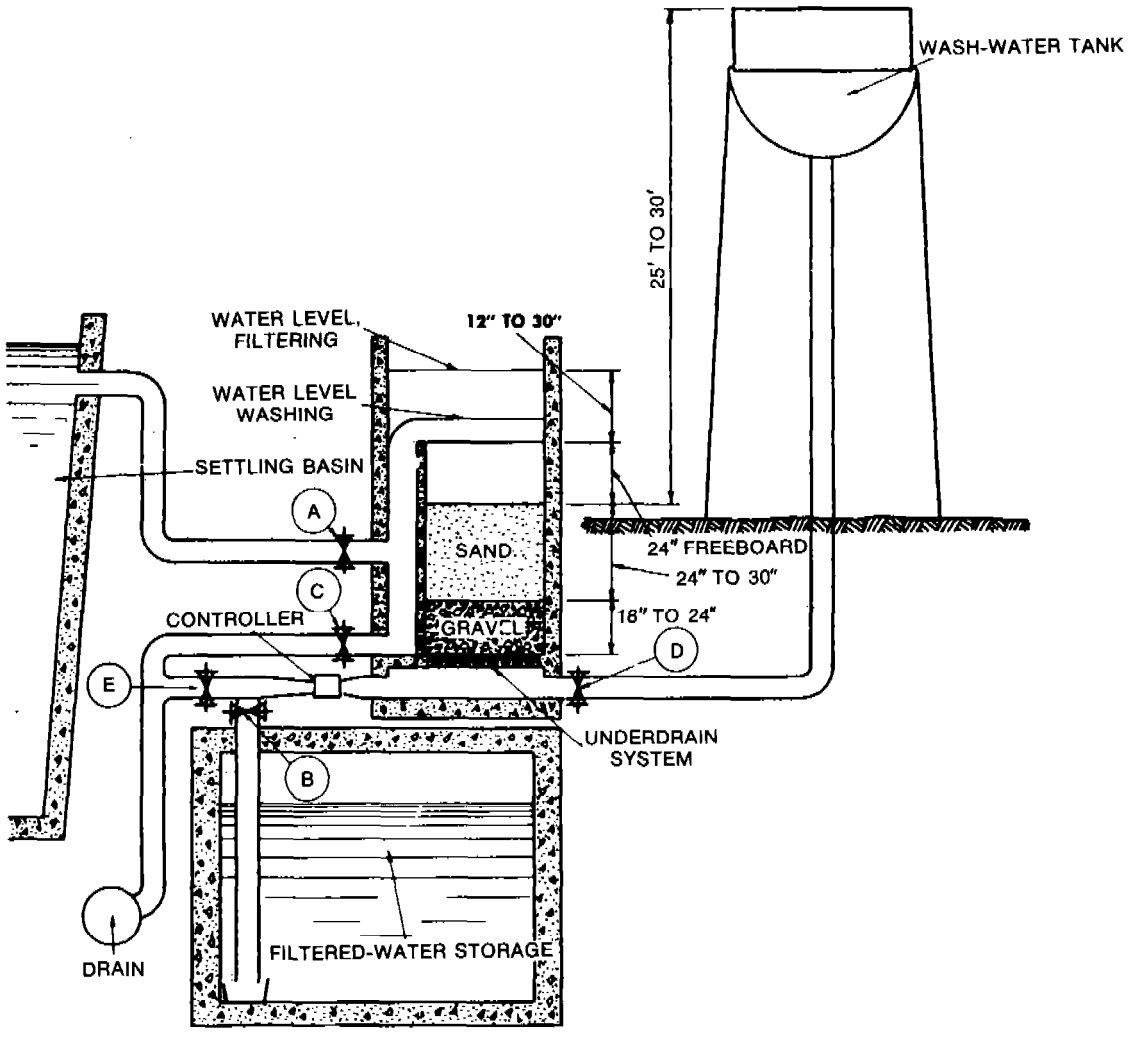


Figure 6-23. Operating a Rapid-Sand Filter.

coarse, dense garnet sand between the filter media and the gravel can help prevent gravel movement.

(1) Probing Filter During Backwash. This method uses a metal rod long enough that the operator can reach the gravel layer while standing on the top of the filter. The rod has a heavy grade screen attached to the end so that it can penetrate the expanded filter media bed, but is stopped by the gravel layer. By probing every few feet along the filter, mounds or holes in the gravel layer can be discovered. A variation in the gravel level of over 2 inches indicates serious problems.

(2) Probing Filter at Rest. The filter can be probed at rest using a metal rod of about ¼-inch diameter that penetrates the sand layer but not the underlying gravel.

b. Loss of Filter Media. Media can be washed from the filter along with the backwash water, or by filtering through the gravel layer along with the product water. Losses in the backwash water can be kept to a minimum by controlling the backwash flow rate, maintaining level backwash troughs at the proper elevation above the media surface and controlling hydraulic short circuiting as a result of clogged media or gravel. Losses through the filter grave can be controlled by placing a layer of coarse gravel between the media and the gravel and by controlling mounding of the filter gravel. Leakage of media can be detected by a small trap located in the effluent line from each filter. Many new filters leak sand for a period and then stop; this is no real problem. However, if sand leakage increases over a period, it is probably an indication of mounded gravel.

6-50. Control of Granular Media Filter Performance. The performance of a filter is evaluated by analyzing the solids remaining in the filtrate. Turbidity is usually the control parameter used. Final turbidity of the filtered water should never be greater than 1 TU. Levels commonly obtained with granular media filters are less than 0.2 TU. Generally, the turbidity of the water is reduced to about 10 TU before the water goes through the rapid sand filters. Higher turbidities can be tolerated, but filter runs are greatly reduced. Mixed media filters can handle turbidities up to 50 TU on a continuous basis. The turbidity in a filter influent and effluent can be monitored by laboratory analysis of samples or by in-line turbidity measurement. The advant-

age of in-line measurement is that it allows the operator to directly monitor the filter performance without relying on a laboratory technician. Turbidity monitoring systems are available which are based on actual visual observations by the operator or an automatic readout that can also be recorded graphically.

6-51. Granular Media Filter Operational Problems:

a. Mud Ball Formation. Mud balls are accumulations of suspended solids removed from the water that build up in the filter due to ineffective backwashing. Mud balls are the primary cause of the serious clogging problems associated with filters. The main preventative measures to eliminate formation of mud balls are sufficient backwash and supplementary surface scour with water or water and air. Existing mud balls can be removed during backwashing by manual dipping or they can be broken up by surface scour.

b. Surface Clogging and Cracking. Surface clogging and cracking occurs on filters with fine-to-coarse gradation or single media as a result of rapid accumulation of solids on the top surface of the fine media. This is usually not a problem with mixed media filters. Improved clarification before filtration can help reduce the solids loading to the filter and reduce the problem.

c. Air Binding and Negative Head. Air binding is a condition where previously dissolved gases in the water come out of solution forming gas bubbles in the filter bed. These bubbles significantly increase the resistance to filtration and contribute to washout of filter media during backwashing. Air binding can be reduced or eliminated by more frequent backwashing to reduce time for bubble formation (keeping actions to a minimum that increases the dissolved air content of the water before filtration), and by increasing the initial hydraulic head applied to the filter. This last control measure is intended to prevent the formation of negative head in the filter (figure 6-22 and paragraph 6-47d). When water pressure in the filter drops below atmospheric levels, air bubbles are formed, causing filter binding.

d. Microorganisms. The main filtration problem associated with microorganisms is clogging of the filter media by a buildup of slime consisting of algae, bacteria, and other microorganisms. In most plants, adequate backwashing is sufficient to remove the slime buildup before it becomes a problem. However, if clogging does occur, methods discussed in paragraph 6-48e must be used to clean the media.

e. Growth of Filter Grains and Effects. Grains of granular filter media can become coated with coagulated turbidity, biological slime, iron deposits, calcium carbonate precipitate, or other materials from the water being filtered. These relatively soft coatings allow the bed of the filter media to be compressed by the hydraulic head applied during filtration. As the bed is compressed, it tends to shrink the most in the middle, which causes the media to pull away from the sidewalls. The gaps along the sidewall may extend as deep as 18 inches. Water to be filtered tends to flow through these cracks rather than the rest of the filter bed. This results in poor quality filtrate and causes the cracks to clog with large masses of solids which are difficult to remove during backwashing. The most important method for preventing and eliminating these problems is adequate backwashing (with auxiliary water or air scour) to keep the media clean. Once problems develop, media cleaning with chlorine or acid may also be required. Calcium carbonate precipitation on media grains can be avoided by proper recarbonation of the softened water to adjust the pH to a level where calcium carbonate deposition does not occur.

f. Gravel Displacement or Mounding. The filter gravel base can be displaced, causing mounds and depressions (as a result of excessive backwash flow rates), inadequate distribution of backwash flow, or clogging of filter gravel or underdrains. Probing the gravel can be used to monitor the movement. Once gravel displacement has occurred, the only alternative is to remove and replace the media and gravel. Often a different type or size of gravel can be used that is less susceptible to displacement.

g. Excessive Floc Penetration. It is desirable that the floc solids penetrate the filter media bed to some extent so that all removal does not occur at the initial bed surface, causing rapid increase in head loss. However, if the floc penetrates the filter bed too far, it will pass completely through the bed, causing a turbid effluent. Excessive effluent turbidity can be caused by surface cracking, improper design or installation of filter media, operating at too high a head loss, or inadequate pretreatment of the water to be filtered. Experienced judgment and testing (trial and error) are the only means of establishing which of these problems is the cause of excessive floc penetration in a particular case.

6-52. Maintenance of Gravity Granular Filters. These maintenance procedures supplement (not substitute for) requirements established by equipment manufacturers.

a. Filter Media:

(1) At monthly intervals, drain the filter to the surface of the filter medium; inspect the surface for uneveness, sinkholes, cracks, and evidence of algae, mud balls, or slime.

(a) If depressions or craters on the surface area are of appreciable size, dig out the sand and gravel, and locate and repair any break in the underdrain system.

(b) Mud balls should be removed in the operating procedure outlined in paragraph 6-51a.

(c) If media shows evidence of algae growth, prechlorinate ahead of filters. If severe algae growths exist on media or walls, remove the filter from service and treat the filter with a strong hypochlorite solution. Add enough hypochlorite to produce 2 to 4 mg/l of free residual chlorine in a volume of water 6 inches deep above the filter surface. Draw down the filter until the water level is just above the bed surface. Allow it to stand 6 to 8 hours, then backwash the surface, and follow this by a complete backwashing. Repeat, if necessary.

(2) Probe the filter for hard spots and uneven gravel quarterly. Examine the sand below the surface by digging to gravel with the water drawn down to the gravel level. If clogged areas appear because of cementation of sand

grains with mud balls, or because grains have increased in size due to calcium carbonate deposit encrustation (for example, in softening plants or where lime and ferrous sulfate are used for coagulation), clean the sand by treating the idle filter with inhibited muriatic acid (hydrochloric acid to which a chemical has been added to reduce corrosion of metal) or sulfurous acid. The utility managers must be advised before these chemicals may be used.

(a) Add the inhibited muriatic acid at the surface and allow it to pass downward through the bed and out the filter drain and "rewash" the line; or add it to an empty filter through a small tap on the bed side of the wash water line.

(b) Use sulfurous acid as follows. Allow the sulfur dioxide gas from a cylinder to discharge into the filter wash water line while slowly filling the filter bed with wash water. Use one 150-pound cylinder to 6,000 gallons of water to produce a 0.3 percent solution. Allow it to stand for 6 hours.

(3) Twice a year, find out if there is any change in the rate of wash water rinse, as determined during operating procedures and check sand expansion (paragraph 6-48b(1)).

(4) Inspect the media twice a year. If visual inspection does not reveal the condition of the media, locate the elevation of the top of the bed to determine if the bed has "grown" in depth. Also, remove a media sample and analyze it as follows:

(a) Make a sampling tube 12 inches square by 36 inches deep. Force a tube to the gravel and drain the bed. Remove the sand from the tube. Collect several such samples from well-scattered locations on the filter bed, mix thoroughly, and reduce sample size by quartering until about 2 pounds remain. Dry this sample, mix, quarter, and reduce to a usable sample size.

(b) Determine loss of weight of a 10 gram sample during acid treatment. Treat sample with 10 percent hydrochloric acid in a pyrex evaporating dish on a water bath for 24 hours. Replace acid loss during treatment period. Wash, dry, and weigh the sand. Determine the weight loss and compare it to the previous analysis.

(c) From the rest of the sand sample, remove 100 grams and run a sieve test. Pass the sand through several standard sieve sizes, weighing the sand grains retained on each sieve. Compare the results to a previous test. Retention of greater amounts of sand on the larger sieve sizes indicates growth of the filter media.

(d) If either inspection, weight loss, or sieve analysis shows growth of sand grains to a point that filtration efficiency is impaired, treat the sand as outlined in a(2) above, and adjust the water treatment process as necessary. If treatment is not effective, remove and replace the filter media.

b. Gravel Inspection. Gravel inspection includes the procedures in (1) through (3) below.

(1) At monthly intervals, use a probe to check the gravel bed surface for unevenness. If ridges or sinkholes are indicated, the filter may need overhauling.

(2) Remove media from an area about 3 square feet twice a year, taking care not to disturb the gravel. Examine the gravel by hand to determine if the gravel is cemented with encrustation or mud balls, or if it is not layered properly.

(3) If any undesirable conditions exist to a marked degree, the media should be removed and the filter gravel relaid. If unevenness or layer mixing is caused by faulty underdrain system, repair it; if it is caused by faulty backwashing, correct the backwashing procedure.

c. Filter Underdrain System. Each year, or as need is indicated by observations, the filter bottom should be inspected. Sand boils (during backwashing), sand craters on the surface or marked unevenness of the gravel layers indicate trouble in the underdrain system. Inspection and treatment procedures are as follows:

(1) To inspect the bottom, remove the media over an area of about 10 square feet. Select an area where sand boils or other indications of trouble have been noticed. Place planking over the gravel to stand on, and remove gravel from areas about 2 feet square. Check underdrains for deterioration of any nature. If underdrains need repair, remove all sand and gravel, make repairs to underdrain, and replace gravel and sand in proper layers.

(2) Where underdrains are of the porous plate type and are clogged with alum floc penetration, flood the underdrain system with a 2 percent sodium hydroxide solution for 12 to 16 hours.

d. Wash Water Troughs. At quarterly intervals, the level and elevation of troughs should be checked. Water should be drawn below the trough weirs, the wash water valve should be cracked and any low points observed where water spills over the weir, before the weir is covered completely.

(1) The troughs should be adjusted as necessary to produce an even flow throughout their lengths on both sides.

(2) At semiannual intervals, metal troughs should be inspected for corrosion. If corrosion exists, the troughs should be allowed to dry, cleaned by wire brushing, and painted with an appropriate protective paint or coating.

e. Operating Tables. Operating controls for filter valves may be mounted on a console, panel, or table. The controls actuate the filter valves that may be powered either by hydraulic or pneumatic means. The controls may be connected to the valve mechanism either by cable or chain and operated through electrical, hydraulic, or pneumatic connections.

(1) These maintenance operations should be performed each week.

(a) Clean the table, console, or panel inside and out, using soap and water if necessary.

(b) If cable operated, inspect for leaks and stop any leakage; if pneumatically operated, check tubing for possible leakage.

(2) Transfer valve maintenance is performed as follows:

(a) Transfer valves (4-way) and handles should be adjusted each month to make sure that all filter valves open at the same rate. Packing glands should be tightened,

or new packing added as necessary.

(b) Transfer valves should be lubricated each month with grease. They should not be overlubricated; one-half turn of the grease screw should be sufficient.

(c) The valve position indicator should be inspected each month and adjusted to make sure that it reads correctly in all positions.

(d) The 4-way transfer valves in the table should be disassembled each year and any worn parts, seats, or washers cleaned or replaced.

(3) The inside of the table, console, or panel should be painted each year to protect against corrosion.

f. Rate Controllers. Rate of flow controllers (figure 6-19) may be either direct acting or indirect acting. Maintenance procedures for both types are in subsequent paragraphs.

(1) Direct Acting Controllers:

(a) Each week, clean exterior, check for leakage through diaphragm pot, and lubricate or tighten packing to stop any existing leakage. Also, make sure that both the diaphragm and the control gate move freely between zero differential and the open and closed positions.

(b) At intervals of 1 or more years, remove and disassemble the diaphragm pot, including the rubber diaphragm. If the water does not cause tubercles, this operation may not have to be done more than once every 3 to 5 years.

(c) Every 3 years, disassemble and service the controller gate and mechanism. Inspect the venturi throat. Paint or apply protective coating, as necessary.

(2) Indirect Acting Controllers:

(a) At weekly intervals, clean the outside of the controller; adjust the packing, lubricate or tighten the fittings as necessary to stop any leakage from the hydraulic cylinder, the controller valve, piping, or the pilot valve. Make sure that the knife edges seat correctly and are free of paint and other foreign matter. Also, be sure that the piston has free vertical travel and does not bind. Replace packing, if necessary.

(b) Each year disassemble, clean, and lubricate the pilot valve. Remove foreign matter from the piston with a cloth. Never use an abrasive to clean the piston. Make sure that the piston is free moving. Disconnect and clean the pilot valve piping and strainers; make sure that no foreign matter enters the pilot valve during the cleaning operation. Check for leaks or cracks in the diaphragm.

g. Gages. Indicating and recording instruments mounted on the operating table or control panel may include filter rate setters; a head loss gage; a flow rate gage; water level; backwash flow rate; wash water rise; summation gages for total filter output, etc.

(1) Mechanically Operated Head Loss Gage. The equipment that operates the indicator, or indicator recorder instrument, requires the maintenance operations described in the following paragraphs. In addition to these instructions, the inspector must consult the manufacturer's instructions for detailed adjustments.

(a) At monthly intervals, check the zero setting in the following way. Open the equalizing valve on mercury float-type head gages and make certain that the indicator arm and the recording pen return to zero. Note the reason for any incorrect reading, and adjust the stop collar or wire cable, if necessary, to bring the indicator to the proper zero reading. On floats and float chambers, which are so equipped, release the air. (On some models, it is possible to release the air by jerking the wire cable lightly.)

(b) At monthly intervals, remove the float from the float chamber; wash the float and remove encrustations; use care not to mar the float. Replace the mercury, if necessary, avoiding any spillage. When replacing the mercury, be sure that the amount is correct. Also paint the interior and exterior of the float chamber and other parts each year to prevent corrosion. In addition, check the pressure pipelines to the float chamber, and remove any encrustation.

NOTE: Mercury fumes are poisonous. Handle carefully since spilled mercury creates a continuing health hazard and is difficult to clean up.

(2) Diaphragm Pendulum Unit Loss of Head Gage. When the actuating mechanism is of this type, the following general maintenance procedures apply. For a more detailed discussion of the procedures, consult the manufacturer's instruction.

(a) The following operations must be performed each month.

1. Purge the diaphragm cases of air, and check the cable to be sure that it leaves the segment at a tangent to the lower end when a zero reading exists on the unit.

2. Remove dirt from the knife edges; if it is necessary, tighten the cam hubs on their shafts.

3. Drain mud from the mud leg as described in g(1)(b) above.

(b) Check the pipelines to the diaphragm twice a year to make sure that they are open and free of encrustation.

(c) Inspect the diaphragms each year for leakage and replace if necessary.

NOTE: Spare diaphragms should be kept underwater.

(d) Disassemble the unit in order to clean and lubricate it when necessary. Check the working parts and the cables (they should be free of knots, splices or fraying). Repack the stuffing box if it is leaking. Make sure that the knife edges rest solely on their edges, when the pendulum is hung vertically, and be sure that all cable ends are knotted tightly.

(3) Mercury Float Type Flow Rate Gages. For more detailed procedures consult the manufacturer's instructions.

(a) Once a month, check the unit by opening the equalizing valve to eliminate the differential pressure in the gage; adjust the indicator, the recording pens, and the register to zero. Check the position of the stop collars on the cables; also inspect and clean the stops on the indicator and recording pen.

(b) Every 6 months, check the accuracy of the rate of flow gages in the following way. Determine the exact time for the water to drop 1 foot, using hook gages. Also, determine the amount of water in this 1 foot depth (calculate, allowing for inlets, gullets, structural members, etc.,

or measure the input, if possible, from the wash water rinse or the drop in the level of the wash water tank). During the period timed for the drop in the water level of 1 foot, note and record the reading of the flow rate. Calculate the rate of flow and percent error, according to the following equations:

$$\text{Gallons per minute} = \frac{V \times 60}{T}$$

Where:
V = volume in 1 foot depth of water (gallons)
T = drop time (seconds)

$$\text{Percent} = \frac{F_1 - F_2}{F_2} \times 100$$

Where:
Percent = percent of error
F_1 = indicated flow rate (gpm)
F_2 = measured flow rate (gpm)

NOTE: If error is greater than ±3 percent, make the necessary adjustments.

(c) Twice a year check the pressure pipelines to the float chamber, and clean and remove encrustation to allow for free flow.

(d) Once a year, clean the float and check the mercury for replacement. Also, paint the interior and the exterior of the float chamber and other parts if necessary in order to protect against corrosion.

h. Piping and Valves. At monthly intervals, check for leaks at the joints; also, check the pipe hangers, and replace any that have deteriorated. Paint piping, valves and hangers if necessary to prevent corrosion. Maintenance procedures for valves appear in chapter 9.

i. Maintenance Schedule. The maintenance operation frequency and schedule of inspections for filtration are presented in table 6-9.

6-53. Operation of Pressure Granular Media Filters. Pressure filters are similar to gravity filters in most aspects of construction and operation. The major difference is that the driving force applied to drive the water through the filter is the static pressure supplied by a pump. The filter is in a steel tank similar to that shown on figure 6-24. Filtration rates, method of backwashing, and media are the same for gravity and pressure systems. Advantages of pressure filtration versus gravity are the higher head loss at which filters can be operated before backwashing is required, the higher residual head in the filter effluent line, and the reduced vertical dimensions of the filter. A major disadvantage is that the operator cannot watch the filter operations to monitor problems (improper backwashing, mud ball formation, etc.).

6-54. Maintenance of Pressure Granular Media Filters. Pressure filters need the same care and attention as gravity filters. The filter must be opened regularly and inspected carefully. The following maintenance procedures apply:

a. Inspect piping and valves for leaks each week. Lubricate and repack valves if necessary.

b. Open the pressure shell and inspect the filter bed surface each month. Follow procedures in (1) through (6).

(1) Use a garden rake or probe during backwashing while the manhole is open in order to test for mud balls in the lower part of the filter bed and for evenness of the gravel layer surface.

(2) Determine if the sand bed level has changed since the last inspection by comparing the bed surface elevation with some reference point.

(3) If the filter does not have a surface wash system, and shows evidence of mud balls, backwash it at the highest rate possible while jetting the surface with a stream of water from a high pressure hose nozzle. Install a permanent surface wash system.

(4) Open the filter each year, remove the sand from an area large enough to inspect the gravel. If the sand or gravel distribution indicates nonuniform distribution of backwash water, the filter media and gravel may need to be removed, and the underdrain system checked.

(5) Clean and paint the exterior of the shell each year.

(6) Every 3 years (or more often if necessary), the filter medium and gravel should be removed, and the underdrain system checked for wash water distribution, and repaired if necessary. Clean the underdrain system, and paint it or apply a protective coating to all parts subject to corrosion, including the inside of the shell. Replace the gravel and the filter medium.

6-55. Precoat Filtration:

a. Filter Media. The precoat material used most is diatomaceous earth, although perlite is considered an acceptable substitute. Powdered activated carbon may be applied in certain cases.

b. Hydraulic Types. Pressure from a pump discharge or vacuum from a pump suction can be used to push or draw the flow through a precoat filter. Pressure systems can operate at higher head losses (typically 50 to 200 feet of water) than vacuum systems (maximum of 20 to 25 feet of water) that are opened to the atmosphere and limited by atmospheric pressure. This allows the filter to operate longer between backwashings. In addition, if dissolved air or other gases are present in the water to be filtered, the gases can form bubbles in the filter during vacuum filtration which causes a rapid increase in head loss and poor quality filtrate. Vacuum filters are typically easier to operate than pressure filters. In general, vacuum precoat filters are used for relatively clear waters (for example, swimming pools), while pressure precoat filters are used for higher turbidity waters, such as treating surface supplies for potable water.

c. Filter Septa and Housing:

(1) Septa. The septa are coarse screen bases made of plastic, metal, or ceramic materials. The septa acts as a base against which the precoat material forms a porous layer. After the water is filtered, the septa convey the filtrate to a collection manifold.

(2) Housing. The septa are housed in steel tanks. Typical arrangements are shown in figure 6-25. The most

Table 6-9. Maintenance Procedures for Gravity Filtration Equipment.

Inspection	Action	Frequency[1,2]
Filter media	Inspect surface for unevenness, sink holes, cracks, algae, mud balls or slime.	M
	Dig out sand and gravel at craters of appreciable size; locate and repair underdrain system breaks.	V
	Chlorinate to kill algae growths	V
	Probe for hard spots and uneven gravel layers; if present, treat filter with acid.	Q
	Check wash water rise rate and sand expansion during backwashing.	SA
	Check sand condition for grain size growth; sample sand, determine weight loss on acid digestion, and run sieve test; acid-treat if necessary, or replace sand, if necessary.	SA
Gravel	Check elevation of gravel surface	M
	Examine gravel for incrustation, cementation, alum penetration, mud balls; if necessary, remove, clean and relay gravel.	SA
Underdrain system	Remove sand from area of 10 sq. ft., and inspect 2 sq. ft. area of gravel (or more); if underdrains are deteriorated, remove all sand and gravel, repair underdrains, replace gravel and sand.	A
	If porous underdrain, clogged by alum floc, treat with 2% NaOH solution for 12 to 16 hrs.	V
Wash water troughs	Check level and elevation, adjust	Q
	Check for corrosion; if present, dry troughs, wire brush, and paint.	SA
Operating tables	Clean table (console or panel) inside and out	W
Cables	Adjust tension	V
Hydraulic lines (or pneumatic)	Check for leakage	V
4-way transfer valves	Adjust, tighten packing glands or add new packing.	M
	Lubricate with grease	M
	Adjust valve position indicator, if necessary	M
	Disassemble, clean, lubricate and replace worn parts.	A
Table	Paint inside	A
Rate controllers		
Direct-acting		
General	Clean exterior, check diaphragm leakage, tighten packing, check freedom of movement and zero differential.	W
Diaphragm pot	Disassemble, clean and replace	A or V
Controller mechanism	Disassemble, service;: clean venturi; paint surfaces needing protection.	Every 3 yrs.

Table 6-9.—Continued.

Inspection	Action	Frequency[1,2]
Indirect-acting		
General	Clean outside, adjust packing, lubricate and tighten fittings; check knife edges, check piston travel; repack as necessary.	W
Pilot valves	Disassemble, clean and lubricate; check piston travel; clean piping and strainers; check for leaks in diaphragm.	A
Controller mechanism	Disassemble, service; clean venturi; clean hydraulic cylinders; paint as necessary.	Every 3 yrs.
Mechanically-operated loss-of-head gages	Check zero setting; adjust stop collars or cable; release air from float chamber.	M
Mud leg	Flush out sediment	M
Float chamber	Remove float, clean; replace mercury if necessary; check pressure pipelines; paint interior and exterior.	A
Diaphragm-pendulum loss-of-head unit	Check zero setting; purge diaphragm cases of air; check cable at segment; remove dirt from knife edges; tighten can hubs on shafts; drain mud from mud leg.	M
Pipelines to diaphragm	Check for free flow and absence of incrustation.	SA
Diaphragm-pendulum unit	Check for leakage; disassemble unit, clean and lubricate; check working parts, cables; repack stuffing box; check knife edges.	A
Mercury-float-type rate-of-flow gages	Check at zero differential, adjust indicator arm and recording pens; check stop collars on cables.	M
	Check accuracy and percent error; if greater than ±3%, adjust.	SA
Pressure lines	Check and clean as necessary	SA
Float chamber	Clean float and check mercury; paint all parts requiring protection.	A
Piping and valves	Check for joint leaks; check pipe hangars, replace, if necessary; paint, as necessary.	M

[1]W-Weekly; M-Monthly; Q-Quarterly; SA-Semiannually; A-Annually; V-Variable, as conditions may indicate.

[2]The frequencies shown are suggested frequencies which may be modified by local command, as individual installation conditions warrant.

common types of precoat pressure filters used in water treatment are vertical leaf filter ((a) and (b) in figure 6-25) and the cylindrical element filter ((c) in figure 6-25).

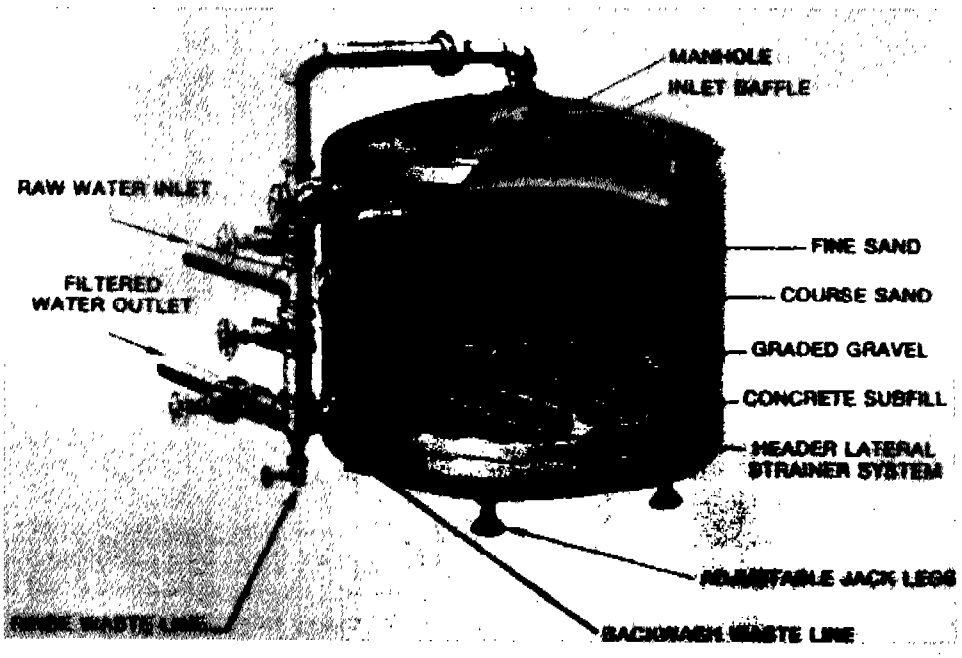
d. Filter Cycle. The filter cycle consists of three steps: precoating of the septa; filtration of water, usually done by applying a small amount of precoat material as a body feed; and backwashing the septa to remove the accumulated filter cake. A flow through diagram for a pressure precoat filter is shown in figure 6-26.

(1) Precoat. The septa are precoated with diatomaceous earth or other material (figure 6-27) at an application rate of 0.1 to 0.2 pounds per square foot of septa. This forms a thin layer of precoat and 1/16- to 1/8-inch thick.

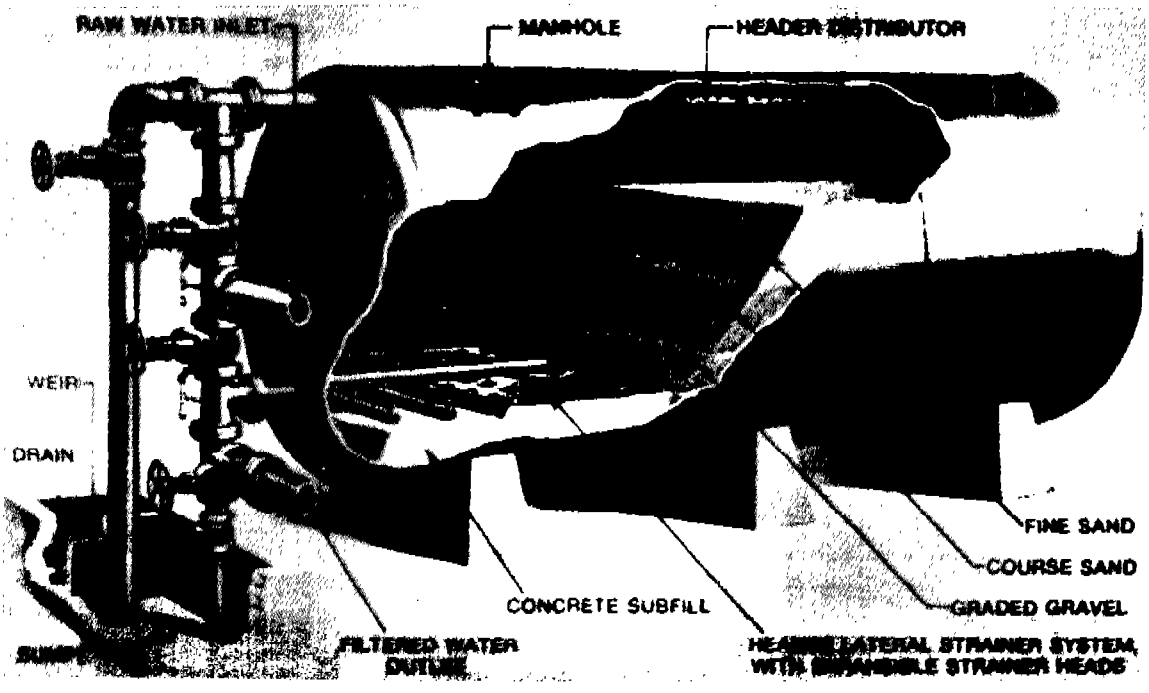
(2) Filtration With Body Feed. To prevent the thin precoat layer from clogging rapidly at the surface due to accumulation of solids, a small amount of filter media material is fed to the filters along with the waterflow as shown in figure 6-28. This material is called body feed, and the quantity required varies considerably, depending on the amount and type of suspended solids to be filtered. The body feed maintains a fresh, porous media through which the filtering water can pass, thus extending the time between backwashings.

(3) Backwash. The precoat and accumulated body feed and turbidity are removed from the septa by various methods of backwashing with air and water. As with granular media filters, it is very important that the backwash operation be performed properly. An insufficiently cleaned area of a septum can rapidly clog during filtration, causing poor quality filtrate.

(a) Vertical leaf filters are commonly cleaned by hydraulically sluicing or in some cases by manually scraping the filter cake to waste. Cylindrical element filters are cleaned by simple reversal of flow using clean filtered water or by "air or mechanical bump" backwashing. In "air bump" backwashing, air is trapped on the filtered water side of the filter septum. This air is compressed to the maximum operating pressure of the filter during the filtra-



VERTICAL PRESSURE FILTER



HORIZONTAL PRESSURE FILTER

Figure 6-24. Hand-Operated Pressure-Type Rapid Sand Filters.

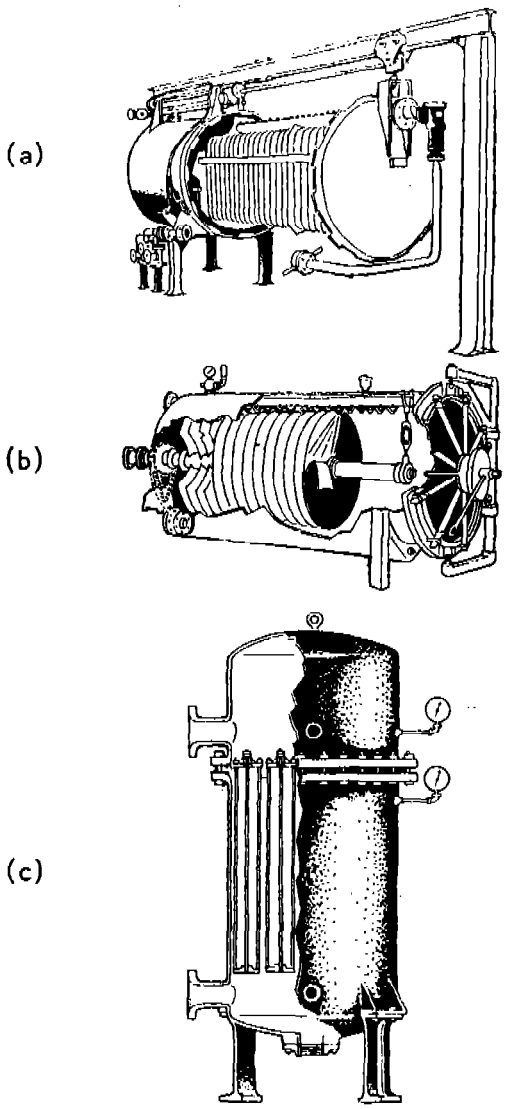


Figure 6-25. Typical Pressure Precoat Filters.

tion cycle. When the filter drain line is opened to the atmosphere, the compressed air expands rapidly, forcing the water back through the septum with explosive force, very effectively dislodging the filter cake.

(b) Precoat filters that use the "mechanical bump" cleaning are equipped with cylindrical filter elements that can be mechanically flexed to dislodge the filter cake.

(c) Vacuum filters may have either vertical leaf or cylindrical element filters. They are usually cleaned by draining the filter unit and cleaned manually or by automatic sluicing.

(d) The manufacturer's instructions should be consulted for specific backwash instructions for the type of precoat filter being used.

e. Precoat and Body Feed Dosage. It is important that sufficient diatomaceous earth, perlite, or other material is applied to the filter, both as precoat and body feed. Insufficient dosage results in poor quality effluent and rapid increase in head loss. However, after a point, higher dosages of precoat or body feed do not cause appreciable improvement of filtrate quality or longer filter runs. Therefore, from an operating economics standpoint, there is an optimum range of precoat and body feed dosages. This can only be derived from experience with the actual water being filtered.

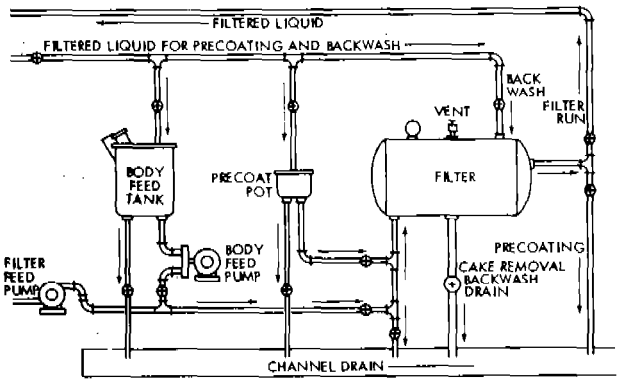


Figure 6-26. Typical Flow-Through Diagram for a Pressure Precoat Filter.

f. Maintenance Procedures. In general, the maintenance procedures for cleaning the filter element are the same for both pressure or vacuum filter types. The following procedures apply.

(1) At monthly intervals, or as often as operating conditions indicate the need, check the filter elements. The need for cleaning is evident when the precoat has apparent bare spots on the elements. Causes of element clogging are iron oxide and manganese dioxide deposits and algae growths.

(a) For iron oxide removal, treat the elements with a 0.5 percent solution of oxalic acid. Information is available from manufacturers on the amount of oxalic acid to use on different size units. The following procedures are used.

1. Start with an empty filter after a regular washing.

2. Close the drain valve and the main outlet valve; open the recirculation valve.

3. Fill the tank to a level covering the top of the elements.

4. Add the proper quantity of oxalic acid, and recirculate for 1 hour.

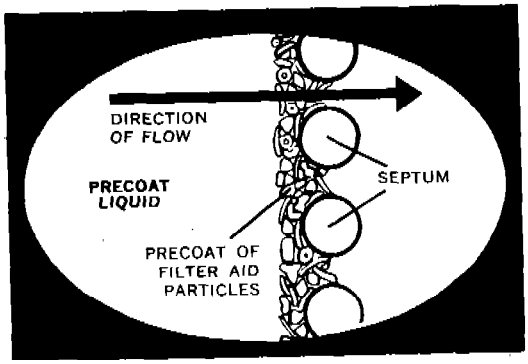


Figure 6-27. Precoat Filter Precoat Layer.

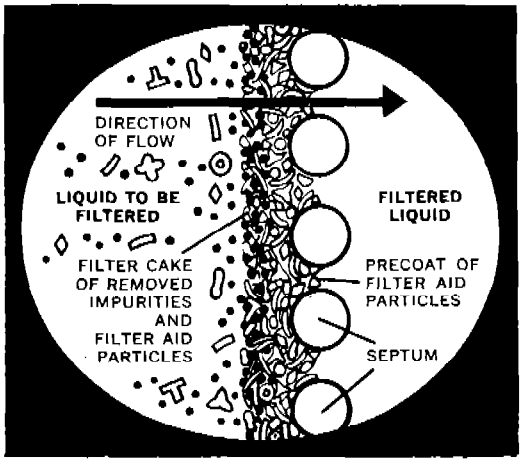


Figure 6-28. Precoat Filter With Body Feed.

5. Drain and hose down the elements and the tank interior.

6. Close the drain valve; refill, circulate a few minutes, and then drain again. If the cleaning is not completely effective, repeat the procedure.

(b) The procedure for manganese dioxide removal is the same as for iron oxide removal, except that anhydrous sodium bisulfite must be added to the solution rather than oxalic acid (see the manufacturer's instructions for the correct amount).

(c) To remove algae growths, add a 12.5 percent hypochlorite solution to the tank volume after filling the tank to the proper level (see the manufacturer's instructions for the proper amounts to use for different sized units).

(2) Check the piping and valves and appurtenant equipment twice a year, including the body feed equipment. Make whatever adjustments that the manufacturer's instructions indicate to be necessary.

(3) Clean and paint all exterior surfaces, if necessary.

6-56. Residue Characteristics. Residues from filtration systems are the solids removed from the water by the filter and spent filtering media. The solids removed from the water may include clays; algae, bacteria, and other microorganisms; coagulating chemicals and coagulant aids; calcium carbonate and magnesium hydroxide precipitates from softening processes; or precipitates of iron or manganese. These solids are removed from filters by backwashing (usually with large volumes of water) to a point that the suspended solids content of backwash residue of granular filters may be about 0.5 percent. Residue from precoat filters is higher in solids, due to the wasted precoat material and smaller volumes of backwash water. Activated carbon is wasted when its absorptive capacity is exhausted; typically the carbon is in a slurry form, very high in solids. Residue treatment and disposal methods are discussed in section K.

6-57. Maintaining Records. Accurate records should be consistently maintained to make sure filtration is the best possible from an operational and economic standpoint. Flow rates, chemical bulk quantities used and dosages applied, operating problems, and corrective measures taken, residual volumes, filter influent and effluent water quality, granular media bed depth, and media characteristics should be recorded in a permanent form.

Section G--Fluoridation

6-58. Fluoridation Objectives. Specific fluoride concentrations are maintained in public water supplies solely for the reduction of dental cavities in children (under 14 years of age). Fluoridation has been clinically shown to reduce the frequency and degree of dental cavities.

6-59. Fluoride Levels:

a. The most effective concentrations of fluoride have been arrived at by countless studies involving millions of people. Variation from these concentrations will adversely affect the water consumer. If the fluoride concentration is reduced to zero, dental decay sharply increases. At a fluoride concentration of approximately 1 mg/l, the maximum reduction in dental cavities occurs. Increasing fluoride concentration beyond the optimum level causes a discoloring (or "mottled") effect on teeth. Fluoride concentrations in excess of about 1.5 mg/l do not significantly decrease decayed, missing, or filled teeth beyond that obtained at 1 mg/l, but do increase teeth mottling. Fluoride concentrations of 5 mg/l or more result in severely pitted tooth enamel, and possible loss of teeth.

b. The optimum fluoride concentration depends on the local air temperature, because children consume more water in a warmer climate. Fluoride concentration can be reduced accordingly to reflect this increased consumption, and conversely, fluoride concentration is increased in cooler climates where water consumption is lower. The recommended control limits of fluoride concentration are given in table 6-10. The range of concentration is determined by the annual average of the maximum daily air temperatures obtained for at least 5 years at a specific location. If the fluoride content drops below the lower control limit, fluoridation is considered ineffective. If it exceeds the upper control limit, fluoride addition must be reduced at once until the proper concentration is obtained. Fluoride

Table 6-10. Recommended Fluoride Concentrations at Different Temperatures.

Annual Avg. of Max. Daily Air Temperatures (°F)	Control Limits		
	Lower	Optimum	Upper
50.0-53.7	0.9	1.2	1.7
53.8-58.3	0.8	1.1	1.5
58.4-63.8	0.8	1.0	1.3
63.9-70.6	0.7	0.9	1.2
70.7-79.2	0.7	0.8	1.0
79.3-90.5	0.6	0.7	0.8

concentrations may not exceed levels established by the National Interim Primary Drinking Water regulations.

6-60. Fluoride Dosage:

a. Effect of Natural Fluoride Content of Water. Fluorine is the thirteenth most abundant element of the earth's crust. Because of the wide distribution of this element, it is found in virtually every water supply used by humans for drinking purposes. This content, however, is generally so small (usually 0.1 to 0.25 mg/l) that fluoridation must be practiced to adjust the water to the best concentration. Even so, the natural fluoride content of the raw water must be considered to determine dosages that provide the best fluoride concentration. Fluoride is generally added following water treatment processes such as coagulation and sedimentation, which tend to remove part of the natural fluoride. The natural fluoride content of the raw water should be measured following these treatment processes and additional fluoride added to bring the total fluoride residual (natural + added) to the best concentration.

b. Fluoride Blending. Blending combines water with a natural fluoride content above the optimum with a water source deficient in natural fluoride, thereby adjusting the fluoride concentration to the best level. Unfortunately, achievement of controlled fluoridation by blending the water from two or more sources is limited to areas where high fluoride water occurs. When blending is possible, the water consumers gain more than dental benefits and economic advantages. They also conserve the supply of drinking water by using quantities of water that otherwise would be considered unacceptable.

c. Chemical Dosage. The amount of chemical fed to obtain the desired dosage of fluoride depends on the fluoride content of the chemical compound used.

(1) Dosage Chart. The nomogram shown in figure 6-29 illustrates a method for approximating the desired dosage of various fluoride bearing chemicals. The fluoride content of the chemical compound used must be taken into consideration when using this or other nomograms for dosage determination. Nomograms of this sort are useful for making rough estimates of chemical requirements or (by working backwards) rough estimates of the theoretical fluoride concentration achieved.

(2) Dosage Settings. Chemical dosages must be set and supervised by properly authorized personnel. Overall dosage checks are made at least daily. Continuous observation of the equipment is a daily routine operation. Hourly checks show any dosage variations and provide a basis for dosage setting change.

6-61. Fluoridation Agents. A number are available which, when combined with water, release fluoride ions (F^-). The compounds most commonly used are sodium fluoride, sodium silicofluoride, hydrofluosilicic acid, while ammonium silicofluoride, hydrofluoric acid, and calcium fluoride (fluorspar) are less commonly used. Characteristics of several fluoride compounds appear in table 6-11. Fluoride compounds are toxic and must be handled according to safety procedures discussed in paragraph 6-65. A discussion of these compounds follows.

a. Sodium Fluoride (NaF). Sodium fluoride is a white, odorless material available either as a powder or in the form of crystals. It has a molecular weight of 42.00; specific gravity of 2.79; and a relatively constant solubility of 4.0 grams per 100 ml of water at temperatures generally encountered in water treatment practice. This solubility property makes accurate feeding easier. Solutions prepared from the usual grades of sodium fluoride exhibit pHs (hydrogen ion concentrations) near neutral. Therefore, sodium fluoride is relatively noncorrosive, although in the presence of moisture, it tends to give off an odor of hydrogen fluoride fumes. It is available in purities ranging from 90 to 98 percent. Powdered sodium fluoride is produced in different densities weighing from less than 65 to about 90 pounds per cubic foot. Crystalline sodium fluoride is produced in various size ranges, usually designated as coarse, fine, or extra-fine. The crystalline type is preferred when manual handling is involved because the absence of fine powder results in a minimum of dust. The major hazards are those of any chemical dust, except sodium fluoride dust is extremely poisonous.

NOTE: An approved respirator must be worn when handling sodium fluoride.

b. Sodium Silicofluoride (Na_2SiF_6). Sodium silicofluoride is a white, odorless, crystalline powder. It is by far the most popular compound used for fluoridation. The primary reason for this popularity is its low cost. Next to fluorspar, it is the cheapest source of fluoride. While it is difficult to dissolve, this drawback can be overcome by selecting the correct dissolving apparatus. Sodium silicofluoride's molecular weight is 188, and its specific gravity is 2.68. Its solubility varies from 0.44 grams per 100 ml of water at 0°C to 2.45 grams per 100 ml at 100°C. A saturated solution usually exhibits a pH between 3.0 and 4.0. These solutions are therefore corrosive and the materials for piping, valves, pumps, and fittings should be chosen with this in mind. Sodium silicofluoride is available in purities of 98 percent or better. The principal impurities are water, chlorides, and silica. Paper bags (100-pound net), paper-lined barrels (425-pound net), and fiber drums (125-pound net) are used for shipping sodium silicofluoride. Dust handling precautions should be observed when handling this chemical.

c. Hydrofluosilicic Acid (H_2SiF_6). Hydrofluosilicic acid (also known as fluosilicic acid) is a colorless, transparent, fuming, corrosive liquid. It has a pungent odor and an irritating action on the skin. A 22 percent solution boils at about 104°C, freezes at about -15.6°C, and has a density of 1.194. A 1 percent solution has a pH of 1.2. Decomposition products of hydrofluosilicic acid tend to abrade even the hardest metal piston pumps. Therefore, oil diaphragm pumps are necessary for handling this chemical. Although this acid is only slightly volatile, its vapor can cause irritation of the respiratory system. Hydrofluosilicic acid should be washed off the hands or parts of the body with liberal amounts of water as soon as possible after exposure. Ade-

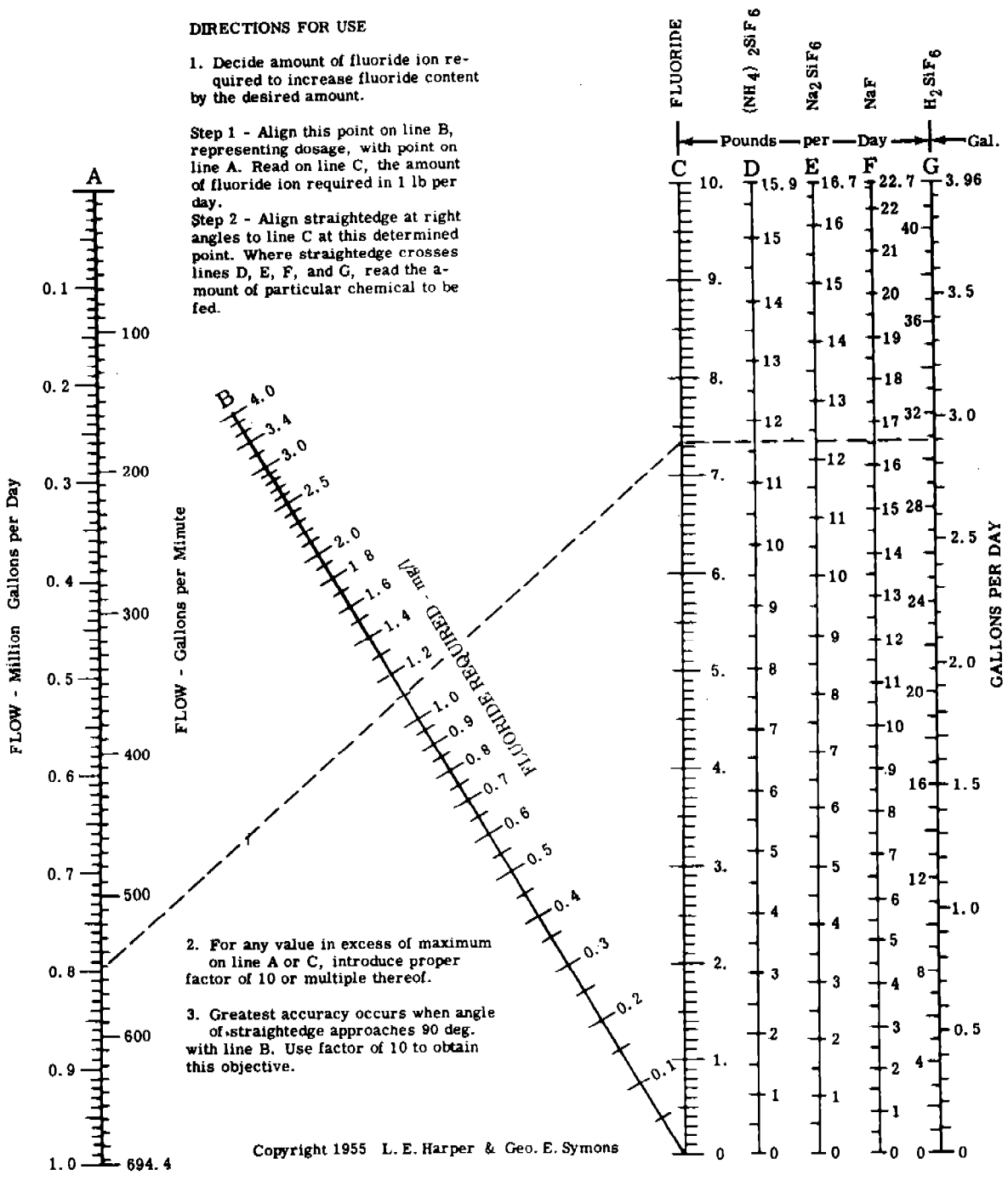


Figure 6-29. Nomogram for Determining Dosage of Fluoride-Bearing Chemicals.

quate ventilation should be provided and protective clothing worn when handling the chemical. Rubber gloves, goggles or face shields, rubber apron, rubber boots, lime slurry barrels, and safety showers are required safety equipment. In a completely enclosed, corrosion resistant system, hydrofluosilicic acid may be handled with fewer accidents than other fluoride compounds.

d. Ammonium Silicofluoride ($(NH_4)_2SiF_6$). The ammonia in ammonium silicofluoride combines with chlorine used for disinfection to form chloramines. The formation of chloramines wastes a substantial amount of chlorine when a free chlorine residual is sought as the disinfecting chemical.

e. Hydrofluoric Acid (HF). Hydrofluoric acid is the primary compound that produces most fluoride containing salts, including sodium fluoride. The objection to using hydrofluoric acid for water fluoridation is related to the hazards involved in handling this potentially dangerous chemical.

NOTE: Due to its extremely corrosive nature and difficulty in safe handling, hydrofluoric acid is not permitted for use at military installations.

Table 6-11. Characteristics of Fluoride Compounds.

Type	Calcium Fluoride (CaF_2)	Sodium Silicofluoride (Na_2SiF_6)	Sodium Fluoride (NaF)	Hydrofluosilicic Acid (H_2SiF_6)	Magnesium Silicofluoride ($MgSiF_6 \cdot 6H_2O$)	Ammonium Silicofluoride ($(NH_4)_2SiF_6$)	Potassium Fluoride ($KF \cdot 2H_2O$)
Form	Powder	Powder	Powder or crystal	Liquid	Crystal	Crystal	Crystal
Molecular weight	78.08	188.05	42.00	144.08	274.48	178.14	94.13
Commercial purity, %	85-98	98.50	90-98	22-30	98.00	98.00	98.00
Fluoride ion, % (100% pure material)	48.80	60.70	45.25	79.20	41.50	63.90	20.20
Weight, lb/cu ft	101.00	55-72	65-90	10.5 lb/gal	73.00	81.00	58.00
Storage space, cu ft/1,000 lb fluoride ion	21-24	23-30	22-34	54-73	34.00	21.00	87.00
lb reqd/mg for 1.0 mg/l fluoride at indicated purity	17.6(97%)	14.00	18.8(98%)	35.2(30%)	20.50	13.30	42.10
Solubility, g/100g H_2O at 25°C (77°F)	0.0016	0.762	4.05	Infinite	64.8(17.5°C)	18.5(17.5°C)	100.00
Gal sat. sol. reqd/mg water at 25°C and 1.0 mg/l fluoride	132,000	219.00	55.6(98%)	3.35	3.50	8.00	8.00
pH of saturated solution	6.70	3.50	7.60	1.2(1% sol.)	1.00	3.50	7.00
Cost as of 1967							
c per lb	2.20	7.25	14.40	7.0(30%)	13.00	15.00	37.50
c per lb available fluoride	4.80	12.00	32.50	29.50	32.00	23.90	189.00
Per mg for 1.0 mg/l	$.40	$1.00	$2.72	$2.46	$2.66	$2.00	$15.77
Per year at 1.0 mgd	$146.00	$365.00	$990.00	$900.00	$973.00	$730.00	$5,760.00

f. Calcium Fluoride (Fluorspar) (CaF_2). Fluorspar is the principal source of commercial fluoride compounds available at the present time. The process for using fluorspar involves a means for dissolving the calcium fluoride, which is almost insoluble in water. As a rule, an aluminum compound called filter alum (aluminum sulfate) is used to solubilize fluorspar. By varying the concentration of alum in solution, any desired quantity of fluoride can be obtained from fluorspar. The resulting solution is used to supply both alum for coagulation and fluoride ion.

6-62. Application of Fluoridation Agent. Fluoridation agents must be in solution before adding them to drinking water. Slurries are not acceptable. Therefore, application of fluoridation agents will require at least one and possibly two distinct operations. These two operations are the preliminary preparation of the fluoridation agent and feeding the prepared fluoridation agent. A more thorough discussion of the operation and maintenance of preliminary preparation and feeding equipment may be found in section I.

a. Preliminary Preparation:

(1) Solid Forms. Most chemicals available for water fluoridation are in solid granular or powdered form. Preliminary preparation of solid chemicals requires that a specific volume or weight of chemical be measured and dissolved in water to form an aqueous solution of definite and known concentration.

(a) One method to prepare this aqueous solution is through the use of a dry feeder which measures the fluoridation chemical and places the chemical in a mixing tank where it is dampened with water. Such feeders are used to make up solutions of sodium fluoride, sodium silicofluoride, and ammonium silicofluoride.

(b) A saturator may also be used to dissolve the fluoridation agent. In this method, the chemical is placed in a container and water is trickled over the chemical at a rate to provide a saturated solution at the exit of the tank. This type of solution feeder can be used for applying of sodium fluoride.

(2) Liquid Forms. Liquid fluoridation agents (such as hydrofluosilicic acid) require no preliminary preparation and may be fed directly into the water supply. Hydrofluosilicic acid should not be diluted as this might cause the acid to gel. However, if required feeding rate is lower than that available on standard solution feeders, an alternative fluoridation agent should be considered.

b. Feeding Requirements. The criteria used in selecting a feeder are capacity, corrosion resistance, pressure capability, accuracy and durability. Feeders perform most accurately in a midrange of both stroke length and stroking frequency and should be selected accordingly. At the extremely low feed rates required by small installations, diaphragm type feeders are superior to the piston types. For additional information on chemical feeders, see section I.

(1) Gravity Feed. For gravity feed, there are several types of solution feeders that operate on a paddlewheel principle.

(2) Solution Feed Pumps. For delivery against pressure, there are two general types of solution feeders, the piston feeder and the diaphragm feeder. In addition to the piston and diaphragm feeders, several types of rotary pumps also qualify as positive displacement feeders. Ordinarily, such feeding solution devices as centrifugal pumps, pot feeders, or head tank and orifice are not used for fluoridation because of their relative inaccuracy. When using a saturator, a metering pump must always be used (regardless of the condition that exists at the point of application) to maintain a constant withdrawal rate.

c. Application Points. Generally, the most desirable point of fluoride application is after all forms of water treatment (such as coagulation, precipitation, filtration, or adsorption) but before final chlorination. A simple rule to remember is that any treatment designed to remove other substances may remove fluorides. Because water has no "fluoride demand," the entire quantity can be accounted

for in the distribution system, unless it is lost through the treatment process. In a water treatment plant, a good application point can be in the water main coming from the filters or in the clear well. In a well pump system, a good application point can be in the discharge line of a pump or in a line leading to an elevated tank, other storage facility, or directly into the distribution system. In any case, fluoride must be added to all treated water. If at all possible, a point through which all the water passes at a fixed rate or rates should be selected. Thus, the fluoride feed rates can be paced from a fixed delivery rate of pumps or well, and thereby make fluoride adjustment in the water distribution system much simpler and constant. If there is no common point through which all water passes, separate fluoride feeding facilities must be provided for each separate water source. The fluoride compound should be applied at a point so that mixing can be secured. Preferably, the point of application should be at a point where the resulting detention time equalizes the dosage and allows the fluoride compound to fully dissolve. When chemicals that contain calcium (calcium hypochlorite, lime, etc.) are used to condition the water, the fluoride injection point should be as far away as possible from the calcium injection point in order to keep loss of fluoride by precipitation to a minimum.

d. Application Problems:

(1) Solubility of Fluoridation Agents. The solubility of any solid fluoride compound depends on the temperature of the solution water and the time of contact allowed between the compound and the solution water. The time factor can be overcome by proper mechanical designs so that the flow rate is low enough to ensure sufficient dissolving time at the operating temperature. Without adequate temperature control, difficulty in maintaining a controlled operation will be experienced with the use of solid compounds. Of the two more commonly used solid compounds, adequate temperature control is more critical with the use of sodium silicofluoride that with sodium fluoride because the former has a wide range of solubility over the normal range of operating temperatures. With a saturator tank, any variation in temperature causes a corresponding variation in the concentration of the solution entering the point of application and will result in inadequate dosage of fluoride. The solubility of the various fluoridation agents may be found in table 6-11.

(2) Corrosiveness. Although the relative corrosiveness of fluoride compounds differs, equipment manufacturers provide about the same corrosion resistant materials for solution feeders, tanks, and appurtenances regardless of the compound used. Corrosion resistant containers are usually in the form of rubber-lined or plastic-lined tanks. Rubber-lined or plastic piping is necessary for conveying these chemicals. The dry powder form of fluorides (such as sodium silicofluoride and sodium fluoride) does not readily take up moisture from the air and is therefore less corrosive than solutions of these chemicals. Hydrofluosilicic acid, on the other hand, should not be used in the presence of ceramic crocks or glass-lined tanks, because this chemical attacks ceramic and glass-lined surfaces. However, hydrofluosilicic acid is seldom used in such containers, because it is usually withdrawn directly from the rubber-lined drums in which it is shipped or stored. Periodic inspection of tank linings and piping is very important and should be made part of routine preventive maintenance.

(3) Encrustations in Feeding Equipment. Encrustations form occasionally in solution tanks, feeders, and feeder lines. The deposits are a direct result of the hardness constituents of the water combining with the strong fluoride solutions to form precipitants. Scale prevention measures include softening the dissolving water, thereby removing the calcium and magnesium, and sequestering the hardness compounds by adding 5 to 15 mg/l polyphosphates. In general, water used for sodium fluoride dissolution should be softened whenever the hardness exceeds 75 mg/l, or even less than this figure if the amount of labor involved in clearing blockages or removing scale is excessive.

(4) Siphonage of Solution. In the event that a vacuum is created at the point of injection in a main, direct siphonage of fluoride solution from the source of supply is possible. The problem can occur as a result of pipeline breakage, abnormal hydraulic conditions at the point of application, check valve failure, or other malfunctions. Normal approaches involve the use of air gaps and various valving arrangements to either keep the probability of siphonage to a minimum or restrict the quantity of fluoride available for siphonage.

6-63. Fluoride Concentration Control:

a. Sampling Location and Frequency. Setting equipment for the calculated dosages is not in itself sufficient control for fluoridation. The fluoride ion concentration of the water after thorough mixing must be determined by chemical testing at least once a day. Systems that require manual control of feeding also require a chemical test of residual fluoride after each dosage change. This test should be carried out by the plant chemist or plant operators. The laboratory examinations of the treated water serve as a check on the concentration of the fluoride ion in the water being furnished to the consumer, as well as a check on the operation of the chemical feed equipment. After the best level is determined, deviations greater than 0.1 mg/l should not be tolerated. Each sampling location should be chosen with care. Subsequent treatment processes may lower the fluoride level, prior treatment processes may introduce interfering ions, or the site chosen could result in a nonrepresentative sample if it is a point where, for instance, insufficient mixing has taken place.

b. Fluoride Control Tests. Because the quantity of fluoride ion being measured is so small (usually about 1 mg/l), the analytical method must be adapted to the accurate measurement of these low concentrations. Thus, if a concentration of 1.0 ± 0.2 mg/l is considered the best level for a certain area, the analysis must be accurate to 0.1 mg/l or better to ensure the actual concentration is within these limits. For information on fluoride analysis see section L.

(1) Low Fluoride Readings. If analyses show that fluoride concentrations are consistently lower than determined from chemical dosage calculations, there are a number of possible explanations:

(a) Incorrect Analyses. Assuming that the calculations of fluoride concentrations are correct, the accuracy of the analysis becomes one of the first questions. Various interfering substances can cause errors in the analyses. Aluminum, from the coagulant alum, can interfere with the colorimetric test. High iron concentrations interfere with the SPADNS method of analysis. In very high concentrations, both chloride and forms of alkalinity can also interfere.

(b) Chemical Purity. Incorrect dosage calculations can be caused by using the wrong purity of the chemical form of the fluoride used. For instance, the purity of fluosilicic acid can vary from 20 to 30 percent. If the purity specified by the manufacturer is questionable, the acid should be analyzed for fluoride content.

(c) Incomplete Solution. It is possible, particularly with sodium silicofluoride, that the chemical does not dissolve completely. This could be caused by an insufficient detention time, an incorrect waterflow rate, or poor baffling in the feeder dissolving chamber.

(d) Incomplete Mixing. With manually prepared solutions, incomplete mixing or improper measuring of the chemical or water could cause errors in the fluoride concentration.

(2) High Fluoride Readings:

(a) Chemical purity and analysis techniques may be sources of error when fluoride concentrations determined by analysis are consistently higher than those determined by calculation.

(b) The presence of polyphosphates is the usual cause of an analytical error in the positive direction. Failure to eliminate chlorine from the water sample can also lead to higher results in colorimetric analyses.

(c) Failure to take into account the fluoride content of the raw water may also result in adding more fluoride than is needed. Fluoride content of surface water can vary considerably and should be analyzed daily in order that the correct dose can be calculated. If the water supply comes from wells, the variability is much less, but in the case of higher than calculated fluoride concentration, this possibility should also be investigated.

(3) Varying Fluoride Readings. The most difficult type of problem to solve is when fluoride concentration is variable, even though calculations show that the fluoride feed rate is in the desired proportion to waterflow rate. Almost all of the factors which can produce consistently low or high fluoride analyses can also produce variable errors.

(a) Check on the delivery rate consistency by taking weight measurements at short intervals.

(b) One cause of varying fluoride content in a treated water system is the addition, on an intermittent basis, of unfluoridated water into the system. This could be from a well or other connection to another system or from a storge reservoir containing unfluoridated water that is a part of the system.

(c) Sampling just below the point of fluoride injection may cause varying readings due to insufficient mixing.

6-64. Defluoridation—General Information:

a. Requirements. If the natural fluoride content of the water supply exceeds the maximum recommended value for the particular area and blending cannot be practiced, excess fluorides must be removed by defluoridation. Although several methods have been studied for removing fluorides, three methods show the most promise: magnesia, calcium phosphate (bone char), and calcined (activated) alumina. The choice of method for defluoridation, as in other treatment processes, depends on the rate of water consumption, characteristic of the raw water, and economy. In plants using lime softening to reduce hardness, fluorides may be reduced by using magnesia. In the magnesia method, the fluorides are removed along with magnesium. Both the fluorides and magnesiums are subsequently removed by settling. In plants where lime softening is not used, pressure contact filters that use calcium phosphate or activated alumina may be more economical. Activated alumina and bone char are used as media in a filter tank, removing fluorides as the water percolates through. The media is periodically regenerated by chemical treatment when it becomes saturated with the fluoride removed from the water.

b. Methods:

(1) Magnesia. Additional lime is sometimes used in lime softening plants for removing fluorides. The amount of fluoride removal is a function of the magnesium removed. It is approximately equal to 7 percent of the initial fluoride times the square root of the quantity of magnesium removed as shown in the following equation:

$$F_R - F_T = 0.07\, F_R \sqrt{Mg_R - Mg_T}$$

where:

F_R = Fluorides in raw water (mg/l)
F_T = Fluorides in treated water (mg/l)
Mg_R = Magnesium in raw water (mg/l)
Mg_T = Magnesium in treated water (mg/l)

Between 45 and 65 mg/l magnesium removal is required for each mg/l of fluoride reduction. When magnesium content of the raw water is too low for adequate fluoride removal, it may be incrased by adding the proper amount of dolomitic lime, magnesia, or magnesium sulfate before or during the lime softening process. Because of the large quantities of chemical required, this process is suitable only for fluoride waters in the 3 or 4 mg/l range that require softening.

(2) Calcium Phosphate (Bone Char). Bone char has an affinity for fluoride and was one of the first methods used commercially for removing fluorides from water. Synthetic calcium phosphates, such as hydroxyapatite, are also used. The granular calcium phosphate or activated bone char is supported on a graduated bed of gravel placed on the bottom of the filter tank. The material, which is from 2 to 5 feet in depth (depending on the rate of flow and amount of fluoride to be removed), can be regenerated when the unit has become saturated with fluoride. The fluoride removal capacity of the material is about 450 grams of fluoride per cubic foot. When the bone char is saturated with fluoride, it is regenerated by backwashing to remove accumulated sand and then a 1 percent solution

of caustic soda is pumped through the media. After the fluorides have been removed by the caustic, the excess caustic remaining in the bone char must be removed by rinsing the bed with raw water until the pH of the effluent approaches that of the raw water. Treated water is not required for regeneration, while about 150 gallons of raw water is used for rinsing each cubic foot of bone char. The volume of water defluoridated between generations depends on the initial fluoride content and the optimum fluoride residual period. The filter and regeneration tanks are specially constructed and lined with corrosion resisting material.

(3) Calcined (Activated) Alumina. Activated alumina, a commercial drying agent for air conditioning equipment, may be economically used for defluoridation. The fluoride removal capacity of the material varies with characteristics of the raw water. Equipment and operation are much like those used with calcium phosphate. When the alumina no longer removes fluoride, the material must be regenerated by backwashing with raw water to remove accumulated solids, then flushed with a weak caustic solution to remove fluorides which have been absorbed by the medium. The next step is to neutralize the residual caustic with a weak sulfuric acid solution followed with final water rinses. The total amount of raw water required for regeneration is approximately 150 gallons per cubic foot of alumina.

6-65. Safety Measures. Water works operators who handle fluoride compounds must realize the toxic nature of these compounds and avoid accidental exposure. Overexposure to fluoride chemicals can result from ingestion, inhalation, or bodily contact with spills.

a. Dust Control. Perhaps the greatest chance for overexposure to fluoride chemicals comes from the inhaling dust. While masks and other protective devices are required, everything possible should be done to keep dust to a minimum. Fluoride sacks should not be dropped and should be opened slowly with an even slit at the top to avoid tearing down the sides. Good ventilation is absolutely necessary in work areas, even if masks are worn and no visible dust can be seen. Dust must be removed at once from the skin by bathing or washing. Spilled fluorides should be removed by wet mopping. Safety with dry powdered chemical can be increased by selecting a greater mesh size that produces less dust.

b. Acid Control. Hydrofluosilicic acid should be treated with respect. Fortunately, it is seldom necessary to handle it in any way other than pumping it through pipes or tubing. If at all possible, it should never be diluted before feeding. The rooms in which acid equipment is housed should be continuously ventilated and the spent air exhausted to the outdoors. All vents on tanks should terminate outdoors in a gooseneck fitting. Acid spills can be neutralized by lime water. Hands should be washed after each loading and daily showers should be taken if the loadings are prolonged. The absorption of fluorides through the skin is negligible, but the acid is corrosive and it is this characteristic that constitutes a hazard in skin contact. Careful handling, quick rinsing of spills or splashes, the use of respirators, and adequate ventilation are the best safety measures.

c. Safety Equipment and Protective Clothing. Operators should always wear rubberized gloves, plastic or rubber aprons, boots, goggles, and respirators when exposed to fluorides. Hydrofluosilicic acid requires large amounts of flowing water for flushing the eyes and rinsing the hands and other parts of the skin.

d. Fluoride Exposure Symptoms. Overexposure to fluorides can cause a variety of symptoms. Vomiting, stomach cramps, and diarrhea are generally the first symptoms to appear in acute poisoning cases. More specific symptom descriptions can be related to the type of exposure or ingestion of fluoride.

(1) Ingestion. When large amounts of fluoride are ingested, the victim's vomit may be white or colored if the fluoride contains dye. Usually the victim becomes very weak, is thirsty, has disturbed color vision, and has difficulty speaking.

(2) Inhalation. Symptoms of acute poisoning by inhalation are sharp biting pains in the nose followed by discharge and bleeding from the nose.

(3) Acid Spill. If exposure is from splashing, the parts of the body affected experience a tingling or burning sensation. Severe eye irritation results if acid splashes into the eye.

6-66. Requirement for Keeping Records:

a. Daily records of fluoride residuals must be maintained. Samples for fluoride analysis should be collected from the water before fluoridation, following the point of fluoride application and the distribution system sampling point. Distribution system sampling points should be numbered and noted by building number. Enter the time the sample was collected.

b. Weight or volume of fluoride chemical or solution fed daily should be recorded.

c. Fluoride feeder rate of feed settings and times of changes should be recorded daily.

d. The quantity of fluoride added and the average results of fluoride tests must be recorded daily on the water utility operating log.

Section H—Disinfection

6-67. Need for Disinfection. Disinfection is the water treatment process that destroys or inactivates disease-causing (pathogenic) organisms. However, disinfection does not necessarily result in sterilization (destruction of all living organisms). All new, altered, or repaired water supply facilities must be disinfected before filtration or sometimes before coagulation and sedimentation to prevent the growth of organisms in the treatment plant. Disinfection after filtration is always required to kill remaining organisms and to provide a safeguard against recontamination. Well water is usually free of pathogenic organisms but is nevertheless usually disinfected as a safeguard.

6-68. Disinfection Agents:

a. Chlorine. Chlorine is the disinfectant agent usually specified for military use. Presently, this is the only widely accepted agent that destroys organisms in water and leaves an easily detectable residual that serves as a tracer element. Sudden disappearance of chlorine residual signals potential contamination in the system. Chlorine is available at a reasonable cost in forms that may be accurately applied. No other available disinfectant is as acceptable or adaptable for potable water treatment operations as chlorine. A major disadvantage is that chlorine reacts with certain organic compounds to form trihalomethanes. One such compound, chloroform, has been identified as carcinogenic and consequently the primary drinking water standards include limits on trihalomethanes. Section L discusses how to control these compounds.

b. Ozone. Ozone is an unstable form of oxygen that kills organisms faster than chlorine. Ozone, as a disinfection agent, is less influenced by pH and temperature of water than chlorine. Another advantage of ozone is that it does not form compounds that create or intensify odors in the water. The main disadvantage of ozone is that no lasting residual disinfecting action is provided. Also, because of its instability, ozone is usually generated at the point of use. Electric energy requirements and capital and operating costs for ozone generation are quite high. The process is not as readily adaptable to variations in flow rate and water quality as chlorine.

c. Chlorine Dioxide. Chlorine dioxide (ClO_2) is red-yellow gas with a very irritating odor. It has over 2½ times the oxidation capacity of chlorine, but its rate of reaction is slower and the mechanism of disinfection completely different. Normal feed rates of 0.5 to 2.0 mg/l are required for microbial disinfection. It is effective over a broad pH range (5–9) and is not affected by sunlight. A major advantage of chlorine dioxide is that it does not hydrolyze in water and will not react with organic compounds to form trihalomethanes. However, because it is highly unstable, chlorine dioxide must be generated on site.

d. Other Disinfectants:

(1) Some physical agents (such as heat, ultraviolet radiation, metal ions, and pH adjustment) result in disinfection but are not practical on a large or continuous basis.

(2) Other chemical disinfectants include iodine, bromine, and potassium permanganate. Economics and germicidal effectiveness generally limit the use of these chemical oxidants.

6-69. Chlorination Principles:

a. Chlorine Reactions:

(1) When chlorine is added to water, the following reaction occurs:

$$Cl_2 + H_2O = HOCl + HCl$$

Chlorine + Water = Hypochlorous Acid + Hydrochloric Acid

Each molecule of chlorine (Cl_2) reacts with one molecule of water (H_2O) to form one molecule of hypochlorous acid (HOCl) and one molecule of hydrochloric acid (HCl). Hypochlorous acid disassociates in water to form hydrogen and hypochlorite ions as follows:

$$HOCl = (H^+ + OCl^-)$$

Hypochlorous acid is more effective as a disinfecting agent than the other reaction products, HCl, H^+, and OCl^-.

(2) Chlorine added to water may react with ammonia to form monochloramines (NH_2Cl), dichloramines ($NHCl_2$), and trichloramines (NCl_3). The relative amount of each depends on the amount of chlorine and ammonia present and the pH. The reactions that occur are as follows:

$$NH_3 + HOCl = NH_2Cl + H_2O$$
$$NH_2Cl + HOCl = NHCl_2 + H_2O$$
$$NHCl_2 + HOCl = NCl_3 + H_2O$$

Chloramines are capable of disinfection, but act slower and less effectively than hypochlorous acid or hypochlorite ions.

(3) Chlorine also reacts with other compounds in solution in the water supply. When these reactions occur, the chlorine is not available for disinfection. Chlorine required to react with chlorine destroying compounds is called the chlorine demand which must be satisfied before disinfection can begin. Some of the compounds in a water supply that exert a chlorine demand include iron, manganese, hydrogen sulfide, ammonia, and miscellaneous organic compounds. Sufficient chlorine must be added to the water supply to satisfy the chlorine demand, in addition to the amount required for actual disinfection.

(4) Chlorine remaining after the chlorine demand is satisfied is termed chlorine residual which is a measure of the amount of chlorine compound available in a water supply for disinfection. Total residual chlorine is the sum of free available residual chlorine and combined available residual chlorine. Free available residual chlorine is that part of the total residual chlorine remaining in water at the end of a given contact time which will react as hypochlorous acid or hypochlorite ion. Combined available residual chlorine is that portion of the total residual chlorine remaining in water at the end of a given contact time which reacts as chloramines or organic chloramines.

b. Types of Treatment:

(1) Combined Residual Chlorination. Combined residual chlorination involves applying chlorine to water to produce a combined available chlorine residual and to maintain that residual throughout the water treatment plant or the distribution system. Combined available chlorine forms are less effective as disinfectants than free available chlorine forms. About 25 times as much combined available residual chlorine is required to obtain equivalent bacterial kills as required for free available residual chlorine under the same conditions of pH, temperature, contact time. About 100 times longer contact is required to obtain equivalent bacterial kills for equal amounts of combined versus free available chlorine residuals under similar conditions. Combined residual chlorination is often used

to control algae and bacterial aftergrowth in potable water distribution systems. Combined chlorine residuals can maintain a stable residual throughout the system to the point of usage at the consumer tap. In some cases, free residual chlorination is practiced to ensure effective disinfection, followed by the addition of ammonia to convert the free residual to a combined available residual.

(2) Free Residual Chlorination. Free residual chlorination practice involves producing a free available chlorine residual through part or all the water treatment plant or distribution system. Free available chlorine residuals are formed from applying chlorine to water, if the water contains no ammonia or other nitrogenous materials. If the water does contain ammonia and combined available chlorine residuals are formed, sufficient chlorine must be added to destroy the combined chlorine residual. Free residual chlorination provides effective disinfection with a contact period of about 10 minutes, whereas combined chlorine residual requires at least 60 minutes. Changes in pH and temperature do not markedly affect the disinfecting powers of the free chlorine residual, while a combined chlorine residual must be increased significantly with increases in pH and decreases in temperature. For many waters, taste and odors are diminished by using a free residual. When practicing free residual chlorination, it is recommended that at least 85 percent of the total chlorine residual be of the free available type.

(a) Breakpoint Chlorination. Breakpoint chlorination is the application of chlorine to produce a residual of free available chlorine, with minimum combined chlorine present. As chlorine is added to water containing ammonia, chloramines are formed. With additional application chlorine residuals increase and generally reach the maximum when the molar ratios of chlorine are equal. As greater dosages of chlorine are applied and the ratio of chlorine to ammonia increases, the ammonia is oxidized by the chlorine and the chlorine residual is reduced. When approximately 10 mg/l of chlorine have been added for each mg/l of ammonia present, chloramine residuals decline to a minimum value. This is defined as the breakpoint and represents a point where further addition of chlorine produces a free residual (figure 6-30). The actual amount of chlorine required to arrive at the breakpoint has been reported to vary between 7 and 15 times the ammonia nitrogen content of the water. Due to the presence of organic and other chlorine reactive materials; however, 25 times as much chlorine as ammonia nitrogen content may be required to reach breakpoint. Beyond breakpoint, the residual should have at least 90 percent free available residual chlorine. The rate of the breakpoint reaction appears to be most rapid between a pH of 7 and 8 and increases with increasing temperature. At pH levels below 8, nitrogen trichloride can be formed following breakpoint treatment, and can impart odors to the water. The water must be exposed to air to provide for the release of nitrogen trichloride.

(b) Superchlorination—Dechlorination. Superchlorination is the application of excess chlorine for destroying taste and odors. The surplus chlorine is later removed by aeration or by dechlorinating agents such as sulfur dioxide or activated carbon.

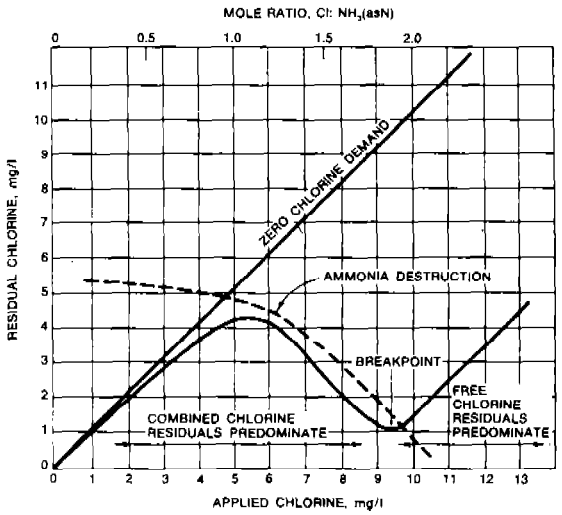


Figure 6-30. Representative Breakpoint Chlorination Curve (N = 1 mg/l).

(3) Chlorine Treatment Policy. Policy on the type of chlorine treatment, chlorine residuals, and chlorine contact times is set by higher level command.

c. Organism Kill. The effectiveness of the disinfection process depends on the following factors:

(1) Chlorine Residual. Effectiveness increases rapidly with increase in residual. As discussed previously, the type of chlorine residual, combined or free, has a great affect on bactericidal effectiveness.

(2) Contact Time. Contact time is defined as the time elapsing between the introduction of the chlorine and the use of the water. The required contact time is inversely proportional to residual, within normal limits. If the residual is halved, required contact period is doubled.

(3) Water Temperature. Greater disinfection efficiency is obtained in warm water than in cold water. Longer contact time or increased chlorine dosages are required when the water temperature is low. Effectiveness of free chlorine at 35 °F is about half of that at 70 °F.

(4) The pH Level. The pH level of the water determines the relative amounts of hypochlorous acid and hypochlorite ion concentrations. At relatively low pH levels, the predominant form of chlorine is hypochlorous acid (HOCl). Hypochlorous acid is a much more effective disinfectant ion than hypochlorite ion. Therefore, effectiveness of free chlorine is highest at pH 7.0 and lower (figure 6-31).

(5) Bacterial Susceptibility. Different strains of bacteria exhibit varying susceptibility to chlorination. Viruses and cysts are not always completely inactivated at chlorine residual levels generally used in water treatment practice.

d. Mixing Requirement. To be effectively disinfected, chlorine and water to be disinfected must be completely and uniformly mixed. Studies have concluded that residuals formed initially (within the first minutes of contact) are more bactericidal than compounds formed later. Rapid initial mixing allows the more lethal residuals to react with bacteria and provide more effective disinfection.

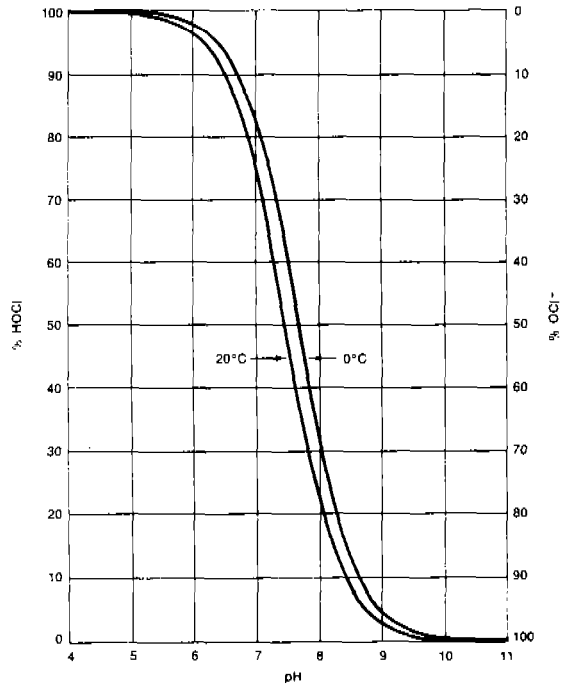


Figure 6-31. Distribution of HOCl and OCl^- in Water at Indicated pH Levels.

e. Application Points. Plain or simple chlorination is the single application of chlorine treatment before the treated water is discharged to the distribution system, as in chlorination of ground water supplies and previously unchlorinated purchased supplies. Prechlorination is the application of chlorine to water before any other unit treatment processes. Postchlorination is the application of chlorine to water following other unit treatment processes, usually for disinfection and to provide residual chlorine in the distribution system after filtration. Rechlorination involves the application of chlorine to water, following previous chlorination treatment, at one or more points in the distribution system or into a previously chlorinated purchased supply to maintain the chlorine residual. The above applications are usually continuous. Very heavy chlorination for a limited period is sometimes applied at specific points of the distribution system to counteract localized contamination.

