An Introduction to Water Treatment

By

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1. GENERAL

1.1 Purpose and scope. This is an introduction to water treatment systems and technology. It is not a design manual or an exhaustive treatise. It is intended for engineers who are not regularly involved in water treatment projects, but who are interested in learning some of the basics involved. Criteria to be followed in determining the necessity for and the extent of treatment are discussed here, as are procedures applicable to the planning of water treatment projects.

1.2 Water treatment projects. State health department, State water resource, and U.S. Environmental Protection Agency personnel, as appropriate, should be consulted in the early stages of project planning regarding supply sources and associated water treatment needs. In addition to the usual treatment that may be required to insure delivery of potable water, consideration will be given to the need for special treatment to protect pipelines, water heaters, plumbing fixtures, and other equipment against scaling, corrosion, and staining, Because of the widely varying conditions and the many types of water, it is not possible to establish criteria for all cases of special water treatment. Treatment for prevention of scaling and corrosion may not be entirely effective; and in many cases a decision as to the necessity of special treatment cannot be reached prior to actual operating experiences. In general, special treatment will be provided only in cases where a study of water analyses and experience with the water definitely show that there will be severe corrosion of the water system or that severe scaling of hot-water heaters, storage tanks, and other parts of the plumbing system will occur. Marginal cases will be deferred and treatment provided only after operating experience determines treatment to be necessary.

2. WATER TREATMENT PROCESS

2.1 Process selection factors. The design of treatment facilities will be determined by feasibility studies, considering all engineering, economic, energy and environmental factors. All legitimate alternatives will be identified and evaluated by life cycle cost analyses. Additionally, energy use between candidate processes will be considered. For the purpose of energy consumption, only the energy purchased or procured will be included in the usage evaluation. All treatment process systems will be compared with a basic treatment process system, which is that treatment process system accomplishing the required treatment at the lowest first cost. Pilot or laboratory analysis will be used in conjunction with published design data of similar existing plants to assure the optimal treatment. It is the responsibility of the designer to insure that the selected water treatment plant process complies with Federal Environmental Agency, State or local regulations, whichever is more stringent.

2.2 Preliminary treatment. Surface waters contain fish and debris which can clog or damage pumps, clog pipes and cause problems in water treatment. Streams can contain high concentrations of suspended sediment. Preliminary treatment processes are employed for removal of debris and part of the sediment load.

2.2.1 Screens.
2.2.1.1 Coarse screens or racks. Coarse screens, often termed bar screens or racks, must be provided to intercept large, suspended or floating material. Such screens or racks are made of l/2-inch to 3/4-inch metal bars spaced to provide 1- to 3-inch openings.
2.2.1.2 Fine screens. Surface waters require screens or strainers for removal of material too small to be intercepted by the coarse rack, These may be basket-type, in-line strainers, manually or hydraulically cleaned by backwashing, or of the traveling type, which are cleaned by water jets. Fine-screen, clear openings should be approximately 3/8 inch. The velocity of the water in the screen openings should be less

than 2 feet per second at maximum design flow through the screen and minimum screen submergence.

2.2.1.3 Ice clogging. In northern areas screens maybe clogged by frazil or anchor ice. Exposure of racks or screens to cold air favors ice formation on submerged parts and should be avoided to the maximum practicable extent. Steam or electric heating, diffusion aeration and flow reversal have been used to overcome ice problems.

2.2.1.4 Disposal of screenings. Project planning must include provision for the disposal of debris removed by coarse and fine screens.

2.2.2 Flow measurement. Water treatment processes, e.g., chemical application, are related to the rate of flow of raw water. Therefore, it is essential that accurate flow-rate measurement equipment is provided. Pressure differential producers of the Venturi type are commonly used for measurement of flow in pressure conduits. An alternative selection for pressure conduits is a magnetic flow meter if the minimum velocity through the meter will be 5 feet per second or more. A Parshall flume can be used for metering in open channels. Flow signals from the metering device selected should be transmitted to the treatment plant control center.

2.2.3 Flow division. While not a treatment process, flow division (flow splitting) is an important treatment plant feature that must be considered at an early stage of design. To insure continuity of operation during major maintenance, plants are frequently designed with parallel, identical, chemical mixing and sedimentation facilities. No rigid rules can be given for the extent of duplication required because a multiplicity of factors influence the decision. Normally, aerators are not provided in duplicate. Presedimentation basins may not require duplication if maintenance can be scheduled during periods of relatively low raw water sediment load or if the following plant units can tolerate a temporary sediment overload. If it is determined that presedimentation at all times is essential for reliable plant operation, then the flow division should be made ahead of the presedimentation basins by means of identical splitting weirs arranged so that flow over either weir may be stopped when necessary, During normal operation, the weirs would accomplish a precise equal division of raw water, regardless of flow rate, to

parallel subsequent units; rapid-mix, slow-mix and sedimentation. The water would then be combined and distributed to the filters. If presedimentation units are not provided, then the flow is commonly split ahead of the rapid-mix units. If a single treatment train is to be provided initially with the expectation of adding parallel units in the future, then the flow-splitting facilities should be provided as part of the original design, with provision for Mocking flow over the weir which is to serve future units.

2.2.4 Sand traps. Sand traps are not normally required at surface water treatment plants. Their principal application is for the removal of fine sand from well water. The presence of sand in well water is usually a sign of improper well construction or development. If sand pumping cannot be stopped by reworking the well, the sand must be removed. Otherwise, it will create serious problems in the distribution system by clogging service pipes, meters, and plumbing. Centrifugal sand separators are an effective means of sand removal. These cyclone-separator devices are available assembled from manufacturers and require no power other than that supplied by the flowing water. They operate under system pressure; therefore, repumping is not necessary. Water from the well pump enters tangentially into the upper section of the cone and centrifugal force moves the sand particles to the wall of the cone. They then pass downwater into the outlet chamber. Sand is periodically drained to waste from this chamber through a valve that can be manually or automatically operated. The clarified water is discharged from the top of the cone, These units are available in diameters of 6, 12, 18, 24, and 30 inches providing a capacity range from 15 to 4500 gallons per minute (gpm) and are suitable for operation up to 150 pounds per square inch (psi). Pressure drop through the unit ranges from 3 to 25 psi, depending on unit size and flow rate. These separators will remove up to 99 percent of plus 150 mesh sand and about 90 percent of plus 200 mesh. The units are rubber lined for protection against sand erosion.

2.2.5 Plain sedimentation. Plain sedimentation, also termed "presedimentation" is accomplished without the use of coagulating chemicals. Whether plain sedimentation is essential is a judgment decision influenced by the experience of plants treating water

from the same source. Water derived from lakes or impounding reservoirs rarely requires presedimentation treatment. On the other hand, water obtained from notably sediment-laden streams, such as those found in parts of the Middle West, requires presedimentation facilities for removal of gross sediment load prior to additional treatment. Presedimentation treatment should receive serious consideration for water obtained from rivers whose turbidity value frequently exceeds 1,000 units. Turbidity values of well over 10,000 units have been observed at times on some central U.S. rivers.

2.2.5.1 Plain sedimentation basins. Plain sedimentation or presedimentation basins may be square, circular, or rectangular and are invariably equipped with sludge removal mechanisms.

2.2.5.2 Design criteria. Detention time should be approximately 3 hours. Basin depth should be in the approximate range of 10 to 15 feet, corresponding to upflow rates of 600 to 900 gallons per day (gpd) per square foot for a detention period of 3 hours. Short-circuiting can be minimized by careful attention to design of inlet and outlet arrangements. Weir loading rates should not exceed approximately 20,000 gpd per foot. Where presedimentation treatment is continuously required, duplicate basins should be provided. Basin bypasses and overflows should also be included.

2.3 Aeration. The term "aeration" refers to the processes in which water is brought into contact with air for the purpose of transferring volatile substances to or from water. These volatile substances include oxygen, carbon dioxide, hydrogen sulfide, methane and volatile organic compounds responsible for tastes and odor. Aeration is frequently employed at plants treating ground water for iron and manganese removal.

2.3.1 Purpose of aeration. The principle objectives of aeration are:

2.3.1.1 Addition of oxygen to ground water for the oxidation of iron and manganese. Ground waters are normally devoid of dissolved oxygen. The oxygen added by aeration oxidizes dissolved iron and manganese to insoluble forms which can then be removed by sedimentation and filtration.

2.3.1.2 Partial removal of carbon dioxide to reduce the cost of water softening by precipitation with lime and to increase pH.

2.3.1.3 Reduction of the concentration of taste-and-odor producing substances, such as hydrogen sulfides and volatile organic compounds.

2.3.1.4 Removal of volatile organic compounds which are suspected carcinogens.

2.3.2 Types of aerators. Three types of aerators are commonly employed. These are: waterfall aerators exemplified by spray nozzle, cascade, and multiple tray units; diffusion or bubble aerators which involve passage of bubbles of compressed air through the water; and mechanical aerators employing motor-driven impellers alone or in combination with air injection devices. Of the three types, waterfall aerators, employing multiply trays, are the most frequently used in water treatment. The efficiency of multiple-tray aerators can be increased by the use of enclosures and blowers to provide counterflow ventilation.