6-70. Chlorine Compounds:

a. Gaseous Chlorine. At ordinary temperatures and pressures, chlorine exists as a greenish-yellow gas and is about 2½ times as heavy as air. Chlorine gas is a respiratory irritant, and most people can smell concentrations in air above 3 mg/l. Chlorine gas is compressed into an amber-colored liquid, and contained in heavy steel cylinders for transportation and storage. Unconfined liquid chlorine rapidly vaporizes with one volume of liquid chlorine yielding about 450 volumes of gaseous chlorine. Chlorine confined in a container may exist as a gas, a liquid, or both. The gas vapor pressure of chlorine in the container is a function of temperature and is independent of the volume of chlorine in the cylinder. Therefore, weight of the cylinder and contents, rather than gage pressure, is used as an indication of quantity of chlorine available. The temperature pressure characteristics of chlorine are shown in figure 6-32. As the chlorine temperature increases, so does the pressure. Although chlorine is not explosive or flammable, it is capable of supporting combustion of certain substances. Chlorine should not be handled or stored near other compressed gases (such as ammonia) or flammable materials. Dry chlorine, either gas or liquid, is not corrosive to most common metals. Moist chlorine, however, is corrosive to almost all common metals.

b. Hypochlorites:

(1) Hypochlorite Forms:

(a) General. Hypochlorites can be classified as either dry or liquid, depending on commercial availability. The same equilibrium is established in water as with gaseous chlorine. However, hypochlorites added to water to form hypochlorite solutions contain an excess of alkaline material, which tends to increase the pH. If the pH of the hypochlorite and water mixture is raised high enough, calcium in the water and in calcium hypochlorite precipitate as calcium carbonate sludge. If this occurs, the hypochlorite and water mixture must be allowed to stand so that the calcium carbonate may settle out. After settlement, the liquid hypochlorite solution can be decanted into a separate tank for use. Hypochlorite solutions are stored in rubber lined or polyvinyl chloride (PVC) lined steel tanks and are fed through fiberglass, Saran-lined, or PVC piping. Dry hypochlorite should not be stored or used in the presence of oil because of the potential for fire.

(b) Calcium Hypochlorite. High-test calcium hypochlorite ($Ca(OCl)_2$) products contain about 65 percent available chlorine and from 3 to 5 percent lime. Calcium hypochlorite is available in granular, powdered, or tablet forms and is readily soluble in water. Granular and tablet forms can be shipped in 35- or 100-pound drums, cases, or smaller reusable cans.

(c) Lithium Hypochlorite. Lithium hypochlorite (LiOCl) contains about 35 percent available chlorine, readily dissolves in water and does not raise the pH as much as other hypochlorite forms. Lithium hypochlorite is available in granular form. It is generally used for disinfecting swimming pool water.

(d) Sodium Hypochlorite. Sodium hypochlorite (NaOCl) is available commercially only in liquid form. Household bleach is a sodium hypochlorite solution containing about 5 percent available chlorine. The usual concentration of sodium hypochlorite is between 5 and 15 percent available chlorine. The solutions are clear, light yellow, strongly alkaline, and corrosive. It is shipped in plastic jugs, carboys, and rubber-lined drums of up to 50-gallon volumes. Sodium hypochlorite solution is also shipped in bulk by trucks.

NOTE: Addition of sodium to the potable water supply may be hazardous to persons with hypertension or on low- or no-sodium diets.

(2) Hypochlorite Usage. Hypochlorite compounds are especially suitable for emergency and field disinfection. They are also used at many small installations serving up to approximately 5,000 persons or where safety conditions

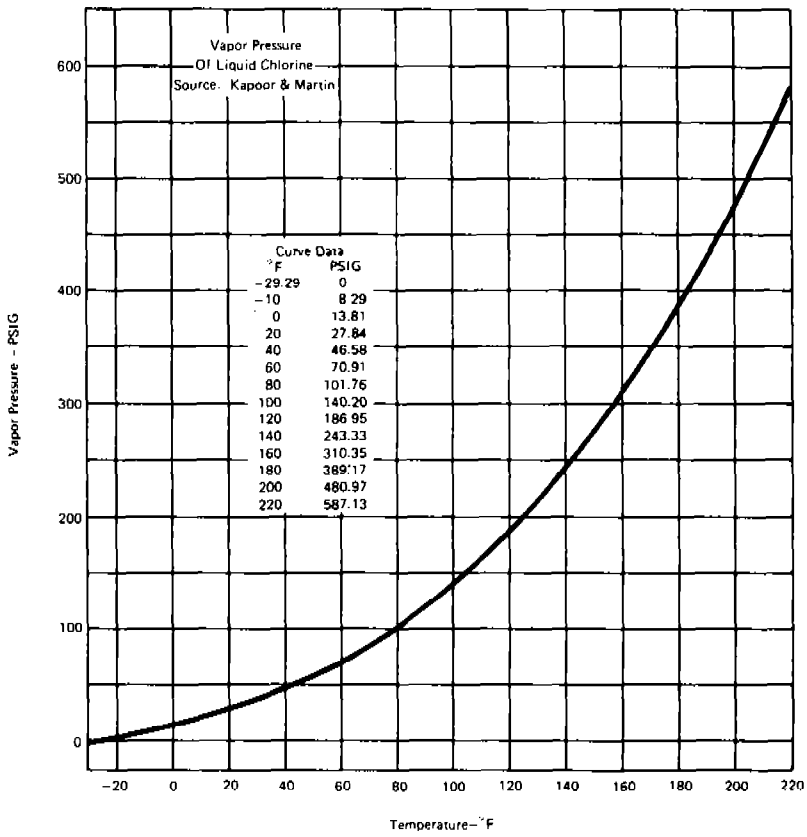


Figure 6-32. Vapor Pressure of Liquid Chlorine.

are the chief determinant in selection of chlorine forms. Chlorine in gaseous form, however, is the most widely used form for disinfection in medium-sized and large installations.

(3) Hypochlorite Storage. High-test hypochlorites are relatively stable. Storage at temperatures below 86°F reduces the rate of deterioration. Unlike calcium hypochlorite which can be stored for up to a year, sodium hypochlorite solutions have a shelf life of only 60 to 90 days. Sodium hypochlorite solutions should be stored in dry, cool, and darkened areas, or in containers protected from light.

(4) On-Site Generation of Hypochlorite. Although more expensive than gaseous chlorine, hypochlorite storage and usage is safer than gaseous chlorine. As a result, on-site manufacture of sodium hypochlorite is being practiced to reduce transportation and storage costs associated with outside purchase and shipment. Several commercial systems are available for producing sodium hypochlorite electrolytically from sodium chloride (NaCl). The electrolytic cell converts the chloride ion to hypochlorite ion according to the following equation:

$$NaCl + H_2O + Energy = NaOCl + H_2$$

Sodium Chloride + Water + Energy = Sodium Hypochlorite + Hydrogen Gas

The raw materials required for hypochlorite ion production are power, water, and salt in a brine solution or in seawater. Calcium and magnesium in the brine form precipitates that can foul the system, so it is desirable that both the salt and water be as free from hardness as possible. Commercial on-site generation units usually consist of a tank in which concentrated brine is produced and stored, a water softener in which dilution water is treated for hardness, electrolytic cell with its power supply and rectifier, and a tank for storing the hypochlorite solution. Water is required for cooling the electrolyte cell. The entire system is generally automated and has automatic shutdown features in the case of malfunction.

c. Chlorine Dioxide. Chlorine dioxide, ClO_2, is a powerful germicide. It is produced by adding sodium chlorite, $NaClO_2$, solution at the discharge end of a gas chlorinator and running the mixture through a small contact chamber before introducing it into the water. At equivalent dosages, this chemical costs more than chlorine gas. It may be applied as posttreatment with postchlorination to destroy chlorophenol taste and odors. When used to oxidize iron and manganese, it usually is applied before coagulation, settling, and filtration, with later addition of chlorine for disinfection.

6-71. Chlorine Containers:

a. Types. Under pressure, chlorine is transported and stored as a liquid in steel cylinders. These cylinders are equipped with one or more safety devices, and are presure-tested at specified intervals. Chlorine containers have fusible metal plugs that melt at about 165°F, allowing the contents of the container to discharge to the atmosphere. Melting of the fusible metal plugs protects the containers

against rupture in the event of overheating.

(1) 150-Pound Cylinders. The most popular size cylinder for water utility practice has a capacity of 150 pounds of chlorine. The cylinder is filled with liquid chlorine to about 85 percent of total volume, with the remaining 15 percent occupied by chlorine gas. The valve connection at the top of the cylinder is the only opening. Therefore, only gaseous chlorine is withdrawn from the cylinders. All cylinders have a fusible plug that is an integral part of the standard operating valve. Cylinders of 150-pound capacity are approximately 10½ inches in diameter, about 55 inches high, and have an empty weight of approximately 95 pounds.

(2) Ton Containers. Ton containers for chlorine are welded, cylindrical steel tanks. They usually have convex ends and the sides are crimped inward for ease in lifting. Containers are usually equipped with 6 fusible plugs, 3 in each end, located 120° apart. Each container is equipped with 2 operating valves at one end. Each of the operating valves is connected inside the container to an induction pipe that ends near the sidewall (figure 6-33). Ton containers are always placed in a horizontal position with the valves in a vertical line, one above the other. In this position, gas is discharged when the upper valve is opened. This allows the selection of either gaseous or liquid chlorine withdrawal. Connections should be tested by passing ammonia vapor near the connections. A white vapor cloud indicates a leak. Ton containers have a diameter of about 30 inches and an average length of about 80 inches. The empty weight is about 1,500 pounds. The containers are filled with about 2,000 pounds of chlorine.

b. Handling Containers:

(1) 150-Pound Cylinders. Cylinders are designed to stand upright, and should not be rolled on their sides. When unloading from trucks or platforms, cylinders must not be dropped to ground level. A handtruck should be used for moving the cylinders from the delivery point to the storage area. Cylinders being moved should always have the valve protection hoods in place. Valve protection hoods are not a proper means of lifting cylinders.

(2) Ton Containers. Ton containers can be moved by trucks and dollies, overhead crane systems, or by rolling. When the containers are lifted, a suitable clamp with a hoist or crane of at least 2-ton capacity should be used. Valve protection hoods should always be in place when ton containers are moved.

c. Container Storage. Containers must be protected from sunlight or other heat sources. If containers are stored outside, they should also be protected from accumulations of rain, ice, and snow. Cylinders must be chained or tied to a solid support to prevent them from tipping or falling. Ton containers must be chocked or cradled to prevent rolling. The valve must be closed on empty containers that are removed from service to prevent moisture from entering the container during storage and transport. The valve protective hood should be kept in place on all containers not in use. Cylinders should be stored in an upright position, while ton containers are stored in a horizontal position. Storage areas should be clean, cool, well ventilated, and fire resistant. Storage in subsurface locations should be avoided.

d. Cylinder Connections:

(1) Gas Withdrawal. Pressure in the chlorine container keeps most of the chlorine in liquid form at ordinary temperatures. When the container valve is opened and gas withdrawn, pressure in the container is relieved and more liquid passes into the gaseous form. The change from liquid to gas requires heat from the surrounding air through the container walls. If gas is drawn off too rapidly, so much heat is taken from surrounding air that frost forms on the container. Maximum sustained safe rates for drawing off gaseous chlorine are 400 pounds per day from each 1-ton container and 40 to 50 pounds per day from each 150-pound cylinder. If the gas discharge rate from a single chlorine cylinder or ton container is not adequate, two or more may be connected to a manifold and discharged simultaneously. Never try to accelerate chlorine gas withdrawal by heating containers or placing them in hot water. This might melt the fusible plugs in the container and allow the chlorine to escape. In addition, the hot iron of the cylinder and the dry chlorine is highly reactive. When a supply header is used, the temperature of all containers connected together must be equal and remain equal during use. If containers of unequal temperature are manifolded together, gas will flow from the warmer container (or containers) and condense in the cooler container (or containers), overloading the cooler container (or containers) with liquid. If the valve of the cooler container (or containers) is then closed, and the ambient temperature increases, expansion of the liquid chlorine could exert sufficient pressure to rupture the container. The temperature of the container storage area should be kept lower than the temperature of the chlorinator area if possible. Chlorine valves should be opened slowly and carefully, using a wrench of proper size (no longer than 6 inches) without an extension on the wrench. Valves should be opened only part way; one full

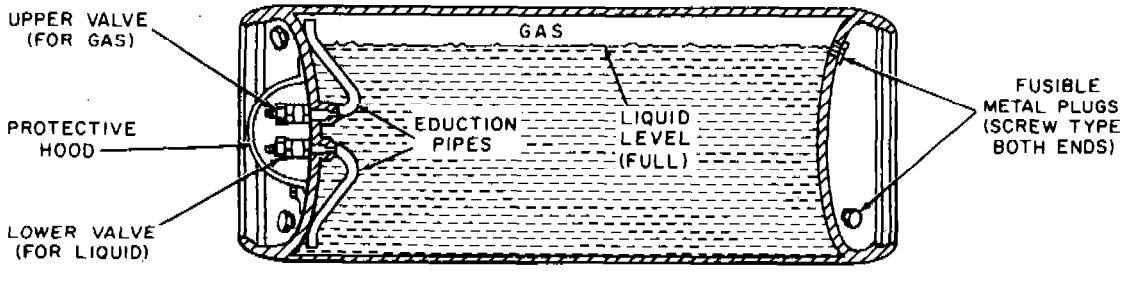


Figure 6-33. Cross-Section Diagram of Chlorine Ton Container.

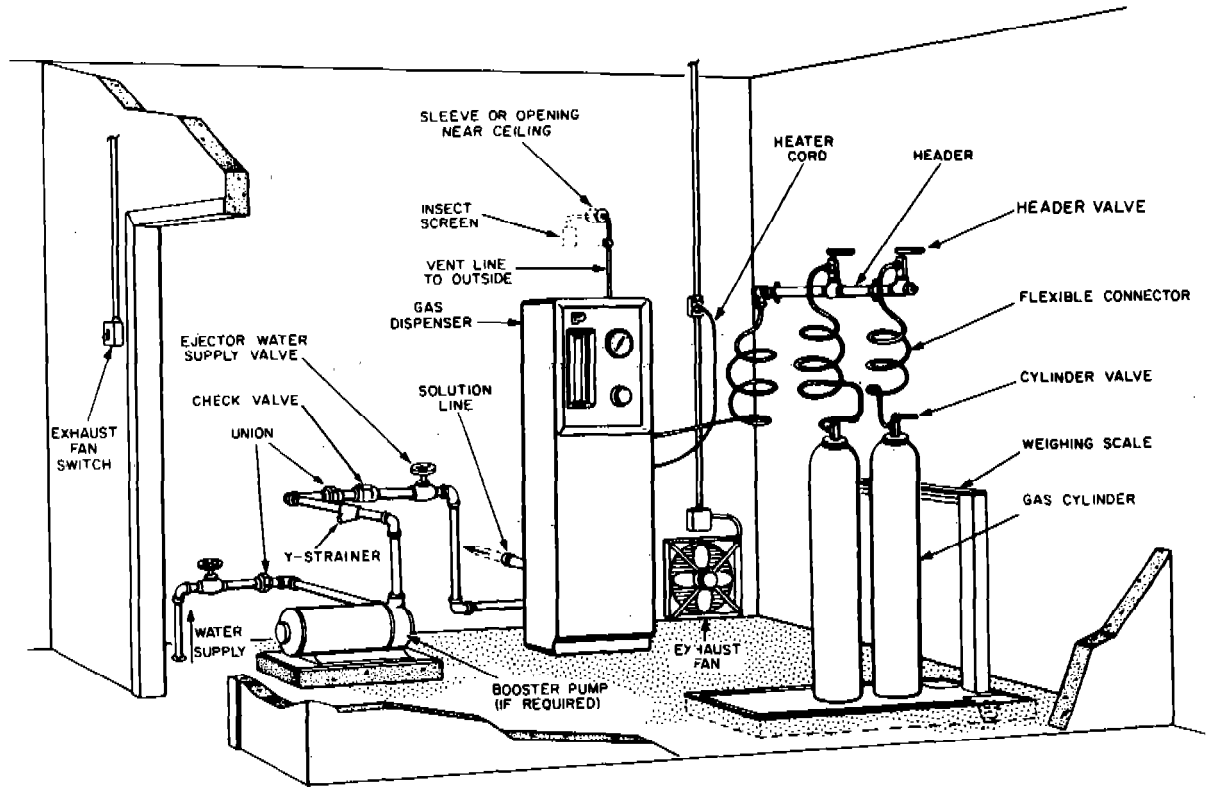


Figure 6-34. Typical Chlorinator Installation Utilizing Gas Withdrawal.

counterclockwise turn of the valve stem permits the maximum discharge. A light tap with a wrench aids the operation of stuck valves. A typical chlorination installation that uses gaseous chlorine withdrawal from 150-pound containers is illustrated in figure 6-34.

(2) Liquid Withdrawal. If sufficient chlorine cannot be withdrawn from several cylinders manifolded together, liquid chlorine may be withdrawn from the lower valve on a ton container. Usually, liquid chlorine is not withdrawn unless chlorine usage is required at a continuous rate greater than 1,500 pounds per day. Evaporators provide the necessary heat to vaporize the liquid chlorine to the gaseous state. After the liquid chlorine is vaporized, it is handled in the normal fashion through the other components of the chlorination system. As with supply headers used for gaseous withdrawal, the temperature of all containers connected to a liquid withdrawal header must be equal and remain equal during use. If containers do not have equal temperatures, liquid chlorine will flow form the warmer container into the cooler container, overloading the cooler container with liquid. Also, liquid chlorine should never be trapped between two closed valves in a pipeline as dangerous pressures could result. A typical chlorination installation that uses liquid chlorine withdrawal from ton containers is illustrated in figure 6-35.

(3) Piping and Valves. Chlorine gas, liquid, and solution are transmitted through piping and valves constructed of materials that do not react with or be corroded by the material being transmitted. Substitution of other materials of construction is not allowed.

(a) Flexible pipe connectors are specifically constructed ⅜-inch soft seamless copper tubing, fitted with 2 leaded naval brass coupling adapters and coupling nuts. The assembly is cadmium plated and tested at an operating pressure of 300 pounds per square inch (psi).

(b) Rigid pipe must be Schedule 80, seamless carbon steel of ¾-inch or 1-inch size, as required.

(c) Threaded pipe joints are made up using Teflon tape or a mixture of litharge and glycerine (prepared by mixing a quantity of litharge with just enough glycerine to form a thin paste). Flanged connections are made up using flanged unions of the tongue and groove ammonia type. Gaskets must be lead or bonded asbestos fiber and must be used in all flanged unions.

(d) Globe or ball-type valves with bodies of forged carbon steel material are used for shutoff service.

(e) The chemical solution line that extends from the chemical solution outlet connection of the injector to the solution distributor is usually constructed of Schedule 80 PVC rigid plastic pipe and fittings, Schedule 40 rubber-lined cast iron fittings or Saran-lined steel pipe with Saran-lined cast iron fittings.

e. Recommended Inventory of Chlorine Containers. A list of recommended inventory of chlorine containers is in table 6-12.

f. Weighing Scales. Weighing scales are an ideal method for determining the weight of chemical used each day, as well as the quantity of liquifying gas remaining in the container or containers still in use. The scale makes it possible to estimate the time for container replacement. Platform

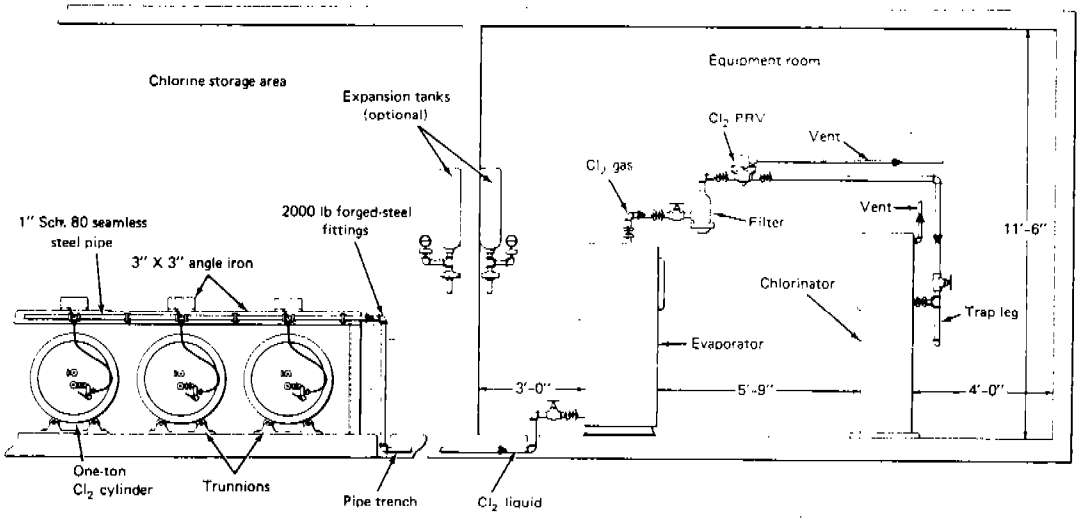


Figure 6-35. Typical Chlorinator Installation Utilizing Liquid Withdrawal.

scales for cylinders should be recessed so that the platform is flush with the floor, or a suitable ramp must be constructed to make loading and unloading the cylinders easier. Many modern scales are designed to permit zeroing out the weight of the empty container, thereby providing a direct indication of the liquid chemical remaining.

g. Automatic Switchover Systems. Most chlorinator equipment manufacturers offer automatic switchover systems that switch chlorine feed from an empty chlorine source to a full one without interrupting service. The systems are vacuum operated and may be equipped to provide an alarm signal when either chlorine source is exhausted.

6-72. Chlorination Equipment:

a. Gas Chlorinators:

(1) Direct Feed. Chlorinators of this type are used chiefly as emergency equipment and in small installations where it is not possible to obtain a water supply suitable for operating a solution-fed, vacuum-operated machine. They cannot be used where the pressure of the water being treated is more than 20 psi, and the only standard mode of operation available is the simple manual type. Gas-feed rate is adjusted by positioning the manual rate valve. Because chlorine is under pressure as a gas at all times, direct-feed chlorinators are highly susceptible to gas leakage into the atmosphere which causes adjacent equipment and structures to corrode. The manufacturer's recommendations and instructions should be followed by the equipment operator. The operator must be thoroughly familiar with the equipment in order to ensure its proper operation, adjustment, and minor repair.

(2) Solution Feed. This type of chlorinator introduces chlorine gas into the water supply by a chlorine solution. The chlorine solution is usually formed by drawing chlorine gas into a jet stream of water at the low pressure point of the injector mechanism of the chlorinator. Two general types are used: the bubbling or pulsating, reduced pressure type, and the vacuum type. The vacuum type is the

Table 6-12. Recommended Chlorine Inventory.

Maximum Chlorine Use (lbs per 24 hr)	Inventory of Chlorine Containers			Approximate Total Supply (days)
	In Service	In Reserve	In Storage Or In Transit	
10	2—150 lb cylinders	2—150 lb cylinders		60
40	2—150 lb cylinders	4—150 lb cylinders	4—150 lb cylinders	37
100	4—150 lb cylinders	4—150 lb cylinders	10-15—150 lb cylinders	27-34
200	6—150 lb cylinders	6-10—150 lb cylinders	20-30—150 lb cylinders	24-34
	or			
	1-2—ton containers	1—ton container	1—ton container	30-40
400	10—150 lb cylinders	10-20—150 lb cylinders	50-60—150 lb cylinders	26-34
	or			
	1-2—ton containers	1—ton container	3—ton containers	25-30
1000	4—ton containers	2—ton containers	7-9—ton containers	26-30
1500	4—ton containers	4—ton containers	10-15—ton containers	24-30
2000	6—ton containers	4—ton containers	10—ton containers & 1 TMU car	35
	or			
	2—ton containers with evaporator	4—ton containers	14—ton containers & 1 TMU car	35

modern form of chlorinator generally installed instead of or used to replace the pulsating type unit. The early bell jar, vacuum type chlorinator is frequently replaced by a more modern type of vacuum operated, solution feed chlorinator.

(a) Pulsating Type. In these units, the gas is metered by displacing water in a volumetric meter that fills and empties at frequent intervals as the chlorine solution is applied to the water. The rate of feed is determined by timing the pulsations of the volumetric meter. A needle valve controls the rate of pulsation. A flow diagram of pulsating type chlorinator is in figure 6-36.

(b) Vacuum Type:

1. These gas chlorinators use a vacuum actuated, spring loaded regulating valve to reduce the gas from a varying supply pressure to a constantly regulated vacuum. Operating vacuum is created by a water jet aspirator, commonly called an injector. The gas is pulled through the various components of the dispenser under vacuum and into the injector where it is thoroughly mixed with the water to form the chlorine solution. This solution is then piped to the main flow of water at the desired point of chemical solution application. Vacuum operated, solution feed gas chlorinators are the safest type of chlorinator. When this type chlorinator is used, the gas flow from the supply system is automatically shut off by the closure of the vacuum actuated, spring loaded regulating valve in the event of loss of operating vacuum. Capacities of up to 8,000 pounds of chlorine a day may be fed through an individual gas chlorinator. Many modes of operation and control are available for regulating the feed rate of a vacuum-operated chlorinator.

2. Injectors are used to create the vacuum required in vacuum operated, solution feed type gas dispensers. The injector also thoroughly mixes the flow of gas with the water to form a chemical solution. Injectors may be of the fixed orifice type, or the variable orifice type. Fixed orifice injectors have a nozzle with a fixed opening though which water is forced under pressure. Variable orifice ejectors have a fixed opening through which protrudes a tapered plug. The position of the plug is adjusted by turning a control knob on the outside of the chlorinator cabinet. The changing plug position causes the size of the opening through which the water is forced under pressure to be varied.

3. A recent development involves the introduction of an all-vacuum system for feeding chlorine. With this system, the chlorinator may be mounted directly on the cylinder, with a vacuum line from the chlorinator to a feed control meter. The injector is mounted directly at the point of chlorine feed so that the line connecting the feed control meter and the injector is also under vacuum. The pressurized chlorine solution line is eliminated with this system. These units are available for mounting directly on a 150-pound cylinder or a ton container.

4. Various types of solution chlorinators flow diagrams are illustrated in figures 6-37 through 6-40.

b. Liquid Chlorine Evaporators. Chlorine evaporators are used to vaporize liquid chlorine from ton containers. Evaporators provide the heat necessary to change the liquid chlorine to a gaseous state so it can be handled in the gas using components of the chlorination system. The evaporator vaporizes the liquid chlorine, but does not cause the chlorine pressure in the system to rise.

(1) The evaporator has a pressure vessel that may be heated by electricity, steam, or hot water. A typical electrically heated evaporator consists of a pressure vessel immersed in a water bath (figure 6-41). The water bath is heated by a thermostatically controlled electric immersion heater. Chlorine liquid is introduced into the pressure vessel by a long tube discharging near the bottom. The liquid chlorine absorbs the heat from the water chamber through the wall of the pressure vessel until it reaches vaporization temperature. As chlorine gas is withdrawn from the pres-

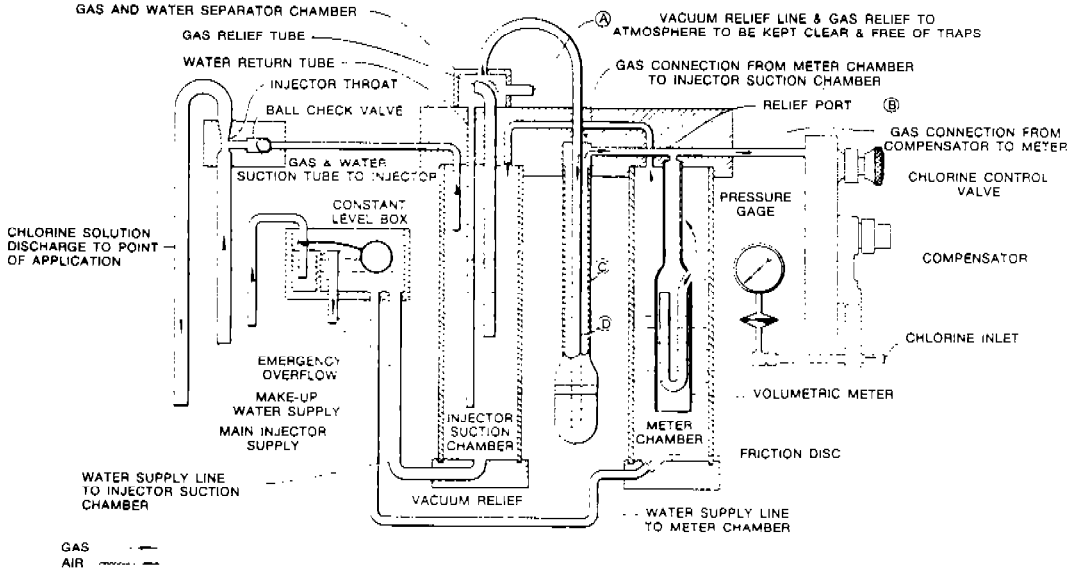


Figure 6-36. Flow Diagram of Pulsating-Type Chlorinator.

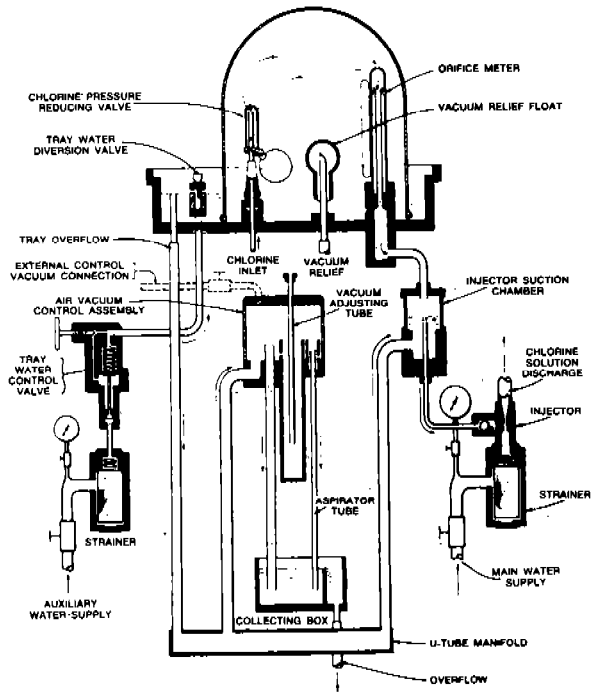


Figure 6-37. Flow Diagram of Vacuum-Type Water-Diaphragm Chlorinator.

sure vessel, more liquid chlorine is allowed to enter the system.

(2) The evaporator is furnished with gages, controls, and alarms that allow the operator to monitor the performance of the equipment.

c. Hypochlorite Feeders:

(1) General Information. Hypochlorite is generally fed in solution form, and is metered by a positive displacement diaphragm pump, of which there are three general types.

(2) Mechanically Actuated Diaphragm Hypochorinator. This type of pump uses a diaphragm that is mechanically acutated by a push rod attached to a driving mechanism. The driving mechanism may be an eccentric operating from a gear reducer powered by an electric motor drive or a secondary diaphragm operated from pressurized water or air. A spring return mechanism is generally used to return the diaphragm from the extended position caused by the driving mechanism. The diaphragm is generally circular in shape and positioned to flex rather than stretch as it is reciprocated. On the suction stroke, the diaphragm develops a partial vacuum within the liquid head, closing the discharge check valve, opening the suction check valve, and allowing hypochlorite solution to flow into the pump head. On the discharge stroke, the push rod reverses direction. The diaphragm is pushed into the feeding chamber and creates pressure that closes the suction valve, opens the discharge valve, and forces the solution out of the pump into the discharge line (figure 6-42). A typical installation that uses an electric motor driven hypochlorinator is shown in figure 6-43.

(3) Hydraulically Actuated Diaphragm Hypochlorinator. The hydraulically actuated diaphragm pump also uses a diaphragm to isolate the pumped liquid from the operating parts. The diaphragm is flexed by operating a plunger reciprocating in a chamber filled with hydralic fluid. As fluid is applied to the back side of the diaphragm, hypochlorite solution is pumped from the opposite side of the diaphragm. The capacity of the pump is thereby controlled by varying the volume of hydraulic fluid pumped

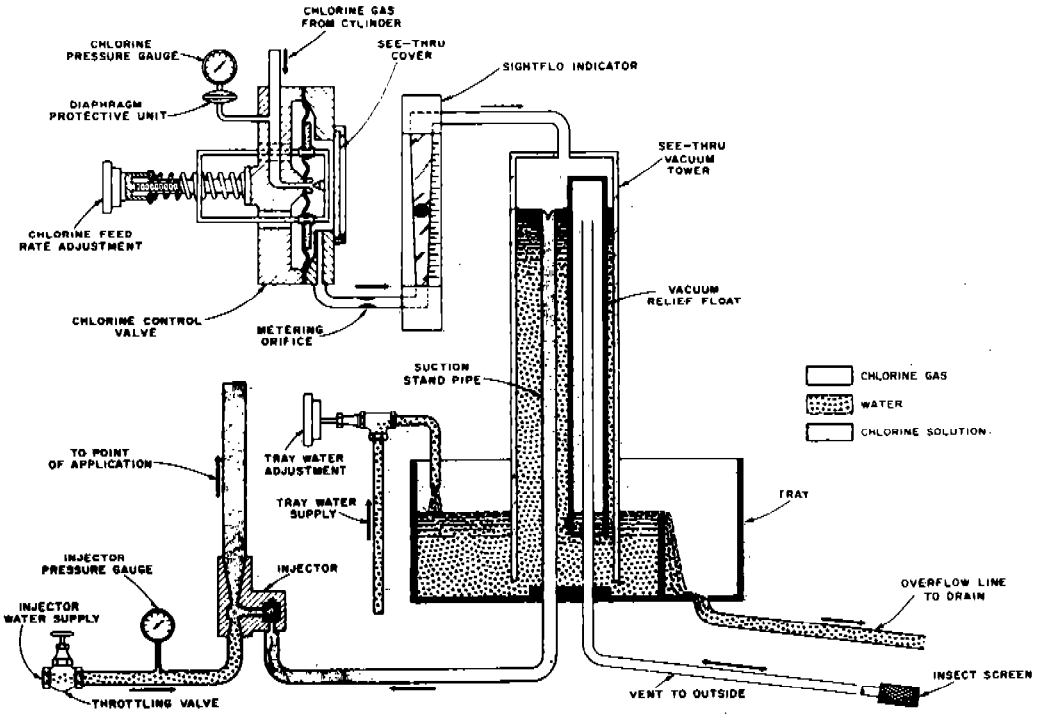


Figure 6-38. Flow Diagram of Vacuum-Type Mechanical-Diaphragm Chlorinator.

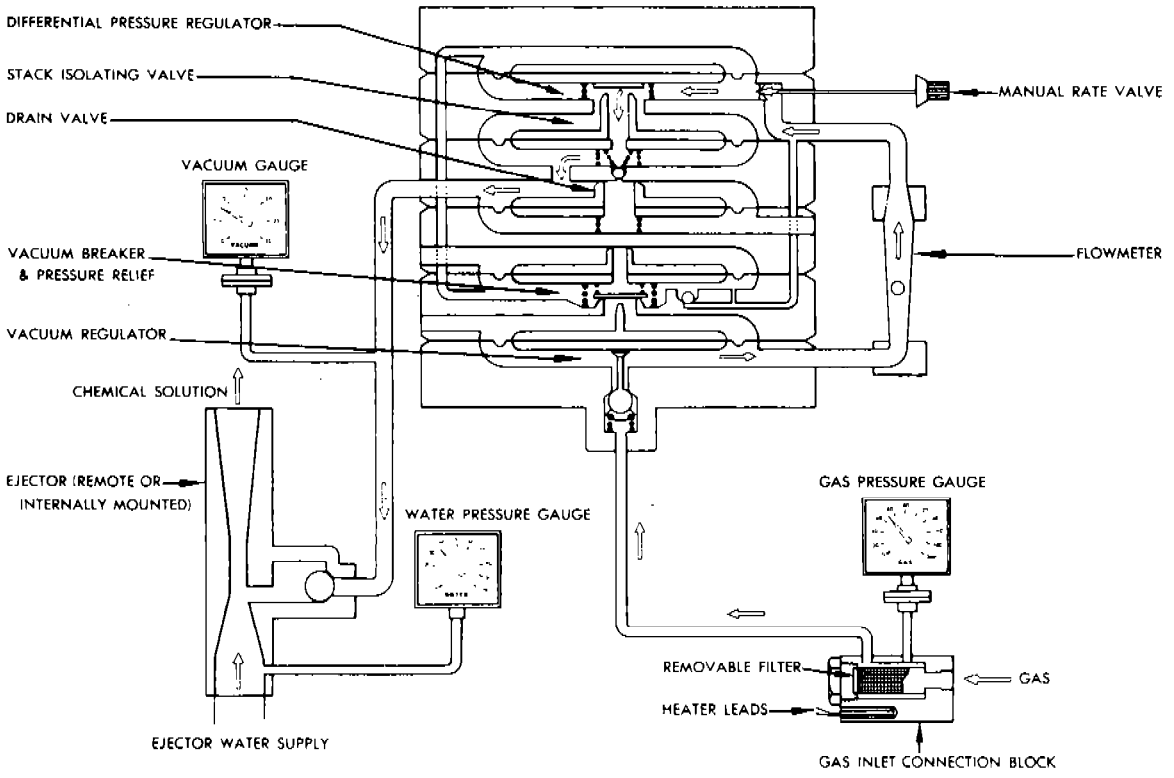


Figure 6-39. Flow Diagram of Vacuum-Type Diaphragm-Controlled Chlorinator.

by the plunger or by passing a portion of the hydraulic fluid displaced by the plunger. This type of pump can be used to pump to higher pressures than the mechanically actuated diaphragm pump, because the diaphragm has pressurized liquid on both sides.

(4) Hydraulically Actuated Diaphragm Water Operated Hypochlorinator. This type of pump is similar to the hydraulically actutated diaphragm pump discussed in (3) above, but uses water pressure to actuate the diaphragm, with a spring return providing the suction stroke. The pump is operated from a pressurized water line, thereby requiring no electricity for operation. The feed rate of the hypochlorite solution may be automatically proportioned to the flow of water through a water meter in the pressurized line (figure 6-44).

(5) Control Methods:

(a) The length of the suction stroke can be adjusted to regulate the feed rate of the pump.

(b) Hypochlorinators with external motors may have the stroke speed adjusted by variable speed drives that accept a pneumatic, electric, or electronic signal proportional to water-flow. Water operated hypochlorinators are paced automatically by a water meter, which changes the stroke rate.

d. Ammoniators and Sulfur Dioxide Feeders. Ammoniators and sulfur dioxide feeders operate in a similar way to solution-feed vacuum type chlorinators. One special requirement for ammoniators, however, is that the injector operating water supply has a hardness of about 35 mg/l or less as calcium carbonate. Otherwise, the rise in pH caused by the introduction of ammonia into the water will cause carbonate deposits to be formed in the solution line, requiring frequent cleaning.

6-73. Chlorination Control:

a. Minimum Chlorine Residual Requirements. The National Interim Primary Drinking Water regulations allow substitution of chlorine residual measurements for a portion of required coliform microbiological tests. The required number of coliform measurements depends on the population being served by the water system. The water supply system operator may substitute chlorine residual measurements for not more then 75 percent of the coliform bacteriological samples, if approved by the state. Four chlorine samples are required for each substituted microbiological sample. Chlorine residual measurement must be made at least daily and a 0.2 mg/l free chlorine residual maintained in the public water distribution system. This residual level is a minimum, and may be higher in some states.

b. Chlorine Residual Monitoring. Chlorine residual monitoring will be in accordance with procedures recommended in the latest edition of Standard Methods. Approved monitoring methods are iodometric, ampherometric, stabilized neutral orthotolidine (SNORT), DPD colorimetric and leuco crystal violet (LCV). The older orthotolidine-arsenite (OTA) test is no longer recommended.

c. Feed Control:

(1) Manual Control. The manually controlled chlorination system requires that the operator start and stop the equipment manually. The feed rate is established by man-

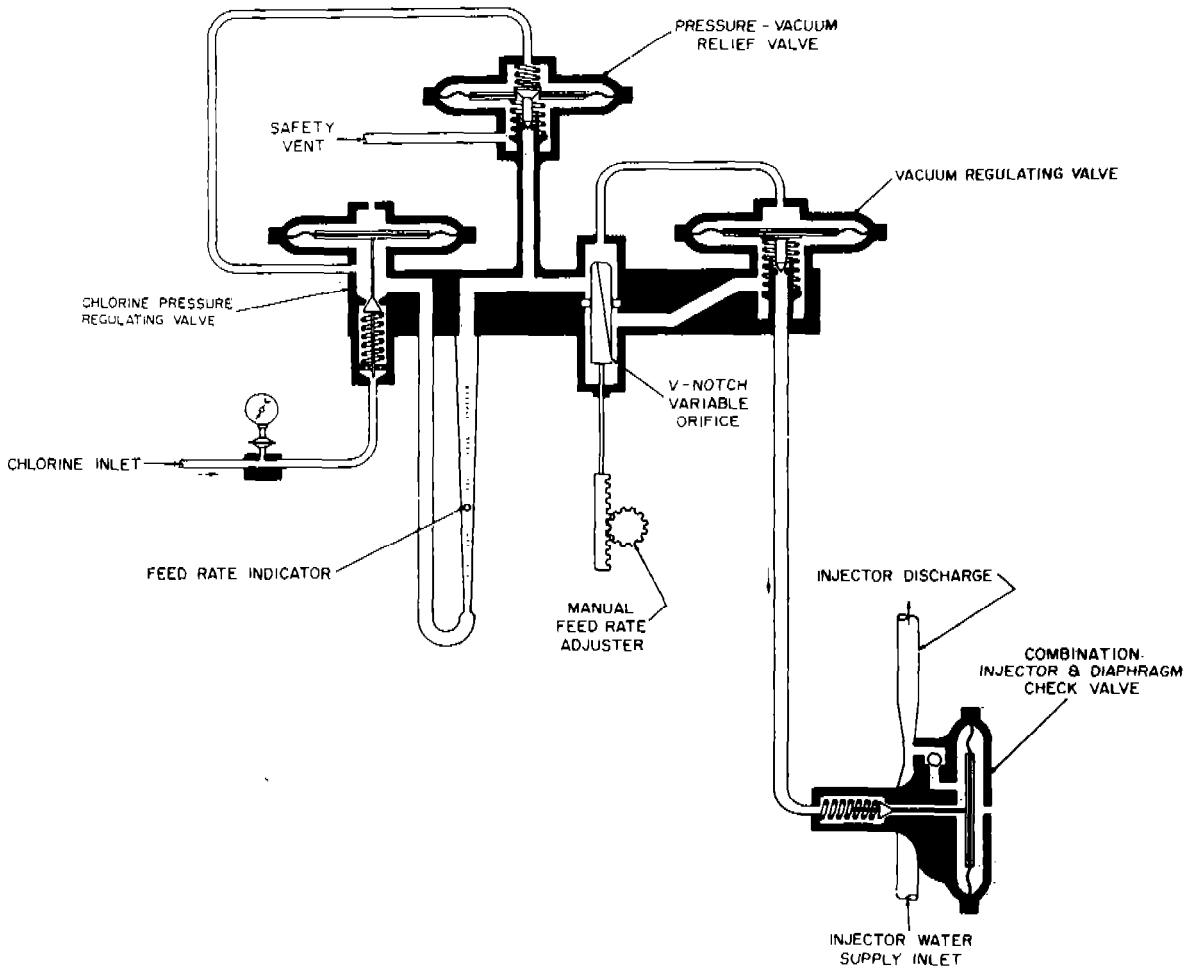


Figure 6-40. Flow Diagram of Vacuum-Type V-Notch Chlorinator.

ual adjustment and continues at the established rate, unless the operator changes it due to a change in flow or chlorine demand. This type of control is generally used for applications where chlorine demand and flow are fairly constant or where an operator is available to adjust the chlorination equipment as required.

(2) Semiautomatic Control. With this type of control the chlorination equipment is set at a constant rate and the equipment is started and stopped in sequence with pump or timer operations. A slight variation in this central mode involves adjustment in chlorine dosage in steps to correspond with the operation of a single pump or combination of pumps.

(3) Automatic Control. Automatic control can be in proportion to the flow rate or can be controlled by the residual in the chlorinated water.

(a) Automatic Proportional Control. With this system, the chlorine equipment will adjust the chlorine feed rate automatically in response to flow changes. The chlorine feeder receives a signal from a meter in the main flow and adjusts the quantity of chlorine being fed to a constant preestablished dosage set for that flow rate.

(b) Automatic Residual Control. This type of control uses a signal from a chlorine residual analyzer-controller to maintain a preset residual in the chlorinated water. This type of control is used where flow variations are small.

(4) Automatic Compound Loop. This system uses signals from a flow transmitter, as well as a residual analyzer, to maintain a preset chlorine residual independent of chlorine demand or flow variation. This system is required only where large flow variations and large changes in chlorine demand are experienced.

d. Estimating Dosage. To estimate dosage where no prior record for chlorination exists or where chlorine demand changes frequently, the following procedures are recommended.

(1) Determine the chlorine demand according to procedures given in the latest edition of Standard Methods for the Examination of Water and Wastewater, or start chlorine feed at a low rate and raise feed by small steps; at the same time make repeated residual tests until at least 0.1 mg/l of the desired residual type is found. Observe the rate of flow treated and the rate of chlorine compound feed at this point. Chlorine demand can then be determined from the following equation:

$$\text{Chlorine Demand (mg/l)} = \frac{\text{Feed Rate (pounds per day)} \times \text{Available Chlorine (percent)}}{8.34 \times \text{Flow (mgd)} \times 100}$$

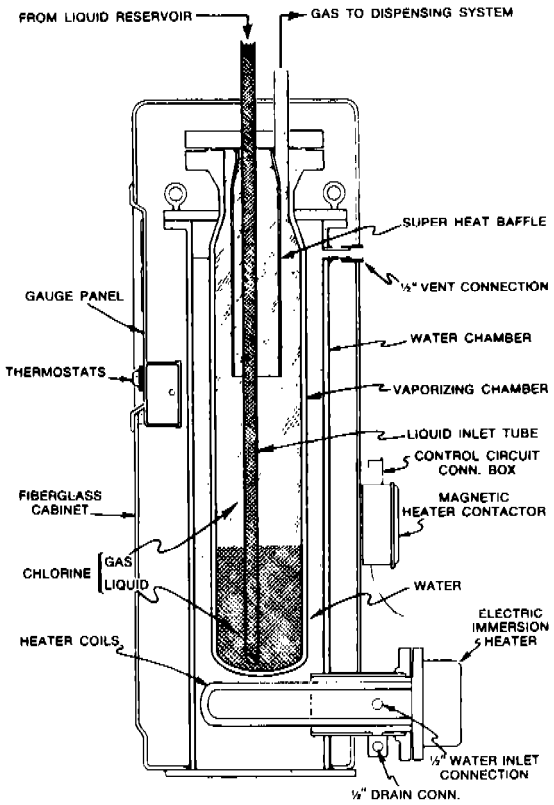


Figure 6-41. Cross-Section Diagram of Chlorine Evaporator.

(2) Add the minimum mg/l of required residual to the chlorine demand (in mg/l) to estimate the mg/l dosage required for a satisfactory residual. Then set the chlorinator feed rate according to the estimated dosage. Further upward adjustments are usually required after making residual tests.

(3) Where distribution system residual losses are relatively high and therefore govern feed rate, the residual required at the point of application is determined from local experience, and is used for immediate control purposes. For example, to maintain a given chlorine residual in the far parts of the distribution system, it may be found that 1.0 mg/l residual is required at the point of application in the summer, and 0.8 mg/l in the winter. Residual tests are

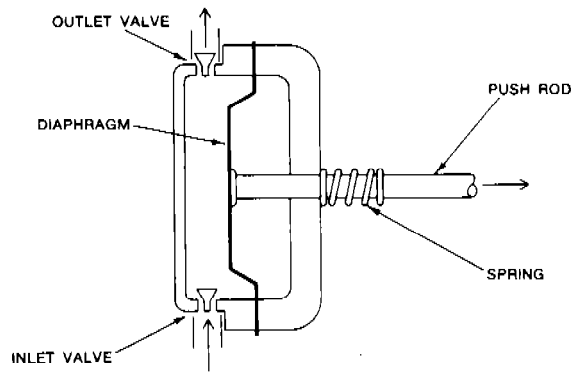


Figure 6-42. Cross-Section Diagram of Mechanically-Activated Diaphragm Hypochlorinator.

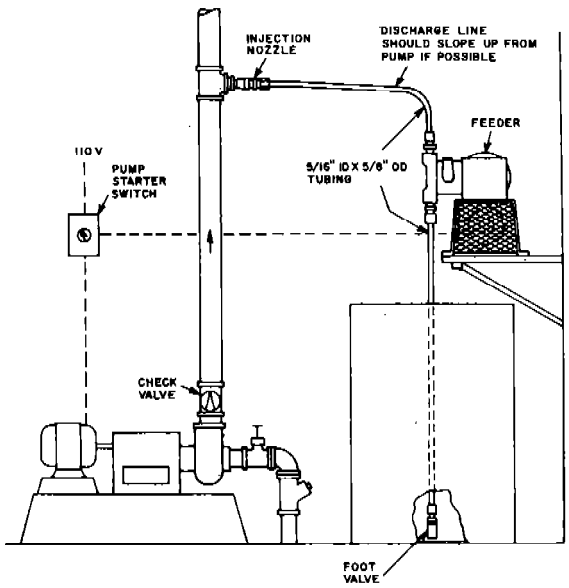


Figure 6-43. Typical Arrangement of Electric Motor-Driven Hypochlorinator.

made hourly at the point of chlorination, and the manual chlorinator is adjusted upwards or downwards as necessary. Less frequent tests are needed with semiautomatic or fully automatic chlorinators, but the residual must be determined in any case at least three times daily; at times of low, average, and maximum flow. However, the relationship between the residual at the point of chlorination and the residual in the distribution system changes with water temperature, quality, rate of consumption, and with the amount of organic matter and slime in the distribution system. Daily testing of residuals in the distribution system is therefore necessary.

e. Checking Rate of Feed. To make sure the chlorinator is feeding the indicated amount, the cylinders are usually mounted on a platform scale. Loss in weight during the check period is observed and the following equation used:

$$\text{Feed Rate (pounds per day)} = \frac{\text{Cylinder(s) Loss in Weight (pounds)} \times 24}{\text{Check Period (hour)}}$$

The rate of feed of hypochlorinators is measured by the change in depth of the solution in its container. Knowing the solution strength, the chlorine used can be calculated in pounds. By substituting this value in the previous equation for the loss in weight, the feed rate in pounds a day may be determined.

f. Preparing Hypochlorite Solutions. The available chlorine content of the chlorine compound used must be known in order to calculate the rate of hypochlorite solution feed. The available chlorine is usually marked on the container as a percentage of weight. Values generally are as shown in table 6-13.

(1) Weight of Chemical Required. To find the actual weight of the chlorine compound to be added, use the equation:

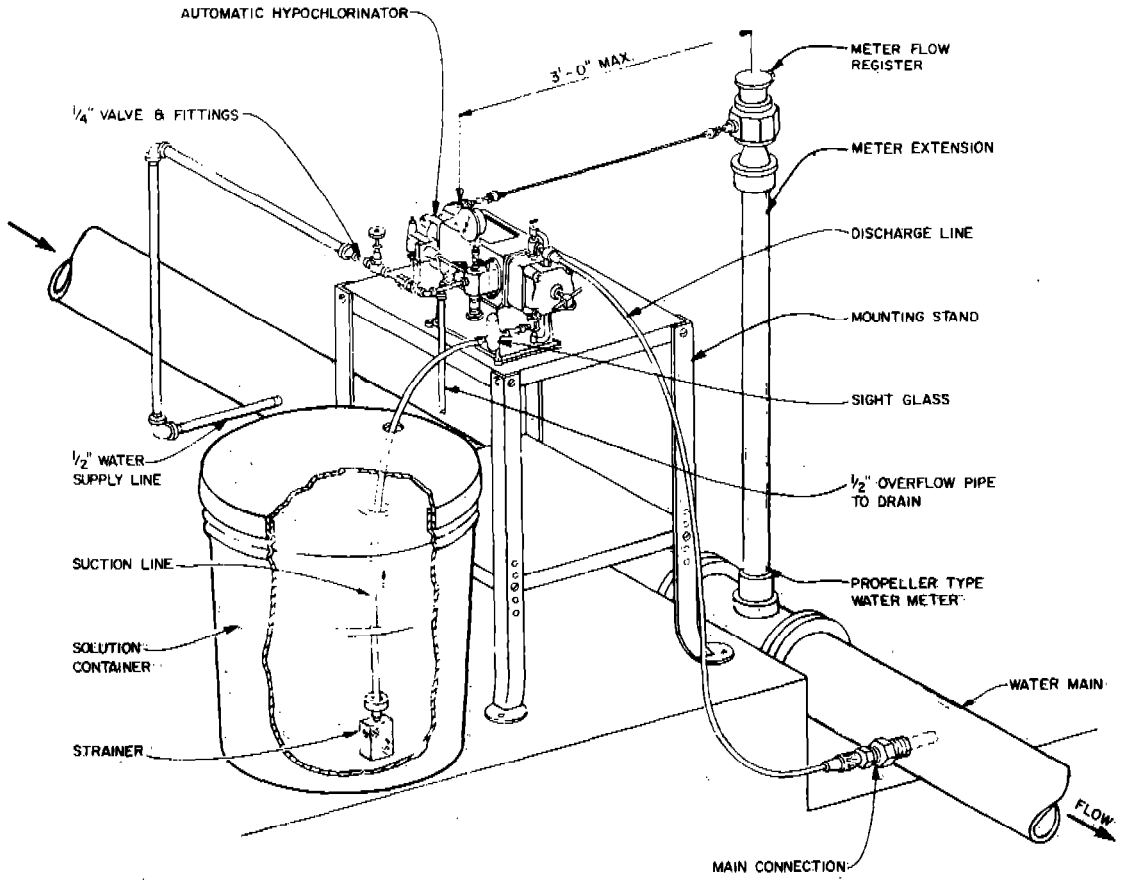


Figure 6-44. Typical Arrangement of Automatic, Water-Operated, Meter-Paced Hypochlorinator.

$$\text{Chemical Required (pounds/day)} = \frac{\text{Dosage (mg/l)} \times 8.34 \times \text{Flow (mgd)} \times 100}{\text{Available Chlorine (percent)}}$$

(2) Dosing Solution Required. To find the amount of 1 percent dosing solution needed to treat a given quantity of water with the desired dosage, use the equation:

$$\text{Dosing Solution Required (gallons)} = \frac{\text{Volume Treated (gallons)} \times \text{Desired Chlorine Dosage (mg/l)}}{10{,}000}$$

(3) Solution Preparation. To prepare various quantities of 1 percent dosing solution, use table 6-13.

(4) Feed Rate. To find the rate of feed or chlorine in gallons a day, use the following equation:

$$\text{Chlorine Rate of Feed (gpd)} = \frac{\text{Flow (gpd)} \times \text{Dosage (mg/l)}}{\text{Dosing Solution Strength (percent)} \times 10{,}000}$$

(5) Solution Strength. To find the number of pounds or chlorine compound needed to prepare a dosing solution of the desired strength, use the equation:

$$\text{Weight of Compound Required (pounds)} = \frac{\text{Weight of Dosing Solution (percent)} \times \text{Volume Required (gallons)} \times 8.34}{\text{Available Chlorine in Compound (percent)}}$$

Table 6-13. Chlorine Compounds Used To Prepare 1 Percent Dosing Solution.

Dosing Solution (gal)	Calcium Hypochlorite 70% Avail. Cl		Hypochlorite Stock Solution (gal) Available Chlorine			
	(lb)	(oz)	15%	10%	6%	5%
5	0	9½	⅓	½	⅝	1
10	1	3	⅔	1	1⅔	2
15	1	12½	1	1½	2½	3
20	2	6	1⅓	2	3⅓	4
25	2	15½	1⅔	2½	4⅛	5
30	3	9	2	3	5	6

(6) Stock Solution Required. To find the gallons of hypochlorite stock solution needed to prepare a dosing solution of the required strength, use the equation:

$$\text{Volume Stock Solution Required (gallons)} = \frac{\text{Strength of Dosing Solution (percent)} \times \text{Dosing Solution Required (gallons)}}{\text{Strength of Stock Solution (percent)}}$$

(7) Cautions Required:

(a) Make dosing solution strong enough so the hypochlorinator can be adjusted to one-half its capacity a day or less. Generally, however, the strength of calcium hypochlorite solutions is limited to about 2 percent unless special precautions are taken.

(b) If the hardness of the water available for dissolving calcium hypochlorite is more than 75 mg/l, the water should be softened before attempting to make a hypochlorite solution. This may be done by adding equal amounts of soda ash with the calcium hypochlorite, allowing it to settle for 24 hours, and then decanting the clear liquor for use. The makeup water may also be softened by conventional ion exchange.

(c) If calcium hypochlorite consistently plugs the equipment with calcium deposits, check into using sodium hypochlorite. Sodium hypochlorite may be fed in solutions of greater concentration than is possible with calcium hypochlorite.

6-74. Disinfection of Mains, Tanks, and Treatment Units:

a. Disinfection Requirements. Water mains, wells, filters, storage tanks, and other components of the water supply system become contaminated during construction and repair. Flushing the system to remove dirt, waste, and surface water is the first step, but is not a sufficient safeguard. To ensure a safe water supply, each unit of the system must be thoroughly disinfected before it is placed in operation.

b. Disinfecting Agents. The chemicals used in disinfecting a water supply system are the same as those used in disinfecting water; that is, a hypochlorite solution or chlorine gas.

c. Dosage Required. The chlorine dosage required to disinfect any unit depends on the contact time and chlorine consuming material present. Minimum dosages for use under average conditions are listed in table 6-14. The volume of water in the unit to be disinfected must be computed before the chlorine dosage can be estimated. Table 6-15 lists the volumes of water contained in different sizes of pipe.

Table 6-14. Minimum Chlorine Dosages for Disinfecting Pipes, Tanks, and Treatment Units.

Unit	Minimum Dosage (mg/l)
Pipe	50
Storage tank	50
Filter	100

Table 6-15. Volume of Water in Various Pipe Sizes Per Foot of Length.

Pipe Diameter (inches)	Volume Per Foot of Pipe (gal)
6	1.47
8	2.61
10	4.08
12	5.88
16	10.45
20	16.32

d. Application Method. The following method of applying disinfectants should be observed.

(1) Liquid chlorine is applied by portable chlorinators. Chlorine cylinders should not be connected directly to mains because water may enter the cylinder causing severe corrosion, and possibly resulting in leaks.

(2) Hypochlorite solution is usually applied by measuring pumps or portable pipe disinfecting units.

e. Procedures for Applying Disinfectant. Personnel applying disinfectant should follow these procedures.

(1) Water Main Disinfection. American Water Works Association Standard C601 sets standard procedures for water main disinfection and should be used to supplement the procedures described below.

(a) Before adding disinfectant, the system should be flushed thoroughly to clear all dirt and mud. A velocity of at least 3 feet per second (fps) is required for adequate scouring.

(b) All branches and other openings must be stopped with plugs, that are properly braced to prevent blowouts.

(c) The water main should be disinfected in sections, introducing the disinfecting agent through taps or watertight connections at hydrants at the ends of each section.

1. A portable gas chlorinator should be used with a booster pump. The booster pump provides pressure to the injector and pumps the chlorine solution into the main to be disinfected.

a. Water from the existing distribution system or other approved source of supply should be fed into the main at a constant measured rate, with the chlorine concentration maintained at a minimum of 50 mg/l residual. Feeding should continue until the water discharging at the other end of the section contains the desired residual chlorine.

b. The chlorinated water should remain in the contaminated unit for 24 hours. During this time, valves and hydrants in the treated section should be operated to make sure they contact the chlorine solution. The treated water should contain a minimum of 25 mg/l residual at the end of the 24-hour period. Flush until the chlorine residual is only that amount usually in the supply. Conduct bacteriological analyses of water samples until the analyses show no further disinfection is required.

2. If a chlorinator is not available, feed a strong hypochlorite solution into the main with a gasoline or electrically powered chemical feed pump designed for feeding chlorine solutions. The remaining disinfection procedures are similar to those described above.

3. Dry calcium hypochlorite fed directly in the mains is not uniformly distributed because of unequal mixing with the water. Therefore, if calcium hypochlorite is to be used, a solution of this chemical should first be prepared.

(d) Broken water mains often cannot be left out of service for 24 hours following repair. The "slug method" of disinfection can be used in these cases by using 500 mg/l residual for a 30-minute contact time. As with the lower residual waters described above, care must be taken when disposing the chlorine solution in the mains after the contact time is completed.

(2) Storage Tank Disinfection:

(a) One method of disinfecting tanks involves adding chlorine directly to the filling water. Gas chlorinators or hypochlorite feeders may be used to add chlorine solution to the tank during the filling process until at least 50 mg/l residual is achieved. This residual should be maintained at least 6 hours.

(b) A second method of disinfection involves spraying the walls and surfaces of the tank with a 500 mg/l chlorine solution. This concentration provides almost immediate disinfection without harm to the tank or reservoir coating. This operation must be coordinated with facility medical personnel and all personnel involved must wear self-contained breathing apparatus and protective clothing.

(3) Well Disinfection. Well disinfection procedures are in section B.

f. Bacteriological Testing. Bacteriological testing must be conducted on waters from all disinfected mains, wells, and storage facilities.

6-75. Chlorination Safety Practices:

a. Chlorine Properties. Chlorine gas is primarily a respiratory irritant, but can cause various degrees of irritation of the skin and mucous membranes, depending on the concentration and time of exposure. When a chlorine leak is detected, the area should be evacuated and the leak reported to the proper authority. Trained personnel with appropriate personal protective equipment will investigate the leak, secure the chlorine source and take corrective action. For additional guidance, see appropriate service safety regulations. Concentrations above 3 mg/l can usually be detected by the smell. In extremely high concentrations, death can occur from suffocation. Liquid chlorine may cause skin and eye burns on contact. Hypochlorite solutions also cause eye and skin injuries, so rubber gloves, face shields, and protective aprons should be worn when preparing and handling hypochlorite solutions.

b. Leak Warnings. The characteristic odor of chlorine gas provides a warning of leaks. A more exact location of the leak can be detected by holding an ammonia-saturated cloth near the suspected area. The chlorine gas reacts with the ammonia to form white fumes that are visible to the eye. Compressed gas containers, piping, and equipment should be tested each day for leaks. Chlorine leak detectors are available from equipment manufacturers that will sense 1 mg/m^3 of chlorine (by volume) in air. Detectors are recommended for new installations. In some states their use is mandatory. Local indicator lights and relay contacts for actuating external alarms are standard equipment. These detectors may be mounted in chlorine storage and chlorinator areas and will actuate local and remote alarms on the presence of chlorine in the air.

(1) If leaks are detected, only trained personnel with suitable gas masks should investigate. Water should not be applied to a leaking chlorine container, because the chlorine and water react to form a corrosive mixture.

(2) Leaking cylinders or containers should be positioned so the gas, instead of liquid, escapes.

(3) If emergency capping devices are available, they should be used, and the supplier or nearest producer of chlorine should be notified for emergency assistance.

c. Ventilation Required. Adequate ventilation is required in all areas where chlorine cylinders are stored or used. Because chlorine is heavier than air, ventilation exhaust ducts are placed at the lower levels in areas where chlorine containers are housed. Switches for the ventilation equipment are placed outside the storage rooms and must be actuated before the operator goes into the storage or chlorine usage area.

d. Heat Requirement. The chlorine container usage area should be maintained at a minimum temperature of 50°F. Below this temperature, chlorine flow becomes sluggish and erratic. Heat for vaporizing the liquid chlorine to a gas is furnished from the air surrounding the cylinders. Heat should never be applied directly to a container, because this may result in rupture of the container.

e. Reliquefaction. Chlorine gas will reliquefy in the piping between the cylinder and the pressure reducing valve in the chlorinator if its temperature is reduced below that of the cylinder contents. Reliquefaction causes erratic chlorinator operation. To prevent gas reliquefaction, install chlorine cylinders at points where their temperatures are the same or slightly lower than room temperature of the chlorinator. Avoid placing cylinders near heating units, in front of a window, or in direct sunlight. Do not allow cold drafts on flooring or piping. If room temperatures are low, artificial heat is required to keep chlorine gas from reliquefying in the piping. However, limit temperature in the artificial heating unit to 100°F.

f. Emergency Equipment:

(1) Emergency Disposal of Chlorine from Leaking Containers. The contents of a leaking chlorine container should be disposed of by placing the container in a position for gas withdrawal and bubbling the gas into a neutralization bath, using a flexible connector. The flexible connector must be removed from the neutralization bath to prevent liquid from being sucked back into the container when it is empty. The neutralization bath can be prepared by mixing caustic soda, soda ash, or hydrated lime with water in 55-gallon drums. One pound of the alkaline ma-

Table 6-16. Pounds of Alkaline Material Required To Neutralize One Pound of Chlorine Gas.

Chemical	Pounds Required
NaOH (Caustic soda)	1.4
Na_2CO_3 (Soda ash)	3.7
$Ca(OH)_2$ (Hydrated lime)	1.3

Note 1. Weight of alkaline material is 25% in excess of theoretical requirements.
Note 2. Recommended solution strength: 1 lb of alkaline material per 1 gal of water.
Note 3. Since $Ca(OH)_2$ is insoluble in water, it must be kept in suspension by mechanical or hand agitation.

terial should be mixed with each gallon of water. The pounds of alkaline material required to neutralize 1 pound of gas is shown in table 6-16. The weight of alkaline material shown in the table is 25 percent in excess of the theoretical requirements. Since hydrated lime is insoluble in water, it must be kept in suspension by constant mixing.

(2) Emergency Kits A and B. Emergency kits are available from chlorine suppliers and may be used in an emergency to stop leaks in either 150-pound cylinders or ton containers. Chlorine Institute Emergency Kit A has devices to stop leaks in either a main cylinder valve, fusible plug, or the 150-pound cylinder itself. Chlorine Institute Emergency Kit B has devices to stop leaks in cylinder valves, fusible plugs, or the ton container. These kits operate on the principle of capping off leaking valves or sealing off the leak in a sidewall. The kits contain step-by-step instructions for using all devices in the kit and all necessary tools are included.

(3) Respiratory Protection. Gas masks should be inspected on a routine basis and maintained in good condition. All respiratory protective equipment should be approved by the National Institute for Occupational Safety and Health for chlorine atmospheres.

(a) Self-contained Breathing Apparatus. This type of apparatus has a full facepiece, positive air pressure, and a cylinder of air or oxygen which is carried on the body. An alternate apparatus produces oxygen chemically. The self-contained breathing apparatus is suitable for high concentrations of chlorine and is the preferred means of respiratory protection.

(b) Airline Respirators. Airline respirators have a full facepiece and have air supplied through a hose from a remote cylinder. This equipment is suitable for use in high concentrations of chlorine gas.

(c) Industrial Canister Mask. This mask has a full facepiece with an attached chlorine filter canister that is colored white with a ½-inch yellow stripe near the bottom. The mask is suitable for moderate chlorine concentrations where a sufficient quantity of oxygen is present in the air. The mask should be used for only relatively short exposure periods. If the user of the mask detects the odor of chlorine or experiences dizziness or difficulty breathing, leave the contaminated area at once. The mask is not working properly, the chlorine concentration is too high, or sufficient oxygen is not available. The manufacturer's recommended limits on maximum nonuse shelf life for canisters should be followed. Overage canisters may not work properly in an emergency.

(4) Emergency Eye Wash and Safety Shower. If chlorine has contacted the eyes or skin, copious amounts of water should be used at once to flush the effected area. Emergency showers and eye washers should be provided in suitable locations for this purpose.

6-76. Chlorination Equipment Maintenance:

a. Gas Chlorinators:

(1) General Information. The operator should be familiar with the equipment to be maintained. An instruction book is furnished with every chlorinator and should be consulted for specific steps to follow in servicing. Should the book become lost, the manufacturer can supply duplicates if model and serial numbers are included with the request for replacement. The manufacturer's suggestions for operation and maintenance should be followed. This paragraph gives general maintenance procedures that apply to all gas chlorinators.

(2) Inspect for Leaks. Examine chlorinator and all piping for chlorine or water leaks each day. All chlorine leaks are serious because they increase rapidly in size and cause extensive corrosion and damage. Red discoloration at gas header connections means that a leak is corroding the fittings. Use an ammonia-water bottle to locate the chlorine gas leak. Use litharge and glycerine cement or Teflon tape in making all metal threaded pipe connections. Do not use grease or oil.

(3) Operate Chlorine Valves. Open and close all chlorine valves each day to ensure proper and complete operation. Do not use force in closing a valve. Repair or replace any faulty valves at once.

(4) Check Water System. Each month, clean the water strainers and check pressure reducing valve for proper operation. Clean the injector nozzle and throat once a year. (Insufficient injector vacuum usually indicates that cleaning is required.) Muriatic acid may be used for cleaning mineral deposits from the injector nozzle and throat.

(5) Check Gas System. Check all piping and parts carrying chloride gas to verify that they are operating properly. Check flexible connectors at the gas supply containers. (To maintain a gas-tight seal, a new lead gasket must be used each time a valve or tube is connected, including each time an empty chlorine cylinder is replaced.) Gas filters should be removed and cleaned periodically. Check the heater each day to make sure it is warm. See that metering devices, pressure reducing and shutoff valves, hose lines, etc., work properly. Disassemble and clean when necessary, to determe the cause of the fault. At first sign of weakening, replace any faulty parts.

(6) Clean Cabinet and Critical Working Parts. Thoroughly clean chlorinator cabinet, glass parts, flow meter, rate valve, vacuum regulator valve, and other parts in

which dirt may interfere with operations or make equipment slightly unsightly. Clean and cover unpainted metal that is subject to corrosion with a proper protective coating.

(7) Disassemble or Operate Hard Rubber Threads, Valves, and Parts. Thoroughly clean ammoniator cabinet, glass parts, metering devices, and other parts that may interfere with operations or make equipment unsightly. Coat unpainted metal that is subject to corrosion with vaseline or a similar protective compound. Do not use water to clean any apparatus except glass parts. Make sure that all metal parts coming in contact with ammonia are dry.

(8) Overhaul Operations. Each year, remove all ammoniator parts, examine, and clean. Reassemble and check for proper operation. Clean and touch up paint on exposed metal spots of cabinet. Repaint inside and out with enamel.

(9) Check Manometer Oil. Annually, check the manometer oil and add as required on those ammoniators so equipped.

b. Liquid Chlorine Evaporators:

(1) General Information. The chlorine vessel on the inside of the evaporator and the water bath mechanism are the primary components requiring maintenance. The chlorine vessel is subject to internal corrosion from chlorine and external corrosion from the water bath. The chlorine vessel and the water bath should be cleaned and inspected every 2 years or after evaporating 250 tons of chlorine, whichever is sooner. The sacrificial anodes in the cathodic protection system in the evaporator should be replaced when the evaporator is taken apart for cleaning and inspection.

(2) Cleaning the Evaporator:

(a) Dismantle and remove the chlorine vessel from the evaporator.

(b) Flush the chlorine vessel with cold water to remove corrosion products from the inside.

(c) Visually inspect the interior for pitting. If pitting is severe, the chlorine vessel should be replaced.

(d) Remove all flushing water, and reassemble evaporator.

(e) Fill the water bath and heat to 180 °F. Attach an aspirator so that a vacuum can be exerted on the inside of the chlorine vessel. The vacuum should be about 25 inches

Table 6-17. Solution-Feed, Vacuum-Operated Gas Chlorinator Troubleshooting Chart.

Symptom	Possible Cause
Flowmeter fails to indicate gas flow.	Gas supply valves closed.
	Gas supply cylinder(s) empty.
	Insufficient ejector vacuum.
	Filter in gas inlet connection block dirty.
	Dirty flowmeter.
	Rate valve closed.
	Rate valve dirty.
	Air leakage in regulator stack.
	Vacuum regulator valve plug stuck in closed position.
Insufficient ejector vacuum.	Ejector water supply valve closed.
	Solution line valve closed.
	Dirty strainer.
	Dirty ejector.
	Partially or fully blocked solution line.
	Ejector throat not full of water (applies only when ejector is mounted in horizontal position and back pressure is zero or less).
	Insufficient water supply flow rate and pressure for existing back pressure conditions.
	Drain valve leaking air.
	Insufficient booster pump discharge pressure.
Gas flow rate cannot be controlled.	Condensed gas vapor (liquid chlorine) in chlorinator.
	Dirty vacuum regulator valve.
	Air leakage in regulator stack.
	Insufficient ejector vacuum.
Maximum gas flow rate produces too low a residual in the treated process liquid.	Chlorinator capacity too low.
	Air leakage caused by dirty sealing surfaces.
Minimum gas flow rate produces too high a residual in the treated process liquid.	Chlorinator capacity range too high.
Flowmeter continues to indicate flow when ejector water supply valve is closed.	Condensed gas vapors (liquid chemicals) in chlorinator.
	Vacuum regulator valve stuck in the open position.
	Solution line draining due to a back pressure of zero or less.
	Ball stuck in flowmeter.
Water leaks from ejector into gasline.	Diaphragm back-flow check valve not seating properly.

Table 6-18. Maintenance Procedures for Chlorination Equipment.

Inspection	Action	Frequency[1,2]
Operation maintenance	Insert new lead gasket in chlorine valves or tubes to cylinders or equipment.	V
Condensation on chlorine cylinders	Ventilate.	V
Chlorine leak detection	Use unstopped bottle of aqua-ammonia to detect leaks; repair immediately.	D
Gas system	Disassemble, clean and replace faulty parts in piping, meters, valves, and tubing.	D
Chlorine valves	Open and close valves to assure that all are operable; check stuffing boxes, and repair or replace faulty valves or packing.	D
Chlorine solution tubes	Look for locations of potential leaks, and for iron and manganese deposits; if Fe or Mn are present, treat with a solution of hexametaphosphate in makeup water.	A
Chlorine feeder water supply	Clean water strainers and pressure reducing valves; adjust float valves and ejector capacity.	M
Hard-rubber threads, valves and parts	Disassemble or operate; use graphite grease to prevent freezing; hand tighten only, do not use tools.	Q
Vacuum relief	Clean out any obstructions.	D
Cabinet and working parts	Clean all parts where accumulation may interfere with proper operation.	W
Overhaul	Disassemble and clean all parts thoroughly; paint cabinet inside and out; examine parts and repair or replace as needed; use care in choice of cleaning agents and lubricants.	A
Direct-feed chlorinators	Use same procedures as for solution feed machines where they apply.	

[1]D-Daily; W-Weekly; M-Monthly; Q-Quarterly; A-Annually; V-Variable, as conditions may indicate.
[2]The frequencies shown are suggested frequencies which may be modified by local command, as individual installation conditions warrant.

of mercury and should be held for 24 hours with the water bath at 180°F, to make sure that all moisture is removed from the inside of the chlorine vessel.

c. Hypochlorite Solution Feeders:

(1) Hypochlorite solutions are highly alkaline. The reaction of this alkaline material with the hardness in the makeup water results in carbonate scale deposits in the pump head, tubing, and the solution diffuser at the point of application. Dilute (5 percent) hydrochloric (muriatic) acid solution can be pumped through the hypochlorinator to remove this scale. Be sure to first flush out the hypochlorite solution with water.

(2) The diaphragm continually flexes, and should be inspected to make sure it operates properly.

(3) Check valves and seats for corrosion, hardening, swelling, scale, or foreign material that might prevent proper seating. Refer to solution feeder maintenance information in section I for additional maintenance procedures.

6-77. Requirements for Keeping Records:

a. Daily Records. Keep daily records of the following on the proper forms.

(1) Total chlorine residuals, free available residuals, and combined chlorine residuals in the treatment plant and at points in the distribution system. Number distribution system sampling points and note them by building number.

(2) Chlorine residuals near points of application, preferably after completion of contact. Enter the time each sample is taken.

(3) Gross and net weight of chlorine cylinders on scale, recorded at the same time each day, preferably at 0800. Also record weight when cylinders are changed.

(4) Weight of chlorine fed, determined from scale readings or volume and percent of hypochlorite solution.

(5) Chlorinator of hypochlorinator rate of feed settings, and time of changes.

(6) Data similar to (3), (4), and (5) above for ammonia, sulfur dioxide, or other chemicals used with chlorine.

b. Water Utility Operating Logs. Enter the following data each day.

(1) Pounds of chlorine used.

(2) Average total chlorine residual, free available residual, and combined residual in distribution system.

Section I—Chemicals and Chemical Application

6-78. Treatment Chemicals. Chemicals commonly used in water treatment are described in table 6-19. Most of water treatment chemicals are either in liquid or solid form.

Table 6-19. Chemicals Used in Water Treatment.

Chemical Name and Formula	Common or Trade Name	Shipping Containers	Suitable Handling Materials	Available Forms	Weight, lb/cu ft	Solubility, lb/gal	Commercial Strength	Characteristics	AWWA Standard
				Coagulation					
Aluminum sulfate, $Al_2(SO_4)_3 \cdot 14H_2O$	Alum, filter alum, sulfate of alumina	100-, 200-lb bags; 300-, 400-lb bbls.; bulk (carloads)	Dry—iron, steel; solution—lead-lined rubber, silicon, asphalt, 316 stainless steel	Ivory-colored: powder granule lump	 38-45 60-63 62-67	4.2 (60° F)	15-22% Al_2O_3	pH of 1% solution, 3.4	B 403
	Liquid alum	Bulk; tank trucks, tank cars		Pale green liquid			8.3% Al_2O_3 liquid	Crystallizes at 5° F	
Ammonium aluminum sulfate, $Al_2(SO_4)_3(NH_4)_2SO_4 \cdot 24H_2O$	Ammonia alum, crystal alum	Bags; bbls.; bulk	Duriron, lead, rubber, silicon, iron, stoneware	Lump Nut Pea Powdered	64-68 62 65 60	0.3 (32° F), 8.3 (212° F)	11% Al_2O_3	pH of 1% solution, 3.5	
Bentonite	Colloidal clay, volclay, wilkinite	100-lb bags; bulk	Iron, steel	Powder, pellet, mixed sizes	60	Insoluble (colloidal sol used)			
Ferric chloride, (a) $FeCl_3$(35-45% solution)	"Ferrichlor," chloride of iron	5-, 13-gal carboys; trucks; tank cars	Glass, rubber, stoneware, synthetic resins	Dark brown syrupy liquid		Complete	37-47% $FeCl_3$, 20-21% Fe		
(b) $FeCl_3 \cdot 6H_2O$	Crystal ferric chloride	300-lb bbls.		Yellow-brown lump			59-61% $FeCl_3$, 20-21% Fe	Hygroscopic (store lumps and powder in tight containers); no dry feed; optimum pH, 4.0-11.0	
(c) $FeCl_3$	Anhydrous ferric chloride	500-lb casks; 100-, 300-, 400-lb kegs		Green-black powder			98% $FeCl_3$, 34% Fe		
Ferric sulfate, $Fe_2(SO_4)_3 \cdot 9H_2O$	"Ferrifloc," Ferrisul	100-, 175-lb bags; 400-, 425-lb drums	Ceramics, lead, plastic, rubber, 18-8 stainless steel	Red-brown powder 70 or granule 72		Soluble in 2-4 parts cold water	90-94% $Fe_2(SO_4)_3$, 25-26% Fe	Mildly hygroscopic; coagulant at pH 3.5-11.0	B 406
Ferrous sulfate, $FeSO_4 \cdot 7H_2O$	Copperas, green vitriol	Bags; bbls.; bulk	Asphalt, concrete, lead, tin, wood	Green crystal granule, lump	63-66	0.5 (32° F), 1.0 (68° F), 1.4 (86° F)	55% $FeSO_4$, 20% Fe	Hygroscopic; cakes in storage; optimum pH, 8.5-11.0	B 402
Potassium aluminum sulfate, $K_2SO_4Al_2(SO_4)_3 \cdot 24H_2O$	Potash alum	Bags, lead-lined; bulk (carloads)	Lead, lead-lined, rubber, stoneware	Lump Granule Powder	62-67 60-65 60	3.0 (68° F), 3.3 (86° F)	10-11% Al_2O_3	Low, even solubility; pH of 1% solution, 3.5	
Sodium aluminate, $Na_2OAl_2O_3$	Soda alum	100-, 150-lb bags; 250-, 440-lb drums; solution	Iron, plastics, rubber, steel	Brown powder, liquid (27° Bé)	50-60	Complete	70-80% $Na_2Al_2O_4$, min. 32% $Na_2Al_2O_4$	Hopper agitation required for dry feed	B 405
Sodium silicate, Na_2OSiO_2	Water glass	Drums; bulk (tank trucks, tank cars)	Cast iron, rubber, steel	Opaque, viscous liquid			38-42° Bé	Variable ratio of Na_2O to SiO_2; pH of 1% solution, 12.3	B 404

Table 6-19. Continued.

Chemical Name and Formula	Common or Trade Name	Shipping Containers	Suitable Handling Materials	Available Forms	Weight, lb/cu ft	Solubility, lb/gal	Commercial Strength	Characteristics	AWWA Standard
Disinfection and Dechlorinating Agents									
Ammonium aluminum sulfate, $Al_2(SO_4)_3(NH_4)_2SO_4 \cdot 24H_2O$	Ammonia alum, crystal alum	Bags; bbls.; bulk	Duriron, lead, rubber, silicon, iron, stoneware	Lump Nut Pea Powdered	64-68 62 65 60	0.3 (32° F), 8.3 (212° F)	11% Al_2O_3	pH of 1% solution, 3.5	
Ammonium sulfate, $(NH_4)_2SO_4$	Sulfate of ammonia	100-lb bags	Ceramics, plastics, rubber, iron (dry)	White or brown crystal		42.5	6.3 (68° F)	Cakes in dry feed; add $CaSO_4$ for free flow	B 302
Anhydrous ammonia, NH_3	Ammonia	50-, 100-, 150-lb cylinders; in bulk (tank cars and trucks)	Glass, iron, monel metal, nickel, steel	Colorless gas		3.9 (32° F), 3.1 (60° F), 1.8 (125° F)	99-100% NH_3		
Aqua ammonia, NH_4OH	Ammonia water, ammonium hydrate, ammonium hydroxide	Carboys; 750-lb drums; 8,000-gal tank cars or trucks	Glass, iron, monel metal, nickel, steel	Colorless liquid		Completely	29.4% NH_3 (26° Bé)		
Calcium hypochlorite, $CaOCl_2 \cdot 4H_2O$	"HTH," Perchloron, "Pittchlor"	5-lb cans; 100-, 300-, 800-lb drums	Glass, rubber, stoneware, wood	White granule, powder	52.5		70% available Cl_2	1-3% available Cl_2 solution used	B 300
Chlorinated lime, $CaO \cdot 2CaOCl_2 \cdot 3H_2O$	Bleaching powder, chloride of lime	100-, 300-, 800-lb drums	Glass, rubber, stoneware, wood	White powder	48		25-37% available Cl_2	Deteriorates	
Chlorine, Cl_2	Chlorine gas, liquid chlorine	100-, 150-lb cylinders; 1-ton containers; 16-, 30-, 55-, 85-, and 90-ton tank cars; tank trucks (about 15-16 tons)	Dry—black iron, copper, steel; wet gas—glass, hard rubber, silver	Liquefied gas under pressure	91.7	0.07 (60° F), 0.04 (100° F)	99.8% Cl_2		B 301
Chlorine dioxide, ClO_2	Chlorine dioxide	Generated as used	Plastics, soft rubber (avoid hard rubber)	Yellow-red gas		0.02 (30 mm)	26.3% available Cl_2		
Ozone, O_3	Ozone	Generated at site of application	Aluminum, ceramics, iron, steel, wood	Colorless gas					
Pyrosodium sulfite	Sodium metabisulfite	Bags; drums; bbls.	Iron, steel, wood	White crystalline powder		Completely in water	Dry, 67% SO_2; sol., 33.3% SO_2	Sulfurous odor	
Sodium chlorite, $NaClO_2$	Technical sodium chlorite	100-lb drums	Metals (avoid cellulose materials)	Light orange powder, flake			82% $NaClO_2$, 30% available Cl_2	Generates ClO_2 at pH 3.0	B 303
Sodium hypochlorite, NaOCl	Sodium hypochlorite	5-, 13-gal carboy; 1,300-2,000-gal tank trucks	Ceramics, glass, plastics, rubber	Light yellow liquid			12-15% available Cl_2		B 300
Sodium sulfite, Na_2SO_3	Sulfite	Bags; drums; bbls.	Iron, steel, wood	White crystalline powder		Complete in water	23% SO_2	Sulfurous taste and odor	
Sulfur dioxide, SO_2	Sulfurous acid anhydride	Steel cylinders; ton containers; tank cars or trucks	Aluminum, brass, Durco D-10, stainless steel 316	Colorless gas		20% at 32° F, complete in water	99% SO_2	Irritating gas	

Table 6-19. Continued.

Chemical Name and Formula	Common or Trade Name	Shipping Containers	Suitable Handling Materials	Available Forms	Weight, lb/cu ft	Solubility, lb/gal	Commercial Strength	Characteristics	AWWA Standard
Fluoridation and Fluoride Adjustment									
Ammonium silico fluoride, $(NH_4)_2SiF_6$	Ammonium fluorsilicate	100- and 400-lb drums	Steel, iron, lead	White crystals		1.7 (63° F)	100%	White, free-flowing solid	
Calcium fluoride, CaF_2	Fluorspar	Bags; drums; bbls.; hopper cars; trucks	Steel, iron, lead	Powder		Very slight	85% CaF_2, less than 5% SiO_2		
Hydro-fluosilicic acid, H_2SiF_6	Fluosilicic acid	Rubber-lined drums; trucks; or R.R. tank cars	Rubber-lined steel, PVC	Liquid		Approx. 1.2 (68° F)	Approx. 35%		B 703
Hydrogen fluoride, HF	Hydrofluoric acid	Steel drums; tank cars	Steel	Liquid			70%	Below 60%, steel cannot be used	
Sodium fluoride, NaF	Fluoride	Bags; bbls.; fiber; drums; kegs	Iron, lead, steel	Nile blue or white powder: light dense	50 75	0.35 (most temps.)	90-95% NaF	pH of 4% solution, 6.6	B 701
Sodium silicofluoride, Na_2SiF_6	Sodium silicofluoride	Bags; bbls.; fiber; drums	Iron, lead, steel	Nile blue or yellowish-white powder	72	0.03 (32° F), 0.06 (72° F), 0.12 (140° F)	99% Na_2SiF_6	pH of 1% solution, 5.3	B 702
Fluoride Adjustment									
Aluminum oxide, Al_2O_3	Activated alumina	Bags; drums	Iron, lead, steel	Powder, granules (up to 1½-in. diam)	Variable	Insoluble	100%		
Bone charcoal	"Flu-Carb"	Bags; drums; bulk	Wood, iron, steel	Granules	Variable			Black; best used in beds for presolution	
Tricalcium phosphate	"Fluorex"	Bags; drums; bulk; bbls.	Iron, steel	Granular, technical	50-63	Insoluble		Also available as white powder	
High-magnesium lime	Dolomitic lime	Bags; bbls.; bulk	Wood, iron, steel	Lump, pebble, ground		Slakes slowly	58% CaO, 40% MgO_2		
Stabilization and Corrosion Control									
Carbon dioxide, CO_2	Carbon dioxide gas, liquid carbon dioxide	20-, 50-lb cylinders Bulk; tank trucks, tank cars			47.4 @ 70° F				
Disodium phosphate, $Na_2HPO_4 \cdot 12H_2O$	Basic sodium phosphate, DSP, secondary sodium phosphate	125-lb kegs; 200-lb bags; 325-lb bbls.	Cast iron, steel	Crystal	60-64	0.4 (32° F), 6.4 (86° F)	19.5% P_2O_5	Precipitates Ca, Mg; pH of 1% solution, 9.1	
Sodium hexameta-phosphate, $(NaPO_3)_6$	"Calgon," glassy phosphate, vitreous phosphate	100-lb bags	Hard rubber, plastics, stainless steel	Crystal, flake, powder	47	1-4.2	66% P_2O_5 (unadjusted)	pH of 0.25% solution, 6.0-8.3	
Sodium hydroxide, NaOH	Caustic soda, soda, lye	100-, 700-lb drums; bulk (trucks, tank cars)	Cast iron, rubber, steel	Flake Lump Liquid		2.4 (32° F), 4.4 (68° F), 4.8 (104° F)	98.9% NaOH, 74-76% NaO_2	Solid; hygroscopic; pH of 1% solution, 12.9	
Sulfuric acid, H_2SO_4	Oil of vitriol, vitriol	Bottles; carboys; drums; trucks, tank cars	Concentrated—iron, steel; dilute—glass, lead, porcelain, rubber	Solution (60-66° Bé)		Complete	77.7% H_2SO_4 (60° Be); 93.2% H_2SO_4 (66° Bé)	Approx. pH of 0.5% solution, 1.2	

Table 6-19. Continued.

Chemical Name and Formula	Common or Trade Name	Shipping Containers	Suitable Handling Materials	Available Forms	Weight, lb/cu ft	Solubility, lb/gal	Commercial Strength	Characteristics	AWWA Standard
Stabilization and Corrosion Control (Continued)									
Tetrasodium pyrophosphate, $Na_4P_2O_7 \cdot 10H_2O$	Alkaline sodium pyrophosphate, TSPP	125-lb kegs; 200-lb bags; 300-lb bbls.	Cast iron, steel	White powder	68	0.6 (80° F), 3.3 (212° F)	53% P_2O_5	pH of 1% solution, 10.8	
Trisodium phosphate, $Na_3PO_4 \cdot 12H_2O$	Normal sodium phosphate, tertiary sodium phosphate, TSP	125-lb kegs; 200-lb bags; 325-lb bbls.	Cast iron, steel	Crystal: coarse medium standard	56 58 61	0.1 (32° F), 13.0 (158° F)	19% P_2O_5	pH of 1% solution, 11.9	
Softening									
Calcium hydroxide, $Ca(OH)_2$	Hydrated lime, slaked lime	50-lb bags; 100-lb bbls.; bulk (carloads) trucks	Asphalt, cement, iron, rubber, steel	White powder: light dense		0.014 (68° F) 0.012 (90° F)	85-99% $Ca(OH)_2$, 63-73% CaO	Hopper agitation required for dry feed of light form	B 202
Calcium oxide, CaO	Burnt lime, chemical lime, quicklime, unslaked lime	50-lb bags; 100-lb bbls.; bulk (carloads)	Asphalt, cement, iron, rubber, steel	Lump, pebble, granule		Slakes to form hydrated lime	75-99% CaO	pH of saturated solution, 12.4; detention time, temperature, amount of water all critical for efficient slaking	B 202
Sodium carbondate, Na_2CO_3	Soda ash	Bags; bbls.; bulk (carloads, trucks)	Iron, rubber, steel	White powder: extra light light dense	23 35 65	1.5 (68° F), 2.3 (86° F)	99.4% Na_2CO_3, 58% Na_2O	Hopper agitation required for dry feed of light and extra-light forms; pH of 1% solution, 11.3	B 201
Sodium chloride, NaCl	Common salt, salt	Bags; bbls.; bulk (carloads)	Bronze, cement, rubber	Rock fine		2.9 (32° F), 3.0 (68° F), 86° F	98% NaCl		B 200
Taste and Odor Control									
Activated carbon, C	"Aqua Nuchar," "Hydrodarco," "Norite"	Bags; bulk	Dry—iron, steel; wet—rubber, silicon, iron, stainless steel	Black granules powder	15	Insoluble (suspension used)			B 600 & B 604
Chlorine, Cl_2	Chlorine gas, liquid chlorine	100-, 150-lb cylinders; 1-ton tanks; 16-, 30-, 55-ton tank cars	Dry—black iron, copper, steel; wet gas—glass, hard rubber, silver	Liquefied gas under pressure	91.7	0.07 (60° F), 0.04 (100° F)	99.8% Cl_2		B 301
Chlorine dioxide, ClO_2	Chlorine dioxide	Generated as used	Plastics, soft rubber (avoid hard rubber)	Yellow-red gas		0.02 (30 mm)	26.3% available Cl_2		
Copper sulfate, $CuSO_4 \cdot 5H_2O$	Blue vitriol, blue stone	100-lb bags; 450-lb bbls.; drums	Asphalt, silicon, iron, stainless steel	Crystal Lump Powder	75-90 73-80 60-64	1.6 (32° F), 2.2 (68° F), 2.6 (86° F)	99% $CuSO_4$		B 602
Ozone, O_3	Ozone	Generated at site of application	Aluminum, ceramics, glass	Colorless gas					
Potassium permanganate, $KMnO_4$	Purple salt	Bulk; bbls.; drums	Iron, steel, wood	Purple crystals		Infinite	100%	Danger of explosion on contact with organic matters	B 603

6-79. How To Apply Chemical Agents. The amounts of chemicals added to water must be carefully controlled to ensure uniform treatment. Because most chemical agents must be in solution form before water is added, the application of these chemicals requires at least one and possibly two distinct operations. These operations are the preliminary preparation of the chemical and feeding of the prepared chemical. This section discusses most common chemical feeders, with the exception of chlorination equipment and lime slaker operation and maintenance, which are covered in sections H and E, respectively.

a. Preliminary Preparation:

(1) Solid Forms. Most chemicals available for water treatment are in solid, granular, or powdered form. Preliminary preparation of the solid forms involves measuring a specific volume or weight of chemical which is dissolved in water to form an aqueous solution. Solid forms may be put in solution with dry feeders or saturators. Dry feeders are used most often because of their great accuracy and simple operation and they are adaptable to automatic or manual control.

(a) Dry Feeders and Mixing Tanks:

1. General Information.

a. A dry feeder is a device for metering a dry chemical at a predetermined rate. The dry chemical may be metered by volume or weight of chemical feed per unit of time, with the former type known as volumetric and the latter as gravimetric. The dry chemical discharged from the feeder falls into a dissolving tank where it is dissolved in water, forming a solution that flows by gravity or is pumped to the point of application.

b. The dissolving tank is often an integral part of the feeder assembly and is generally equipped with a mechanical or baffle chamber mixing device. The rate of solution withdrawn from the dissolving tank is generally constant, as is the corresponding makeup water addition to the dissolving tank.

c. The waterflow through the dissolving tank is in excess of that water quantity required for dissolving the chemical. As the feed rate of the dry feeder is changed, a varying quantity of chemical is added to the constant volume of water flowing through the mixing tank. Thus, a varying concentration of solution is withdrawn from the feeder.

d. The rate of dry chemical addition may be controlled manually, in direct proportion to pH or the rate of flow being chemically treated, or in response to the level of chemical in the treated water.

2. Dry Feeder Selection. The type of dry feeder most suitable for a given application depends largely on the amount of material to be fed per hour and the nature of the material. Generally, volumetric dry feeders are simpler, less expensive, and deliver slightly less accuracy than gravimetric dry feeders. Volumetric feeders deliver as little as 3 to 4 ounces of dry chemical an hour. Gravimetric dry feeders, on the other hand, are capably of delivering large quantities, are extremely accurate, more expensive, and are readily adapted to automatic control. Gravimetric feeders are also used for feeding dry chemicals into small water quantities when high accuracy is required.

a. Dry feeding mechanisms may be classified (in increasing order of feeding capacity) as rotating disc, oscillating, rotary gate, belt, and screw type. Any of these mechanisms may be controlled volumetrically or gravimetrically. Volumetric feeders may be converted to the gravimetric type by providing a weighing device or a platform scale and a loss in weight controller that will continuously adjust and control the weight of the chemical fed.

b. The rotating disc feeder (figure 6-45) is probably the most widely used, particularly in the smaller plants. It is the most accurate of all continuous volumetric feeding mechanisms and is suitable for such water treatment chemicals as hydrated lime, soda ash, and activated carbon. Accuracy is well within ± 1 percent of volume or ± 3 percent by weight, with a noncompressible material in a shallow hopper. The rotating disc feeder is generally used where average feeding rates of 10 pounds an hour are desired.

c. The oscillating feeder (figure 6-46) has an average rate of 10 to 100 pounds an hour with an accuracy of within ± 3 percent by volume. With compressible materials (such as hydrated lime), this range of variation may

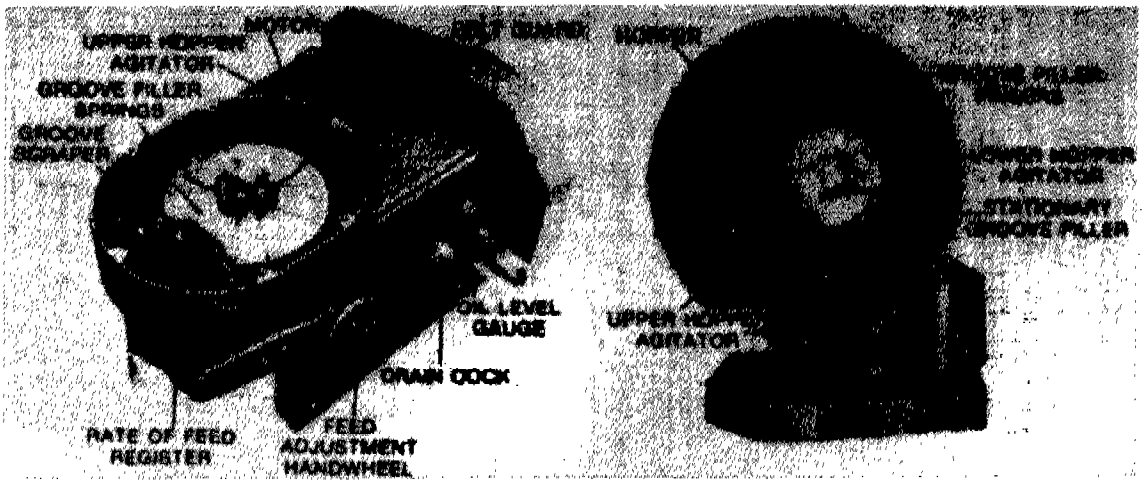


Figure 6-45. Rotating Disc Chemical Feeder.

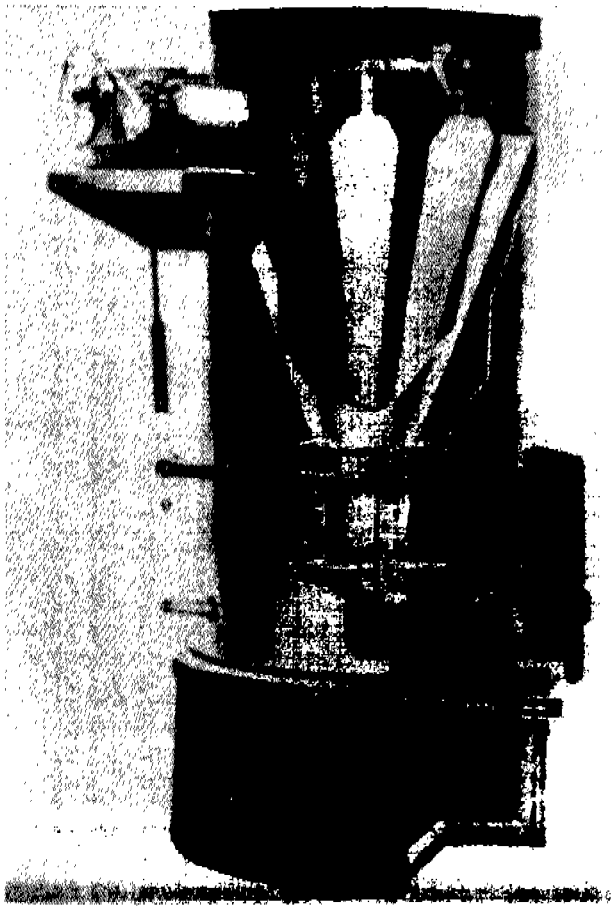


Figure 6-46. Oscillating Chemical Feeder.

increase to 5 to 6 percent.

d. The rotary gate dry feeder (figure 6-47) is suitable for rates between 200 and 500 pounds per hour if the material has free flowing characteristics. Depending on the compressibility of the material, an error less than ± 5 percent by volume can be expected.

e. The belt type feeder (figure 6-48) is generally used with gravimetric controls. The belt type gravimetric feeder is suitable for average feeding rates of from 500 to 20,000 pounds an hour. For water treatment applications, however, only occasionally do requirements reach 5,000 an hour. The belt mechanism is attached to a scale to keep a certain weight of chemical on the belt. Feed rate accuracy is identical at the maximum and minimum rates because the same load is being weighed at all rates of feed. The adjustment in feed rate is made by changing the belt speed and not by altering the weight on the belt. The average accuracy of the belt type gravimetric feeder is ± 2 percent.

f. Screw type feeders (figure 6-49) deliver very small or very large amounts of material, depending on the size of the conveyor. These feeders are generally controlled volumetrically. The feed rate can range from 10 to 24,000 pounds an hour, depending on material density. An accuracy of ± 2 percent can be expected.

g. Unless the savings in chemicals resulting in the greater accuracy of the gravimetric control are warranted, the smaller feeders are generally volumetric. An exception to this rule-of-thumb is in the great accuracy required in feeding fluoride compounds. Only when a minimum demand for fluoride chemicals is less than about 10 pounds an hour should a feeder other than a gravimetric feeder be considered.

h. Provided bridging is overcome through a vibrating mechanism, errors in feeding dry chemicals with a volumetric feeder are mainly due to compressibility in the material being fed. With a fluffy compressible material, the weight being fed for a given displacement of the volumetric feeding mechanism is greater when the hopper is full than when the hopper is empty.

3. Volumetric Type Dry Feeders. Volumetric feeders are essentially a combination of a driving mechanism, a means for delivering a constant volume of dry compound, a hopper for holding the compound, and a chamber for dissolving the compound before feeding to water supply. The hopper should be equipped with an agitator to prevent arching and to ensure a continuous chemical feed at all times. The feeder must feed the chemical uniformly. Rate adjustment apparatus permits precise control of the feeding rate. The feeding mechanism must be completely enclosed to prevent dust from escaping. The dissolver or solution chamber must be constructed of proper materials and provided with a removable cover and dust tight flex-

Figure 6-47. Rotary Gate Chemical Feeder.

ible connection to the feeding mechanism. The volume of the dissolver is sized according to the feed rate and the corresponding quantity of water and detention time required to dissolve the specific chemical being handled.

4. Gravimetric Feeders. Gravimetric feeders deliver chemicals at a constant weight, rather than a constant volume, during a given period. A higher degree of accuracy is obtained, but the savings in chemical cost may not offset the increased costs of a gravimetric feeder. The scales, hopper, weighing mechanism, and dissolver or solution chamber should be completely enclosed. A totalizer should show the total amount of chemical fed, in pounds, on a direct reading counter without using multipliers. The accuracy of the totalizer should be better than 99 percent.

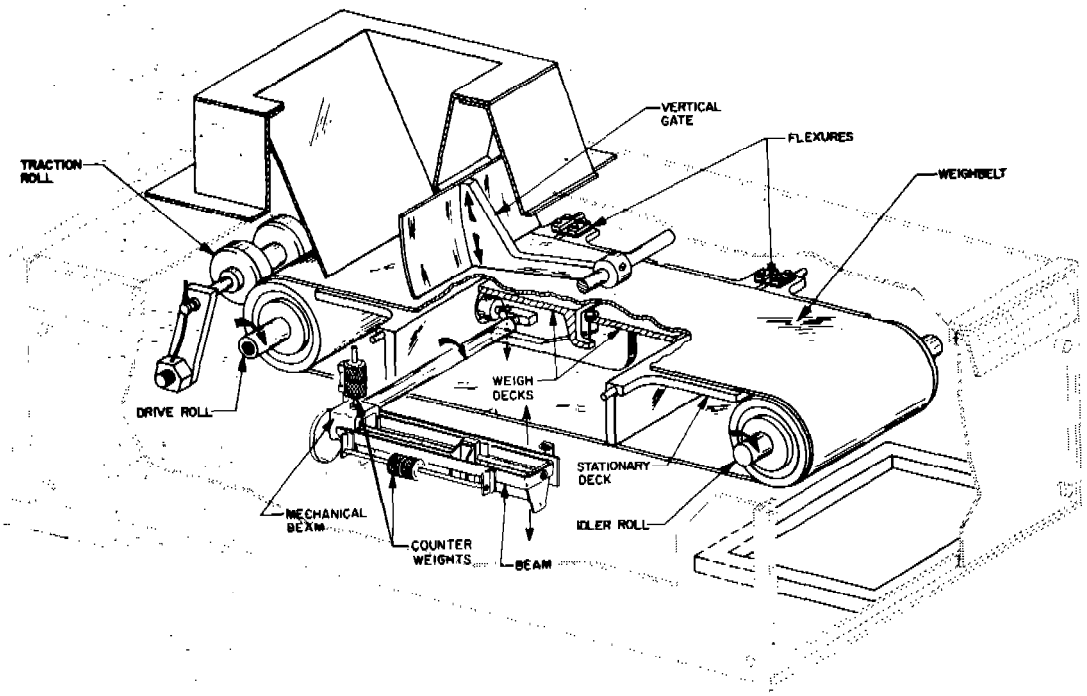


Figure 6-48. Gravimetric Belt-Type Chemical Feeder.

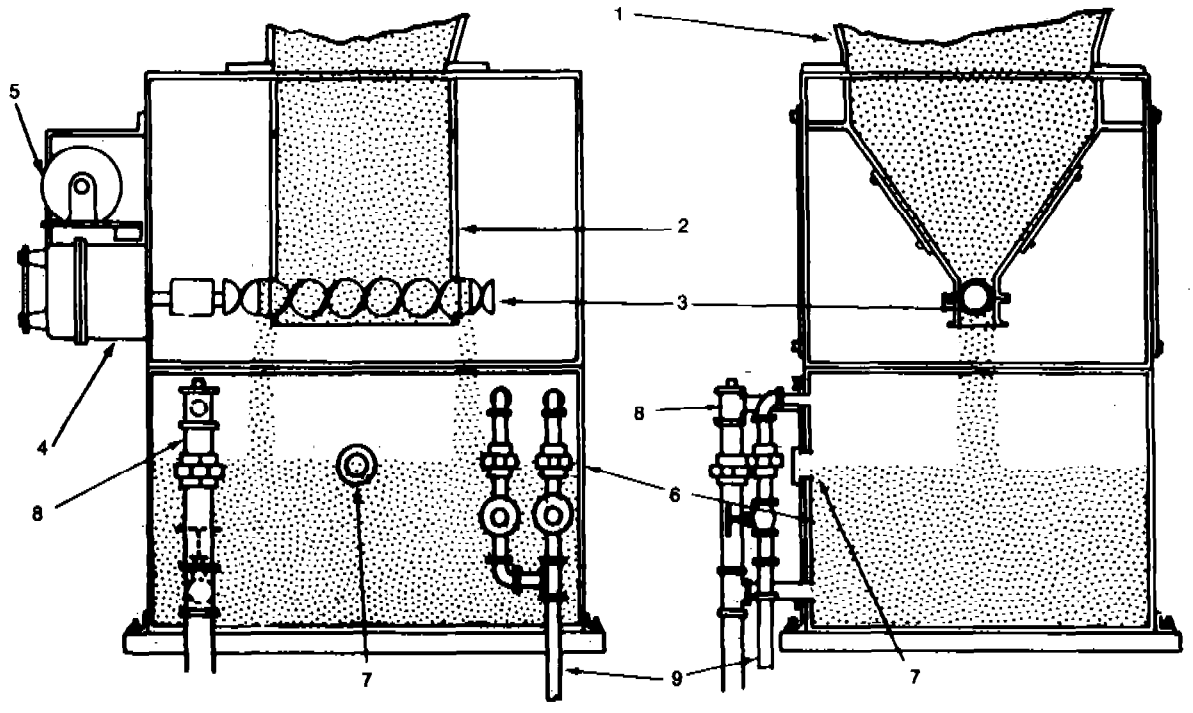


Figure 6-49. Screw Chemical Feeder.

The hopper should be filled from the floor on which the feeder is placed on or from overhead charging chute or funnel extending to the floor above. The hopper should be fitted with suitable agitators to prevent arching. The dissolver or solution chamber should meet the same requirements as for volumetric feeders. Although the belt type method is typically used in gravimetric feeder installations, other methods previously discussed can be converted to the gravimetric approach. The weight measuring device can measure either the rate of loss in weight of the material in the hopper or the weight of material placed on a moving belt. Many gravimetric dry feeders also incorporate some of the features of volumetric feeders, in that they have a rotary feed mechanism between the hopper and the weighing section or use a mechanical vibrator to move chemicals out of the hopper. Because ultimately it is the weight of material per unit of time that is measured and regulated, such variables as material density or consistency have no affect on feed rate. This accounts for the extreme accuracy that these feeders are capable of providing.

(b) Saturators. A saturator (figure 6-50) often eliminates the need for weighing chemicals, measuring solution water volume, and mixing to completely dissolve the chemical. Basically, excess chemicals are placed in a container and water is trickled over at a rate to provide a saturated solution at the container exit. In a downflow saturator, a filtration barrier is provided by layers of sand and gravel to prevent particles of undissolved chemical from leaving the tank. An upflow saturator eliminates the need for a filtration barrier. A feeder adds the prepared saturated solution, at the desired rate, to the water system. The only operator attention required is to see that an adequate quantity of chemical is kept in the saturator and that the saturator is kept in a reasonably clean condition. This type of solution feeder is particularly useful when a chemical exhibits an unusually stable concentration during widely varying conditions of temperature and time of contact between chemical and water.

(2) Liquid Forms. Several chemicals shown in table 6-19 are available in liquid form and can usually be applied directly to the water without preliminary preparation. However, certain instances may require that the liquid chemical be diluted before it is added to the water supply.

b. Feeding Criteria. The criteria used in selecting a feeder are capacity, corrosion resistance, pressure capability, and of course, accuracy and durability. Chemical solutions can be fed by gravity or through small pumps under pressure.

(1) Gravity Feed:

(a) Gravity Flow. Solutions from dissolving tanks for dry feeders and saturators may be piped directly to the point of application in open channels and basins. The solution may also be transferred by gravity to another tank from which a feeder applies the solution to the water being treated. The level of water in the dissolving tank provides the pressure needed to push the solution through the piping.

(b) Rotating Cup. Several types of solution feeders are available for gravity feed that operate on a paddle wheel principle. A rotating wheel equipped with small cups dips solution from a constant head tank (figure 6-51) and

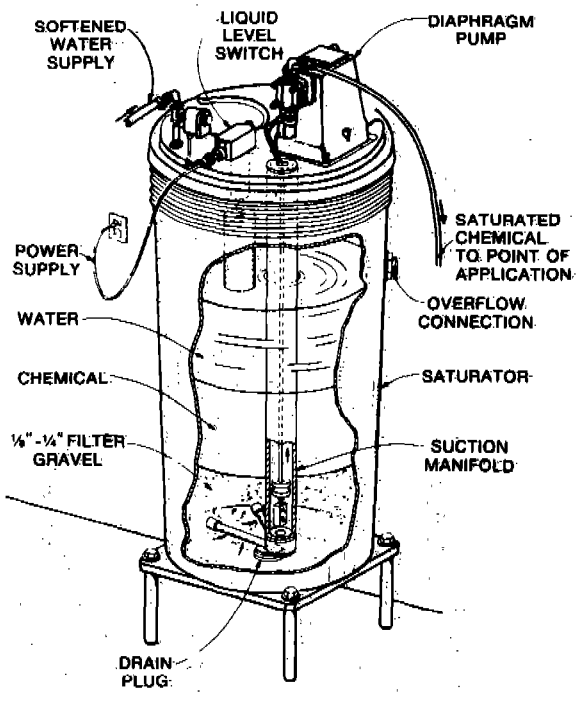


Figure 6-50. Chemical Saturator.

discharges the solution to the water to be treated. The rate of feed can be varied by changing the rate of rotation of the wheel, or by varying the proportion of the cup contents that are emptied.

(c) Decanter Feed. The decanter feeder (figure 6-52) uses a tank in which a chemical solution of suitable strength is prepared and stored. The drawoff head on the tank is varied in proportion to the volume of water to be treated, thereby feeding the chemical solution at a variable rate. The chemical may be delivered to the point of application by chemical pump or gravity discharge. The decanter feeder is usually designed for small chemical feed capacities in the range of 0.1 to 50 gallons per hour.

(2) Pressure Feed. Where gravity delivery cannot be achieved, piston or diaphragm feeders (figure 6-53) are generally used to deliver chemical solutions under pressure. Other pressure feeding methods include pot type and differential feeding whereby flow of water through a pressurized line creates a partial vacuum, drawing solution into contact with the water. The pot type and differential feeding methods are generally inaccurate, but they do find some use in water treatment.

(a) Diaphragm Feed. The diaphragm feeder has a flexible diaphragm driven either directly or indirectly by mechanical linkage that alternately forces solution out of the chamber and then, on its return stroke refills the chamber by pulling solution from a reservoir. When an electric motor drives the feeder, a gear box or system of belts and pulleys determines the number of strokes in a given time interval. Pneumatic or hydraulic drives are also available. These drives permit the meter contactor to provide proportioning to waterflow. Most piston and diaphragm feeders perform accurately near midrange of both stroke length and stroking frequency and should be selected accordingly. At the extremely low feed rates required by small installations, diaphragm feeders are superior to the piston type.

(b) Piston Feed. In the piston feeder, a reciprocating piston forces solution out of the chamber and then refills the chamber by pulling solution from a reservoir. The piston pump is more economical than the diaphragm feeder because of its simplicity, compactness, and ability to perform the double function of both metering and injection. Changes in concentration, viscosity, and density in chemicals typically used for water treatment do not materially affect volumetric measurements. Because of the incompressibility of water solutions, the proportioning pump gives an accuracy of 1 percent by volume when used with solutions that do not carry suspended solids or abrasive materials. The piston type pumps are available in a wide range of materials and sizes with feed rates from a fraction of 1 gallon an hour to 50 gallons a minute. The

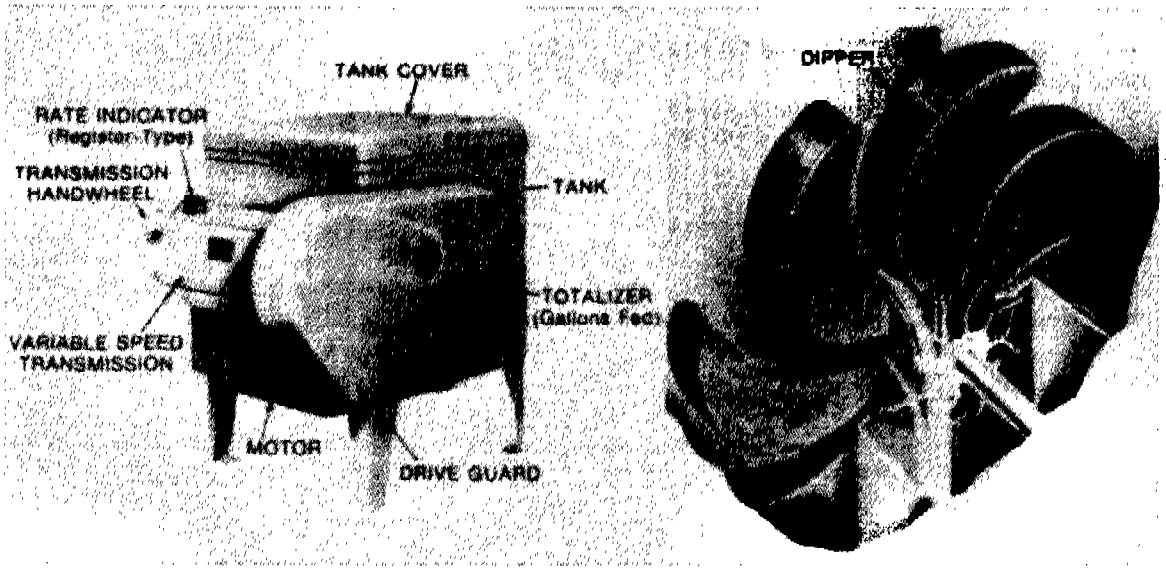


Figure 6-51. Rotating Dipper Feeder.

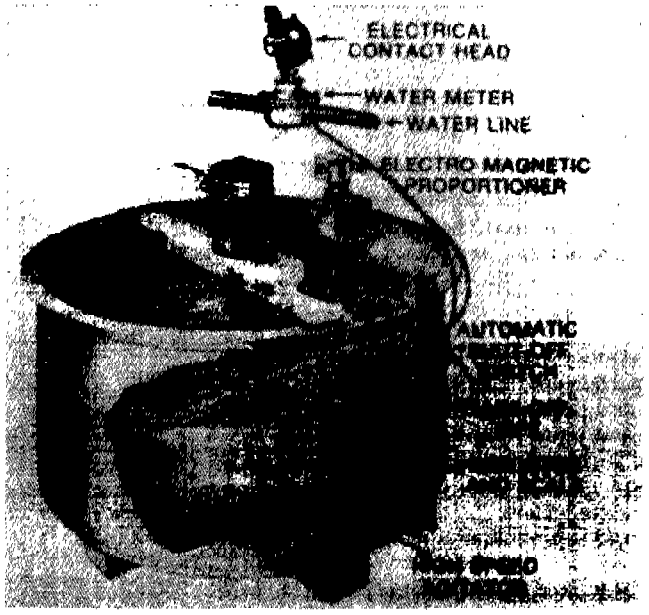


Figure 6-52. Decanter Solution Feeder.

amount of chemical fed a minute or an hour is adjusted by changing the stroke length. For some applications, change of speed is also used, although this adds to initial cost.

(c) Pot Feeders. A pot feeder uses a pressure differential across an orifice tube in the water line to divert a small stream of water into the pot. An equal volume of chemical is displaced into the raw water line. Pot feeders are only suitable for chemicals with low solubility that maintain a saturated solution for long periods of time. Chemicals that dissolve quickly, such as soda ash, filter alum, and others, should not be applied with pot feeders. Uniformity of chemical application cannot be assured due to temperature-solubility variations, bed channeling, and limited contact time at high flows.

(d) Other Feeders:

1. Several types of rotary pumps that qualify as pressure feeders include gear, swinging vane, sliding vane, oscillating screw, eccentric, and cam pumps (figure 6-53).

2. Solution feeding devices such as centrifugal pumps or head tank and orifice feeders are sometimes used. These devices are not used, however, when extremely accurate feed rates are required.

6-80. Chemical Feeding Equipment Maintenance:

a. Dry Chemical Feeder Maintenance:

(1) Overall Maintenance. The following daily maintenance procedures apply to all types of volumetric and gravimetric feeders. Maintenance procedures for dry chemical feeders are summarized in table 6-20.

(a) Clean and Inspect. Clean the feeder, feeder mechanism, and the feeder surroundings. Use a vacuum cleaner or brush to remove spilled chemicals or chemical dust. Make sure that the orifice, knife edges, scrapers, shakers, and openings are free of chemical accumulations in volumetric feeders. Remove chemical accumulations from belt rolls and belts in the belt type gravimetric feeders. Check the feeder for general performance. Note and investigate unusual noises. Observe the condition of electric wiring, fuses, and connections. Check for oil drips and

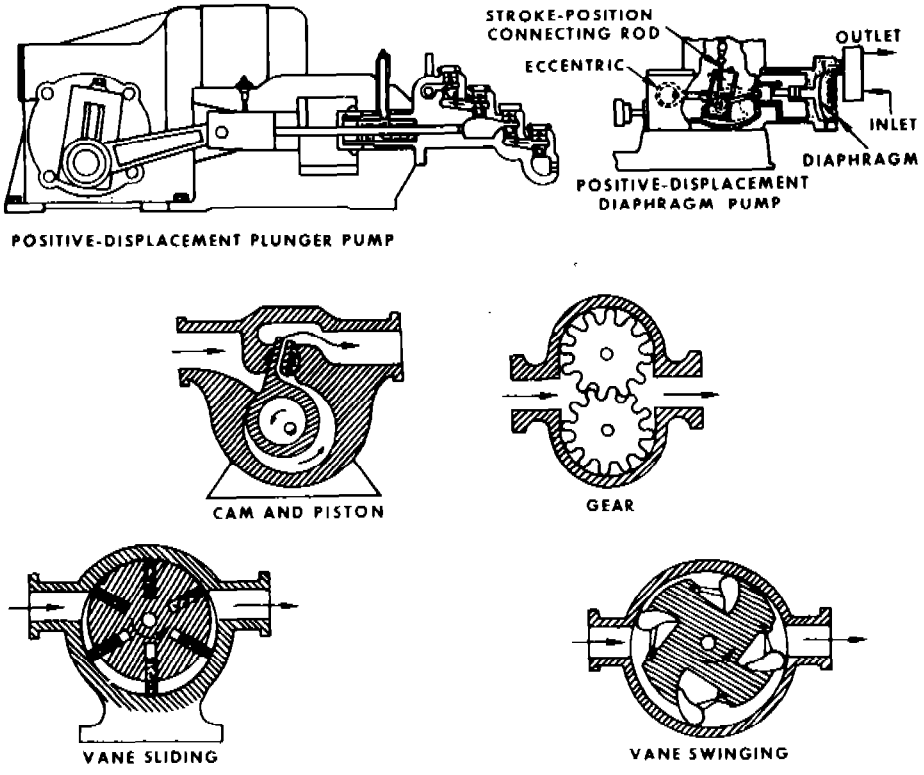


Figure 6-53. Pressure Solution Feed Pumps.

Table 6-20. Maintenance Procedures for Dry Chemical Feeders.

Inspection	Action	Frequency [1,2]
Dry feeders	Remove chemical dust accumulations; check feeder performance; check for loose bolts; clean solution tank of accumulated sediment; lubricate moving parts.	D
Drive mechanisms and moving parts.	Service and lubricate	Q
Calibration	Check feed-rate accuracy and adjust, as necessary	M
Overhaul feeders	Thoroughly clean feeder and feeding mechanism; paint; service and lubricate drive mechanisms, bearings; clean and paint solution tanks.	A
Feeders out-of-service	Clean, remove all chemicals from hopper and feeder mechanism.	V
Disc feeders	Clean rotating disc and plow.	M
Oscillating feeders	Check and adjust mechanism and adjustable stroke rod.	M
Rotary gate feeders	Clean pockets of star feeder and scraper	M
Belt-type feeders	Check vibratory mechanism, tare-balance, feeding gate, belt drive and belt; calibrate delivery.	M
Loss-in-weight feeders	Check feeder scale sensitivity, tare-weight and null balance.	M
Screw feeders	Clean screw, check ratchet drive or variable speed drive.	M
Dust collectors		
Motors	Lubricate motors	V
Filter bags	Check condition and attachment. Securely attach sound bags; replace damaged or torn bags.	V

[1]D-Daily; M-Monthly; Q-Quarterly; A-Annually; V-Variable, as conditions may indicate.

[2]The frequencies shown are suggested frequencies which may be modified by local command, as individual conditions warrant.

general deterioration. Wipe all parts of the feeder and inspect for loose bolts, cracks, defective parts, and leaks. Make necessary repairs to eliminate undesirable conditions.

(b) Solution Tank. Check the solution tank for sediment or undissolved chemicals; remove accumulated material. In dissolvers lined with asphalt or other protective coatings, the lining should not be skinned from the steel. Follow the manufacturer's instructions to repair such linings.

(c) Moving Parts. Quarterly, service moving parts and lubricate according to manufacturer's instructions.

(2) Test Calibration. Make monthly calibrations to check the accuracy of feed rate and control mechanisms. Indicate or record feed rates and amounts. The following test procedures apply to various feeders:

(a) Volumetric Dry Feeders:

1. Make at least three tests within the normal operating range of the feeder. If the feeder is not on a scale, use a pan or other container of known weight to catch the discharge of the feeder for a definite period. Weigh the discharged material, calculate the rate of feed an hour, and compare the results with the rate setting, rate indicator, and recorder (if one is used).

2. If a feeder is on a scale, balance the scale while the feeder is stopped; start the feeder and run for a definite period; rebalance the scale. From the difference in the two scale readings, calculate the amount fed in the measured time and then calculate the feeding rate in pounds per hour.

3. Repeat all tests and average the data for several tests to compare with the rate setting and rate indicator (or indicator and recorder). Take particular care in the timing and weighing operations. Make any adjustments necessary to bring the feed rate within ± 5 percent by weight of the rate setting.

(b) Belt Type Gravimetric Feeder:

1. After the belt and feeder have been cleaned, balance the scale and operate the feeder until feeder scale beam is in full balance and indicates a proper load on the belt. If the feeder is proportionally paced, set the proportioning equipment on "manual control;" set the rate of feed at maximum and proceed with this calibration test.

a. Stop the feeder and make sure that the scale moves freely and is in exact balance.

b. Adjust the amount of chemical on the belts by adding or removing chemical at the rear of the belt, until an exact balance is obtained.

c. Free the belt revolution counter or weight integrator, start the feeder and run until a definite weight

of chemical has been discharged (about two-thirds of a belt load) and then stop the feeder.

d. Balance the scale precisely. The difference between this scale reading and that at the test is the weight of material discharged.

e. Check this amount against the number of pounds fed as indicated by the revolution counter. If the weight of the chemical delivered differs from that indicated by more than ± 1 percent, adjust the poise on the scale beam and repeat the test. (Moving the poise to a lower value reduces the loading on the belt and vice versa.)

f. Repeat testing and adjustment until a belt loading is found that agrees with the amount fed, as indicated by the totalizer counter.

NOTE: Whenever a feeder is used for a different chemical, the calibration must be repeated.

2. Some belt type gravimetric feeders may be made to discharge into a container of known weight, in which the feed rate may be checked by actually weighing the amount discharged at a definite time.

(c) Loss-in-Weight Gravimetric Feeder. Test calibration of this feeder is similar to the belt type gravimetric feeder. When the feeder is empty, the tare weight should be checked to make sure that the scale shows 0 weight. All other determinations and adjustments are similar to the belt type gravimetric feeder.

(3) Overhaul:

(a) Annual overhaul includes a thorough cleaning of the feeder, feeding mechanism, housing, and storage hopper; painting the exterior (and interior where desirable); servicing and lubricating all drive mechanisms, bearings, and other mechanical parts; and cleaning, repairing, and painting the solution and makeup tanks.

(b) Gravimetric feeders require additional cleaning and servicing of the feeder mechanism.

1. For belt gravimetric feeders, remove the feeder belt, assembly motors, belts and appurtenances, and overhaul completely as necessary.

2. Loss-in-weight gravimetric feeders must be disassembled, cleaned, and inspected for wear, and repaired where damaged. Parts must be replaced as necessary.

(4) Out-of-Service Feeders. Out-of-service feeders should contain no chemicals. Check to make sure that the condensation is not causing corrosion or deterioration. Belt feeders should have no chemical on the belt while the feeders are out-of-service.

(5) Specific Feeder Maintenance. The following feeders have special monthly maintenance procedures.

(a) Oscillating Feeder. The connecting rod to the oscillating hopper and the micrometer screw that sets the strokes should be inspected. The hopper agitators should be checked to make sure that they move freely.

(b) Rotary Gate Feeder. Inspection should ensure that the pockets in the face of the star-rotor are clean and free of accumulations of chemicals, so that the rotor neither binds in the housing nor is loose enough to allow leakage. The rotor driving mechanism should be checked. Make sure that the scrapers that clean the pockets are doing an effective job.

(c) Belt Type Gravimetric Feeder. The vibratory mechanism, tare weight balance, feeding gate, belt drive, and belt should be inspected each month.

(d) Loss-in-Weight Gravimetric Feeder. The feeder scale should be inspected each month to make sure that it is sensitive to small weight changes; when the feeder is empty, the tare weight should be checked to see if the scale shows 0 weight.

(e) Screw Type Feeder. The screw should be cleaned monthly and all chemical accumulations or corrosion removed. If used, the ratchet drive and variable speed drive should be checked.

(6) Dust Collection Equipment. Maintenance of dust collector equipment involves motor lubrication according to conditions of usage and location. The manufacturer's instructions should be consulted on motor lubrication. Inspect the filter bags for tears or other damage. Also, check the filter bags frequently to make sure that they are properly and securely attached to the manifold plate at the bottom of the dust collector cabinet. Install new filter bags when damage is evident.

b. Solution Feeder Maintenance. Maintenance procedures for solution feeders are summarized in table 6-21.

(1) Pot Feeder. Maintenance consists of daily operator inspection, monthly cleaning, and annual overhaul as follows:

(a) Daily operator inspection includes observing the amount of chemical fed to determine whether flow through the pot is effective.

(b) The sediment trap should be cleaned and the needle valve checked at monthly intervals.

(c) The chemical pot and orifice should be cleaned twice a year.

(d) Annual overhaul includes cleaning and painting the pot feeder and appurtenances.

(2) Decanter Feeder:

(a) Check the swing pipe each month.

(b) Inspect the reducing gears, pawl, ratchet, and motor twice a year.

(c) An overhaul should be performed each year, or as necessary, including cleaning, repairing, and painting all parts that require attention.

(3) Rotating Cup Feeder. The motor should be maintained according to the manufacturer's instructions. Other parts of the feeder should be maintained according to the following instructions.

(a) Change transmission oil after 100 hours of operation. Every 6 months, drain and flush transmission, clean interior to remove rancid and spent oil, and refill to gage level with oil specified by manufacturer.

(b) Lubricate dipper shaft bearings each week.

(c) Each month, clean the drive chain and lubricate, check alignment, and check and lubricate sprocket teeth.

(d) If an agitator is used, clean and lubricate at intervals recommended by the manufacturer.

(e) Check the alignment, tension, and inner cords of belt drives each month.

Table 6-21. Maintenance Procedures for Solution Chemical Feeders.

Inspection	Action	Frequency[1,2]
Pot feeders		
Flow through pot	Determine amount of chemical fed to ascertain if flow through pot is effective.	D
Sediment trap	Clean trap and check needle valve	M
Chemical pot	Clean pot and orifice	SA
Overhaul	Clean and paint pot feeder and appurtenances	A
Differential solution feeders		
Chemical storage tank	Inspect and clean	SA
Oil volume	Check and replenish	SA
Pitot tubes and needle valve	Check and replace as necessary	A
All equipment	Paint as necessary	V
Decanter feeder		
Swing-pipe	Check to make certain it does not bind	M
Motor ratchet, pawl, reducing gears.	Check and lubricate	SA
Overhaul	All parts to be inspected, cleaned, repaired and painted as necessary.	A or V
Rotating dipper feeder		
Motor	Follow manufacturer's instructions	V
Transmission	Change oil after 100 hr. operation	100 hr
	Drain and flush, clean interior and refill	SA
Shaft bearings	Lubricate	W
Drive chain	Clean, check alinement; check sprocket teeth; lubricate chain and sprockets.	M
Agitator	If used, clean and lubricate according to manufacturer's instructions.	V
Belt drives	Check alinement, tension and inner cords of belt drives.	M
Dipper and float valve	Check dipper clearance and adjust float valve setting.	SA
Proportioning pumps		
Operator inspection	Inspect sight feeders, rate of flow, piping, joints	D
Feeder	Clean feeder	W
Solution tank	Clean	M
Linings	If cracks occur, special linings should be repaired	A
Overhaul	Disassemble, clean and overhaul	A

[1]D-Daily; W-Weekly; M-Monthly; SA-Semiannually; A-Annually; V-Variable, as conditions may indicate.
[2]The frequencies shown are suggested frequencies which may be modified by local command, as individual installation conditions warrant.

(f) Check float valve seating, replace worn washers, and worn valve seats twice a year. Check dipper clearance and adjust.

(4) Proportioning Pumps. Procedures for maintaining piston-type and diaphragm type proportioning pumps are in (a) through (c) below.

(a) Operator Inspection. Regardless of the type of feeder, certain maintenance procedures apply to proportioning pumps. These include:

1. Inspecting site-feed indicators each week to make sure that the solution is being delivered from the feeder. Checking automatic controls and chemical feed rate under varying rates of flow of water being treated, if proportional feeding is used.

2. Checking piping joints and packing glands each week to detect leaks.

(b) Cleaning Requirements. Each month:

1. Remove and clean the site feed glass and plastic parts. Use a 5 percent solution of muriatic acid to remove white deposits left by hard water.

2. Clean and flush the solution storage tank. Clean suction hose, strainer, and screens on the water lines.

3. Operate the shutoff and rate control valves and mechanisms that control the output of the feeder.

4. Disassemble, inspect, and clean the feeding mechanism (diaphragm or plunger). Check the suction and discharge valves.

(c) Overhaul Requirements. Each year, remove, inspect, clean and replace, as necessary, the feeding mechanism (diaphragm, plunger, orifice, needle valves, check valves, etc.). Replace all worn parts and packing. Check

for corrosion. Reline piston pumps, if necessary. Replace cracked diaphragms in diaphragm pumps. Paint or touch up all exposed metal parts.

Section J—Water Desalination

6-81. General Information:

a. Need for Desalination. Some geographic locations, including coastal areas, islands, and some inland regions, have little or no freshwater even though unlimited supplies of saline water are available. When it is necessary to establish and maintain military installations in such areas, the water supply must be derived by converting saline water into freshwater.

b. Source and Characteristics of Saline Water:

(1) Seawater. Oceans contain huge quantities of saline water readily available for those installations located nearby. Seawater, however, contains about 35,000 mg/l of total dissolved solids. By contrast, 200 to 500 mg/l is generally considered to be an acceptable minimum level of total dissolved solids in public drinking water supplies.

(2) Brackish Water. Brackish waters contain about 1,000 to 10,000 mg/l of total dissolved solids. Sources of brackish water include highly mineralized ground water and diluted seawater found in estuaries. Some inland lakes and rivers are also saline in nature. Irrigation, industrial, and potable water uses add salinity to already brackish waters.

c. Desalination Processes. Several methods are available for converting saline waters to freshwater, but they are all quite expensive and complicated to use. These methods include distillation, ion exchange, electrodialysis, and reverse osmosis. Other methods (such as freezing, hydrate formations, solvent extractions, and solar evaporation) are still in the developmental stage and are not practical desalination methods.

6-82. Distillation Processes.

Distillation is generally considered to be the most reliable and most economical of the currently available seawater desalination processes.

a. Process Characteristics:

(1) Saline water conversion by distillation consists of heating the water to produce steam, cooling to condense the steam, and collecting the distilled water in a separate container. Changing boiling water to steam requires a large amount of heat, known as latent heat of vaporization. The salt and other dissolved substances in the saline water do not vaporize and remain behind. Thus the distilled water is freed of salt. The latent heat of vaporization must then be removed by cooling to change the steam back to water.

(2) Water produced by distillation is very soft, practically free of dissolved impurities, and contains no bacteria. It should be chlorinated, however, to provide a measurable chlorine residual to keep bacteria from entering through incompletely covered tanks or other possible sources of contamination.

b. Energy Use. Heat is required to boil the saline water. This heat can be provided from the sun, but is generally produced by burning fuels.

c. Multiple Effect Distillation. When distilling water in large quantities, the steam is condensed by circulating cooling water around the steam line in the condenser. The cooling water thus becomes heated. Multiple-effect distillation attempts to save some of the heat given up by the condensed water. In this process, water is boiled in an evaporator to produce steam at ordinary atmospheric pressure. This steam is then condensed and cooled. The cooling water from this step is used as feedwater to a second evaporator (second effect) which is operated under a somewhat lower pressure so that the boiling temperature of the water is lower. Steam produced in the second evaporator is condensed, and the cooling water is used to produce additional steam in an evaporator (third effect) operated at still lower pressure. In this way the heat losses are reduced and the fuel is used more economically. The amount of fuel required per gallon of water produced is about one-third as much for triple-effect distillation as for single effect distillation. Multiple-effect systems with as many as 17 effects have been made. The two principal types of distillation processes which use multiple-effect distillation are long tube vertical and multi-stage flash methods.

(1) The long tube vertical system evaporates seawater as it flows downward by gravity inside tubes surrounded by steam or hot vapors. The seawater inside the tube is boiled and the generated-steam passes it to the next stage where it heats the incoming feedwater and condenses on the outside of the tube bundle, thereby forming the distilled water. The long-tube vertical distillation system is illustrated in figure 6-54.

(2) The multistage flash distillation process first heats water under pressure in tubes. The heated water is introduced into a chamber under reduced pressure where some of the water immediately expands (flashes) and subsequently condenses on tubes that are cooled by the incoming seawater supply as it flows toward the heat input section. The condensed steam is collected on trays and pumped to use. Multistage flash is the most reliable method for desalinating water. The multistage flash distillation process is illustrated in figure 6-55.

d. Vapor Compression Distillation. Another distillation process used at military installations is the vapor compression or thermocompression method. Like the multiple-effect process, the vapor compression process also conserves

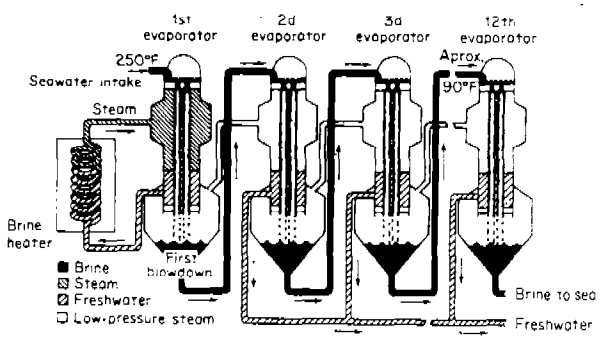


Figure 6-54. Simplified Diagram of the Long-Tube Vertical Distillation Process.

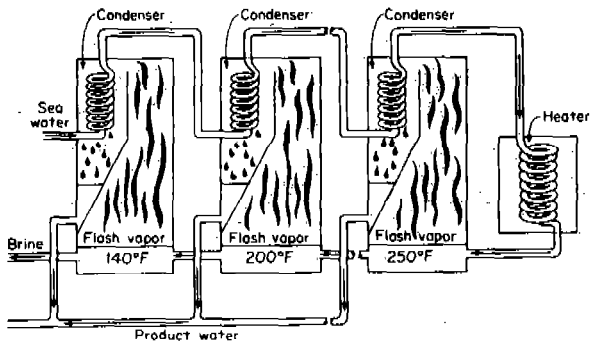


Figure 6-55. Simplified Diagram of the Multistage Flash Distillation Process.

the heat given up by the condensing steam. However, it generally does this in a single stage, which results in a smaller and more compact unit.

(1) Principles of Operation. The vapor compression distillation process is illustrated in figure 6-56.

(a) Heat Pump Principle. The unit operates on a heat pump principle. Heat is removed from the vapor (steam) produced and transferred back to the water being heated in the evaporator. The steam from the evaporator is compressed in the compressor. Compressing the steam causes its temperature to rise so that it is above the temperature of the steam in the evaporator. The compressed steam then passes to the heat exchange section of the evaporator where the increased heat is transferred to the evaporating water to produce more steam. The compressed steam is condensed to water at the same time. The newly formed steam is compressed in turn, and the cycle is repeated.

(b) Closed Heat Cycle. In giving up its latent heat, the compressed steam is reduced in temperature to the point where it becomes distilled water, the final product. This use of a combination evaporator-condenser with a steam compressor creates a closed heat cycle that permits the continued reuse of the latent heat of vaporization. The heat in the distillate, blowdown, and engine gases is economized by transferring it to the feedwater in heat exchangers. In this way, as much heat as possible is conserved. The concentrated brine is continuously blown

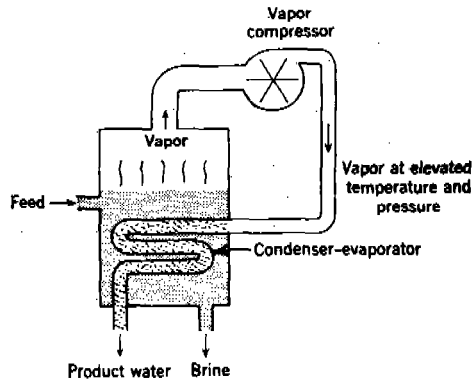


Figure 6-56. Simplified Diagram of the Vapor Compression Distillation Process.

down through an overflow pipe to prevent the saltwater in the evaporator from becoming too highly concentrated. A high rate of blowdown is desirable to keep the brine concentration down. The operator is then chiefly concerned with varying the rate of blowdown and rate of feedwater to get the best results.

(2) Equipment. The principal components of a vapor compression distillation plant are described in the following paragraphs.

(a) Evaporator. After preheating by flowing through the heat exchangers, the feedwater enters the evaporator at a temperature near the boiling point. Heat given up by the condensing steam in the steam chest is transferred through the vertical tubes, causing the feedwater to reach the boiling point and to partially vaporize. The steam and water rise inside the tubes to the upper section of the evaporator, which is simply a steam generator. A baffle arrangement allows the steam to pass on into the suction pipe of the compressor, but prevents the liquid from so doing. The liquid spills into the overflow pipe and is pumped out of the system to waste.

(b) Engine. The engine supplies the power to operate the vapor compressor and the pumps. It also furnishes heat to start the system and make up for heat loss. When electric motors are used to power the compressor, boilers are used to supply the initial heat to start the operation and to provide operational makeup heat.

(c) Vapor Compressor. The vapor compressor draws the vapor from the steam separator section of the evaporator, then compresses it about 3 psi and discharges this vapor into the steam chest of the evaporator. The temperature of the steam discharged is increased to a point about 10 °F higher than that of the boiling water inside the tubes, hence the vapor condenses on the outside of the tubes and is drawn off as distillates.

(d) Vent Condenser. The vent condenser is used to condense steam vented with the noncondensable gases from the steam chest. Since the feed water is not deaerated, the initial air in the system plus the air constantly entering the feed water must be vented. An air vent valve is provided for this purpose on the vent condenser. This valve must be opened sufficiently to completely vent the evaporator.

(e) Pumps. Centrifugal pumps draw the feedwater from the raw water source and circulate it through the feed system into the evaporator, to force the distillate and blowdown to recover heat for the feedwater. A small part of pump the distillate from the cooler or the heat exchangers to storage.

(f) Heat Exchange and Cooler System. Heat exchangers or coolers are used to cool the distillate and blowdown to recover heat for the feed water. A small part of the heat cannot be recovered and must be replaced by the heat from the compressor engine, or in the case of electric motor driven compressors, from auxiliary boilers.

(3) Starting Vapor-Compression Units. Before starting or operating a vapor-compression unit, operators should study the manufacturer's instructions manual that pertains to the specific unit in question. The unit should not be started until the operator is familiar with the entire

sequence of operations. All mechanical controls, equipment, fuel lines, electrical connections, lubricating points, and utilities should be checked as indicated in the manufacturer's instructions. Electric motor-driven compression-unit boilers are used to supply heat to start the cycle and make up heat lost through radiation and other heat leaks. When internal combustion (usually diesel) engines are used to drive the compressors, the heat from the engine-cooling jacket is used to start and maintain the cycle. Distillation begins when sufficient heat has been added to the system to vaporize the water in the evaporator.

(4) Balancing Vapor-Compression Units. As distilled water is removed from the system, additional saltwater must be supplied to it. The system is maintained in balance by an automatic feed valve or by proper adjustment of the hand valve. Adjustment of feed must be made very slowly to prevent sudden entry of large amounts of cold water into the evaporator. Time is required before a small change of the feed valve becomes effective. Therefore, at least 2 minutes should be allowed between adjustments. To obtain a proper balance, valve adjustments must be made on the feed flow, heat exchangers, oil coolers, and vent control valves. Adjustments depend on such operating conditions as compressor speed, condition of evaporator tubes, temperature of feedwater, and the ambient (air) temperature. After the unit has been brought into balance, it reaches a stable operating condition with considerably fewer and less frequent adjustments required. Operating temperatures, blowdown, and mechanical operating units (pumps, compressors, etc.) should be checked daily and lubricated as necessary.

e. Scale. Scale may be deposited on the evaporator tube surfaces of distillation equipment. This scale can lead to operating difficulties and loss of efficiency by reducing the rate of heat transfer. As the temperature at which the evaporators are operated increases, the scale problem also increases.

(1) To prevent concentrations reaching a point where scale would form on heating surfaces or salt would precipitate in large quantities, a portion of the feedwater is discharged to waste in amounts equal to the distillate produced. This wastewater is known as blowdown.

(2) Additional treatment is sometimes required. Polyphosphates or small additions of acid are often used to control the formation of alkaline scales. In some cases, saline water may be softened before desalination, but this is most often uneconomical. Some materials or chemicals may be used as scale inhibitors. In other cases, equipment is specially designed for thermal shocking to remove part of the brittle scale.

f. Solar Evaporation. Much attention is being paid to the developing of distillation equipment in which the sun serves as the heat source. Shallow troughs of saline water covered with transparent plastic or glass are exposed to the sun. Water vapor rises from the trough and condenses on the sloping cover. The condensed water droplets converge and flow down the cover to a container. A large area is needed for each gallon of water produced. Solar distillation is not yet developed sufficiently to provide large quantities of potable water in areas of plentiful sunshine.

g. Maintenance of Distillation Equipment:

(1) Multiple-Effect Evaporators. As described previously, these evaporators may be of two types:

(a) Submerged Tube Evaporator. Regardless of the model or manufacturer, scale must be removed from the evaporator tubes as soon as it becomes $\frac{1}{16}$-inch thick.

1. Thermal Cracking of Scale. In the tube model, the scale may be cracked by suddenly flooding the shell with cold water after the tubes have been preheated with steam at the first effect coil steam pressure. This method of cracking is the most satisfactory when the scale is less than $\frac{1}{16}$-inch thick.

2. Mechanical Cracking of Scale. Where thermal cracking is not effective, mechanical cracking may be used.

a. Tube Model. The scale may be cracked by inserting a bar between the lines of tubes.

b. Coil Model. Manual cracking may be done by bouncing the coils on a hardwood block in order to crack the heavier coating; this should be followed by wire brushing the coils. The manufacturer's instuctions should be consulted. CAUTION: Using a chipping hammer to remove the scale may seriously damage the coils.

3. Acid Cleaning. In the coil model, scale generally may be dissolved quickly by immersing the coil in 20 percent solution of inhibited muriatic acid (commercial hydrochloric acid). The coils must be thoroughly washed in water before they are reinstalled in the evaporator.

4. Zinc Plate Replacement. When the zinc plates have been reduced to about one-quarter of the original size, they should be replaced.

5. Condenser and Cooler Tube Cleaning. When the design uses these tubes, they should be cleaned by flushing, wire brushing or scraping, and flushing again before they are reinstalled.

6. Shutdown Protection. If the plant is to be shut down for an indefinite period and is subject to freezing conditions, all water should be removed from all parts of the evaporator.

(b) Flash-Type Evaporators. Specific maintenance instructions are in the manufacturer's instructions, although the following procedures are the minimum required:

1. Check the evaporator stages for corrosion or encrustation each quarter; clean and repair as necessary.

2. Check the steam tube side of the evaporator twice a year; and repair as necessary.

3. Each year, inspect all parts of the unit (both interior and exterior) for signs of deterioration, and inspect the piping and valves. Repair or renew parts as necessary; paint interiors.

(2) Vapor-Compression Distillation Units. Detailed maintenance procedures are found in the manufacturer's instructions. The following procedures are the minimum required:

(a) After 200 to 400 hours of operation, check the evaporator for corrosion or encrustation. If the tubes are encrusted, use either chemical or mechanical means for scale removal. Mechanical cleaning is used for hard scale

that is not removed by chemical treatment.

1. For chemical treatment, add sodium bisulfate ($NaHSO_4$) directly, or in solution, to the evaporator. Sulfamic acid and inhibited muriatic acid are better than sodium bisulfate, but should be used only if approved by the utility managers. The amount of acid to be added varies depending on the size and type of unit. Consult the manufacturer's instructions. Generally, the acid cleaning is continued during a 2-hour recirculation period; methyl orange is used as the indicator to show when the acid is spent. After treatment, drain the unit, flush well, rinse with alkaline solution to neutralize any remaining acid, and return to service.

2. To remove scale formation mechanically, the equipment needed includes an electric drill with bit and wire brush attachments that fit the evaporator tubes (figure 6-57). The tubes must be wet before the drilling is started. Water is fed through the drill bit during operation. Drill each tube and then wire brush. Remove scale from the evaporator shell or head by scraping; remove all dislodged particles of scale from the evaporator. Reassemble the evaporator and return it to service.

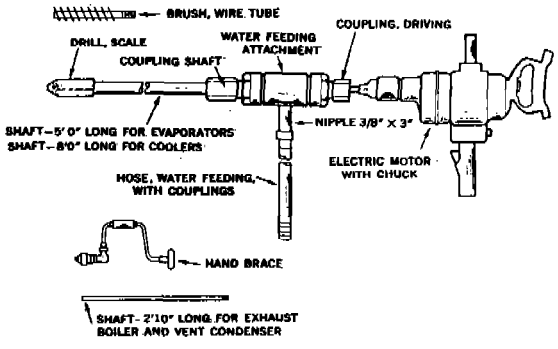


Figure 6-57. Mechanical Tube Cleaning Equipment.

NOTE: The electric drill used for removing scale must be properly grounded and the operator protected from electrical shock resulting from using an electric drill in a wet environment.

(b) Check all mechanical controls, fuel lines, electrical connections, lubrication points, and valves each quarter.

(c) Check the engine, vapor compressors, vent condensers, heat exchanger, cooler system, and instrumentation twice a year. Clean, adjust, and repair as necessary.

(d) Check the entire system, clean, repair each year, and paint as necessary.

(3) Maintenance Procedure Schedule. Maintenance operation frequencies and the schedule of inspection for distillation equipment are in table 6-22.

6-83. Ion-Exchange Processes:

a. Process Characteristics. This process is not generally used for demineralization of highly saline waters such as seawater, but it is adaptable to most brackish waters. It can best be applied when total dissolved solids do not exceed 3,000 mg/l. When the salt content is higher than this, the cost of the process begins to exceed that of efficient evaporation processes. A typical ion exchange demineralization process generally involves two steps. In the first step, the water is passed through a hydrogen cation exchanger that takes out calcium, magnesium, and sodium and adds hydrogen ions to form hydrochloric, sulfuric, and carbonic acids. These acids are removed in a second step that uses an anion exchanger to neutralize the acids formed in the cation exchanger and produce a demineralized water. A more recent development is the mixed-bed exchanger in which equivalent quantities of cation and anion exchanger are contained in a single column. When the mixed-bed is regenerated, the resins are separated by differential backwashing, because cation- and anion-exchange resins usually have different densities. Treatment and disposal of ion-exchange regeneration brines are discussed in section K.

(1) Cation- and Anion-Exchange Regeneration. Cation-exchange resins are regenerated with acid, while anion-exchange resins are regenerated with alkali. As a rule, the hydrogen ion (cation) exchanger is regenerated with sulfuric acid after backwashing, but some newer resins are capable of being regenerated with weaker acids such as carbonic acid (formed from regeneration of the exchanger with carbon dioxide). The anion-exchanger resin is usually regenerated with a solution of sodium hydroxide or soda ash, but some new resins have been developed that can be regenerated with less expensive ammonia or lime solutions.

(2) Advantages. Ion-exchange processes for desalination of low salinity waters require a relatively small capital investment. The anion cycle may be omitted for some waters with large bicarbonate quantities.

(3) Disadvantages. Because acid and alkali materials are used for regenerating the cation and anion exchangers, the total minerals requiring disposal from the process are increased. The process is complex and requires well-trained personnel and effective control of chemicals and equipment.

b. Process Modifications:

(1) Desal Process. The brackish water to be demineralized with the Desal process first flows to an anion exchanger and then to a cation exchanger. This flow scheme is the reverse of the normal scheme in which the water generally goes to the cation unit before going on to the anion exchanger. In this process, the anions in the water are replaced by bicarbonate. Cations are then removed by weak acidic cationic resin. The water flows to a third bed containing an anion-exchange resin where the carbon dioxide from the cation resin bed effluent is recovered.

(2) Sul-biSul Process. The Sul-biSul process is used for desalination of waters that have a total dissolved solids concentration over 1,000 mg/l in which most of the anions are in the sulfate form. The flow is passed through a cation bed followed by an anion-exchanger process. A decarbonation step is used between the cation exchanger and the anion unit. The cation bed is regenerated with acid, while the anion resin is regenerated with a lime slurry.

(3) Sirotherm Process. This method of ion-exchange desalination is still in the developmental stage. The process uses hot water to regenerate the ion-exchange resin.

Table 6-22. Maintenance Procedures for Distillation Equipment.

Inspection	Action	Frequency[1,2]
Distillation equipment		
Multiple-effect evaporators.		
Submerged tube		
Tubes or coils	Remove scale by cracking or acid wash (see manufacturer's instructions).	V
Zinc plates	Remove and replace when reduced to one-quarter original size.	V
Condenser or cooler tubes.	Clean, as necessary, by wire brushing and flushing	V
Flash-type		
Evaporator stages	Check for corrosion or incrustation; clean and repair as necessary.	Q
Steam side of evaporator.	Clean and repair	SA
Entire unit	Check for signs of deterioration; repair or renew parts, as necessary; paint exterior.	A
Vapor compression distillation units.		
Tubes in evaporator	Clean	Every 200–400 hrs
	Chemically	V
	Mechanically	V
Mechanical and electrical controls.	Inspect, clean, repair or replace worn parts	Q
Engine, vapor compressors, vent condenser, heat exchanger, cooler system, etc.	Inspect, clean, repair, adjust	SA
Entire unit	Check, clean, repair and paint as necessary	A

[1]Q-Quarterly; SA-Semiannually; A-Annually; V-Variable, as conditions may indicate.
[2]The frequencies shown are suggested frequencies which may be modified by local command, as individual installation conditions warrant.

c. How To Maintain Ion-Exchange Equipment. Ion exchange equipment used for demineralization is highly specialized and must be maintained according to manufacturer's instructions. Basic maintenance information on ion-exchange equipment is in section E.

6-84. Electrodialysis:

a. Process Characteristics. When most common minerals, salts, alkalies, and acids are dissolved in water, they go into solution in such a way that they form oppositely charged minute particles called ions. The solution of common table salt (NaCl) in water (in which the molecule splits up to form positive sodium ions (Na^+) and negative chloride ions (Cl^-), is an example. If such a solution is placed in an electric cell containing two electrodes (a positive pole called the anode and the negative pole called the cathode) and a direct electric current passed between them, the positive sodium ions move to the negative pole and the negative chloride ions are attracted to the positive pole. The solutioins near the poles will, therefore, have higher concentrations of salts, while the zone between will tend to be purified of them. The electrical membrane process uses selectively permeable membranes to enclose this purified zone, thus preventing movement of saltwater from other parts of the solution into the area. To accomplish this, however, the membranes must be of two types; one that allows the passage of positive ions only toward the cathode, and the other that allows the passage of the negative ions alone toward the anode. Thus the membranes do not allow water to pass through them but do allow the passage of only certain ions; the zone of purified water may be drawn off and used for specific purposes. For an electrical membrane process to be economically and practically useful, however, the capacity of a cell must be increased many fold. This is done by the adding a number of compartments in the cell. These compartments are alternate pairs of cation and anion membranes, spaced between the electrodes. Water from the demineralized compartments is drawn off for its intended purpose and water from the compartment that is highly mineralized is wasted. By such an arrangement the unit becomes more efficient. A simplified diagram of the electrodialysis process is shown in figure 6-58.

(1) Membranes. Membranes are generally in the

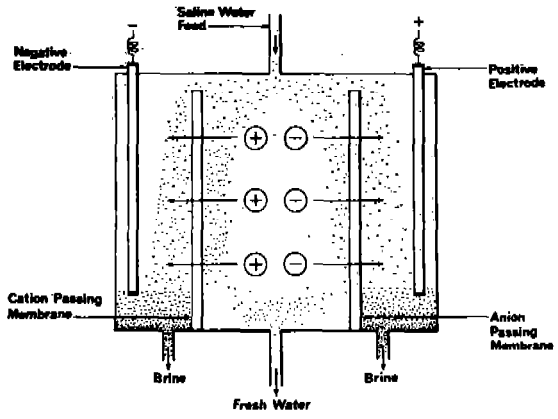


Figure 6-58. Simplified Diagram of the Electrodialysis Process.

range of 5/1,000 to 30/1,000-inch thick and are manufactured from materials that are permeable to positive ions (cations) or negative ions (anions). These membranes are the most critical part of the apparatus and the particular membrane used greatly affects the cost of the unit. A 5-to 10-year membrane life is possible.

(2) Electrodes. Electrodes are generally constructed of graphite, nickel alloy, or stainless steel, although recent developments include platinum coated electrodes to lower erosion of the electrode material.

(3) Characteristic of Waters Subject to the Electrodialysis Process. Considerably higher concentrations of total dissolved solids may be removed from water by this method than by the standard ion-exchange processes. Units are available that treat seawater of 35,000 mg/l total dissolved solids or brackish waters of 1,000 to 6,000 mg/l of dissolved solids. Because the primary function of the process is to remove minerals from the water, units using this method are not designed to handle heavy turbidity, bacteria, or organic loading. Out of the list of contaminants in the primary and secondary drinking water standards, selenium, copper, iron, manganese, chloride, lindane, radiation, and most color and odor causing compounds can be effectively removed by electrodialysis. Pretreatment of some waters in which these conditions exist may therefore be necessary to prevent fouling of the equipment. In addition, ferrous, calcium, and magnesium cations tend to precipitate on the membranes thus shortening their useful life and increasing operating costs. Where these constituents are high, it is desirable to reduce them to minimum concentrations.

b. Types of Units and Capacities. Assembled units, or "packaged" units, are available in capacities varying from 1,000 to 100,000 gallons a day. Dissolved solids removal may vary from 40 to 92 percent, depending on the requirement and number of stages used. Capacities vary with the percent of removal required. The best demineralization rate is 40 percent of the feedwater ionic concentration per treatment stage, and the best wastage rate is 20 percent of the produce water, regardless of the number of stages used.

c. Deposit Formation and Control. The concentration of ions near the surfaces of membranes sometimes results in scale formation. This scale creates increased electrical resistance in the membrane, resulting in loss of efficiency and a waste of product water with blowdown. Preventive measures for control of scale include feeding of hydrochloric or sulfuric acid in the brine stream and to the rinse liquid for the negative electrode compartments. The acid feed compensates for the increased pH caused by hydroxyl ions at the negative electrode and helps reduce buildup of calcium carbonate and magnesium hydroxide scale. Alternate methods of scale control include periodic reversal of electropolarity, (the brine compartments become freshwater compartments and vice versa). This necessitates changing of flow connections when the current is reversed. Another scale control method involves applying frequent, brief pulses of reverse current.

d. Operation and Maintenance. Operation of electrodialysis units is automatic and continuous. In some units the effluent and quality of the product is controlled by dial setting to the quality permissible for potable use (usually between 100 and 500 mg/l of dissolved solids). Direct current for the demineralization is furnished by a power package. Automatic controls operate to stop the process when difficulties arise such as high or low water pressures, failure to reach desired salinity reduction in the effluent, and power failure. Operating procedure requires the blowdown or disposal of concentrated brine solution produced at the electrodes, as previously described. This is usually done as a solution, using part of the water being processed as flushing water. Higher technical authority should be consulted for the method of disposal of this brine solution. Detailed instructions of the manufacturer of the equipment used should be followed in setting operating and maintenance procedures.

6-85. Reverse Osmosis:

a. Process Characteristics. Reverse osmosis is a desalination process in which saline water is pumped against a semipermeable membrane under great pressure. The membrane allows relatively pure water to pass through while retaining the salt brine. Extremely high pressures must be used to get a useful volume of water passing through a unit area of membrane a day. The reversed osmosis process is illustrated in figure 6-59. Reverse osmosis removes selenium, copper, iron, manganese, chloride, lindane, radiation, and most color and odor causing compounds more effectively than electrodialysis.

b. Operating Factors:

(1) Water Pretreatment. In order to avoid fouling of the membrane surface, pretreatment of the feedwater to remove suspended solids is required. The desired turbidity of the feedwater to be introduced to the membrane is 1 TU or less. Scaling by calcium carbonate is prevented by lowering the pH of the water to the range of 5 and 6. It may be necessary to apply biocides, (such as chlorine) to the influent saline water to prevent microbial growth on the membrane surfaces. Inhibitors, which have been approved by the facility bioengineer, are sometimes required to prevent salt precipitation fouling of the membrane surfaces.

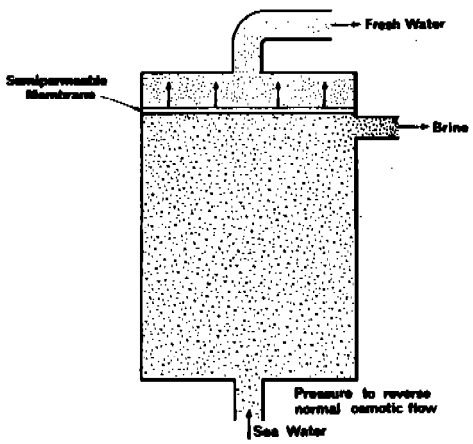


Figure 6-59. Simplified Diagram of the Reverse Osmosis Process.

(2) Pumps. Reverse osmosis equipment uses pumps with an output pressure of 400 to 1,500 psi. These pumps are specialized and require careful operation and maintenance.

c. Membrane Types. Membranes used in reverse osmosis may be constructed of cellulose material or nylon. Estimates of life range from a few months to several years. Membranes are available in a variety of configurations.

(1) Tubular. Membranes are placed inside porous tubing, generally about ½-inch diameter.

(2) Spiral. This type of unit consists of layers of membrane and separator material rolled into a spiral and inserted into a pressure vessel. The saline water is pumped against the outside of the roll, and purified water flows through the membrane walls of the roll to a point where it is collected.

(3) Flat Plate. This method uses flat membrane sheets which are stacked in an alternating pattern with plates. The sheets and plates are assembled in a way similar to a filter press.

(4) Hollow Fiber. Hollow fibers are bundled and the ends are encased with resin. The bundle is inserted into a cylindrical pressure vessel, where the saline water is pumped through the fiber walls and along the inside of the hollow fiber to an exposed end where it is collected.

d. Maintaining Reverse Osmosis Equipment. This equipment is very specialized in nature and must be maintained in strict accordance with manufacturer's instructions.

6-86. Other Processes:

a. General Information. Several other methods of desalination are currently available, but are not in general use due to their high cost, unreliability, or lack of development on a commercial basis.

b. Freezing Process. This process uses ice crystals formed from saline water in which the ice does not contain trapped salt crystals. The ice must be separated from the brine and melted to give the desalinated water product. One advantage of the freezing process is that less energy is required to produce each pound of water than in the distillation process. Because the freezing process takes place at low temperatures, corrosion and scale deposition are less troublesome than with distillation. The main disadvantages of freezing include handling the solid crystals and the difficulty in separating the crystals from the brine.

c. Hydrate Formation. In this process, brine is cooled in the presence of a hydrocarbon refrigerant, such as propane. The propane and water form crystals of solid hydrate. These solid crystals are then separated from the brine. After separation, the hydrate is melted (with the final product being propane vapor and liquid water). The main problem with this process is the difficulty in separating the solid hydrate from the brine, and then subsequent separation of the water and propane to form the two end products.

d. Solvent Extractions. This process is based on the principle that some organic solvents are capable of extracting mostly pure water from saline water in one temperature range, while being able to release the water at a different temperature. To actually carry out this process, however, a large amount of heat is required and some solvent is generally retained in the freshwater. The solvent must then be removed in solvent recovery operations.

6-87. Laboratory Control Tests. Salinity is usually measured by total dissolved solids, so the total dissolved solids test is the primary control test to be used. In addition, tests should be made for suspended solids, iron, manganese, or other constituents that require pretreatment of the saline water before desalination assume importance. Chlorine residual must be monitored in the water sent to the distribution system. Concentrations of chemicals fed to control corrosion or scale deposition must also be analyzed.

6-88. Daily Records. A daily log should be maintained of the hours of operation and the performance of the desalination unit. The daily log must indicate any unusual trends in the product water, power requirements, pressures, and operating characteristics. The manufacturer often recommends other specific data that should be recorded daily. Reviewing the logs will call attention to existing and pending mechanical difficulties and facilitate good maintenance. The form and content of the daily log is set up by local command on the recommendations of the Utilities Division. Records of laboratory control tests should be maintained as part of the daily log.

Section K—Water Treatment Plant Residues

6-89. Source of Residues:

a. The most common residues from water treatment processes are designated either slurries or sludges. Slurry solids are usually spent activated carbon or waste diatomaceous earth from diatomaceous filters. Sludges may be mud-like, natural sediments; gelatinous aluminum, magnesium, or iron oxides and hydroxides; or calcium carbonate (lime sludge). Water treatment processes that produce these sludges are presedimentation of raw water; chemical coagulation, flocculation, and sedimentation; lime-soda

ash softening; iron and manganese removal; and filter backwashing.

b. Other residues are surface water intake screenings and aqueous solutions of sodium, calcium, and magnesium chlorides that result from regeneration of cation exchange water softening resins.

c. Refer to the applicable sections of this chapter for a discussion of the residue characteristics of the various water treatment processes.

6-90. Disposal Methods. Water treatment plant residues often contain chemicals that can be recovered for reuse. With or without recovery, residues must be disposed of in a way that is both economically and environmentally acceptable. Recovery and disposal systems often require that the solids content of a residue be increased by water removal. The required solids concentration (and the method of concentration) depends on the chemical recovery or final disposal alternatives used. A summary of water treatment plant residue handling systems which are in current use is in table 6-23.

NOTE: No residue should be discharged to a natural watercourse or public sewer without the applicable federal, state and local authorities' approval.

a. Solids Concentration and Dewatering Processes. The solids content of residues may be increased by removing water, using the following systems:

(1) Lagoons. Lagoons are large, open ponds in which sludge is dewatered by natural evaporation and seepage. Lagoons also provide long-term storage in case subsequent disposal systems are temporarily inoperative. Advantages of lagoons include long-term storage, minimal day-to-day operation, and low construction cost if land is already available. Disadvantages include high labor requirements for removing dewatered sludge, large land requirements, and adverse effects of wet weather on dewatering. In cold regions, sludge freezing and thawing in lagoons helps dewatering of aluminum hydroxide coagulant sludges.

(2) Sand Drying Beds. Sand drying beds can be considered high efficiency drying lagoons. Drying beds consist of a 4- to 9-inch layer of sand placed over a 10- to 18-inch layer of graded gravel or stone. The gravel layer is underlain by sloped, open-jointed drain pipes. Sludge is applied in successive layers at an annual loading rate of about 20 pounds of dry sludge solids per square foot. Dewatering is the result of evaporation and seepage, as in a lagoon, except that the sand-grave underdrain system increases the seepage rate, resulting in faster dewatering. Also like lagoons, the performance of drying beds is limited by rainy weather. For this reason, drying beds are sometimes covered. The major operating expense is for removing the dewatered sludge (by hand shoveling, or using a small, light end-loader).

(3) Evaporation Ponds. Evaporation ponds are used to concentrate the salt brine from cation exchange resin regeneration. The ponds are very similar to sludge drying lagoons. Because of the adverse effect that rainfall has on pond performance, evaporation ponds are only used in warm, dry climates.

(4) Mechanical Dewatering. Sludges and slurries may be dewatered by using a wide variety of mechanical equipment. The most commonly used types are vacuum filters, centrifuges, and filter presses.

(a) Vacuum Filtration. A vacuum filter is a rotating drum, with porous filter media of cloth on metal coils stretched around the drum. About one-third of the drum diameter is submerged in a trough of liquid sludge (figure 6-60). A vacuum is pulled from the inside of the drum. As the drum rotates, liquid sludge is picked up on the filter media, and slowly dewatered by the vacuum. The water removed from the sludge (called filtrate) is collected on the inside of the drum and pumped back to the plant influent. A scraper removes the dewatered sludge from the filter media just before that portion of the drum rotates into the sludge trough. To decrease blocking of the filter media by gelatinous sludges (such as metal hydroxides (alum sludge)) and to reduce the quantity of solids passing through the filter media, the media may be coated with a porous precoat layer of diatomaceous earth, 2- to 4-inches thick. As the scraper knife removes the dewatered sludges, a very thin layer of the precoat is also peeled away, leaving a fresh filtering surface for the next revolution of the drum. Polymer addition or other chemical conditioning is required to coagulate the sludge before dewatering. Vacuum filters can concentrate lime sludges to 40 to 60 percent solids and magnesium hydroxide sludges to 10 to 25 percent solids.

(b) Centrifugation. Centrifugal equipment is operated on the principle that when a liquid or solid mixture is rotated at high speed, the solids are affected by increased gravitational forces and tend to separate from the liquid. This principle is illustrated in figure 6-61. Centrifuges can be used either to dewater sludges and slurries, or to separate different sludge components that have different densities, such as calcium carbonate and magnesium hydroxide. With proper polymer addition, centrifuges can dewater sludges to solids contents similar to vacuum filters. Alum sludges are more readily dewatered by precoat vacuum filters than by centrifuges or conventional vacuum filters.

(c) Pressure Filtration. Filter presses contain several parallel plates made of porous filter cloth supported by an outside rim. The plates are usually vertically mounted on a horizontal frame as shown on figure 6-62. Sludge is supplied along the length of the series of plates at pressures as high as 250 psi in order to squeeze the water from the sludge cake. The plates are then separated to allow the sludge cake to drop out from between the plates. Pressure filters are capable of dewatering lime sludges to solids contents to 50 to 70 percent and alum sludges to 25 to 40 percent solids with proper chemical conditioning.

(d) Other Methods. Other methods available for dewatering or drying sludges include belt filter presses and dual-cell gravity thickeners, heat treatment systems, freezing, and lime sludge pelletization.

(5) Gravity Thickening. The volume of residue to be handled by dewatering processes can sometimes be economically reduced by gravity thickening. Gravity thickening is essentially an extended clarification process, taking

Table 6-23. Water Treatment Plant Residue Disposal Summary.