2.3.3 Design criteria.

2.3.3.1 Multiple-tray, tower aerators.

2.3.3.1.1 Multiple-tray aerators. Multiple-tray aerators are constructed of a series of trays, usually three to nine, with perforated, slot or mesh bottoms. The water first enters a distributor tray and then falls from tray to tray, finally entering a collection basin at the base. The vertical opening between trays usually ranges from 12 inches to 30 inches. Good distribution of the water over the entire area of each tray is essential. Perforated distributors should be designed to provide a small amount of head, approximately 2 inches on all holes, in order to insure uniform flow. In aerators with no provision for forced ventilation, the trays are usually filled with 2- to 6-inch media, such as coke, stone, or ceramic balls to improve water distribution and gas transfer and to take advantage of the catalytic oxidation effect of manganese oxide deposits in the media. The water loading on aerator trays should be in the range of 10 to 20 gpm per square foot. Good, natural ventilation is a requirement for high efficiency. For multiple tray aerators designed for natural ventilation, the following empirical equation can be used to estimate carbon dioxide (CO_2) removal:

$C_r = C_o \,(10^{-kn})$

C_r = mg/l CO_2 remaining after aeration

C_o = mg/l CO_2 present in water in distribution tray

n = number of trays, including distribution tray

k = 0.11 to 0.16 depending on temperature, turbulence, ventilation, etc.

Where icing is a problem and the aerator must be housed, artificial ventilation by fans or blowers is necessary. An enclosed induced- or positive-draft aerator requires approximately 3.5 to 6 standard cubic feet of ventilating air per gallon of water aerated. Thus, for an enclosed aerator operating at a rate of 1.5 million gallons per day (mgd), air requirements will be in the range of 3600 to 6200 standard cubic feet of air per minute. Positive-draft aerators employing the higher air-flow rates exhibit the highest efficiency for the addition and removal of dissolved gases and oxidation of iron, manganese, and sulfide. Power requirements for a natural draft, multiple-tray aerator having an overall height of 10 feet will be approximately 1.7 kilowatts per mgd of aeration capacity. Power demands for forced draft units will be greater.

2.3.3.1.2 Counter-current packed column aeration. A counter-current parked column aerator tower is similar to operation to counter-current multiple tray aerators, but are particularly efficient at the removal of volatile organic compounds (VOCs) through air-stripping. Packed column aerators consist typically of a long thin tower filled with either a random dumped media (Rasching rings, Ber) saddles, Pall rings) or corrugated sheet media, held by a packing support plate. Water is pumped to the top of the tower over a distribution plate and allowed to fall through the media. Air is blown up through the tower by a fan counter to the falling water. Redistributor plates are used throughout the column to prevent channeling of the water or air stream. Efficiency of the tower is dependent on the extent of contact between the air and water. Detailed design can be found in various chemical engineering literatures and handbooks or AWWA, EPA publications.

2.3.3.2 Diffusion aerators. Compressed air is injected into the water as it flows through a rectangular basin. A variety of air injection devices may be employed

including perforated pipes, porous plates or tubes and various patented sparger devices. Basin size is determined by desired detention time, which commonly ranges from 10 to 30 minutes. Tank depth is usually from 10 to 15 feet. Air requirements, supplied by a compressor, generally range from 0.1 to 0.2 standard cubic foot per gallon of water aerated. Major advantages of a diffusion aeration system include practically no head loss and freedom from cold-weather operating problems. An additional advantage is that a diffusion aerator may also be used to provide chemical mixing. Power requirements are those associated with air compression and range from 1.0 to 2.0 kilowatts per mgd of aerator capacity. Aeration efficiency in terms of addition of oxygen or removal of carbon dioxide is generally similar to that provided by multiple-tray aerators employing natural ventilation.

2.3.3.3 Mechanical aerators. Mechanical aerators typically consist of an open impeller operating on the waters surface. Basin size is determined by detention time required. Basin depth can vary from 5 to 17 feet with the average depth being 10 feet. Major advantages of mechanical aerators are practically no head loss and the ability to provide mixing. Mechanical aerators are generally not as efficient as aeration towers or diffused aerators and longer detention times are required.

2.3.3.4 Criteria for installation of aerators. Aeration is a gas transfer process which is not needed at all water treatment plants. A decision as to whether to aerate or not requires assessment of the economic and water quality benefits achieved by its use.

2.3.3.4.1 Addition of oxygen. Aeration processes are commonly used in adding oxygen to groundwaters and to oxidize iron, manganese, hydrogen sulfide and to a limited extent, organic matter. Groundwaters are usually deficient in oxygen and acration is an effective means of adding it. Oxygen addition is normally required if iron and manganese removal is a treatment objective. Aeration will also help oxidize hydrogen sulfide and some organic matter.

2.3.3.4.2 Partial removal of volatile substances. Aeration is a useful method of removing volatile substances from water. Groundwaters while being deficient in oxygen can contain objectionable levels of carbon dioxide. An efficient aerator will result in near saturation with oxygen and about 90 percent reduction of the carbon dioxide content of groundwater. At lime-soda water softening plants, any carbon dioxide dissolved in the

water at the point of lime application will consume lime without accompanying softening. For high (>50 mg/L) carbon dioxide concentrations, as encountered in some groundwaters, aeration for its removal is probably justified. For concentrations on the order of 10 mg/L, or less, aeration is probably not economically valid. Before deciding to aerate for carbon dioxide removal, the cost of purchasing, maintaining and operating the aerator should be compared to the value of the lime saved. At softening plants, each mg/L of carbon dioxide removed will effect a saving of about 1.3 mg/L quicklime (95 percent calcium oxide). It will also reduce the quantity of softening sludge produced proportionately.

2.3.3.4.3 Reduction of hydrogen sulfide. Aeration is also used for removing hydrogen sulfide from well water. It may be sufficient in itself if the hydrogen sulfide concentration is not more than about 1.0 or 2,0 mg/L. Otherwise, it maybe used in conjunction with chlorine to oxidize the hydrogen sulfide not removed by aeration.

2.3.3.4.4 Reduction of Volatile Organic Compounds (VOCs). Recent studies have shown that aeration can be successfully employed to reduce volatile organic compounds (VOCs) such as total Trihalomethane (TTHM) concentration in chlorinated water to meet current US EPA regulations limiting TTHM concentrations. Aeration by diffused air or multiple-tray aerators can reduce TTHM concentration at low cost, with cost increasing with higher concentrations of Trihalomethane (THM). Counter-current packed tower aeration is most efficient in achieving mass transfer of VOC.

2.3.3.5 Aeration summary. Where icing is a problem and the aerator must be housed, artificial ventilation by fans or blowers is necessary. An enclosed induced- or positive-draft aerator requires approximately 3.5 to 6 standard cubic feet of ventilating air per gallon of water aerated. Thus, for an enclosed aerator operating at a rate of 1.5 mgd, air requirements will be in the range of 3600-6200 standard cubic feet of air per minute. Positive-draft aerators employing the higher air-flow rates exhibit the highest efficiency for the addition and removal of dissolved gases and oxidation of iron, manganese, and sulfide. Counter-current packed column aeration is particularly efficient to remove volatile organic compounds, Requirements for a natural draft, multiple-tray aerator having an overall height of 10 feet will be approximately 1,7 kilowatts per mgd of aeration capacity, Power demands for forced draft units will be greater. In general,

aeration is worthy of consideration in connection with the treatment of groundwater supplies in conjunction with lime softening and for the removal of some VOCs. Surface waters usually exhibit low concentrations of carbon dioxide, no hydrogen sulfide and fairly high dissolved oxygen. As a consequence, aeration is not required for the removal or addition of these gases. However, surface waters contain higher levels of THM precursors than groundwaters and therefore a need for aeration may arise to reduce TTHM following chlorination. Water high in the bromine-containing THMs are difficult to treat by aeration and other methods of removal should be used, such as coagulation and flocculation or contact with granular activated carbon.

2.4 Coagulation and flocculation. Coagulation and flocculation processes are defined as follows: "Coagulation" means a reduction in the forces which tend to keep suspended particles apart. The joining together of small particles into larger, settleable and filterable particles is "flocculation." Thus, coagulation precedes flocculation and the two processes must be considered conjunctively.

2.4.1 Purposes of coagulation and flocculation. Raw water supplies especially surface water supplies, often contain a wide range of suspended matter, including suspended minerals, clay, silt, organic debris and microscopic organisms ranging in size from about 0.001 to 1.0 micrometer. Small particles in this size range are often referred to as "colloidal" particles. Larger particles, such as sand and silt, readily settle out of water during plain sedimentation, but the settling rate of colloidal particles is so low that removal of colloidal particles by plain sedimentation is not practicable. Chemical coagulation and flocculation processes are required to aggregate these smaller particles to form larger particles which will readily settle in sedimentation basins. The coagulation-flocculation processes are accomplished step-wise by short-time rapid mixing to disperse the chemical coagulant followed by a longer period of slow mixing (flocculation) to promote particle growth.

2.4.2 Chemical coagulant. The most frequently used chemical coagulant is aluminum sulfate ($Al_2 (SO_4)_3$ $14H_2O$). This aluminum coagulant is also called "alum" or "filter alum,"

and dissociates in water for form $SO_4 = Al^{3+}$ ions and various aluminum hydroxide complexes. Other aluminum compounds used as coagulants are potash alum and sodium aluminate, principally the latter. Iron coagulants include ferric sulfate, ferrous sulfate and ferric chloride.   Magnesium hydroxide ($Mg(OH)_2$), is also an effective coagulant, Organic polyelectrolyte compounds, applied in low dosages alone or in combination with the metal coagulant, are also employed. Polyelectrolytes are high-molecular-weight polymers that dissociate in water to give large highly charged ions, The polyelectrolytes and dissociated ions destabilize the colloids and promote their settling, These polymers can be classified an anionic, cationic or nonionic according to their dissociated polymeric ions being negatively charged, positively charged or both negatively and positively charged.

2.4.3 Coagulation for Removal of Trihalomethane Precursors. Recent US EPA regulations limit allowable TTHM concentrations in finished potable water*.* To help meet the current maximum contaminant level (MCL) of 0.10 mg/L for TTHM, trivalent metal ion coagulant, such as aluminum sulfate or ferrous sulfate, and a variety of organic polyelectrolytes have been used to remove THM precursors before chlorination. Naturally-occurring THM precursors, such as humic and fulvic compounds, are only partially removed by coagulation and filtration. For coagulation with alum, a pH of between 5 and 6 is the optimum for the removal of fulvic and humic acid compounds. Ferrous sulfate exhibits an optimum pH for removing organic compounds of between 3 and 5. Fulvic acids require twice the dosages of alum needed for humic acids, The addition of anionic polymers at doses from 1 to 10 mg/L can also provide some removal of humic compounds. The efficiency of removal depends upon the type and concentration of organic compounds present in the water supply, pH, coagulant dose, and solids-liquid separation step. Optimum precursor removal can only be estimated using laboratory simulation techniques, such as simple jar testing, followed by settling or removal of precipitated colloids with membrane filters. This procedure can provide the information necessary to determine the optimum conditions for the removal of trihalomethane precursor compounds. Monitoring of the removal of organic precursor

compounds by coagulation and filtration can be facilitated by the measurement of total organic carbon.

2.4.4 Design criteria for mixing. Criteria for rapid- and slow-mix processes have been developed on the basis of detention time, power input, velocity gradient (G) and the product (G_t) of velocity gradient and detention
time. The values of G and G_t are computed from:

$G = (P)^{1/2}/uV$, and

G_t = product of G and t, a dimensionless number where

G = velocity gradient (fps/foot; of sec^{-1})

P = the power dissipated in the water (ft-lb/sec)

u = water viscosity (lbf sec/ft^2) = 2.73 x (10^{-5}) @ 50° F

V = volume of mixing basin (cubic feet)

t = mixer detention time (seconds)

2.4.5 Rapid mixing. For rapid-mix units, detention periods usually range from 10 to 30 seconds with installed mixer power approximately 0.25 to 1.0 hp per mgd. Power and detention time should be matched so that values of G will be in the approximate range: 500-1000 sec^{-1}. A wire-to-water efficiency of 80 percent, a water temperature of 50 'F, a power input of 1.0 hp per mgd and a detention time of 10 seconds yield a G value of about 1000 sec^{-1} and a G_t value of 10,000. Similarly, a 30-second detention time
gives a G value of about 600 and a G_t value of 18,000. Long detention period for rapid-mix basins should be avoided because of higher power requirements and inferior coagulation results. The rapid-mix basin should be designed to minimize short circuiting.

2.4.6 Slow mix. For slow-mix (flocculating) units, detention periods should range from 30 minutes to 60 minutes, with installed mixer power of approximately
0.1 to 3.5 hp per mgd. G values in the range of 20 sec^{-1} to 100 sec^{-1} are commonly employed. Corresponding G_t values will, therefore, be in the range of 36,000 to

360,000. Tapered, slow mixing with G decreasing from a maximum of about 90 sec^{-1} down to 50 sec^{-1} and then to 30 sec^{-1} can be used and will generally produce some improvement in flocculation. Somewhat higher G values, up to 200 sec^{-1}, are employed in some water softening plants. For normal flocculation, using alum or iron salts, the maximum peripheral speed of the mixing units should not exceed about 2.0 fps and provision should be made for speed variation. To control short circuiting, two to three compartments are usually provided. Compartmentation can be achieved by the use of baffles. Turbulence following flocculation must be avoided. Conduits carrying flocculated water to sedimentation basins should be designed to provide velocities of not less than 0.5 fps and not more than 1.5 fps, Weirs produce considerable turbulence and should not be used immediately following flocculation.
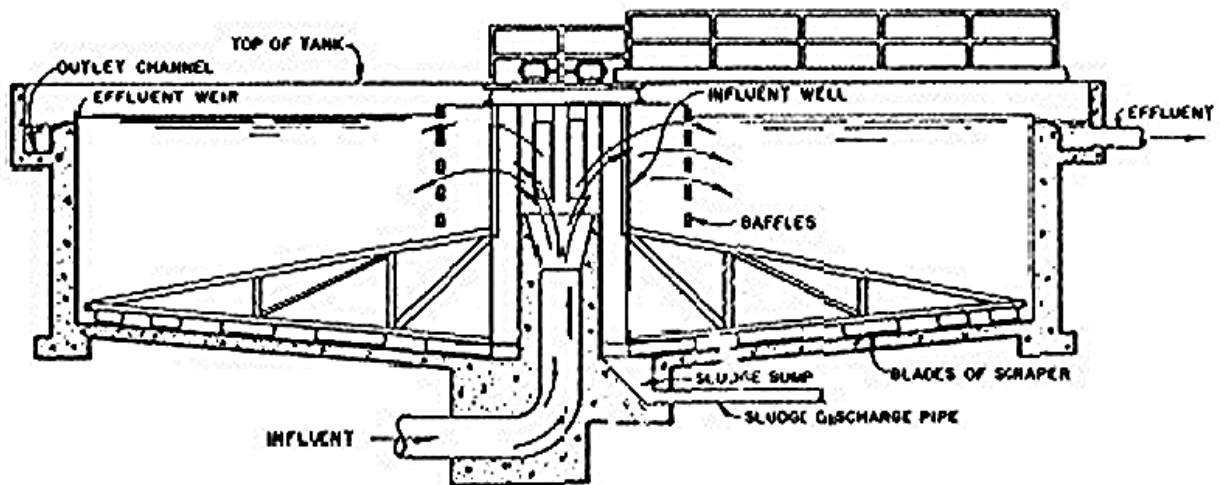
2.5 Sedimentation basins. Sedimentation follows flocculation. The most common types of sedimentation basins in general use are shown in figures 2-1 and 2-2. A recent innovation in clarifiers is a helical-flow solids contact reactor, consisting of an above ground steel conical basin. However, these above ground basins require a high head and additional pumps may be required. A minimum of two basins should be provided to allow one unit to be out of service for repair or maintenance. The design must include arrangements that permit use of a single basin when necessary.

2.5.1 Design criteria. The design of a sedimentation tank is based on the criterion as listed in table 2-1. The sedimentation basins should have adequate capacity to handle peak flow conditions and to prevent excessive deteriorated effluent water qualities. The above design data represent common conditions, higher overflow rates may be used at lime softening plants and at some plants employing upflow clarification units as indicated in the tables of Water Treatment Plant Design by ASCE, AWWA, CSSE. Unusual conditions may dictate deviation from these general criteria. Detention time in the range of 8 to 12 hours, or more provided in several stages, maybe necessary for
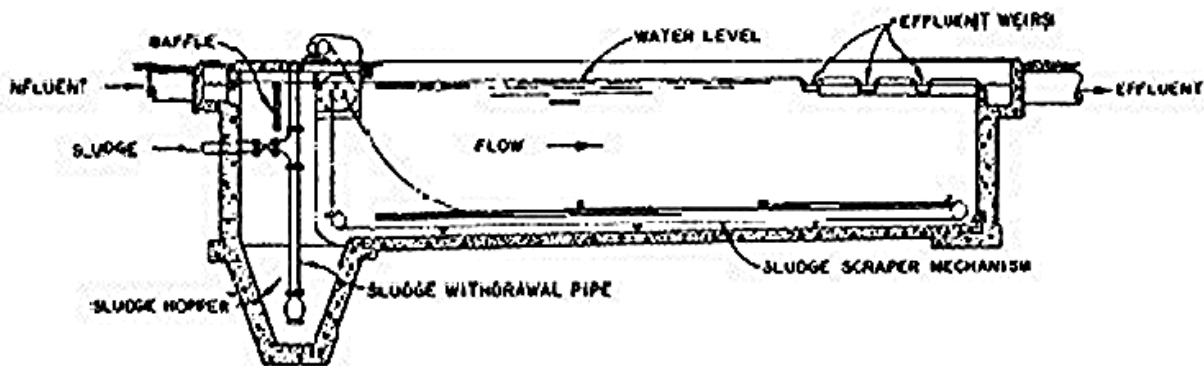
Rectangular Sedimentation Basin

Figure 2-1

Circular Sedimentation Basin

Figure 2-2

treating highly turbid waters. On the other hand, conical clarifiers are more efficient in softening and/or turbidity removal and require a detention time of one hour or less. The design data shall be examined by laboratory analysis or pilot plant studies especially for larger plants. Jar test of coagulant dosage in conjunction with settling column analysis to determine the optimal design criteria will be beneficial for design. If the space available for sedimentation basins is limited, multiple-story basins, in which the water flows horizontally along one level and then passes upward and then flows horizontally

along another level may be utilized. A newer commercial development in sedimentation, the "tube" settler, may be used if the capacity of existing sedimentation basins must be increased or if little space is available for the construction of new sedimentation basins. Detailed information relative to the size, capacity, and configuration of tube settlers may be obtained from the manufacturers. Steel basin conical clarifiers may also be used to expand sedimentation plants when space available is limited. Conical clarifiers stand on a pedestal base and require less space than conventional sedimentation basins. Sedimentation basin inlets, outlets, and baffles must be carefully designed to minimize short circuiting. The solids (sludge which settles to the bottom of the basin) must be removed before the depth of the sludge becomes great enough to interfere with effective sedimentation. In general, mechanical sludge removal equipment is a requirement. All basins must be provided with drains and overflows. Basin covers, usually in the form of a superstructure, will be required in northern localities where ice is a problem.