Type of Wastes	Quantities and Characteristics	Treatment Required	Disposal Possibilities
Screenings	Vary widely; particular water source must be evaluated; check other plants using same water source or other similar plants.	None.	Return to watercourse if quantities are small. Truck to landfill along with other plant solid waste. Investigate disposal with wastewater treatment plant screenings.
Presedimentation sludges	Vary widely; particular water source must be evaluated; check other plants using same water source or other similar plants.	Dewatering in lagoon, sand drying bed, or mechanical unit may be required.	Dredging or draglining and hauling to landfill; multiple, drainable basins make cleaning easier.
Chemical clarification sludges	Composed of raw water impurities and coagulation chemicals. Solids content - 0.1% to 2%; 75-90% of total is suspended; 20-40% of total is volatile. Dry unit weight 75-95 lbs/ft³. Gelatinous.	Gravity thickening often desirable, recycling supernatant to plant influent. Sludge concentrations of 0.5-1.0% can be obtained. and/or Drying beds. Freeze/thaw treatment processes are effective for alum sludge dewatering but expensive except in climates where sludges can be lagooned and frozen naturally. Pressure filtration dewaters sludge to 25-40% solids, often requiring lime as conditioner. Centrifuges and vacuum filters dewater sludges up to about 15% solids. Pre-coat vacuum filters dewater sludge up to 25% solids. Coagulant recovery should be evaluated.	Send concentrated sludge or continuously withdrawn sludge to wastewater treatment plant.[1] Haul dried sludge to landfill.
Filter wash water[2]	Normal wash generates about 150 gal/ft² filter area. Chemically-precipitated raw water impurities and coagulation chemicals. For alum plants, total solids varies with time up to 1,000 mg/l, average 400 mg/l. Plants removing iron and manganese may be 4 times higher in total solids.	Flow equalization and concentration through sedimentation and decanting.	Same as for coagulation sludges. Combine with coagulation sludge where applicable. Where no coagulation used, dispose as softening sludge. Gradually return entire flow to plant influent.
Lime softening sludges	Assume 3 lb dry sludge solids per lb quicklime added. Clarifier underflow. Solids concentration is generally approximately 5%, but may range from 2 to 30%. Non-gelatinous. Typically 85-95% calcium carbonate, with some magnesium hydroxide.	Dewatering lime softening sludges is not particularly difficult. The following methods can be used following thickening: (1) Lagooning (up to 50% solids). (2) Vacuum filtration (40-50% solids). (3) Centrifuging (50-60% solids). Return to water plant influent.	Discharge to wastewater treatment plants.[1] Dewatered sludge hauled to landfill (agricultural applications possible). Recalcining generally limited to large plants (>20 mgd) by economic considerations.
Diatomaceous earth sludges	See filter manufacturer's literature for quantities. Solids normally 60-70% diatomaceous earth; remainder raw water impurities; dry density about 10 lbs/ft³; specific gravity 2.	Lagooning, with supernatant recycled to plant influent.	Haul solids from lagoon to landfill.
Carbon slurries	Quantities and characteristics variable.	Granular carbon can be regenerated and recycled. Powdered carbon cannot be regenerated; must be disposed of following dewatering.	Haul solids to landfill. Incinerate dewatered solids (high heating value).
Cation exchange resin regeneration brines	See manufacturer's literature for quantities. Total dissolved solids up to 45,000 mg/l. Chlorides up to 12,000+ mg/l. Almost no suspended solids.	Evaporation lagoons where concentration is desired and climate permits.	Best solution is ocean disposal. Return to watercourse only if brine can be greatly diluted. Discharge to wastewater treatment plant only if greatly diluted. Disposal wells possible but are easily plugged and dangerous to ground water.

[1]For discharge to sanitary sewers, avoid cross connections and slug flow and always check:
(a) Possible damage to sewer system from residue discharge.
(b) Effects of residues on liquid and solids treatment processes at the wastewater treatment plant.
(c) Hydraulic capacity of the wastewater treatment facilities.
[2]Sedimentation basins or solids contact reactors ahead of filters will generally remove 70-90% of total plant solids. The remainder of solids will appear in the filter wash water.

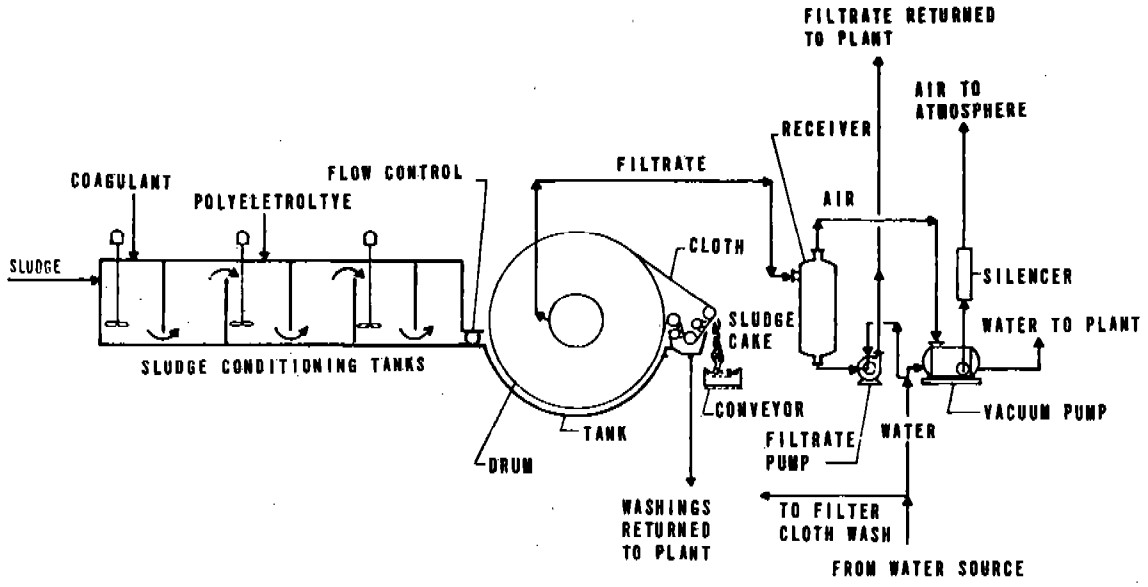


Figure 6-60. Typical Vacuum Filter Flow Diagram.

place in a basin or tank designed for thickening rather than clarification.

b. Recovery Processes. Alum, ferric chloride, ferrous sulfate, magnesium carbonate, and lime can be recovered from sludge using various methods. In addition, the water used to backwash filters may be treated in a separate tank using coagulation and sedimentation methods similar to those used for treating the raw water. The effluent from this tank can be bled back with the incoming raw water, resulting in a substantial reduction in the quantity of water wasted for backwashing purposes. The small quantity of predominantly alum sludge from the filter backwash treatment process can be handled in the same way as the sludge from the sedimentation basin.

(1) Recovery of Aluminum or Iron Salts. Alum (aluminum sulfate) forms a white, gelatinous, aluminum hydroxide floc in water. If sulfuric acid is added to concentrated aluminum hydroxide sludge, soluble aluminum sulfate is formed, which can be reused as a coagulant in the water treatment plant. The reaction is as follows:

$$2Al(OH)_3 + 3H_2SO_4 = Al_2(SO4)_3 + 6H_20$$

Aluminum Hydroxide	+	Sulfuric Acid	=	Aluminum Sulfate + Water

The remaining sludge, consisting of sediment removed from the raw water by the coagulants, must still be disposed of. Most existing alum recovery plants operate on this system, but potential also exists for recovery of aluminum as aluminum chloride ($AlCl_3$) by adding hydrochloric acid rather than sulfuric acid. In some cases, iron salts used for coagulation may also be recovered by this process.

(2) Magnesium Carbonate Recovery. Magnesium carbonate reacts with lime to form magnesium hydroxide, a light, gelatinous floc with coagulation properties similar to the aluminum hydroxide formed by alum addition. This reaction occurs in lime water softening when magnesium is present in the raw water. The magnesium hydroxide can be separated from the other sludge materials and recovered as magnesium carbonate, to be reused as a coagulant substitute for alum. By removing the gelatinous magnesium hydroxide from the calcium carbonate sludge, dewatering is improved and the total volume of sludge to be handled is reduced. Also, removing the magnesium hydroxide facilitates recovery of lime by recalcining.

(3) Lime Recovery. Calcium carbonate sludge from lime water softening operations can be converted to calci-

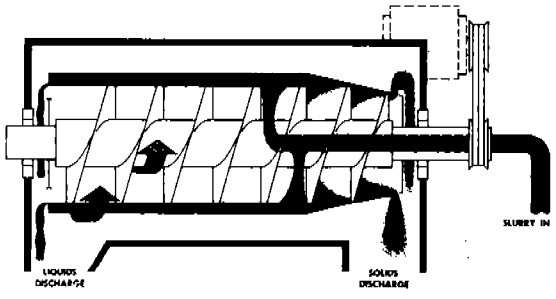


Figure 6-61. Centrifuge Operation.

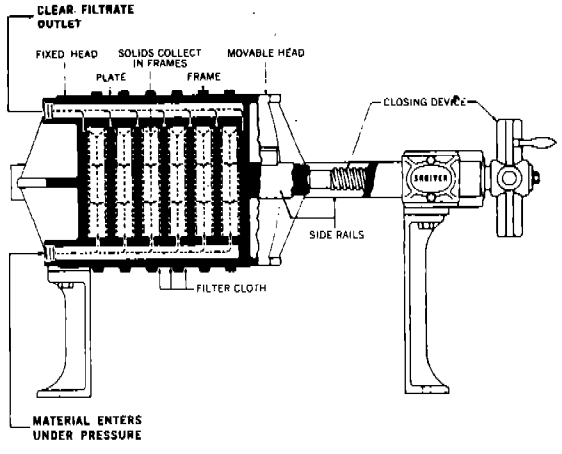


Figure 6-62. Filter Press.

um oxide (quicklime) by recalcination (burning the calcium carbonate sludge in a furnace at about 1,850°F). Magnesium hydroxide, clay, or other inorganic materials in the sludge are not completely oxidized, and remain in the quicklime as impurities, eventually building up in the recirculating system. For this reason, magnesium and other inerts should be removed from the sludge before recalcining and disposed of separately.

c. Ultimate Disposal. Traditionally, water treatment plant wastes have been disposed of by discharge to rivers and lakes, either directly or by way of a storm sewer. Current environmental laws do not allow this because of adverse effects on the receiving body of water (cloudy water, toxicity to aquatic life, formation of sludge banks, etc.). Following are alternative methods of ultimate sludge disposal, which, in some cases, may be economical and environmentally sound solutions.

(1) Discharge to Sanitary Sewer. In general, water treatment plant residues can be disposed of by discharge to a sanitary sewer without upsetting the wastewater treatment processes. However, if the amount of sludge is too great, problems can result.

(a) The sewer can be overloaded hydraulically by large batch dumps of sludge. This problem can be handled by storing the sludge in a holding tank, then bleeding the sludge slowly into the sewer during periods of low wastewater flow (such as after midnight). However sewer flow should be sufficient to prevent accumulation of sludge solids in the sewer that may create clogging problems.

(b) The water treatment sludge solids increase the amount of sludge to be disposed of at the sewage treatment plant; the dewatering and disposal problems are not eliminated, but simply shifted elsewhere. Water treatment plant sludge is not affected by sludge digestion processes at the sewage treatment plant; it just takes up digester volume. In some cases, water plant sludges have been reported to clog digesters.

(2) Landfill. Modern sanitary landfills are designed and operated to keep the amount of water leaching from the filled material to a minimum. For this reason, landfill regulations often require that sludges contain at least 20 percent dry solids, and sometimes require as high as 50 to 60 percent. Wet sludges are not acceptable because they are difficult to mix well with other solid wastes before covering, and because the large amount of water could percolate through the soil and pollute water supplies.

(3) Lagoons. Disposal lagoons are simply drying lagoons that are never cleaned out, thus eliminating the main operating problem of drying lagoons. The main disadvantage is that large land areas are permanently committed for use as lagoons. For plants with small sludge quantities and plentiful land, lagoons can be a practical method of sludge disposal.

(4) Brine Disposal Wells. In some areas of the country, large aquifers of salty ground water exist. In these areas, it may be feasible to dispose of cation exchange resin regeneration brines by injection wells leading to the salty ground water. However, environmental regulatory agencies require proof that any injection well system does not cause any environmental damages.

(5) Ocean Disposal of Brine. In coastal areas, cation exchanger brine can be disposed in the ocean. As a rule, this does not cause any adverse environmental effects. Approval of federal, state, and local authorities must be obtained, however, before initiating this method of disposal.

(6) Land Spreading of Lime Sludge. In many agricultural areas, particularly in the midwest, farming practices require that lime or limestone be added to the fields periodically to control soil pH. Sludge from lime water softening processes can be used for this purpose if it is sufficiently dewatered to allow easy handling.

6-91. Laboratory Control Tests. The main control tests involved in sludge handling and disposal are the solids tests (total solids and suspended solids) which are used to determine the effectiveness of dewatering processes. Some recycling processes require careful pH control.

6-92. Maintaining Records. The dewatering and ultimate disposal of water plant sludges and other residues can be expensive in many cases. Processes for recovery of water treatment chemicals can offset these costs to some degree, but strict process control is required. To adequately manage water treatment plant residues, records must be maintained on residue quantities and characteristics, chemical quantities used for residue treatment processes, results of laboratory control tests, and operating notes.

Section L—Control of Organics

6-93. General Information. The Safe Drinking Water Act (SDWA) provides for the establishment of standards to control the levels of synthetic organic chemicals in drinking water supplies. Synthetic organic chemicals, at various levels, can be hazardous to human health. Historical data have indicated that many of these chemicals are carcinogenic (cancer causing substances). Organic chemicals of concern can be put in three groups: pesticides, trihalomethanes (THMs), and volatile synthetic organic chemicals (VOCs).

6-94. Pesticides Group:

a. Sources of Pesticides. Six organic chemicals make up the pesticides group. These chemicals are: endrin, lindane, methoxychlor, and Toxaphene, which are chlorinated hydrocarbons, and two chlorophenoxys, 2, 4-D and 2, 4, 5-TP Silvex. Pesticides are not naturally ocurring. Water supplies become contaminated from direct application of pesticides to water for control of nuisance vegetation, fish, and aquatic insects; from storm runoff from agricultural, urban, and suburban areas where pesticides have been used; from accidental pesticide spills; or directly from a point source wastewater discharge containing pesticides.

b. Treatment. Activated carbon adsorption is the most effective method available for removing pesticides. Some pesticide removal occurs during conventional treatment by coagulation, sedimentation, and filtration. However, removals are very small and are usually less than 10 percent.

Chemical oxidation with chlorine, ozone, or potassium permanganate also results in some pesticide removal. Removals are generally less than 10 percent.

(1) Conventional water treatment followed by activated carbon adsorption effectively removes pesticides from drinking water. Use of activated carbon adsorption in water treatment is discussed in section C. Powdered (PAC) or granular activated carbon (GAC) can be used for pesticide removal. The effectiveness of carbon adsorption depends on the concentrations of adsorbent and adsorbate, contact or residence time, and the competition for available adsorption sites, as well as the temperature and pH of the water. Because of these variabilities, no general rule can be given for carbon dosage or design criteria for activated carbon treatment. Dosage and design requirements should be determined by laboratory methods or pilot plant operations.

(2) Because pesticides and their carrier solvents have odors, water treatment for removing of these odors provides some reduction in pesticide levels. However, where a few milligrams per liter of PAC may be adequate for odor control, several milligrams per liter more are generally required to effect organic removals. Relying on odors to signal pesticide contamination or relying on intermittent odor control by PAC to ensure a safe pesticide level is risky and is considered poor practice. Where PAC is used, multiple points of injection should be considered for maximum efficiency of the adsorbant (maximize pesticide removal). A disadvantage of PAC is that the sludge formed after application is sometimes troublesome and difficult to manage.

(3) The uncertainities involved in pesticide occurrence make granular activated carbon beds that are continuously on line the best protection against pesticide contamination. Organic pesticides have been demonstrated to be very strongly adsorbed both on virgin GAC and on exhausted GAC used for odor control. The life of a GAC bed for pesticide removal is not indefinite, but replacing or reactivating a GAC bed because of odor penetration is also considered to be an adequate guideline for controlling pesticides.

6-95. Trihalomethanes Group:

a. Sources of Trihalomethane. Chlorine, when used for bacterial and viral disinfection of water supplies, interacts with organic precursors present in natural waters to form chlorinated organic compounds, primarily trihalomethanes (THM). These can cause potentially chronic health problems. Chloroform is the most common THM found in drinking water and is also usually present in the highest concentration. Other THMs found as a result of chlorine disinfection are bromoform, bromodichloromethane, and dibromochloromethane. Because the natural organic precursors are more commonly found in surface waters, water taken from a surface source is more likely than ground water (with some exceptions) to have high THM levels after chlorination.

b. Treatment. Treatment options available to meet the THM standards are to substitute new disinfectants for chlorine that do not generate or produce less THMs; to reduce organic precursor concentrations before chlorination; and to remove THMs after formation.

(1) Ozone, chlorine dioxide, and chloramine are possible alternate disinfectants that do not produce measurable quantities of THM. Use of these chemicals for disinfection purposes are discussed in section H. The microbiological quality of the treated and distributed water should be carefully observed during the transition period to an alternate disinfectant.

(a) A disadvantage of ozone is that a disinfectant residual is not produced that can be carried throughout the distribution system. Also, the health hazard, if any, of the byproducts formed by the reaction of ozone with organic matter is not known. The use of ozone would increase the cost of disinfection significantly.

(b) An advantage of using chlorine dioxide as a disinfectant is that a residual is produced. Chlorine dioxide does not produce THMs in the water treatment process and is roughly 100 times more effective than chlorine as a disinfectant. However, chlorine dioxide is somewhat more expensive. Supplementing chlorine dioxide with chlorine for continuous disinfection of water supplies holds some promise. However, not enough data have been collected to determine the degree of THM formation in the distribution system after disinfection.

(c) Ammonia reacts with chlorine to form chloramines which are weak disinfecting agents that are not as reactive as free chlorine. Adding ammonia with chlorine (ammoniation) does not reduce the formation of THMs on chlorination. This process does, however, reduce the growth of THMs from the point of ammoniation on through the distribution system. Chloramines alone are weak disinfectants and would have to be used in very high concentrations to achieve complete disinfection.

(2) Treatment processes to reduce or control precursor levels include off-line raw water storage, aeration, improved coagulation, ion exchange resins, adsorption on PAC and GAC, ozone enhanced biological activated carbon (BAC), and adjustment of the chlorine application point. Bench and pilot plant studies must be performed to determine which treatment process is most effective at reducing precursor levels. Carbon adsorption is the only process considered effective for high precursor removals at the present time.

(a) Aeration has been useful for taste and odor control as well as iron and manganese oxidation. However, to be effective for the removal of volatile organics, the air-water ratio required is much higher than that for taste and odor control or iron and manganese removal. Also, the high air to water ratio promotes the growth of aerobic organisms (such as algae) and can be a significant problem. Aeration is discussed in section A.

(b) It has been demonstrated that some removal of volatile organics takes place during the coagulation process. These organics often adhere to the particulate matter that settles. Some research has indicated that as much removal occurs from the volatilization during the mixing of the coagulants as from the coagulation itself. Coagulation

is discussed in section D.

(c) High doses of PAC only removes a portion of the precursors. High costs and sludge problems limit the use of PAC for precursor control.

(d) GAC has the ability to adsorb a wide spectrum of organics. GAC adsorbs most THM precursors so that chlorine disinfection can be practiced following GAC treatment without forming much TMHs. Carbon adsorption is discussed in section C.

(e) One of the quickest and least expensive ways of maintaining low TMH levels in chlorine treated water is to chlorinate the highest quality of water (water with the lowest possible organic content). If water is filtered, the highest quality of water is filter effluent. However, unless additional contact tanks are constructed, the contact time is not sufficient to permit adequate disinfection. Chlorination of coagulated and settled water reduces (but does not eliminate) THM levels in finished water. THMs continue to form during distribution. An advantage of disinfection before filtration is that bacterial growth in the filters will be limited. The absence of a disinfectant at the beginning of treatment may cause problems because of the growth of algae, slime, and higher forms in the early part of water treatment plants.

(3) Technology available for THM reduction include PAC, GAC, aeration, and ozonation. Very high doses or PAC and ozone are required to get substantial (but not complete) THMs removal. Cost of these processes would be prohibitively expensive for the removals obtained. GAC filters effectively remove THMs (as well as other organics) below contaminant levels. Locating the aeration process after chlorination will remove some THMs from the finished water. However, organic precursors not removed in the water treatment process continue to react with the remaining chlorine residual after aeration to raise THM levels in the distribution system. Therefore, removing THMs from finished water by aeration is not considered the best THM control method.

6-96. Volatile Synthetic Organic Chemicals (VOCs):

a. Sources of VOCs. Historically, ground water has been relatively pure and it is generally used as drinking water source without major treatment other than disinfection. However, recent studies from EPA and state monitoring surveys indicate that a significant number of drinking water supplies derived from ground waters, as well as surface waters, contain some VOCs. Contamination is most common in urban or industrial areas, and is generally believed to be the result of improper disposal of hazardous wastes and industrial activities disposal of system discharges. Synthetic organic chemicals most commonly detected include:

(1) Dichloroethylene
(2) Trichloroethylene
(3) Tetrachloroethylene
(4) Carbon Tetrachloride
(5) 1, 1, 1-Trichloroethane
(6) 1, 2-Dichloroethane
(7) Vinyl Chloride
(8) Benzene
(9) Chlorobenzene
(10) Dichlorobenzene
(11) Trichlorobenzene

(a) The presence of one of these compounds, even at a low level, is a concern since these are manufactured chemicals not naturally in the environment and their presence indicates the potential for further contamination of that source water.

(b) Ground water is of particular concern in that these waters move very slowly and do not have a rapid natural cleansing mechanism. Thus, once ground waters are contaminated, they will generally remain so for many years or decades.

b. Treatment. Methods for removal of VOCs include aeration and granular activated carbon (GAC). Powdered activated carbon treatment or conventional drinking water treatment (i.e., coagulation, sedimentation and filtration) have not proven effective. Methods such as reverse osmosis and macromolecular resins may eventually prove to have value for removing VOCs.

6-97. Planning Requirements to Modify Plant for THM Control. A community water system must get state approval before making any significant modifications to its treatment process for complying with total THMs requirement. It must submit a detailed plan of proposed modifications and safeguards that it implements to make sure that the bacteriological quality of the drinking water serviced is not adversely affected by such modification. Each system must comply with the provisions set forth in the state approved plan. At a minimum, a state approved plan requires the system modifying its disinfection practice to:

a. Evaluate the water system for sanitary defects and evaluate the source water for biological quality.

b. Evaluate its existing treatment practices and consider improvements that keep disinfectant demand to a minimum and the best finished water quality throughout the distribution system.

c. Provide baseline water quality survey data of the distribution system. Such data should include the results from monitoring for coliform and fecal coliform bacteria, fecal streptococci, standard plate counts at 35°C and 20°C, phosphate, ammonia, nitrogen, and total organic carbon. Virus studies should be required where source waters are heavily contaminated with sewage effluent.

d. Conduct additional monitoring to ensure continued maintenance of optimal biological quality in finished water (for example, when chloramines are introduced as disinfectants or when prechlorination is being discontinued). Additional monitoring should also be required by the state for chlorate, chlorite, and chlorine dioxide when chlorine dioxide is used as a disinfectant. Standard plate count analyses should also be required (by the state as appropriate) before and after any modifications.

e. Demonstrate an active disinfectant residual throughout the distribution system at all times during and after the modification.

6-98. Maintaining Records. Sampling and analyzing for organic contaminants are required by law. The details of these requirements are explained in section M. Laboratory testing is done by a certified laboratory and cannot usually be done by plant personnel.

Section M—Water Sampling and Analyses

6-99. Purpose of Examination. Chemical analyses and bacteriological examinations of raw and treated water are required on a routine basis at water treatment facilities. Some chemical tests are necessary to ensure correct operation of the water supply, treatment, and distribution systems. Analyses are conducted during treatment to ensure proper chemical dosages, physical characteristics, and potability. Microbiological examinations and other chemical analyses are conducted to determine the safety of the water following treatment.

6-100. Sampling Methods. The water treatment operator takes the necessary samples for testing quality control; and in coordination with the installation's bioenvironmental engineer, may be required to take samples for health reasons. This is an important function. Unless the water sample is representative the uncontaminated test results may not indicate the actual condition of the water supply. Sample containers should be of material that will not contaminate the sample. Chemically resistant glass is a suitable material for all sample containers, and polyethylene may be used for samples for most chemical analyses. The size of the sample container used depends on the amount of water needed for a particular test.

6-101. Testing of Water for Health Reasons:

a. Collection of Samples. The results of any test is no better than the sample used; a poor sample will produce poor test results regardless of the quality of the test. Good sampling techniques are the key to a meaningful and useful monitoring program.

b. Required Testing. Applicable service component regulations listed in paragraph 1-19 define sampling times, sampling procedures and test methods for each contaminate covered by the NIPDWR (40 CFR 141).

6-102. Plant Control Tests:

a. General Information. Plant quality control tests differ from tests conducted to monitor compliance with maximum contaminant levels in the SDWA in that they are generally conducted by plant personnel, are used to enhance and control plant performance, and are not required by law.

(1) Analyses and tests conducted at water treatment facilities are to control water treatment processes, record plant performance, and improve future plant performance. Analyses designed to aid in plant control should present evidence that the water has been properly prepared for each major step in the treatment process and that each process has proceeded according to plan. The analyses should also indicate the finished water is clear, free from taste and odor, and is desirable and safe for human consumption. Special emphasis should be placed on the analyses that are of immediate value in assessing the water quality and safety of the finished water reaching the distribution system. The residual chlorine, fluoride, and turbidity tests are three good examples of such analyses.

(2) The number of water samples to be examined each day depends on the quality of the raw water, the rate at which the raw water quality changes, the complexity of the treatment processes used, and the total number of unit processes involved. Usually water treatment systems that treat surface water supplies require more frequent testing than those treating ground water supplies because of the variability of the raw water quality. In general, the number of water samples collected and analyzed at each stage of the total treatment process should be adequate to provide positive plant control and ensure the delivery of safe high quality water to the public. The given frequencies are generally the maximum required for the larger, more sophisticated facilities. They may be adjusted downward for smaller, simpler facilities on recommendations from higher technical authority.

b. Chemical Control Tests:

(1) Chlorination. Analysis for chlorine residual must be made hourly to daily near the point of treatment. This test is used only for immediate chlorine feed control. Water samples should also be collected daily from several points in the distribution system to determine the chlorine residual near points of consumption. Various taps within the distribution system should be sampled on a rotating basis.

(2) Fluoridation. In fluoridation practice, the target residual is set within specified limits based on the annual average of maximum daily air temperatures taken over the past 5 years. Lower and upper fluoride limits, as well as an optimum concentration, are established by medical personnel based on these temperatures. To ensure that the concentration of fluoride in the finished water leaves the treatment facility at the correct concentration, fluoride analyses should be conducted and recorded every 3 hours. Depending on the variation in quality of the water supply source, fluoride analysis should be occasionally conducted on the raw water to determine the natural background level. These data are necessary for fluoride dosing control.

(3) Iron and Manganese Removal. Certain water treatment facilities must use iron and manganese removal to enhance the finished water for laundering and to prevent fixture staining. To check the efficiency of the removal process, analyses must be made daily on the finished water to find out if the required degree of removal is being achieved. The unit process is adjusted accordingly.

(4) Chemical Clarification and Filtration:

(a) In water treatment facilities using surface supplies that fluctuate rapidly in quality, it is necessary to conduct jar tests periodically to determine the chemical dosages to achieve proper coagulation. Also, check filter effluent periodically for aluminum hydroxide carryover when using alum coagulant. Alkalinity, pH, and turbidity must be checked every 3 hours to control the operation of the coagulation units.

(b) Turbidity analysis is an important control tool that should be run every 3 hours to check filter breakthrough, thus denoting when it is necessary to backwash. Turbidity must also be checked daily at the point where finished water enters the distribution system, if the raw supply is obtained in whole or in part from a surface source.

(5) Taste and Odor. Both surface and ground waters must have threshold taste and odor analyses made on the raw water, finished water, and at various points within the distribution system when there are complaints of tastes and odors in the finished water or rapid changes in the raw surface water quality. Accordingly, treatment can be adjusted to help correct the taste and odor problems.

(6) Softening by Chemical Precipitation. To control chemical softening units, periodical dosage testing (correlated with actual plant results with given dosages) is required. In addition, the following tests must be run every 3 hours.

(a) Hardness. Test total and calcium hardness of raw, settled, and filtered water every 3 hours, or more often if necessary for proper control.

(b) Calcium Carbonate Stability. Tests should be made on the calcium carbonate stability of recarbonated and filtered water every 3 hours.

(c) Carbon Dioxide, Carbonate, and Noncarbonate Hardness. Calculate carbon dioxide, carbonate, and noncarbonate hardness from total hardness, alkalinity, and pH tests made every 3 hours from samples collected from the softening units.

(7) Zeolite Softening. Water treatment facilities using zeolite softening must make the following tests to detect the need for recharging and for operational monitoring of the units:

(a) Total Hardness. Total hardness tests must be made on the raw and softened water each day.

(b) Chlorides. For control purposes, chloride analysis must be made on the last wash water after each regeneration.

(8) Corrosion Control. Losses due to corrosion, and the steps taken to avoid such losses, represent large costs in the operation of a water treatment facility and its distribution system. Under certain conditions, the annual losses due to corrosion may exceed the operating costs. For this reason, it is necessary to run the following tests to check a facility and distribution system for corrosion:

(a) pH. Determine pH each day, or more frequently, if indicated.

(b) Dissolved Oxygen. Take samples from several representative points in the distribution system each month and test for dissolved oxygen.

(c) Test Loops. Examine test loops each month.

(d) Silica. Test each month, or at intervals recommended by higher technical authority, for soluble silica at points at varying distances from the treatment plant.

(e) Polyphosphate. If polyphosphate is used in corrosion control, test each week for polyphosphate residuals at various locations.

(f) Ferrous and Ferric Iron. Test for ferrous and ferric iron at periodic intervals. The frequency depends on the nature of the treated water (aggressive or nonaggressive) and the type of metal used in the distribution system.

(9) Deposit Control. Deposit control within a distribution system is important for system longevity. The following tests must be made to control deposit formation:

(a) Polyphosphate. Test each week for polyphosphate residual at various points in the distribution system if polyphosphate addition is practiced.

(b) Calcium Carbonate Stability. Test calcium carbonate stability each day (lime-softening plants only).

(c) Tests Loops. Inspect test loops each month.

c. Microbiological Tests for Supply and Treatment System. The frequency and nature of microbiological testing is directly related to the water source and the size and type of treatment plant. Routine microbiological treatment control tests are made at a water treatment facility to control and measure the results of treatment throughout the plant. Microbiological analyses are reported on the basis of the following tests.

(1) Coliform Bacteria. Conduct MPN presumptive or membrane filter tests for coliform bacteria each day on raw, settled, and filtered water. Make MPN completed or membrane filter test each day on finished water.

(2) Standard Plate Count. Conduct total colony count each day on raw, settled, filtered, and tap water.

(3) Microscopic Examination. Conduct microscopic examination of raw water when conditions in the raw water dictate such examination (for example, algae blooms, iron bacteria, etc).

6-103. Record Keeping:

a. Records for water sampling and analyses must be maintained daily. The general water utility operating logs discussed in paragraphs 1-9 and 1-10 may be used as the basic operating record on which plant control analyses can be recorded. DD Form 686, Fluoride/Bacteriological Examination of Water, may be used to record information concerning fluoride and bacteriological water examination. The installation may wish to supplement DD Form 686 with record forms pertaining to particular processes peculiar to that installation.

b. Details of requirements for maintaining water quality analytical records on tests required by the NIPDWR (40 CFR 141) and the assignment of such responsibilities are identified in the applicable service regulations listed in paragraph 1-19.

6-104. Reporting and Notification:

a. General Information. Results of quality control tests, which are required by law (40 CFR 141), are to be reported to the State or EPA. If the results of testing for a particular contaminant are shown to be in violation of the standards, the law says the public must be notified.

b. Reporting Requirements. Details of requirements for reporting (and public identification and the assignment of such responsibilities) are identified in the appropriate service regulations listed in paragraph 1-19.

Chapter 7

CORROSION AND DEPOSIT CONTROL

Section A—General Information

7-1. Water System Objectives. Both corrosion and deposit formations affect the integrity of the water system. Either or both can occur in various system components such as piping, treatment facilities, and storage tanks. The extreme effect of either can be system component failure. However, even in less than extreme cases, system performance is reduced to less than optimum. Deposit formation and especially corrosion can be the result of a complex combination of contributing factors. Nevertheless, a basic understanding of these factors is not difficult to achieve. Information presented here is aimed at providing sufficient theory and practical application data to guide planning and operating personnel in the control of both actual and potential problems.

7-2. Definition of Corrosion and Deposits:

a. Standard definitions of corrosion and deposits vary. Broadly defined, corrosion has been interpreted as the deterioration of any material. Deposits have been considered to be the accumulation of foreign material on a structural or process component. To be more specific, the following definitions are used:

(1) Corrosion is a chemical or electrochemical reaction in which a metal deteriorates or is destroyed. This takes place due to interaction of the metal and the fluid or soil with which it is in contact. Example: Action of acid attacking a steel pipe. Corrosion has been sometimes described as the process of a metal reverting to a more stable form, which is the ore from which it was obtained.

(2) Degradation is often referred to as a special type of corrosion where the material subject to deterioration is a nonmetal. Example: Action of organic solvent on plastic.

(3) Deposit is a residue of insoluble material such as sludge, dirt, or corrosion byproducts attached to piping or equipment surfaces. Examples:

(a) Suspended dirt in the entering water settles in pipes of a water system.

(b) Iron oxides produced by corrosion in the pipes form tubercles in a water system.

(4) Scale is a specific type of deposit which is very adherent and is caused by precipitation of mineral salts from the fluid being conveyed. Example: Scale formed in a hot water heater. It should be noted that mill scale formed on such materials as steel pipe during manufacture does not strictly conform to this definition. Mill scale actually is a corrosion byproduct left as a deposit on the metal surface.

b. Corrosion and degradation appear to be independent and the opposite of scale or deposits. While this is in effect partially true, they can often be very directly related. One common type of corrosion is that caused by the effect of dissolved oxygen in water on the pipe metal. This results in the formation of an iron oxide (rust) which precipitates to form a deposit. A continuous scale film can act as a protective coating on the inside pipe surface, arresting corrosion. A discontinuous scale layer can actually accelerate corrosion. Corrosion and scaling, therefore, can and do (under some circumstances) occur simultaneously.

7-3. Economics and Safety:

a. A cost-effective system design to minimize corrosion, degradation, scale, and deposits involves critical assessment of construction materials as well as the available means to control environmental factors. This may involve selecting a corrosion-resistant pipe such as an alloy steel rather than carbon steel, or, if possible, changing the characteristics of the fluid handled so that steel pipe can be used. If for any reason material deterioration or deposits do occur, the system performance will be affected, resulting in conditions like deterioration of water quality, higher pumping cost, less efficient heat usage in water heaters, or system leaks with wasting of water. All of these result in added cost. Repair can require system shutdown, seriously affecting facility operation.

b. Safety is also affected by corrosion and deposit control. Interruption in functioning of the water supply due to maintenance (or reduced flow capacity due to deposits) would cause serious problems in the event of a fire or other normal or emergency facility demand that requires using the full system capacity.

Section B—Corrosion Control

7-4. Fundamental Corrosion Principles:

a. General Information. As previously defined, corrosion of metals and degradation of nonmetals are both processes in which any part of the water system (such as a pipe, flume, or structural component) deteriorates. This may be evident as a general uniform thinning of a steel pipe wall, pitting, or in the case of plastic materials, a general change such as softening or increasing brittleness. The result is due to a reaction between the system component and its environment. The environment can be the water or fluid that a pipe conveys, the soil in which the pipe is buried, or the atmosphere to which it is exposed.

(1) Without defining the various corrosion mechanisms and their causes at this point, it is necessary to emphasize the part played by the environment in the corrosion process. Carbon steel pipe carrying water free of dissolved oxygen may serve satisfactorily for many years without visible deterioration. However, the same water, if aerated, may cause serious pitting and limit the useful life of pipe to a very short period. A carbon steel pipe buried in well-drained sandy soil would probably show little corrosion over a long period of use. On the other hand, if the soil were swampy with decaying vegetable matter, expected pipe life would be very limited.

(2) Although the corrosion process is essentially the

same for all metals, different metals and alloys can be affected to a varying degree by a given set of environmental conditions. An aerated well-water supply that would cause failure in a carbon steel pipe would probably have no ill effect on a stainless steel or an aluminum pipe. In water supply and treatment facilities, cast iron, steel, and copper are the most common metals used; although other materials such as aluminum, stainless steel, and zinc (galvanized coatings) are often encountered.

b. Chemical and Electrochemical Reactions. Various classifications have been used to identify the corrosion process. For purposes of simplicity, two general classifications can be used:

(1) Direct Chemical Corrosion. This is typified by direct reaction of a metal, such as iron, exposed to air or oxygen at an elevated temperature. Another example is the direct attack of an acid on a metal at a pH below 4.5:

$$2HCl + Fe^{+2} = FeCl_2 + H_2 \text{ (gas)}$$

Hydrochloric Acid	+	Ferrous ion	=	Ferrous Chloride	+	Hydrogen

(2) Electrochemical Corrosion. Electrochemical corrosion involves an electrolytic cell wherein the functioning principle is the same as that in an electric battery. The system contains the following components:

(a) An anode.
(b) A cathode.
(c) An electrolyte.
(d) An external electrical circuit.

(3) Cell Description. The anode is the cell component from which a positive metal ion (such as Fe^{+2}) migrates from the pipe to the electrolyte leaving a negative charge on the bare metal. The cathode is the electrode where the electric current reenters the base metal from the electrolyte. The pipe serves as the external electrical circuit. The electrolyte is the water, soil, or other environmental material in contact with the metal. It should be noted that the conventional description of current flow in the external electrical circuit is from the positive electrode (cathode) to the negative electrode (anode). Actually, the negatively charged electrons flow in the opposite direction (figure 7-1).

7-5. Erosion and Cavitation. Certain physical and mechanical factors that influence corrosion include:

a. Erosion. Erosion is the wearing away of metal by mechanical action, as a pump impeller may be eroded by sand carried in water. This abrasive action is not a form of corrosion, but may accelerate the destruction of metal because corrosion products are more easily eroded than the metal itself. A bare-metal surface is thereby exposed which is often more subject to attack. Liquids and gases, especially at high velocities, can cause this mechanical wear and wash away protective coatings on metal surfaces.

b. Cavitation. Cavitation (sometimes called cavitation erosion) is the damage caused by the formation and collapse of gas bubbles in liquid where the metal and liquid are in contact. For example, as liquid flows over a turbine blade, a suction or low pressure area forms and creates

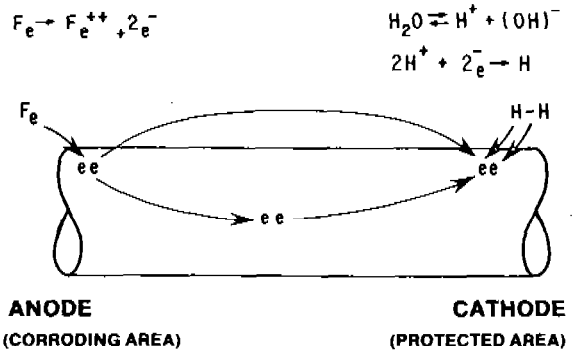


Figure 7-1. Characteristics of Metallic Corrosion.

bubbles in the liquid. When the bubbles collapse, they cause pitting in the metal at that point. Cavitation can occur where irregular waterflow takes place, particularly if high velocities and vacuums are involved. Gas bubble formation can be caused by the release of dissolved gas at the reduced pressure. With warm water and at very low pressures, partial vaporization of the water (flashing) can also be a source of the gas bubbles. Water hammer can also lead to cavitation damage of pipe.

7-6. Degradations of Nonmetallic Materials. Nonmetallic materials are being used as a substitute for metals in many water system applications. Among these materials are concrete, asbestos-cement pipe, and plastics of various kinds. Nonmetallic materials are also used as protective coatings or linings for metallic pipes or tanks.

a. Concrete. Concrete in contact with water is deteriorated by leaching of cement from the concrete into the water. The concrete also absorbs substances from the water such as sulfates that react with soluble materials in the pores to damage the hydrated cement. Leaching increases the porosity, making the concrete more subject to attack by absorption if high sulfates are present in the water. Certain organic coatings, such as those with linseed oil base, are not recommended for use on concrete. Concrete surfaces can be protected against deterioration by chlorinated rubber, epoxy or bitumen coatings, and sodium silicate can inhibit sulfate attack.

b. Wood. Wood can deteriorate due to delignification caused by a high concentration of alkalinity or chlorine (greater than 1.0 mg/l) and also by direct biological attack of various microorganisms. Wood can also produce organic acids that tend to corrode surrounding metal. Fungal attack is the primary cause of wood rot although bacteria, beetles, termites, and marine borers can decrease the structural use of many woods. Fungi need oxygen and water (at least 20 percent moisture in wood) for growth. Common control measures are the use of creosote, tar oil, or paraffin oils in the wood. If deterioration is noticed, corrective action can be taken by applying toxic metal salts, insecticides, or other fungicides. Cracking in wood can be reduced by using wood impregnated with silicone solutions. It should be noted that most of these do not apply to potable water systems.

c. Plastics and Rubber. Plastics such as polyvinyl chlo-

ride (PVC) and polyvinyl dichloride (PVDC), as well as rubber, also find use in water systems. Carbon black or other heavy pigment is used to protect the many products that deteriorate in sunlight. Plastics and rubbers deteriorate by chemical attack on their structure. However, this usually is only in stronger acid environments, or in the presence of organic solvents, such as acetone, carbon tetrachloride, and gasoline. Plastics tend to soften on heating and therefore are limited to cold or warm water use. Plastic tapes and coating are widely used as protective coating for metal. Plastic pipes for water mains are available and are highly corrosion resistant.

d. Asbestos-Cement Pipe. Asbestos-cement pipe has been used in water systems, particularly in corrosive soils. Pipes made of asbestos-cement are subject to corrosion where acids or hydrogen sulfide are present. Linings and coatings have found variable success in stopping corrosion. Use should be restricted in acid conditions. Asbestos-cement is a nonconductor and is thus immune to electrolytic corrosion.

7-7. Types of Corrosion. Various classifications for types of corrosion have been made. Some types and characteristics of electrochemical metallic corrosion are displayed in table 7-1. In each type of corrosion an anode and a cathode must exist. An electrolyte to allow ionic migration of corrosion reaction products and a conductor to allow the flow of electrons must be present. Corrosion control is obtained by systems that control the formation of cathodes and anodes, control cathodic or anodic reactions, isolate corroding surfaces from the electrolyte, or used materials that inhibit electron flow in the corroding material.

Table 7-1. Corrosion Types and Occurrence.

Type	Characteristics	Conditions of Occurrence	Possible Cures
Uniform	Attack over entire surface area.	Low pH, low calcium or alkalinity, high dissolved salt level, few metals in high pH.	Change water characteristics. Use coatings.
Pitting	Attack isolated spots in metal. Such spots due to flaws in metal or localized deposits on metal.	Holes in plating or coating, small anodic area, large cathodic area, low dissolved oxygen or high chloride at anodic areas. Copper greater than 0.02 ppm in solution acting on aluminum metal.	Cathodic protection. Complete coating.
Galvanic	One of two different metals in contact corrodes.	Metal anodic to other metal corrodes.	Proper design.
Concentration cell	Most prevalent type in which character of electrolyte is different at points in the metal.	Different soil types along pipe, different oxygen, carbon dioxide, temperature, or stress from one point in metal to another.	Cathodic protection. Scale control.
Crevice	Corrosion of crevice or crack in pipe.	Crevices where low dissolved oxygen levels set up concentration cell.	Cathodic protection. Coatings.
Stress	Corrosion around welds, rivets, bends, or points of stress in pipe.	Material differences caused by stress set up a concentration cell. Alternating stress can cause fatigue corrosion.	Cathodic protection. Coatings.
Cavitation	Collapse of gas bubbles where they come out of solution.	High velocity, changes in velocity; enhanced in presence of erosion which scours protective film. Nitrogen gas important as well as oxygen, hydrogen, and carbon dixoide gases.	Proper design. Cathodic protection.
Stray current	Corrosion at point where stray currents leave pipe.	Direct current discharges from pipe, as from electric railways. Discharge at low resistance areas in soil.	Cathodic protection. Coatings.
Bacterial	Acid attack by anaerobic bacterial products.	Waters high in sulfate and conducive to bacterial growth. Low dissolved oxygen levels below scale or deposits.	Clean surfaces. Change water characteristics.
Chemical attack	Acid attack from other causes.	Low pH waters or waters where sulfates and chlorides are high.	Inhibitors. Coatings.
Tuberculation	Tubercles are iron deposits which can produce low dissolved oxygen levels and enhance acid attack.	Corrosive conditions where high dissolved iron levels occur.	Change water characteristics. Clean surfaces.
Metal leaching	Metal is replaced by corrosion product.	Graphitization of cast iron in low pH, high mineral waters. Dezincification of brass in soft waters with high carbon dioxide.	Change water characteristics.

7-8. Corrosion Reactions. Various reactions can occur to cause corrosion. The rates of the reactions are influenced by several variables. At the cathode, the metal has excess electrons which are given up to a charged particle, such as hydrogen, in the solution. Corrosion continues if the hydrogen combines with oxygen to produce water or is removed by water movement. The positively charged metal at the anode also reacts with charged particles in solution and a metal oxide or hydroxide is formed. Aluminum, zinc, and chromium form impermeable oxide layers that inhibit corrosion. Iron and steel form a porous ferric hydroxide which does not inhibit corrosion. Oxygen in the solution removes hydrogen from the cathode and metals from the anode. The character of the solution influences the rate of ionic migration and the material influences electron migration. Corrosion control is aimed at eliminating, controlling the rate, or directing these reactions.

7-9. Factors Influencing Corrosion:

a. Biological Corrosion. Factors influencing biological corrosion are the direct influence of microorganisms, as well as that of their metabolic waste products.

(1) Soil Corrosion. Biological soil corrosion results from chemicals produced by soil microorganisms. Iron structures buried in soil are attacked by sulfate-reducing bacteria, which thrive in wet, poorly drained soil with low aeration. These bacteria are anaerobic (requiring the absence of oxygen) and require adequate amounts of sulfate in the soil. The organisms promote the reaction of iron, acidic sulfate compounds, and water to form ferrous hydroxide and ferrous sulfide. Iron bacteria, on the other hand, are aerobic (requiring oxygen). They do not appear to attack iron directly but, by consuming ferrous iron from the environment in equilibrium with the pipe metal, cause some further corrosion and form iron hydroxide deposits that may cause tubercles on the metal surface.

(2) Fouling. Fouling is caused by microorganisms that form slimy deposits and underwater growths on metal. Important in the marine environment are algae, sponges, mollusks, and barnacles. Bacterial slimes can form on internal pipe surfaces and result in a noncontinuous deposit and under certain conditions prevent normal protective film formation. Internal biological fouling of pipes may be due to a large variety of organisms. The exposed surface of the organism deposit may include aerobic organisms such as the iron and sulfur bacteria while inner layers may contain anaerobic organisms such as the sulfate-reducing organisms.

b. Chemical. Chemical factors influencing corrosion include:

(1) Mineral Salts. Mineral salts, particularly those of calcium and magnesium, dissolved in the water precipitate as scale when the concentration exceeds the solubility limit. Scale formation is discussed more fully in section C. The scale thus formed, if continuous, can insulate the metal and protect it from corrosion. High concentrations of soluble sulfates or chlorides increase the corrosiveness of water by increasing the conductivity of the electrolyte.

(2) Dissolved Oxygen. Dissolved oxygen is a depolarizing agent that reacts with the hydrogen from metal surfaces submerged in water, allowing oxygen to combine with the metal and form oxides. This results in cavities or pitting. For example, air accumulating in the top of a vertical hot water tank causes corrosion on the water side. This corrosive attack is increased by the presence of carbon dioxide.

(3) Carbon Dioxide:

(a) When dissolved in water, carbon dioxide forms a weak acid (carbonic acid). This acid combines chemically with iron to cause corrosion. The products of the reaction are ferrous bicarbonate and hydrogen gas. This form of corrosion is encountered in hot-water lines, steam condensate return lines, and associated equipment. The action of carbon dioxide is not usually serious above the pH range of 5 to 6 if oxygen is absent. Failures occur most frequently in thin-wall sections (such as at threaded joints). Dissolved oxygen, in combination with carbon dioxide, accelerates the corrosive process.

(b) The process of aeration is used to lower the carbon dioxide level to 5 to 15 mg/l, to increase pH in certain iron removal processes, and to reduce the lime required in water softening. An increase in pH by carbon dioxide removal helps, but usually does not completely adjust water quality to form a protective film. The oxygen introduced by aeration may actually accelerate corrosion. The relationship between carbon dioxide and alkalinity for waters is shown in figure 7-2.

(4) Hydrogen ion concentration (pH). The pH is formally defined as the logarithm of the reciprocal of the hydrogen concentration:

$$pH = \log \frac{1}{[H+]}$$

It is an intensity measure of acidity, just as temperature is a measure of heat intensity. The lower the pH, the higher the concentration of hydrogen ion or acidity. Because it is a logarithmic function, a pH of 4 represents a hydrogen ion concentration 10 times that of pH of 5 and 100 times that of a pH of 6.

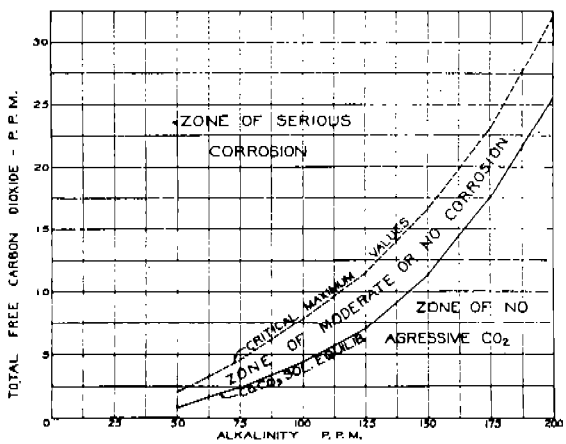


Figure 7-2. Relationship of Carbon Dioxide Versus Alkalinity.

(a) The effect of pH on the corrosion rate of iron is shown in figure 7-3. The corrosion rate is lowest at a pH of 14, increasing as pH decreases to 10, and remains essentially uniform as pH decreases to about 4.3. When considering the effect of pH alone, the rate and type of corrosion in water containing dissolved oxygen falls into three pH zones:

1. Acid. When pH is less than 4.5, corrosion is generally over the entire iron surface and hydrogen gas is formed. Rate of corrosion increases rapidly as the pH is decreased. Rust or tubercles do not form on the metal.

2. Neutral. Iron oxide (rust) forms when the pH is between 4.5 and 9.0, which is the range of most natural waters. Rate of corrosion is nearly independent of pH, but increases with temperature and concentration of oxygen. Corrosion occurs mainly in fairly well-defined areas that become more definite as pH increases. Other parts of the iron surface are attacked very little. Even in the absence of oxygen, iron corrodes in water at a very slow rate to form black iron oxide magnetite (Fe_3O_4) and hydrogen.

3. Alkaline. When pH is 9.0 or more, corrosion decreases rapidly with an increase in pH. Rust coating is denser and more adherent. Pitting can occur under the tubercles. Sodium ferrite can form in extremely high pH waters and cause uniform corrosion at a high rate in high sodium waters.

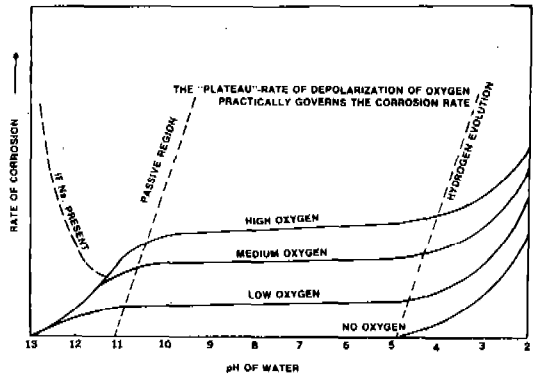


Figure 7-3. Effect of pH and Dissolved Oxygen on the Corrosion Rate of Iron in Water.

c. Physical and Mechanical. Physical and mechanical factors that influence corrosion include:

(1) Erosion and Cavitation. Discussed in paragraph 7-5.

(2) Metal Porosity. Porous areas in metal may be formed during the casting process. Sandholes or blowholes left in the metal not only weaken it structurally but allow deeper penetration due to concentration cell formation.

(3) Pressure. Pressure alone does not appear to affect the rate of corrosion; however, it increases the solubility of oxygen in water, and adds stress to metal in pressure vessels, both of which are conditions favorable to corrosion.

(4) Temperature. Changes in temperature increase or decrease the rate of corrosion reaction, the effect depending on other conditions. For example, in a closed system where no variation in dissolved oxygen can occur, corrosion is accelerated by increases in temperature, as shown on figure 7-4. In an open system, the maximum rate of corrosion occurs at 176°F. The corrosion rate is a function of both temperature and dissolved oxygen content. Above 176°F the higher corrosion effect due to temperature is offset by the lower solubility of oxygen. As a rule, the higher the temperature, the more rapid the chemical reaction and the higher the corrosion rate.

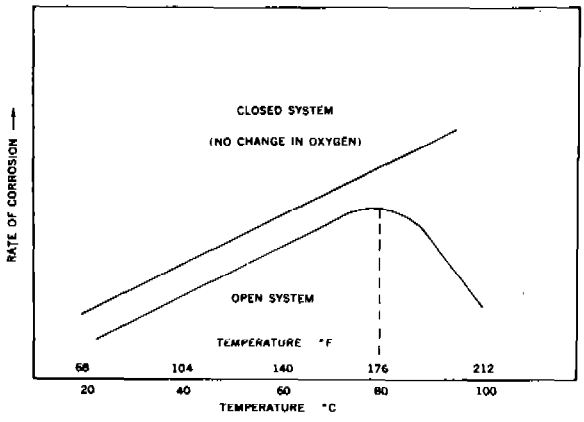


Figure 7-4. Effect of Temperature on Corrosion of Iron.

(5) Time. The length of time metal is exposed to corrosive environment may affect the rate of corrosion. The initial rate is generally high, but may decrease as natural protective coating corrosion products are formed on the surface of the metal.

(6) Velocity. As liquid velocity increases, the liquid can remove protective coatings and supply more corrosive media to the area of contact, thus stimulating corrosion. Motion of liquid may have a uniform effect over the whole metal surface and prevent localized corrosion, or it may set up turbulence at certain points and cause pitting. For iron, at constant pH and dissolved oxygen values, the rate of corrosion reaches a maximum at a velocity of 1.3 feet per second (fps); it then decreases sharply up to 3 fps, and increases beyond that velocity because of combined erosion and corrosion effects. High localized velocities may cause corrosion by means of particles striking the metal surface at high speeds. In those instances where the water is adjusted to deposit a thin protective film either by Langelier control (paragraph 7-17) or by adding an inhibitor, higher velocities of 4 to 6 fps can be beneficial.

d. Electrochemical. When a difference in electric potential exists between two parts of a metal structure that are in contact with an electrolyte, a flow of electric current occurs. The potential may be set up by two dissimilar metals, by a difference in temperature, amount of oxygen, or concentration of the electrolyte at two points of contact with the metal. The anode is the point where current flow is from the metal to the electrolyte; it is here that corrosion occurs. The cathode, which is usually not attacked, is the point of current flow from the electrolyte to the metal. Some forms of electrochemical corrosion are:

(1) Concentration Cell. A concentration cell is an electrolytic cell producing a current due to a difference in

the ionizable material concentration of the electrolyte or oxygen at the anode and cathode. Crevice corrosion is typical of this reaction. For example, if pipe is laid in soil that is not uniformly compacted or is backfilled improperly, crevices in the backfill may cause one area of the pipe to be aerated more than another. This creates a difference in potential that promotes corrosive action.

(2) Galvanic Action. When two dissimilar metals immersed in an electrolyte are in direct contact or are connected by a conductor, an electric current is induced.

(a) For example, in a flashlight battery, carbon and zinc are placed in an electrolyte and connected by an external circuit. In producing current, zinc (the anode) goes into the solution in the form of zinc ions. After continued use, most of the zinc is removed and pit holes form. This wastage of zinc is referred to as galvanic corrosion (figure 7-5). This behavior is analogous to galvanic cells found in a pipeline with dissimilar metal couplings. There, the rate of corrosion is a function of the difference in activities (galvanic series) between the anode and cathode as well as the conductivity of electrolyte and the external electrical circuit. One other factor can also affect the extent of the problem. When the anode area is small, with respect to the cathode area, corrosion is much more rapid than when the reverse is true. A brass valve in a steel pipe carrying water acts as a galvanic cell; with the brass being the cathode, the current passes through the water (the electrolyte in this case) to the brass valve, and returns through the metal to the anode area (figure 7-6). The iron is the anode and has substantially more area of contact with the electrolyte than the brass. Corrosion depth in the metal is usually minimal in iron water pipes from galvanic action. However, an iron valve in a brass or copper line has a more intensive attack at the junction of the two metals. Another example is where a piece of new pipe is connected in an old line. The new line is generally the anode and therefore corrodes (figure 7-6).

(b) When two dissimilar metals are located in a moist soil (electrolyte), one acts as an anode and the other as a cathode according to their relative position in the galvanic series. The relative position of commonly used metals is shown in table 7-2. If any two metals in this series are placed in an electrolyte and externally connected, the metal listed nearest the top of the series will be anodic and will corrode.

Table 7-2. Galvanic Series for Common Metals.

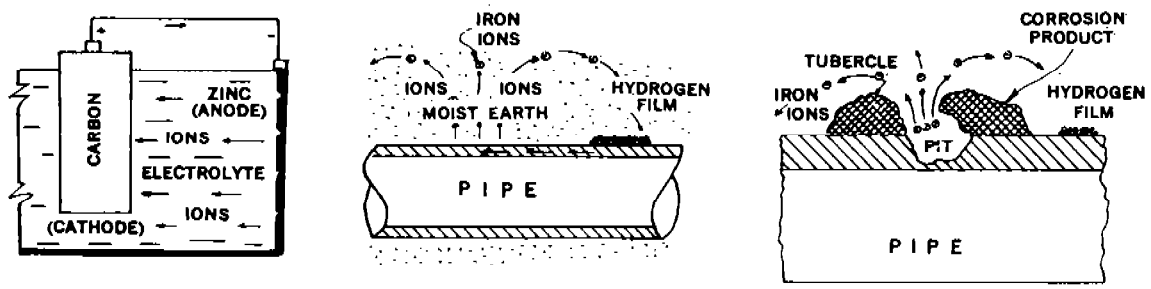
Anodic End	Copper
Magnesium	Bronze
Zinc	Cupro Nickel
Aluminum	Type 304 S.S.
Carbon Steel	Type 316 S.S.
Cast Iron	Silver
Lead	Carbon
Tin	Gold
Brass	Cathodic End

(c) Galvanic action can also occur between identical metals in different electrolytes. For instance, dissimilarity between soils in which a pipeline is laid can result in a flow of electricity. The degree of galvanic corrosion is determined largely by the type of soil in which the line is buried. Corrosion is generally most rapid in acid soils. Soils are generally classified by resistivity, as high resistance or low resistance soils. A pipeline passing through soils of different resistivities corrodes in the low resistance soils (paragraph 7-11).

(3) Electrolysis. Corrosion caused by stray direct current (DC) is an example of electrolysis. It is the production of a chemical change as the result of the passage of an external source of electricity. These stray currents occurred primarily from electric railways where the current left the rails and took the path of least resistance through underground metal structures (such as pipelines and cables) instead of returning to the generator through the rails. Presently, this is only important in those very few cases where there is a grounded DC system for equipment operation or near structures that are being cathodically protected by an impressed DC. Corrosion occurs where the current leaves the pipeline to return to the generator. Because of the reversal in direction of current flow, alternating current (AC) does not cause this action.

e. Metallurgical. Metallurgical considerations affecting corrosion include stresses set up in metals through the fabrication process or by such operations as welding, soldering, and riveting. Such stresses may make metals more subject to corrosion, and the combination can result in stress cracking.

7-10. Examples of Corrosion in Water Treatment. Some types of corrosion can be identified by examination of

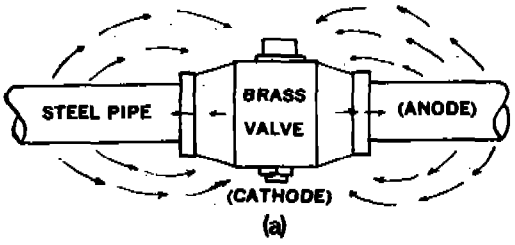


(a) BATTERY ACTION

(b) IONS IN MOTION START CORROSION

(c) CORROSION PROCEEDS WITH PITTING & TUBERCULATION

Figure 7-5. Principles of Galvanic Corrosion.



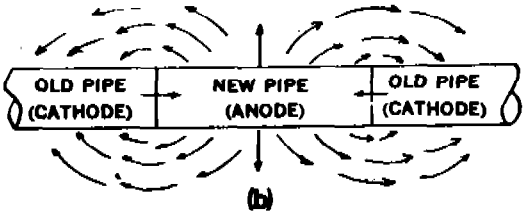


Figure 7-6. Corrosion Caused by Dissimilar Metals.

metallic surfaces. The interior of pipelines can be examined when removed for repair or replacement and corrosion products examined as a clue to corrective action. A severely tuberculated pipe with a resultant reduction in flow capacity is shown in figure 7-7. The effect of corrosive attack by carbon dioxide and oxygen is shown in figure 7-8.

7-11. Design for Corrosion Control. For any particular system material and environmental conditions, corrosion may be the result of one or many causes; hence, control measures must be planned to meet the specific conditions. Because it is impossible to give specific measures covering all local problems, the following overall control measures are listed in sufficient detail to guide personnel in establishing corrosion control measures and solving specific problems:

a. Designing Against Corrosion:

(1) Two steps are necessary in general design to aid in corrosion control:

(a) Features that keep corrosion to a minimum must be incorporated into the original design of the system.

(b) Conditions must be established that will make it easier to combat corrosion if encountered in subsequent operations.

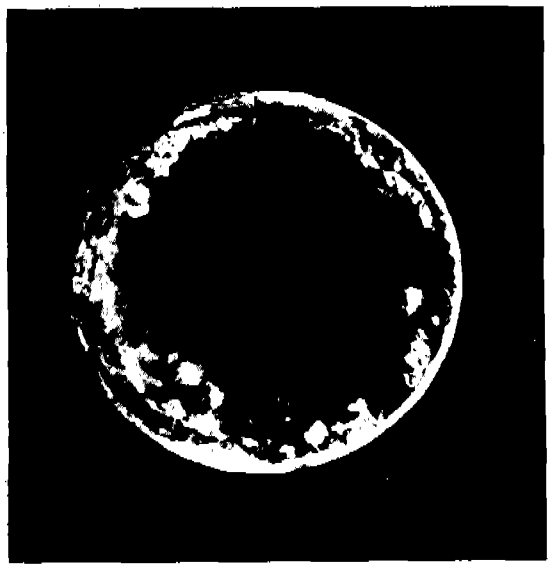


Figure 7-7. Water Line With Excessive Corrosion.

Figure 7-8. Corrosive Attack by Carbon Dioxide and Oxygen.

(2) Good design includes:

(a) Selecting proper materials.

(b) Allowing extra metal thickness where corrosion may occur.

(c) Protecting metals by protective coatings and linings.

(d) Installing cathodic protection.

(e) Providing adequate water treatment.

(f) Making easy access to structure and equipment (such as handholes and ease of disassembly) for inspection, replacement, or suitable protective measures that may become necessary in the future.

b. Selecting Materials:

(1) Proper Choice of Materials:

(a) A basic step in preventing corrosion is selecting the most resistant material economically justified for a given environment. The term corrosion resistant may be misleading if applied to a material in general terms. Corrosion resistance must always be measured in terms of a specific application in a particular corrosive medium.

(b) Manufacturers usually offer a choice of materi-

als for critical parts of equipment, such as pumps, that may be exposed to a corrosive environment. Among light metals, aluminum, magnesium, and cadmium are relatively corrosion resistant. Among heavy metals, copper and bronze are generally more resistant to corrosion than the ferrous metals.

(c) Nonmetallic materials that may be substituted for metal in some applications are concrete, plastic, and asbestos-cement. Concrete, wrought iron, or asbestos-cement pipe are excellent for salt water and soft and corrosive waters, but not acids. For corrosive water conditions, cement-lined cast-iron pipe should be used in place of plain cast iron. In good soils, it is safe to use cast-iron pipe. In highly corrosive soils, it is preferable to use either asbestos-cement pipe, cement-lined and coated steel pipe, or coal-tar enameled pipe.

(d) Copper piping for service connections and interior plumbing is highly resistant to corrosion. It should not be used, however, for very soft waters with large amounts of carbon dioxide. Brass piping containing 85 percent or more of copper is also very highly resistant to corrosive waters. Commercially, lead pipe is usually satisfactory for hard waters, but not for soft waters because of the toxicity of the lead salts. Current practice in the military services is to completely avoid using lead. Lead can be dissolved from the pipe material and be present in potable water being carried in the pipe.

(2) Avoiding Dissimilar Metals. By using the same metal as far as possible throughout the piping system, galvanic action can be kept to a minimum. Where it is necessary to use dissimilar metals, afford protection and keep galvanic corrosion to a minimum. Insulating joints, sleeves, and bushings used between dissimilar metals can prevent galvanic current flow. These are made from nonconductive materials such as neoprene, Bakelite, and nylon. Galvanic corrosion can also be reduced by inserting short sections of nonconductive piping, such as plastic or hard rubber piping, between the dissimilar metals.

(3) Existing System. Materials used in the existing water system, including house plumbing, must be considered when the type of material is selected for system expansion or modification.

c. Avoiding Corrosive Environments. Water environments (including steam and vapor) are the chief cause of corrosion. Water, in its many forms, is the most corrosive electrolyte. Soil and atmosphere are other important corrosive environments.

(1) Water:

(a) Water is rarely free of dissolved and suspended substances. It may contain various dissolved salts, gases, and suspended matter. All of these must be considered as potential corrosion factors. Water essentially free of solids, carbon dioxide, and oxygen does not seriously corrode iron and steel piping in the near neutral and higher pH range when its temperature is below the boiling point. Likewise, water adjusted to have slightly scaling properties produces a thin protective film which inhibits corrosion. Softened water (low calcium and magnesium content) or water relatively free of solids can be quite corrosive at near neutral pH range if any significant dissolved oxygen is present.

(b) In electrochemical corrosion, water is the environmental media through which metal ion transport takes place with a resulting electric current flow. Salt water has an especially high rate of conductivity and is very corrosive. Direct factors in creating a corrosive water environment may be the introduction of hydrogen sulfide by sewage discharges, addition of brines to cooling waters, demineralization of water, increase in water acidity from industrial wastes and acid mine waters, and similar local conditions. The corrosiveness of salts in solution is indicated in table 7-3.

(2) Soil. Soil conditions are responsible for the exterior corrosion of metal structures under or in contact with the ground. When two identical electrodes (such as two sections of a pipeline) are connected in dissimilar electrolytes (such as different soils), current flows from one electrode, through the electrolytes, to the other electrode, setting up a corrosion cell. Among the many causes of differential electrolyte cells in the soil are: nonuniform texture of soil in contact with a tank or pipe; differential aeration or difference in the availability of oxygen at two points on the metal surface; two or more different types of soil, such as sand and clay, in contact with a metal object; presence of foreign matter, such as cinders, in the soil; and differences in the moisture content of the soil around a metal object. In general, salt-bearing soils, highly alkaline soils,

Table 7-3. Corrosiveness of Salts in Solution.

Constituent	Concentration, mg/l	Degree of Corrosion
Chlorides, Cl^-	10-25	Slightly corrosive.
Chlorides, Cl^-	100-500	Very corrosive.
Chlorides, Cl^-	500 and over	Extremely corrosive.
Sulfates, $SO_4^{=}$[1]	20-30	Slightly corrosive.
Sulfates, $SO_4^{=}$[1]	300 and over	Severely corrosive.
Sodium carbonate, Na_2CO_3	100 and over	Severely corrosive.
Nitrates, NO_3^-		Active and undesirable.

[1]Sulfate is harmfull to concrete in situations where it can be converted to sulfuric acid by biological or other action.

clay, brackish marshes, and poorly drained soils are conducive to corrosion (table 7-4).

(3) Atmosphere. In atmospheric corrosion, moisture is the main controlling variable. The action of salt air, hydrogen sulfide, sulfur dioxide, and other substances is more rapid in moist than dry air. The presence or absence of certain foreign elements in the metal sometimes has a marked effect. Metals, such as zinc, aluminum, nickel, and copper, form a protective coating that retards further corrosion if atmospheric contaminant concentrations are not too high.

7-12. Controlling Inhibitors:

a. Corrosion Inhibitors. Water is frequently treated to eliminate the causes or reduce the intensity of corrosion. Water may be mechanically deaerated to remove corrosive gases such as oxygen and carbon dioxide or treated chemically to remove these gases. Removal of these corrosive gases can make an otherwise aggressive water noncorrosive. Chemical treatment adjusts the pH or other characteristics of the water that promotes deposition of a film on the metal surface. This film, when evenly formed, effectively isolates the metal surface and prevents direct contact between water and metals. Following is a discussion of the more common methods of chemical treatment used:

(1) Anodic Inhibitors. In near neutral water containing a low concentration of chlorides, phosphates and silicates cause passivation of steel when oxygen is present, hence they behave as anodic inhibitors. They prevent corrosion without affecting the potability of water; other anodic inhibitors such as chromates are toxic and cannot be used in potable waters. Anodic inhibitor's dosages must be large enough to stop anodic reaction completely. If the inhibitor does not cover the entire anodic area, the corrosion reaction is concentrated, and pitting may be greater than when no inhibitor is used. Correct dosage is determined by previous experience or by a closely controlled trial period.

(a) Phosphates. The molecularly dehydrated phosphates (polyphosphates)—such as sodium hexamethaphosphate and similar compounds—are widely used to control corrosion in both cold and hot water systems. These polyphosphates are manufactured by heating certain orthophosphates to a high temperature followed by rapid cooling.

$$NaH_2PO_4 + Heat = NaPO_3 + H_2O$$

This reaction tends to reverse, particularly at higher water temperatures, reforming the orthophosphate. The orthophosphate is not as effective as a corrosion inhibitor. Some polyphosphates are more resistant than others to reversion and specific materials should be evaluated before use, particularly in hot water systems. Corrosion is inhibited by the adsorption of the phosphate or one of its complexes on the metal surface, forming a protective film. For initial system operation, it is desirable to have a high feed (10 mg/l) to form a film as quickly as possible. As soon as the protective film has formed, the dosage may be reduced to the range of 2 to 5 mg/l to maintain a film on the metal. In some cases, polyphosphate compounds with small amounts of zinc have improved corrosion protection. Phosphates are useful in pH range of 5.0 to about 8.0, with best results obtained when the pH ranges from 6.5 to 7.0. In starting treatment in corroded pipe systems, difficulty is often experienced with the removal of corrosion products. Therefore, care is required to avoid complaints. Chemical feed is usually by solution feed pumps. Since polyphosphate solutions support growth, use a small amount of hypochlorite (2 to 3 mg/l total residual chlorine) in the solution to avoid such growth.

(b) Sodium Silicate. The addition of sufficient quantities of soluble silicates to water produces a precipitation of calcium silicate or other metal silicates on the metallic surface to be protected. While the concentration of silicate required for protection depends on the salinity of the water, for most installation water supplies, about 5-10

Table 7-4. Corrosion of Ferrous Metals by Soils.

Class	Degree of Corrosion	Soil Types	Soil Characteristics
1	Light	Loams: coarse sand or sandy; light textured silt; porous; clay oxidized to great depths.	Aeration good; no mottling anywhere in soil profile, and very low water table.
2	Mild	Sandy loams Silt loams	Aeration fair; slight mottling in lower part of soil profile, and low water table; no artificial drainage required for raising crops.
3	Heavy	Clay loams Clay	Aeration poor; heavy texture and mottling close to surface with water table at about pipe depth; artificial drainage required for crop raising.
4	Extreme	Muck Peat Tidal marsh Adobe clay Arid region soils with a high salt content.	Aeration very poor; water table at surface; extreme impermeability because of colloidal material present. Condensation of atmosphere water around pipe causes corrosion.

Table 7-5. Corrosion and Scaling Classification of Potable Waters. (All units in mg/l unless otherwise noted)

Category	Calcium (Ca)	Sulfate (SO_4)	Silica (SiO_2)	Dissolved Oxygen	Character	Suggested Treatment
1A	0 to 18	As found	0 to 25	1 to 10	Extremely corrosive hot and cold.	(For categories 1A to 2B).
1B	0 to 18	0 to 25	0 to 15	0 to 1	Moderately corrosive hot and cold. Extreme corrosion with CO_2 above 8.0.	Polyphosphate 5 to 10 ppm.[1] Lime to pH 8.5 plus silicates 10 as SiO_2.[2]
1C	0 to 18	0 to 60	Above 15	1 to 5	Slight corrosion on cold; considerable on hot. Aggressiveness reduced, and may not be troublesome because of high natural SiO_2.	Tetra sodium pyrophosphate 8 to 10.[3] Disodium phosphate anhydrous 5 to 8 plus soda ash for pH.[4]
2A	18 to 35	Greater than Ca, but not less than 25.	0 to 15[1]	1 to 10	Considerable corrosion hot and moderate cold. May be slightly scale forming on very hot water.	Lime alone on basis of Langelier Index, and calcium carbonate saturation test.[5]
2B	18 to 35	0 to 25	0 to 15	1 to 10	Moderate to slight corrosion hot and cold. May be scale forming hot.	
2C	18 to 35	Less than Ca	Above 15	1 to 8	Corrosion unlikely; may be scale forming hot.	Polyphosphate 2.0 to 4.0 (if scale forming).
2D	18 to 35	Less than Ca	As found	0 to 1	Corrosion unlikely; may be scale forming hot.	Polyphosphate 2.0 to 4.0 (if scale forming).
3A	35 to 75	Less than 1½ Ca.	0 to 15	1 to 10	Moderate corrosion on hot, slight on cold. Scale formation considerable hot.	Polyphosphate 2.0 to 4.0 silicates in excess of 8.0 as SiO_2.
3B	35 to 75	Greater than 1½ Ca.	0 to 15	1 to 10	Considerable corrosion on hot. Slight to moderate on cold. Considerable scale hot.	Polyphosphate 2.0 to 4.0 if corrosion. Silicates above 8.0 as SiO_2.
3C	35 to 75	Less than 1½ Ca.	Above 15	1 to 10	Scale forming considerable and slight corrosion on hot.	Polyphosphate 2.0 to 4.0.
3D	35 to 75	As found	As found	0 to 1	Scale forming considerable; corrosion unlikely.	Polyphosphate 2.0 to 4.0.
3E	35 to 75	Greater than 1½ Ca but less than 3 Ca.	Above 30	1 to 10	Corrosion unlikely hot and cold; scale formation excessive.	Polyphosphate 2.0 to 4.0.
4A	Above 75	Less than 2 Ca.	0 to 30	1 to 10	Scale formation excessive; corrosion unlikely to slight on cold water, slight to moderate hot.	Polyphosphate 2.0 to 4.0.
4B	Above 75	Greater than 2 Ca.	0 to 30	1 to 10	Scale formation excessive; bimetallic corrosion hot and cold considerable.	Polyphosphates 2.0 to 4.0 plus silicate above 8.0 (SiO_2).
4C	Above 75	Less than 3 Ca.	Over 30	1 to 10	Scale formation excessive; corrosion unlikely.	Polyphosphates 2.0 to 4.0.

[1]If Cl > 100 mg/l, water more corrosive than indicated.
[2]If CO_2 > 5 mg/l, will accelerate corrosion.
[3]If CO_2 > 20 mg/l, water will be corrosive.
[4]Add 5 mg/l polyphosphate per each mg/l of iron in water.
[5]With SiO_2 over 15, corrosion reduced in proportion to SiO_2 content.

ppm are required initially followed by a gradual reduction to about 2-3 ppm after a protective deposit is established. Silicates are best adapted to the treatment of very soft waters. Adding a small quantity of lime to the water may be helpful by raising the pH and providing calcium for the calcium silicate coating. The use of silicates in high magnesium waters is not recommended because of the danger of silicate scale formation, particularly in hot water heaters.

(2) Cathodic Inhibitors. Cathodic inhibitors, such as calcium carbonate, deposit film on cathodic areas because of the greater alkalinity at these areas. The film excludes oxygen from cathodic areas, thus reducing the cathodic reaction. The object is to raise the pH of the water above its calcium carbonate saturation value so that a thin calcium carbonate film will be continuously deposited on the metal. Use of the Langelier or other similar indices (described in paragraph 7-17) is helpful in establishing chemical adjustments required. Treatment varies with the condition of the water. Hard alkaline waters may require the addition of only slight quantities of soda ash. Soft waters of low alkalinity may need both lime and soda ash. Two main factors must be considered when treating the water, pH and temperature. Slight changes in either could change the water from a corrosive water to a scale-forming one. Naturally hard water containing calcium carbonates or silicates often deposit these mineral coatings on metals, thus affording a natural protection against corrosion.

b. Classification Table. A general category classification of waters, with respect to corrosion and scaling properties, is shown in table 7-5. Suggested inhibitor treatments for corrosion control and threshold treatments for scale control are indicated.

7-13. Protective Coatings. Protective coatings and linings serve as barriers between the material to be protected and the corrosive environment. In many cases, it may be more economical to use a protective coating than to use a more resistant material. Depending on circumstances, protection may be exposed to the soil or to the atmosphere. Protective coatings and linings may either be nonmetallic or metallic. Nonmetallic protection includes paint and enamel coatings, cement, masonry, plastic linings, rubber sheeting, and glass and ceramic coatings. When installing pipe, extreme care must be taken not to damage coatings as corrosion will be exceptionally severe where the coating has been damaged. A general rule cannot be made regarding the selection of protection methods, because each has its application in special circumstances.

a. Paints. Painting or coating is by far the most generally accepted method of corrosion control. In current terminology, paint is described as a coating most often applied as a decorative measure but it gives protection in a mildly corrosive environment, such as atmospheric exposure. The thickness of a paint film is small—usually only a few mils. Coatings are liquid-applied films, usually 10 mils or thicker, used principally to combat corrosive attack. Coatings must be selected to suit the particular conditions encountered. Any foreign material between the metal and protective paint interferes with effective protection. Therefore, it is important that the surface be clean and free from all loose scale and rust before it is painted. Grease and oil should be removed with a solvent. Oxidized surfaces can be cleaned by pickling, sand blasting, or scratch brushing. A brief description of some of the more common types of coating materials follows.

(1) Iron Oxide. Red iron oxide is widely used as pigment in protective coatings. There are many grades in varying concentrations of pigment; containing zinc oxide, zinc chromate, or red lead. Such paints, with excellent corrosion-inhibiting values, are used not only as primers but as surface coats over red lead primers.

(2) Carbon Surface. Black paints are usually used as finishing coats on steel structures. Carbon pigments (such as carbon black, oil black, and natural and artificial graphite) are generally used as base pigments in these paints.

(3) Zinc. Zinc oxide is a rust-inhibiting pigment because iron is cathodic to zinc and is protected at the expense of the zinc in contact with it. Zinc dust, in specially prepared vehicles, acts to some extent as galvanizing. A liquid galvanizing product has been prepared from a finely divided zinc dust emulsion in boiled linseed oil.

(4) Aluminum. Aluminum paints, which rank high as metal protectors, can be used as finishing coats or rust-inhibiting primers. They consist of aluminum-bronze powder in a suitable oil-varnish vehicle. They are widely used for coating surfaces submerged in water, with the aluminum powder dispersed in a hard-drying, synthetic resin vehicle.

(5) Bituminous. Bituminous coatings are prepared by blending refined coal-tar pitch, asphalt, and linseed oil. The mixture is thinned down in suitable mineral solvents. These coatings are used in protecting the underground elements of systems from soil and bacterial corrosion. Special blends are used for protecting water tanks and submerged metal surfaces. American Water Works Association (AWWA) specifications for cast-iron water pipes and fittings cover the approved practices for coating cast-iron pipes with hot coal-tar pitch varnish. Similar approved coal-tar enamel specifications are available for steel water mains.

b. Wrappers. A specialized form of protective materials, wrappers are used mainly on buried pipelines coated with bituminous compounds. They act as additional protection and are resistant to rot, decay, and acid and alkaline soils. The asbestos-felt wrappers or plastic tapes are flexible and sufficiently sturdy to protect the pipeline coating from physical damage. Severe localized corrosion may occur in areas where the protective coating has been accidentally removed by improper handling during installation.

c. Metallic Coatings. Zinc coatings are most widely used in waterworks. Galvanizing particularly applies to steel and wrought iron and provides good protection against atmospheric corrosion encountered in industrial areas or at the seacoast. It provides poor protection against aggressive and corrosive waters. Other metallic linings and coatings available for protecting piping aginst atmospheric and spe-

cial corrosive environments are aluminum, copper, chromium, and nickel. They are applied by spraying, dipping, or electroplating. Other processes provide for adding an inhibitor (passivators) to a metal to change the electrochemical potential to a more cathodic value.

d. Cement Linings and Coatings. Cement-lined cast-iron and steel piping and fittings are commercially available for corrosion protection. Mains and hot water storage tanks may be lined in place by various patented commercial processes. Glass-lined hot water storage tanks are readily available on the market and their use is recommended where corrosive water conditions are encountered. Care must be taken in their handling and installation in order not to crack the lining.

e. Sliplining. Buried corroded pipes or broken lines can sometimes be repaired by sliplining. A seamless plastic pipe liner is pulled into position inside the old pipe. This is convenient where the lines are under streets, parking lots, and other structures and reduces digging cost. Line capacity loss is minimal considering the low friction coefficient of plastic pipe versus that of conventional sewer piping materials.

7-14. Cathodic Protection. When current leaves a metal surface located in an electrolyte, electrically charged particles of the metal go into solution, causing wastage of metal or corrosion. If the flow of this current can be stopped or reversed, theoretically the metal does not corrode. In cathodic protection, the normal current flow associated with the corrosion process is retarded by inducing an opposing current flow.

a. Definition. Cathodic protection is defined as the application of sufficient direct current (DC) to a metal object to prevent currents from leaving the anodic areas of the structure. The entire metal object then becomes negative or cathodic to its surroundings. For each environment, a certain minimum current must be applied to reduce corrosion. The source of current is immaterial as long as the amount of current is adequate.

b. Design. Design standards and specifications for cathodic protection are in military engineering design manuals that are available to engineering personnel involved in design of such systems.

c. Methods. The flow of protective current may be produced by sacrificial anodes (galvanic method) and by impressed current.

(1) To achieve cathodic protection by the galvanic method, a sacrificial anode (a metal that is more anodic and that corrodes more readily than the object to be protected) is put in the electrolyte and electrically connected to the protected item. Electric current then flows from the more anodic or corroding metal through the electrolyte to the metal for which protection is desired. The electrical connection between the two objects completes the circuit, allowing the current to return to the corroding metal. The corroding metal becomes the anode of a purposely established dissimilar metal cell, and the metal to be protected becomes the cathode.

(a) Generally, the relative position of the metals in the galvanic series (table 7-2) determines the direction of current flow. The current from the corroding sacrificial anode is strong enough to prevent all current from leaving what were the anodes of the metal to be protected. The anodes are consumed in time and must be replaced.

(b) Metals such as magnesium and zinc, which are higher in the electromotive series, have been found to be effective sacrificial anodes when coupled with iron or steel (figure 7-9). Iron, on the other hand, is more anodic than copper and may be used to protect copper sheathings and structures.

(c) For large structures or piping systems that require large currents, cathodic protection by the galvanic method is not economical and an externally supplied or impressed current must be used.

(2) To achieve cathodic protection by the impressed current method, DC from an external source, such as storage batteries, rectifiers, or engine generators, must be used. The positive terminal of the generator is connected to iron, carbon, or graphite electrodes buried near the structure to be protected and the negative terminal of the generator source is connected directly to the structure. The external power source is used to force the current through the ground to the structure and then back to the power source through the negative terminal. This current neutralizes the normal galvanic current flowing from the structure into the ground. This form of cathodic protection is illustrated in figure 7-10.

d. Limitations. Cathodic protection is limited to structures in contact with an electrolyte, such as soil or water. In steel elevated water storage tanks, it is the inside surfaces of the riser and the submerged bowl that can be protected; protection of the outside of the tank from atmospheric corrosion must be accomplished by some other means. The application of cathodic protection for a few metal structures is discussed briefly below.

(1) Buried Pipelines. Buried pipelines are most commonly protected by cathodic means using an external power source. It is necessary, therefore, to introduce the current into the soil, through the soil to the pipeline to be protected, and return it to the source. The principal difficulty is forcing the current into the soil. Contact is made with the earth by burying high silicon cast iron, carbon rods, or scrap metal such as rails and pipe. Carbon rods in a conventional installation is shown in figure 7-10. The current required to provide complete cathodic protection varies over an extremely wide range, but in general depends on the pH of the electrolyte, temperature of the pipe, electrical resistance of the pipe coating, and area of exposed metal on or electrically connected to the structure to be protected.

(a) The major factor is the amount of current required in the area of bare or exposed metal. For example, a mile of 12-inch bare pipe may require 100 to 150 amperes of current for adequate protection. For a mile of a well-coated or wrapped 12-inch pipe-line, a fraction of an ampere may be sufficient, which indicates the importance of a good coating in reducing current requirements.

(b) For preliminary estimating, 0.002 amperes per

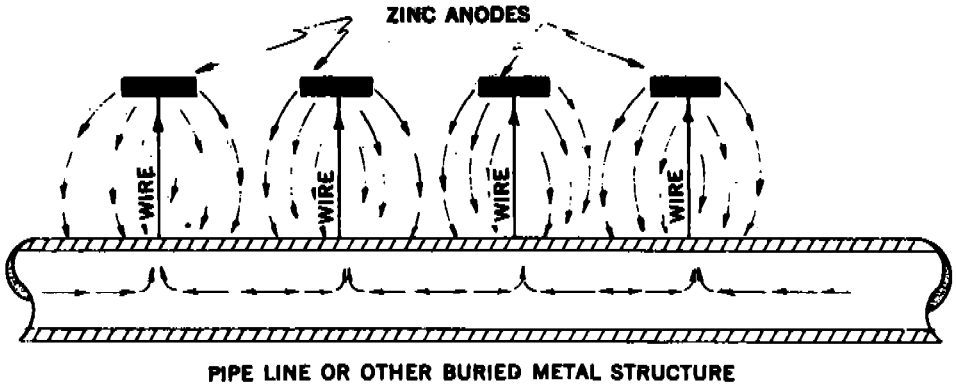


Figure 7-9. Principle of Cathodic Protection.

square foot of bare surface are used for underground iron or steel structures. After installing cathodic protection, sufficient external current is applied until the pipe-to-soil potential is raised in the negative direction of at least −0.85 volts as measured by a high resistance voltmeter using a copper sulfate reference electrode. When this potential is maintained, corrosion on pipelines will be greatly reduced or stopped. Protection of individual areas where soil resistivity is low may be more economical than total system protection.