Table 2-1

Design Criteria for Sedimentation Tank

Design Element	Criteria
Tank depth (ft)	10 to 16
Length/width ratio (rectangular)	3:1 to 5:1
Diameter (circular)(ft)	10 to 100
Flow-through velocity (fpm)	0.5 to 3
Entrance velocity of inlet ports (fps)	0.5 to 2
Detention time (hours)	2 to 4
Surface overflow rate (conventional coagulation plant)(gpm/ft^2)	0.35 to 1.5
Weir overflow rate (gpm/ft^2)	< 15

2.5.2 Flocculation-sedimentation basins. Units of this type, usually circular, combine the functions of flocculation, sedimentation and sludge removal. Flocculation is

accomplished in a circular center well. Sedimentation occurs in the annular space between the flocculation section and the perimeter effluent weir. Design criteria are generally similar to those applicable separate units.

2.5.3 Suspended solids contact basins. Basins of this type combine rapid-mixing. Flocculation, sedimentation, and sludge removal in a single unit.   Coagulation and flocculation take place in the presence of a slurry of previously formed precipitates which are cycled back to the mixing and reaction zone. Upflow rates at the point of slurry separation should not exceed about 1.0 gpm per square foot for units used as clarifiers following coagulation and approximately 1.5 – 1.75 gpm per square foot for units used in conjunction with lime softening.

2.6 Filtration. Filtration of water is defined as the separation of colloidal and larger particles by passage through a porous medium, usually sand, granular coal, or granular activated carbon. The suspended particles removed during filtration range in diameter from about 0.001 to 50 microns and larger. Several different types of medium arrangements and rates of flow through filters can be used. The filtration process most commonly used is gravity filtration, but pressure filters and diatomite filters are used at smaller installations. Recently high-rate filters have been developed which require less space and have higher solids-loading capacity than conventional filters.

2.6.1 Rapid Sand Filters.
2.6.1.1 Filtration Rate. Rapid sand filters are those filters which commonly operate at rates between approximately 2 and 8 gpm per square foot. The rate of filtration to be employed at a specific plant can be determined only after careful consideration by the designer of raw water quality and the probably efficiency of pretreatment that will consistently be provided. Good quality water is not assured by low filtration rates. Adequate pretreatment and filter design will allow application rates of up to 6 gpm oper square foot with little difference in water quality. It is emphasized that if high rates are to be used in design, great care must be taken to insure that all prefiltration treatment processes including coagulation, flocculation, and sedimentation will perform

satisfactorily and consistently. High-rate filter operation definitely requires excellence in pre-filtration treatment, especially in the case of surface waters. It is recommended that data from laboratory or pilot studies be utilized whenever possible rather than an arbitrary selection of criteria.

2.6.1.2 Filter medium.

2.6.1.2.1 Sand. Silica sand is the most commonly used filter medium and its depth should be at least 24 inches and not more than 30 inches. When sand is employed, its "effective size" should fall in the range of 0.35 to 0.5 millimeters (mm) with a uniformity coefficient of 1.3 to 1.7. Filter sand usually ranges in size from that passing a 16-mesh (U.S. Series) sieve to that retained on a 50-mesh (U.S. Series) sieve. Approximately 100 percent by weight, of the sand should pass the 16-mesh sieve and 90 to 100 percent be retained on a 50-mesh sieve. Filter sand should be clean silica sand having a specific gravity of not less than 2.5. The hydrochloric acid volubility of the sand should be less than 5 percent.

2.6.1.2.2 Anthracite. Anthracite is an alternative medium consisting of hard anthracite coal particles. The effective size commonly ranges from about 0.45 mm to 0.6 mm with a uniformity coefficient not to exceed 1.7. The hardness should not be less than 2.7 on the Moh scale and the specific gravity not below 1.4. Also, the anthracite should be visibly free of clay, shale, and dirt.

2.6.1.2.3 Multimedia. Multimedia filters employ two or three layers of media of different size and specific gravity. A common arrangement, the dual media filter, is 20 inches of anthracite overlaying a sand layer of approximately 8 to 12 inches. The anthracite layer has size range of about 0.8 to 2.0 mm; the sand layer, about 0.4 to 1.0 mm. Tri-media filters employ an 18-inch anthracite layer, an 8-inch sand layer, and an underlying 4-inch layer of garnet or ilmenite having a size range of 0.2 to 0.4 mm. Garnet has a specific gravity of about 4, and ilmenite about 4.5.

2.6.1.3 Filter gravel and underdrains. The filter media is commonly supported by a 10- to 18-inch layer of coarse sand and graded gravel. The gravel depth may range from 6 inches to 24 inches, depending on the filter underdrain system chosen. The gravel should consist of hard, rounded stones having a specific gravity of at least 2.5 and an acid volubility of less than 5 percent. A 3- to 4-inch transition layer of coarse

(torpedo) sand, having a size range of about 1.2 to 2.4 mm, is placed on top of the filter gravel. Gravel size usually ranges from about 0.1 inch to about 2.5 inches. Filter underdrains may be constructed of perforated pipe grids or various proprietary underdrain systems. A variety of the latter are available. Design details for pipe underdrains are given in numerous texts and handbooks. Manufacturers will furnish design and installation criteria for proprietary systems.

2.6.1.4 Sand, anthracite, gravel specifications. Detailed specifications for filter sand, anthracite and gravel are contained in AWWA B100.

2.6.1.5 Number of filters. Not less than two filters should be installed regardless of plant size. For large plants, rough guidance as to the number of filters to be provided may be obtained from:

$N = 2.7 \, Q^{1/2}$

N = number of filter units

Q = design capacity in mgd

Thus, a 9 mgd plant would require eight filters.

2.6.1.6 Size of filter units. The maximum filter size is related to wash water flow rate and distribution. Normally, individual filters sizes do not exceed about 2100 square feet corresponding to a capacity of about 6 mgd at a flow rate of 2.0 gpm per square foot. A unit of this size would require a maximum backwash water rate of about 60 mgd, which is excessive. Consequently, it should be divided into two parts of equal size arranged for separate backwashing. Total filter depth should be at least 9 feet.

2.6.1.7 Filter backwash. Backwash facilities should be capable of expanding the filter media 50 percent. This will require wash rates in the range of 10 to 20 gpm per square foot. Backwash water can be supplied by a backwash pump or from elevated storage provided specifically for this purpose. Filter down-time during wash periods commonly average 10 to 20 minutes including a 5- to 15-minute wash period. For a 15-minute backwash of a single unit, at maximum rate, the wash water volume will be 300 gallons per square foot of filtration area in that unit. In addition to backwashing, auxiliary scour is commonly provided. This aids in cleaning the filter and is commonly accomplished by rotary or fixed surface-wash equipment located near the top of the bed. It is operated for a time period equal to that of the backwash, Water pressures of 40-100 psi are required

for surface-wash operation at a rate of 0.5 gpm per square foot. Air scour may also be employed but is not generally used. If an independent washwater storage tank is used, it must refill between washes. Tank capacity should be at least 1.5 times the volume required for a single wash.

2.6.1.8 Wash water troughs. Wash water troughs equalize the flow of wash water and provide a conduit for removal of used water. Two or more troughs are usually provided. The elevation of the trough bottoms should be above that of the expended bed. The clear horizontal distance between troughs should not exceed 5 to 6 feet, and the top of the troughs not more than 30 inches above the top of the bed.

2.6.1.9 Filter piping and equipment. Essential filter control valves, etc., are shown schematically in figure 2-3.   Each filter should be equipped with a rate-of-flow controller plus associated equipment for automatic filter water-level control. The latter senses the water level in the main influent conduit and transmits a signal to the flow controllers. The controllers, in response to this signal, adjust filtration rates to match the inflow from the sedimentation basins. Thus, within practical limits, total filter outflow always equals total inflow and the filter water level remains virtually constant. A device that will sense maximum permissible clearwell level should also be provided. This should be arranged so that at maximum allowable clearwell water level, a shut-off signal will be transmitted to all filter controllers and also to an audible alarm. Other designs, not involving rate controllers, such as "influent flow splitting" and "variable declining rate" have been developed and may be employed at the discretion of the designer. In general, each filter must have five operating valves: influent, wash water, drain, surface wash, and filter-to-waste. It is emphasized that the filter-to-waste piping must not be directly connected to a plant drain or sewer. An effluent sampling tap must be provided for each filter. Valves can be manually, electrically, hydraulically, or pneumatically operated. Butterfly type valves are recommended for filter service. Design velocities commonly employed for major filter conduits are as follows:
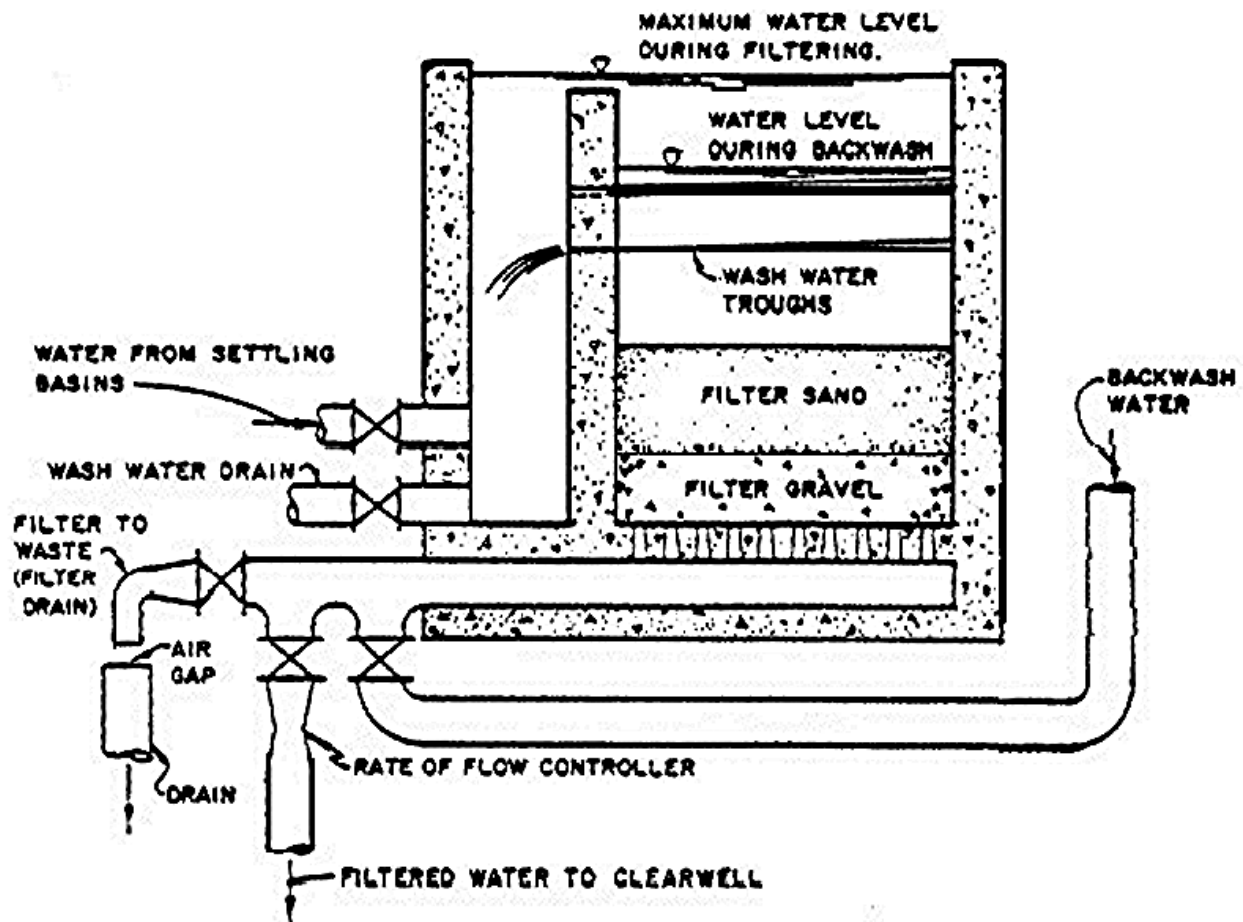
Figure 2-3

Schematic of Rapid Sand Filter Operational Controls

Conduit	Design Velocity (ft/sec)
Influent	1 – 4
Effluent	3 – 6
Wash water	5 – 10
Drain	3 – 8
Filter-to-waste	6 – 12

The effluent conduit must be trapped to present backflow of air and provide a seal for the rate controllers. The filter pipe gallery should have ample room and good drainage, ventilation, and lighting.   Dehumidification equipment for the gallery should receive

careful consideration. Filters should be covered by a superstructure except under favorable climatic conditions. Drainage from the operating floor into the filter should be prevented by a curb. Access to the entire bed should be provided by a walkway at operating floor level around the filter. Filters may be manually or automatically controlled from local or remote locations. Facilities permitting local, manual control are recommended irrespective of other control features. Used backwash water should be discharged to a wash water recovery basin or to a waste disposal facility. Regulatory agencies generally view filter wash water as a pollutant and forbid its direct discharge to the natural drainage.

2.6.1.10 Essential instrumentation. Minimum essential instrumentation for each filter will be provided as follows: rate-of-flow indicator; loss-of-head indicator; effluent turbidity indicator; wash water rate-of-flow indicating and totalizing meter. If a wash water storage tank is provided, it must be equipped with a waterlevel indicator. While not absolutely required, a turbidity indicator on the main filter influent is desirable.

2.6.2 Diatomite filters. Filtration is accomplished by a layer of diatomaceous earth supported by a filter element termed a septum, This layer of diatomaceous earth is about l/8-inch thick at the beginning of filtration and must be maintained during filtration by a constant feed of diatomaceous earth (body feed) to the influent water. At the conclusion of a filter run, the layer of diatomaceous earth will have increased in thickness to about 1/2 inch. Filtration rates generally vary from 0.5 to 2.0 gpm per square foot. The principal use of diatomite filters has been for swimming pool waters, but some have been installed for the treatment of potable water.

2.6.3 Pressure filters. Pressure filters are similar in construction and operating characteristics to rapid sand filters. However, in a pressure filter the media, gravel bed, and underdrains are enclosed in a steel shell. There are a variety of new pressure filters in use today. The most common of these are the conventional downflow filter, the high-rate downflow filter and the upflow filter. An advantage of any pressure filter is that any pressure in waterlines leading to the filter is not lost, as in the case of gravity filters, but can be used for distribution of the filter effluent. Between 3 and 10 feet of pressure head

are lost through the filter. The primary disadvantage of a pressure filter is that, due to the filter being enclosed in a steel shell, access to the filter bed for normal observation and maintenance is restricted. Also, the steel shells require careful periodic maintenance to prevent both internal and external corrosion. The use of pressure filters is not advantageous in most systems. However, if the pressure requirements and conditions in a particular system are such that repumping of filtered water can be eliminated, cost savings will be realized,

2.6.3.1 Conventional downflow filters. Conventional downflow pressure filters consist of a bed of granular media or multi-media and are good in removing suspended solids comprised of floe. The advantages over gravity filters include lower installation cost and adaptability y to different piping systems. Hydraulic loadings range from 1 to 4 gpm/sq. ft.

2.6.3.2 High-rate downflow filters. High-rate downflow filters have filtration rates of 10-20 gpm/sq. ft. The higher downflow velocities require coarser media which allow suspended solids to penetrate deeper into the medium. As a result, more solids can be stored in the filter bed before backwashing is required, Many units exhibit a 1-4 lbs/sq. ft. solids-loading capacity, The higher filtration rates also allow smaller or fewer filters to be used over conventional filters. However, the high solids-loading capacity of this filter requires higher backwashing flow rates and hence larger backwashing water storage tanks.

2.6.3.3 Upflow filters. Upflow multi-media filters allow filtration of high solids-loaded liquids in concentration up to 1,000 mg/L. The advantage of upflow multi-media filters is that the coarser material at the inlet collects the heavier particles, while the finer material collects the smaller particles, thus efficiency of the filter is increased.

2.6.3.4 Upflow continuous backwash sand filters. Upflow continuous backwash sand filters continuously clean the filter medial by recycling the sand internally through an air lift pipe and sand washer. The regenerated sand is then redistributed to the top of the sand-bed. Once the sand migrates down to the bottom of the bed it is again airlifted and repeats the cycle. Upflow continuous backwash sand filters require no backwash valves, storage tanks, or backwash pumps, therefore their operation is greatly simplified.

2.7 Disinfection. Disinfection involves destruction or inactivation of organisms which may be objectionable from the standpoint of either health or esthetics. Inasmuch as the health of water consumers is of principal concern to those responsible for supplying water, design of facilities for disinfection must necessarily be carefully executed.

2.7.1 Chlorination. The application of chlorine to water is the preferred method of disinfecting water supplies.

2.7.1.1 Definitions. Terms frequently used in connection with chlorination practice are defined as follows:

2.7.1.1.1 Chlorine demand. The difference between the concentration of chlorine added to the water and the concentration of chlorine remaining at the end of a specified contact period. Chlorine demand varies with the concentration of chlorine applied, time of contact, temperature, and water quality.

2.7.1.1.2 Chlorine residual. The total concentration of chlorine remaining in the water at the end of a specified contact period,

2.7.1.1.3 Combined available residual chlorine. Any chlorine in water which has combined with nitrogen. The most common source of nitrogen is ammonia, and compounds formed by the reactions between chlorine and ammonia are known as chloramines. The disinfecting power of combined available chlorine is about 25 to 100 times less than that of free available chlorine.