(2) Steel Elevated Water Storage Tanks. Cathodic protection stops corrosion by flow of DC to the tank wall that is reverse to the anodic current created by corrosion. The equipment consists of a rectifier to produce a DC from the alternating supply, control rheostats, an ammeter, and anodes suspended from the tank roof into the water.

(a) The anodes, made of platinum, aluminum, or high silicon cast iron, are connected to the positive wire of a DC circuit. The negative wire is connected to the steel tank completing the circuit for current flow from the anodes to the tank surface. Current density required can range from 0.4 to 42 milliamperes per square foot of bare metal surface area. Much less current is required if the tank is protected by a coating. For even distribution of current, it is essential to locate the anodes at certain predetermined configurations, otherwise full protection for the entire submerged surface is not secured.

(b) In large-diameter water tanks, it is necessary to

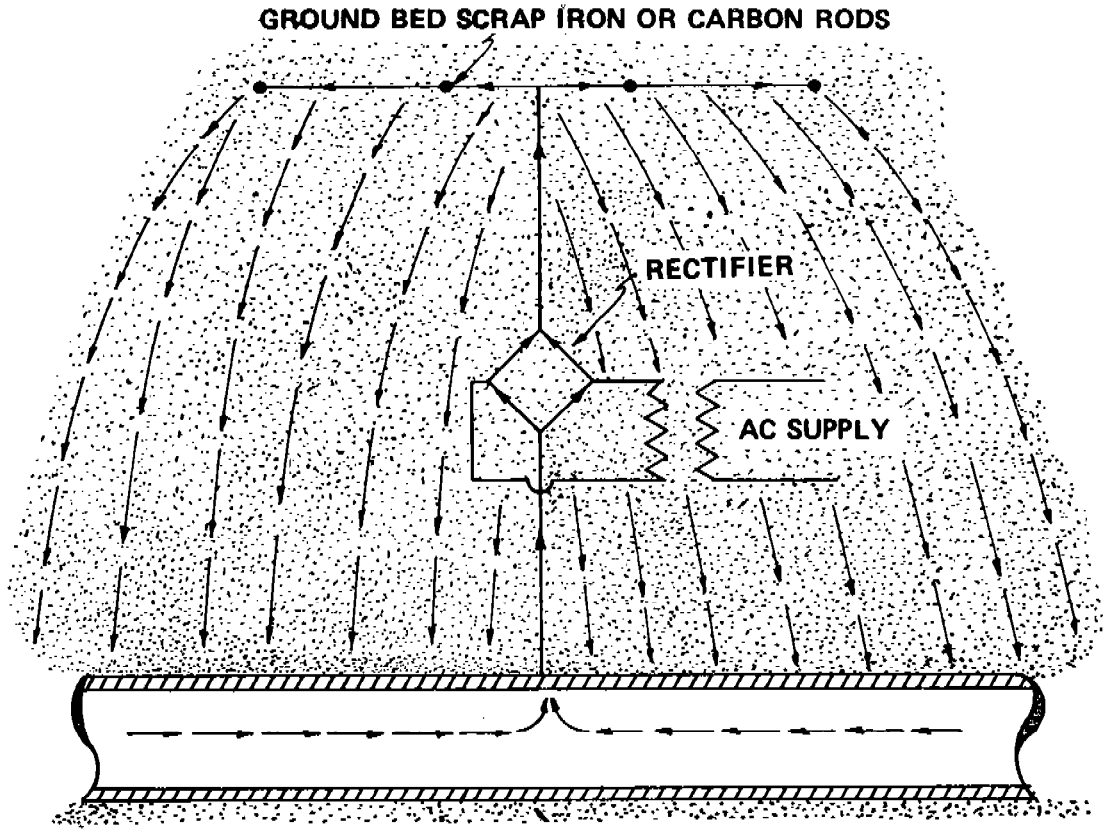


Figure 7-10. Cathodic Protection of Buried Pipeline Using External Power Source.

locate a group or circle of anodes near the tank sidewalls, with one or more circles of stub anodes around the center area to protect the tank floor. To protect the riser, a long anode or, in most cases, strings of saugage-type anodes are usually suspended within the entire length of the riser.

(c) The current required to provide complete cathodic protection varies with a number of factors, the most important of which are the pH, temperature, and velocity of the water.

(d) A great deal of emphasis is usually placed on the corrosion occurring on the intermittently submerged surface of the tank, because only submerged surfaces can be protected cathodically. This and the problem of corrosion due to moist air on the surfaces above the high waterline are controlled by a protective coating. To reduce current requirements, the entire interior of the tank is usually painted with the proper protective coating system.

(3) Hot Water Tanks. Hot water tanks are most commonly protected with sacrificial metals that are anodic to the tank structural material and, therefore, do not require an external power source. Galvanizing should not be used for this purpose because the potential of zinc can become more noble than steel at temperatures above 145 °F. Magnesium rod anodes are extensively used for small domestic hot water tanks. These anode rods are easily installed through a special outlet or through the hot water outlet by using a special fitting. The anodes come in solid rods, or in link sections for tank locations where the headroom is limited. The anodes are usually equipped with ¾-inch plugs. These special magnesium anode rods can be furnished by commercial firms. Special fittings for the hot water outlet are illustrated in figure 7-11. The anodes should be full length and should come within a few inches of the tank bottom, but should not touch it. A good contact should be made at the hot water outlet to obtain continuous current flow from the rod through the water to control corrosion by cathodic protection. Tanks containing corrosive water need to have the anode replaced more often than tanks containing less corrosive water.

Section C—Deposit Control

7-15. Types of Deposits:

a. The five basic types of deposits are:

(1) Scales resulting from precipitation of salts present in the water.

(2) Deposits or tubercles formed in the corrosion process.

(3) Iron or manganese deposits from precipitation of these metals from the water.

(4) Suspended matter, such as dirt, settling out of the water at points of low velocity.

(5) Biological growth deposits such as slimes, bacteria, etc.

b. Deposits are not desirable because they:

(1) Affect the functioning of control devices such as safety valves.

(2) Reduce the carrying capacity of pipes and channels.

(3) Reduce heat transfer in equipment such as cooling systems, heating coils, and boilers.

(4) Increase the cost of operation due to greater pumping cost, maintenance requirements, and replacement demands.

7-16. Mechanism of Scale Formation. In many systems, scale is the major type of deposit encountered. However, in the process of scale formation, other types of deposit materials may be incorporated and held as a heterogeneous deposit by the cementing action of the scale.

a. Scale is formed by the precipitation and deposition of compounds present in the water due to one or more mechanisms causing a decrease in solubility. The mechanisms

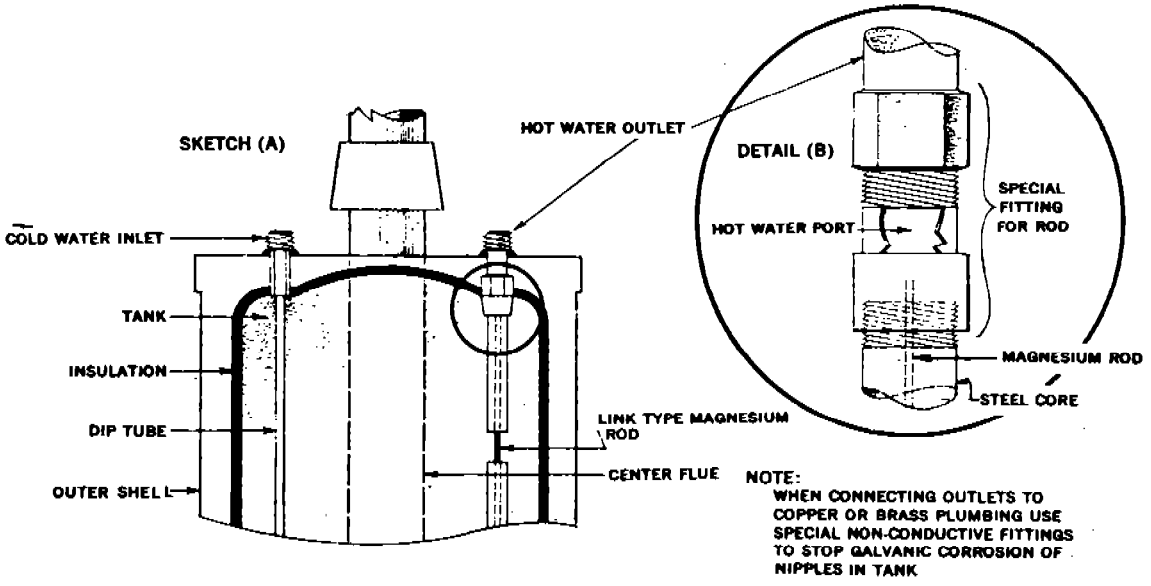


Figure 7-11. Hot Water Tank Showing Magnesium Rods and Special Fittings.

causing such scale formation are:

(1) Loss of solids-free water (for example, by evaporation) producing a more concentrated residual solution. This occurs in cooling tower systems.

(2) Lower solubility of some compounds at a higher temperature. Calcium sulfate exhibits this inverse temperature solubility characteristic.

(3) Direct action of heat converting one compound to another which is less soluble. Typical of this is the action of heat on calcium bicarbonate to form calcium carbonate. Calcium carbonate is only slightly soluble.

$$Ca(HCO_3)_2 + \text{Heat} = CaCO_3 + H_2O + CO_2$$

Calcium Bicarbonate + Heat = Calcium Carbonate + Water + Carbon Dioxide

(4) In some instances, all of these mechanisms can be progressing simultaneously.

b. Some of the more common scale-forming materials are:

(1) Calcium Carbonate. This is probably the most commonly encountered scaling material due to the presence of calcium bicarbonate in most natural waters. The equilibrium between calcium bicarbonate and calcium carbonate is governed by the presence of carbon dioxide. Any condition that tends to remove carbon dioxide shifts the equilibrium toward the formation of calcium carbonate which has a solubility of only 25 to 50 mg/l at normal ambient temperature. Such conditions include applying heat or the aeration of a well supply with a high carbon dioxide content. A million gallons of water containing 500 mg/l of calcium bicarbonate (expressed in terms of calcium carbonate) could deposit over 4,000 pounds of scale if all of the calcium bicarbonate is converted to calcium carbonate by heating.

(2) Calcium Sulfate. Calcium sulfate is a more soluble salt than calcium carbonate, but its solubility decreases as water temperature increases. It deposits directly on metallic surfaces and forms a hard scale that builds up in thickness.

(3) Magnesium and Silica. The silica content of water is usually a minor factor in scale formation except when high amounts are present or when the magnesium content and pH values are high. When waters containing magnesium and silica are subject to heat, the resulting scale is magnesium hydroxide and silica, which greatly reduces the heat-transfer efficiency of the heating elements. Important factors in scale formation by magnesium and silica are the retention period of the water, the rate of heat input, the temperature, and the pH value. In general, however, magnesium deposits begin to form if the concentration of the salt exceeds 24 mg/l (as magnesium) at a temperature of 160°F and a pH of 8.8. At lower pH values, magnesium hydroxide scale formation is reduced. However, silica becomes less soluble at lower pH values.

(4) Calcium Phosphate. This type of scale is sometimes encountered in those systems using a polyphosphate as a corrosion inhibitor and calcium carbonate is the scale inhibitor. The polyphosphate, under continued heating, reverts slowly to an orthophosphate that reacts with calcium to form insoluble calcium phosphate.

(5) Iron. Another type of deposit sometimes considered as scale is produced by deep-well water supplies containing iron. Well water containing iron before exposure to air is usually colorless. On exposure to air, however, dissolved iron is oxidized to the ferric form and, upon hydrolysis, forms a yellow to red-brown precipitate of ferric hydroxide. Iron concentrations exceeding 0.5 to 1.0 mg/l result in distribution system deposits in water meters, spray nozzles, and other equipment. This may be particularly troublesome on heat transfer surfaces.

7-17. Scale Formation Prediction:

a. General Information:

(1) In the absence of inhibitors, scale formation can be predicted on the basis of the solubility product principle. This principle in essence states that a dissolved salt precipitates if the concentration of the cation multiplied by the concentration of the anion exceeds a constant value. This can be stated in equation form as follows:

$$[Ca^{++}] \times [CO_3^{=}] = K_{sp}$$

where:

$[Ca^{++}]$ is the concentration of calcium.

$[CO_3^{=}]$ is the concentration of carbonate.

K_{sp} is a constant called the solubility product.

In actual practice, the concentration of totally dissolved solids and temperature of the water affect the value of K_{sp}. In the case of calcium carbonate, which is probably the most commonly encountered scale-forming salt, the computation is further complicated by the equilibrium that exists between the carbonate ion ($CO_3^{=}$), the bicarbonate ion (HCO_3^{-}), and carbon dioxide (CO_2) in the water. This has been simplified by the computation of the Langelier or the Ryznar index from the water analysis. Other similar calculation methods include Dye Momentary Excess Index and McCauley Driving Force Index.

(2) Under properly controlled conditions, scale formation can be limited to maintain only a thin film necessary to minimize corrosive action.

(3) The marble test has also been used as an alternate, direct-contact method of determining the excess or deficiency of calcium carbonate in the water.

(4) The potential for scale formation by other salts, such as calcium sulfate, magnesium hydroxide, and calcium phosphate, is generally determined by less sophisticated, solubility product-type computations.

b. Langelier Index. The Langelier index is the numerical difference between the actual pH of the water and the pH water must have to be in equilibrium with calcium carbonate. To calculate the Langelier index, certain properties of the water under consideration must be known. These are totally dissolved solids, total alkalinity, calcium hardness, hydrogen-ion concentration (pH), and temperature. From these analytical data, the saturation pH(pH_s) can be determined by the Langelier formula using the curves shown in figure 7-12. If the actual pH of the water is greater than

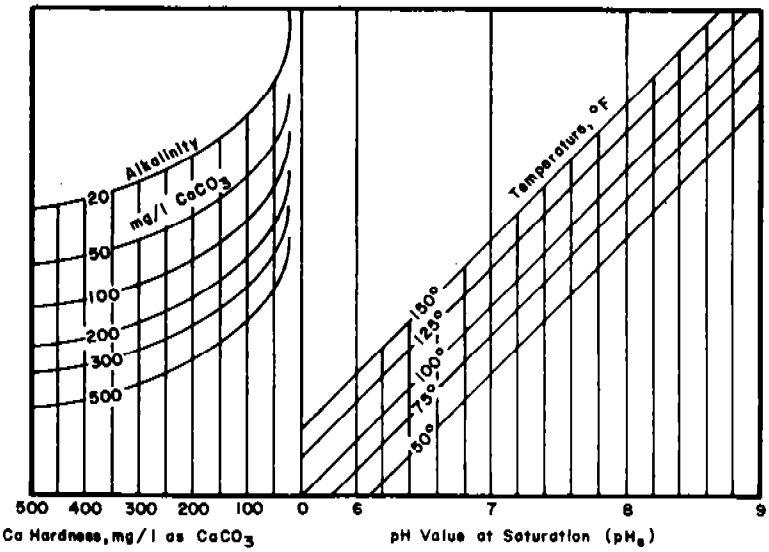


Figure 7-12. Determination of pH_s From Hardness, Alkalinity, and Temperature.

the saturated pH_s, the water is supersaturated; if not, the water is undersaturated (pH − pH_s = index). A zero index indicates the water is at its maximum stability. A positive index indicates scale forming water at the selected temperature. The magnitude of the index has little meaning unless compared with the amount of calcium (as Ca) present. For example, a positive index of 1.0 does not mean that heavy scale will form from a water containing little scale-forming material. Conversely, an index of 0.3 in a water heavily loaded with calcium and magnesium would present a real scale problem. What the index really discloses is the balance point at a given temperature.

(1) Some sources report that the shortcomings of the Langelier index can be avoided by use of the Ryznar index which is computed as follows:

$$2pH_s - pH = \text{Ryznar index}$$

If the Ryznar index is above a value of 7.0, the water is considered to be corrosive. If the index is below a value of 6.0, the water is considered to be scale forming. Comparing the Langelier and Ryznar indices, differences can be shown in scale-forming tendencies for high pH waters with medium calcium and low alkalinity concentrations. The following analysis is used:

pH	9.5
Total dissolved solids	400 mg/l
Temperature, ° F	125
Calcium (as Ca)	50 mg/l
Alkalinity (as $CaCO_3$)	50 mg/l

Computed pH_s = 8.0
Langelier index = 9.5 − 8.0 = +1.5
(Scale forming)
Ryznar index = 16.0 − 9.5 = 6.5
(Neither scale forming nor corrosive)

(2) Some important factors in determining the scaling indices are given below:

(a) The importance of an accurate pH evaluation is evident. A slight error can give a false indication of scale-forming or corrosive tendencies. To use the curves and interpolate between the figures, pH must be carefully determined soon after the sample is taken.

(b) The precipitation or scale-forming tendency depends on the excess quantity of calcium in the water. For example, for a Langelier index of +0.1, the tendency to form scale is three times as great at pH 8.2 (6 mg/l excess calcium) as at pH 9.2 (2 mg/l excess calcium).

(c) The net effect of temperature changes on the saturation index can be either positive or negative. For example, when water of low alkalinity (low buffering capacity) and high pH is heated, the Langelier index can decrease; that is, the actual pH decreases to a value lower than the saturation pH. On the other hand, when water of higher alkalinity and lower pH is warmed, the index increases. For example, assume a water supply with the following properties:

Total dissolved solids, 300 mg/l
Total alkalinity as $CaCO_3$, 200 mg/l
Calcium hardness as Ca, 100 mg/l
pH, 7.4

1. From the curves in figure 7-12, the saturation pH (pH_s) for temperatures of 50 °F, 100 °F, and 150 °F are found to be 7.9, 7.4, and 6.9 respectively.

2. The Langelier indices are, therefore,

At 50 °F, index = 7.4 − 7.9 = −0.5
At 100 °F, index = 7.4 − 7.4 = 0
At 150 °F, index = 7.4 − 6.9 = +0.5

3. Since the index is negative at 50 °F, the water is undersaturated at this temperature and therefore corrosive. When water reaches its maximum stability at 100 °F, the index is positive, which indicates scale-forming tendencies. It is apparent, therefore, that waters in general can be stabilized by pH adjustment or by controlling their mineral

content for a very narrow temperature range only. Unfortunately, water use cannot be limited to a given temperature range; the use of hot as well as cold water is almost as common as that of water at normal temperatures.

c. Marble Test. There are several variants of the marble test, the principal one consisting of a few simple steps. In the first step, either the alkalinity or the pH value of a portion of water sample is determined. In the second step, chemically pure, washed, precipitated calcium carbonate is added in excess to another portion of the same sample (a teaspoonful to 150 ml of the water). This is stirred a few minutes, allowed to settle, and then filtered. The alkalinity or pH value of the filtered portion is determined as in the first step. Comparing the two portions, the following possibilities and conclusions are noted:

(1) If the alkalinity or the pH value of the second portion is greater than the first, the water is not saturated with calcium carbonate and may be corrosive.

(2) If the alkalinity or the pH values in both portions are equal, the water is in equilibrium with respect to calcium carbonate.

(3) If the alkalinity or the pH value of the second portion is less than the first, the water is supersaturated with calcium carbonate and may deposit scale.

7-18. Nonscale Type Deposits. Nonscale deposits include suspended matter settling in the system, corrosion deposits, and biological deposits.

a. Suspended Matter. Deposits of suspended matter are controlled by removing turbidity. Main flushing and cleaning (paragraph 8-3d(1)(d)) are used to remove accumulated deposits. In nonpotable systems such as cooling towers, certain dispersants can sometimes be used to inhibit deposition.

b. Corrosion Deposits. When metallic materials corrode, the products of corrosion can form deposits on pipe walls. Control can be obtained by reducing the iron and manganese levels in the water by treatment, reducing water corrosiveness, and by main cleaning. Inhibitors such as polyphosphates can be used to keep corrosion products from forming deposits.

c. Organic Deposits. Main cleaning, providing an environment unfavorable to biological growth, and chemical treatment are used to control organic deposits.

7-19. External Treatment. External water treatment for scale control involves lime softening (in which the soluble salts of calcium and magnesium are precipitated out in the form of sludge) or cation exchange (in which calcium and magnesium are exchanged for sodium to avoid formation of insoluble compounds). The various methods for softening water are discussed in chapter 6, section E.

7-20. Hydrogen-ion Concentration (pH) Adjustment. The solubility of scale-forming salts is influenced by pH. The pH can be adjusted upward with lime, or downward with acid to render the water less subject to scale formation. Care must be taken that the water is not made corrosive (figures 7-3 and 7-13).

7-21. Scale Control:

a. Threshold Treatment. Carbonate scale can be prevented by adding very low concentrations of polyphosphates to the water. There is no true chemical reaction, but rather an absorption on the potential scaling substance altering crystal structure. The phosphate molecules are strongly adsorbed on calcium carbonate surfaces, as well as on those of many metals and their salts and oxides. In this adsorbed form, the mineral salts cannot be deposited as scale, but stay in solution (figure 7-14). The water is stabilized without actual removal of the scale forming constituents.

(1) The maximum concentration of calcium bicarbonate (the source of potential calcium carbonate scale) that can be stabilized by threshold treatment varies with the temperature and alkaline concentrations to which the water is subjected. Scale formation in waters with a hardness as high as 400 mg/l can be controlled by adding from 1 to 5 mg/l of a polyphosphate. Generally, with a polyphosphate dosage of 2 mg/l, up to 300 mg/l of calcium bicarbonate can be maintained without depositing at 180° F. For normal temperatures in the range of 50° F to 70° F, water with a much higher calcium bicarbonate content can be stabilized with 2 mg/l of this phosphate.

(2) When polyphosphates are used for scale control, dosage must be carefully controlled. With increasing temperatures and higher concentrations of calcium carbonate, the effective dosage is limited to a narrow range. Overdosing may result in renewed scale formation. This is due to the reversion of the polyphosphate to orthophosphate and the precipitation of calcium phosphate. The loss of polyphosphate by reversion removes its inhibiting effect on calcium carbonate scale formation.

(3) Polyphosphates are also useful in complexing iron up to an iron concentration of about 2 mg/l. A weight ratio of 5 mg/l of polyphosphates to 1 mg/l of iron or manganese is generally required to prevent depositing metallic oxides. When treating iron-bearing waters, the phosphate should be added before water is aerated or chlorinated so that mixing takes place before oxidation of iron or manganese can occur, if satisfactory stabilization is to be achieved. For suggested threshold treatment for scale control, see table 7-5.

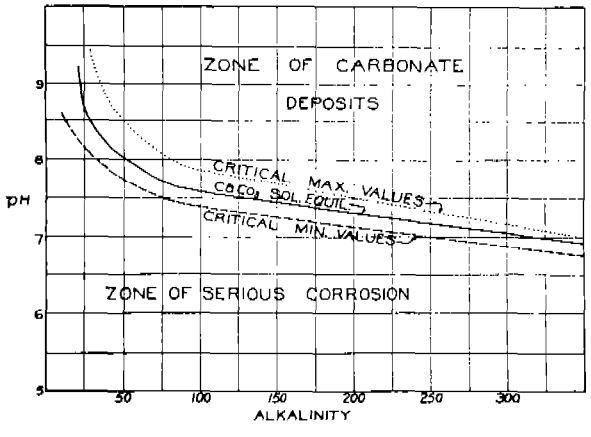


Figure 7-13. Relationship of pH Versus Alkalinity.

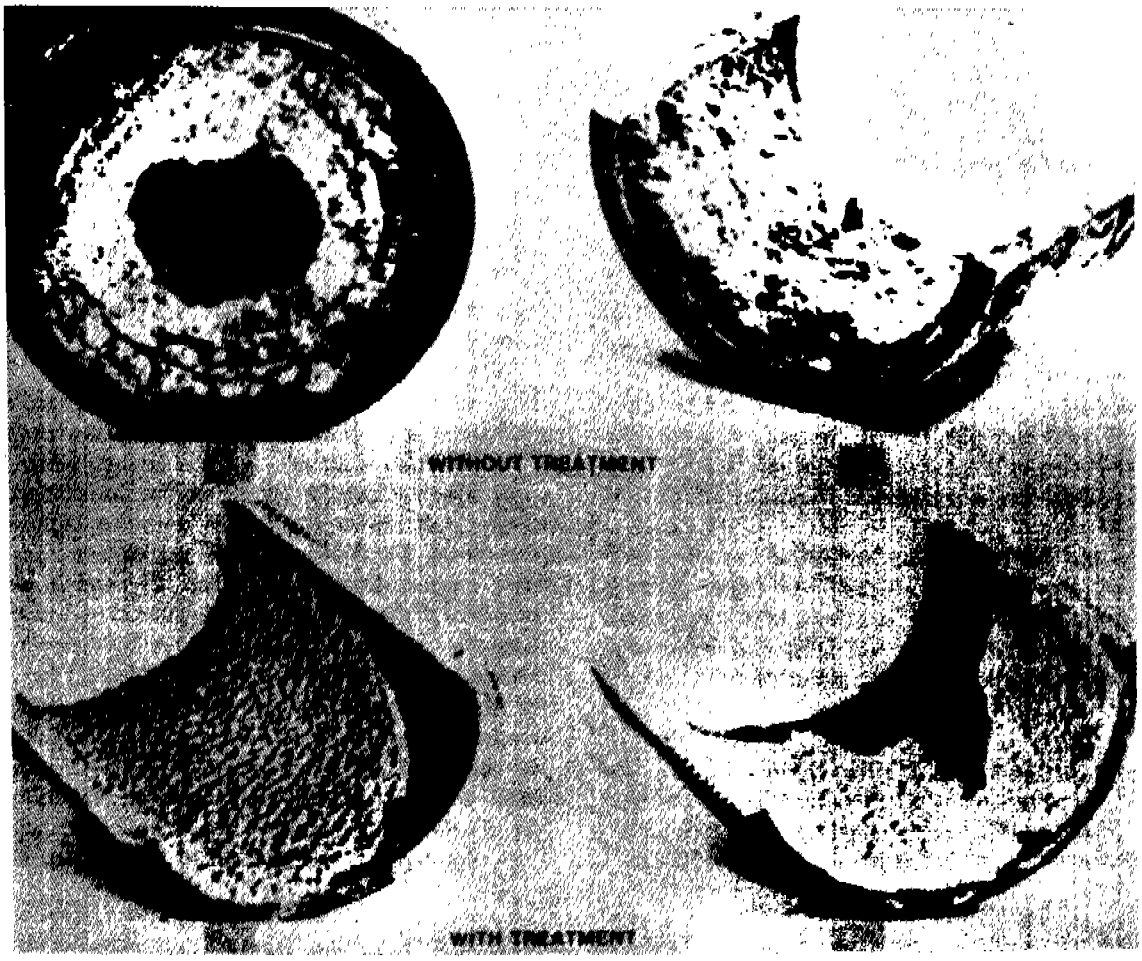


Figure 7-14. Effect of Threshold Treatment.

b. Thermal Control. Thermal (heat) control may be used to advantage where scale formation is difficult to prevent, as in high sulfate waters. Because scale formation increases with temperature, operating temperatures should be kept as low as practical. For instance, the critical water temperature in domestic hot water heaters is about 140° F. Above this temperature, chemical reactions speed up rapidly with a resultant accelerated deposition of scale and rate of corrosion.

7-22. Scale Removal. Scale deposits can be removed by mechanically cleaning if their adherence properties are not great. Reversing flow may remove loose scale. Calcium sulfate scale can be cracked off heating coils by a rapid change in temperature. This calcium sulfate scale can be removed by treatment with one of the orthophosphates. Carbonate scale can be removed by applying commercial grade inhibited hydrochloric (muriatic) acid. Inhibitors are polar organic compounds that permit acid reactions with the scale while reducing the acid action with metals.

Section D—System Surveillance and Testing

7-23. Development of Control Methods:

a. Organized Studies. Continuing studies of corrosion and scale problems are made by government agencies, by industry, and by such technical groups as the National Association of Corrosion Engineers (NACE), the Electrochemical Society, and the American Society for Testing Materials (ASTM).

b. Water Analysis. At each military installation, a complete inorganic chemical analysis should be made each year if the water is from surface sources or once every 3 years if the water is from ground sources. These analyses form the basis of recommendations to the installations for initiating specific water treatment control measures.

c. Water-Formed Deposits Analyses. In initiating corrosion and scale control programs, it is often necessary that the character of the corrosion or scale products be known. This is particularly true when it is desired to initiate specific treatment or to clean and remove built-up products by using chemical cleaners and inhibitors. To help installations and commands in solving corrosion and scale problems, laboratory services for analyzing water-formed deposits for chemical content are available from laboratories specified by higher technical authority. The following instructions must be followed when collecting and submitting samples to these laboratories for analyses.

(1) Select a sample from an area representative of the trouble experienced; usually an area of failure or heaviest deposition of scale or corrosion products. When the affected area is not available for spot sampling, select a sample from an adjacent area that is directly related to the area of failure or the area of principle concern and that will also provide an adequate sample.

(2) Deposits should be carefully removed and maintained in their original state as much as possible. Contamination with any outside material should be avoided. A quantity amounting to 1 to 3 ounces is usually sufficient. It is desirable to submit a small section of the affected area of pipe containing the deposit.

(3) Containers for shipping samples should be wide-mouth glass bottles or plastic vials. Metal containers can be used if the samples are dry when collected.

(4) A description of the sample should be attached to the container.

d. Command and Installation Activities. Installations in different locations encounter corrosion problems of varying kinds and scope. Technical problems of a complex nature should be referred to command level; command engineers are available for technical assistance on request by an installation.

7-24. Laboratory and Field Testing. Many corrosion and scale problems appear only in the course of operating a utility or other system. Causes must be accurately determined before effective remedial action can be taken.

a. Laboratory Test. Of the two general classes of corrosion and scale tests, laboratory and field, the field test is more accurate and dependable because actual service conditions are involved. It is essential that laboratory tests simulate these service conditions as closely as possible and that no new factors be added. For example, continuous service should be used in a laboratory test to imitate the long-term effects of corrosion and scale on equipment in normal service. For details of specific laboratory tests for corrosion and scale, consult higher technical authority.

b. Field Test. Field tests for corrosion and scale may be made as follows:

(1) Testers:

(a) Nipples. Test or observation stations should be established at each installation. Stations should be located in the hot water heating plant of a dining facility, near the point where treatment chemicals are added to the water supply, and about the middle and the far end of the installation distribution system. At least one set of cold-water nipples should be installed. If water is treated for corrosion control, a second set should be installed after chemical treatment. The layout for test nipples used to check on corrosion is shown in figure 7-15. Pipe diameters are the same as that of the discharge pipe from the hot water tank, so velocity of flow remains the same. Test nipples should be the same as those existing, or should be installed with special insulated connectors. Installations that have nonferrous piping need not install test sections.

(b) Strips. Test strips may be installed at selected

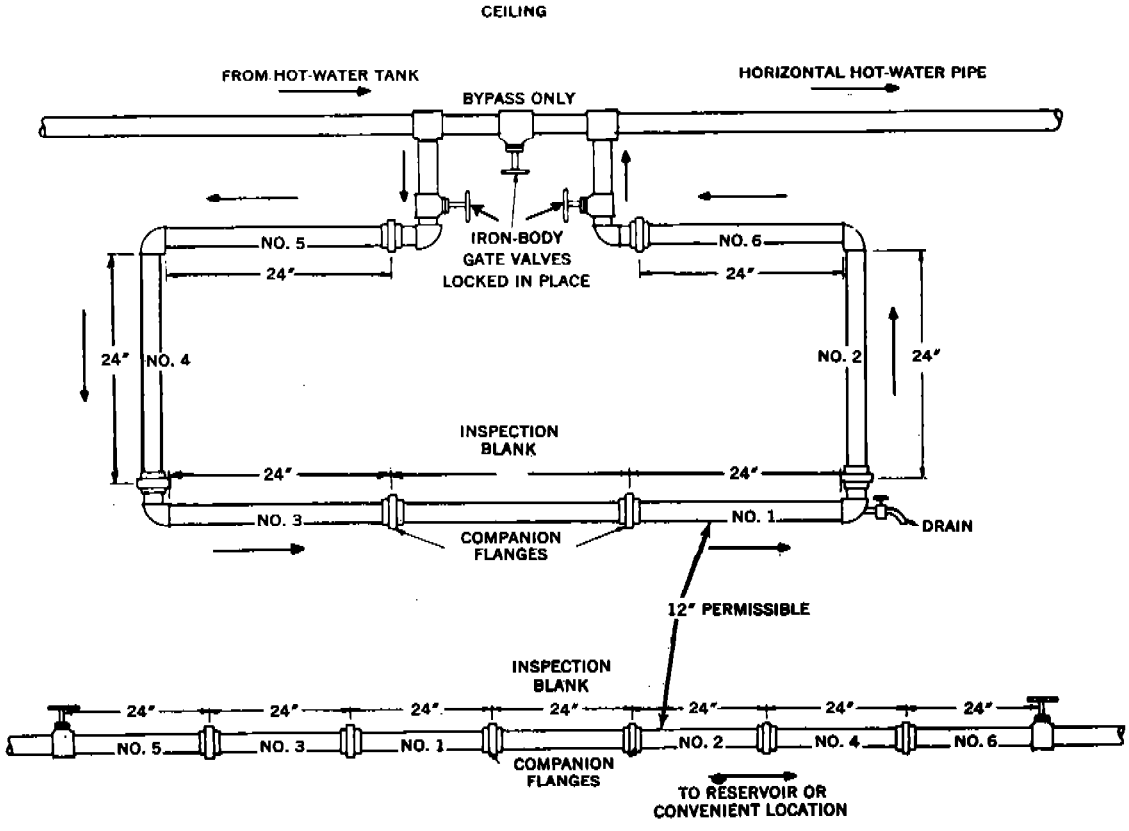


Figure 7-15. Layout of Test-Pipe Loop To Observe Treatment of Corrosive Water.

locations if local conditions warrant. These strips allow the effect of different corrosion inhibitor treatments to be observed directly.

(c) Evaluation. The degree of scale control is shown by the thickness of scale in the test nipple. Corrosion and scale deposits are cleaned off the strips and nipples and the depth of pitting is measured to determine the corrosiveness of water. If a number of test nipples of the same material is installed in a test loop when treatment is started, it is possible to obtain progressive data on the results. For example, the depth of pits may decrease and the pits may widen as treatment progresses. Each subsequent test nipple removed may show this.

(2) Steel Coil Test. Steel coils can also be used to test the effectiveness of corrosion and scale treatments.

(3) Steel Distribution System Test Points. At installations with steel pipe distribution systems, a bypass may be built at any convenient point. A section of the bypass should be removed periodically and examined to determine whether any change in corrosion control is necessary.

(4) Samples of Test Specimens. Samples of test specimens from building plumbing and distribution systems should be retained at the installation as a permanent record of scale and corrosion conditions.

7-25. Comprehensive Testing and System Studies: Corrosion and scale surveys conducted by competent engineers are warranted at installations where material wastage is critical or interruptions in service seriously affect the base mission. Surveys by consultant engineers must be authorized and approved according to current directives from a higher command. Data necessary for a survey usually include such factors as:

a. Operations or processes conducted at the installation.
b. Corrosive substances usually present.
c. Operating pressures and temperatures.
d. The degree of aeration and agitation of media.
e. Galvanic factors.
f. Types of metal in use.
g. Details of failures experienced, such as general corrosion, pitting, vapor attack, and scale formation.

7-26. Reporting Data. Regular inspections and reports to higher authority are essential to ensure effective scale and corrosion control.

a. Inspection Requirements:

(1) Inspect heaters and tanks every 3 months or more frequently if conditions are severe.

(2) Make sure that water temperatures are under 140° F, except in mess hall hot water heaters.

(3) Examine test strips, nipples, steel coils, and bypasses each 6-month period or at intervals recommended by higher technical authority.

b. Reporting Requirements:

(1) Notify higher technical authority of effectiveness of scale and corrosion treatment.

(2) Submit laboratory and other reports of water analysis on request.

(3) Report any abnormal control problems.

(4) Enter amount of daily chemical feed (in pounds), results of analytical control tests, and results of observation of inspections on the daily operating log according to paragraph 1-10.

7-27. Safe Drinking Water Act Corrosivity Monitoring:

a. All community water supply systems are required to determine the corrosive characteristics of water entering the distribution system. Samples are to be taken at each plant at a representative entry point into the distribution system. For ground water sources, one sample per plant is required. Two samples within 1 year are to be taken from each treatment plant, using a surface water source. Determination of the corrosivity characteristics of the water must include measurement of pH, calcium hardness, alkalinity, temperature, total dissolved solids (total filterable residue) and calculation of the Langelier Index, or Aggressive Index (if approved by the state). Testing and reporting procedures are identified in appropriate service regulations listed in paragraph 1-19.

b. Community water supply systems also have to identify whether the following construction materials are present in their distribution system and report to the state:

(1) Lead from piping, solder, caulking, interior lining of distribution mains, alloys, and home plumbing.

(2) Copper from piping and alloys, service lines, and home plumbing.

(3) Galvanized piping, service lines, and home plumbing.

(4) Ferrous piping materials such as cast iron and steel.

(5) Asbestos cement pipe.

Chapter 8

DISTRIBUTION AND STORAGE

Section A—Distribution System

8-1. General Information:

a. System Elements. The elements of a system include distribution mains, arterial mains, storage reservoirs, and system accessories (including booster stations, valves, hydrants, main-line meters, service connections and backflow preventers).

(1) Distribution mains are the pipelines that make up the distribution system. Their function is to carry water from the water source or treatment works to users.

(2) Arterial mains are distribution mains of large size. They are interconnected with smaller distribution mains to form a complete gridiron system.

(3) Storage reservoirs are structures to store water. They may serve to equalize the supply or pressure in the distribution system.

(4) System accessories include:

(a) Booster stations that pump from a storage or a relatively low pressure main to the distribution system or may serve a portion of the system that is at a higher elevation.

(b) Valves that serve to control the flow of water in the distribution system by isolating areas for repair or regulating system flow or pressure.

(c) Hydrants that are designed to allow water from the distribution system to be used for fire-fighting purposes.

(d) Main-line meters (discussed in chapter 5) that serve to record the flow of water in a part of the distribution system.

(e) Service connections that connect either an individual building or other system plumbing to the distribution system mains.

(f) Backflow preventers that protect the water source from contamination.

b. System Layout and Size:

(1) When distribution systems are carefully planned, the pipes are usually laid out in a grid or belt system. A network of large pipes divides the community or base into areas of several blocks each. The streets within each such area are served by smaller pipes connected to the larger ones. If possible, the network is planned so the whole pipe system consists of loops, and no pipes come to a dead end. In this way, water can flow to any point in the system from two or more directions, hence the water supply need not be cut off for maintenance work or a break in a pipe.

(2) Older water systems frequently grew without planning and developed into a tree system. This consists of a single main that decreases in size as it leaves the source and progresses through the area originally served. Smaller pipelines branch off of the main and may divide again, much like the trunk and branches of a tree. A tree system is not desirable because the size of the old main limits the expansion of the system needed to meet increasing demands. Also there are many dead ends in the system where water remains for long periods, causing tastes and odors in nearby service lines.

c. Record Keeping. As noted in paragraph 1-11, accurate record keeping of the location, type, and size of all mains, pipes, valves, meters, hydrants, backflow preventers, and other accessories of the distribution system is essential. The operator must be thoroughly familiar with the water supply system and be able to locate any component on a moment's notice. Records must be kept up-to-date so that in an emergency the particular trouble spot can be readily located allowing prompt and proper action to be taken. The operator should never keep a mental map of the system, but should put the information on paper. Records and maps must be evaluated periodically to make sure that they are a useful part of the system. A typical general system map is shown in figure 8-1. Detailed maps or drawings of sections or elements of the overall system should be maintained.

d. Miscellaneous Systems:

(1) Trailer Park Systems:

(a) General Information. Underground piping for trailer park water systems must be installed, operated, and maintained in the same way as for water distribution systems as outlined in this regulation. Potable water only is supplied at each trailer site. An approved backflow preventer will be installed at each trailer connection.

(b) Service Connections. Each trailer space must be provided an individual water connection that has a riser pipe that terminates above the ground surface so flexible tubing may connect the trailer with the riser pipe.

(2) Ship-to-Shore Connections. Facilities used in ship-to-shore water connections are hoses, potable water outlets, and sometimes portable meters. Hoses are subject to contamination by dragging along decks, dropping into the river or sea, or improper handling in storage. Potable water outlets may be contaminated by splash, spray, dust, or dirt. The danger of contamination should be recognized and facilities and equipment used for connections must be properly stored, protected, or disinfected when not in use. Interconnections between potable and nonpotable supplies must not occur.

(a) Connection to Ship Potable Water System:

1. Shore station personnel should use the following procedures to make ship-to-shore potable water connections:

a. Remove cap and disinfect potable water outlet just before use as follows:

(1) Flush outlet 15 to 30 seconds.

(2) If outlet drains, swab all interior surfaces back to control valve with solution containing not less than 100 mg/l chlorine.

(3) If outlet does not drain, calculate pipe volume back to control valve and fill with a solution containing not less than 50 mg/l chlorine.

(4) Let stand not less than 2 minutes and

then flush 15 to 30 seconds.

b. Deliver clean disinfecting hose at dockside outlet just before connection is made.

c. Remove hose caps or plugs, connect hose, and then flush for 1 minute.

d. Make ship-to-shore connections.

e. After use, thoroughly flush potable water outlet cap and attach.

f. Disinfect hose by filling with a solution containing not less than 50 mg/l of chlorine, let stand not less than 2 minutes, and then flush for 1 minute.

g. Hang on rack in a clean place for draining and air drying.

h. Cap and plug hoses and roll or hang indoors in a clean place.

i. Keep portable meters in a sanitary condition at all times.

2. Ship's hoses or personnel should not be used for supplying the vessel with potable water except as may be necessary in those emergency conditions involving safety of a ship from fire or explosion.

(b) Connection to Ship Fire and Flushing System:

1. Connections between potable water supply systems ashore and nonpotable systems aboard ship are prohibited where the ship system is not protected at each individual potable hose connection usable for this purpose, including each outlet of manifolds, by an effective backflow-prevention device. An inadvertant operation of the ship's pumps could force polluted water into the drinking water system ashore, causing contamination and endangering the health of personnel ashore and personnel of ships using the system. Where a municipal water supply system is involved, such connections may constitute violation of laws or local regulations.

2. As a general rule, ships operate their installed salt water pumping systems to provide fire and flushing water.

(3) Industrial Operation:

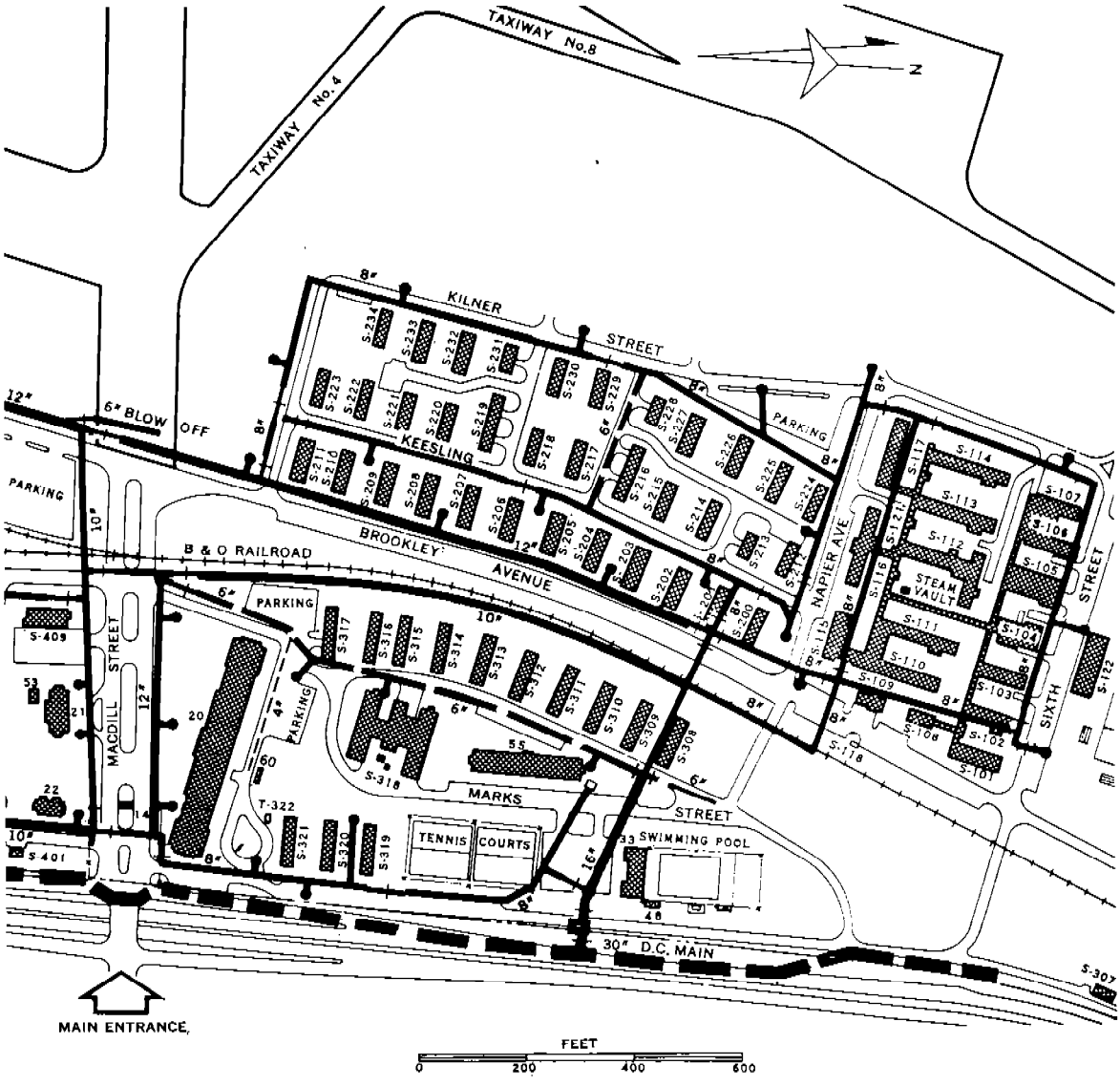


Figure 8-1. Typical Distribution System Layout.

(a) Operating personnel should become familiar with service connections, in-plant water systems, and water requirements of installation industrial operations.

(b) Industrial water systems should be inspected to make sure that no interconnection of potable and nonpotable water systems can occur.

8-2. System Dependability. A dependable water distribution system will reliably provide high quality potable water in sufficient quantity and at adequate pressure for domestic and fire protection purposes. Factors involved include maintaining water quality, providing fire flow, eliminating cross-connections, and maintaining pressure.

a. Maintaining Water Quality. Water quality requirements are identified in chapter 2.

(1) Sampling and Analysis. One of the most important phases of proper distribution system operation is to make sure that water leaving the treatment plant in an acceptable and aesthetic condition remains so until it is delivered to the ultimate user. Sampling stations should be established at several points in the distribution system (the number depending on the size and extent of the system) and periodic samples of the water collected and tested to form a continuous monitoring system. The analyses and procedures discussed in chapter 6, section L, should be used as guidelines in assessing quality.

(2) Sabotage. Contamination of military distribution systems can be intentional. Frequent quality samples linked with adequate fencing, lighting, and surveillance of the system, and prompt reporting to the proper authorities of any unusual observations or conditions are the best defense against this type of activity.

b. Fire Flow. Providing of the required flows under any condition is of vital importance. At depots, the value and contents of warehouses usually far exceeds the value of the buildings. In some cases, a loss of strategic materials can seriously hamper military operations. At many installations, the major construction cost of a water supply system results from the necessity of fire protection, rather than domestic or industrial supply. Without proper operation and maintenance of the system, the entire effectiveness for fire protection is nullified.

c. Cross-Connections. Cross-connections are the physical links through which it is possible for contaminated materials to enter a potable water supply. The contaminant enters the potable water system when the pressure of the polluted source exceeds the pressure of the potable source. The flow of the contaminated water to the potable system may be called backsiphonage or backflow.

(1) Pumping Hazards. Large quantities of contaminated water can enter the distribution system if pressure in the distribution system is lowered by pump malfunction. High fire flow or ship-to-shore connections can cause a negative pressure in portions of the distribution system. The reduced pressure allows contaminants to enter the system from sources that would not be a hazard under normal system pressure.

(2) Backsiphonage. Backsiphonage most commonly occurs where a pipe, hose, or tubing delivers water under pressure below the surface of a tank or other vessel. If negative pressures occur in the distribution system or service connection, water is siphoned back into the potable water system. The situation can be corrected by providing an air gap between the pipe and tank surface. If physical separation by an air gap is not possible, a backsiphonage prevention device (chapter 9, section E) should be installed.

(3) Backflow Prevention:

(a) The flow of nonpotable water or other liquid into a potable water distribution system is known as backflow. Backflow can occur when negative or differential pressures result from line shut off due to main breaks and repairs; high fire flows, especially with pumpers; inadequately sized or tuberculated pipe; pressure surges and water hammer; and excessive water consumption. Each situation may exist in the system. Main disinfection, quality sampling, and system surveillance are steps taken to detect and prevent adverse effects of backflow.

(b) The backflow-prevention methods are described in chapter 9, section E. Approval of higher technical authority is required before using these methods. The higher technical authority must get local health agency concurrence when necessary.

d. Pressure Maintenance. The goal of many operation and maintenance functions described later in this chapter is the maintenance of system pressure under normal and emergency conditions. As has been discussed, inadequate pressure can cause contamination in the distribution system.

8-3. System Operation. The operation of a distribution system consists essentially of setting and operating valves, keeping records of waterflows and levels, and correctly balancing the system flow to maintain desired pressure in all parts of the system. The properly designed and operated system delivers sufficient water to meet the normal maximum demand at all points of use. The system must also deliver sufficient water to provide fire flow at any point.

a. Operational Activities. Particular actions that apply to distribution systems include the following:

(1) Distribution system capacity and reliability must be periodically evaluated.

(a) The distribution system and supply lines must be able to supply critical areas with enough water to fight fires, despite power or main failures at any point. Plans for providing temporary alternative supply facilities at critical points should be formulated. If construction changes are needed, approval should be requested through normal channels.

(b) Additional valves may be required in the system to localize areas that would be affected by failure of a single main. Additional valves may also keep loss of water due to such failures to a minimum.

(2) Distribution system operational procedures include the following:

(a) Adequate stocks of essential repair parts must be maintained. To keep repair stocks at a minimum, carry standard size valves and sleeves, and provide reducers to

adapt standard size fittings to all pipe sizes in the system.

(b) Investigate the availability of manpower, materials, and equipment that may be borrowed for emergencies from nearby municipal and civil defense officials.

(c) Inspect all valves, hydrants, pressure regulators, and other equipment and consider the need for increased inspection frequency at critical points. Immediate repairs should be made where needed. Valves and hydrants are essential parts of the system and must be tested periodically and kept in good working order at all times.

(d) Maintain complete and accurate maps and records. Make sure that copies of maps and records used by operating and maintenance personnel are not available to unauthorized persons.

(e) Conduct inspections for improper connections that may be health hazards, including cross-connections between the water system and any unsafe or unapproved systems. Eliminate direct connections with the sewage system and direct connections with dishwashing equipment, hospital sterilizers, flush-valve-operated toilets and siphon-jet urinals.

(f) Leak and flow surveys should be conducted at periodic intervals in order to determine system efficiency. Data should be sufficiently complete to determine changes, additions, and improvements required for emergency conditions.

b. Distribution System Organization:

(1) Personnel. Personnel are assigned responsibility for day-to-day operations of the distribution system. Special relationships are needed to effectively handle emergency procedures as discussed in this manual.

(2) Training. Water supply presonnel must be given in-service training relative to their particular duties and the relationship of those duties for operating the system as a whole. Training must be according to state or applicable American Water Works Association (AWWA) training and certification requirements. Normal service pressures must be maintained during this training and connections may not be made to nonpotable sources. The distribution system operation training includes:

(a) Study of the general water utility to illustrate the broader features of supply, treatment, storage, and distribution.

(b) Study of all strategic valve locations and methods of controlling valves to isolate any area with the least sacrifice to fire protection.

(c) Actual field practice in isolating assumed minor breaks and broken hydrants and in using interconnections with other potable water systems or other alternate sources of supply.

(d) Drills, in cooperation with the fire department, in making connections to emergency supply sources.

(e) Close study and discussion to familiarize all personnel with the procedures and requirements of this manual.

(3) Standard Operating Procedure. A standard operating procedure (SOP) for emergencies must be established. The SOP is given to all key personnel and is posted in pumping stations, distribution system shops, fire stations, installation engineer's office, telephone exchange, and usually in the office of the installation commander. It must include:

(a) Names of water supply personnel and alternates to be notified or alerted.

(b) Method of notification during day and night.

(c) Duty or reporting station for each employee.

(d) Responsibility of each employee.

(e) Action to be taken by each employee in case of an emergency, such as a fire, main break, or power outage.

(4) Emergency Procedures. Quick decisive action needs to be taken in the event of a fire, main break, or power outage.

(a) Fire. Personnel must take specific actions, such as putting additional equipment in service, opening valves, or raising pressures as needed. A water supply employee familiar with the system should provide valve keys, valve and hydrant location maps and records, and valve opening assistance to firefighting personnel.

(b) Main Break. Personnel need to be assigned to isolate the main break, repair the break, and disinfect the distribution line or lines affected. A major line break may require special procedures to provide alternate water supplies to the affected areas. Emergency water supplies that can be used for fire protection include:

1. Wells not usually in operation.

2. Interconnections with municipal or other potable water systems.

3. Emergency reservoirs, swimming pools, ponds, rivers, sea water, and other nonpotable sources from which a fire pumper can draw water directly. Intake pipes with pumper connections should be installed in the emergency sources so they can be used quickly in case of fire.

4. Separate supply and distribution systems from a nonpotable source. Cross-connections between these systems and potable water systems are prohibited.

5. Pumping potable water from a river or similar body of water into the potable water system. This method is prohibited except in extreme emergencies. If this method is used, the potable system must be taken out of service and all users of water notified of the emergency condition. After such use, the system must be disinfected before placed back into normal service. The base surgeon must be notified in advance when possible.

(c) Power Outage. Many of the above considerations apply when service is interrupted due to a power failure. Standby power sources and procedures and responsibilities for restoring lost power need to be included in the emergency procedures.

c. Detailed Information. The types of data needed and possible forms for record keeping are discussed in chapter 1. Personnel responsible for controlling and maintaining adequate distribution system performances must have access to the information and records in (1) through (10) below. They must be correctly informed of pertinent information contained in them:

(1) System maps and valve location records.

(2) Valve and hydrant preventive maintenance and in-

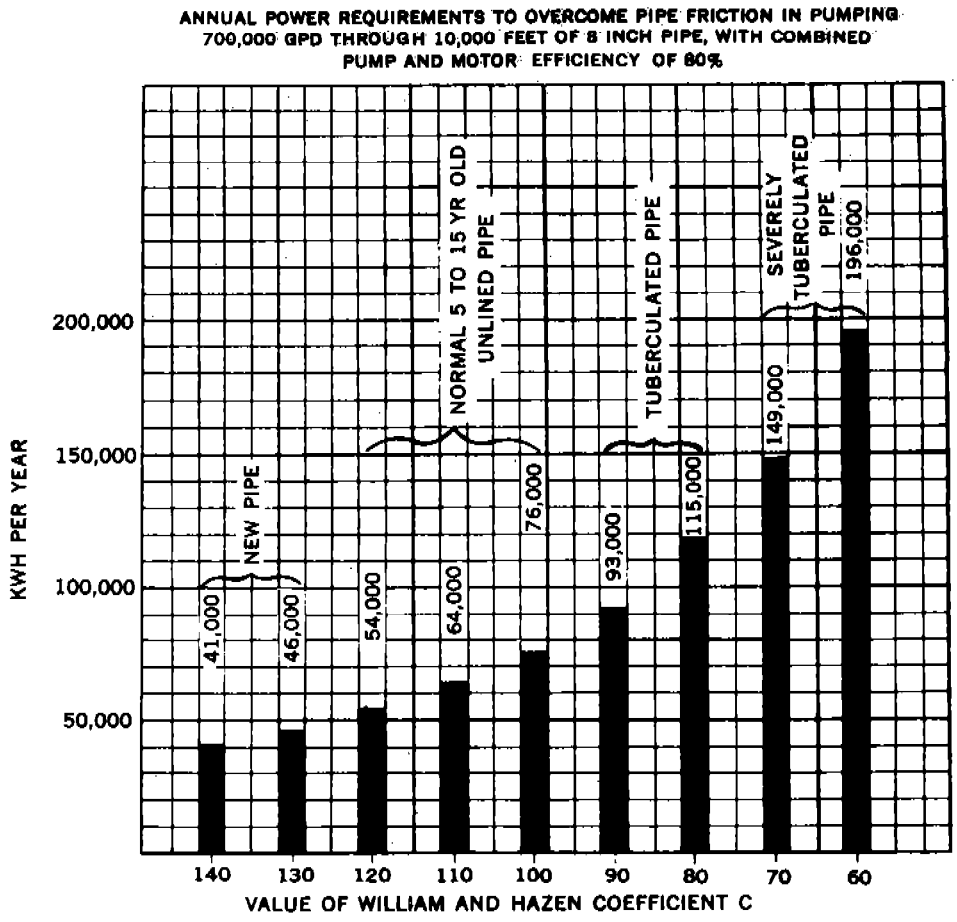


Figure 8–2. Power Required To Overcome Friction in Encrusted Pipe.

spection records.

(3) Well records.

(4) Pump characteristic curves, with plotted results of efficiency tests for each pump.

(5) Volume of water in storage.

(6) Equipment and mains under repair.

(7) Location of materials needed for emergency repair.

(8) Methods of flow control to, in, and from pumping stations and reservoirs.

(9) Possible sources and methods of additional water supply for firefighting, such as swimming pools.

(10) Weak points in the system and plans for coping with failures or deficiencies caused by them.

d. System Component Operation:

(1) Water Mains:

(a) Capacity. As an installation expands, the demand on the water distribution system for normal use and fire protection becomes greater. At the same time, because of corrosion, scale, and sedimentation in the pipes, the carrying capacity of the system slowly decreases. Therefore, it is necessary to check the capacity of the system each year to determine the need for additional feeder or looping mains and the need to clean and line existing pipes. The cost-effectiveness of piping capacity loss is illustrated in figure 8–2.

1. Test procedures for determining the capacity of mains include pitometer surveys, computer simulations, hydrant flow tests, and pressure tests. Capacity loss is discussed in paragraph 8–4d(3).

2. Computations for some tests can be made by hand using the procedures in paragraph 8–4d(3). More extensive evaluations can be made by computer. Higher authority should be contacted to have these evaluations made.

(b) Main Disinfection:

1. New or Repaired Mains. When new water mains are installed or an existing water main is opened for repair, particularly for insertion of a new section or length of pipe, the line must be disinfected. The procedure for main disinfection is discussed in detail in chapter 6, section H.

2. Dead Ends. Dead end pipes should be flushed and disinfected at least once a year. If quality complaints are received, the possibility of a dead end line being the cause should be investigated and remedial action taken.

(c) Main Breaks Repairs:

1. General Information. Rapid repair of main breaks requires thorough training of personnel and careful advance planning. The following procedures should be followed to eliminate delay in beginning repairs:

a. Post telephone numbers of key personnel

conspicuously in the water plant.

b. Keep valve keys in a definite place at all times.

c. Have digging tools, trench-shoring material, and a self-priming, centrifugal portable pump, and motor available at all times.

d. Keep a stock of split-sleeve and mechanical-joint repair fittings in sizes to fit critical mains.

2. Repair Fittings. Split-sleeve and mechanical-joint repair fittings offer the best method for quick, effective repairs. They can be installed underwater if necessary. Several companies manufacture split-sleeve and mechanical-joint repair fittings. Methods of installation and most advantageous use of each should be understood so the proper selection can be made for any particular repair.

3. Temporary Repairs. Wood plugs can be used to stop small holes temporarily. They can later be replaced with permanent metal plugs. Temporary wood plugs can be used to plug ends of pipes up to 8 inches in diameter. Plugs must be braced to withstand the pressure in the main.

4. Disinfection. After a main is dewatered for repairs, it must be disinfected according to paragraph 6-74.

(d) Flushing and Cleaning:

1. Flushing. Matter that is deposited or formed in the distribution system over a certain period is removed by periodically flushing the system. Flushing of water mains in the vicinity of a nuisance, particularly at dead ends, may remove or reduce taste, odor, color, or tubidity. Flushing may permanently cure problems caused by foreign material left in new or repaired mains. Find and eliminate conditions that make repeated flushing necessary. It may be a dead end or a low point in the main that allows sediment to accumulate, or the growth of slime organisms because of insufficient chlorination.

a. Flushing is also helpful in clearing the part of the water system that is nonpotable. The frequency varies for different waters and pipe materials, but usually once a year is enough. The frequency of flushing depends on the condition of the water or amounts of silt, corrosion products, or slimes in dead ends or mains opened for repair.

b. Start flushing at the supply source and continue to the ends of the distribution system. Do not start flushing at the ends of the system, because accumulated debris must then be drawn through the entire length of the system. To get maximum scouring velocity, flush each section of pipe independently by closing off intersection pipelines; this directs the full flow through the section to be flushed.

c. Flushing Plan. A flushing plan to assure complete cleaning of the system is drawn up as follows:

(*1*) Using distribution maps, prepare a list of hydrants and blowoffs to be opened, and arrange in an order that will flush the system from source to ends.

(*2*) List, in correct order, valves to be closed and opened for each flushing point.

(*3*) If service in any section will be disrupted by the plan, arrange to flush it at night. Notify heating plant and firefighting personnel in such sections.

d. Operating Guides:

(*1*) Remove service meters from section being flushed.

(*2*) Flush each pipe section until water is reasonably clear.

(*3*) Take care not to damage unpaved roads, walks, or improved grounds. If necessary, use a section of lightweight pipe to direct flow so damage does not occur.

(*4*) Place all valves in normal operating position before proceeding to the next flushing point.

(*5*) To permit flushing dead ends, install a blowoff at the end of each end main. Old hydrants in good repair, but not suitable for fire service, can be used. They must be painted a different color than fire hydrants and prominently marked as blowoff hydrants only. Dead ends may need flushing more often than other sections of the system.

2. Cleaning. Corrosion, scale, and deposited matter reduce pipe diameter, thus decreasing capacity of the distribution system and increasing power costs. When capacity is reduced below fire flow requirements by increased system head loss, mechanical cleaning is necessary. As a rule, this work is done on a contract basis with firms specializing in main cleaning. The mains may be relined to restore original smoothness of the interior. If this is properly done, 95 percent or more of the original capacity can be restored. If the mains are not lined with a corrosion resistant material after cleaning, start chemical treatment to prevent accelerated corrosion (see chapter 7).

(e) Thawing Frozen Systems:

1. General Information. In frigid or near frigid climates, freezing presents a major problem to a water distribution system. Pipes must be insulated and heated or carried in heated conduits in areas where the ground is permanently frozen. Where seasonal freezing is the only problem, pipes must be buried below the frost penetration depth. It is also necessary to heat stored water in cold areas. Because of lack of proper protection against freezing, and sometimes despite it, pipes frequently may freeze in temperate as well as frigid zones. When this happens, the pipes must be thawed.

2. Electrical Thawing. Electrical thawing is quick and relatively inexpensive. The electrical circuit for the thawing operation consists of a source of current (a DC generator, such as a welding unit, or a transformer connected to an AC outlet), a length of the frozen pipe, and two insulated wires connecting the current source and the pipe (figure 8-3). As current flows through the pipe, heat is generated and the ice within the pipe begins to melt. As the water starts to flow, the rest of the ice is progressively melted by contact with the flowing water. The wires from the current source may be connected to nearby hydrants, valves, or exposed points at the ends of the frozen section.

a. Current and Voltage. Some data concerning current and voltage required to thaw various sizes of wrought iron and cast iron pipe are given in table 8-1.

b. Required Time. Time required for thawing varies from 5 minutes to over 2 hours, depending on pipe

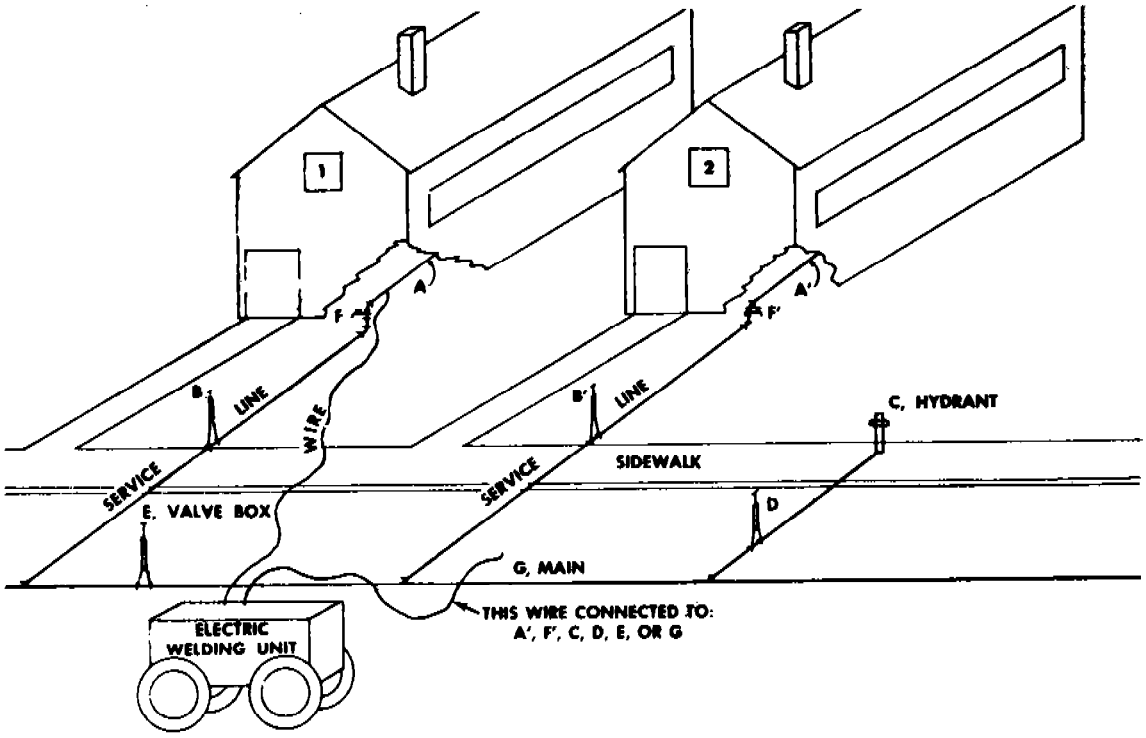


Figure 8-3. Connection Points for Thawing Service Lines.

size and length, intensity of freezing, and several other factors. The best practice is to apply current until water flows freely.

c. Precautions To Take:

(*1*) Never use a higher current than listed in table 8-1. When in doubt, use a lower current for a longer period.

(*2*) Select contact points on the pipe as close as possible to the frozen section.

(*3*) Make sure contact points are free of rust, grease, or scale.

(*4*) Remove meters, electrical ground connections, and couplings to building plumbing in the line to be thawed.

(*5*) If pipe joints have gaskets or other insulation at pipe joints, thaw the pipe in sections between such joints, or use copper jumpers to pass current around insulated joints.

d. Thawing Procedures:

(*1*) DC Generator. To thaw pipe with a welding generator or similar DC source, set generator to the correct amperage for pipe to be thawed and connect leads to pipe.

(*2*) AC Circuit. Transformers are required to adjust the amperage of an AC circuit to the pipe being thawed. Consult the installation electrical engineer for the best transformer arrangement, which depends on line voltage, available transformers, and required amperage. To keep hazards to a minimum, a competent electrician must set and connect transformers, make the connections and assist in the thawing procedure. Where frequent thawing is necessary at different points, the transformers may be mounted on a trailer for ready use.

3. Steam Thawing. Steam thawing is slower and is used only when insulating material in pipe joints or couplings makes the use of electricity impracticable. In steam thawing, a hose connected to a boiler is inserted through a disconnected fitting and gradually advanced as the steam melts the ice. Steam thawing is commonly used on fire hydrants.

(f) Quality Control:

1. Quality parameters of operating importance include bacteriological quality, taste and odors, color and turbidity, and chemicals and radioactive contaminants. The Safe Drinking Water Act (SDWA) is a law that regulates the amounts of particular substances that may be found in the treated water distribution system. Chapter 6, section M, discusses the monitoring required by law.

Table 8-1. Current and Voltage Required To Thaw Wrought Iron and Cast Iron Pipe.

	Pipe Size (inches)	Pipe Length (feet)	Approx. Volts	Approx. Amps
Wrought Iron	¾	600	60	250
	1	600	60	300
	1½	600	60	350
	2	500	55	400
	3	400	50	450
Cast Iron	4	400	50	500
	6	400	50	600
	8	300	40	600

a. Bacteriological Quality. Frequent checks for chlorine residual and bacteriological quality of water must be made at various points in the distribution system to guarantee continuous potability. Some common causes of bacterial contamination of water in distribution systems are:

(*1*) Failure to disinfect after installing new mains or repairing existing mains.

(*2*) Cross-connections, backflow and back-siphonage due to pressure loss in the distribution system.

(*3*) Pipe joints made with jute in which bacteria can grow and multiply, in spite of chlorination for periods of time up to several months.

(*4*) Uncovered storage tanks and reservoirs where treated water is stored before being pumped into the distribution system.

(*5*) Frostproof outdoor water closets and hydrants, and (obsolete but still frequently found) plumbing fixtures that cross-connect water and sewer systems.

b. Taste and Odor. The senses of taste and smell are so sensitive that even very small amounts of certain otherwise harmless substances can reduce palatability.

(*1*) Over a period of years in an inadequately chlorinated system, growths of slime or deposits of organic material may coat the inside of water pipes. This is particularly true in dead ends. Fire flows, mechanical vibrations, reversals in direction of flow, or increased chlorination may cause sloughing of the coating, which may then produce objectionable tastes and odors.

(*2*) Somes tastes and odors may be in the water supply itself because of dissolved gases, high iron content in well water, or decaying leaves and other organic material washed into streams by rainfall.

(*3*) Iron and sulfur organisms within the distribution system are particularly troublesome. Crenothrix live in oxidizing iron from the ferrous to ferric state in the presence of dissolved carbon dioxide. These organisms are rusty red color. Sulfur organisms produce hydrogen sulfide. These organisms can also cause or increase iron pipe corrosion by providing food for Crenothrix organisms.

(*4*) Taste and odor problems caused by slime growths and iron and sulfur organisms may generally be prevented by main flushing and maintenance of an adequate chlorine residual in the distribution system. Tastes and odors present in the raw water should be removed by procedures discussed in chapter 6, section C.

c. Color and Turbidity. Like tastes and odors, color and turbidity in water are caused by impurities. Of the two, color is the more difficult to remove since it is caused by colliodal or soluble material and cannot be readily settled or filtered out. Turbidity is a cloudiness in the water due to small particles of organic or inorganic matter in suspension. The same impurities that impart taste and odor may cause color and turbidity, although there may be no connection between the nuisances.

d. Chemical Characteristics. Water is a universal solvent. Ground, surface, and rainwater supplies come into contact with many chemical constituents both from the natural and artificial environments, which to some degree are soluble in water. As a consequence, all water supplies contain many extraneous chemical compounds. Many of these compounds are not removed by the treatment process; thus end up in the distribution system. Due to their greater exposure, surface-water supplies tend to contain a greater variety of chemicals (which alters the quality of the water) than rainwater or ground water. A great many of the chemicals dissolved in water cause no real problems, except from a nuisance or aesthetic standpoint. There are, however, certain chemicals (both inorganic or organic) in raw water supplies that are toxic and pose a threat to human health. The levels and specific kinds of toxic chemicals are discussed in applicable service regulations (see paragraph 1-19).

e. Radiological Analysis. Water can be the predominant source of radioactive materials to humans should potable water supplies be directly contaminated. Contamination could result from natural sources or as a result of accidental or planned release of radioactive materials. Water samples from the distribution system must be analyzed for radioactivity. Details of specific monitoring procedures are identified in applicable service regulations (see paragraph 1-19).

2. Sampling Points. The regulations of the Safe Drinking Water Act (SDWA) require quality measurements to be made from samples taken at the consumer's tap, except in the case of turbidity and sodium, which should be measured at the point of entry to the distribution system. The intent of the law was to require random selection of distribution system sampling points. Fixed sampling stations may be set up in the distribution system to monitor quality parameters other than those required by the SDWA law.

3. Preventing Corrosion:

a. Interior Corrosion. If water is highly corrosive, some form of corrosion-prevention treatment is necessary to eliminate frequent mechanical cleaning. Analyses and experiments must be made by competent persons before treatment measures are adopted; for further details see chapter 7. Cement lining of in-place mains or sliplining with PVC may be economical if corrosion is severe. Cement-asbestos pipe or pipe with a protective lining, such as cement or bitumen (paragraph 7-13), should be considered when extending the system.

b. Exterior Corrosion. Exterior corrosion is largely due to soil conditions. Saltmarsh soil, damp ash and clay, fill made from mill and industrial wastes, and land near waste discharges of chemical works may be very corrosive. Electrolysis due to stray currents from nearby DC lines also causes exterior corrosion. Exterior corrosion can be eliminated by replacing mains with concrete or cement-asbestos pipe; coating the outside of the main with paint, tar, or cement or encasing the line with bitumen-treated or polyethylene wrapping; or by placing the piping inside another conduit (paragraph 7-13). Cathodic protection, generally used on oil lines, may be applicable in some cases (paragraph 7-14).

(2) Fire Hydrants:

(a) Location. Hydrants are located according to

regulations established by higher technical authority. Mislocated hydrants should be relocated if possible. The following principles apply to locating fire hydrants:

1. Place about 400 feet apart in housing areas. Every building should be reached from two hydrants with not more than 300 feet of hose.

2. About 300 feet apart in warehouse and airfield hanger areas.

3. At least 25 feet from a building; 50 feet is perferred.

4. At least 6 feet from a paved road surface and more on major streets and roads, if possible.

5. Not more than 7 feet from the closest point to which a fire pumper can approach; in exceptional cases where ditches or other conditions interfere, 16 feet is permitted between hydrant and pumper.

6. At least 3 feet from any obstruction and not directly in front of homes, entrances, and driveways.

7. At least 18 inches between the lowest hydrant outlet and grade, but not more than 4 feet between the operating nut and grade. If grades are materially changed, hydrants must be raised or lowered.

8. Principal discharge facing the nearest road.

(b) Protection and Painting. Hydrants that cannot be located away from traffic, as in loading dock and warehouse areas, are protected with sturdy barriers designed so they do not obstruct the hydrant for fire use. For rapid identification, hydrants are to be painted in accordance with National Fire Protection Association (NFPA) Code 291.

(c) Operating Precautions:

1. Allow only responsible civil engineering employees (such as fire fighters or utilities maintenance personnel) to operate hydrants.

2. Use only hydrant wrenches on a hydrant; ordinary wrenches ruin the operating nut.

3. Do not connect pipes to hydrants without specific authorization; this authorization can be given only in an emergency.

(d) Frozen Hydrants. Hydrants must be protected against freezing. Ordinarily, when a hydrant is closed, water standing in the barrel drains out through a weep hole, which opens when the main hydrant valve closes. In freezing weather, if the ground-water level is above the weep hole, plug the hole and pump out the hydrant barrel with a portable pump after each use.

1. Frozen hydrants may be thawed by using salt or calcium chloride; by the heat from an insulated wire wound around the exposed portion of the hydrant and fed an adequate current; or the injection of live steam into the hydrant barrel. Salt and calcium chloride are slow acting, but reliable.

2. In subzero weather, hydrants near important structures should be inspected each week; other hydrants should be inspected each month. Do not flush hydrants on such inspections.

(3) Valves. Details on valves are covered in Chapter 9. Distribution system valve functions are discussed below.

(a) Isolation Valves. Isolating (gate, butterfly, plug) valves are placed in distribution systems so the flow of water in a pipe may be shut off. When a pipe breaks, the nearest valve on each side of the break must be closed to prevent the loss of water through the break. This also allows the section of pipe to be dewatered so it can be readily inspected, repaired, or replaced. Without these valves, it would be necessary to shut down the whole system for these procedures.

(b) Control Valves. Aside from completely stopping flow, valves are used for throttling or controlling quantities of water flowing in a pipe channel. Other uses include pressure and level control, and proportioning flow. Appurtenances that aid in controlling valves include valve boxes floor stands, and post indicators. The construction, description, and maintenance of the following valves are discussed in chapter 9:

1. Check.
2. Float.
3. Altitude.
4. Pressure-reducing.
5. Corporation cocks and curb stops.
6. Globe.

e. Water Hammer and Surge:

(1) Description:

(a) Water Hammer. Water hammer is a rapid pressure fluctuation above and below the line pressure in a closed pipe system, caused either by a sudden stopping or starting of flow or by too rapid a change in rate of flow. Rapid closing of a valve causes pressure waves of short duration, but of considerable force. The force exerted may burst the pipe or force joints open. Banging and chattering in waterlines are common signs of water hammer. Installation of a valve that cannot be closed too quickly, an air column, or proper instructions to operating personnel can frequently relieve the condition.

(b) Surge. Surge in a water pipe is a rise in pressure that is caused by sudden variations in water velocity due to changes in water demand or pumping. A surge usually lasts for several minutes and can be detected by pressure gauges. It does not fluctuate above and below the line pressure rapidly, as does water hammer, nor does it deliver as damaging a force. Sufficient pressure rise, however, can cause pipe failures. Surge may sometimes be controlled by installing air chambers in the system to absorb the pressure rise and return it to the system evenly and at a slow rate.

(2) Treatment. If water hammer or surge causes operating difficulties, recommendations for eliminating or reducing them can be obtained from higher technical authority.

8-4. System Maintenance. This paragraph is designed to assist in maintaining distribution system equipment in good working condition and aid in detecting and correcting minor defects before major repairs are required.

a. Keeping Records. The results of operation, preventive maintenance, and control inspections, as well as major overhaul and repair work, must be kept on record forms as established by command regulations. Historical files should be carefully prepared and maintained for each com-

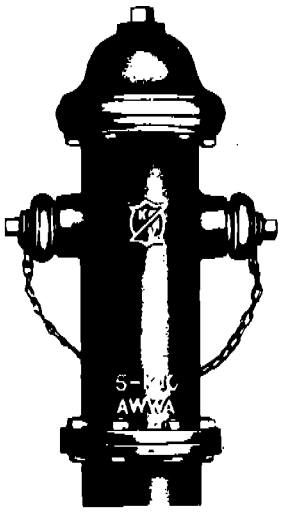
Standard Model

Compression Type

Test Pressure:
Water 300 lbs.

Working Pressure:
Water 150 lbs.

Sizes:
Main Valve 4¼", 4½", 5¼"
Standpipe ID 7"



Exterior view showing marking cast on standpipe. Direction to open cast on cap.

PART	MATERIAL
CAP BOLT NUTS	BRONZE
OPERATING STEM NUT	BRONZE
ALEMITE FITTING	STEEL
"O" RING WEATHER SEAL	BUNA N SYNTHETIC RUBBER
CAP	CAST IRON
ALLEN HEAD SETSCREW	STEEL
LOCK NUT	BRONZE
COVER PLATE	CAST IRON
COVER PLATE BOLTS AND NUTS	RUST-PROOFED STEEL
"O" RING PRESSURE SEAL	BUNA N SYNTHETIC RUBBER
COVER PLATE GASKET	CORK FIBRE
NOZZLE CAP HOOK	STEEL
NOZZLE CAP GASKET	RUBBER
NOZZLE	BRONZE
NOZZLE CAP	CAST IRON
NOZZLE SCREW	BRONZE
NOZZLE CAP CHAIN	STEEL
UPPER STANDPIPE SECTION	CAST IRON
STANDPIPE BOLTS AND NUTS	RUST-PROOFED STEEL
STANDPIPE GASKET	SPECIAL COMPOSITION
STEM	C.R. STEEL
SEAT REMOVING WRENCH GUIDE	BRONZE
WRENCH GUIDE SETSCREW	BRONZE
LOWER STANDPIPE SECTION	CAST IRON
DRAIN VALVE FACING	TREATED LEATHER
DRAIN VALVE	BRONZE
ELBOW BOLTS AND NUTS	RUST-PROOFED STEEL
ELBOW GASKET	CORK FIBRE
SEAT RING	BRONZE
SEAT RING GASKET	ASBESTOS FILLED COPPER
DRAIN VALVE KEY	STEEL
TOP PLATE	CAST IRON
MAIN VALVE	BALATA
FULL COVER BOTTOM PLATE	CAST IRON
ELBOW	CAST IRON
DRAIN TUBING	BRONZE

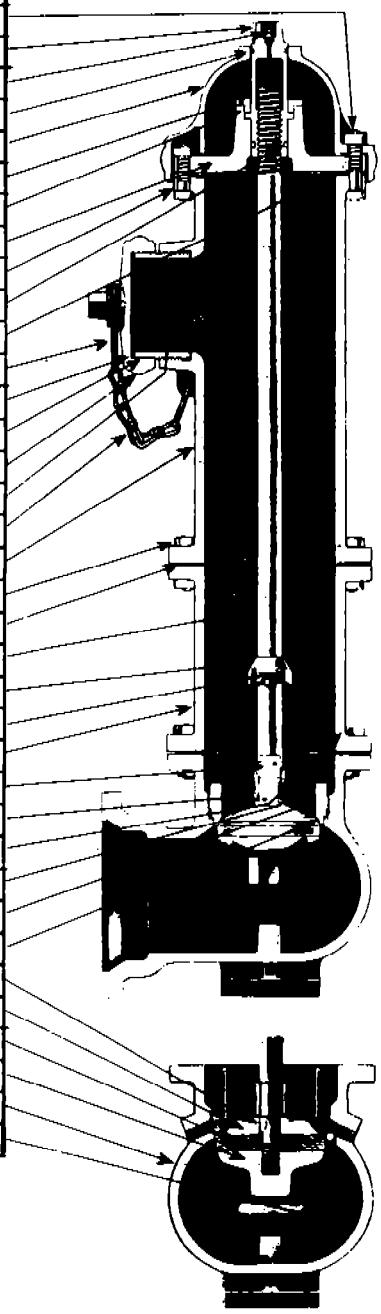


Figure 8-4. Typical Fire Hydrant.

ponent of the water distribution system. Such files should contain data and information from which the economy and reliability of various parts of the system may be determined. Information on corrosion prevention, available tools and test equipment, and proper safety measures should be maintained, in addition to the information outlined above.

b. Hydrant and Valve Inspection:

(1) Valves.

(a) Valves for water utility systems are described and illustrated in chapter 9. Valve maintenance can be reduced to a minimum by periodic inspection. The inspection frequency depends on the specific service conditions and how often the valve is operated. In case of reactivation of a system, all main-line valves must be tested.

(b) Common sources of trouble are "lost" valves, inoperable valves, and valve boxes covered or obstructed by road grading or filled with foreign matter.

(2) Hydrant Inspection. Hydrants are inspected and tested by water utility personnel accompanied by a fire department representative, according to command and field engineering office directives. Hydrants can usually be

maintained by replacing all worn parts and seats through the top of the hydrant (figure 8-4). The operator must be sure that the proper tools are used. Each year, test the hydrant for tightness of joints and fittings in the following manner:

(a) Remove one hydrant cap and replace it with a cap fitted with a pressure gauge. Open the valve slowly until it is wide open. Record pressure:

(b) Check for leakage at the following points:

1. Hydrant Top. If a leak is found, remove the cover plate and tighten or repack the seal.

2. Nozzles Entering Barrel. For leaks here, caulk the connection with lead.

3. Nozzle Caps. If the nozzle caps are leaking, replace any defective gaskets.

4. Cracks in Barrel. For leaks from cracks in the barrel, install a new barrel or a new hydrant.

5. Drain Valve. This valve should be closed when the hydrant is open. If water comes out of the drain or saturates the ground around the hydrant when the hydrant valve is open, replace the drain valve facing or gasket.

(c) Close the hydrant valve, open the second nozzle, open the hydrant valve, and flush the hydrant. Record the pressure with the hydrant valve open.

(d) Close the hydrant valve slowly and note the lowering of the water level in the hydrant after the valve is closed. If the water level does not drop, the main valve is leaking or the drain valve is plugged.

c. *Quality Maintenance:*

(1) Source Protection. The quality of water in the distribution system is a function of source quality. Information on conditions that could affect the water source is in chapter 3.

(2) Quality Complaint Records. Records of consumer complaints about water quality should be maintained. These records often help pinpoint a trouble area in the distribution system, as well as provide a further check on the adequacy of the sampling program and sample station locations.

(3) Inspection and Testing Backflow-Prevention Devices. The frequency with which backflow-prevention devices are inspected and tested depends largely on the make and model of the unit. This is true, also, of the test procedures to be followed. Therefore, consult the manufacturer's instructions for detailed procedures. Additional testing and maintenance information is in chapter 9.

(4) Quality Sampling. Automatic samplers can be used as part of the sampling station program. These should be maintained as outlined in the manufacturer's recommended procedures.

d. Pressure Maintenance:

(1) Main Condition. The mains in the distribution system are underground and part of a closed system. The mains removed in repair work should be examined to determine internal condition.

(2) Pressure Equalization. Pumps, valves, and storage reservoirs are used to distribute pressure evenly in a distribution system. Each must be maintained to fulfill its function.