2.7.1.1.4 Free available residual chlorine. That part of the chlorine residual which has not combined with nitrogen.

2.7.2 Chlorination practice.

2.7.2.1 Combined residual chlorination. Combined residual chlorination entails the application of sufficient quantities of chlorine and ammonia, if ammonia is not present in the raw water, to produce the desired amount of combined available chlorine (chloramine) in a water. If enough ammonia is present in raw water to form a combined chlorine residual, only chlorine need be added to the water. Combined residual chlorination is generally used only when maintaining an adequate free chlorine residual in the distribution system is difficult or when objectionably high levels of TTHMs would

be formed as a result of free residual chlorination. Due consideration of other TTHM control alternatives should be made before using chloramines.

2.7.2.2 Breakpoint chlorination. If a water contains ammonia or certain nitrogenous organic matter which reacts with chlorine, the addition of chlorine causes the formation of chloramines until the ratio of elemental chlorine to ammonia compounds is about 5 to 1. Further addition of chlorine results in the oxidation of chloramines to gaseous nitrogen and nitrogen oxides, which decreases the quantity of chloramines present. After all of the chloramines have been oxidized, additional chlorine added to the water forms only free available chlorine. The point at which all of the chloramines have been oxidized and only free chlorine is formed is called the "breakpoint ." If no ammonia is present in the water, there will be no breakpoint. The chlorine required to reach the breakpoint is usually about 10 times the ammonia nitrogen content of the water. However, in certain waters, because of the presence of other chlorine consuming substances, as much as 25 times the ammonia nitrogen concentration may be required. Enough chlorine should be added past the breakpoint to ensure an adequate free chlorine residual.

2.7.2.3 Marginal chlorination. Marginal chlorination involves the application of chlorine to produce a desired level of total chlorine residual regardless of the relative concentrations of free or combined chlorine present. In marginal chlorination the initial chlorine demand has been satisfied but some oxidizable substances remain.

2.7.2.4 Chlorine dosages. Figure 2-4 provides minimum cysticidal and bactericidal free chlorine residuals and minimum bactericidal combined chlorine residuals for various pH and temperature levels. Since waterborne bacteria are the major concern at fixed installations, minimum bactericidal levels will be maintained in treated water in all parts of the distribution system under constant circulation. Even at lower pH levels, free chlorine residuals should not fall below 0.2 mg/L and combined chlorine residuals should not fall below 2.0 mg/L. If marginal chlorination is practiced, the total chlorine residual must not be less than 2.0 mg/l. Whenever epidemological evidence indicates an outbreak of a nonbacterial waterborne disease such as amebiasis, infectious hepatitis, or schistosomiasis in the area of a fixed military installation, cysticidal free chlorine residuals shall be maintained in the water supply.
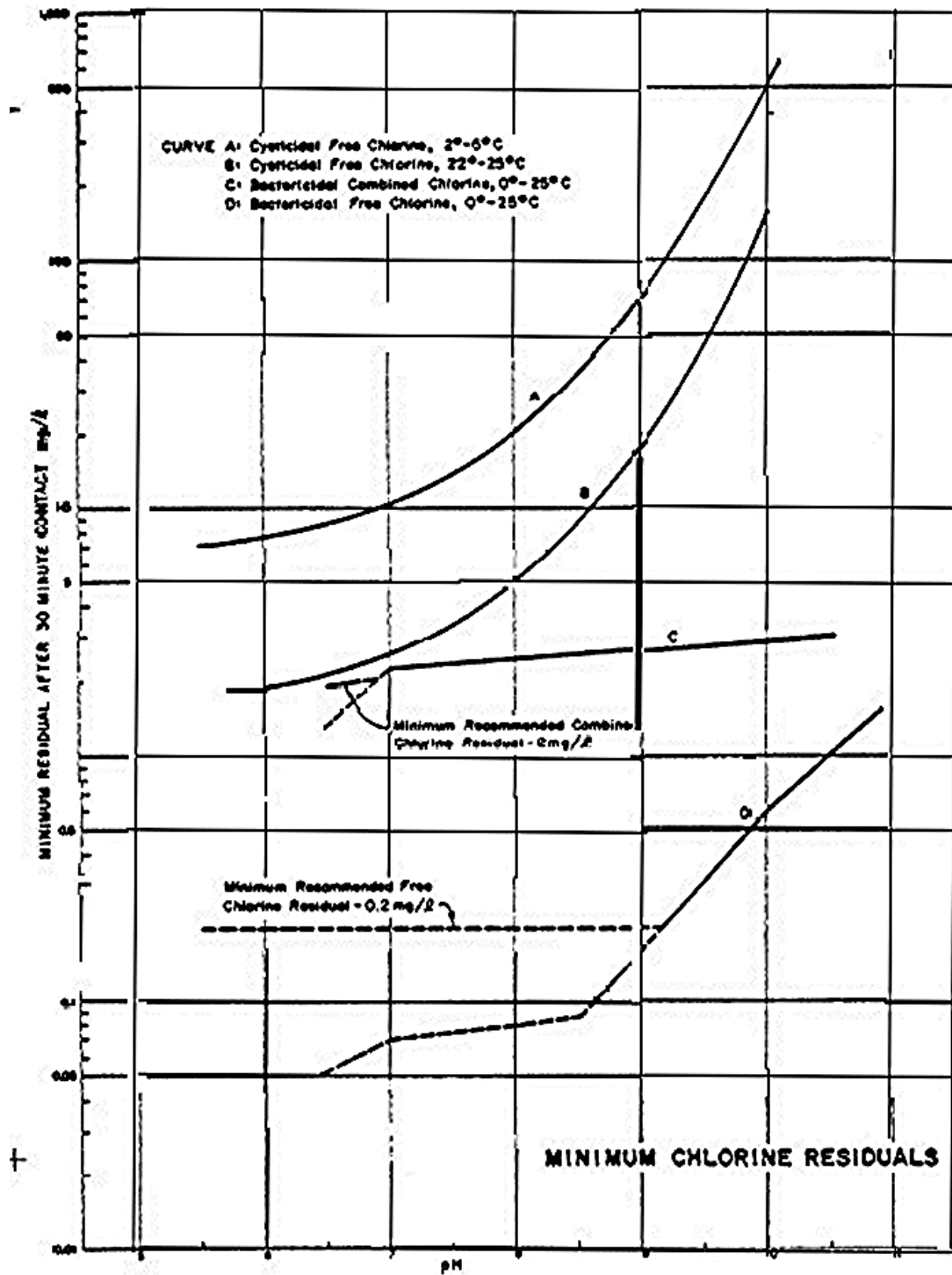
Figure 2-4

Minimum Chlorine Residuals

2.7.3 Other effects of chlorination. In addition to the disinfection achieved with chlorination, other beneficial effects should be noted. Since the oxidizing power of chlorine is high, in the presence of free chlorine, hydrogen sulfide is oxidized, nitrites are oxidized to nitrates, and soluble iron and manganese are oxidized to their insoluble oxides. Free chlorine also reacts with naturally occurring taste, odor and color-producing organic substances to form chloro-organic compounds, e.g., trihalomethanes. The US EPA, after much discussion over costs/ benefits, has chosen a maximum contaminant level for serving above 10,000 persons and has indicated a water treatment industry to avoid costly modifications to existing plants. To reach the US EPA's future maximum contaminant level for TTHM's, more significant changes in disinfection practices will be required.

2.7.4 Application of chlorine. Chlorine may be applied to water of two forms: As gaseous elemental chlorine or as hypochlorite salts. Gaseous elemental chlorine shall be used for water disinfection at all fixed installations. The cost of hypochlorite salts is prohibitive in all plants larger than 0.5 mgd. For remote sites at fixed installations, some well sources require 5 gpm or less. These sources with small demands can use hypochlorite for disinfection.

2.7.4.1 Point of application. Chlorine may be applied to water in a variety of locations in the water treatment plant, storage facilities, or distribution system. It is absolutely essential that the chlorine applied to the water be quickly and thoroughly mixed with the water undergoing treatment. If required, special chlorine mixing facilities should be provided. In conventional water treatment plants, chlorine may be applied prior to any other treatment process (prechlorination), following one or more of the unit treatment process (postchlorination), and again in the more distant points of the distribution system (dechlorination).

2.7.4.1.1 Prechlorination. Prechlorination has often been used so the water would maintain a chlorine residual for the entire treatment period, thus lengthening the contact time. The coagulation, flocculation, and filtration processes were thought to be improved by prechlorination of the water, and nuisance algae growths in settling basins were reduced. In prechlorination, the chlorine was usually injected into the raw water at or

near the raw water intake. Prechlorination was the most accepted practice of disinfection in the past. However, since many surface waters contain THM precursors that will combine with the free chlorine during prechlorination and form potentially carcinogenic THMs, such as chloroform, the point of application has been shifted further down the treatment process to take advantage of precursor removal during treatment.

2.7.4.1.2 Postchlorination. Postchlorination generally involves the application of chlorine immediately after filtration and ahead of the clear well. The design and construction of water treatment plants for should include the necessary provisions for changing the locations of chlorine applications as may later be desirable for improving treatment or disinfection processes.

2.7.4.1.3 Dechlorination. Dechlorination is the practice of adding chlorine to water in the distribution system to maintain a minimum chlorine residual throughout the system.

2.7.4.2 Chlorination equipment. Hypochlorite salts must be applied to the water in solution form. Hypochlorite solutions are pumped by a diaphragm pump through an injection system into the water to be chlorinated. If elemental chlorine is used for disinfection, it shall be injected by solution-type chlorinators. Since chlorine solutions are acidic, many components of a chlorination system must be constructed of corrosion resistant materials such as glass, silver, rubber, or plastics. Maintaining the chlorination apparatus in a trouble-free state is essential, Key spare parts and repair kits for chlorination systems must be kept on hand. Critical components of the chlorination system shall be installed in duplicate.

2.7.4.3 Automatic control. If automatic chlorination control is utilized, the chlorine feed rate should be controlled primarily by the rate of flow of water, with a signal from a downstream residual chlorine analyzer used to trim the feed rate. Provision for manual control during emergency situations must be included.

2.7.5 Superchlorination and dechlorination. Superchlorination may be necessary if there are large variations in chlorine demand or if available contact time is brief. Water which has been superchlorinated generally requires dechlorination before discharge to the distribution system. Dechlorination may be achieved through the application of sulfur dioxide, sodium bisulfite, or sodium sulfite, or by passing the water through granular

activated carbon filters. The dechlorination process (and subsequent dechlorination, if necessary) shall be controlled so that the free residual chlorine remaining in the water is at least 0.2 mg/L. Careful monitoring must be practiced to assure that potentially harmful levels of TTHMs are not exceeded.

2.7.6 Safety precautions for chlorination. *The* AWWA manual "Safety Practice for Water Utilities" contains safety recommendations regarding the use of chlorine.

2.7.7   Alternate Disinfectants. If the use of chlorine as a disinfectant causes unacceptably large concentrations of chlorinated organic compounds, and if all other methods for reducing TTHM's have been exhausted, such as moving the point of chlorination, aeration, and special coagulant (for chloroform which is the main constituent of TTHMs in many cases) and if an alternate raw water source, such as a ground water source, is not available, an alternative disinfectant must be considered. Any alternate disinfectant system installed as the primary means of water disinfection shall have chlorination facilities available and operative for stand-by use. Five alternative disinfectants are discussed below; ozone, chlorine dioxide, chloramines, ultraviolet (UV) radiation, and UV and Ozone combined. While chlorine is the least costly disinfectant, considering dosage and energy consumption basis. However alternate disinfectants are not significantly more expensive.

2.7.7.1 Ozone. Ozone is an extremely powerful disinfectant that has been used in Europe either as a sole disinfectant, or in conjunction with postchlorination to impart a persistent chlorine residual in the water distribution system. United States potable water plants have in the past used ozone to control taste and odor. Today ozonation is being increasingly used as a primary disinfectant prior to rapid mixing, flocculation and filtration. Ozonation does not produce THMs. It is reduced to oxygen and does not leave any residual disinfectant. Hence, the need for postchlorination. Ozone is generated electrically, as needed using the electric discharge gap (corona) technique. Air or oxygen stream, a cooling water stream and alternating electric current are required. Efficient cooling is essential to reduce thermal decomposition of ozone. Bubble diffusers appear to be the most economic ozone contractors available.

2.7.7.2 Chlorine Dioxide. Chlorine dioxide is a highly effective disinfectant producing minimal THMs in the presence of their precursors. Chlorine dioxide uses in the United States have been limited to taste and odor control although it has been used elsewhere as a primary disinfectant and is presently receiving more attention in the United States. The common method of chlorine dioxide production is to react chlorine gas from a conventional chlorinator with a sodium chlorite solution. Following the mixing of the chlorine and sodium chlorite streams and prior to introduction into the main stream the mixed stream is passed through a packed column contactor to maximize chlorine dioxide production. A major disadvantage of chlorine dioxide is the formation of chlorate and chlorite which are potentially toxic.

2.7.7.3 Chloramines. The use of chloramines as a disinfectant fell into disuse after the introduction of breakpoint chlorination. To achieve the same disinfection ability of chlorine, 10 to 15 times the amount of chloramines are needed or longer contact time is required. More chloramines are needed if high concentrations of organic material are found in the influent water, Chloramines are easy to generate, feed, and produce a persistent residual that will remain through the water distribution system. Chloramines may be produced by introducing ammonia to the water stream prior to the addition of free chlorine. This process can be optimized for minimum THM production and maximum disinfection. Recently however there has been some concern over chloramine toxicity.

2.7.7.4 Ultraviolet Radiation. Ultraviolet (UV) radiation has undergone development, but has not been used on a large scale for drinking water supply disinfection. Most of its uses include product or process water disinfection where high purity, sterile water is needed. UV radiation has been used to disinfect drinking water at remotely located hotels and on cruise ships. Few large scale water processing plants use UV disinfection, although its application is feasible. UV disinfection does not leave a disinfectant residual and should be accompanied by postchlorination. Ultraviolet irradiation is also effective in oxidizing organic compounds in water, Water turbidity will inhibit the effectiveness of UV disinfection.

2.7.7.5 UV and Ozone. Recently there has been some experimentation in a combined UV and ozone contactor. Results from these tests show promise. However, there is no known water treatment plant operating with this method of disinfection.

2.8 Fluoride adjustment

2.8.1 Health effects. An excessive fluoride concentration will damage the teeth of children using the water for extended periods. On the other hand, moderate concentrations, 0.7- 1.2 mg/L, are beneficial to children's teeth. Most natural waters contain less than the optimum concentration of fluoride. Upward adjustment of the fluoride concentration can be achieved by application of a measured amount of a fluoride chemical to the water.

2.8.2 Fluoridation chemicals. Chemicals most frequently used for fluoridation are: Sodium silicofluoride, sodium fluoride, and fluosilcic acid. For a particular installation, the choice of chemical will depend principally on delivered cost
and availability.

2.8.2.1 Sodium fluoride. This chemical is commercially available as a white crystalline powder having a purity of 95 to 98 percent. (Sometimes it is artificially colored nile blue.) Volubility is approximately 4 percent at 770 F. The pH of a saturated solution is 6.6. The 100 percent pure material contains 45.25 percent fluoride. It is available in 100-pound bags, 125 to 400 pound drums, and bulk.

2.8.2.2 Sodium silicofluoride. This compound is commercially available as a white powder with a purity of 98 to 99 percent. Volubility is only about 0.76 percent at 770 F. The pH of a saturated solution is 3.5. The 100 percent material contains 60.7 percent fluoride. It is available in 100 pound bags, 125 to 400 pound drums, and bulk.

2.8.2.3 Fluosilicic acid. This chemical is commercially available as a liquid containing 22 to 30 percent by weight of fluosilicic acid. It is sold in 13 gallon carboys, 55 gallon drums, and in bulk. The 100 percent pure acid contains 79.2 percent fluoride. The pH of a 1 percent solution is 1.2, and the use of fluosilicic acid as a fluoridation agent in a water of low alkalinity will significantly reduce the pH of the water. It should not

be used for fluoride adjustment of waters of this type unless pH adjustment is also provided.

2.8.3 Point of application. It is essential that all water pass the point of injection of the fluoridation chemical and that the flow rate past this point be known with reasonable accuracy. At a water treatment plant, the preferred application point is usually the combined effluent of all filters. The fluoride chemical can be fed at an earlier stage of treatment, for example, the combined filter influent, but part of the fluoride applied will be removed by the filtration process. Coagulation and lime softening will also remove a small amount of the applied fluoride. A larger dose is required to offset treatment process losses. If ground water is the supply source, the fluoride chemical should be injected into the discharge pipe of the well pump. Where the supply is from several wells, each pumping independently to the distribution system, it will be necessary to provide an injection point at each well. If flow past the injection point is variable, automatic equipment that will feed fluoride chemical at a rate proportional to flow is a requirement.

2.8.4 Fluoride feeders. Volumetric or gravimetric dry feeders equipped with dissolvers are suitable for sodium fluoride or sodium silicofluoride. Feeders should be equipped with weighing devices that will accurately measure the weight of chemical fed each day and the feed equipment should be designed to minimize the possibility of free flow (flooding) of chemical through the feeder. Normally, the feed machine's supply hopper should hold no more than 100 to 200 pounds of chemical. Large extension hoppers holding much greater quantities of dry fluoride chemical increase the danger of flooding and overfeeding and are not recommended for most installations. Solutions of sodium silicofluoride are acidic and corrosion-resistant dissolvers and solution piping must be provided where this chemical is employed. If fluosilicic acid is used, it can be applied by means of a small metering pump into an open channel or a pressure pipe. Storage tanks, feeders, and piping for fluosilicic acid must be made of corrosion-resistant material. The acid is slightly volatile and the feed system should be enclosed. If not

enclosed, special exhaust ventilation should be provided to protect personnel from fluoride fumes.

2.8.5 Fluoride removal. Fluoride removal can be accomplished by passage of the water through beds of activated alumina, bone char, or tri-calcium phosphate. When the capacity of the bed to remove fluoride is exhausted, it can be regenerated by treatment with a caustic soda solution followed by rinsing and acid neutralization of the residual caustic soda. Other methods of fluoride removal include electrodialysis, reverse osmosis and ion exchange. Some fluoride reduction can be obtained by water softening using excess lime treatment. Fluoride reduction by this method is associated with magnesium precipitation and the extent of fluoride removal is a function of the amount of magnesium precipitated from the water. All removal processes produce liquid wastes and suitable provision must be made for their disposal. Guidance as to the fluoride removal process to be employed can be obtained from laboratory studies of process effectiveness and fluoride removal capacity, using samples of the water that is to be treated.