(3) Capacity Loss. Decreases in the carrying capacity of pipelines result from increased friction in the system that is caused by an increase in the interior roughness of the pipe and decreased interior diameter. Causes of increased roughness, or decreased line size, include corrosion and pitting, tuberculation, sediment deposits, slime growths, and air accumulation at high points in the line. Procedures used to identify these adverse conditions include fire-flow tests (hydrant-flow tests), loss-of-head tests, pressure tests, simultaneous flow and pressure tests, and leak surveys.

(a) Flow Tests. Flow measurement and loss-of-head tests in mains are best made by pitometer surveys. These tests are best performed by an outside contractor. The tests may show closed or partly closed valves, obstructions, air pockets, or loss of carrying capacity due to encrustation. These tests should be made when the operating conditions indicate there is a need. In place of a pitometer survey, hydrant-flow tests may be used to check a limited part of the system.

(b) Hydrant-Flow Tests. Hydrant-flow testing must be conducted in accordance with the latest edition of NFPA 291, Recommended Practice for Fire Flow Testing and Marking of Hydrants, Chapter 1, or International Fire Service Training Association (IFSTA) Manual 205, Section 2, Fire Hydrants.

(c) Pressure Tests. If pressure recorders do not exist on the system, particularly at high and low points, then annual checks should be made of pressures at various elevations and locations within the system.

(4) Remedies for Pressure Loss. There are four methods of remedying carry-capacity loss:

(a) Cleaning. Cleaning should be done whenever flow tests or loss-of-head tests indicate there is a need. Mains that exhibit carrying-capacity loss may be cleaned in two ways.

1. Small pipes containing calcium carbonate deposits or tubercles may be cleaned with inhibited muriatic acid; this treatment is not feasible for large pipes.

2. Large mains are cleaned with scrapers. This operation is usually done by outside contractors, but may be done by utility personnel. The scraper is inserted through a cut in the main and is moved forward by water pressure behind it until it exits at another cut in the line. Debris is flushed out of the line ahead of the scraper. Pipes so cleaned are subject to further tuberculation if the character of the water causes tuberculation.

3. Use a high initial concentration of a zinc-containing polyphosphate immediately after cleaning to minimize red water and tubercle formation.

(b) Cleaning and Lining. To avoid the necessity for repeated cleaning by scrapers, the in-place pipe should be sliplined with PVC or lined with cement after it has been cleaned. This operation should be done by an outside contractor.

(c) Operational Changes. Some of the conditions causing loss in carrying capacity may be remedied by changes in operating procedures.

1. If the water supply is corrosive, or lacks buf-

fering capacity as it enters the distribution system, it will aggravate tuberculation. To offset this condition, a change in treatment may be instituted to stablize the water and increase its pH.

2. If carrying-capacity loss is caused by slime growth, special chlorination procedures may be adopted to remedy the condition.

3. Where accumulation of sediment is the cause of carrying-capacity loss, periodic flushing of the entire system, through hydrants and blowoffs, is mandatory. Refer to paragraph 8-3d.(1)(d) for flushing procedures.

(d) Pipe Replacement. Mains will eventually have to be replaced. Sliplining with plastic pipe should be considered as an alternative where high cost digging is required such as under streets and parking lots. The new main will increase carrying capacity to design capacity.

(5) Leaks:

(a) Location. Leaks in pipelines reduce the capacity of the system, cause water to be wasted, and reduce water pressures.

1. To determine the location of leaks, surveys shall be made at the time of minimum water use.

2. All valves should be shut off, except those which will direct all waterflow through the section under study.

CAUTION: Notify the firefighting authorities prior to closing any section of the system. Insert a pitometer in the pipe, and determine if the flow is above normal for that time of day; if so, divide the district being served by the pipe into smaller areas until the area of the leak is pinpointed.

3. Once the area has been located, finding the leak may be done in several ways; none of them is universal in its effectiveness:

a. House-to-house inspection.

b. Observation of ground surface.

c. Observation of sewer flows.

d. Study of hydraulic gradelines.

e. Listening for the sound of a leak with a sonoscope or geophone.

f. Blowing air in pipe, for submerged line.

(b) Plan and Preparation. Since water main breaks must be repaired as rapidly as possible, personnel must be trained and repair plans must be made in advance. Follow the planning procedures discussed in paragraph 8-3a(2). In addition, keep the following items available and ready for use at all times: valve keys, hand tools, digging tools, pavement breakers, trench shoring, portable centrifugal pump, floodlights, emergency chlorinator, and hypochlorite. Make advance arrangements with either a municipal utility, public works department, or outside contractor for the use of large construction equipment (for example, power shovels, cranes, etc.) which may be needed, but are not normally stocked by the installation.

(c) Repair. The technique of repairing leaks depends on the type of leak. The following general procedures apply:

1. Wood plugs may be used to stop small holes temporarily. They can be replaced with metal plugs, or repairs may be made by other means. Temporary wood plugs may be used to plug the ends of pipe up to 8 inches in diameter, but such plugs must be braced to withstand existing main pressure.

2. Joint leaks shall be repaired by recaulking the joint, if caulking has been used in the joint.

3. Cracks in mains usually require that the valves be shut off in the affected area, especially in severe main breaks. Notify the firefighting authorities in case of main shut off. Leaks in mains may be repaired by one of these methods:

a. Use a split sleeve.

b. Cut out a section of the cracked pipe and replace it with a piece of pipe and mechanical couplings. Mechanical couplings are manufactured by several companies for various types of repair jobs. For the methods of installation and most advantageous use of each, consult the manufacturer's instructions in order that the proper selection and installation may be made. If the break is too long for a short insertion piece, a whole length of pipe is to be inserted.

(d) System Component Maintenance Guides. Tabular maintenance guides for mains, valves, and hydrants are presented for reference. Maintenance guides for storage are presented in paragraph 8-7.

1. Mains. Maintenance consists of tests, inspections, and repairs as summarized in table 8-2.

2. Valves. Descriptions of valves and accessories and maintenance procedures are presented in chapter 9.

3. Hydrants. Hydrants are special valves. Procedures for hydrant maintenance are presented in table 8-3.

Section B—Storage

8-5. General Information:

a. Storage Function. Storage serves to equalize demand, improve flows and pressure, and provide reserves for firefighting and power outages.

(1) Equalize Demand. The normal water demand in a community or installation varies considerably between night and day and for different days of the week. It is not economical to provide wells or pumps large enough to meet peak demands of the system. During low demand periods, water is placed in storage for use during periods when the demand exceeds the capacity of the source, supply lines, treatment plant, or pumps.

(2) Improve Flows and Pressure. Water in storage can be used to equalize distribution system pressure in response to flow. In an interconnected system, the pressure at a point in the system is a function of elevated storage, pressure imparted by pumps, and system head loss as the result of flows from the system. Storage serves to even distribution flow patterns. Water is kept at the desired level by valves and regulators discussed in chapter 9.

(3) Reserves for Firefighting and Power Outages. The fire demand may have to be met at any time. Storage enables water to be supplied during emergency conditions resulting from fires, power failures, breakdown of supply pumps, failure of supply mains, flooding, and other condi-

Table 8-2. Maintenance Procedures for Distribution System Mains.

Inspection	Action	Frequency [1,2]
Flow tests	Make tests as conditions indicate need	V
Pressure tests	Make tests as conditions indicate need	V
Loss-of-head tests	Determine, using pitometer	A
Cleaning	Employ outside contractor	V
Cleaning and lining	Employ outside contractor	V
Operating procedure	Change procedures as conditions dictate	V
Leak location	Use standard techniques	V
Leak remedies	Plan and prepare in advance	V
Leak repair	Apply standard techniques	V
Disinfection	See Chapter 6H	V
Thawing	Apply standard techniques	V

[1]M-Monthly; A-Annually; V-Variable, as conditions may indicate.

[2]The frequencies shown are suggested frequencies which may be modified by local command, as individual installation conditions warrant.

tions that may result from natural causes, accidents or enemy action.

b. Sizing Stored Water:

(1) The rate or water withdrawal from the distribution system during maximum hourly use may be several times the overall rate needed for the average daily demand. A mass balance diagram indicating the amount of water used during peak periods versus the amount that can be supplied from treatment plants sized for average flow determines the storage capacity needed. The operation of storage facilities in the distribution system is largely a matter of maintaining water levels in the reservoir by adequate pumping and controlling waterflow through the proper valves.

(2) Operational experience must be used to determine economy of varying operations to meet seasonal demand changes.

c. Fire Demand. A storage reservoir serves the dual pur-

Table 8-3. Maintenance Procedures for Fire Hydrants.

Inspection	Action	Frequency [1,2]
Dry-barrel hydrants	Check drain valve to be sure it opens	M
	Where ground water level rises into barrel, plug drain valve and dewater barrel by a pump.	M
Wet-barrel hydrants	Check packing glands and valve seats; repair as necessary.	Q
Pit-type hydrants	Check for water accumulation; dewater as necessary	M
All hydrants		
On dead ends	Flush; check barrel after flushing	SA
Not on dead ends	Flush; check barrel after flushing	A
	Check water flow	A
	Repair as necessary; if main shut down is required, notify fire department.	V
In winter	Check for freezing; thaw, if necessary	W* M**
Leakage tests	Inspect all places where leaks might occur; repair as necessary.	A
Valve parts		
Operating nut	Check for rounded corners; replace as necessary; lubricate.	A
Nozzle threads	Check for damage; replace as necessary	A
Chains	Check for paint fouling; clean	A
Flow tests	Determine hydrant flow	A

[1]W-Weekly; M-Monthly; Q-Quarterly; SA-Semiannually; A-Annually; V-Variable, as conditions may indicate.

*Weekly near important structures.

**Monthly elsewhere.

[2]The frequencies shown are suggested frequencies which may be modified by local command, as individual installation conditions warrant.

pose of equalizing flow and providing reserve water for fire flow. A given tank has a certain volume of water allocated for each purpose in design. Under no conditions should the amount of stored water be reduced to a point below that reserved for firefighting. Daily records, maintained by the operator, help ensure against such a condition.

8-6. Storage System Types:

a. Ground Storage Reservoirs:

(1) Ground storage reservoirs should have waterproof covers to prevent contamination, because open reservoirs are subject to pollution from airborne dust and bacteria, animals and their excreta, leaves and similar debris, and dangerous materials intentionally or accidentally introduced by people. The covers are also safeguards against drownings. Covered reservoirs or tanks must be vented to allow the passage of air to and from the reservoir as the water level is changed. The vents must be finely screened to prevent entrance of animals and insects, and the screens kept in good repair. Access manhole covers should always be kept in place to prevent accidents and contamination. The ground should slope away from the reservoir in all directions so no surface water can flow towards it. Leaks in the cover or walls that permit the entrance of surface water or shallow ground water are dangerous and must be repaired at once.

(2) In freezing areas, inspect vent screens frequently to keep them clear of ice and frost. Where ground storage tanks are used only for fire protection, operate fire pumps and recirculate tank contents as frequently as required to prevent or reduce ice formation. The construction of earth banks around storage tanks will help insulate tanks and prevent freezing. Where these measures do not stop freezing, install steam or hot water coils or paint the tanks a dark, absorbent color.

b. Underground Reservoirs. If storage tanks are constructed below ground level, or are surrounded by an earthen embankment, the inspection and repair include only the interior walls, roofs, appurtenances, and embankment. If the earthen embankment, surrounding soil, or interior of the tank shows evidence of tank leakage, the earth may need to be excavated and repairs made on the walls.

c. Elevated Storage. Elevated storage is provided by means of elevated tanks that are supported on columns or legs. The tanks may be cylindrical, spherical, ellipsoidal, conical, or other shapes. Steel is generally used for tanks, but smaller temporary ones are sometimes made of wood. Water is maintained at the desired level by means of valves and regulators. The function of elevated storage is similar to that of ground storage. The choice between the two depends on the elevation at which water should be stored for the best operation of the distribution system, and the topography of the land. In general, it is desirable to have at least 50 percent of storage as elevated or high-level storage. However, the problems of freezing and corrosion are more difficult in the case of elevated tanks.

(1) Freezing Prevention. To guard against freezing of water within the elevated tank riser pipe, cover it with insulating material. In climates where insulation alone may not give adequate protection, install steam coils in the riser and pipe steam to the coils from a nearby boiler plant, or connect a circulating hot water heater into the rise to take water about 15 to 20 feet above the riser base and return it near the base. In the latter case, adding a small recirculating pump is desirable because it provides a large amount of recirculation with limited heat rise. Inspect vent screens frequently throughout the winter and keep them clear of frost. An ice ring several inches thick may form inside elevated tanks, especially if water circulation is slow. In the spring, the ring melts loose from the tank sides and floats to the top of the water. The top of the ice ring is then considerably higher than the water surface. To keep the ring from damaging the top of a closed tank or projecting above the top of an open tank, set altitude valves to maintain a freeboard of at least 14 percent of the tank depth during the winter.

(2) Corrosion Prevention. For methods of preventing the corrosion in tanks and standpipes, see chapter 7. Even though cathodic protection prevents corrosion below the water surface, when it is used, the complete interior of the tank roof, and exterior need other protection, such as periodic painting.

d. Standpipes. Elevated storage may be provided by standpipes which are large diameter cylinders that rest on the ground. They are usually located on a hill or other land higher in elevation than the surrounding area.

e. Pneumatic Tanks. Pneumatic tanks are usually found in use at smaller installations. They have a pressure vessel partly filled with water in order to leave an air cushion above to produce the desired water pressure. Pneumatic tanks may be located within buildings, on outside surface locations, or underground. While the operation of these units is usually automatic, the operator is responsible for operating pressure equipment effectively. It is important to see that the air cushion is maintained at all times. Air may be depleted by leaks and by dissolving in the water. The manufacturer's instructions should be consulted for methods of starting, stopping, and operating this pressure equipment.

8-7. How To Maintain Storage Facilities. Storage facilities are maintained according to procedures in table 8-4.

8-8. Paint Systems for Steel Storage Tanks:

a. Surface Preparation. Good surface preparation is required to ensure adequate bonding of the paint to the metal to be protected.

(1) New Tanks:

(a) Mill scale should be removed from new steel tanks before applying the prime coat. Blast cleaning or pickling is used for mill scale removal in the shop, while blast cleaning is the most effective method for field use. A prime coat should be applied almost immediately after the surface preparation is completed. Field-welded joints should be cleaned by blasting or other methods such as grinding, sanding, or wire brushing before applying the primer.

Table 8-4. Maintenance Procedures for Storage Facilities.

Inspection	Action	Frequency [1,2]
Foundations, concrete	Check for settlement, cracks, spalling and exposed reinforcing; repair as necessary with 1 part cement to 1 part sand.	SA
Foundations, wood	Check wood foundations and pads for checked, split, rotted or termite infested members; also check for direct contact of untreated wood with soil; repair or eliminate undesirable conditions as necessary.	SA
Concrete tanks (ground level storage).		
Walls	Check exterior for seepage; mark spots	SA
	Check exterior and interior for cracks, leaks, spalling, etc.	A (Spring)
	Remove loose, scaly, or crumbly concrete; patch with rich cement grout; paint grout with iron waterproofing compound.	A
	Chip out cracks, repair with cement slurry	A
	For cracks in prestressed tanks, consult designing and/or erecting company.	A
Expansion joints	Check for leakage; check for missing filler; clean and repair as necessary.	SA
Roofs	Check condition; check hatches; check screens on openings. Clean as necessary.	SA
Earth embankments	Check for erosion, burrowing animals, improper drainage and leakage through embankment; repair as necessary; if leakage through embankment exists, drain tank and look for cracks in tank walls or bottom.	SA
Concrete tanks (underground storage).	Check interior walls, roof, appurtenances and embankment; if leakage is evident, excavate and repair walls.	SA
Concrete tanks (elevated storage).	Check and repair	SA or A.
Steel tanks (ground level storage).	Check for ice damage in spring; repair as necessary.	A
Walls and bottom	Examine exterior and interior for rust, corrosion products, loose scale, leaky seams, and rivets and for condition of paint.	SA
	Replace rivets or patch leaking areas, as necessary.	V
	Check painted surfaces for deterioration; paint as necessary.	SA
Roofs	Check condition, hatches, screens, manholes and paint; lock hatches; remove spider rods if corroded; repair, replace or paint as necessary.	SA
Steel tanks (standpipes).	If problem is noted during inspection, arrange for an outside contractor to repair the steel tank.	SA
Steel tanks (underground storage).	Check tank interior, roof and appurtenances.	SA
Steel tanks (elevated storage).	If problem is noted during inspection, arrange for an outside contractor to repair the steel tank	SA

(b) Primers that dry hard and glossy (such as those with phenolic bases) should not be used for shop priming because the first coat of paint applied in the field will not stick to the relatively slick surface. This type of primer is satisfactory for field use if the second coat is applied before the primer has dried to the hard, glossy finish. Zinc dust phenolic primers are suitable for shop priming since they do not dry to a glossy finish.

(2) Old Tanks:

(a) If the original surface preparation was poor and

Table 8-4. Continued.

Inspection	Action	Frequency[1,3]
Tanks	Use contractor	SA
Tower structures	Check for corrosion; loose, missing, bowed, bent or broken members; loose sway bracing; misalignment of tower legs; evidence of instability; repair as necessary.	SA
	Check surface of lattice bars, anchor bolts, boxed channel columns and pockets where water or trash collects; clean, repair, provide drainage or fill pockets; paint as necessary.	SA
Roofs	Check obstruction and navigation lights, hoods, shields, receptable and fittings for missing or damaged parts, or inoperation; also check lightning rods, terminals, cables and ground connections; repair, replace or renew; paint as necessary.	SA
Risers and heating systems.	Two months before freezing weather, check riser pipe insulation and repair as necessary; also check heating system operation.	A
	One month before freezing weather, operate heating system for eight hours; repair or adjust defective parts.	A
Cathodic protection	In addition to the following instructions, see Chapter 7.	A or V
	Check flow of current; if absent, check fuses, electrodes, ground wire connections and immersion of electrodes; adjust or repair as necessary; if current flow or amperage is above desired level, adjust as necessary; make certain that connections to rectifier are not reversed.	V
	Check operating records to make sure that electrodes are immersed at all times.	V
	Check anode condition; replace as necessary	V
	In freezing climates, protect electrodes against ice damage, or remove and store for winter season.	V
	Test effectiveness of cathodic protection	V
Wooden tanks		
Towers	Check for loose, missing, twisted, bowed, cracked or split pieces; also for termite infestation, misalinement of legs and evidence of loose sway bracing; repair and eliminate undesirable conditions; paint as necessary.	SA
Tank	Check operating records to make certain tank is kept filled; also check structural condition of tank for soundness, evidence of leakage and corrosion of steel bands; also check all appurtenances, ladders, roofs, screens, etc.; make any repairs or adjustments necessary.	SA
	Paint metal parts; paint timber only if necessary for appearance.	A

the mill scale was not removed at the time the tank was originally painted, blast cleaning is required before repainting. If the original surface preparation was adequate, but the old paint has completely broken down, blast cleaning of areas with loose or failing paint is usually warranted. If the old paint is still in good condition, only those areas with loose paint need to be removed by wire brushing or sanding.

(b) All areas that have been cleaned of loose paint down to the bare metal require priming before rust has a chance to form.

b. Paint Application Methods:

(1) Paint may be applied by a number of methods:

(a) Brushing.

(b) Air spraying.

(c) Airless spraying.

Table 8-4. Continued.

Inspection	Action	Frequency[1,2]
Pneumatic tanks	Inspect air pump and motor; check operating record of time cycle; check for air leaks, if time cycle is too short; check valve operations, particularly pressure relief valves.	Q
	Check tank for signs of corrosion; take steps necessary to eliminate corrosion or protect against it.	A
Appurtenances	Check ladders, walkways, guardrails, handrails, stairways and risers for rust, corrosion, poor anchorage, missing pieces, general deterioration or damage; replace or repair parts as necessary.	SA
Miscellaneous appurtenances.	Check all electrical connections and conduits leading to tanks; make any repairs or adjustments necessary.	SA
Grounds	Check for accumulations of debris, trash and foliage; clean the area.	SA

[1]Q-Quarterly; SA-Semiannually; A-Annually; V-Variable; as conditions may indicate.

[2]The frequencies shown are suggested frequencies which may be modified by local command, as individual installation conditions warrant.

(d) Roller application.

(e) Special methods for applying heavy coatings.

(2) The method best suited for application depends on the type of paint, degree of complexity of the surface being painted, paint viscosity, and other considerations such as the amount of spray carryover with spray painting techniques. The paint manufacturer and a professional painting contractor are able to advise installation personnel of the best application method for the particular tank being painted. All paint application should be according to Tri-Service Manual (DOD) TM5-618, NAVFAC MO-110, AFM 85-3.

c. Paint Selection:

(1) There are several types of paint systems available from paint manufacturers. Varying environmental conditions on the exterior of the tank and water characteristics on the interior of the tank need different painting systems for tanks located in different areas. A reputable paint manufacturer can provide valuable guidance in paint selection based on laboratory testing results and experience with painting systems on similar tanks.

(2) Paint testing may be required on tanks for which a particular paint system has proven unsatisfactory. Various painting systems can be used on different areas of the tank to determine which system performs the best.

(3) The thickness of the dried paint film shold be specified and measured after the painting has been completed. Various paints require varying dry-film thickness for optimum life.

(4) In general, it is best to use paints that require similar surface preparation procedures for both the interior and exterior of the tank since these procedures are usually conducted in a single operation.

(5) American Water Works Association Standard D102, Painting and Repainting Steel Tanks, Standpipes, Reservoirs, and Elevated Tanks for Water Storage, includes standards for several outside and inside paint systems. The standard gives general information on suitability of the paint systems under varying conditions, as well as information about surface preparation, paint film thickness, and procedures for applying paint. Paint systems used for painting tanks on military installations should meet or exceed the requirements established in this standard.

Chapter 9

VALVES

Section A—General Information

9-1. Valve Types. A water supply system requires valves that perform various functions. Besides being used to shut off flow, valves are used for throttling or controlling the quantity of water, regulating pressures within the system, level control in storage facilities, and proportioning flow. A wide variety of valves are available to perform these functions. Valve designs most generally used are discussed in this chapter.

9-2. Valve Operation:

a. Automatic Operation. Automatic valves include check, float, altitude, pressure-reducing, pressure-relief, and air-release valves. Their action is caused by conditions in the water system. Improper functioning of this type of valve is a maintenance matter which is described under the particular type of valve.

b. Manual Operation. Small valves or valves that are used infrequently are generally operated manually. Valves operated manually should be opened all the way, then closed down one-quarter turn of the handwheel. This prevents the valve from sticking in the open position. The valve should be opened and closed slowly and at an even rate to reduce the hazard of a hammer. Unless otherwise indicated, valves are opened by turning the handwheel counterclockwise. Always consult the manufacturer's instructions for operating a specific type of valve.

c. Power Operation. The most common power sources for valve operation are electric motors and hydraulic or pneumatic pressure. Only minimal attention is required for operating power-operated valves, except in the case of power failure. The manufacturer's instructions for emergency manual operation should be consulted in this event. Most power-operated valves are equipped with safety devices to allow for emergency manual operation.

9-3. Valve Accessories. Various accessories are necessary to operate valves properly, depending on their location and use.

a. Valve Boxes. Underground valves must have means for the valve key to reach the operating nut. This is generally done by a valve box as shown figure 9-1. The valve box has a cast iron or plastic pipe about 6 inches in diameter, with a special yoke at the bottom to rest on the valve bonnet, and an adjustable top section with a cover at the street or ground level. Valve boxes are adjustable in height; some have covers with lock nuts to prevent unauthorized access.

(1) Maintenance Schedule. Valve boxes must be maintained on the same basis as the valve maintenance schedule, as shown in table 9-1.

(2) Maintenance. Debris in the valve box should be cleared out, the valve box checked for corrosion, and the elevation of the top and alignment of the box checked to make sure that the valve key can be inserted readily. If the valve box has corroded and is no longer serviceable it should be removed and replaced with a new unit. Height of the valve box should be adjusted so that the cover is at street or ground level.

b. Floor Stands. Valves below a floor may be operated manually or by automatic controls mounted on a floor stand. Some floor stands are equipped with an indicator to show when valves are open or closed. Floor stands are essentially an extension of the valve stem. There are three designs: rising stem, nonrising stem, and nonrising-stem-indicator. They may be plain, ball bearing, or gear operated. Maintenance operations include the following procedures.

(1) Quarterly, lubricate the stem and, on indicator types, the rising-indicator collar.

(2) Each year inspect the condition of the floor stand, clean out corrosion, and paint.

c. Valve-Position Indicators. Different types of valves have different types of valve-position indicators. Nonrising-stem gate valves may have indicators on the floor stand. Filter plant valves may have indicators on the filter operating table. Butterfly valves, or other valves used for flow control or throttling, may have electrical indicators units that resemble an ammeter.

(1) Post Indicators. These indicators are used principally on nonrising-stem gage valves in fire flow systems. The indicator post is operated by an attached operating wrench that acts like a locking device when not in use. The valve is opened by turning the wrench to the left (counterclockwise), unless otherwise indicated. The open or closed position of the valve is clearly indicated by the target plates that show the words "OPEN" and "SHUT" in glass protected openings on both sides of the post. Most post indicators on valves controlling waterflow to fire hydrants are sealed open for safety's sake. If the seal has been broken, the operator should report the tampering to a higher authority at once. Lubricate post indicators at quarterly intervals.

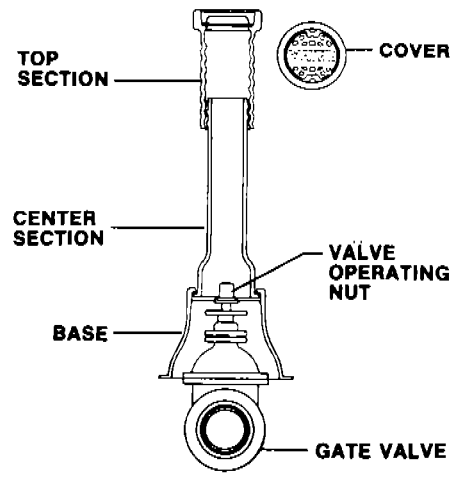


Figure 9-1. Valve Box Applied to Gate Valve.

Table 9-1. Maintenance Procedures for Valves and Accessories.

Inspection	Action	Frequency[1,2]
Manually-operated valves		
Gate valves		
Distribution system valves.	Locate, check operation, lubricate stem packing; if packing leaks, dig up valve and tighten packing gland or replace packing; check stem alignment; check for broken stem or stripped stem or chewed nut.	SA
Valve bypass	Check for position, inspect and lubricate	SA
Gears	Check and lubricate; correct any deficiencies	SA
Vault	Check condition, clean, check masonry; make repairs, as necessary.	SA
Treatment plant valves	Operate inactive valves	Q
	Lubricate as required (including gears)	A
	Replace or resurface leaking valve seats	V
	Lubricate chain wheels	Q
Butterfly valves	Check valve stem for watertightness, and adjust, if necessary.	SA
	Check operation and inspect for tight closure	A
Rotary valves		
Cone valves (and ball valves).	Operate; lubricate metal-to-metal contacts in pilot mechanism; lubricate packing glands; lubricate all parts of seating and rotating mechanisms.	M
	Dismantle, remove corrosion products, wire brush plug and valve body; paint valves with corrosion-resistant paints.	A
Plug valves	Lubricate with lubricant stick	M or Q
	Operate all valves; check for corrosion and foreign matter between plug and seat; lubricate gearing.	Q
	Inspect; dismantle if necessary; clean, wire brush, remachine plug and body or replace if condition is beyond remachining.	A
Curb stops	Remove and replace whenever necessary	V
Multiport valves	Lubricate with grease	SA
Globe valves	Operate valve to prevent sticking; check for leakage, adjust packing nut and replace packing if necessary.	Q
	Check valve closure for tight shutoff; if valve does not hold, remove valve stem and disk and regrind seat and disk.	SA
Diaphragm valves	Operate valve; check valve stem and lubricate as necessary; check for tight closing.	Q
	Check diaphragm for cracks; renew as necessary	A
Sluice gates	Operate inactive gates; lubricate stem screws and gears.	M
	Clean valve with wire brush and paint with corrosion-protective paint.	A
	Check seating wedges on valves seating against pressure.	A
Backflow preventers		
Reduced pressure	Test tightness of unit	M
Power-operated valves		
Hydraulic-cylinder-operators.		
Hydraulic cylinder	Check through one valve operation cycle	M
Piston rod and telltale rod.	Oil packing; tighten packing gland if leakage exists; replace packing if necessary.	M

Table 9-1. Continued.

Inspection	Action	Frequency [1,2]
Waste line discharge	Check for water flow when valve is wide open and shut; if leakage occurs, disassemble valve and piston, check leathers for wear and replace as necessary.	M
Cylinder and piston	Disassemble; inspect for scoring and corrosion; check cup leathers; polish any scored areas; remove corrosion products from piston surfaces and cylinder heads.	A
Pneumatic valve operators.	Check packing and air hose; lubricate as necessary	M
	Check piston, cylinder and leathers; clean and maintain similar to hydraulic valve operators.	A
Valve operator pilot controls.	Check control through one full cycle of operation	M
	Lubricate pins, linkage, packing glands and adjustment rod threads as necessary; remove corrosion products; check for leakage and repair.	M
	Disassemble; inspect unit and clean strainers; examine diaphragm for failure; regrind or replace worn valve seats.	A
Automatic valves		
Air-release valves, valve unit.	Remove valve from service; inspect float for leaks, and pins and linkage for corrosion; remove corrosion products; clean orifices.	A
Vault	Inspect for condition of masonry, steps and manhole covers; repair as necessary.	A
Altitude valves		
Pilot controls	Inspect and lubricate	M
Valve unit and operator.	Disassemble; inspect hydraulic cylinder and repair; inspect valve, repair and paint, as necessary.	A
Check valves	Inspect the closure control mechanism (if any); clean and adjust as necessary; check pin wear if balanced disk type; check seating on ball type.	A
	Disassemble; clean, reseat and repair, as necessary	V
Float valves	Inspect float; repair as necessary	M
	Inspect valve and valve operating mechanism	A
Pressure-regulating valves.	Inspect, clean, adjust, disassemble and repair as necessary (see manufacturer's instructions).	A
Valve accessories		
Gear boxes	Lubricate gears (see manufacturer's instructions)	M or Q
	Check gear operation through full operating cycle; listen for undue noise, etc.	SA
	Check housing for corrosion; paint as necessary	A
Valve boxes	Clean debris out of box; inspect for corrosion; check alignment and adjust as necessary.	SA
Floor stands	Lubricate stem and indicator collars	Q
	Inspect condition; clean and paint	A
Valve position indicator.		
Post indicators	Lubricate	Q
Electric position indicators.	Check contact points, wiring, etc.	A

[1]W-Weekly; M-Monthly; Q-Quarterly; SA-Semiannually; A-Annually; V-Variable, as conditions may indicate.

[2]The frequencies shown are suggested frequencies which may be modified by local command, as individual installation conditions warrant.

(2) Electric Position Indicators. These indicators should be checked for contacts, posts, wiring, etc., at annual intervals. Consult the manufacturer's instructions for maintenance details.

d. Gearboxes. Large manually operated valves and motor-operated valves are operated by gears. These gears are housed in gearboxes. Maintain gearboxes as follows:

(1) Lubrication. Monthly or quarterly, lubricate the gearing according to the manufacturer's instructions.

(2) Operation Inspection. Twice a year, check the gear operation through a complete cycle of opening and closing. Listen for undue noise and observe smoothness of the valve opening operation. Check for lubricant leakage from flanges. If there is any evidence of improper operation, the operator should open the gearbox, inspect the gears, and make repairs as necessary.

(3) Corrosion Control. Each year inspect the housing for corrosion; clean and paint if necessary.

Section B—Automatic Valves

9-4. General Information. Automatic valves are generally of specialized design and control. This type of valve is operated and maintained according to the manufacturer's instructions.

9-5. Air-Release Valves:

a. Valve Uses. This type of valve allows air to escape automatically from a pipe (figure 9-2). As a rule, this type of valve is installed at the high point of a main or transmission line. The purpose of the valve is to prevent accumulations of air at the high point in the line which could reduce the flow capacity of the line and possibly even stop the flow at low pressures. Lines subject to dewatering may have a combination air-release, vacuum-relief type of valve.

b. Valve Inspection and Maintenance. Once a year, at least, remove the valve from service; check the float for leakage; check the pin and linkage for corrosion; remove corrosion products and treat for corrosion; and clean the orifices.

9-6. Altitude Valves. This type of valve is used on inlet lines to elevated storage tanks and standpipes to prevent overflows. Altitude valves are nonthrottling-type valves that remain fully open until the set "shutoff" pressure (level) in the reservoir is reached. One-way-type valves are used where the supply pressure is always greater than the pressure created by the maximum reservoir level. Water must be withdrawn through a separate discharge pipe. The one-way valve opens to refill the reservoir when the water level lowers below the shutoff level. Two-way-type valves close at the set "shutoff" pressure (level) in the reservoir and open for return flow when pressure at the valve inlet lowers below the reservoir pressure.

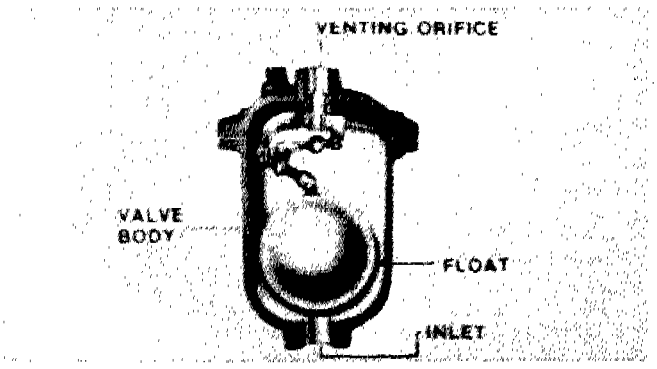


Figure 9-2. Air-Release Valve.

a. Operating Description. The altitude valve is opened and closed by a hydraulic cylinder, which is driven by line pressure. The hydraulic cylinder is controlled by a pilot valve that may be actuated by one of three systems.

(1) A diaphragm-operated pilot valve, which is a hydraulic-cylinder-operated valve that closes when the pressure on the diaphragm reaches a preset value. A hydraulically actuated altitude valve is shown in figure 9-3.

(2) A floated-operated electric switch that actuates a solenoid pilot valve.

(3) A float-operated pilot valve with connecting cable or rod from the float to the pilot valve.

b. Operation and Maintenance. Necessary operation and maintenance checks and procedures vary greatly with the design of the altitude valve. As a rule, the pilot control valve should be lubricated and checked each month as described in paragraph 9-20. As described in paragraph 9-18, disassemble, inspect, and repair the hydraulic cylinder each year. Also, inspect the main valve and repair and paint it when necessary.

9-7. Check Valves. This type of valve permits the flow of water in one direction in a line and closes when the direc-

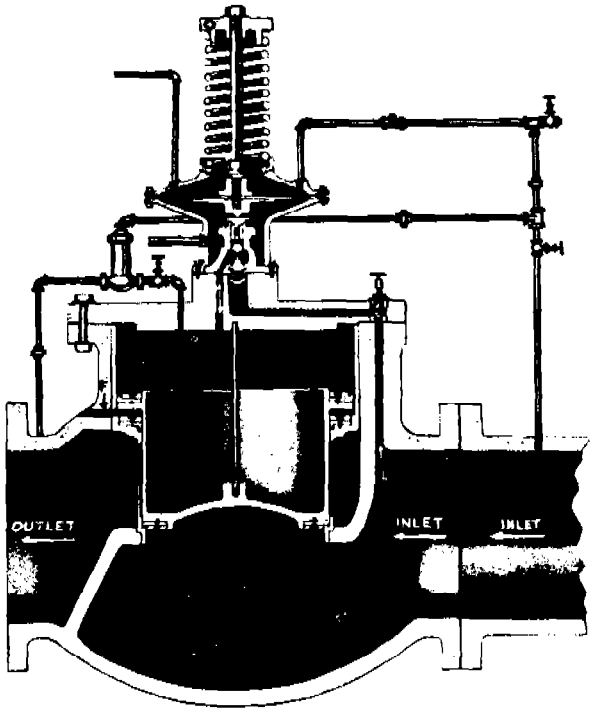
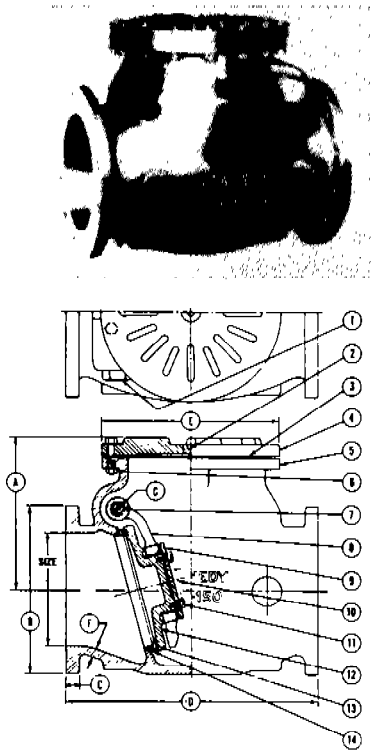


Figure 9-3. Hydraulically Actuated, Globe Pattern Altitude Valve.

tion of flow reverses. Check valves are used in lines where reversal of flow is not desirable, such as in pumping station discharge lines, at pump discharges, or a booster pumping station.

a. Operating Description. Operation of the valve is initiated by a reversal of flow direction. Valve design varies from a simple swinging disc to valves with closure controlled by a spring, weight, or hydraulic cylinder that prevents check slam and water hammer. These external controls on the movement of the disc can assist the disc in closing, allow a predetermined head to accumulate against the disc before it is opened, or assist the disc in opening. The disc seats on a metal, rubber, or leather ring, generally at an angle to the direction of flow. An improperly seated check valve permits leakage. A typical check valve used in water system is shown in figure 9-4.

b. Maintenance. If the check valve has a controlled closure, each year check the spring, lever, or hydraulic cylinder. If a hydraulic cylinder, follow the procedures in paragraph 9-18. Check for pin wear on the balanced disc check valve. When improper operation is found, disassemble the check valve and make whatever repairs are necessary.



Part No.	DESCRIPTION	MATERIAL	A.S.T.M. SPEC.
1	Side Plugs	Bronze Rod	B-139 Alloy B-2
2	Counter Sink Pipe Plug	Bronze	B-62
3	Gasket	Asbestos Sheet	
4	Cap	Cast Iron	A-126 Class B
5	Body	Cast Iron	A-126 Class B
6	Cap Bolts & Nuts	Steel (Rust Proof)	A-307 Grade B
7	Hinge Pin	Bronze Rod	B-139 Alloy B-2
8	Hinge	Malleable Iron	A-47
9	Disc Retaining Plate	Steel Plate	
10	Lock Wire		
11	Hex Head Cap Screws	Steel (Rust Proof)	A-307 Grade B
12	Disc	Cast Iron	A-126 Class B
13	Disc Ring	Bronze	B-62
14	Seat Ring	Bronze	B-62
15	Disc Holder	Malleable Iron	A-47
16	Lock Wire		
17	Disc Plate	Bronze	B-62
18	Hex Head Cap Screws	Steel (Rust Proof)	A-307 Grade B
19	Disc	Rubber	

Figure 9-4. Typical Swing Check Valve.

9-8. Float Valves. This type of valve is used as a control valve in wash-water tanks and sedimentation basins and occasionally as an altitude valve in distribution systems. Vertical movement of the float in a tank mechanically opens and closes the valve. The valve may be one of a number of different types, depending on the application. Maintenance requirements vary with the design of the valve. Monthly inspection of the float is desirable. Proper operations of the external float valve mechanism is critical. Inspection schedule should be set to assure proper operation. Inspection and maintenance of the internal parts of the valve itself should follow that specified for the type of valve body being used (that is, gate, globe, etc.).

9-9. Pressure-Regulating Valves:

a. Pressure-Reducing Valves. These valves throttle the flow in pipes to reduce pressure on the discharge side and keep it constant. They are used for feeding water from a high-pressure system to a low-pressure system. Valve design and operating principles depend on the manufacturer. A typical pressure-reducing valve is shown in figure 9-5. Most designs use a pilot valve to actuate the main valve. Within limits, the discharge pressure can be varied by changing the setting of the pilot valve.

b. Pressure-Relief Valves. Pressure-relief valves discharge water from pipes or systems when the desired pressure is exceeded. They are installed on low-pressure systems fed through pressure-reducing valves from high-pressure supplies to avoid damage if the pressure-reducing

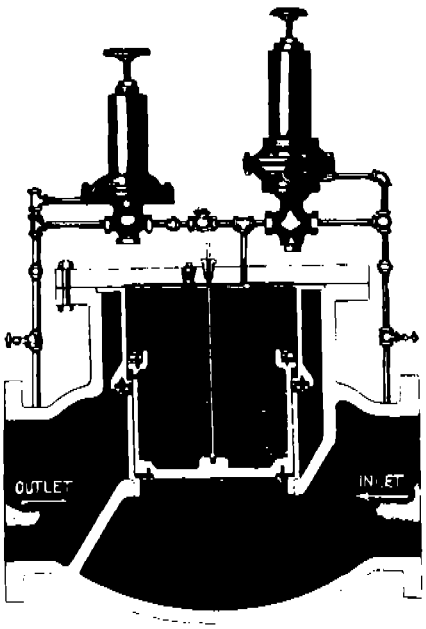


Figure 9-5. Pressure Reducing Valve.

valves fail to operate. They are also used on pump headers discharging into large supply mains to relieve the high surge pressure that builds up between the time a pump is started and the time water in the main reaches full velocity. Relief valves are essentially pressure-reducing valves in which the control mechanism responds to pressure on the inlet rather than the outlet end.

c. Pilot Valve Maintenance. Maintenance procedures for the pilot valve should follow the instructions given in paragraph 9-20. Other inspection and maintenance should conform to the manufacturer's instructions, but should be conducted at least once a year.

Section C—Manually Operated Valves

9-10. Gate Valves. This type of valve is either generally closed to prevent the flow of water in a pipe or fully open, permitting unobstructed flow of water. Using throttled gate valves to control flow leads to excessive wear, and may result in vibration problems. Gate valves are used in distribution systems, pumping stations, and water treatment plants. When used in the distribution system, gate valves may be buried or placed in special vaults.

a. Description and Types. Gate valves are of simple construction, consisting of a stem, a gate, a body, and a bonnet. Differences in types of gate valves are associated with the type of stem and disc used. Various parts of a typical gate valve are shown in figure 9-6.

(1) Rising Stem. This type of gate valve has a stem that rises out of the valve body as the valve is opened. Rising-stem valves used in waterworks generally have screwed threads on the outside of the stem, a yoke, and are operated by a handwheel. This type of gate valve is generally used inside buildings where the valve can get fairly frequent maintenance. Use in buried installations is not desirable because of the rising stem. Use in vaults or unattended locations is not desirable because the operation of the valve may be affected by corrosion or lack of maintenance on the stem.

(2) Non-Rising Stem. This type of gate valve is commonly used in the distribution system. The valve stem does not rise as the valve is opened.

b. Distribution System Valves. These gate valves are usually equipped with an operating nut 2 inches square, which requires a valve key for operation. Most distribution system valves are buried and the operating nut is accessible through a valve box, as described in paragraph 9-3. Common difficulties with distribution system valves are "lost" valves, inoperable valves, and valve boxes that have been covered by road work or filled with foreign matter.

(1) Location Records. The "lost" valve problem can be handled by recording all valve locations in an indexed valve record book in which all pertinent data can be recorded. The location should be referenced with respect to fixed markers. If a valve is "lost", use a dip needle, miner's compass, or a metal detector to locate the valve box. The valve record must include maintenance operations performed, whether the valve was opened or closed at the time of inspection, and any errors in location. One copy of the valve record book should be kept with the maintenance crew and one should be on file in the utility room.

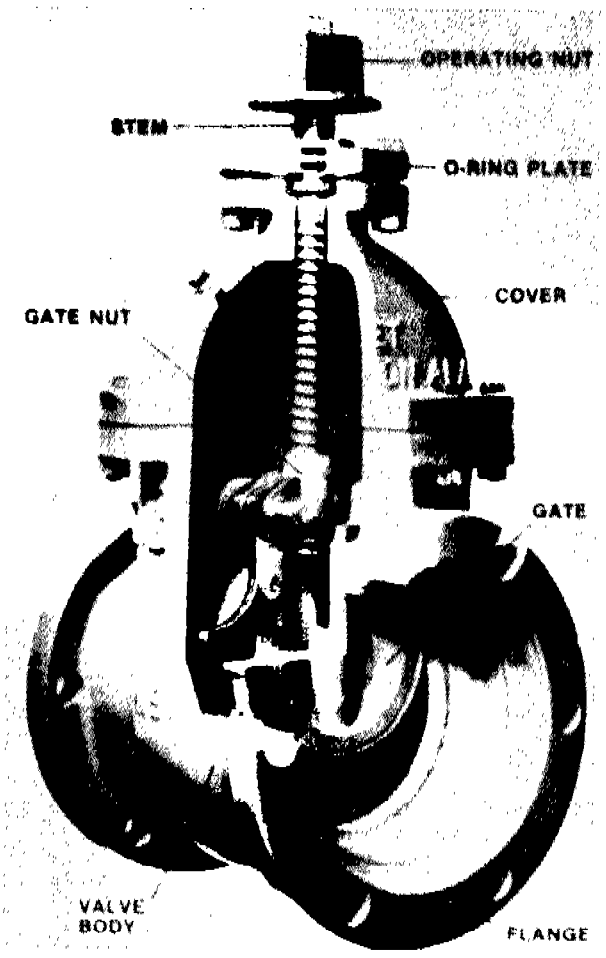


Figure 9-6. Typical Non-Rising Stem Gate Valve.

(2) Operation and Maintenance. Periodic inspection, operation, and maintenance of distribution system valves keep problems to a minimum. Distribution system valves are usually left open and only operated during emergencies; proper maintenance helps make sure that the valves operate when needed.

(a) Frequency of Inspection and Operation Procedure. Each valve should be operated twice a year and any indicated maintenance carried out. To check the operation of the valve, first close the valve completely and then open completely. Back off on the valve about one turn to avoid locking the valve in an open position.

(b) Maintenance Procedures. If proper valve operation is not obtained, necessary maintenance and repair should be done at once.

1. Valve Seating. If the valve does not seat properly in closed position, the problem is usually due to the accumulation of foreign matter on the valve seat. Open the valve slightly to give a high-velocity flow across the valve seat. If necessary, open a hydrant to increase flow enough to flush foreign matter from the valve seat.

2. Valve-Stem Sealing:

a. Packing. Check and lubricate the valve-

stem packing. If the packing is dry, it impedes valve closure at all points of the stem movement. Lubricate dry packing by pouring a mixture of half kerosene and half lubricating oil down a ½-inch pipe to discharge the mixture onto the stem below the operating nut. If the packing leaks, dig up the valve, tighten the packing gland, or replace the packing as necessary. To reduce leakage while replacing packing, open the valve as wide as possible.

b. O-Ring Seals. Most modern valves use O-rings seals, rather than packing. If water is leaking around the stem, the O-rings must be replaced.

3. Valve Stem. Valve stems may be out of alignment, broken, or have the threads stripped. If the valve stem is out of alignment, the valve operates easily near open or closed positions, but not when the valve is partially closed. A broken or stripped stem permits unlimited turning of the stem without closing the valve. All of the above conditions require replacement of the valve stem. Follow the manufacturer's instructions for removing and inserting the stem. If the valve-stem nut is missing or damaged, replace it.

4. Refacing the Valve Seat. When a gate-valve seat leaks, remove the valve and reface the valve seat. The procedure to follow is detailed by the manufacturer's instructions; it includes these general steps:

a. Remove the bonnet; inspect and clean all working parts.

b. Check all working parts for signs of wear or deterioration.

c. Remove old packing or O-rings.

d. Refinish the working parts by grinding, sanding or polishing, and lapping; replace all parts beyond repair.

e. Replace the valve parts; repack and test the valve for proper operation.

5. By-pass Valve. Larger gate valves sometimes have a small valve installed parallel to the larger valve. The purpose of the smaller valve is to facilitate opening and closing the large valve. When closing, shut the larger valve first, and then the by-pass valve. To open the larger valve, open the by-pass valve to make pressure equal on both sides of the larger valve, and then open the larger valve. If the by-pass valve is a gate valve, follow the maintenance procedures outlined above. When the by-pass valve is a globe valve, follow maintenance procedures in paragraph 9-13.

6. Valve Gears. Large gate valves often have geared operators to reduce the amount of torque required to open and close the valve. Maintain valve gears according to paragraph 9-3d.

7. Vault Maintenance. If the valve is installed in a manhole or vault, check the masonry each year for deterioration and the steps for rust damage. Inspect manhole covers for proper sealing and grade; repair covers and correct the grade, if necessary, to keep water from entering.

c. Treatment Plant Valves. Valve inspection and maintenance procedures are as given below. Inactive valves should be operated at quarterly intervals to prevent sticking. The threads on all rising-stem valves should be cleaned and lubricated quarterly also. All valves should be lubricated each year according to the manufacturer's instructions. If valve gearing is open, wash the gears with kerosene and lubricate them with a recommended lubricant (see table 11-5). Chain-wheel valve operators should be lubricated quarterly.

9-11. Butterfly Valves. This type of valve is used in both treatment plants and the distribution system. Properly designed butterfly valves can be used in any application that gate valves are, including as buried valves in distribution systems.

a. Description. A butterfly valve consists of a body, valve disc, valve seat, and bearing on each end of the shaft, as shown in figure 9-7. When closed, the valve disc is forced against the valve seat, which is a rubber or rubber-like synthetic compound. All but very small butterfly valves are either gear or power operated. Butterfly valves are more adaptable to throttling than gate valves, but care must be given to avoid eccentric forces on the valve disc to keep excessive wear on valve components to a minimum.

b. Operation and Maintenance. Due to the simplicity of design and method of operation, little maintenance is required.

(1) Valve Operation. Only a quarter turn of the shaft is required to bring the butterfly valve from completely open to completely closed. All large valves are geared to prevent rapid valve closing and associated water hammer problems. The number of turns needed to close each butterfly valve within the system should be known and a part of the valve record. Valves should be checked each year for proper operation and tight closure.

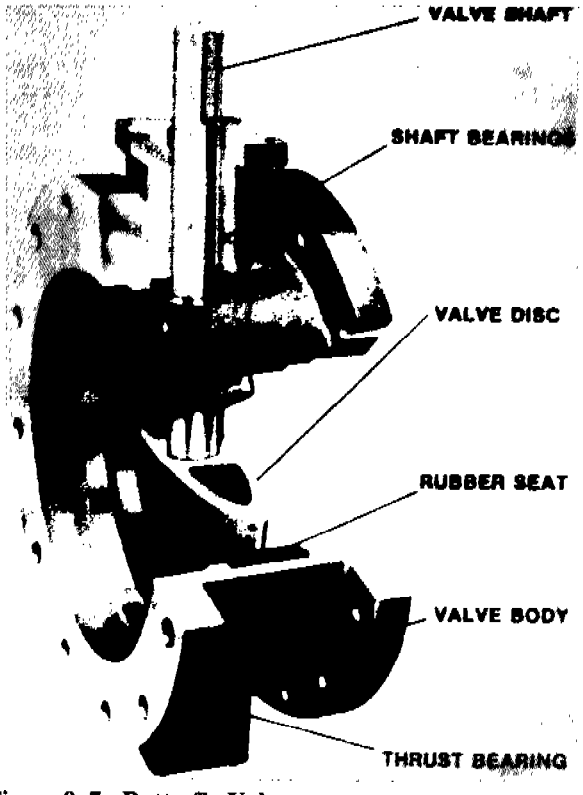


Figure 9-7. Butterfly Valve.

(2) Valve Stem. Valve stems should be checked for water-tightness twice a year and adjusted if necessary according the manufacturer's instructions. Some butterfly valves require lubrication of shaft journal bearings. On these valves, lubrication should be done after approximately 1,000 cycles of operation.

(3) Valve Operator. Problems with improper operation are generally a result of difficulties with the proper gears or the valve operator. See the manufacturer's instructions regarding gearing; maintenance of valve operators is covered in paragraphs 9-16 through 9-20.

(4) Valve Seat. Tight valve seating is a result of the interference between the rubber seat and the disc. Proper quality of the valve seat depends on the number of times the valve is operated. Most butterfly valves allow valve seat adjustment. To maintain tight closure, adjust the valve seat according to the manufacturer's instructions. To replace the valve seat or other valve components, the valve must be removed from the installation.

9-12. Rotary Valves. All rotary valves go from a completely closed to a completely open position with a one-quarter turn of the valve shaft. This type of valve has a rotating body that, in the closed position, seals off the entire cross-sectional area of the valve. An opening through the rotating body allows the water to flow through the valve in the open position.

a. Plug Valves. The rotating body on this type of valve has a solid cylinder with a hole through it. There are a number of different designs, so manufacturer's instructions regarding operation and maintenance should be checked. The most commonly encountered plug valves in water systems are lubricated plug valves, curb stops, and corporation cocks.

(1) Lubricated Plug Valves. This type of plug valve is lubricated by oil under pressure. Pressure is applied to the oil by a screw. The oil is forced through grooves in the plug and collected in a small chamber beneath. A typical lubricated plug valve is shown on figure 9-8.

(a) Lubrication. Each month or quarterly, depending on the manufacturer's recommendations, lubricate the valve with a stick lubricant made specifically for this purpose. Supply enough lubricant so that turning down the screw will supply the needed amount.

(b) Operation and Maintenance. The following operation and maintenance procedures are the minimum required and apply to lubricated plug valves. Check the manufacturer's instructions for required variations.

1. Quarterly, operate valve check for possible corrosion and entrance of foreign matter between the plug and the seat. Lubricate gears where they exist.

2. Each year, inspect the valve to see if it should be dismantled and reconditioned. Consult the manufacturer's instructions for reconditioning techniques.

(2) Curb Stop. This type of plug valve (figure 9-9) is commonly placed on the waterline running from the distribution main to the individual user. As such, it is one of the most common valves in a water distribution system. These valves are almost always buried with a valve key box above to permit access to the curb stop. A regular inspection and maintenance schedule is not followed for this type of valve. When necessary, the curb stop is dug up, replaced, and taken to a maintenance shop for repairs.

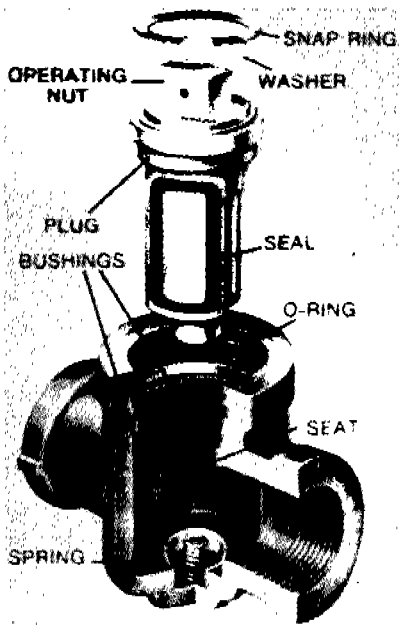


Figure 9-8. Lubricated Plug Valve.

(3) Corporation Cock. These valves are used to connect the individual service line to the distribution main. They generally have a threaded end which is tapped directly into the main pipe well, with the other end of the valve used for the service line. These valves are buried, without access through a valve box, and must be dug up for closure or repair.

b. Cone and Ball Valves. A cone valve is a plug valve with a tapered, rotating body, which allows the cone plug to seat against the valve body. In a ball valve the rotating body is ball-shaped with a hole through it.

(1) Valve Operation. In cone and ball valves, the rotating body seats against the valve body. During opening

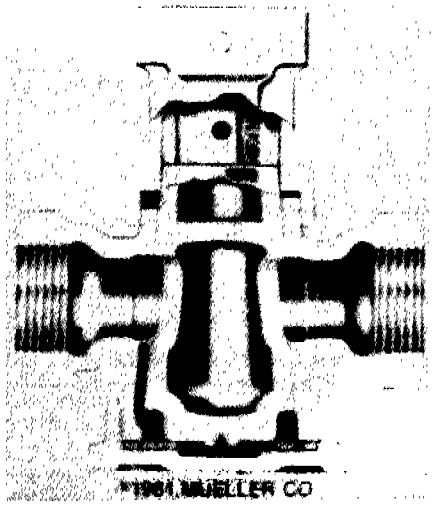


Figure 9-9. Curb Stop.

or closing, the valve is lifted off its seat, revolved, and reseated. In small valves the operation is entirely manual, but larger sizes require hydraulic cylinders for operation. The hydraulic cylinder may be activated either manually or automatically.

(2) Inspection and Maintenance. There are a number of different designs for these two types of rotary valves. Follow the manufacturer's instructions for inspection, lubrication, and maintenance. As a rule follow the maintenance schedule given in table 9-1.

c. Multiport Valves. These valves are used almost exclusively on ion-exchange water softeners or pressure filters.

(1) Description. Each manufacturer's design differs in some respect from that of other manufacturer's. Basically there is a valve body with openings for a raw water inlet form pipes to the top and bottom of the treatment tank, to the distribution system, to a waste drain, and for the brine supply. Flow from the various inlets can be directed to the top or the bottom of the tank by changing the position of the valve within the body. The valve is a plug-like body that rotates and has slots placed in it to allow the various flow patterns to take place. The multiport valve may be operated manually or automatically.

(2) Inspection and Testing. Each valve must be inspected, tested for leaks, and repacked (if necessary) twice a year.

(3) Lubrication. Twice a year, service and lubricate the valve in strict conformance with the manufacturer's instructions. Lubricate by applying grease with a pressure gun to each grease fitting while the valve is set in "service" or "wash" position. Turn valve half a turn and add more grease. Give the valve several full turns to spread the lubricant. The lubrication procedure does not require that the unit be removed from service, but if the waterflow is stopped, grease will not get into the water. Older multiport valves without grease fittings must be disassembled for lubrication. Comply with the manufacturer's instructions on disassembly and lubrication.

9-13. Globe Valves. This type of valve is best suited for applications that require flow throttling or frequent operation. Globe valves may be used as by-pass valves for large gate valves or within water treatment plants. Because of the valve configuration, they offer more resistance to flow and pressure drop than gate or butterfly valves, and thus are not well suited for locations where keeping pressure drop to a minimum is desirable.

a. Description. In a globe valve, both the valve disc and valve seat are arranged parallel to the direction of flow as shown on figure 9-10. It is this configuration that makes this a good throttling valve with few maintenance problems and causes the high head loss through the valve. Since these are generally small valves, they are usually manually operated with a rising stem.

b. Operation and Maintenance. Operate the valve quarterly to prevent sticking. At the same time, check the valve for stem leakage. To eliminate stem leaks, first adjust the packing nut; if stem leakage does not cease, open the valve wide, remove the packing nut and packing and replace old packing with new packing. Check the valve closure twice a year for possible leakage between the valve seat and disc. If the valve does not hold, remove valve stem and disc and replace the valve disc with a new one. If both the valve seat and disc are worn, regrind or install a new disc and seat. Comply with the manufacturer's instructions for repairing globe valves.

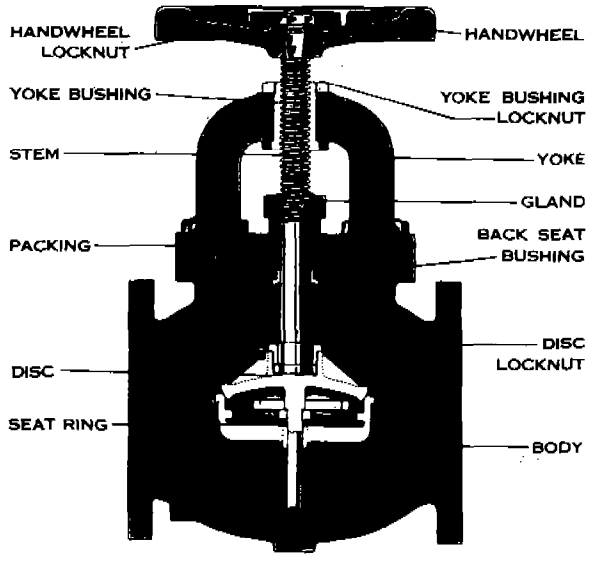


Figure 9-10. Outside Screw and Yoke Globe Valve.

9-14. Diaphragm Valves. The only part of the valve in contact with the fluid is a natural or synthetic rubber sleeve. This valve structure is very resistant to corrosive fluids and in water supply systems is used in chemical feed lines.

a. Description. In this type of valve a compressive force is applied to the outside of the rubber sleeve to narrow and finally close the sleeve opening. The compressible sleeve allows the valve to be used for throttling and assures a completely closed position, even around solid materials that may be in the valve. The outside compressive force may be applied mechanically (two parallel metal plates being drawn together) or by pneumatic or hydraulic pressure greater than the internal pressure. The compressive force acts on the area on the outside of the sleeve, thus forcing it to close.

b. Operation and Maintenance. Operate the valve quarterly and check for tight closing. Check the valve stem and lubricate as necessary. Check the diaphragm each year for cracks or other signs of deterioration. Install a new diaphragm as necessary, following the manufacturer's instruction.

9-15. Sluice Gates. This type of valve is used to open or close openings in walls or to control flow in open channels. They may be used in water treatment plants or the structures conveying raw water to the treatment plant.

a. Description. The valve is a rectangular metal gate which slides in a trackway along each side (figure 9-11). A sluice gate that seats with the pressure must be on the water

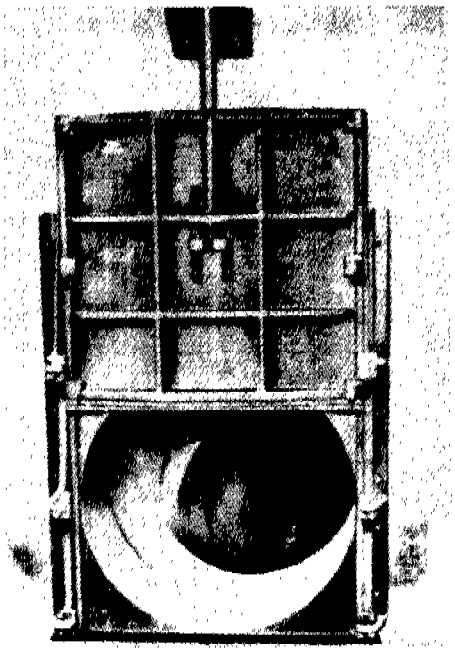


Figure 9-11. Sluice Gate.

side of the wall and the one that seats against the pressure must be on the outside of the wall. Sluice gates seating against pressure have wedges in the trackway to provide a tight closure. The gate is operated manually, by a handwheel through a gear drive, or by motor drive.

b. Operation and Maintenance. Operate all inactive gates and test all sluice gates for proper operation every month. Lubricate stem screws and gears. Clean the sluice gate each year with a wire brush and paint with a corrosion resistant paint. If the gate is one that seats against pressure, check all wedges and adjust as necessary to provide a uniform force at all wedges.

Section D—Valve Operators

9-16. General Information. Many valves in water treatment plants are equipped with power operators. The power operator is designed to open and close the valve at the proper rate to prevent water hammer and may also be used to set throttling characteristics of the valve. Power operators may be actuated by manual control, either at the operator or form a remote location, or automatically by various instrumentation. The power operators may be used on a variety of valve types.

9-17. Motorized Valve Operators. This type of valve operator serves where electric power is used to actuate the operator or where large forces are required to open, close, or position the valve. The motor-driven operator provides a uniform force for valve closing.

a. Description. The valve operator consists of an electric motor and a set of gears. The gears connect the electric motor to the valve shift. Proper gearing is necessary to give the desired rate of valve closing and to develop the proper amount of torque. A number of different methods are available to control the operation of the electric motor. The motor must be reversible.

b. Operation and Maintenance. The controls concerning the operation of the electric motor should be inspected and maintained according to the manufacturer's instructions. Limit switches should be checked quarterly.

(1) Electric Motors. Electric motor maintenance is described in paragraph 4-5b.

(2) Gear Drives. Quarterly or after 500 hours of operation, drain and change lubricant. Follow the manufacturer's instructions for selecting lubricant and other inspection and maintenance work.

9-18. Hydraulic Valve Operators. This type of valve operator uses hydraulic pressure to provide the power to open, close, and position valves.

a. Description. A hydraulic cylinder is directly attached to the valve stem or is attached by a gear arrangement to provide proper movement of the valve stem for valve operation. Pressurized fluid for operating of the hydraulic cylinder is provided from a central system or a hydraulic pump that may supply several hydraulic operators.

b. Operation and Maintenance. The hydraulic cylinder should be checked while the valve goes through an operating cycle at monthly intervals. Disassemble the cylinder and piston each year.

(1) Monthly Maintenance. Oil the packing around the piston rod and the tell-tale rod. Tighten the packing gland if leakage exists and replace the packing if normal tightening of the packing nut does not stop leakage. If the waste line continues to discharge water when the valve is in either the open or closed position, disassemble the cylinder and check position cup leathers for wear.

(2) Annual Maintenance. Polish out scoring in cylinder liners with fine emery cloth. Check cup leathers for wear and replace if necessary. Where the piston and telltale rods contact the packing, check for scoring and polish out as necessary. Remove any corrosion products from the cylinder head and piston surfaces. Apply protective paint where required.

9-19. Pneumatic Valve Operators. Pneumatic and hydraulic valve operators are very similar; the main difference is that air pressure is used to operate the cylinder of the pneumatic operators. The necessary air pressure is supplied by a compressor and air distribution system. Operation and maintenance procedures are almost the same as those for hydraulic valve operators.

9-20. Valve Pilot Controls:

a. General Information. Hydraulic and pneumatic valve operators and automatic valves with internal cylinders are usually actuated by pilot valves. This type of valve may follow a variety of designs and can be operated manually, by a pressure differential, an electric motor, or by a solenoid.

b. Operation and Maintenance. Because of the wide variety of designs, the manufacturer's instructions should be followed in addition to the following maintenance procedures:

(1) Monthly Maintenance. Check the pilot control valve during one complete cycle of operation. Lubricate the pins and linkage, the packing glands, and the threads and adjustment rods. Remove any corrosion products that might interfere with proper operation. Check for leakage at any point where it might exist and make necessary corrections.

(2) Annual Maintenance. Disassemble and inspect the pilot valve unit. Clean strainers and piping lines, examine diaphragm, and grind or replace valve seats that show evidence of pitting and leakage.

Section E—Backflow Preventers

9-21. General Information. Backflow preventers are used to prevent flow through potential cross-connections. Any connection between a potable water system and a nonpotable one through which a contaminating flow can occur is a cross-connection. Cross-connections can occur at numerous places within a water system, and contamination of the potable water system can lead to poor aesthetic quality, wide-spread illness, and even death from toxic substances. Thus, identifying the need for backflow preventers, selecting the proper type of backflow preventer, and the proper operation and maintenance procedures are necessary to ensure the security of the potable water system.

9-22. Classes of Backflow Devices:

a. Approved backflow devices must be installed based on the degree of hazard. These hazards are divided into three classes, which are defined below:

(1) Class I—Low Degree of Hazard. If a backflow were to occur, the resulting health significance would be limited to minor changes in the esthetic quality, such as taste, odor, or color. The foreign substance must be nontoxic and nonbacterial in nature, with no significant health effect.

(2) Class II—Moderate Degree of Hazard. If backflow were to occur, the resulting effect on the water supply would be significant changes in esthetic qualities. The foreign substance must be nontoxic to humans.

(3) Class III—High Degree of Hazard. If a backflow were to occur, the resulting effect on the water supply could cause illness or death if consumed by humans. The foreign substance may be toxic to humans either from a chemical, bacteriological or radiological standpoint. Effects of these contaminants may result from short- or long-term exposure.

b. Devices that protect the potable water supply from these hazards are listed in table 9-2. Terms contamination, pollution, backflow and backsiphonage are explained in attachment 1.

Table 9-2. Approved Backflow Devices.

Degree of Hazard	Allowed Approved Devices
Class I	Air Gap
	Atmospheric Type Vacuum Breaker
	Pressure Type Vacuum Breaker
	Double Check Valve Assembly
	Reduced Pressure Principle Device
Class II	Air Gap
	Double Check Valve Assembly
	Reduced Pressure Principle Device
Class III	Air Gap
	Reduced Pressure Principle Device

9-23. Approved Backflow Devices:

a. Air Gap. An approved air gap may be used under any and all conditions of hazard and pressure conditions.

b. Vacuum Breakers. Pressure and atmospheric vacuum breakers are primarily in-plant or end-of-service line solutions to cross connection. They are not used in water service connections. They are placed at the end of a line, and at fixtures or equipment that discharge to atmospheric pressure. These do not protect against back pressure, only against backsiphonage. There must be no valve downstream from an atmospheric type vacuum breaker.

c. Reduced Pressure Principle Device. This device protects against both back pressure and backsiphonage and can be used for any degree of hazard.

d. Double Check Valve Assembly. This device works in a back pressure or backsiphonage mode. This device neither discharges water, nor does it provide a visual sign of backflow or unit malfunction. Therefore, it does not offer the degree of protection provided by the reduced pressure principle device.

NOTE: Vacuum breakers are permitted on irrigation systems regardless of hazard class for protection from backsiphonage only.

9-24. Installation Practices. The selection of proper devices is very important. However, having the proper device on the connection is not sufficient; the device must be installed correctly.

a. Before installing any device, the pipeline should be thoroughly flushed to remove any foreign material.

b. If the approved device does not have shutoff valves, valves should be installed on each side of the device, so the device can be maintained and tested. A ¼-inch test cock must be installed on the inlet side of the inlet shutoff valve.

c. Devices must be installed according to manufacturer's instructions.

d. Devices must be installed in an accessible location, with ample clearance to aid in testing and maintaining the device.

e. Discharge from reduced pressure principle devices' relief valve must not be into sumps, drains, etc. The minimum clearance above floors or grade is to ensure an air gap between the relief valve and any water that might puddle beneath the device. The maximum height is needed so the device can be easily maintained and tested. Devices should be protected from freezing in a protective insulated enclosure or installed within the building. In extremely cold areas some form of heat should be provided within the enclosure.

9-25. Reduced Pressure (RP) Principle Devices. The proper installation of an RP device on a building service con-

nection is shown in figure 9-12. The RP device can also be used for internal protection.

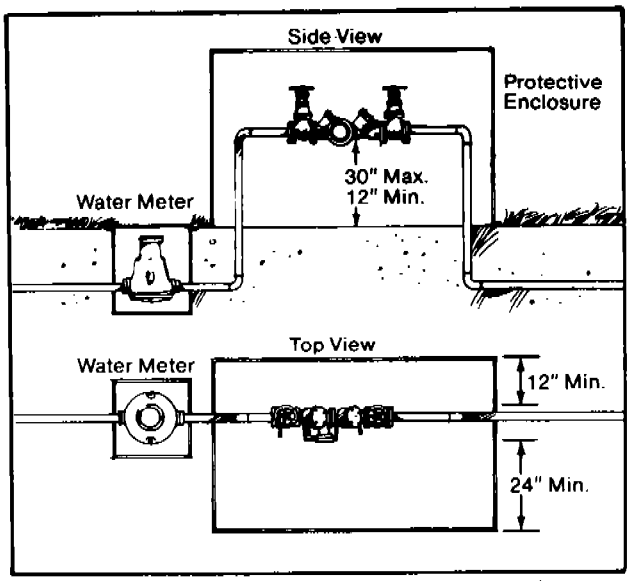


Figure 9-12. Installation of a Reduced Pressure Principle Device.*

9-26. Double Check Valve. A typical installation of a double check valve on a service connection is shown in figure 9-13. This device can also be used for internal protection as well. Minimum and maximum distances are the same as that for the RP device.

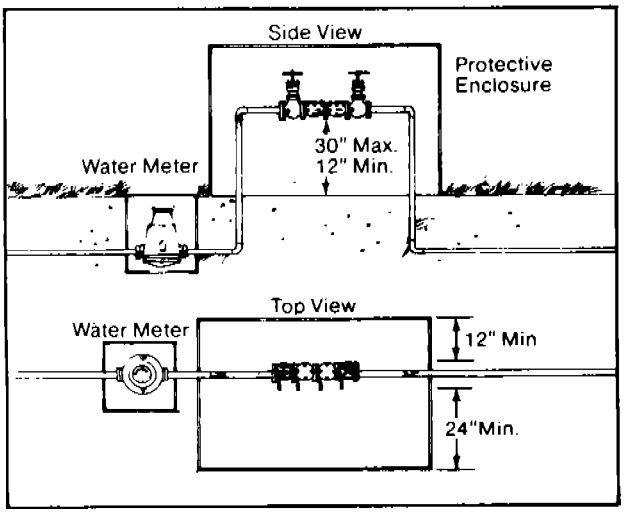


Figure 9-13. Double Check Valve.*

9-27. Pressure Vacuum Breaker (PVB). The pressure vacuum breaker cannot be installed where there can be back pressure, only where there can be backsiphonage. The pressure vacuum breaker can have shutoff valves downstream of the device. The pressure vacuum breaker must be installed at least 12 inches above the highest outlet or, if it is feeding an open tank, at least 12 inches above the highest overflow rim of the tank. A typical installation on a lawn sprinkler system is shown in figure 9-14.

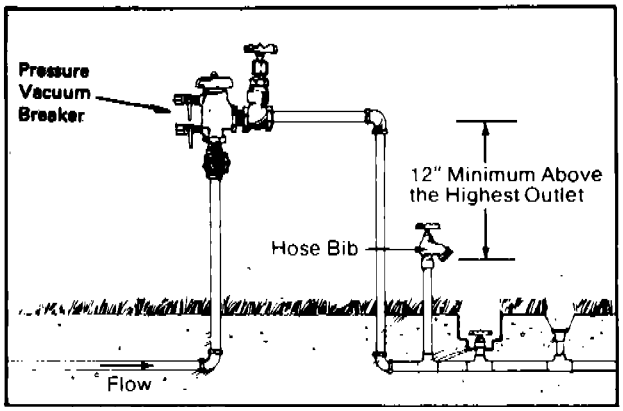


Figure 9-14. Pressure Vacuum Breaker.*

9-28. Atmospheric Vacuum Breaker (AVB). Just as the pressure vacuum breaker, the atmospheric vacuum breaker cannot be installed where there can be back pressure, only where there is backsiphonage. The AVB cannot have any shutoff valves downstream of it. It must be installed at least 6 inches above the highest outlet or the top most overflow rim of a nonpressure tank. A typical installation on a sprinkler system is shown in figure 9-15.

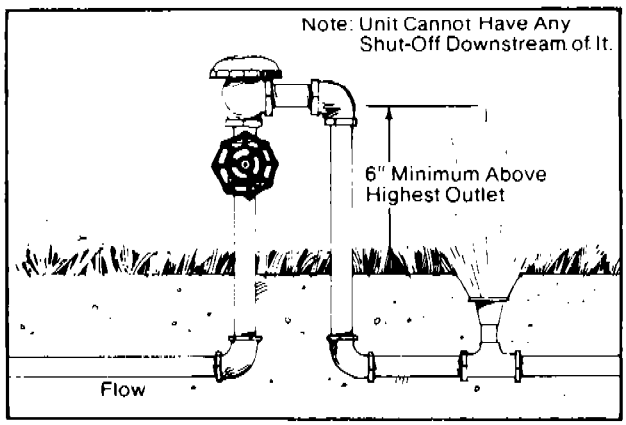


Figure 9-15. Atmospheric Vacuum Breaker.*

9-29. Air Gap. An air gap shown in figure 9-16 is the physical separation of a potable water system supply line and the flood rim of an open receiving tank. The gap must be at least two times the diameter of the supply pipe, but not less than 1 inch.

9-30. Battery (Parallel Installation). Critical potable water supplies should have parallel installation of the proper approved backflow prevention device. The installation of parallel reduced pressure principle prevention is illustrated in figure 9-17. This avoids interruption to water service when maintenance or testing is required. This type installation also provides higher flow capacity than provided by one backflow preventer.

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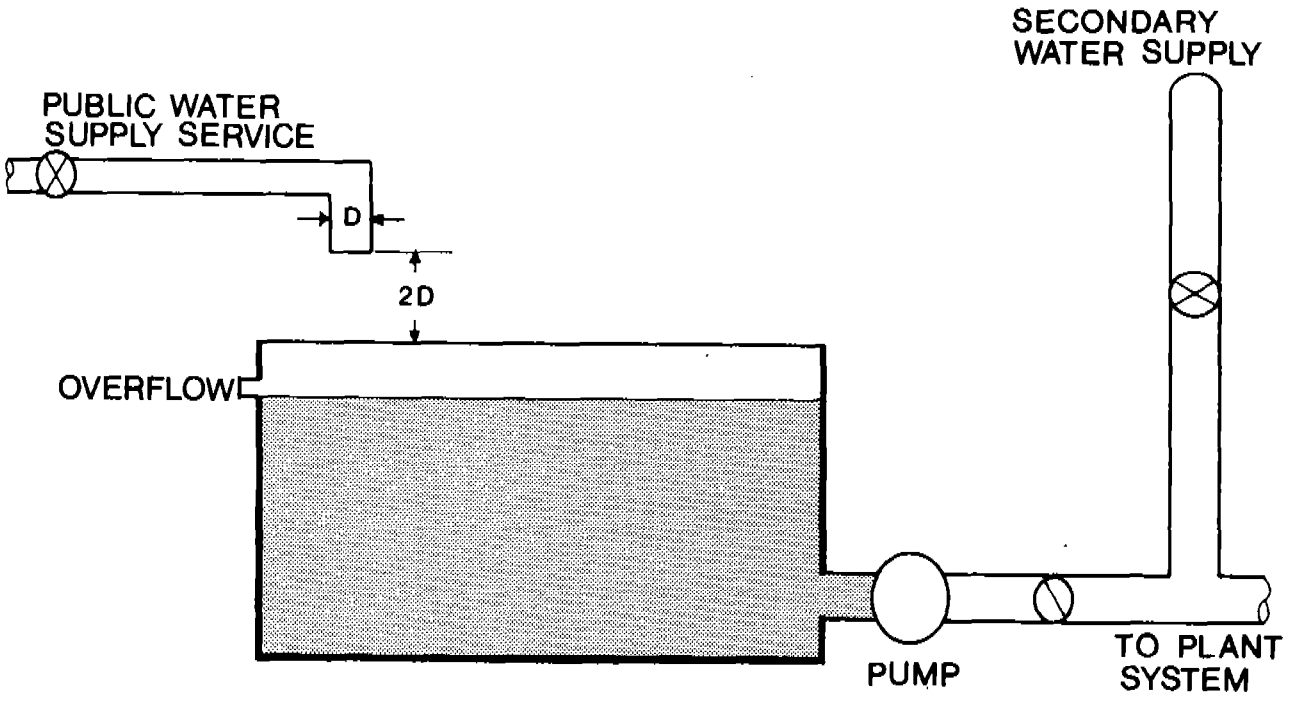

Figure 9-16. Safe Air Gap—Ground Level Storage Tank.

9-31. Unapproved Methods. Other methods and devices have been promoted for the separation of auxiliary systems or for the prevention of backflow. Among these are the single check valve, the swivel connection, the removable section or spool, and the barometric loop. None of these methods are approved for use in military water systems. Reasons for their unacceptability are discussed below:

a. A single check valve offers no visual or mechanical means of determining malfunctioning and, since all such mechanical devices are subject to wear and interference resulting from deposits and other factors, the single check valve is not considered an adequate backflow preventer.

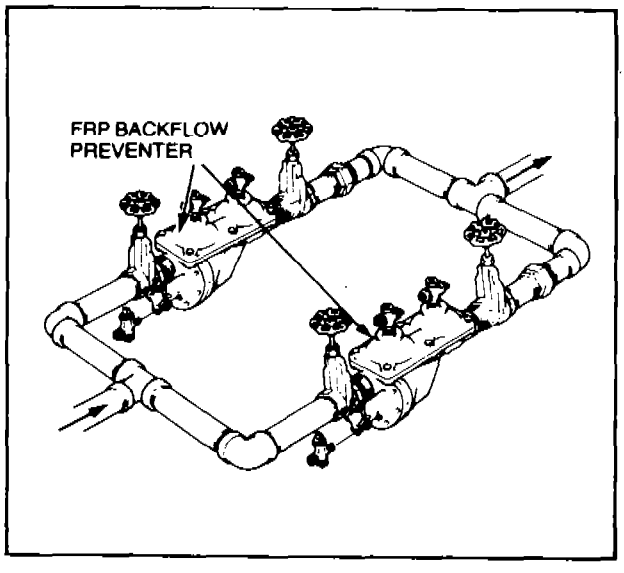

Figure 9-17. Parallel Installation.**

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b. The swivel connection and removal section or spool are too easily allowed to remain in place to be considered an acceptable means of backflow prevention.

c. A barometric loop consists of a vertical section of pipe, extending at least 35 feet above the highest fixture. The principle is that a complete vacuum cannot raise water to an elevation greater than 33.9 feet. The device does not provide for protection against backflow, due to back pressure, and the installation of a pipe loop of this height is usually costly and impractical.

9-32. Testing and Inspection Schedule. A schedule for testing and inspecting all backflow protection devices, including air gaps is required at each installation. The frequency between testing, inspecting, and overhauling of each device must be set up according to the age, condition of each device, and degree of hazard. All devices installed on Class III high degree of hazard cross connections must be inspected at least once every 6 months (table 9-3). Overhaul intervals are as recommended by the manufacturer, but must not exceed 5 years. The inspecting and testing schedule must be placed in the recurring work program.

Table 9-3. Suggested Time Intervals for Inspection.

Degree of Hazard	6 Months	12 Months	24 Months
Class I			X
Class II			X
Class III	X		
Class III (Air Gap)		X	

9-33. Inspection of Cross-Connections. A certified backflow inspector must inspect all cross connections, to ensure that:

a. An approved air gap is maintained.

b. Backflow prevention devices are in good condition.

c. Proper installation of newly installed devices and debris resulting from the installation do not interfere with functioning of the device. (This inspection must be done within 1 week after acceptance and 3 months after installation.)

9-34. Testing of Devices. All testing must be according to the manufacturer service instructions. If found to be defective, the device must be repaired and retested until found to be in satisfactory condition.

9-35. Records of Inspection. An appropriate form approved by the military service must be used to record data on all cross-connections. The location, degree of hazard, description of air gap or protective device installed, and a sketch of the installation must be provided on the form. After each inspection is completed, the date of inspection, test results, observations, corrective action taken, and name of the inspector must be recorded on the appropriate form. For an air gap, the test consists of a visual inspection and "OK" recorded. For other backflow devices the testing is more involved.

9-36. Location Records. Records of all cross-connection control or backflow prevention devices must be prepared and maintained. These records are to include an inventory listing of all locations and an individual record on each location. These records must be properly maintained at all times.

9-37. Maintenance of Backflow Preventers. Maintenance is necessary for any mechanical equipment to keep it operational. Therefore, any mechanical protective device must be installed in a location where it is accessible for routine inspection, testing, and required maintenance. These devices are mechanical in nature and subject to breakdown, and they must be isolated during periods of inspection and repair. If there is only one service line from the potable system and if water service is required 100 percent of the time, a by-pass and a second reduced pressure principle backflow preventer must be installed, in order to provide an uninterrupted protected supply from the potable system.

Chapter 10

SWIMMING POOLS

Section A—General Information

10-1. Objectives and Importance of Good Pool Operation:

a. General Information. Swimming is one of the best forms of exercise for improving muscle tone and the coordination of all parts of the body. It is also an excellent and enjoyable means of recreation. For these reasons and the obvious fact that the lives of military personnel may sometimes depend on their ability to swim, swimming for recreation and training is strongly encouraged. Accordingly, most military installations have swimming pools. The enjoyment and benefits derived from swimming and the safety associated with it depend on how these pools are operated. Good pool operation requires trained, competent operators. It is the duty of these operators to provide safe, sanitary swimming water in an economical way.

b. Health Hazards. Although there is little evidence that swimming pools present a significant health hazard, disease can be spread by contaminated swimming pool water or by contact with contaminated objects or persons in the pool or pool area. Some of the illnesses known to be spread by contaminated water are: colds and respiratory infections, typhoid fever, amebic and bacillary dysentery, cholera, diarrhea, hookworm, tapeworm, infectious hepatitis, intestinal disorders, and miscellaneous eye, ear, nose, throat, and skin infections. It is highly important to eliminate the organisms that cause these diseases from swimming pool water.

c. Safety Requirements. Cloudy water caused by improper operation of the swimming pool water treatment system could possibly obscure a struggling or drowning swimmer. This and other hazards due to poor operation must not be allowed to develop.

d. Aesthetics. To be enjoyed properly, a pool must be sparkling clear and attractive. Otherwise much of the recreational value is lost. With good operation, the water in even a poorly equipped pool can be maintained in an inviting condition, while excellent filtration equipment will produce cloudy and dirty water if not properly operated.

e. Economy Practice. Money, materials, and water can be wasted unless good economy is practiced in pool operation. Pool equipment must be cared for so that frequent replacement of major items will not be necessary. Daily operations must be carefully controlled to prevent the waste of chemicals, manpower, and other items. If poor operation results in contaminated water, it may be necessary to dump the pool, thereby wasting thousands of gallons of water and placing the pool out of use for some time. Routine maintenance often prevents expensive repairs to equipment, structures, and facilities.

10-2. Types of Pools. Depending on the location, terrain, climate, source of water, and type of use for which the pool is intended, many different types and variations of pools are built.

a. Fill-and-draw and flow-through pools that do not filter and recirculate the water are not commonly used and are not approved for military installations.

b. In circulating pools, the water is constantly removed, filtered, disinfected, and pumped back into the pool. Water is added as needed to make up for losses due to evaporation, leakage, and water discharged to waste through overflow troughs. This is the most sanitary, satisfactory, and economical type of pool and is the type approved for military installations.

(1) The basic differences in circulating pools, other than sizes and shapes, are in the perimeter overflow systems. The primary purpose of a pool overflow system is to provide a continuous skimming of the water surface. Overflow occurs as filtered water is added and as water is displaced by swimmers. This displaced water, containing much of the debris and other wastes, is usually returned to the filters but in some pools, is wasted. In some pools all of the water recirculated through the filters is taken from the overflow system. In other pools some or all of the recirculated water is taken from the main drain at the bottom of the pool.

(2) Pool overflow systems can be separated into three general categories:

(a) Trough or Gutter Type. A continuous gutter or trough is provided around the inside walls of the pool. These gutters are built into the pool wall and can be fully or partially recessed or at the top of the wall in an open position (often called roll-out type gutters). The gutters, particularly the recessed typed, can also serve as a handhold for swimmers.

(b) Rimflow Type. Water in this type of perimeter overflow system is maintained to the level of the surrounding deck. No overflow troughs are used but trenches are placed in the deck in positions surrounding the pool and adjacent to the pool wall. The trenches are covered with metal gratings or tile with drain openings. The deck and pool edges are sloped toward the perimeter drains. The deck can easily be cleaned, but care should be taken that cleaning detergents used do not cause problems such as foaming in the recirculation system.

(c) Surface Skimmers. This overflow system consists of slots built into the wall of the pool at regular intervals of 15 to 25 feet. Within each wall opening there are floating weirs that control the water overflow. Surface skimmers are built to provide about 6 inches between the water level and deck level. Each overflow weir usually discharges into a cylindrical opening. This opening has an access cover at the deck level and a pipe at the bottom that drains the pool overflow to the recirculation system. A removable leaf-strainer basket fits in the bottom of this overflow receiver.

10-3. Sanitation Requirements:

a. Bacteriological Tests. Bacteriological tests of the

pool water are made at regular intervals by the installation surgeon to determine if the water is safe for swimming. The tests require 1 to 2 days for completion; hence, they reveal the bacteriological quality of the water as it was at the time of sampling, not as it is now. Thus, bacteriological testing serves primarily as a check on good pool operation rather than a check of the water at the time it is in use.

b. Physical and Chemical:

(1) Turbidity Explained. The cloudiness in water caused by suspended dirt, undissolved chemicals, algae, or other material is called turbidity. Besides making the water unattractive in appearance, turbidity interferes with chlorine destruction of microorganisms. Turbidity may also pose a safety hazard. Drownings may occur in turbid waters because struggling swimmers below the water surface are difficult to see. Turbidity can also cause accidents by obscuring vision so that collisions with the pool bottom, sides, other bathers, or underwater objects may occur. If a 6-inch black disc on the bottom of the deepest part of the pool cannot be clearly seen, the pool must be closed until the water is cleared. A better measure of turbidity by the use of turbidity units (TU), measured with a spectrophotometer. Established values for pool clarity are:

(a) Exceptional: 0.1 to 0.2 TU.

(b) Good: 0.2 to 0.3 TU.

(c) Acceptable: 0.3 to 0.5 TU.

(d) Poor (unacceptable): >0.5 TU.

(2) Chlorine Residual. Maintaining safe chlorine residual in swimming pool water is as important as maintaining it in drinking water. Drinking water is protected, while swimming pool water is constantly contaminated by the bathers. Water spit out by one bather may quickly be swallowed by another. The length of time the chlorine has to act may be very short. Hence, chlorine residuals must be kept high enough for rapid, thorough disinfection, yet not so high as to cause irritation of the swimmers' eyes and mucous membranes. At all military swimming pools, the free available chlorine residual must be maintained at a level of about 0.4 to 0.6 mg/l. This level of chlorine residual prevents the growth of algae, kills bacteria rapidly, and still does not irritate swimmers' eyes.

(3) pH Values. The pH of swimming pool water should be maintained between 7.2 and 7.8. At pH values higher than 8.0, the effectiveness of chlorine is reduced and algae growth is encouraged. At high pH, alkalinity can exist in the carbonate form which causes eye irritation and discolors the pool by plating out lime on the side and bottom surfaces. Eye irritation and corrosion of pool piping also result at pH values of 7.0 and below.

(4) Water Tempeature. The water temperature in artificially heated pools should not exceed 78°F. The air temperature at any enclosed, artificially heated pool should not be more than 5 degrees warmer nor 2 degrees colder than the water in the pool. It is desirable that the air temperature be kept about 5 degrees warmer than the pool temperature.

c. General Pool Sanitation:

(1) Foreign Matter in Pool. Sand, grass, leaves, dust, and other foreign matter may be tracked into the pool by bathers or blown in by the wind. To keep this to a minimum, direct access to the pool from unpaved areas should be prevented by routing bathers entering the pool area through foot sprays or showers.

(2) Removal of Floating Matter. Maintaining the level of water in the pool so it constantly overflows into the perimeter overflow system will remove floating matter from the water surface. This overflow or skimming is particularly effective if done during periods when the pool is closed to bathers. The quiescent condition of the water allows all floating material to rise to the top and float out of the pool. With surface skimmers, the leaf baskets should be checked and emptied daily if necessary.

(3) Scum Ring. If the water level in the pool is allowed to fall below the overflow devices, the oil and scum that float on the water surface are deposited in a slime ring around the pool. This is very unsightly, unsanitary, and difficult to clean. Such a ring around the pool is a clear indication of improper pool operation.

(4) Removing Sediment. Material accumulated on the pool bottom should be removed at least once a day with the pool suction cleaner (figure 10-1). All pools are required to have one or more suction cleaner outlets around the pool or to have a portable suction cleaner. Always discharge the suction cleaner effluent to waste. In addition to these maintenance measures, the pool should be emptied and scrubbed with detergent and water when deemed necessary by the surgeon. As a rule, this should not be more than once during the season.

(5) Walkways and Decks. Pool walkways and decks must be kept thoroughly clean to maintain sanitation and prevent accidents. Persons wearing shoes should not be allowed on the pool deck. Cracks and low spots should be promptly repaired.

(6) Overflow Devices, Ladders, Stepholes, and Pool Walls. These and all other components of the pool must be maintained in a clean and safe condition.

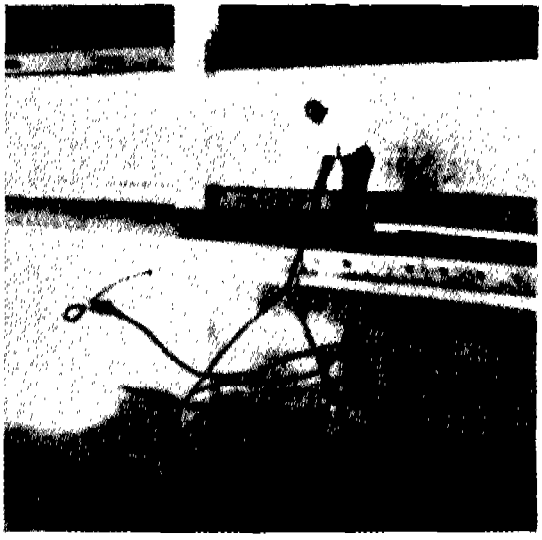


Figure 10-1. Suction Cleaner in Use.

Section B—Pool Water Treatment

10-4. General Information. For the most part, swimming pool water treatment is very similar to drinking water treatment. Additional information on this subject may be found in chapter 6. A sketch of a typical pool water treatment installation is in figure 10-2. Although this chapter describes the principles for operating all types of swimming pool equipment, it is not possible to discuss each manufacturer's equipment in detail. At each military installation, operating instructions and diagrams printed by the manufacturer of the particular equipment must be kept on hand. Charts that illustrate the operation of the filters and chlorinator with valves and parts numbered to correspond to instructions printed on the charts must be posted for ready reference. Similarly, post a flow diagram of the entire pool system. If these instructions, charts, and diagrams are not available, get them from the manufacturer of the equipment in question, or from higher technical authority.

10-5. Source of Water. The water supply must be obtained from a source approved by the surgeon. Water is added to the pool directly through a pipe elevated above the surface of the pool water, or into a surge or makeup tank. Cross-connection between the pool water and the installation water supply is not permitted.

10-6. Water Filtration:

a. General Information. After the water passes through strainers, or hair catchers, it still contains suspended matter that must be removed by filtration.

(1) In general, filtration includes pumping water or allowing it to pass by gravity through a finely divided bed of sand or other material so that the suspended solids in the water are removed and left behind in the filter. Filtration equipment for swimming pools must meet National Sanitation Foundation (NSF) specifications and bear the NSF seal of approval. (For a complete discussion of water filtration see chapter 6, section F.) Removing suspended solids from the filter is increased by using a filter aid or coagulant.

(2) Filter sizes for swimming pools should be such that, at design filter rates, the amount of water in the pool is filtered every 6 to 8 hours. For example, a pool containing 150,000 gallons of water would require about 120 square feet of filter surface area to filter all the water every 7 hours at a filter rate of 3 gpm/ft^2.

$$\frac{150{,}000 \text{ gallons}}{7 \times 60 \text{ minutes}} \div \frac{3 \text{ gpm}}{\text{ft}^2} = 120 \text{ ft}^2$$

(3) Swimming pool filters are generally installed in a bank of 3 to 5 filters. This is because the filter pump may also be used for backwashing. The backwash rate for rapid sand filters should be about five times the filter rate. By backwashing the filters one at a time, this rate is approached. Backwash rates for swimming pool water are somewhat higher than backwash rates for drinking water. This is because pool water is usually much warmer than drinking water, with the result that the viscosity of the water is considerably less and a higher rate of flow is required to sufficiently clean the filter.

b. Granular Media Filters. Sand, crushed anthracite

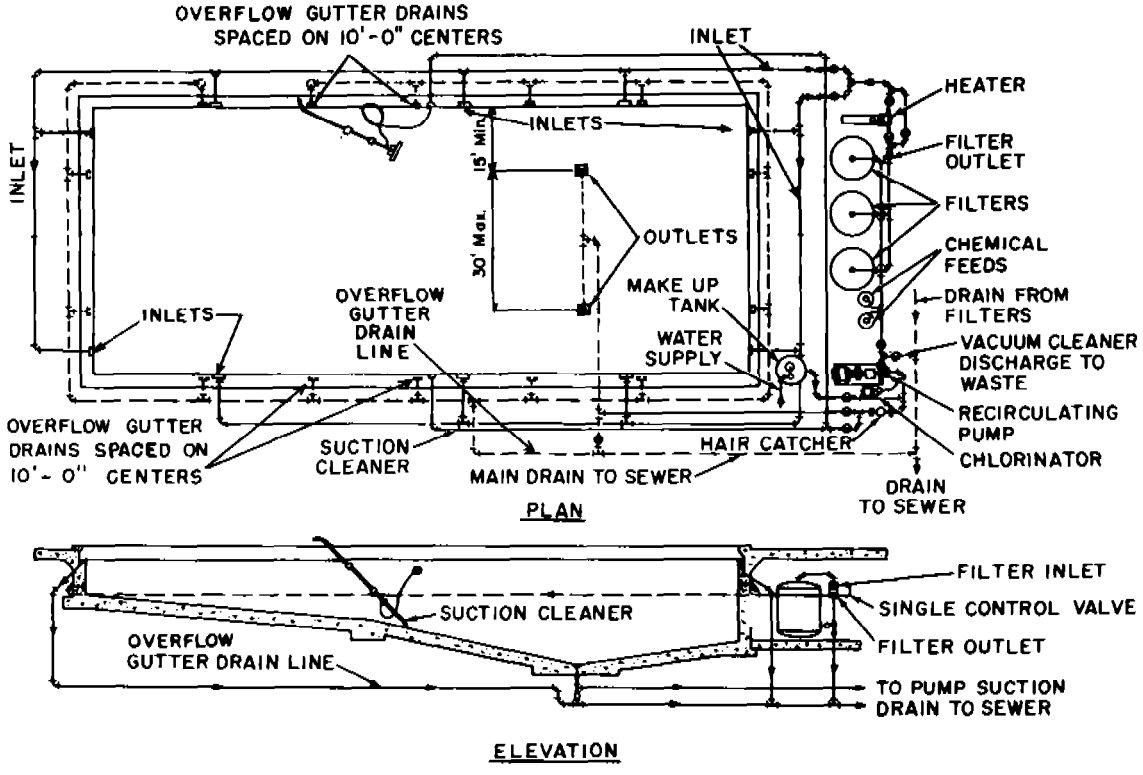


Figure 10-2. Typical Pool Water Treatment Installation.

coal, and combinations of sand and anthracite are used as filtration media for pool water treatment, similar to drinking water treatment. The filtration process may be driven by either gravity or pump discharge pressure. The only difference between granular media filtration of swimming pool water and drinking water is the method of coagulating chemicals usage (see d below). Operating instructions for a typical swimming pool with pressure sand filtration system are illustrated in figure 10–3.

c. Diatomaceous Earth Filters. Diatomaceous earth is composed of the skeltons of microscopic aquatic organisms called diatoms. A slurry of diatomaceous earth is applied to a porous screen with openings too small to allow penetration by the diatomaceous earth. Thus, the diatomaceous earth coats the screen, forming a fine straining mechanism for removing suspended material from water passed through the coated screen. When the filter is backwashed, the diatomaceous earth precoat with the filtered solids crumbles off and is wasted with the backwash water. A new precoat is then applied. Operating instructions for a typical swimming pool with pressure diatomaceous earth filtration system are illustrated in figure 10–4.

d. Coagulation With Filtration. Chemical coagulation is used to increase suspended solids and turbidity removal in granular media filters. The chemical generally used is aluminum sulfate or "alum" which forms a white, gelatinous, snow-flake-like floc of aluminum hydroxide when dissolved in water. Ammonium alum must not be used because it increases the ammonia concentration of the pool water.

(1) Treatment Application. In conventional water treatment processes, the alum is continuously added to the water forming a floc. With gentle mixing, the floc particles contact and coagulate the suspended solids in the water. The alum floc, with the enmeshed suspended solids and turbidity, is then settled out of the water in quiet settling basins, followed by filtration to remove any remaining floc particles and coagulated solids. In this process, only the relatively small amount of alum floc that did not settle out reaches the filters. In swimming pool water treatment, alum is applied in a different manner to save space. The alum is added at the beginning of each filter run, and the entire floc is captured in the filter bed. The alum floc accumulation results in much smaller pore spaces between granular media particles, resulting in better suspended solids and turbidity removal as pool water is passed through the filter.

(2) Using Alum for Pool Water Treatment. Alum dosage is usually about 2 ounces per square foot of filter surface area, to be fed over a 4 to 6 hour period immediately following backwash. The alum is dissolved in a mix tank and then fed into the pool waterline on the suction side of a pump to take advantage of the mixing action of the pump. Clogging of chemical feed lines and equipment can be avoided by flushing with water after each use.

(3) pH Effects. Because alum is slightly acidic, alum addition tends to lower the pH of the pool water. Alum coagulation is best in the pH range of 7.2 to 7.6. Alum flocs tend to dissolve at pH values below 7.0, causing sticky hair and eye irritation. For these reasons, pool water pH must be closely monitored and controlled during alum addition.

10–7. Disinfecting by Chlorination. Chlorination is the only widely accepted method of disinfecting swimming pool water. Organic matter and nitrogen compounds that are not removed by filtration are effectively oxidized and removed by chlorination. In addition, algae are killed and oxidized by proper chlorination.

a. Free Available Chlorine Residual. Chlorine forms several chemical compounds in pool water, particularly when ammonia or other nitrogen compounds are present. Chlorine residuals in pool water can be either in the combined available or free available form, the sum is known as the total chlorine residual. For best pool operating results, most of the total chlorine residual should be of the free available type. The method of establishing a free chlorine residual as the principal form of chlorine residual present is known as breakpoint chlorination, in which the combined residual is destroyed and a free residual is established as the predominant form. The chemical forms of chlorine called free available chlorine residual are the most effective for disinfection, oxidation, and algae control. Proper free available chlorine residuals also result in excellent pool water clarity, giving the pool a clean, polished look.

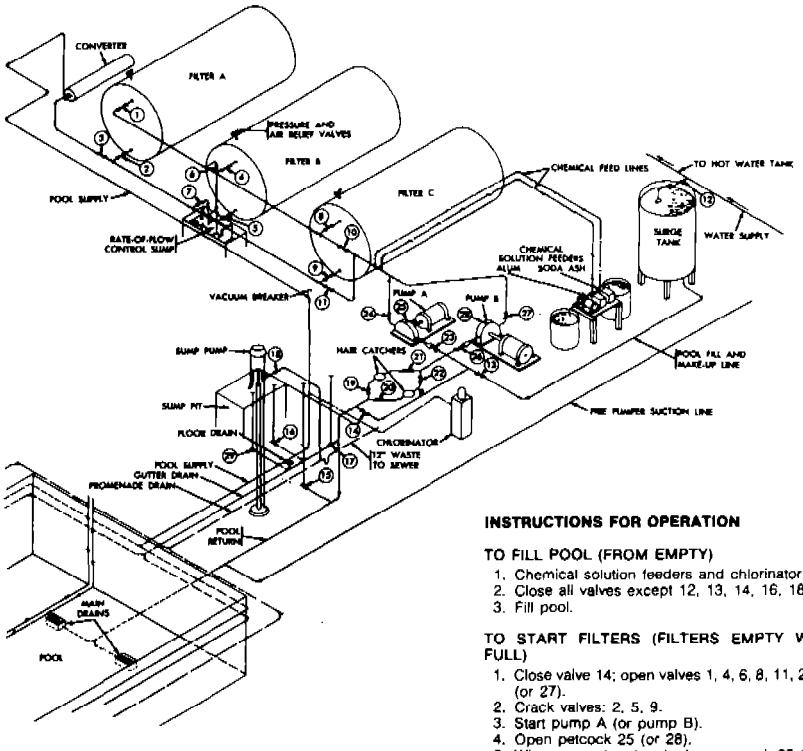
b. Chloramines Formation. Chlorine in water reacts with ammonia and other nitrogen compounds to form a number of chlorine-nitrogen compounds called chloramines. These compounds constitute combined available residual chlorine. Chloramines have only a fraction of the disinfecting and oxidizing power of free available chlorine. They are odorous compounds generally responsible for the "chlorine" odor in pools. In some cases, chloramines can cause eye irritation. To eliminate chloramines, the chlorine dosage should be increased to about ten times the concentration of combined chlorine present. This process, called superchlorination, results in destruction of chloramines in a way similar to that of breakpoint chlorination. Chloramines are converted to harmless nitrogen gas and water. The procedure should be done overnight, so that the chlorine may dissipate before the pool is reopened.

c. Chlorine Sources. Chlorine for swimming pool water treatment may be obtained from either chlorine gas or hypochlorites. Information on characteristics, applications, and safety for various chlorine forms is in chapter 6, section H and chapter 12.

(1) Chlorine Gas. Gaseous chlorine is the least expensive form of chlorine and is the form most commonly used for swimming pool water disinfection. The main disadvantage of using chlorine gas is the potential safety hazards that require special training and equipment.

(2) Hypochlorites. Sodium, calcium, or lithium hypochlorites (NaOCl, $Ca(OCl)_2$, or LiOCl) are also used to provide chlorine for swimming pool disinfection.

(a) Sodium hypochlorite is a pale green crystal soluble in cold water. It is unstable in air unless mixed with sodium hydroxide and it decomposes in hot water. Sodium



GENERAL NOTE ON OPERATION

1. Alternate pumps A and B daily.
2. Fill all filters slowly through bottom outlets.
3. Open or close all valves slowly.
4. When loss of head gages on hair catcher C (or D) is 5 ft, open valves 20, 22 (or 19, 21), close valves 19, 21 (or 20, 22), and clean hair catcher.
5. Valve 29 closed at all times except when draining pipe tunnel floor.
6. Start exhaust fan before entering chlorination room.
7. Test pressure relief and air relief valves on filters daily.
8. Backwash filters when loss of head gages on filters read 8 ft, or as recommended by filter manufacturer, or at least once daily.
9. Keep wood filters wet at all times.
10. Keep valve 12 open at all times.

PRINCIPLES OF OPERATION

1. Set valves at all pool inlets for uniform circulation of water from inlets to main drain.
2. Adjust valves on filters for equal distribution through each filter several times daily or as necessary.
3. Make jar test for best alum and soda ash proportions for feeding.
4. Prepare alum and soda ash solutions and adjust stroke of chemical feed pumps.
5. Feed chlorine to maintain a free residual of about 0.4-0.6 mg/l throughout pool.
6. Test pool water every hour at different locations for chlorine residual. Use DPD tester.
7. Increase chlorine feed with increase of number of persons in pool.
8. For northern climates adjust converter to maintain temperature of water in pool from 73° to 75° F.
9. Keep operation records daily when pool is in use.
10. Clean pool daily. Skim surface into scum gutters, scrape sides, vacuum clean bottom.

INSTRUCTIONS FOR OPERATION

TO FILL POOL (FROM EMPTY)

1. Chemical solution feeders and chlorinator off.
2. Close all valves except 12, 13, 14, 16, 18.
3. Fill pool.

TO START FILTERS (FILTERS EMPTY WITH POOL FULL)

1. Close valve 14; open valves 1, 4, 6, 8, 11, 23 (or 26), 24 (or 27).
2. Crack valves: 2, 5, 9.
3. Start pump A (or pump B).
4. Open petcock 25 (or 28).
5. When pump is primed, close petcock 25 (or 28), open valve 19 (or 20), and slowly open valve 21 (or 22). Then close valve 13. When water flows through valve 6, open valves 7, 10 and close 11, 6.
6. Adjust valves 2, 5, 9 to equalize flow through filters A, B, C at 3 gpm per sq ft as shown on rate-of-flow indicator of each filter.
7. Test air relief valve on each filter.
8. Check converter for steam.
9. Open valve 3, close valve 7.
10. Equipment is now in filter position.

TO BACKWASH FILTERS (FROM FILTER POSITION)

1. Shut off chemical solution feeders and chlorinator.
2. Open valves 6, 11 and close valves 3, 10.
3. To backwash filter A, close valves 5, 9.
4. To backwash filter B, close valves 2, 9; open valve 5.
5. To backwash filter C, close valves 2, 5; open valve 9.
6. Backwash each filter as directed by filter manufacturer.
7. Equipment is now in backwash position.

TO RINSE TO WASTE (FROM BACKWASH POSITION)

1. Open valves 2, 5, 7, 10. Close valves 6, 11.
2. Start chemical solution feeders.
3. Rinse to waste as directed by filter manufacturer.
4. Equipment is now in rinse to waste position.

TO FILTER (FROM RINSE TO WASTE POSITION)

1. Open valve 3; close valve 7.
2. Start chlorinator.
3. Check converter for steam.
4. Adjust valves 2, 5, 9 for equal flow of 3 gpm per sq ft as shown on rate-of-flow indicator of each filter.
5. Equipment is now in filter position.

TO EMPTY POOL (FROM FILTER POSITION)

1. Shut off chemical solution feeders, chlorinator, and steam at converter.
2. Open valve 6.
3. Close valves 2, 5, 9, 1, 4, 8, 3.
4. When pump A (or B) draws air, stop pump and open valve 15.

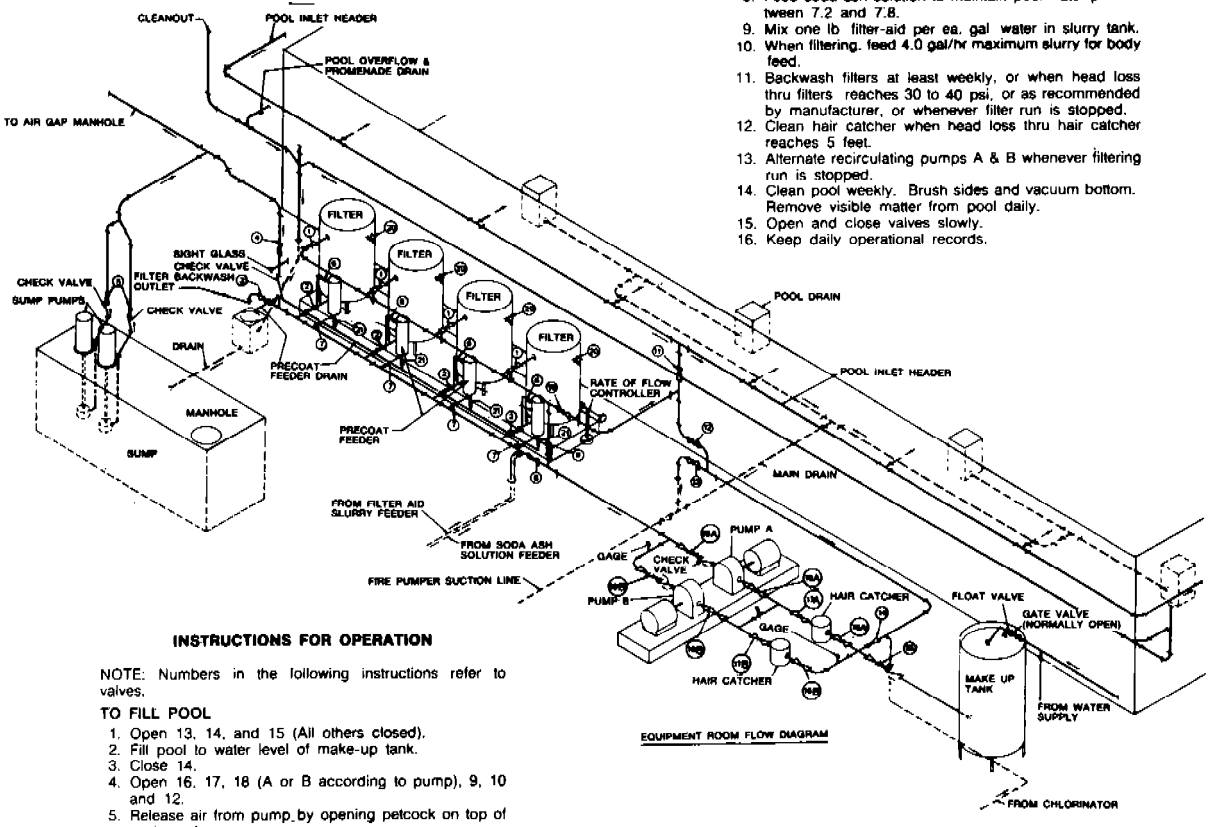
TO RECIRCULATE GUTTER DRAIN WATER USE ONLY WHEN ORDERED

1. Close valve 16; open valve 17.

Figure 10-3. Operation Instructions for Typical Swimming Pool With Pressure Sand Filtration System.

GENERAL NOTES ON OPERATION

1. Set rate-of-flow controller at design flow.
2. Adjust pool inlet fittings to provide equal distribution throughout the pool.
3. Test chlorine residual at different pool locations once every hour of pool use.
4. Feed chlorine to maintain a free residual of about 0.4-0.6 mg/l.
5. Check loss of weight of chlorine cylinders on scale daily.
6. Start exhaust fan 5 minutes before entering chlorinator room.
7. Check pool water every 3 hours.
8. Feed soda-ash solution to maintain pool water pH between 7.2 and 7.8.
9. Mix one lb filter-aid per ea. gal water in slurry tank.
10. When filtering, feed 4.0 gal/hr maximum slurry for body feed.
11. Backwash filters at least weekly, or when head loss thru filters reaches 30 to 40 psi, or as recommended by manufacturer, or whenever filter run is stopped.
12. Clean hair catcher when head loss thru hair catcher reaches 5 feet.
13. Alternate recirculating pumps A & B whenever filtering run is stopped.
14. Clean pool weekly. Brush sides and vacuum bottom. Remove visible matter from pool daily.
15. Open and close valves slowly.
16. Keep daily operational records.



EQUIPMENT ROOM FLOW DIAGRAM

INSTRUCTIONS FOR OPERATION

NOTE: Numbers in the following instructions refer to valves.

TO FILL POOL

1. Open 13, 14, and 15 (All others closed).
2. Fill pool to water level of make-up tank.
3. Close 14.
4. Open 16, 17, 18 (A or B according to pump), 9, 10 and 12.
5. Release air from pump by opening petcock on top of casing; close.
6. Start pump (A or B), open 19 (A or B to suit pump) and fill pool to 2 below overflow gutter.
7. Close 13.

TO FILL EQUIPMENT

1. Close 9.
2. Open 8, 2 (all), 1 (all), 20 (all) and 14.
3. Close air release valves 20 (all) when water flows from filters.
4. Close 15 and stop pump.

TO PRECOAT FILTERS AFTER FILLING POOL

1. Remove covers from precoat feeders.
2. Place 7 to 14 lbs filter-aid in each precoat feeder, add water and mix. Replace covers.
3. Open 6 and 7 (all) and start pump.
4. Partially close 2 (all) to provide flow thru precoat feeders.
5. Recirculate water until all filter-aid is deposited on elements and water runs clear.
6. Close 6 and 7 (all).
7. Fully open 2 (all).

NOTE: Continuous flow thru filter must be maintained between precoat and filter run operations or filter cake will drop off elements.

TO FILTER POOL WATER

1. Start chlorinator and soda-ash and filter-aid feeders.
2. Open 13 and 11.
3. Close 12.
4. Continue filtering until filter head loss reaches 30 to 40 psi, or for a maximum of one week.

TO BACKWASH FILTERS

1. Stop chlorinator and soda-ash and filter-aid feeders.
2. Close 10.
3. Wait until maximum pressure is built up on the filter.
4. Close 1 (all) and 2 (all) and 8, and stop pump.
5. Open air release valves 20 (all) to shock filter cake from elements.
6. Open 3 and 2 (all) and drain all filters.
7. Close 3 and 20 (all).

TO RINSE TO WASTE

1. Open 1 (all), 4 and 9, start pump, and backwash until water is clear in sight glass. NEVER RINSE FILTERS TO SUMP AFTER DRAINING—THIS WOULD FLOOD EQUIPMENT ROOM.

TO PRECOAT FILTERS AFTER BACKWASHING

1. Close 4, 9, 11 and 13.
2. Open 8, 10, and 12.
3. Remove covers from precoat feeders.
4. Open 21 (all) and drain precoat feeders.
5. Close 21 (all). Place 7 to 14 lbs of filter-aid in each precoat feeder, add water and mix. Replace covers.
6. Open 6 and 7 (all).
7. Partially close 2 (all) to provide flow thru precoat feeders.
8. Recirculate water until all filter-aid is deposited on elements and water runs clear. Proceed with filtering as above.

NOTE: Pump may continue running between operations. However, pump should never be operated against a closed valve for any extended period of time.

Figure 10-4. Operation Instructions for Typical Swimming Pool With Pressure Diatomaceous Earth Filtration System.

hypochlorite is usually stored in solution. Addition of sodium hypochlorite directly to the pool should be avoided.

(b) Calcium hypochlorite is usually a solid crystal or powder which is dissolved in water before adding to the pool water system. To make sure the calcium hypochlorite solution is free of suspended solids, it should stand 1 day before use. A strainer may also be recommended.

(c) Lithium hypochlorite is also granular, but readily dissolves in water. It does not have the scale forming tendencies associated with calcium hypochlorite.

d. Point of Application. Chlorine should be added to the swimming pool recirculating water system on the return line to the filtering system. Chlorine added at this point has the following advantages:

(1) Biological slimes on the septums of diatomaceous earth filters are destroyed.

(2) Bacteria colonies are not able to grow in the bed of sand filters. These bacteria, if not destroyed by chlorine, eventually entangle organic material and dirt, resulting in the formation of mudballs. Mudballs reduce the efficiency of the filters and can eventually require replacement of the filter media.

e. Chlorine Cylinder Handling, Storage, and Safety. Due to the highly toxic and explosive nature of chlorine gas, extreme care must be used in storage and handling (paragraphs 6-71, 6-75, and 12-1). Chlorine cylinders should be stored in cool, dry rooms separated from areas accessible to swimmers. Additionally, suitable detection and alarm systems are recommended in chlorinator areas which will alert life guard personnel in case of gas leakage so that appropriate evacuation of the pool and pool area can be exercised.

f. Chlorine Residual Control. The free chlorine residual can be controlled either manually (using testing kits for monitoring) or automatically (using continuous chlorine residual recorder-controllers). Direct application of liquid or solid chlorine compounds to the pool should be avoided. Poor soluability and inadequate mixing will result in hot spots of high chlorine content that can be hazardous to swimmers.

g. Chlorine Residual Stabilization. Chlorine residual in water is dissipated by ultraviolet light from the sun, unless stabilized by adding cyanurates. This usually involves the initial addition of 25 to 50 mg/l of cyanuric acid followed by periodic or continuous dose of some form of chlorinated isocyanurate. If cyanurates are used for chlorine residual stabilization, higher levels of chlorine residual are required to get equivalent disinfection. Cyanuric acid should not be allowed to build up in pools to levels exceeding approximately 100 mg/l. The concentration of cyanuric acid present in pool water is determined by the melamine cyanurate turbidometric method. Test kits are available to carry out this analysis. The chemical supplier furnishing the cyanurate chemicals can provide detailed information about test kits and testing procedures.

10-8. Hydrogen-ion Concentration (pH) and Alkalinity:

a. The pH indicates the degree of acidity or alkalinity of a solution. The pH does not indicate the amount of alkalinity or in which of three forms the alkalinity exists. At pH values above 8.3, alkalinity can exist in the carbonate form, causing eye irritation. Controlling the pool water pH within the range 7.2 to 7.8 is essential to prevent eye or skin irritation, algae growth, and corrosion.

b. Sodium or calcium hypochlorite, sodium carbonate (soda ash), or sodium bicarbonate may be used to raise the pH of swimming pool water. Sodium bicarbonate also increases the alkalinity of the water. pH is lowered by adding chlorine gas, alum, sodium bisulfate (sodium acid sulfate), or hydrochloric (muriatic) acid. Sodium bisulfate also reduces the alkalinity of the water. It is important that all chemicals be added slowly and gradually, not batch-wise, to avoid over-dosing.

10-9. Corrosion and Deposit Control:

a. Equilibrium Prediction. As discussed in chapter 7, the Langelier saturation index may be used to predict whether a water is in equilibrium with its calcium content. A water equilibrium neither deposits a calcium scale nor dissolve an existing calcium scale. A simplified formula has been established to calculate the Langelier saturation index for swimming pool waters:

$$\text{Langelier's saturation index} = pH + TF + CF + AF - 12.1$$

The values of TF (temperature factor), CF (calcium hardness factor), and AF (alkalinity factor) can be obtained from table 10-1.

b. Index Control. The saturation index should be kept as close to 0 as possible, but a range of $+0.5$ to -0.5 is considered acceptable for swimming pool operation. Negative index values indicate aggressive, corrosive water, while positive index values indicate a scale-forming, nonaggressive water. To correct a negative index, add soda ash (Na_2CO_3) or sodium bicarbonate ($NaHCO_3$). If the alkalinity is low and the pH is greater than 7.7, sodium bicarbonate is preferred over soda ash. Soda ash should be used to raise a low pH when the alkalinity is high.

c. Example. Determine Langelier's saturation index for a 76°F swimming pool water having a pH of 7.6 calcium hardness of 150 mg/l (as $CaCO_3$), and alkalinity of 100 mg/l (as $CaCO_3$). From factors on table 10-1, the Langalier saturation index is:

$$7.6 + 0.6 + 1.8 + 2.0 - 12.1 = -0.1$$

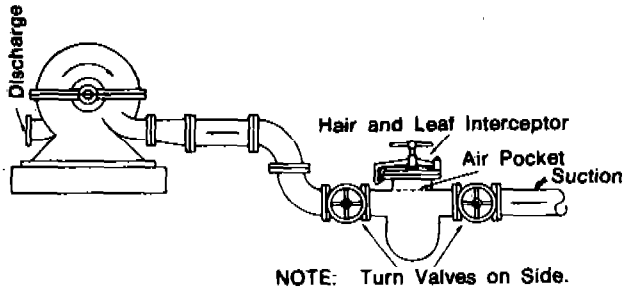
This water is in the acceptable range for saturation index values.

10-10. Miscellaneous Equipment:

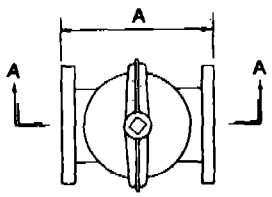
a. Hair Catcher. Water to be returned to the filter is first passed through a hair catcher (figure 10-5) to remove hair, lint, and other large bits of foreign matter. The hair catcher consists of a wire mesh or slotted metal bucket inserted in the pool effluent line on the suction side of the pump. The hair catcher should be equipped with two buck-

TABLE OF DIMENSIONS					
Pipe Size	A	B	C	D	Wt. lbs.
2"	8½"	5⅝"	6"	½"	31
2½"	7⅞"	5⅝"	5½"	¾"	32
3"	8¾"	6¾"	6"	¾"	40
4"	11⅞"	7½"	8"	1"	66
5"	12¼"	9"	10"	1"	99
6"	13¾"	9¾"	12½"	1¼"	131
8"	17⅛"	11"	15½"	1½"	212
10"	21½"	14"	15¾"	2"	356
12"	25⅛"	15"	23¾"	2"	516

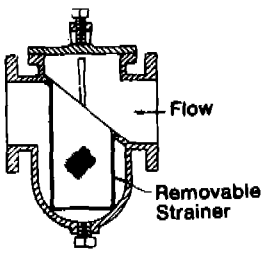
NOTE: All sizes std. 125 lbs. flange connections



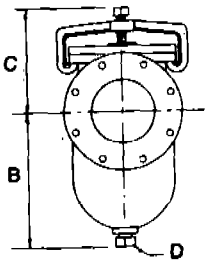
CORRECT INSTALLATION OF HAIR AND LEAF INTERCEPTOR



TOP VIEW



SECTION A-A



END VIEW

Figure 10-5. Hair Catcher.

ets so that one can be cleaned while the other is in use. The buckets should be cleaned at least once a day. A pressure gage located on the discharge side of the hair catcher is helpful in indicating loss of pressure head. The hair catcher is designed so that changing the buckets is a quick and simple operation. It is importnat to close the valves on each side of the hair catcher when opening it to change the bucket.

b. Pumps. At swimming pools, pumps (meeting NSF specifications) are used to recirculate the pool water through the treatment system, backwash the filters, dewater sumps, and provide suction for pool bottom cleaning. Often the same pump may be used for water recirculation as for filter backwashing. Complete discussion of pumps is included in chapter 4.

c. Return Water Inlets. The filtered water is returned to the pool through a number of inlets along the pool walls or on the bottom. Each inlet is equipped with adjustable control so that the amount of water flowing through it can be regulated. By setting the valves properly the flow can be controlled so that the water is distributed back to the pool in a way that makes for most uniform replacement. Chlorine residuals and pH readings must be uniform throughout the pool when the inlet valves are properly set.

d. Gages, Meters, and Rate Controllers. It is essential that pressure gages be maintained accurately to determine if the filters are operating properly and to indicate need for backwashing. The rate-of-flow meter is used to control and maintain the proper filter backwash rates. Too high a filter rate will not produce clear water, whereas too low a

Table 10-1. Factors for Calculating Simplified Langelier Saturation Index for Swimming Pool Water.

Temp. (°F)	TF	Calcium hardness (ppm $CaCO_3$)	CF	Total alkalinity (ppm $CaCO_3$)	AF
32	0.0	5	0.3	5	0.7
37	0.1	25	1.0	25	1.4
46	0.2	50	1.3	50	1.7
53	0.3	75	1.5	75	1.9
60	0.4	100	1.6	100	2.0
66	0.5	150	1.8	150	2.2
76	0.6	200	1.9	200	2.3
84	0.7	300	2.1	300	2.5
94	0.8	400	2.2	400	2.6
105	0.9	800	2.5	800	2.9
128	1.0	1000	2.6	1000	3.0

filter rate does not provide the number of pool turnovers required to maintain good water quality. Similarly, if backwash rates are not carefully controlled, the filters may be damaged, or the backwashing will not be sufficient to clean the filters. Larger pools are equipped with rate controllers so that about the same filter rate is automatically maintained regardless of whether the filters have just been cleaned or have been in use for some time.

e. Water Heater. Indoor pools in cool climates should be provided with water heating equipment capable of maintaining the entire pool contents at any desired temperature between 70° and 78°F. The equipment should be thermostatically regulated and so designed and controlled that any danger of scalding bathers is eliminated. Provide thermometers in the piping system to indicate the temperature of the water entering and leaving the pool.

f. Heating and Ventiliation Equipment. Heating and ventilating equipment should be properly maintained and operated to enhance the comfort of water sport participants and spectators, as well as to protect pipes, electrical, and other building fixtures from damage by excess moisture.

10-11. Filter Room Requirements:

a. Room Lighting. Filter rooms should be adequately lighted for all operation, maintenance, and repair work.

b. Room Ventilation. Filter rooms should be well ventilated to prevent condensation on any of the piping or equipment. Condensation promotes corrosion.

c. Pipe Color Code. The piping system should be marked for easy identification of lines. This can be done by painting colored bands and placing markers on pipes with arrows to indicate direction of flow. Pipe color code and marking of pipes should be done in accordance with MIL-STD-101.

10-12. Testing Frequency, Control Levels, and Procedures:

a. Bacteriological Testing. A minimum of two samples of the pool water is taken twice a week by the surgeon and analyzed for coliform organisms and total bacteria content. Samples must be taken during periods of maximum bathing load.

b. Physical Condition:

(1) Water Turbidity. The pool turbidity should be checked at least once each day (or if indicated, more often) either by actual measurement of the turbidity or by the use of a black disc. Place a black disc 6 inches in diameter on a white field on the bottom of the pool at the deepest point. It should be clearly visible from the sidewalks of the pool at all distances up to 10 yards measured in a horizontal distance from the vertical projection of the disc on the pool surface.

(2) Water Temperature. The temperature of the pool water (and of the air for heated indoor pools) should be monitored daily at outdoor pools and twice daily at indoor pools.

c. Chemical Requirements:

(1) pH Testing:

(a) Frequency of Testing. A pH testing kit must be provided and tests made and recorded at each end of the pool every 3 hours.

(b) pH Limits. Maintain the pH between 7.2 and 7.8.

(c) Testing Procedure. For testing procedure see instructions on the testing kit.

(2) Chlorine Testing:

(a) Frequency of Testing. A chlorine residual testing kit must be provided and tests made at each corner of the pool every hour during pool operation. Record the chlorine residual every 3 hours on the proper form (attachment 3).

(b) Chlorine Limits. Maintain a free available chlorine residual of approximately 0.4 to 0.6 mg/l. At no time should the free available residual be allowed to fall below 0.4 mg/l. The free available residual should always be greater than one-half the total chlorine residual. The DPD colorimetric method should be used for testing chlorine residuals in swimming pool water.

(3) Alkalinity. The total alkalinity of the pool water should be checked daily. Total alkalinity, as measured by the procedure outlined in Standard Methods for the Examination of Water and Wastewater, should be in the range of 75 to 125 mg/l (expressed as $CaCO_3$).

10-13. Troubleshooting Information. Troubleshooting information for pool operation is compiled in table 10-2.

Section C—Seasonal Care

10-14. Winter and Early Spring. Pools that are closed during winter should be inspected once a month during the off-season. Particular attention should be given to any moisture forming in the filter room or chemical storage areas. If excess moisture is prevalent, diatomaceous earth filter elements should be removed and stored in a dry place to avoid corrosion. Chemicals stored during the off-season should be kept dry to prevent caking or corrosion. The off-season is also a good time to paint interiors and to repair deck furniture, bathhouse facilities, and electrical fixtures and wiring.

10-15. Pool Opening. Before opening a pool for swimming in the late spring or early summer, certain operation and maintenance routines must be followed:

a. Inspection and Repair. Several months before opening, a thorough inspection should be made of all equipment and supplies (including pool shell, deck area, pool inlets and outlets, control valves, drains, heaters, filters, pumps, chemical feed equipment, and electrical systems). Cracking or spalling concrete should be patched with special hydraulic cement or other approved compounds. If necessary, surfaces should be repainted using procedures recommended by the paint manufacturer. The amount and condition of filter media should be checked and replaced when necessary. Adequate chemical supplies should be ordered. The base bioenvironmental engineer and the base safety officer should be contacted to determine whether

safety and health hazards noted during the previous year's postseason inspection have been corrected.

b. Sanitation. The week the pool is to be opened, the pool and deck should be scrubbed thoroughly, using a hypochlorite solution and well rinsed. The bathhouse floors, walls, showers, toilets, etc., should be cleaned and sanitized.

c. Pool Startup. The following procedures should be followed for proper pool startup:

(1) Add Water. If water is added to makeup tank, the pump is started and the filters are placed in operation when the makeup tank is nearly filled. If the water is added directly to the pool, allow the pool to fill about one-third full and then turn on the pump and filters. If the only return to

Table 10-2. Troubleshooting Guide for Swimming Pool Operation.

Symptom	Possible Cause of Trouble	Remedy
Cloudy water	Poor coagulation and filtration.	Establish correct alum dosage; backwash filters and apply fresh floc to filters; maintain proper chlorine residual.
Cloudy water—Greenish	Algae—Chlorine too low.	Maintain proper chlorine residual.
	Copper corrosion—pH low.	Adjust pH by adding soda ash; maintain Langelier saturation index within recommended range.
Cloudy water—Milky	pH low.	Adjust pH by adding soda ash.
	pH high in hard waters.	Adjust pH by adding sodium bisulfate or dilute hydrochloric acid. (Note: Use of these chemicals is for special cases only and requires permission of base medical officer.)
	Too much alum.	Reduce alum dosage.
	Defective diatomaceous earth filter element.	Repair or replace.
Cloudy water—Rusty	Iron corrosion—pH low.	Adjust pH by adding soda ash; maintain Langelier saturation index within recommended range.
	Iron in makeup—Poor filtration.	Establish correct alum dosage; backwash filters and apply fresh floc to filters; maintain proper chlorine residual. Insure filters are in proper operational order by conducting required inspection and maintenance.
Discolored side walls or bottom:		
Green	Algae—Chlorine too low.	Maintain proper chlorine residual. If adjustment of chlorine residual does not adequately remove the problem, it will be necessary to drain pool and scrub walls and bottom with 5 mg/l chlorine solution. Rinse well before refilling pool.
	Copper corrosion—pH low.	Adjust pH by adding soda ash; maintain Langelier saturation index within recommended range.
Rusty	Iron corrosion—pH low.	Adjust pH by adding soda ash; maintain Langelier saturation index within recommended range. If problem is severe, drain pool and scrub walls with strong soap solution. If this fails to remove stain, scrub with 2 to 5 percent solution of muriatic acid. Rinse well and refill pool.
	Iron in makeup—Poor filtration.	Establish correct alum dosage; backwash filters and apply fresh floc to filters; maintain proper chlorine residual. Insure filters are in proper operational order by conducting required inspection and maintenance. If problem is severe, drain pool and scrub with strong soap solution. If this fails to remove stain, scrub with 2 to 5 percent solution of muriatic acid. Rinse well and refill pool.
Eye irritation	pH low.	Adjust pH by adding soda ash.
	Chlorine high.	Adjust chlorinator to maintain proper chlorine residual.

Table 10-2. Continued.

Symptom	Possible Cause of Trouble	Remedy
	Chlorine low.	Adjust chlorinator to maintain proper chlorine residual.
Inlet flow low	Pumps not operating.	Look for clogged suction or discharge lines or air leaks in suction line. Check pump switches, valves, stuffing box, internal parts.
	Hair catcher needs cleaning.	Clean.
Filter runs short	Too much alum.	Reduce alum dosage.
	Pool needs cleaning.	Use pool suction cleaner; remove floating material by overflowing into perimeter gutter system.
Odor—Strong chlorine	Chlorine too high or too low.	Adjust chlorinator to maintain proper chlorine residual.
Skin irritation	pH high.	Adjust pH by adding sodium bisulfate or dilute hydrochloric acid. (Note: Use of these chemicals is for special cases only and requires permission of base medical officer.)
Slime on sides or bottom	Chlorine too low.	Drain pool and scrub walls and bottom with 5 mg/l chlorine solution. Rinse well before refilling pool. Maintain proper chlorine residual.
Water feels slippery	pH high.	Adjust pH by adding sodium bisulfate or dilute hydrochloric acid. (Note: Use of these chemicals is for special cases only and requires permission of base medical officer.)

the filters is from overflow of the pool, the pool must be filled and overflowed before water is made available to the pump and filters, which then should be started. When sand and anthracite filters are first started, add floc (paragraph 10-6d) and waste the filter effluent for a few minutes until effluent is clear.

(2) Chemical Feed. Start chlorination as soon as filtration begins. Start pH control as soon as pH tests of the water indicate. Take frequent pH and residual chlorine readings.

(3) Reduce Water Supply. When the pool is filled, reduce the amount of makeup water from the water supply to the amount that will produce a constant overflow about ¼ inch deep all around pool overflow troughs or deck level.

(4) Final Check. When pool is ready for use, check turbidity, pH, temperature, alkalinity, and chlorine residual. Do not open pool until all readings are satisfactory.

d. Preseason Inspection. After the pool has been readied for use, it must be jointly inspected by civil engineering, recreation services, medical and safety representatives. This inspection must be conducted at least 48 hours before the scheduled opening to allow time for bacteriological analyses of water samples taken during the inspection.

10-16. Pool Closing. The following procedures should be followed when closing outdoor pools at the end of the season:

a. Wash Filters and Clean Equipment. Wash filters (backwash) several times thoroughly, perform any necessary filter cleaning with the proper chemicals, and rinse with fresh water. Pump fresh water through all chemical feed lines and equipment. Carefully check operation of all equipment, including pump and motor.

b. Dewater. Open main pool, filter, and other drains to waste to dewater pool and equipment. Make sure there is a valve at the lowest point in piping system so that all water can be drained. Leave this valve and pool drain valves open to allow rain and snowmelt to runoff. In pools where it is necessary to maintain water to prevent the pool shell from cracking or floating out of the ground, close the main pool drains to maintain desired water level. Drain the filters and all the piping system and check the main drain valves to be sure there is no leakage.

c. Inspection. Make complete inspection of all equipment and supplies as stated in paragraph 10-15a.

d. Equipment Protection. In order to prevent deterioration of equipment during storage, take the following steps:

(1) Open diatomaceous earth filters and check filter elements for cleanliness. If any dirt or grease remains on the elements, use a cleaner recommended by the filter manufacturer or higher technical authority. Handle elements carefully to prevent damage. After cleaning, reassemble and wash the filter several times.

(2) Drain all pipelines, pump cases, and the hair catcher. Clean the hair catcher buckets and store them in a dry place.

(3) Clean and recondition all check valves, sump pumps, sight glasses, gages, and meters.

(4) Thoroughly wash all bearings of pumps and pump motors with an approved solvent. Fill bearings with an approved rust-preventive compound.

(5) Clean all oxidation from exposed copper surfaces on transfer switches, safety switches, pump starters, and other electrical equipment.

(6) In cold climates, remove and empty all traps on lavatories in the bathhouse.

(7) If the pool is to be left full of water, logs or other materials approved by higher technical authority should be floated to prevent ice damage. Material should be fastened to maintain spacing and prevent bunching. Plastic covers should be securely fastened to prevent algae growth and to keep out debris.

(8) Remove the diving boards and store them flat and in a dry place to prevent warping.

(9) Remove ladders and clean them with a chrome cleaner or polish. Put one ladder back in place in the pool, while storing the remaining ladders in a safe place.

e. Postseason Inspection. A joint inspection by civil engineering recreation services, medical and safety representatives will be made within 15 days after the pool closing date. The findings are used to identify offseason maintenance needs and to enable orderly funding and work completion.

Section D—Records and Operating Log

10-17. Purpose of Records. Records are important to good operation. They ensure the routine performance of necessary operations, indicate troubles in operation and help detect the causes, and promote general efficiency. They also serve as evidence in case of legal actions or investigations arising from accidents or equipment difficulties.

10-18. Inventory Records. Keep current records of the quantity and condition of chlorine, alum, diatomaceous earth, pH indicator, chlorine residual indicator, and all other expendable supplies. Advance ordering should be based on this inventory.

10-19. Operating Log. The proper swimming pool operational log must be maintained current. Make all entries while the readings are taken, not before or after. The accuracy of this form is important to enable the data to indicate operational difficulties. Enter the readings as they are, not as they should be. Air Force activities use AF Form 708 and the Army installations use DA Form 3164R.

Section E—Wading Pools

10-20. General Operation and Maintenance. The operation and maintenance of wading pools are similar to that of swimming pools, except more attention is required to maintain good sanitation. Children constantly track sand and dirt into the water and frequently urinate or defecate in the water. As a result, the addition of filtered water at a rate sufficient to produce one complete pool turnover every 3 hours is recommended. Wading pools must be frequently vacuumed, skimmed, and scrubbed down. The free available chlorine should be maintained at approximately 0.4 to 0.6 mg/l and the pH between 7.2 and 7.8.

Chapter 11

GENERAL MAINTENANCE

Section A—General Information

11-1. Maintenance Requirements. Maintenance is the recurring routine work required to keep a facility in such condition that it may be continuously used (at its original or designated capacity and efficiency) for its intended purpose. Specific maintenance requirements for water supply, treatment, and distribution equipment have been discussed in previous chapters of this publication in which the equipment was described. This chapter is intended to provide maintenance for the general system.

11-2. Inspection and Services. This chapter deals with maintenance inspections and general maintenance services of water supply systems at military installations. In addition, this chapter contains tables specifying tools and equipment, lubricants, and materials and supplies required to perform general and specific equipment maintenance tasks.

11-3. Types of Inspection and Repair. Water supply system personnel are concerned with three categories of inspection, and to some degree with overhaul and repair:

a. Operator Inspection. Regular inspection of equipment or of a system is part of an operator's routine duties to ensure proper functioning of the system. Such inspection includes lubrication, minor adjustments, and renewal of parts that do not require major overhaul or repairs, plus detecting and reporting (to the proper authority) any observed abnormal conditions (appearance, leaks, unusual noises, etc.).

b. Preventive Maintenance Inspection. Cleaning, lubricating, minor adjustment and renewal of parts that do not require major overhaul and repairs, plus detecting and reporting (to the proper authority) any observed abnormal conditions (appearance, leaks, unusual noises, etc.) comprise preventive maintenance inspection. Such inspections may be conducted by personnel who have been assigned specific areas of inspection responsibility, or by personnel actually operating a particular piece of equipment or system.

c. Control Inspection. Scheduled examinations or tests of public works and public utilities are made to determine the physical conditions of maintenance standards. These examinations are termed control inspections and are performed by personnel assigned to the Inspection Branch, or by others at the request of the Inspection Branch. Control inspection includes electrical, mechanical, and structural types of inspection.

d. Major Overhaul and Repairs. As a rule, major overhaul and repairs are not made by operating personnel, but rather by the Maintenance Division at the request of and according to schedules developed by the Utilities Division. In some instances, outside contractors may be used.

11-4. Power and Water Failure. Power failure may disturb certain water treatment processes or cause damage to equipment. To prevent this, prepare a list of consecutive actions to be followed in case of sudden power interruptions; post the list centrally in each plant. Because water-cooled units or equipment using continuous water pressure may be damaged if water is shut off, necessary precautions in case of water failure must also be posted.

11-5. Operating Under Winter Conditions. Protecting operating and standby equipment against damage is especially important in cold climates. Make sure lubricants are changed to winter grades. Drain equipment temporarily out of use or on standby service or provide proper antifreeze coolant to prevent the freezing and bursting of units (such as the housings of pumps, radiators, piping and similar items).

11-6. Removing Equipment From Service:

a. Short Period. Precautions should be taken to prevent damage to equipment removed from service for a short time. Factors to be considered and precautions to be taken depend on the type of equipment and outside conditions. If the outage is likely to last more than a week, the equipment must be test-operated once a week during that time.

b. Protracted Period. Special precautions are necessary for equipment that is to be out-of-service for long periods. Failure to retire or to adequately protect equipment may cause serious damage during idleness or on resumption of operation. When it is known that the outage will be protracted, the equipment should be dismantled, if practicable, and protected against corrosion and other damage by using suitable greases, oils, and rust-preventative compounds or coverings.

11-7. Records and Reports:

a. Record Forms. The results of inspections and maintenance procedures must be kept on record forms as established by higher technical authority. Types of forms that apply include the inventory record, inspection checkoff card, inspection record sheet, inspection frequency file, and other forms for specific uses.

b. Historical Files. Historical files should be carefully prepared and maintained for each part and each piece of equipment in the water supply system. Such files should contain data and information by which the economy and reliability of the various parts of the system may be determined. For example, historical files that have the data and conditions of the installation, types of material, record of time out-of-service, the causes of such out-of-service, and the costs of operation and maintenance can be used in studies to determine proper replacements.

Section B—Tools and Equipment

11-8. Tool Inventory. Effective maintenance requires tools to service the facility properly. A list of suggested tools that should be available at the activity for general maintenance use is in table 11-1. Specific tools may be re-

Table 11-1. Suggested Tools for Water Treatment Plants[1].

Axes, spare axe handles.
Awls.
Bars.
  Crow.
  Wrecking.
Bit brace and assortment of bits for wood and metal.
Blacksmith's anvil, tools, forge, and hand blower.
Bolt stock and dies.
Breast drill and assortment of drills.
Calipers.
  Inside and outside.
  Micrometer.
Caulking tools, water main type (assorted sizes and types).
Chisels.
  Assorted.
  Bull point.
  Cape.
  Cold.
  Diamond point.
  Round nose.
  Assorted, wood.
  Assorted, for air hammer.
"C" Clamps, assorted.
Cotter pin puller.
Countersink, assorted for wood or metal.
Cutters, wire.
Cutters, ½-inch bolt.
Dies, assorted for bolt and pipe threading stocks.
Drills.
  Assortment.
  Electric portable ⅝-inch for twist drills No. 60 to ⅝-inch with drill press stand mount.
  Electric portable ¼-inch for twist drills No. 0 to No. 60.
  Hand.
  Press, bench type.
  Star drills of various sizes.
Extractors, screw, various sizes.
Files.
  Assorted sizes.
  Flat.
  Half round.
  Round.
  Taper (triangular).
  Wood rasp.
Fire pot, including metal foot and wrought steel ladle for use with B and S cast iron pipe.
Flanging tools, for use with copper pipe.
Flaring tools, for use with copper pipe.
Fuse puller.
Gages.
  Set of shims.
  Test for pressure and vacuum.
Glass cutter.
Grinder.
  Electric or hand, bench type.
  Wheels, coarse, fine and wire brush.
Hacksaw, adjustable frame with extra blades.
Hammers.
  Ball peen, assorted sizes.
  Blacksmith's type.
  Caulking.
  Claw.
  Mason's.
  Rubber mallet.
  Sledge type, various sizes.
Hatchet.
Jacks, screw or hydraulic, various sizes.
Joint runner, asbestos, for use with lead joints.
Lathe.
  Metal, 12-inch swing, 24-inch centers.
  Tools and appurtenances.
Lead pot and ladles.
Levels.
  Line.
  Spirit, metal frame, 18 inch.
Line, Mason.
Manhole cover lifting hooks.
Mattock.
Nail sets, various sizes.
Oil cans, several types and sizes as required.
Packing hooks.
Packing tools, assorted.
Pipe Cutter.
Pipe Cutter, wheels (spare).
Pipe taps.
Pipe thread taps (combination), ¼ to 2 inch.
Pipe threading stock with assorted dies.
Pipe tripod.
Plane, smooth, bench, 7 inch.
Pliers.
  Assorted sizes.
  Diagonal cutting.
  Gas.
  Combination slip joint.
  Needlenose.
  Wrench.
Plumb bob.
Puller, gear set.
Punches, assorted sizes, center, drift.
Putty knives.
Reamers, hand, taper, pipe expansion.
Rules, 6 foot folding.
Saws, rip, crosscut, compass and keyhole.
Saw set.
Saw vise.
Scale platform.
Screwdrivers, various sizes.
Screw pitch gage.
Scribers.
Sharpening stone.
Shears, tinsmith's, straight and curved blades, assorted sizes.
Shovels.
  Square point, long and short handle.
  Round point, long and short handle.
Snake, 25-foot spiral.
Soldering iron and appurtenances.
Specific tools for specialized equipment.
Square, steel, large and small.
Stamping tools, steel, letters and numerals.
Straight edge, steel.
Tampers.
Tape, 50-foot steel.
Tar pot.
Torch, blow and gasoline.
Trowels.

[1] Authorization (Table of Allowances) for specific tools are issued by individual services.

Table 11-1. Continued.

Floats, steel, and cork assorted.
Pointing.
Valve resetting tool.
Vises, bench and pipe, portable chain vise and stand.
Voltage tester.
Wall scrapers.
Washer or gasket cutter for making own washers.
Welding outfit with appurtenances, goggles and gloves.
Wire stripper.
Wrenches.
Adjustable, various sizes.
Allen set screw.
Box wrench set.
Hydrant.
Monkey.
Open end, various sizes.
Ratchet, socket set.
Socket, set of various sizes.
Spanner.
Stillson, various sizes.
Torque.
Valve.

quired for specialized equipment. Special test equipment may also be needed. Consult the manufacturer's instructions for such equipment.

11-9. Tool Care and Usage. Tools have specific uses and must not be used for other purposes. When the proper tool is not available, it should be obtained.

a. Tool Storage. Tools should be kept on a tool board or in a tool-box, both of which should be painted (if appropriate) at least once a year; both should also be kept clean. Tools not in their proper places should be in use; if not, they should be found and returned to their proper places.

b. Tool Inspection. Tools must be inspected each month. Damaged or worn tools must be replaced, and edged tools (chisels, planes) must be kept sharp. Tools should be cleaned and lubricated before they are returned to storage.

c. Caution and Usage. Do not use a screwdriver as a chisel, pliers as a wrench, or a wrench as a hammer; and do not use toothed-jaw (stillson-type) wrenches on hard rubber pipe, or on bolts or nuts.

11-10. Equipment and Supplies. In addition to proper tools, a water treatment plant should be adequately supplied with equipment, implements, and supplies that are essential to proper maintenance. Because good housekeeping is a part of maintaining both buildings and grounds, as well as of operating equipment, the equipment and materials needed must include housekeeping and gardening tools, equipment, and material supplies. A list of suggested implements is in table 11-2, and table 11-3 lists the suggested materials and supplies that should be available at the activity.

Section C—Lubrication Practices

11-11. General Information. Proper lubrication prevents damage to wearing surfaces, reduces the maintenance required, and cuts power costs and equipment outages. The instructions that follow list the recommended lubricants for various uses. Directions for lubricating specific equipment are presented in tabular form and, where desirable, are repeated in the text that applies to the specific equipment items. These instructions may be modified as necessary by operator judgement to meet individual situations, but such modifications must have the approval of the utility manager.

11-12. Types of Lubricants. Oils, greases, and preservatives for water works are given in table 11-4. This list does not contain all the lubricants available under military specifications, but it has been developed in an effort to establish good lubrication practice for normal operating conditions with as small a number of good lubricants as is feasible. Use of tables 11-4 and 11-5 does not relieve the responsible activity from using lubricants that meet the requirements of the equipment manufacturer's recommendations. The information in table 11-4 should be familiar to all maintenance and operating personnel. This list is subject to modification at the judgement of maintenance personnel, providing the modification is approved by the utility manager.

11-13. Lubricant Uses. A listing of uses for lubricants that are generally satisfactory when used on equipment operating under normal ranges of temperature, pressure, and corrosion is contained in table 11-5. However, in view of the wide variation in characteristics of equipment and conditions of operation, the manufacturer's instructions for lubrication should be checked to make sure that listed lubricants meet the requirements of the manufacturer's recommended lubricants.

11-14. Lubricating Precautions. In order to avoid plant failures due to improper lubrication, the following precautions should be observed:

a. Do not overlubricate. Overlubrication causes antifriction bearings to heat and may damage grease seals; it may also cause damage to the windings in electric motors.

b. Do not lubricate totally enclosed or insufficiently guarded equipment.

c. Keep lubricant containers tightly closed, except when in use, to prevent contamination of the lubricant by the entrance of dust, grit, and abrasives. Lubricants should be stored in dust-free areas. Before using lubricant containers, the spouts and lips should be wiped; before using grease guns, the gun and fitting should be wiped to ensure the absence of foreign matter.

11-15. Grease Fittings. The same grease gun fitting should be provided on all lubrication points requiring the same grease. This practice reduces the number of grease guns required, keeps the use of improper lubricants to a minimum and simplifies operation.

Table 11-2. Suggested Equipment for Water Treatment Plants.

EQUIPMENT

Alemite or zerk grease guns for plant equipment.
Block and tackle for ½-inch and ¾-inch rope.
Boots, rubber.
Brooms, street, ordinary, industrial.
Brushes, flue, paint and whitewash, scrubbing, wire.
Caulking gun for windows.
Chain hoist, 1-ton capacity.
Electric drop light, explosion-proof with 200-foot extension cord.
Electric torch light, 1½ or 3 volt.
Flashlights, hand.
Gloves, rubber and canvas work.
Hydrometers, battery and alcohol.
Ladders, step, extension (20 foot).
Lanterns, red and white globe.
Leak detectors.
Manhole lifter.
Mop and handle.
Paint sprayer.
Pick.
Rope, ½-inch, ¾-inch, 1-inch, and sash cord.
Safety equipment: Barricades.
Electric blankets.
First aid equipment.
Gas detector.
Gas mask (chlorine).
Harness (safety belt) with 25 feet of ¾-inch rope.
Respirator for paint spraying, dust, etc.
Warning signals.
Squeegees, floor and window.
Torches, bomb-type.
Two-wheel hand trucks.
Vacuum cleaner.
Valve key.
Waste cans.
Wheel barrow, rubber-tired.
Wringer buckets.

GARDEN IMPLEMENTS

Brush hooks.
Garden trowel.
Hedge clippers.
Hoe.
Hose: Garden type (300 feet).
Nozzle (Shut-off type).
Insect sprayer.
Lawn roller.
Mower, lawn (hand or motor).
Pruning shears.
Rakes, wood, steel.
Scythe.
Sickle.
Spade.
Sprinklers.

11-16. Identifying Lubricant Items. The product symbol and identifying color should be marked on lubricant containers and grease guns, and at or near all oil cups and grease fittings to assure the choice of the proper lubricant for that location.

Section D—Protective Coatings

11-17. General Information. The prevention of corrosion and surface deterioration is standard maintenance practice in waterworks. All exposed surfaces, whether external or internal, should be protected. Protective coatings and linings may be nonmetallic or metallic. The former includes paint, enamel, bitumen, cement, plastic, and rubber. Metallic coatings include zinc, aluminum, and lead. Other corrosion control treatments are used on metal equipment surfaces that cannot be painted. Cathodic protection is used where electrolytic corrosion occurs.

11-18. Paint Protection. Surface coating by paint is the most general method of corrosion prevention. Paint should be selected to meet the existing conditions; the choice depends on whether or not the equipment or structure is indoors or outdoors.

11-19. Paint Application. Surface paint must be prepared and applied according to procedures in Tri-Service (DOD) Manual TM85-618, NAVFAC MO-110, AFM 85-3:

a. Surface Preparation. Surfaces to be painted must be prepared properly before the paint is applied. Foreign substances on the surface interfere with the protective action of the coating. Therefore, loose scale, rust, dust, oil, or grease should be removed completely. Only clean surfaces should be painted. Metal surfaces should be sandblasted where this preparatory treatment is required. Sandpaper on a wire brush should be used where required. Dust should be wiped off and greasy or oily surfaces should be cleaned with solvent cleaners.

b. Preparation of Paint. Paint should be mixed properly and screened, if necessary, to remove grit and film. Paint containers should be covered when not in use. Brushes, rollers, and spray applicators should be cleaned before and after use. For damp surfaces, where drying temperatures are less than 40°F, specially prepared paint should be used.

11-20. Corrosion-Preventive Compounds. Corrosion-preventive compounds are used in pits, pump dry-wells, and damp areas. Paint does not serve this purpose. Two corrosion preventive compounds commonly used in waterworks are shown in table 11-4.

Section E—Cleaning Solvents

11-21. Acceptable Cleaning Solvents. Cleaning solvents used in water plants are limited to dry-cleaning solvent,

kerosene, and wood alcohol. Because of low flash points of such solvents as benzene, gasoline, and naphtha they are not suitable for this purpose. Benzene (or benzol) is also extremely toxic.

11-22. Handling Precautions:

a. Store all cleaning solvents in properly marked and capped cans away from heat.

b. The indoor use of kerosene for cleaning purposes is a fire hazard. Thorough ventilation and caution during use are the best safeguards against ignition. The area should be free from sources of ignition.

11-23. Cleaning Solvent Usage:

a. Solvents must be completely evaporated before cleaned equipment is returned to use. Cleaned bearings or machine parts should be placed on clean rags or paper until dry, then immediately lubricated or dipped in oil. Do not let rust-susceptible parts become exposed to air after cleaning.

b. Before using a solvent to clean electrical equipment, remove all loose dirt and dust by blowing, brushing, or wiping, then dip a rag in the solvent and wipe it on the insulation. Spraying can be used but requires extra precautions against fire or health hazards and must be done only under the supervision of fire protection personnel.

c. Solvents used to clean bearings and machinery other than electrical windings can be reused after insoluble matter is removed by filtering the solvent into a container through cloth placed in a funnel. Label containers plainly with the word "USED".

Section F—Measuring Operating Temperatures

11-24. General Information. Safe operating temperature limits must be observed for maintaining equipment properly. If these limits are not known, consult the manufacturer, giving the actual measured operating temperatures. The "feel" of equipment is not a reliable indication of its condition, especially when operating temperatures exceed 125°F. The manufacturer must be given the ambient temperature (temperature of air around the equipment), temperature of the equipment, and location of the thermometer when taking the equipment temperature.

11-25. Temperature Limitations. The surface temperature of the insulation is the only temperature measurement that can be made on motors. In the case of bearings, the only possible measurement is temperature outside the boxing or bearing shell. Transformer measurement is limited to the temperature outside the case and, in some instances, the oil temperature.

11-26. Taking Measurements. Thermometers used for measuring of operating temperatures must have a min-

Table 11-3. Suggested Materials and Supplies for Water Treatment Plants.

Alcohol or anti-freeze.
Assortment of bolts, nuts, washers, screws, cotterpins, rivets, lock washers, cap screws, stud bolt, etc., stored in jars or cans.
Bricks, common.
Calcium chloride (for icy pavements).
Calking compound.
Calking compounds, Durolite or equal, for glass house windows.
Calking yarn.
Cement.
Cement, asbestos.
Chain, assorted sizes and lengths.
Chamois skins.
Cleaning compound, broiler.
Cleaning powders, assorted.
Cleaning solvents (kerosene, dry-cleaning solvent, wood alcohol).
Cups, drinking.
Cutter wheels, spare.
Disinfectants
Emery cloth, assorted grades.
Fittings, brass or iron, assorted sizes.
Flashlight batteries.
Fuses, assorted.
Glass.
Graphite.
Grease, for lubrication.
Hose, nipples, and clamps for garden hose, extra.
Iron and boiler cement.
Kerosene.
Lead and lead wool.
Light bulbs.
Measures, oil, 1 quart and 1 pint.
Mops.
Nails, assorted sizes.
Oakum.
Oil for lubrication.
Oil, rust removing, penetrating.
Packing for pumps.
Paint remover.
Painter's drop cloths.
Paints, turpentine, linseed oil, thinners, etc.
Pipe joint compound.
Pipe stock, depending on system.
Plugs, rubber expansion.
Polish, brass.
Putty.
Rags, clean and sterilized.
Sand, stone or gravel.
Sandpaper, assorted grades.
Soap.
Solder.
Soldering paste.
Spare handles for hammers, hatchets and axes.
Spare parts for all machines and apparatus.
Sponges.
Steel wool.
Tape, friction and electrician's.
Thermometers, assorted.
Toilet paper.
Towels.
Valve grinding compound.
Waste, wiping.
Wicks, for torches and lanterns.
Wire, annealed. No. 10 and No. 16.

Table 11-4. Lubricating Oils, Greases, and Preservatives.

Product	Military Specification Number	Symbol	Approximate SAE Grade[1]	National Stock Number[2]	Temperature Range
					(Above)
Lubricating oil, general purpose	MIL-L-15016A	2075	20W		-10° F
		2110[3]	10W-75W	9150-00-223-4137	0° F
		2135	20W-75W	9150-00-231-6664	0° F
		2190	30W	9150-00-231-6639	35° F
		2250	40W		35° F
		3050[3]	20W	9150-00-223-4138	0° F
		3065	30W-80W		5° F
		3080	40W-90W	9150-00-223-8890	15° F
		3150	140W	9150-00-240-2258	25° F
Lubricating oil, compounded	MIL-L-15019B	4065	40W	9150-00-243-3196	35° F
		6135	140W	9150-00-231-6645	60° F
		8190	30W	9150-00-231-9033	35° F
Lubricating oil, mineral, cylinder	MIL-L-15018B	5190	140W	9150-00-240-2260	60° F
Lubricating oil, steam turbine (noncorrosive)	MIL-L-17331B	219OTEP	30W	9150-00-235-9061	60° F
Lubricating oil, internal combustion engine, subzero	MIL-L-10295A	OES		9150-00-242-7603	-65° to 0° F
Lubricating oil, instrument jewel-bearing, nonspreading low temperature	MIL-L-3918	OCW		9150-00-270-0063	-40° F
Lubricants; chain, exposed-gear and wire rope	VV-L-751A	CW-11B		9150-00-246-3276	All
Lubricating oil, internal combustion engine	MIL-L-2104A	OE-10	10W	9150-00-265-9425	-20° F
		OE-30	30W	9150-00-265-9433	0° F
		OE-50	50W	9150-00-265-9440	15° F
Grease, automotive and artillery	MIL-G-10924A	GAA		9150-00-190-0907	-65° to 125° F
Grease, ball and roller bearing	MIL-G-18709	BR		9150-00-249-0908	125° to 200° F
Grease, graphite	VV-G-671C	GG-1		9150-00-272-7652	125° max.
Lubricating oil, internal combustion, preservative	MIL-L-21260	PE-1		9150-00-111-0201 9150-00-111-0208	
Lubricating oil, preservative, medium		PL-MED		9150-00-231-2356	
Corrosion preventive, petroleum, hot application	MIL-G-11796A	CL-3		8030-00-231-2353	
Corrosion preventive, compound, solvent cutback, cold application	MIL-C-16173B	CT-1		8030-00-231-2362	

[1]SAE numbers 10W through 50W are for crankcase lubricattion. SAE numbers 75W through 140W are for transmission lubrication.

[2]National stock numbers are for 5-gallon containers for lubricating oils and 35-pound containers for grease, except ½-ounce can for MIL-L-3918. For other containers see Federal Supply Catalog.

[3]Quenched.

imum of exterior fittings such as guards or mounts. Ordinary mercury thermometers, calibrated by the user for the range required, are satisfactory.

a. Fasten thermometers to the unit with adhesive tape so the bulb is touching the surface where temperature is being measured. Spread a ¼-inch thickness of glazier's putty around the thermometer bulb.

b. If possible, when measuring bearing temperatures, insert thermometer in inspection hole on top of bearing. Take care to position thermometer so it will not be broken. Do not use putty on the thermometer.

c. Wait for thermometer reading to reach a constant value before recording temperature.

Table 11-5. Lubricating Oil and Grease Uses.

Equipment	Oil or Grease Symbol
Air compressors.	
Vertical with splash lubrication.	
Gage pressure less than 100 psi.	2110, 3050.
Gage pressure greater than 100 psi.	2135, 2190, 3050.
Horizontal	2135, 2190, 3050.
External lubrication, sight feed, wick feed, hand oiling.	2135, 2190, 3050.
External lubrication, circulating systems or splash type crankcase.	2110, 2135, 3050.
Cylinders: Wet conditions	8190.
Dry conditions	2190, 2250, 3065.
Bearings:	
Ball, all temperatures to 200° F.	BR.
Ball, low-pitch line speed.	
Operating temperature below 32° F.	2075.
Operating temperature 32° to 150° F.	2190, 2250, 3065.
Ball, medium-pitch line speed.	
Operating temperature below 32° F.	2075.
Operating temperature 32° to 150° F.	2135, 3050.
Ball, high-pitch line speed.	
Operating temperature below 32° F.	2075.
Operating temperature 32° to 150° F.	2110, 3050.
Ring-oiled, small, miscellaneous.	2110.
Kingsbury thrust bearing	2190TEP.
Thrust (other than Kingsbury, subject to water).	4065.
Thrust (other than Kingsbury, not subject to water).	2135, 2190.
Bronze guide	GAA.
Countershaft	CG 1.
Differential (enclosed)	3150, 5190, 6135.
Eccentric	3065.
Guide	GAA, CG 1.
Oilite bronze bushings	OE10, OE30
Pillow block	GAA.
Underwater-babbitted	GAA, CG 1.
Universal joint, slip splines	BR.
Chain Drives.	
Roller	3080, GAA, CG 1.
Roller (enclosed)	Winter, 2075; Summer, 3065.
Roller (semienclosed)	Winter, 3080; Summer, 6135.
Slow-speed	CW-IIB.
Medium-speed	5190.
Chemical feeders	See manufacturer's instructions.
Clarifier equipment	Do.
Couplings	6135.
Drive jaw clutch	OE50
Gear case or gear head	Low temperature, 3080, High temperature, 5190.
Gears.	
Herringbone	Winter, 2075; Summer, 3065.
Helical	Do.
Motor reducers	Winter, 3050; Summer, 2135.
Open	5190.
Planetary	Winter, 2075, 2110; Summer, 2135.
Worm and pump transmission	Winter, 3080; Summer, 6135.
Instruments	OCW.
Motors	See manufacturer's instructions.
Packing, Sludge Pumps	4065, 6135.
Pumps	See manufacturer's instructions.
Seal packings	GAA.
Shafting.	
Large	2190, 3065.
Small	2110, 2135, 3050.
Shear pins	WB.
Sheaves	CG 1, GAA.
Solenoid oilers	3050.
Valve stems	GAA.

Chapter 12

SAFETY AND HEALTH

12-1. Occupational Safety and Health Act (OSHA) Responsibilities. All military agencies are subject to the OSHA. Portions of the act that apply to operation and maintenance of water plants fall under Part 1910, Occupational Safety and Health Standards, and its subparts. These OSHA standards are implemented at military installations via specific service regulations which are available through the installation's safety, occupational health, and fire department officers. Books, manuals, and movies are also available through the library or training office. Only general information on health and safety is provided in this chapter. Specific instruction and guidelines are in the appropriate service regulations. These should be available in the workplace.

12-2. Nature of Hazards. Personnel who are involved in operating and maintaining of water plants and distribution systems are exposed to a number of safety hazards.

a. Falls. The potential danger of falls from stairways, ladders, catwalks, and excavations is obvious, but injurious falls may also result from slippery floors. Adequate safety measures can eliminate or keep these hazards to a minimum.

b. Improper Lifting. When possible, mechanical lifting equipment should be used; such equipment should only be operated by trained personnel. Injuries often occur when personnel attempt to lift or lower loads that are either too heavy or too bulky for the number of individuals involved. Supervisors will ensure that personnel assigned to manual lifting tasks are trained and use proper lifting techniques (1) through (5) below:

(1) Place feet in stable, wide stance.
(2) Get a firm grip.
(3) Keep back vertical and straight.
(4) Bend knees and lift with legs, not with back.
(5) Turn entire body, do not twist back.

c. Electrical Shock. Dangerous and potentially fatal electric shocks can be avoided by effective maintenance of power tools and electrically driven equipment. All wires and connections should be dry, unfrayed, unbroken, and properly taped if necessary. Effective grounding must be provided. Rubber gloves and rubber-soled shoes are recommended.

d. Sharp-Edged Tools. Most injuries involving sharp-edged tools are the result of negligent usage, use of the improper tool for the job to be done, or use by untrained personnel.

e. Infections. Laboratory bacteriological work can result in infections by harmful organisms unless precautions below are taken:

(1) No smoking, eating, or drinking is permitted while performing this type of work.

(2) Thorough washing of hands following work is important.

(3) Avoid splashing fluids containing bacteria on the skin—particularly on the face.

f. Confined Areas. Manholes, deep pits, and empty tanks often have less than adequate air or oxygen supplies. Personnel experiencing any difficulties in breathing while working in these areas should immediately get out until the atmosphere can be checked for adequate oxygen content.

g. Toxic Dusts. The handling of many of the chemicals (powdered activated carbon, alum, ferrous sulfate, sodium fluoride, sodium silicofluoride, lime, and soda ash) used in water treatment can produce dusts which, if breathed, can be toxic or cause injury to the eyes upon contact. A worker should wear a face shield or goggles, breathing apparatus, and protective clothing that keep contact with dust to a minimum. Proper operation of available ventilation and exhaust systems is important.

h. Dangerous Chemicals. Many laboratory and water treatment plant chemicals may be corrosive, poisonous, or explosive under certain conditions. They should be handled in accordance with the manufacturer's technical data or appropriate service safety regulation.

i. Fire Prevention. The frequency of fire occurrences is reduced by good preventive maintenance procedures. Clean working and storage areas, well-maintained electrical connections, adequate ventilation, care in handling of chemicals, and frequent disposal of flammable rags contribute to fire prevention. Personnel should be aware of the location and use of fire extinguishers and the location of emergency exits.

j. Toxic or Flammable Gases and Vapors. Toxic and flammable gases such as methane often are found in poorly ventilated manholes. Proper ventilation using explosion-proof systems is required before any further work. Both chlorine and chlorine dioxide gases are toxic, as well as explosive, under certain conditions. Areas where flammable materials are stored may accumulate explosive vapors unless properly ventilated. Explosion-proof motors and lights, and spark-proof tools must be used in areas where flammable materials are known to be stored. Welding and smoking are prohibited in flammable-storage areas.

12-3. Basic Safety Measures. There are several basic safety measures that can be taken to help prevent accidents. These apply to all aspects of water supply, treatment, and distribution work.

a. Safety Record Keeping. A conscientious program of recording the occurrence of accidents is essential to pinpoint types and sources of accidents, to determine responsibility, and to properly evaluate an overall safety program. A record should be kept for each employee, as well as for each facility or operation. It is important that all accidents and injuries be reported, and that the reports be complete and accurate.

b. Locating and Correcting Safety Hazards. Many accidents can be prevented by eliminating or altering the situa-

tion that caused them. Analysis of accident records helps locate such hazardous situations. Suggestions from individual personnel are equally helpful, and should be encouraged at all times.

c. Equipment, Plant Arrangement, and Working Methods. Basic safety measures in these areas help to avert accidents:

(1) Equipment. Safety devices such as handguards, seatbelts, alarms, sequenced manual controls, etc., which are included on equipment should be maintained in working order and used at all times. Minor inconveniences resulting from their use are more preferable than the potential of serious injury that could result from not using them.

(2) Plant Arrangement. Spacing and arrangement of equipment and materials for both operation and storage within the water treatment plant should include safety considerations. Adequate working space, ample walkways, exits, fire prevention and control, minimized climbing and lifting, adequate lighting, noise protection, and ventilation are some of the aspects that operation and maintenance personnel, particularly supervisors, should consider when planning plant arrangements.

(3) Working Methods. Proper use of tools, lifting techniques, climbing safety, underground safety, equipment handling, and teamwork can be improved by a relatively small amount of informal instruction or discussion, particularly with new workers.

d. Emergency Plans. Management should prepare an Emergency Operating Instruction (EOI) that provides emergency situation guidance for supervisors and employees. Personnel should be aware of emergency procedures to be followed in the event of an accident or fire. Information of phone numbers for contacting medical facilities, fire stations, and other emergency activities should be prominently posted. The location of emergency equipment (such as inhalators, respirators, fire extinguishers, first aid kits, and chlorine container emergency kits) should be clearly identified at their respective storage areas and a separate list describing available equipment and designated storage location maintained near the listing of emergency phone numbers. Posted first aid instructions and emergency procedures should be backed up by periodic demonstrations and drills.

e. Personal Protective Equipment. Personal protective equipment must include protection against hazards to eyes, face, head, respiratory organs, hands, feet, and body. Supervisors should make sure that personnel are trained in the use of this equipment and that the equipment is worn by personnel when required. Safety procedures and equipment are described in the service occupational and safety regulations:

(1) Face and Eye Protection. Personnel should be provided with suitable spectacles, cap goggles, or face shields to be worn during any operation in which fragments of materials, chemicals, or fluids containing disease-causing biological organisms, are likely to strike the operator's eyes or face.

(2) Head Protection. Provision should be made for protective hats of metal, plastic, or fiberglass crowns suspended on an adjustable headband, when operations are in an area in which tools or materials may fall on the worker. Metal hats will not be used where electrical hazards are likely to exist.

(3) Respiratory Protection. In dusty areas, or where toxic powders, fumes, vapors, gases, or oxygen-deficient atmospheres exist, adequate ventilation must be provided. Ventilation should be supplemented by filter respirators, cartridge respirators, or a breathing apparatus supplied with air or oxygen. Contact medical personnel concerning selection of specific respiratory protection for particular hazards.

(4) Hand and Foot Protection. These procedures are basic:

(a) Ordinary work gloves are necessary for hand protection against friction, minor scratches, or bumps. Specifically, resistant gloves (leather, rubber, asbestos, plastic, etc.) should be worn for handling rough, sharp or hot materials, or chemically active substances.

(b) Rough-soled safety shoes are preferable for slippery surfaces, as are rubber boots for work in wet areas. Safety-toe workshoes may be worn in all cases, but must be provided where tools or materials may fall. Heavy metal foot guards may be required in some cases, such as when hot, molten lead is being poured, or for jackhammer operators.

(5) Body Protection. Overalls or coveralls may be sufficient for ordinary work. Rubber boots and gloves may be required when there is danger of electrical shock. Where chemicals are being handled, rubber aprons or laboratory coats may be needed. When working on scaffolding or at dangerous heights, safety belts are necessary as safeguards against falls.

f. Safety Instructions. Periodic, mandatory instructions on the working methods, with an emphasis on safety considerations, can prevent accidents. This particularly applies to new workers and also can be helpful in reducing carelessness by experienced personnel. In many cases, instruction may be effective in informal sessions conducted by the first-line supervisor at the worksite.

(1) Proper Use of Tools. Accidents caused by improper use of tools can be reduced materially if basic rules are followed.

(a) Always select the proper tool for the job; never use a makeshift tool.

(b) Check the condition of a tool at frequent intervals; repair or replace if defective.

(c) Do not use tools on moving machinery; stop the machine fully before making adjustments.

(d) Check the clearance at the workplace to make sure there is sufficient space to avoid accidental injury if the tool should slip.

(e) Have a steady footing so there is no hazard of slipping, stumbling, or falling.

(f) Protect hands by wearing gloves in confined spaces, except when using hammers; do not wear rings.

(g) Carry sharp or pointed tools in covers, or be sure they are pointed away from the body in case of a fall.

(h) Wear eye protection when using impact tools on

hard, brittle materials.

(i) After using tools, wipe them clean and place them where they will not be damaged or create a work hazard.

(j) Do not randomly lay tools on places where they can fall on someone below, such as on stepladders or scaffolds.

(k) Learn and use the proper technique for working with all hand tools.

(l) Use tools made from nonsparking materials where fire or explosion are potential hazards.

(2) Handling Materials and Equipment. Lifting, lowering, and handling materials should be done safely; and proper procedures apply to such items as wheelbarrows, hand-trucks, scaffolds, and ladders. Chemical handling and storage require both common sense and safe practices. Power equipment (motors, gasoline engines, and diesel engines) not only need safety protection in the form of guardrails around dangerous or moving parts, but also need safety practices with respect to oiling, repairs, solvents and storage of fuel, etc.

g. Fire Protection. The following are important points of an effective fire prevention system:

(1) Working areas should be kept neat and orderly to prevent accumulation of flammables, and to allow passage by personnel escaping or fighting fires.

(2) Extinguishers should be properly inspected and maintained, and conspicuously located in readily accessible places. The proper type of extinguisher should be provided for the particular type of fire anticipated.

(3) Emergency exits should be conspicuously located and marked, and personnel should be aware of their locations.

(4) Telephone numbers of the proper firefighting department should be posted at every telephone station for quick reference in an emergency.

(5) Flammable materials should be stored in isolated areas. These areas should have explosion-proof lights and electric motors, nonsparking tools, fire doors, and fire alarms. Automatic sprinkler systems may be warranted.

(6) Fire alarms should be installed and regularly tested.

h. Power Drives and Shaft Guards. Large equipment used in waterplants, wellhouses, or in the field should have adequate handguards around moving parts, such as flywheels, drivebelts and shafts, and reciprocating parts. At stationary facilities guardrails should be installed also.

i. Adequate Help and Teamwork. Many common injuries resulting from lifting or lowering, climbing, and other hazards could be avoided by providing adequate help and teamwork to keep risks to a minimum. This is an obvious point, but one that is often disregarded in order to reduce operating costs.

j. Protection of Public. Protection of the public is a particularly important consideration during work along busy streets. Warning signs and lights should be placed conspicuously. Barricades and cones should direct automotive and pedestrian traffic around the working area. Pipes, hoses, and construction debris should be secure and out of the way of traffic. In some cases, a person may be needed to give signals. The overall effect should be a minimum amount of traffic disruption.

BY ORDER OF THE SECRETARIES OF THE AIR FORCE, THE ARMY, AND THE NAVY

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SUMMARY OF CHANGES

This revision adds the latest technology in the field of water supply, treatment, and distribution systems; adds appropriate information relating to the Safe Drinking Water Act (Public Law 93-523); and expands coverage of meters, controls, and valves.

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GLOSSARY OF TERMS

Absorption—The process of taking in or soaking up liquids; not to be confused with adsorption.

Acid—A compound, usually having a sour taste, which is able to neutralize an alkali or base; a substance that dissolves in water with a formation of hydrogen ions.

Acidity—A quantitative measurement of the total acid constituents of a water, both in the ionized and unionized states expressed as pH.

Acre-Foot—A measurement used for reservoirs of water storage that is equivalent to one acre (43,560 square feet) one foot deep, or 43,560 cubic feet or 325, 830 gallons.

Adsorption—The adherence of dissolved, colloidal, and finely divided matter on the surfaces of solid bodies with which they are brought in contact, not to be confused with absorption.

Aeration—The bringing about of intimate contact between air and a liquid by one of the following methods: spraying the liquid in the air; bubbling air through the liquid; or by agitation of the liquid to promote surface absorption of air.

Aerobic—Requiring the presence of free oxygen.

Agglomeration—The gathering together of dispersed suspended matter into larger flocs or particles which settle rapidly.

Air Binding—The condition whereby entrained air clogs or otherwise interferes with proper operation of a sand filter, pump or pipe.

Algae—Tiny plant life, usually microscopic, existing in water. They are mostly green, blue-green, or yellow-green, and are the cause of most tastes and odors in water.

Alkalinity—A term used to represent the content of carbonates, bicarbonates, hydroxides, and occasionally borates, silicates, and phosphates in water.

Anaerobic—Requiring the absence of free oxygen.

Anion—A negatively charged ion in an electrolyte solution, attracted to the anode under the influence of electric potential.

Appurtenances—Structures, devices and appliances, other than pipe and conduit, which are used in connection with a water distribution system, for example, valves, hydrants, corporation cocks, services, etc.

Aquiclude—A geologic formation which, although porous and capable of absorbing water slowly, will not transmit it rapidly enough to furnish an appreciable supply for a well or spring. The permeability is so low that, for all practical purposes, water movement is precluded or severely restricted.

Aquifer—A water-bearing formation or stratum beneath the earth's surface which transmits water from one point to another.

Artesian—An adjective applied to ground water, or items connected with ground water, for example, a well, under ground basin, etc., where water is under pressure and will rise to a higher elevation if afforded an opportunity to do so.

Backblowing—Reversal of the flow of water under pressure in a well to free the screen or strainer and the aquifer of clogging material.

Backflow—The backing-up of water through a conduit or channel in the direction opposite to normal flow.

Backflow Preventer—A device for a water supply pipe to prevent the backflow of water into the water supply system from the connections on its outlet end.

Backsiphonage—The flowing back of contaminated or polluted water from plumbing fixture or cross-connection, into a water supply line, because of a lowering of the pressure in the line. Also termed "backflow."

Backwash—The reversal of flow through a filter to wash clogging material out of the filtering medium and reduce conditions causing loss of head. Also called filter wash.

Bacteria—Primitive microscopic plants, generally free of pigment, which reproduce by dividing in one, two, three plants. Do not require light for their life processes.

Bacterial count—An estimate of the total number of bacteria of all kinds in 1 ml sample which will grow at the stated temperature, usually 37 °C. Also standard plate count.

Base—An alkali or hydroxide of the alkali metals, and of ammonia, which neutralizes acids to form salts and water. Ionizes to form (OH^-) ions. A hydroxide. An alkali.

Basin—A natural or artificially created space or structure, surface or underground, which by reason of its shape and the character of its confining material, is capable of holding water. The term is sometimes used for a receptacle midway in size between a reservoir and a tank.

Blowoff—A controlled outlet on a pipeline, tank, or con-

duit used to discharge water or accumulations of material carried by the water.

Boom—A floating structure, usually of timber or logs, used to protect the face of a dam or other structure from damage by wave action, by floating material being dashed against it by the waves, or to defect floating material away from such a structure.

Brackish Water—Water rendered unfit for drinking because of salty or unpleasant tastes caused by the presence of excessive amounts of dissolved chemicals, chlorides, sulfates, and alkalies.

Capillarity—The degree to which a material or object containing minute openings or passages, when immersed in a liquid, will draw the surface of the liquid above the hydrostatic level.

Cathodic Protection—Reduction or elimination of corrosion by making the metal a cathode by means of an impressed direct current (DC) or attachment to a sacrifical anode (usually Mg, Al or Zn).

Centigrade—Pertaining to the Centigrade thermometer scale; water freezes at 0 °C, and boils at 100 °C.

Centrifugal—Moving or directed outward from the center.

Chemical Feeder—A device for feeding chemicals to water at a known, controlled rate.

Chloramines—Compounds of organic amines or ammonia with chlorine.

Chlorination—Treatment of water by the addition of chlorine either as a gas or liquid, or in the form of hypochlorite, usually for the purpose of disinfection, oxidation, etc.

Chlorination, Breakpoint—The application of chlorine to water containing free ammonia to provide a free available chlorine residual.

Chlorination, Post—The application of chlorine to water subsequent to any treatment. The term refers only to the point of application.

Chlorination, Pre—The application of chlorine to water prior to any treatment.

Chlorinator—A device to apply chlorine to water at a known, controlled rate.

Chlorine, Combined, Available Residual—That portion of the total residual chlorine remaining in water at the end of a specified contact period, which will react chemically and biologically as chloramines, or organic chloramines.

Chlorine Demand—The difference betwen the amount of chlorine added to water and the amount of residual chlorine remaining at the end of a specified contact period.

Chlorine, Free Available Residual—That portion of the total residual chlorine remaining in water at the end of a specified contact period, which will react chemically and biologically as hypochlorous acid, HOCl, or hypochlorite ion, (OCl^-).

Chlorine Ice—A solid hydrate of chlorine sometimes formed at the diffuser or in the bell jar of a chlorinator, where the gas comes in contact with the cold water.

Chlorine Residual—The total amount of chlorine (combined and free available chlorine) remaining in water at the end of a specified contact period following chlorination.

Clarification—Process of subsidence and deposition by gravity of suspended matter carried by water or other liquids. Also called settling, it is usually accomplished by reducing the velocity of flow of the liquid below the point where it can transport the suspended material.

Coagulant—A chemical or material which when added to water will combine with added or naturally present chemicals to form a precipitate, called a floc, which will settle and aid in the removal of suspended matter in the liquid.

Coagulation—The destabilization and initial aggregation of colloidal and finely divided suspended matter by the addition of a floc-forming chemical.

Coagulation Basin—A basin employed for the coagulation of suspended or colloidal matter, with or without addition of a coagulant, in which the liquor is mixed gently to induce coagulation, flocculation, and agglomeration, in preparation for subsequent sedimentation.

Coefficient—A numerical quantity or factor, determined by experimental methods, put into a formula, which expresses the relationship between two or more variables, commonly used to adjust the theoretical relation to that found in actual practice.

Coefficient, Discharge—The factor or number by which the theoretical discharge of fluids through orifices, nozzles, tubes, weirs, etc., must be multiplied to obtain the actual discharge.

Coefficient, Roughness—A factor, in the Kutter, Manning, and other formulas for computing the average velocity of the flow of water in a conduit. It represents the effect of roughness of the confining material of the channel or conduit upon the energy losses in the flowing water.

Coefficient, Uniformity—The degree of variation in the size of the grains that constitute a granular material. It is

the ratio of: (1) the diameter of a grain of a size that is too large to pass through a sieve which allows 60 percent of the material (by weight) to pass through, to (2) the diameter of a grain of a size that is too large to pass through a sieve which allows 10 percent of the material (by weight) to pass through. The coefficient is unity for any material whose grains are all the same size, and it increases above unity with variation in the size of the grains.

Coliform Organisms—A group of bacteria, predominantly inhabitants of the intestine of humans, but also found on vegetation, including all aerobic and facultative anaerobic bacilli, that ferment lactose to produce a gas as one of the byproducts.

Colloids—Finely divided solids which will not settle, but may be removed by coagulation or biochemical action.

Color, Apparent—Pigmentation due to the presence of suspended solids in a water supply.

Color, True—Pigmentation due to the presence of finely divided particles or droplets either dispersed, or in solution, in a water supply.

Community Water System—A public water system which serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents.

Compound—A substance containing molecules or two or more different elements which have entered into chemical combination with each other to form another substance unlike any of the constituent elements.

Concentration—A measure of the amount of dissolved substances contained per unit volume of solution. May be expressed as grains per gallon, pounds per million gallons, milligrams per liter.

Contaminant—As referred to in the Safe Drinking Water Act, means any physical chemical, biological, or radiological substance or matter in water.

Contamination—A general term signifying the introduction into water of micro-organisms, chemicals, wastes, or sewage, which renders the water unfit for its intended use. Usually considered to imply the presence, or possible presence, of disease-producing bacteria. A specific type of pollution.

Corrosion—The destruction of a substance; usually a metal, or its properties because of a reaction with its (environment) surroundings.

Crenothrix—A genus of bacteria characterized by unbranched, attached filaments having a gelatinous sheath in which iron is deposited. They precipitate metallic oxide deposits in pipes, etc., which sometimes color the water. Also, after death, they cause disagreeable taste and odors in water.

Cross-Connection—In plumbing, a physical connection through which a supply of potable water could be contaminated, polluted, or infected. A physical connection between water supplies from different systems.

Dam—A barrier constructed across a watercourse for the purpose of (1) creating a reservoir, (2) diverting water therefrom into a conduit or channel, (3) creating a head which can be used to generate power, and (4) improving river navigability.

Dechlorination—The partial or complete reduction of residual chlorine in a liquid by any chemical or physical process.

Demanganization.—In water treatment, the removal of compounds of manganese from water.

Demineralization.—Reduction of the mineral content of water by a physical or chemical process; removal of salts.

Deoxygenation—Depletion of the dissolved oxygen content in a liquid.

Detention Time—The theoretical length of time for water to pass through a basin or tank, of all the water moves through with the same uniform velocity ; mathematically equal to the volume of basin divided by the rate of flow.

Diffuser—A porous plate, tube, or other device through which air is forced and divided into minute bubbles for diffusion in liquids. Commonly made of Carborundum, Alundum, metal, or plastic materials.

Discharge—(1) As applied to a stream, the rate of flow or volume of water flowing at a given place within a period of time. (2) The process of water or other liquid passing through an opening or along a conduit or channel. (3) The water or other liquid which emerges from an opening or passes along a conduit or channel.

Disinfectant—Any oxidant, including but not limited to chlorine, chlorine dioxide, chloramines, and ozone added to water in any part of the treatment or distribution process, that is intended to kill or inactivate pathogenic micro-organisms.

Disinfection—The process of killing most (but not necessarily all) of the harmful and objectionable micro-organisms in a fluid by various agents such as chemicals, heat, ultraviolet light, ultrasonic waves, radiation, etc.

Dissociation—The dissolving of molecules of a substance in water into positive and negative ions. Also called ionization.

Dissolved Solids—Solids that are present in solution.

Distillation—The process of converting a liquid to a gaseous or vaporous state and condensing the resulting vapor to liquid under the influence of heat (and possibly reduced pressue or partial vacuum), followed by cooling. Used to remove impurities from a liquid in order to improve its purity.

Dose Equivalent—The product of the absorbed dose from ionizing radiation and such factors as account for differences in biological effectiveness due to the type of radiation and its distribution in the body as specified by the International Commission on Radiological Units and Measurements.

Drawdown—The lowering of the water surface in a well, and of the water table or piezometric surface adjacent to the well, resulting from the withdrawal of water from the well by pumping. Drawdown is the difference between static level and pumping level.

Dry Feeder—A feeder for dispensing a chemical or other fine material in the solid state to water or wastewater at a rate controlled manually or automatically by the rate of flow. The constant rate may be either volumetric or gravimeteric.

E. Coli—See Escherichia coli.

Effective Size—The size of sieve which will permit 10 percent (by weight) of the sand sample to pass but will retain the remaining 90 percent. A measure of the relative ability of a filtering material to permit the passage of water.

Effluent—(1) A liquid which flows out of a containing space. (2) Water, or other liquid, partially or completely treated or in its natural state, which flows out of a reservoir, basin, treatment plant, or part thereof.

Electrolysis—Chemical changes in an electrolyte caused by an electrical current. The use of this term to mean corrosion by stray currents should be discouraged.

Element—A substance which cannot be subdivided into simpler substances by ordinary chemical changes.

Elevated Storage—In any distribution system, storage of water in a tank supported on a tower.

Escherichia Coli (E. Coli)—One of the species of bacteria in the coliform group. Its presence is considered indicative of fresh fecal contamination.

Eutrophic Lake—Lake or other contained water body rich in nutrients. Characterized by a large quantity of planktonic algae, low water transparency with high dissolved oxygen in upper layer, zero dissolved oxygen in deep layers during summer months, and brown- or black-colored organic deposits.

Evaporation—(1) The process by which water passes from a liquid state, at temperatures below the boiling point, to vapor. It is the principal process by which surface or subsurface water is converted to atmospheric vapor. (2) The quantity of water that is evaporated; the rate is expressed in depth of water, measured as liquid water, removed from a specified surface per unit of time—generally in inches or centimeters per day, month, or year.

Evapotranspiration—Water withdrawn from soil by evaporation and/or plant transpiration. Considered synonymous with consumptive use.

Facultative Bacteria—Bacteria which can adapt themselves to growth in the presence, as well as in the absence, of oxygen.

Fahrenheit—Pertaining to the Fahrenheit thermometer scale. Water freezes at 32 °F and boils at 212 °F.

Filter—A device or structure for removing solid or colloidal matter (which usually cannot be removed by sedimentation) from water, or other liquids or semiliquids, by a straining process whereby the solids are held on a medium of some kind (granular, diatomaceous earth, woven, porous, etc.) while the liquid passes through.

Filter Bottom—The underdrainage system for collecting the water that has passed through a filter and for distributing the wash water that cleans the filter medium.

Filter, Diatomite—A filter employing diatomaceous earth as the filtering material.

Filter, Gravity—An open filter, the operating level of which is placed near the hydraulic grade line of the influent and through which the water flows by gravity.

Filter, Pressure—A filter of the closed type, having a vertical or horizontal cylinder of iron, steel, wood, or other material inserted in a pressure line.

Filter, Rapid Sand—A filter used in the purification of water. Water which has been previously treated usually by coagulation and sedimentation is passed downward through a filtering medium, consisting of a layer of relatively coarse sand, or prepared anthracite coal, or other suitable material; usually from 24 to 30 inches thick, resting on a supporting bed of gravel or porous medium such as Carborundum. The filtered water is removed by an underdrainage system which also distributes the wash water during backwashing. Filter rates commonly range from 2 to 3 gallons per minute per square foot of filter area. Also called mechanical filter.

Filter Rate—The rate of application of material to some process involving filtration; for example, waterflow to a rapid sand filter.

Filter Rate Controller—An automatic device inserted in the effluent pipe of a filter to maintain the rate of flow constant throughout the filter run.

Filter, Slow Sand—A filter used in the purification of water where water without previous treatment is passed downward through a filtering medium consisting of a layer of sand or other suitable material; usually finer media than for a rapid sand filter, and from 24 to 40 inches thick. The filtered water is removed by an underdrainage system and the filter is cleaned by scraping off and replacing the clogged layer. It is characterized by a low rate of filtration, usually from 3 to 6 million gallons per day per acre of filter area.

Fines—The finer grained particles of a mass of soil, sand, or gravel.

Finished Water—Treated water.

Fire Demand—The quantity of water and rate of flow required for firefighting purposes; based on the types and sizes of structures to be protected and the duration of the fire.

Fixed Installation—An installation which, through extended use, has gained those structures and facilities not initially found or intended for use at a "temporary" standard facility.

Flashboard—A temporary barrier, of relatively low height and usually constructed of wood, placed along the crest of the spillway of a dam to allow the water surface in the reservoir to be raised above the spillway level to increase storage capacity. Construction is such that it can be readily removed or lowered, or carried away by high flow or floods.

Floc—Small gelatinous masses which are accumulations of microparticles, bacteria, and other organisms; formed in a liquid by the addition of chemical coagulants, or by the gathering together of particles by mixing.

Flocculation—The formation of flocs subsequent to the process of coagulation.

Flume—An open conduit, constructed of wood, masonry, or metal, and constructed on a grade; sometimes elevated.

Flume, Control—A flume arranged for measuring the flow of water or other liquids; generally including a constricted section wherein a minimum energy head exists at all stages.

Flume, Parshall—A device for measuring the flow of liquid in an open conduit.

Fluoridation—The addition of a chemical to increase the concentration of fluoride ions to a predetermined limit causing a reduction in the incidence of dental cavities.

Foot Valve—A valve placed in the bottom of the suction pipe of a pump, which opens to allow water to enter the suction pipe but closes to prevent water from passing out of it at the bottom end.

Friction, Hydraulic—The resistance to flow exerted on the perimeter or contact surface of a body of water moving in a stream of conduit, caused by the roughness that is characteristic of the confining surface and which induces turbulence and consequent loss of energy. Energy losses arising from excessive turbulence, impact at obstructions, curves, eddies, and pronounced channel changes are not ordinarily ascribed to hydraulic friction.

Friction Loss—Pressure lost in overcoming friction of pipe material on flowing water.

Gage—(1) A device for indicating magnitude or position in specific units, when such magnitude or position undergoes change, for example: the elevation of a water surface, the velocity of flowing water, the pressure of water, the amount of intensity of precipitation, the depth of snowfall, etc. (2) The act or operation of registering or measuring magnitude or position when characteristics are undergoing change. (3) The operation, including both field and office work, of measuring the discharge of a stream of water in a waterway.

Gage, Loss of Head—A gage on a filter which indicates the loss of head involved in the filtering operation whereby the operator is able to ascertain the need for filter washing.

Gage, Pressure—A device for registering the pressure of solids, liquids, or gases. It may be graduated to register pressure in any units desired.

Gage, Recording—A gage which makes a continuous record. Also called a register.

Gage, Water-Level—A gage, recording or otherwise, which indicates the water level in a reservoir, still well, or other receptacle.

Gaging, Stream—Measuring the (1) velocity of a stream of water in a channel or open conduit and the (2) area of the water cross section, for the purpose of determining the discharge.

Gallery—(1) An underground structure designed and installed for the purpose of collecting subsurface water. (2) A passageway in a structure, such as a dam water treatment plant, etc., used for obtaining access to interior parts, or to carry pipes, or to house machinery.

Galvanic Series—A list of metals arranged according to their relative corrosion potentials in some specific environment; sea water is often used.

Grade, Hydraulic—In closed circuit under pressure, a line joining the elevations to which water would rise in pipes freely vented and under atmospheric pressure.

Gram—A metric unit of mass defined as one thousandth of a kilogram. Practically equal to the weight of a cubic centimeter of water.

Greensand—A common name for glauconite, a natural zeolite, used in water softening.

Gross Alpha Particle Activity—The total radioactivity due to alpha particle emission as inferred from measurements on a dry sample.

Gross Beta Particle Activity—The total radioactivity due to beta particle emission as inferred from measurements on a dry sample.

Ground Water—Water occurring in a stratum (aquifer) below the surface of the ground. The term is not applied to water which is percolating or held in the top layers of the soil, but to that below the water table.

Ground Water Recharge—Water descending to the zone of saturation under natural conditions or as added through the activities of man.

Halogen—One of the chemical elements fluorine, chlorine, bromine or iodine.

Hardness—A characteristic of water, chiefly due to the existence therein of the carbonates and sulfates (and occasionally the nitrates and chlorides) of calcium, iron, and magnesium; causes "curding" of water when soap is used, increased consumption of soap, deposition of scale in boilers, injurious effects in some industrial processes and sometimes objectionable taste in the water. Commonly computed from the amounts of calcium and magnesium in the water and expressed as equivalent calcium carbonate.

Head, Friction—The head lost of water flowing in a stream or conduit as the result of the disturbances set up by the contact between the moving water and its containing conduit, and by intermolecular friction. In laminar flow the head lost is approximately proportional to the first power of the velocity; in turbulent flow it is it approximately proportional to the square of the velocity. While strictly speaking, head losses due to bends, expansions, obstructions, impact, etc., are not included in this term, the usual practice is to include all such head losses under this term.

Head, Loss of—The decrease in head between two points.

Head, Negative—The loss of head in excess of the static head (a partial vacuum) produced by clogging of rapid sand filters near the end of a filter run.

Head, Pressure—The head represented by the expression, p/w, where p is pressure and w is weight. When p is in pounds per square foot and w is the weight of the liquid per cubic foot, h becomes head in feet.

Head, Static—The vertical distance between the free level of the source of supply, and the level of the free discharge surface.

Head, Static Suction—The vertical distance from the free surface level of the source of supply to the center line of the pump.

Head, Total—The difference in elevation between the surface of water at the source of supply and the elevation of the water at the outlet at the source of supply and the elevation of the water at the outlet (static head), plus velocity head, and friction head.

Head, Velocity—The theoretical vertical height through which a liquid body may be raised due to its kinetic energy. It is equal to the square of the velocity divided by twice the acceleration due to gravity.

Hydraulic Grade—A line connecting all points representing the head in any system. Frequently, it is mistakenly called hydraulic gradient, but it is simply a curve representing line pressures at various points along a line or throughout a water system.

Hydraulic Radius—The right cross-sectional area of a stream of water divided by the length of that part of its periphery in contact with its containing conduit; the ratio of area to wetted perimeter.

Hydrogen-ion Concentration (pH)—A measure of the acidity or alkalinity of a solution. A value of seven is neutral; low numbers are acid, large numbers are alkaline. Strictly speaking, pH is the negative logarithm of the hydrogen-ion concentration.

Hydrologic Cycle—The complete cylce of phenomena through which water passes, beginning as atmospheric water vapor, passing into liquid or solid form as precipitation, thence along or into the ground surface, and finally again returning to the form of atmospheric water vapor.

Impeller—A rotating set of vanes designed to produce the rotation of a mass of fluid. The peripheral speed of the vane tips determines the head produced and the working pressure of a pump. The rotating unit in a centrifugal pump.

Infiltration—(1) The flow or movement of water through

the pores of a soil or other porous medium. (2) The absorption of liquid water by the soil, either as it falls as precipitation, or from a stream flowing over the surface. Also called seepage.

Infiltration Gallery—A sizable gallery with openings in its sides and bottom, extending generally horizontally into a waterbearing formation, for the purpose of collecting the water contained therein.

Influent—Water flowing into a reservoir, basin, treatment plant, or a part thereof.

Inorganic Matter—Chemical substances of mineral origin; not of basically carbon structure.

Intermittent Stream—A stream or portion of a stream that flows only in direct response to precipitation. It receives little or no water from springs and no long-continued supply from melting snow or other sources.

Interstice—A pore or open space in rock or granular material, not occupied by solid matter. Also called void or void space.

Ion—An electrically charged atom (Na^+, Al^{+3}, Cl^-, S^{-2} or group of atoms known as "radicals" (NH_4^+, SO_4^{-2}, PO_4^{-3}).

Ion Exchange—A process whereby water is passed through a granular material and ions of the granular material are replaced by ions contained in the water. For example, in the zeolite softening process the sodium ions (Na^+) of the granular zeolite are replaced by the calcium ions (Ca^{++}) in the water to leave the water free of calcium, the cause of hardness, but containing an equivalent amount of sodium.

Ionization—The process of the formation of ions by the splitting of molecules of electrolytes in solution.

Jar Test—A laboratory test used to determine the optimum amounts of coagulant to be added or most efficient coagulation.

Jetting—(1) A method of well sinking wherein the casing is sunk by driving while the material inside is washed out by a water jet, and carried to the top of the casing. (2) A method of sinking piles by means of a water jet. (3) A method of inserting well points by means of a water jet.

Lagooning—The placement of solid or liquid material in a basin, reservoir, or artificial impoundment for purposes of storage, treatment, or disposal.

Langelier Index—An expression to indicate the hydrogen-ion concentration that a water should have to be in equilibrium with its content of calcium carbonate.

Lateral—The smaller pipes of a filter underdrainage system which are connected to the main pipe, or manifold, and which contain orifices through which the filtered water flows.

Level, Hydrostatic—The level of elevation to which the top of a column of water would rise, if afforded opportunity to do so, from an artesian aquifer, or basin, or from a conduit under pressure.

Level, Pumping—The elevation at which water stands in a well when the well is being pumped at a given rate.

Level, Static—The elevation of water table or pressure surface when it is not influenced by pumping or other form of extraction from the ground water body. It is the level of ground water in a well before pumping.

Lime-Soda Ash Softening—A process of softening water by adding lime to precipitate carbonate hardness and soda ash to precipitate noncarbonate hardness, with subsequent removal of precipitate by sedimentation and filtration.

Liter—1,000 milliliters; practically 1,000 cubic centimeters.

Main—A pipeline on the discharge side of a water pumping station.

Maintenance—The upkeep necessary for efficient operation of physical properties. It involves labor and materials, but is not to be confused with replacement or retirement.

Man-Made Beta Particle and Photon Emitters—All radionuclides emitting beta particles and/or photons listed in Maximum Permissible Body Burdens and Maximum Permissible Concentration of Radionuclides in Air or Water for Occupational Exposure, NBS Handbook 69, except the daughter products of Thorium-332, Uranium-235, and Uranium-238.

Manometer—Single or double (U-tube) glass tube containing a liquid; and indicating instrument used for measuring flow pressure or liquid level.

Maximum Contaminant Level—The maximum permissible level of a contaminant in water which is delivered to the free flowing outlet of the ultimate user of a public water system, except in the case of turbidity where the maximum permissible level is measured at the point of entry to the distribution system. Contaminants added to the water under circumstances controlled by the user, except those resulting from corrosion of piping and plumbing caused by water quality, are excluded from this definition.

Maximum Total Trihalomethane Potential (MTP)—The maximum concentration of total trihalomethanes produced in a given water containing a disinfectant residual after 7 days at a temperature of 25 °C or above.

Membrane Filtration—A method of quantitative or qualitative analysis of bacterial or particulate matter in a water sample by filtration through a membrane capable of retaining bacteria.

Meter—A unit of length; 100 centimeters; 1,000 millimeters; a device for measuring the flow of fluid.

Micro-Organism—A minute plant or animal in water or earth that is visible only through a microscope.

Milligrams Per Liter—A unit of the concentration of water or wastewater constituent. It is 0.001 g of the constituent in 1,000 ml of water. It has replaced the parts per million unit, to which it is approximately equivalent, in reporting the results of water and wastewater analyses.

Mineral—(1) Any of a class of substances occurring in nature, usually comprising inorganic substances (such as quartz and feldspar) of definite chemical composition and usually of definite crystal structure, but sometimes also including rocks formed by these substances as well as certain natural products of organic origin, such as asphalt and coal. (2) Any substance that is neither animal or vegetable.

Mixer, Flash—A device for quickly dispersing chemicals uniformly throughout a liquid.

Mole—Molecular weight of a substance expressed in grams.

Most Probable Number (MPN)—The best estimate, according to statistical theory, of the number of coliform (intestinal) organisms present in 100 ml of a water sample.

Mud Balls—The end results of the cementing together of sand grains in a filter bed by gelatinous material, such as a coagulant. They may vary in size from a pea to 1 to 2 inches in diameter.

Nitrogen Cycle—The unending cycle in nature through which the nitrogen passed from plant and animal proteins, to organic nitrogeneous material, to ammonia, to nitrites, to nitrates, and then to plant and animal proteins again.

Noncommunity Water System—A public water system that is not a community water system.

Nonpotable Water—Water that has not been examined, properly treated and approved by appropriate authorities as being safe for domestic consumption. All waters are considered nonpotable until declared potable.

Operating Log—Daily detailed records of operation.

Organic—(1) Characteristics of, pertaining to, or derived from living organisms. (2) Pertaining to a class of chemical compounds containing carbon.

Orifice—(1) An opening with closed perimeter, usually sharp edged, and of regular form in a plate, wall, or partition through which water may flow; generally used for the purpose of measurement of control of water. (2) The open end of a small tube, such as a pitot tube, piezometer, etc.

Oxidation—Loss of electrons; as when a metal goes from the metallic state to the corroded state (opposite of Reduction). Thus, when a metal reacts with oxygen, sulfur, etc., to form a compound as oxide, sulfide, etc., it is oxidized.

Packer—In well drilling, a device lowered in the lining tubes which swells automatically or can be expanded by manipulation from the surface at the correct time to produce a watertight joint against the sides of the borehole or the casing, thus entirely excluding water from higher horizons.

Pathogenic—Disease producing.

Peak Demand—The maximum monetary load placed on a water plant or pumping station. This is usually the maximum average load over a period of time such as peak hourly demand, peak day demand, or instantaneous peak demand.

Perched Ground Water—Ground water that is separated from the main body of ground water by an aquiclude.

Percolation—(1) The movement of flow of water through the interstices or pores of a soil or other medium. (2) The flow or trickling of a liquid downward through a contact or filtering medium. The liquid may or may not fill the pores of the medium.

Permeability—The property of a material which permits appreciable movement of water through it when saturated and actuated by hydrostatic pressure of the magnitude normally encountered in natural subsurface water. Perviousness is sometimes used in the same sense as permeability. The rate of permeability is measured by the quantity of water passing through a unit cross section in a unit time when the gradient of the energy head is unity.

Person—An individual, corporation, company, association, partnership, state, municipality, or Federal Agency.

Perviousness—The property of a material that permits appreciable movement of water through it when it is saturated and the movement is actuated by hydrostatic pressure of the magnitude normally encountered in natural subsurface water. More properly called permeability.

pH—A measure of the acidity or alkalinity of a solution. A value of seven is neutral; low numbers are acid, large numbers are alkaline. Strictly speaking, pH is the negative logarithm of the hydrogen-ion concentration.

Photometer—An instrument that measures the intensity of light or the degree of light absorption.

Photosynthesis—The synthesis of complex organic materials, especially carbohydrates, from carbon dioxide, water, and inorganic salts with sunlight as the source of energy and with the aid of a catalyst such as chlorophyll.

Picocurie (pCi)—That quantity of radioactive material producing 2.22 nuclear transformations per minute.

Piezometer—An instrument for measuring pressure head in a conduit, tank, soil, etc. It usually consists of a small pipe or tube tapped into the side of the container, connected with a manometer pressure gage, mercury or water column, or other device for indicating pressure head.

Piezometric Surface—An imaginary surface that everywhere coincides with the static level of the water in an aquifer. If at any given place the water from different depths in the aquifer rises to different levels, the aquifer has more than one piezometeric surface.

Pitometer—A device which utilizes the principle of the pitot tube for determining the velocity of flowing water in closed conduits, usually flowing under pressure.

Pitot Tube—A device for measuring the velocity of flowing water, using the velocity head of the stream as an index of velocity. It consists essentially of an orifice held to point upstream, connected with a tube in which the rise of water due to velocity head may be observed and measured. It may also consist or two orifices or openings, one facing upstream, one downstream, each connected to tubes (or water columns), in which case the difference in height, or the water differential, in the two columns is an index of velocity.

Pollution—The addition of sewage, industrial wastes, or other harmful or objectionable material to water. A general term that does not necessarily signify the presence of disease-producing bacteria.

Potable—Water which does not contain any objectionable substances or pollution, and is satisfactory for human consumption.

Precipitate—To separate a substance, in the solid form, from a solution. The substance in solid form which has been separated out.

Precipitation—(1) The total measurable supply of water received directly from clouds, as rain, snow, hail, and sleet; usually expressed as depth in a day, month, or year, and designated as daily, monthly, or annual precipitation. (2) The process by which atmospheric moisture is discharged onto a land or water surface. (3) The phenomenon which occurs when a substance held in solution in a liquid passes out of solution into solid form.

Pressure—(1) The total load or force acting upon a surface. (2) In hydraulics the term when used without qualifications usually means pressure per unit area (pounds per square inch, or kilograms per square centimeter) above local atmospheric pressure.

Pressure, Atmospheric—The pressure exerted by the atmosphere at any point. Such pressure decreases as the elevation of the point above sea level increases. One atmosphere is equal to 14.7 pounds per square inch, 29.92 inches or 760 millimeters of mercury column or 33.90 feet of water column at average sea level under standard conditions. Also called standard atmospheric pressure and standard pressure.

Pressure, Hydrostatic—The pressure, expressed as a total quantity or per unit of area, exerted by a body of water at rest.

Pressure, Negative—A pressure less than the local atmospheric pressure at a given point.

Pressure Tank—A tank used in connection with a water distribution system, either for a single household or for several houses, which is airtight and holds both air and water, and in which the air is compressed, the pressure so created being transmitted to the water.

Primacy—A state government has primary enforcement authority under the Safe Drinking Water Act. Primacy is delegated to the state by the Environmental Protection Agency (EPA) Administrator. Before assuming primacy, the state must establish drinking water regulations no less stringent than the present National Interim Primary Drinking Water Regulations (NIPDWR).

Primary Regulations—Regulations governing constituents that affect the health of consumers are applicable to all public water systems and are enforceable by Environmental Protection Agency (EPA) or states with primary enforcement authority.

Priming—(1) The action of starting the flow in a pump or siphon. (2) The first coat applied to a surface to prevent corrosion or to protect the surface.

Public Water System—A system for the provision to the public of piped water for human consumption, if such a system has at least fifteen service connections or regularly serves an average of at least 25 individuals daily at least 60 days out of the year. Such term includes any collection, treatment, storage and distribution facilities under control of the operator of such system and used primarily in connection with such system, and any collection or pretreatment storage facilities not under such control which are used primarily in connection with such system.

Pump—A mechanical device for causing flow, or for raising or lifting water or other fluid, or for applying pressure to fluids.

Pump, Air-Lift.—A pump, used largely in lifting water from wells, where air under pressure is discharged into the water at the bottom of the well in fine bubbles, which mix with the water and reduce the apparent specific gravity of the air-water mixture. The surrounding water causes the resulting mixtures of water and air to rise in the discharge pipe to the outlet.

Pump, Booster—A pump installed on a pipeline to raise the pressure of the water on the discharge side of the pump.

Pump, Centrifugal—A pump consisting of an impeller fixed on a rotating shaft and enclosed in a casing, having an inlet and a discharge connection. The rotating impeller creates pressure in the liquid by the velocity derived from centrifugal force.

Pump, Displacement—A type of pump in which the water is induced to flow from the source of supply through an inlet valve and into the pump chamber by a vacuum created by the withdrawal of some physical device which on its return displaces a certain volume of the water contained in the chamber and forces it to flow through the discharge valves and discharge pipes.

Pump, Piston—A reciprocating pump; wherein the cylinder is tightly fitted with a reciprocating piston.

Pump, Plunger—A reciprocating pump which has a plunger that does not come in contact with the cylinder walls, but enters and withdraws from it through packing glands. Such packing may be inside, outside, or outside the center; according to the design of the pump.

Pump, Regenerative Turbine—A centrifugal pump where the velocity energy of the water is partially converted into pressure head as it leaves the impeller, by fixed guide vanes.

Pump, Reciprocating—A type of displacement pump consisting essentially of a closed cylinder containing a piston or plunger, as the displacing mechanism, drawing liquid into the cylinder through an inlet valve, and forcing it out through an outlet valve. When the piston acts on the liquid in one end of the cylinder, the pump is termed single-action and when it acts in both ends, it is termed double-action.

Pump, Rotary—A type of displacement pump consisting essentially of elements rotating in a pump case which they closely fit. The rotation of these elements alternately draws in and discharges the water being pumped. Such pumps act with neither suction nor discharge valves, operate at almost any speed, and do not depend on centrifugal forces to lift the water.

Pump, Vertical Turbine Well—A centrifugal pump adapted for deep well use, consisting of a series of stages, each stage comprising a set of vanes in a case or bowl. The number of stages increases with the operating head.

Radius of Influence—The distance from a well, or group of wells, during pumping, within which the water table or other piezometric surface is lowered by withdrawal of the water. The area varies in extent with the rate and duration of pumping.

Rate of Flow—The volume of water per unit of time which is passing a certain observation point at a particular instant. Common expressions are cubic feet per second (cfs), gallons per minute (gpm), gallons per day (gpd), million gallons per day (mgd).

Raw Water—Untreated water; usually the water entering the first treatment unit of a water treatment plant. Water used as a source of water supply taken from a natural or impounded body of water, such as a stream, lake, pond, or ground water aquifer.

Recarbonation—The diffusion of carbon-dioxide gas through water to restore the carbon dioxide removed by adding lime to water in water softening.

Recharge Basin—A basin excavated in the earth to receive the discharge from streams or storm drains for the purpose of replenishing ground water supply.

Rem—The unit of dose equivalent from ionizing radiation to the total body or any internal organ or organ system. A "millirem" (mrem) is $\frac{1}{1000}$ of a rem.

Reservoir—A pond, lake, tank, basin, or other facility, either natural in its origin, or created in whole or in part by the building of engineering structures, which is used for the storage, regulation, and/or control of water.

Runoff—(1) In the general sense, that portion of the precipitation which is not absorbed by the deep strata, but finds its way into the streams after meeting the persistent demands of evapotranspiration. (2) That part of the precipitation which runs off the surface of a drainage area and reaches a stream or other body of water or a drain or sewer.

Sanitary Survey—Study of environmental conditions of a water source or system which might affect its potability or safety.

Saturation—The condition of a liquid when it has taken into solution the maximum possible quantity of a given substance at a given temperature and pressure.

Scale—An accumulation of solid material, precipitated out of waters containing certain mineral salts in solution, and formed on the interior surfaces of pipelines, tanks, boilers, etc., under certain physical conditions.

Secondary Maximum Contaminant Level—The advisable maximum level of a contaminant in water that is delivered to the free-flowing outlet of the ultimate user of a public

water system. Contaminants added to the water under circumstances controlled by the user, except those resulting from corrosion of piping and plumbing caused by water quality, are excluded from this definition.

Secondary Regulations—Standards dealing with the aesthetic quality of drinking water, which are not federally enforceable and are intended as guidelines for the states.

Sedimentation—Process of subsidence and deposition by gravity of suspended matter carried by water or other liquids. Also called settling, it is usually accomplished by reducing the velocity of flow of the liquid below the point where it can transport the suspended material.

Sedimentation Basin—A structure designed to hold water in a quiescent state or at a reduced velocity for a sufficient interval of time to permit the gravitational depositing of suspended matter, with or without the aid of previous flocculation or coagulation. Settling basin. Settling tank.

Self-Purification—The natural process of purification in a moving or still body of water whereby the bacterial content is reduced, the organic content is stabilized, and the dissolved oxygen returned to normal.

Sequestering Agent—A chemical that causes the complexing of certain phosphates with metallic ions in solution so that the ions may no longer be precipitated. Hexametaphosphates are an example.

Service Connection—Any pipeline, with its appurtenances, which branches off or connects with a water main and carries water from the main to a consumer.

Silting, Reservoir—The reduction of storage capacity in reservoirs due to the deposition of silt.

Slake—To mix with water. For example, when calcium oxide (unslaked lime) is mixed with water, calcium hydroxide (slaked lime) is formed.

Sludge Dewatering—The process of removing a part of the water in sludge by any method such as draining, evaporation, pressing, vacuum filtration, centrifuging, exhausting, passing between rollers, acid flotation, or dissolved-air flotation with or without heat. It involves reducing from a liquid to a semi-dry condition capable of being shoveled rather than merely changing the density of the liquid (concentration) on the one hand or drying (as in a kiln) on the other.

Sluice Gate—A gate, used for sluicing, constructed to slide vertically and fastened into or against the masonry of dams, tanks, or other structures.

Slurry—A suspension of small undissolved particles in a very high concentration.

Softening, Water—The process of removing from water certain mineral substances which produce a condition called hardness. There are two softening processes in general use: chemical precipitation and the zeolite ion-exchange process.

Solids-Contact Process—The name given to the process of chemical mixing, coagulation, flocculation, and sedimentation when carried on in a single tank in such a manner that the mixed chemicals are introduced into a zone already precipitated floc which serve as nuclei for further floc formation.

Solution—A gas, liquid, or solid dispersed homogeneously in a gas, liquid or solid.

Solution Feeder—A feeder for dispensing a chemical or other material in the liquid or dissolved state to water at a rate controlled manually or automatically by the quantity of flow. The constant rate is usually volumetric.

Sparger—An air diffuser designed to give large bubbles, used singly or in combination with mechanical aeration devices.

Specific Capacity—The rate at which water may be drawn from a formation through a well, to cause a drawdown of a stipulated depth. The usual units of measurement are gallons per minute per foot and liters per minute per meter.

Specific Gravity—Ratio of the weight of a unit volume of a substance to an equal volume or water under standard conditions.

Spillway—A waterway in or about a dam or other hydraulic structure, for the escape of excess water.

Spring—A surface feature where water issues from a rock or soil onto the land or into a body of water, the place of issuance being relatively restricted in size. Springs are classified in accordance with many criteria, including character of water, geologic formation, geographical location, etc.

Stabilization—(1) In lime-soda water softening, any process that will minimize or eliminate scale-forming tendencies. (2) In corrosion control, pH adjustment of water to maintain carbonate equilibrium at the saturation point.

Standpipe—(1) A pipe or tank connected to a closed conduit and extending above the hydraulic grade of the conduit, installed to afford relief from surges in pressure in pipelines. (2) A tank resting on ground, with its height greater than its diameter, used to store water in distribution systems. (3) A fixed vertical pipe for furnishing water to the upper part of buildings in case of fire.

State—The agency of the state government which has

jurisdiction over public water systems. During any period when a state does not have primary enforcement responsibility pursuant to section 1413 of the Safe Drinking Water Act (Public Law 95-523), the term "state" means the Regional Administrator, US Environmental Protection Agency.

Sterilization—Destruction of all living organisms, usually by a chemical compound or heat.

Stratum—A geological term used to designate a single bed or layer of rock which is more or less homogeneous in character.

Streamflow—The water that is flowing in a stream channel. Commonly used interchangeably with stream discharge to designate the rate of flow.

Superchlorination—The application of chlorine to water to provide free residual chlorination, in which the residual is usually so large as to require dechlorination.

Supplier of Water—Any person who owns or operates a public water system.

Surge—A monetary increase in flow (in an open conduit) or pressure (in a closed conduit) which passes longitudinally along the conduit, due usually to sudden changes in velocity.

Survey, Hydrographic—An instrumental survey to measure and determine characteristics of streams and other bodies of water within an area, including such things as location, area extent, and depth of water in lakes or the ocean; the width, depth, and course of streams; position and elevation of high water marks; location and depth of well, etc.

Suspended Solids—All visible material in water which at the time of sampling is not dissolved, and which can be removed by filtration.

Suspension—a system consisting of small particles kept dispersed by agitation or by molecular motion in the surrounding water. The permanency of suspension is dependent on the degree of agitation and the size of particles. A colloid is a special kind of suspension.

Temperature—(1) The thermal state of a substance with respect to its ability to communicate heat to its environment. (2) The measure of the thermal state on the arbitrarily chosen numerical scale, usually Centigrade or Fahrenheit.

Threshold Odor—The point at which, after successive dilutions with odorless water, the odor of the water sample can just be detected. The threshold odor is expressed quantitatively by the number of times the sample is diluted with equal quantities of odorless water.

Threshold Treatment—The prevention of the deposition of calcium carbonate in water after the softening treatment by the addition of a small quantity of sodium hexametaphosphate.

Total Trihalomethanes (TTHM)—The sum of the concentration in milligrams per liter of the trihalomethane compounds (trichloromethane (chloroform)), dibromochloromethane, bromodichloromethane and tribromomethane (bromoform)), rounded to two significant figures.

Transpiration—The process by which plants dissipate water into the atmosphere through their leaves and other surfaces.

Treated Water—Water that has underground processing such as sedimentation, filtration, softening, disinfection, etc., and is ready for consumption. Included is purchased potable water which is retreated (chlorinated, fluoridated, etc.).

Tributary—A stream or other body of water, surface, or underground, which contributes its water, even though intermittenly and in small quantities, to another and larger stream or body of water.

Trihalomethanes (THM)—One of the family of organic compounds, named as derivatives of methane, wherein three of the four hydrogen atoms in methane are each substituted by a halogen atom in the molecular structure. Technically, THM belong to the group of chemicals classified as volatile synthetic organic chemical (VOC) compounds. The EPA, however, has addressed THMs and VOCs separately.

Tuberculation—Localized corrosion at scattered locations resulting in knoblike mounds.

Turbidity—(1) A condition in water caused by the presence of suspended matter, resulting in the scattering and absorption of light rays. (2) A measure of fine suspended matter in liquids. (3) An analytical quantity usually reported in arbitrary turbidity units determined by measurements of light diffraction.

Unit Weight—The weight of a unit volume of material, such as pounds per cubic foot or per cubic inch.

Vacuum—Condition existing in a closed space from which all gas, vapor, or other matter has been removed. Commonly applied to a closed space in which pressure is much lower than surrounding atmospheric pressure; any space where negative pressure exists.

Vacuum Breaker—A device for relieving a vacuum or partial vacuum formed in a pipeline, thereby preventing backsiphonage.

Vacuum Filter—A filter consisting of a cylindrical drum

mounted on a horizontal axis, covered with a filter cloth, and revolving with a partial submergence in liquid slurry. A vacuum is maintained under the cloth for the larger part of a revolution to extract moisture. The cake is scraped off continuously.

Valve—A device installed in a pipeline for the purpose of controlling the magnitude and direction of the flow. It consists essentially of a shell and a disc or plug fitted to the shell.

Valve, Altitude Control.—A valve which automatically shuts off the flow when the water reaches a predetermined elevation in an elevated tank, and opens when the pressure on the pump side is less than that on the tank side of the valve.

Valve, Check—A valve provided with a disc hinged on one edge, a spherical ball, or other device so arranged that it opens in the direction of normal flow, and closes with reversal of flow.

Valve, Gate—A valve where the closing element consists of a disc which slides over the opening or cross-sectional area through which water passes, and fits tightly against it.

Valve, Needle—A valve with a circular outlet through which the flow is controlled by means of a tapered needle which extends through the outlet, reducing the area of the outlet as it extrudes, and enlarging the area as it retreats.

Valve, Pressure-Regulating—A valve placed at either end of a pressure-regulating apparatus inserted in a water main to regulate the pressure in a waterline either upstream or downstream from the valve.

Valve, Four-Way—A valve constructed with four waterways and with a movable element operated by a quarter turn to provide passage between either pair of adjacent waterways.

Vaporization—The process by which water changes from the liquid or sublimation to the gaseous state.

Velocity, Mean—The average velocity of a stream flowing in a channel or conduit at a given cross section or in a given reach. It is equal to the discharge divided by the cross-sectional area of the section, or the average cross-sectional area of the reach. Also called average velocity.

Venturi Meter—A meter for measuring the rate of flow of a liquid through closed conduits or pipes, consisting of a venturi tube and one of several proprietary forms of flow registering devices.

Virus—The smallest (10 to 300 millimicrons in diameter) form capable of producing infection and diseases in humans or other large species. The true viruses are insensitive to antibiotics. They multiply only in living cells where they are assembled as complex macromolecules utilizing the cells' biochemical systems. They do not multiply by division as do intracellular bacteria.

Volatile—Passing off readily in the form of a vapor.

Volatile Synthetic Organic Chemicals (VOCs)—A general class of organic chemicals which are relatively volatile. The primary VOCs identified by the EPA as affecting safety of drinking water are trichloroethylene, tetrachloroethylene, carbon tetrachloride, trichlorethane, dichloroethane, methylene chloride, and vinyl chloride. These chemicals in water supplies result from industrial contamination.

Water—A chemical compound consisting of two parts of hydrogen and one part of oxygen by volume and usually having other solid, gaseous, or liquid materials in solution or suspension.

Water-Bearing Formation—A term, more or less relative, used to designate a geological formation that contains considerable ground water. It is usually applied to formations from which the ground water may be extracted by pumping, drainage, etc.

Watercourse—A channel in which a flow of water occurs, either continuously or intermittently, and if the latter, with some degree of regularity. Such flow must be in a definite direction. Watercourses may be either natural or artificial, and the former may occur either on the surface or underground. A different set of legal principles may apply to rights to use water from different classes of watercourses.

Water Hammer—The phenomenon of oscillations in the pressure of water in a closed conduit, flowing full, which results from a too rapid acceleration or retardation or flow. From this phenomenon, momentary pressures greatly in excess of the normal static pressure may be produced in a closed conduit.

Water Meter—A device installed in a pipe under pressure for measuring and registering the quantity of water passing through it.

Water Quality—The chemical, physical, and biological characteristics of water with respect to its suitability for a particular purpose. The same water may be of good quality for one purpose or use, and bad for another, depending on its characteristics and the requirements for the particular use.

Watershed—(1) The area contained within a divide above a specified point on a stream. In water supply engineering, it is called a watershed or a catchment area. (2) The divide between drainage basins.

Water Supply—In general, the sources of water for public or private uses.

Water Table—The upper surface of a zone of saturation

(in ground water) where the aquifer is not confined by an overlying impermeable formation.

Weir—An obstruction placed across a stream or other flowing water so as to cause the water to pass through an opening or notch, thus allowing the quantity of water to be measured.

Well—An artificial excavation that derives water from the interstices of the rocks or soil which it penetrates.

Well, Artesian—A well tapping a confined or artesian aquifer in which the static water level stands above the bottom of the confining bed and the top of the aquifer. The term is used to include all wells tapping such basins or aquifers. Those in which the head is insufficient to raise the water to or above the land surface are called subartesian wells.

Well, Bored—A well that is excavated by means of an auger (hand or power) as distinguished from one which is dug or drilled.

Well Casing—Metal pipe used to line the borehole of a well.

Well, Drilled—A well that is excavated wholly or in part by means of a drill (either percussion or rotary) which operates by cutting or by abrasion; the materials are brought to the surface by means of a bailer, sand pump hollow drill tool, or by a hydraulic or self-cleaning method.

Well, Driven—A well that is constructed by driving a casing, at the end of which there is a drive point, without the use of any drilling, boring, or jetting device.

Well, Dug—A well that is excavated by means of picks, shovels, or other hand tools, or by means of a power shovel or other dredging or trenching machinery, as distinguished from one put down by a drill or auger.

Well Field—A tract of land containing a number of wells.

Well, Flowing—A well that discharges water at the surface without the aid or application of a pump or other lifting device.

Well, Gravel-Packed—A type of well in which the sand adjacent to the well screen has been removed and replaced by gravel.

Well Log—A chronological record of the soil and rock formations encountered in the operation of sinking a well, with either their thickness or the elevation of the top and bottom of each formation given. It also usually includes statements about the lithologic composition and water-bearing characteristics of each formation, static and pumping water levels, and well yield.

Well Point—A device, consisting of a perforated metal tube or screen attached to a jetting or driving head end, to permit passage of water.

Well Screen—A special form of slotted or perforated well casing that admits water from an aquifer consisting of unconsolidated granular material, while preventing the granular material from entering the well.

Well, Subartesian—A nonflowing well in which the water rises by hydrostatic pressure above the saturation zone, but not to the land surface.

Yield, Safe—The maximum dependable draft which can be made continuously upon a source of water supply (surface or ground water) during a period of years in which the probable driest period or greatest deficiency in water supply is likely to occur.

Zeolite Process—The process of softening water by passing it through a substance known in general as a zeolite, which exchanges sodium ions for hardness constituents in the water.

ABBREVIATIONS

AC—alternating current
Btu—British thermal unit
C—Centigrade; also Hazen and Williams pipe friction coefficient
cal—calorie
cm—centimeter
cu—cubic
cfm—cubic feet per minute
cfs—cubic feet per second
DC—direct current
DPD—n, n, - diethyl-p-phenylenediamine
DO—dissolved oxygen
F—Fahrenheit
fpm—feet per minute
fps—feet per second
ft—feet
g—gram
gal—gallon
gpd—gallons per day
gpcd—gallons per capita per day
gpg—grains per gallon
gpm—gallons per minute
gps—gallons per second
h—head
ha—hectare
hp—horsepower
in—inch
kg—kilogram
km—kilometer
kw—kilowatt
kwh—kilowatt-hour
l—liter
lb—pound
m—meter
mg—milligram
mgd—million gallons per day
mg/l—milligrams per liter
mil—million
min—minute
ml—milliliter
mm—millimeter
MPN—most probable number
mrem—millirem
pcf—pounds per cubic foot
pci—picocurie
ppm—parts per million
psf—pounds per square foot
psi—pounds per square inch
Q—rate of flow (quantity)
rpm—revolutions per minute
s—slope (hydraulic)
sec—second
sq—square
TO—threshold odor number
TU—turbidity units
v—velocity
vol—volume

CHARTS AND TABLES

Table A3-1. Conversions From Commonly Used English Units of Measurement to Metric Equivalents.

Multiply English Unit	By	To Obtain Metric Unit
acre	0.405	ha
acre-ft	1,233.5	cu m
Btu	0.252	kg-cal
Btu/lb	0.555	kg-cal/kg
cfm	0.028	cu m/min
cfs	1.7	cu m/min
cfa/acre	4.2	cu m/min/ha
cfa/sq mile	0.657	cu m/min/sq km
cu ft	0.028	cu m
cu ft	28.32	l
cu in	16.39	cu cm
cu yd	0.765	cu m
ft	0.3048	m
gal	0.003785	cu m
gal	3.785	l
gpd/acre	0.00935	cu m/day/ha
gpd/ft	0.0124	cu m/day/m
gpd/sq ft	0.0408	cu m/day/sq m
gpm	0.0631	l/sec
gpm/sq ft	40.7	l/min/sq m
hp	0.7457	kw
in	2.54	cm
lb	0.454	kg
lb/1,000 cu ft	16.0	g/cu m
lb/acre/day	0.112	g/day/sq m
lb/day/acre	11.2	kg/day/ha
lb/day/acre-ft	3.68	g/day/cu m
lb/day/cu ft	16.	kg/day/cu m
lb/day/cu yd	0.6	kg/day/cu m
lb/day/sq ft	4,880.	g/day/sq m
lb/ft	1.51	km
lb/mil gal	0.12	g/cu m
mgd	3,785.	cu m/day
mgd/acre	9,360.	cu m/day/ha
mile	1.61	km
pcf	16.02	kg/cu m
psf	4.88	kg/sq m
psi	0.0703	kg/sq cm
sq ft	0.0929	sq m
sq ft/cu ft	3.29	sq m/cu m
sq in	6.452	sq cm
sq miles	2.590	sq km
tons (short)	907.	kg
tons (short)	0.907	metric tons

Table A3-2. Temperature Conversion.

(Centigrade To Fahrenheit — Fahrenheit To Centigrade)

—459.4° to 0°			1° to 60°			61° to 290°			300° to 890°			900° to 3000°		
C	CENT. OR FAH.	F	C	CENT. OR FAH.	F	C	CENT. OR FAH.	F	C	CENT. OR FAH.	F	C	CENT. OR FAH.	F
—273	—459.4		—17.2	1	33.8	16.1	61	141.8	149	300	572	482	900	1652
—268	—450		—16.7	2	35.6	16.7	62	143.6	154	310	590	488	910	1670
—262	—440		—16.1	3	37.4	17.2	63	145.4	160	320	608	493	920	1688
—257	—430		—15.6	4	39.2	17.8	64	147.2	166	330	626	499	930	1706
—251	—420		—15.0	5	41.0	18.3	65	149.0	171	340	644	504	940	1724
—246	—410		—14.4	6	42.8	18.9	66	150.8	177	350	662	510	950	1742
—240	—400		—13.9	7	44.6	19.4	67	152.6	182	360	680	516	960	1760
—234	—390		—13.3	8	46.4	20.0	68	154.4	188	370	698	521	970	1778
—229	—380		—12.8	9	48.2	20.6	69	156.2	193	380	716	527	980	1796
—223	—370		—12.2	10	50.0	21.1	70	158.0	199	390	734	532	990	1814
—218	—360		—11.7	11	51.8	21.7	71	159.8	204	400	752	538	1000	1832
—212	—350		—11.1	12	53.6	22.2	72	161.6	210	410	770	549	1020	1868
—207	—340		—10.6	13	55.4	22.8	73	163.4	215	420	788	560	1040	1904
—201	—330		—10.0	14	57.2	23.3	74	165.2	221	430	806	571	1060	1940
—196	—320		— 9.4	15	59.0	23.9	75	167.0	227	440	824	582	1080	1976
—190	—310		— 8.9	16	60.8	24.4	76	168.8	232	450	842	593	1100	2012
—184	—300		— 8.3	17	62.6	25.0	77	170.6	238	460	860	604	1120	2048
—179	—290		— 7.8	18	64.4	25.6	78	172.4	243	470	878	616	1140	2084
—173	—280		— 7.2	19	66.2	26.1	79	174.2	249	480	896	627	1160	2120
—169	—273	—459.4	— 6.7	20	68.0	26.7	80	176.0	254	490	914	638	1180	2156
—168	—270	—454	— 6.1	21	69.8	27.2	81	177.8	260	500	932	649	1200	2192
—162	—260	—436	— 5.6	22	71.6	27.8	82	179.6	266	510	950	660	1220	2228
—157	—250	—418	— 5.0	23	73.4	28.3	83	181.4	271	520	968	671	1240	2264
—151	—240	—400	— 4.4	24	75.2	28.9	84	183.2	277	530	986	682	1260	2300
—146	—230	—382	— 3.9	25	77.0	29.4	85	185.0	282	540	1004	693	1280	2336
—140	—220	—364	— 3.3	26	78.8	30.0	86	186.8	288	550	1022	704	1300	2372
—134	—210	—346	— 2.8	27	80.6	30.6	87	188.6	293	560	1040	732	1350	2462
—129	—200	—328	— 2.2	28	82.4	31.1	88	190.4	299	570	1058	760	1400	2552
—123	—190	—310	— 1.7	29	84.2	31.7	89	192.2	304	580	1076	788	1450	2642
—118	—180	—292	— 1.1	30	86.0	32.2	90	194.0	310	590	1094	816	1500	2732
—112	—170	—274	— 0.6	31	87.8	32.8	91	195.8	316	600	1112	843	1550	2822
—107	—160	—256	0.0	32	89.6	33.3	92	197.6	321	610	1130	871	1600	2912
—101	—150	—238	0.6	33	91.4	33.9	93	199.4	327	620	1148	899	1650	3002
— 96	—140	—220	1.1	34	93.2	34.4	94	201.2	332	630	1166	927	1700	3092
— 90	—130	—202	1.7	35	95.0	35.0	95	203.0	338	640	1184	954	1750	3182
— 84	—120	—184	2.2	36	96.8	35.6	96	204.8	343	650	1202	982	1800	3272
— 79	—110	—166	2.8	37	98.6	36.1	97	206.6	349	660	1220	1010	1850	3362
— 73	—100	—148	3.3	38	100.4	36.7	98	208.4	354	670	1238	1038	1900	3452
— 68	— 90	—130	3.9	39	102.2	37.2	99	210.2	360	680	1256	1066	1950	3542
— 62	— 80	—112	4.4	40	104.0	37.8	100	212.0	366	690	1274	1093	2000	3632
— 57	— 70	— 94	5.0	41	105.8	43	110	230	371	700	1292	1121	2050	3722
— 51	— 60	— 76	5.6	42	107.6	49	120	248	377	710	1310	1149	2100	3812
— 46	— 50	— 58	6.1	43	109.4	54	130	266	382	720	1328	1177	2150	3902
— 40	— 40	— 40	6.7	44	111.2	60	140	284	388	730	1346	1204	2200	3992
— 34	— 30	— 22	7.2	45	113.0	66	150	302	393	740	1364	1232	2250	4082
— 29	— 20	— 4	7.8	46	114.8	71	160	320	399	750	1382	1260	2300	4172
— 23	— 10	14	8.3	47	116.6	77	170	338	404	760	1400	1288	2350	4262
— 17.8	0	32	8.9	48	118.4	82	180	356	410	770	1418	1316	2400	4352
			9.4	49	120.2	88	190	374	416	780	1436	1343	2450	4442
			10.0	50	122.0	93	200	392	421	790	1454	1371	2500	4532
			10.6	51	123.8	99	210	410	427	800	1472	1399	2550	4622
			11.1	52	125.6	100	212	413.6	432	810	1490	1427	2600	4712
			11.7	53	127.4	104	220	428	438	820	1508	1454	2650	4802
			12.2	54	129.2	110	230	446	443	830	1526	1482	2700	4892
			12.8	55	131.0	116	240	464	449	840	1544	1510	2750	4982
			13.3	56	132.8	121	250	482	454	850	1562	1538	2800	5072
			13.9	57	134.6	127	260	500	460	860	1580	1566	2850	5162
			14.4	58	136.4	132	270	518	466	870	1598	1593	2900	5252
			15.0	59	138.2	138	280	536	471	880	1616	1621	2950	5342
			15.6	60	140.0	143	290	554	477	890	1634	1649	3000	5432

Locate temperature in middle column. If in degrees Centigrade, read Fahrenheit equivalent in right hand column; If in degrees Fahrenheit, read Centigrade equivalent in left hand column.

Conversion Formulas $C = \frac{5}{9}(F - 32)$, $F = \frac{9}{5}C + 32$

Table A3-3. Length Conversion Factors.

Multiply Number of → / by / to Obtain ↓	Centimeters	Feet	Inches	Meters	Millimeters	Yards
Centimeters	1	30.48	2.540	100	0.1	91.44
Feet	3.281×10^{-2}	1	8.333×10^{-2}	3.281	3.281×10^{-3}	3
Inches	0.3937	12	1	39.37	3.937×10^{-2}	36
Meters	0.01	0.3048	2.540×10^{-2}	1	0.001	0.9144
Millimeters	10	304.8	25.40	1000	1	914.4
Yards	1.094×10^{-2}	0.3333	2.778×10^{-2}	1.094	1.094×10^{-3}	1

* Metric multiples: $10^6\ \mu = 10^3$ mm $= 10^2$ cm $= 10$ dm $= 1$ m $= 10^{-3}$ km $= 10^{10}$ Å.

Table A3-4. Conversion Factors.

Multiply Number of → / by / to Obtain ↓	Square Centimeters	Square Feet	Square Inches	Square Meters	Square Millimeters	Square Yards
Square Centimeters	1	929.0	6.452	10	0.01	8361
Square Feet	1.076×10^{-3}	1	6.944×10^{-3}	10.76	1.076×10^{-5}	9
Square Inches	0.1550	144	1	1550	1.550×10^{-3}	1296
Square Meters	0.0001	9.290×10^{-2}	6.452×10^{-4}	1	10^{-6}	0.8361
Square Millimeters	100	9.290×10^{4}	645.2	10^{6}	1	8.361×10^{5}
Square Yards	1.196×10^{-4}	0.1111	7.716×10^{-4}	1.196	1.196×10^{-6}	1

1 Acre = 43,560 square feet

Table A3-5. Volume Conversion Factors.

Multiply Number of → / by / to Obtain ↓	Cubic Centimeters	Cubic Feet	Cubic Inches	Cubic Meters	Cubic Yards	Gallons	Liters
Cubic Centimeters	1	2.832×10^{4}	16.39	10^{6}	7.646×10^{5}	3785	1000
Cubic Feet	3.531×10^{-5}	1	5.787×10^{-4}	35.31	27	0.1337	3.531×10^{-2}
Cubic Inches	6.102×10^{-2}	1728	1	6.102×10^{4}	46,656	231	61.02
Cubic Meters	10^{-6}	2.832×10^{-2}	1.639×10^{-5}	1	0.7646	3.785×10^{-3}	0.001
Cubic Yards	1.308×10^{-6}	3.704×10^{-2}	2.143×10^{-5}	1.308	1	4.951×10^{-3}	1.308×10^{-3}
Gallons	2.642×10^{-4}	7.481	4.329×10^{-3}	264.2	202.0	1	0.2642
Liters	0.001	28.32	1.639×10^{-2}	1000	764.6	3.785	1

Table A3-6. Weight Conversion Factors.

Multiply Number of → / by / to Obtain ↓	Grains	Grams	Kilograms	Milligrams	Ounces	Pounds	Tons (Short)
Grains	1	15.43	1.543×10^{4}	1.543×10^{-2}	437.5	7000	
Grams	6.481×10^{-2}	1	1000	0.001	28.35	453.6	9.072×10^{-7}
Kilograms	6.481×10^{-5}	0.001	1	10^{-6}	2.835×10^{-2}	0.4536	907.2
Milligrams	64.81	1000	10^{6}	1	2.835×10^{4}	4.536×10^{5}	9.072×10^{8}
Ounces	2.286×10^{-3}	3.527×10^{-2}	35.27	3.527×10^{-5}	1	16	3.2×10^{-5}
Pounds	1.429×10^{-4}	2.205×10^{-3}	2.205	2.205×10^{-6}	6.250×10^{-2}	1	2000
Tons (Short)		1.102×10^{-6}	1.102×10^{-3}	1.102×10^{-9}	3.125×10^{-5}	0.0005	1

Table A3-7. Rate of Flow Equivalents.

Units	Cubic Feet Per Second	Cubic Feet Per Minute	US Gallons Per Minute	US Gallons Per 24 Hours	British Imperial Gallons Per Minute	Liters Per Minute	Acre-Feet Per Hour	Acre-Feet Per 24 Hours
1 cu ft per sec	1.0	60.0	448.831	646,317.0	373.729	1,698.98	0.082645	1.98347
1 cu ft per min	0.016667	1.0	7.48052	10,771.9	6.22882	28.3163	0.0013774	0.033058
1 US gal per min	0.0022280	0.13368	1.0	1,440.0	0.83267	3.78533	0.0001841	0.0044192
1 US gal per 24 hr	1.547×10^{-6}	9.283×10^{-5}	0.0006944	1.0	0.0005782	0.0026287	0.279×10^{-7}	3.069×10^{-6}
1 British Imperial gal per min	0.0026757	0.16054	1.20095	1,729.37	1.0	4.54601	0.0002211	0.0053072
1 liter per min	0.0005886	0.035315	0.26418	380.416	0.21997	1.0	4.864×10^{-5}	0.001167
1 acre-ft per hr	12.1	726.0	5,430.86	7,820,434.0	4,522.13	20,557.6	1.0	24.0
1 acre-ft per 24 hr	0.50417	30.25	226.286	325,851.0	188.422	856.567	0.41667	1.0

Table A3-8. Volume and Capacity Equivalents.

Units	US Gallons	British Imperial Gallons	Liters	Cubic Feet	Cubic Inches	Acre-Feet
1 US gallon	1.0	0.832672	3.78533	0.133681	231.0	3.069×10^{-6}
1 British Imperial gallon	1.20095	1.0	4.54601	0.160544	277.420	3.686×10^{-6}
1 liter	0.264177	0.219973	1.0	0.035315	61.0250	8.107×10^{-7}
1 cubic foot	7.48052	6.22882	28.3163	1.0	1,728.0	2.296×10^{-5}
1 cubic inch	4.329×10^{-3}	3.605×10^{-3}	0.016387	5.787×10^{-4}	1.0	1.329×10^{-4}
1 acre-foot	325,851.0	271,328.0	1,233,456.0	43,560.0	75,271,680.0	1.0
1 inch deep on 1 acre	27,154.3	22,610.6	102,788.0	3,630.0	6,272,640.0	0.083333
1 inch deep on 1 square mile	17,378,743.0	14,470,801.0	65,784,344.0	2,323,200.0	4,014,489,600.0	53.3333
1 meter deep on 1 hectare	2,631,705.0	2,199,675.0	9,999,734.0	353,145.0	610,233,780.0	8.10708
1 centimeter deep on 1 square meter	2.64171	2.19967	9.99973	0.353145	610.234	8.107×10^{-6}
1 pound of water at 39.2° F	0.11983	0.099778	0.45349	0.016019	27.6805	3.677×10^{-7}
1 pound of water at 50° F	0.11986	0.099806	0.45372	0.016023	27.6880	3.678×10^{-7}
1 pound of water at 62° F	0.11997	0.099892	0.45411	0.016037	27.7121	3.682×10^{-7}
1 US gallon per minute for 24 hours	1,440.0	1,199.05	5,450.88	192.5	332,640.0	0.0044192
1 cubic foot per minute for 24 hours	10,771.9	8,969.50	40,775.4	1,440.0	2,488,320.0	0.033058

Table A3-9. Pressure Equivalents.

Units	Pounds Per Square Inch	Pounds Per Square Foot	Kilograms Per Square Centimeter	Inches of Mercury at 32° F	Feet of Water at 39.2° F	Feet of Water at 62° F	Atmospheres
1 pound per square inch	1.0	144.0	0.0703067	2.0360	2.30671	2.30934	0.068044
1 pound per square foot	0.00694444	1.0	0.0004882	0.014139	0.016019	0.016037	0.0004725
1 ounce per square inch	0.0625	9.0	0.0043942	0.12725	0.144169	0.0144334	0.0042528
1 kilogram per square centimeter	14.2234	2,048.17	1.0	28.9582	32.8092	32.8467	0.967820
1 kilogram per square meter	0.0014223	0.204817	0.0001	0.0028958	0.0032809	0.0032847	9.678×10^{-5}
1 inch of mercury at 32° F	0.49117	70.7285	0.034533	1.0	1.13299	1.13428	0.033421
1 inch of water at 39.2° F	0.036127	5.20222	0.0025399	0.073552	0.083333	0.083428	0.0024582
1 inch of water at 62° F	0.036085	5.19628	0.0025370	0.073468	0.083238	0.083333	0.0024554
1 foot of water at 39.2° F	0.43352	62.4266	0.030479	0.88262	1.0	1.00114	0.029498
1 foot of water at 62° F	0.43302	62.3554	0.030444	0.88162	0.99886	1.0	0.029465
1 atmosphere	14.6963	2,116.27	1.03325	29.9210	33.9001	33.9388	1.0

Table A3-10. Values of Hazen and Williams C for Various Types of Pipe.

Type of Pipe	Values of C		
	Range — High = Best, Smooth, Well Laid — Low = Poor Or Corroded	Average Value For Good, Clean, New Pipe	Commonly Used Value For Design Purposes
Cement — Asbestos	160-140	150	140
Fibre	—	150	140
Bitumastic-enamel-lined iron or steel centrifugally applied	160-130	148	140
Cement-lined iron or steel centrifugally applied	—	150	140
Copper, brass, lead, tin or glass pipe and tubing	150-120	140	130
Wood-stave	145-110	120	110
Welded and seamless steel	150-80	140	100
Continuous-interior riveted steel (no projecting rivets or joints)	—	139	100
Wrought-iron	150-80	130	100
Cast-iron	150-80	130	100
Tar-coated cast-iron	145-80	130	100
Girth-riveted steel (projecting rivets in girth seams only)	—	130	100
Concrete	152-85	120	100
Full-riveted steel (projecting rivets in girth and horizontal seams)	—	115	100
Vitrified	—	110	100
Spiral-riveted steel (flow with lap)	—	110	100
Spiral-riveted steel (flow against lap)	—	100	90
Corrugated steel	—	60	60

Table A3-11. Relation of Friction Loss When C=100 to Friction Loss at Other C Values.

Where C = Hazen and Williams coefficient of friction

$$K = \frac{\text{actual friction loss}}{\text{friction loss when C = 100}}$$

C	K	C	K
40	5.50	90	1.22
45	4.30	95	1.10
50	3.50	100	1.00
55	3.00	105	0.92
60	2.58	110	0.84
65	2.23	115	0.77
70	1.96	120	0.71
75	1.72	125	0.66
80	1.51	130	0.61
85	1.37	135	0.57
		140	0.54

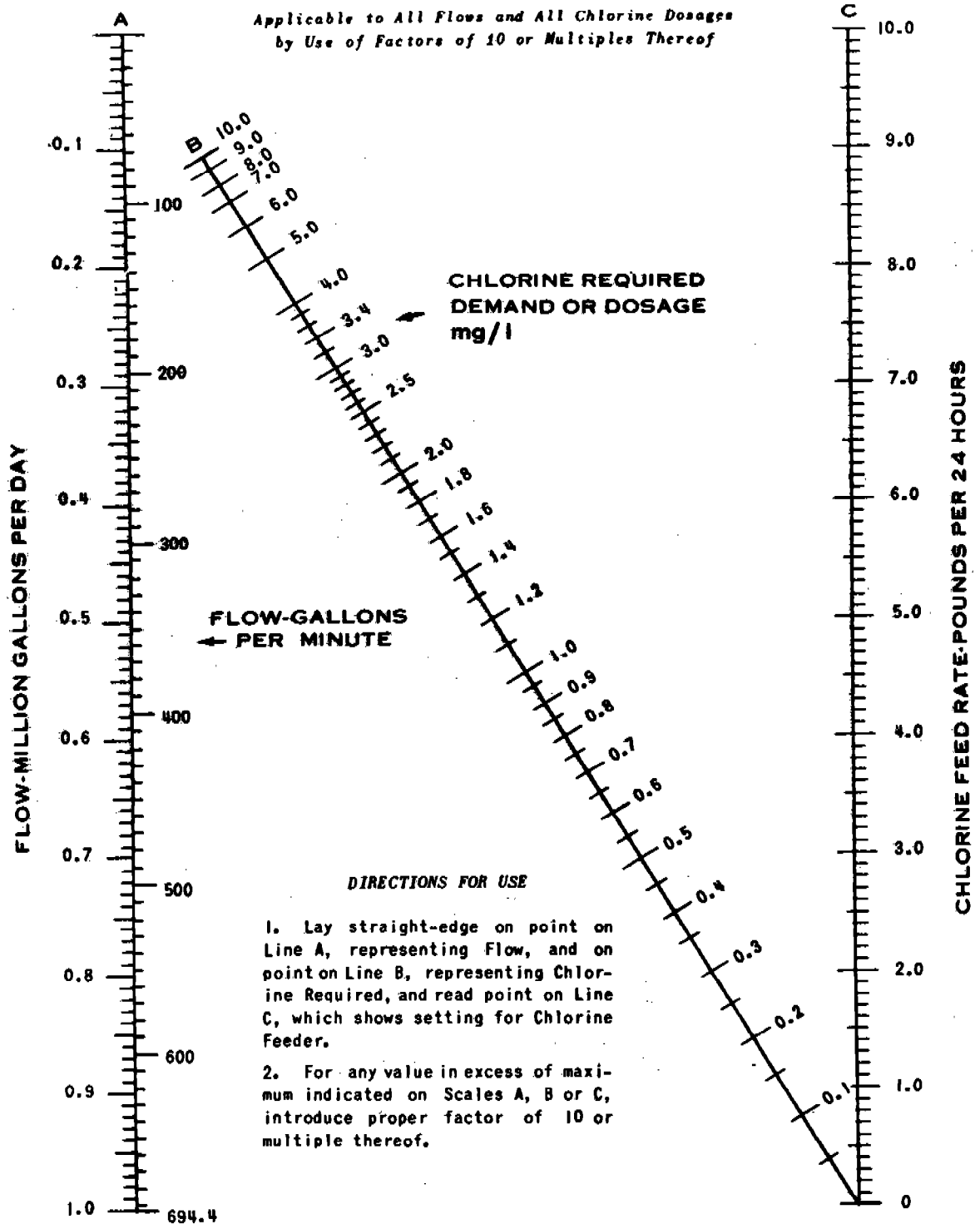

Figure A3-1. Nomogram for Chlorine Dosage Control.

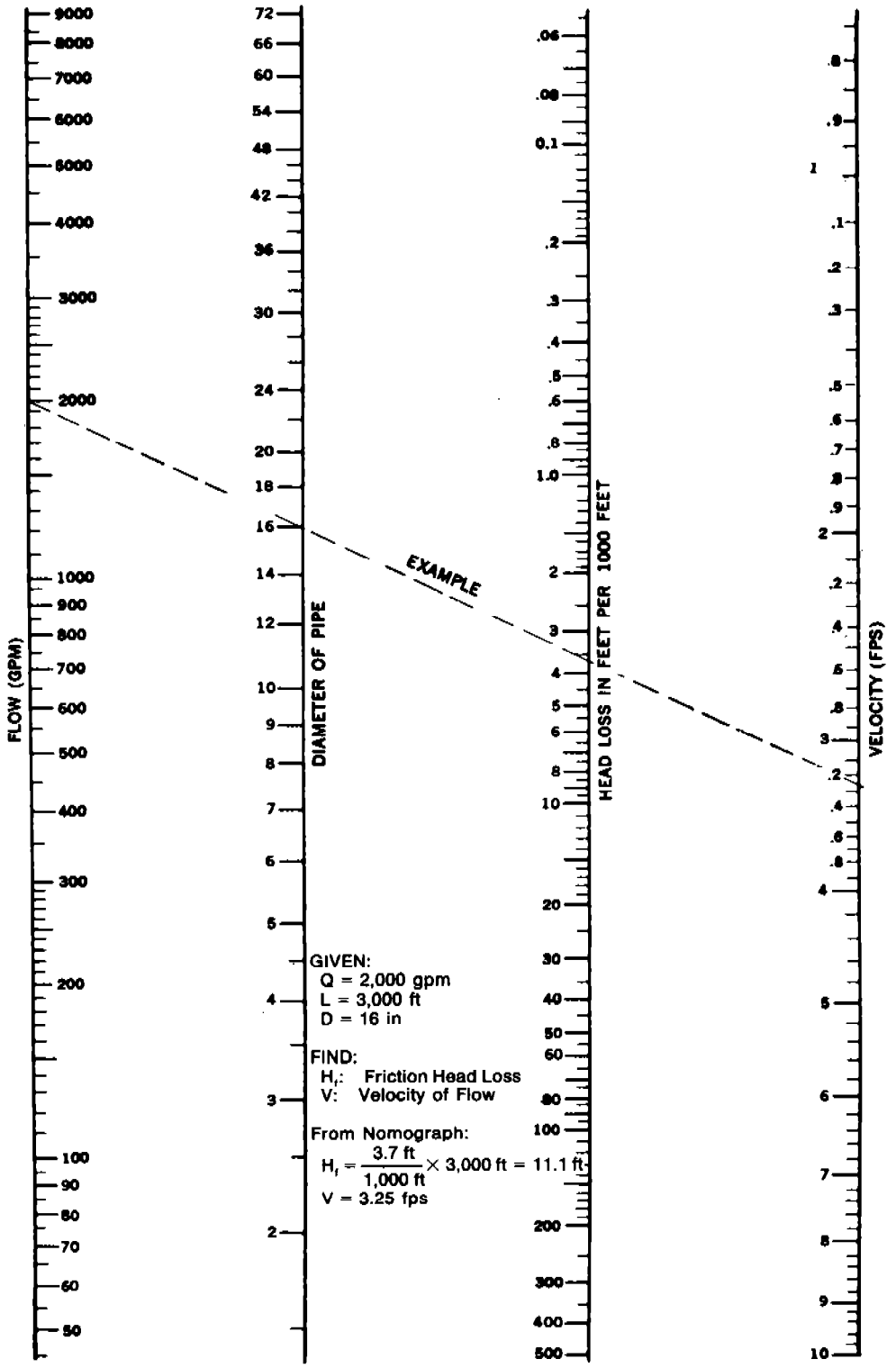

Figure A3-2. Nomogram for Determining Pipe Flow, Friction Loss, and Velocity for C = 100.

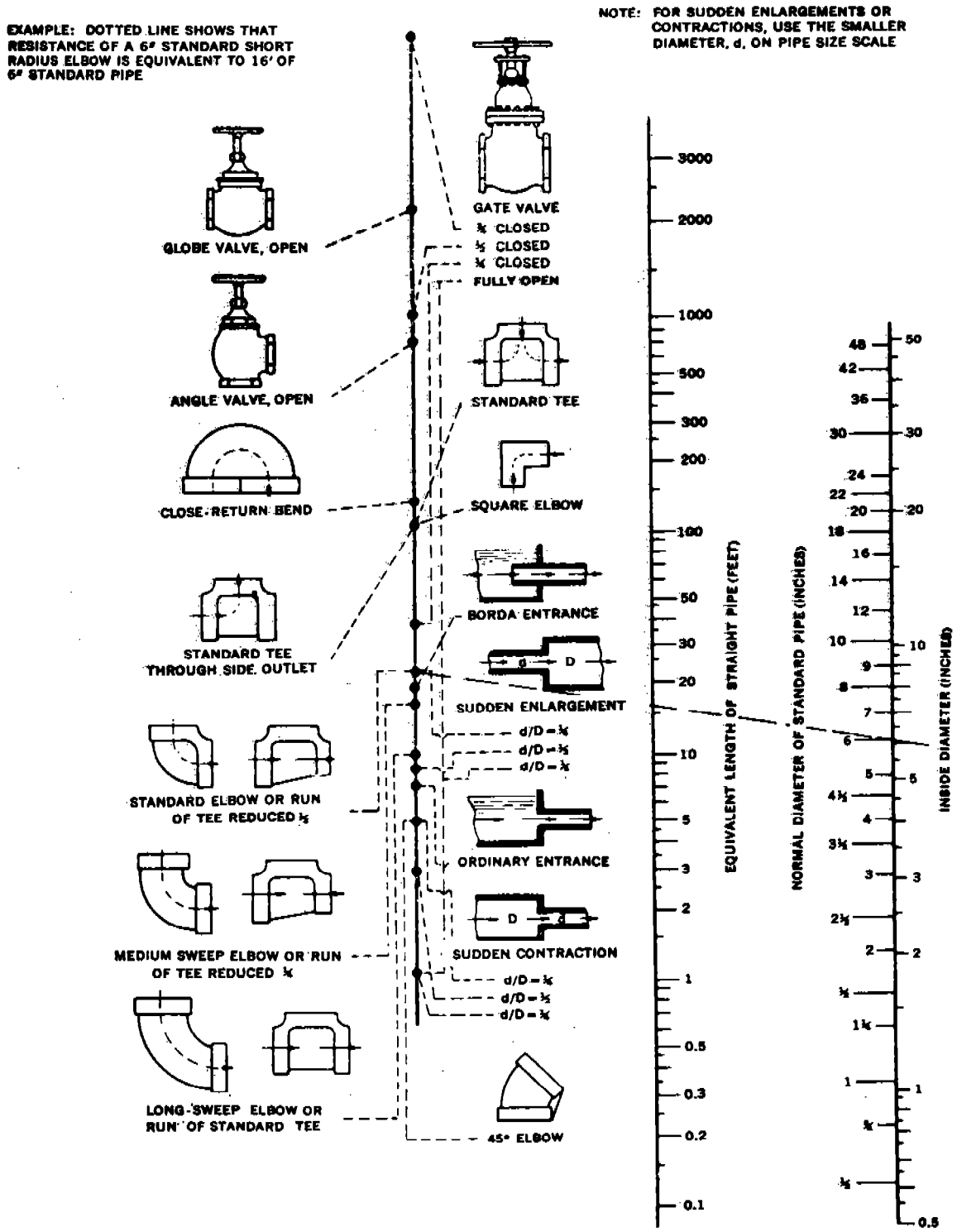

Figure A3-3. Friction Chart for Valves and Fittings.

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