2.9 Taste and odor control. Most taste and odors in surface water are caused by low concentrations of organic substances derived from decomposing vegetation, microscopic organisms, sewage and industrial waste pollution, etc. Treatment for taste and odor removal involves destruction of the odorous substance by chemical oxidation or its removal by aeration or adsorption or activated carbon.

2.9.1 Chemical oxidation. Chemical oxidizing agents which have been found effective and which can be used in the treatment of potable water are chlorine, chlorine dioxide, potassium permanganate, and ozone. No single chemical is completely effective under all operating conditions.

2.9.2 Aeration. Aeration is helpful in eliminating odor caused by hydrogen sulfide, but is ineffective in significantly reducing odor associated with dissolved organics.

2.9.3 Absorption. Powdered activated carbon is commonly used for removal of tastes, odor and color by adsorption. The carbon can be applied to the water at any point in the treatment plant prior to filtration, but it is usually advisable to apply it early in the treatment process to prolong contact. For maximum effectiveness, carbon should be applied well ahead of chlorine, and preferably in advance of lime softening, The influent to a presedimentation basin is normally an effective carbon application point. Powdered carbon dosages usually range from 5 to 10 mg/L, but as much as 50 mg/L may be required. The use of powdered activated carbon adds more suspended solids and increases the amount of sludge, thereby creating a sludge disposal problem. Powder activated carbon is marginally effective in reducing TTHMs. Granular activated carbon (GAC) has also been used for taste and odor removal. It has been employed as a separate treatment step in the form of carbon columns and as a substitute for sand in the filtration process. Used in this way, the granular carbon serves in a dual capacity as a filtration medium and for taste and odor removal. Granular activated carbon is also excellent at reducing TTHMs. Granular activated carbon must be reactivated on a regular basis to keep its absorptive abilities. Because of the cost of reactivation of GAC, other methods of taste-and-odor control and reduction of TTHMs should be considered. Aeration is generally more cost-effective than GAC contractors.

2.10 Softening. Whether water softening is provided will depend entirely on the type of project and the uses to be made of the water. Two general types of processes are used for softening: The "lime-soda ash" process and the "cation-ion exchange" or "zeolite" process.

2.11 Iron and manganese control.

2.11.1 Occurrence of iron and manganese. Dissolved iron and manganese are encountered principally in ground waters devoid of dissolved oxygen, Normal, oxygenated surface waters do not contain significant concentrations of these metals; however, stagnant water, found in the bottom of thermally-stratified reservoirs,

sometimes contain dissolved iron and manganese. Their presence in solution is associated with anaerobic conditions near the bottom of the reservoir.

2.11.2 Effects of iron and manganese. Dissolved iron in excess of 1 or 2 mg/L will cause an unpleasant taste, and on standing, the water will develop a cloudy appearance. Iron concentrations appreciably greater than 0.3 mg/L will cause red stains on plumbing fixtures and laundry. Similarly, manganese will cause black stains if present to the extent of more than about 0.05 mg/L. Deposits of iron and manganese can build up in water distribution systems and periodic "flushouts" of these deposits result in objectionable color and turbidity at the consumer's tap.

2.11.3 Removal by oxidation and filtration. Oxidation can be accomplished with dissolved oxygen, added by aeration, and by the addition of an oxidizing chemical, such as chlorine, chlorine dioxide, potassium permanganate, or ozone. Manganese is more difficult than iron to oxidize and precipitate. In the absence of manganese, iron can often be removed with minimum treatment, consisting of aeration followed by direct filtration. In general, aeration alone will not oxidize manganese unless the pH is raised to about 9,5. Strong oxidants, such as chlorine or potassium permanganate, are effective at lower pH values. To insure oxidation, precipitation and agglomeration of iron and manganese and their essentially complete removal, at least three treatment steps are usually necessary: aeration, contact time, and filtration. An aerator containing trays of coke, limestone, etc., is commonly used. Reaction time is provided by a contact or contact-sedimentation basin having a detention period of at least 30 minutes. Filtration is accomplished by conventional single or multimedia filters designed for a filtration rate of at least 3.0 gpm per square foot. The aeration step is frequently supplemented by a chemical oxidant, such as chlorine or permanganate. Flocculation is advantageous in the contact basin, particularly if iron exceeds about 2 mg/L.

2.11.4 Removal by ion exchange. The cation exchange (sodium zeolite) softening process, under proper conditions, is capable of removing limited amounts of dissolved (unoxidized) iron and manganese. For application of this process, it is essential that the

raw water and wash water contain no dissolved oxygen and that the sum of the iron and manganese concentrations not exceed about 0.5 mg/L. The presence of oxygen or higher concentrations of iron and manganese will cause rapid fouling of the exchange resin with consequent loss of removal capacity. If fouling occurs, treatment of the resin with sodium bisulfite solution and dilute hydrochloric or sulfuric acid will be required to restore capacity.

2.11.5 Removal by lime-soda softening. Lime-soda softening is an effective means of removing both iron and manganese.

2.11.6 Stabilization of iron and manganese. Under some circumstances, stabilization of iron and manganese by application of a polyphosphate compound may be acceptable. The iron and manganese in the water are maintained in a dispersed state through the completing action of a polyphosphate compound. Dosages of about 5 mg/L of sodium hexametaphosphate for each mg/L of iron and manganese are reasonably effective however, the total polyphosphate dosage should not exceed 10 mg/L. The polyphosphate stabilizing compound *must be* added to the water prior to chlorination. If the chlorine is applied first, it will oxidize the iron and manganese to insoluble forms rendering the stabilizing agent ineffective. Stabilization of concentrations of iron and manganese in excess of approximately 1.0 mg/L is generally not satisfactory. Also, stabilization will not persist if the water is heated because heating coverts polyphosphates to orthophosphates which have no stabilizing power. Stabilization, although helpful, is not a substitute for iron and manganese removal, and, in general, should be viewed as a temporary expedient to be used pending installation of removal facilities.

2.12 corrosion and scale control. "Corrosion" can be defined as the deterioration of metal by direct chemical or electrochemical reaction with its environment. "Scale" refers to an accumulation of solids precipitated out of the water. In water treatment, corrosion and scale are closely associated. Both must be considered in connection with the design and operation of treatment works. This scale may be desirable because it can

provide a measure of protection against corrosion. However, thick layers of scale are detrimental in both hot and cold water systems. It is essential to produce a "balanced" water that is neither highly corrosive nor excessively scale forming.

2.12.1 Corrosion.

2.12.1.1 The extent and nature of corrosion reactions depend upon many factors. Among the most important are the chemical and physical nature of the water, its velocity, pipe metallurgy and pipe coating. In existing systems, where corrosion is a problem, most of these factors, with the exception of the chemical nature of the water, are not readily susceptible to change. Consequently, for these situations, emphasis must be placed on adjustment of the water's chemical quality as the only practical means of corrosion control in an existing system. Controllable factors are principally calcium content, alkalinity and PH. Certain corrosion inhibitors can also be used, but relatively few are suitable for potable water systems.

2.12.1.2 Treatment to insure deposition and maintenance of a thin layer of calcium carbonate on the pipe interior is one widely used means of corrosion control. This control method, while not infallible, has been fairly successful in minimizing the corrosion rate of iron pipe. The rate of formation of calcium carbonate is favored by high concentrations of calcium and bicarbonate and carbonate alkalinity. Protection of this type cannot be attained in waters containing very low concentrations of calcium and alkalinity.

2.12.1.3 Corrosion rates may also be reduced by the use of certain inhibitors. For potable water systems, the most practical inhibitors are silicates and certain polyphosphate compounds. Sodium silicate can be used to a limited extent in very soft water. Polyphosphates can be applied for scale as well as corrosion control. They are considered most effective for corrosion control in the pH range 5.0 to 8.0 and their effectiveness is greatly influenced by velocity. Low velocity, such as encountered in dead-end mains, reduces the effectiveness of all corrosion control methods.

2.12.1.4 Dissolved oxygen and carbon dioxide have a significant effect on corrosion rates. Carbon dioxide lowers the pH and makes the water more aggressive. Carbon dioxide can be removed chemically, but it is generally not feasible to attempt chemical

removal of oxygen from potable water supplies. Most surface waters are normally saturated with oxygen while ground waters, initially free of oxygen, usually absorb some during treatment and distribution. When considering the removal of carbon dioxide by aeration, it should be kept in mind that while efficient aeration will remove most of the carbon dioxide, it will, in doing this, practically saturate the water with oxygen.

2.12.1.5 Corrosion rates are influenced to some extent by all mineral substances found in water, but corrosion effects are so interrelated that it is not possible to isolate the quantitative influence of individual ions. It is known that high concentrations of chloride and sulfate ions will produce increased corrosion rates. However, their adverse effects are somewhat mitigated by alkalinity (carbonate, bicarbonate) and calcium ions. To obtain appreciable benefit from alkalinity and calcium, the total alkalinity, expressed as calcium carbonate, should be at least 50 mg/L, preferable in the range of 50 to 100 mg/L. The calcium concentration, calculated as calcium carbonate, should also be at least 50 mg/L. In general, the higher the concentrations of alkalinity and calcium, the greater is the water's capacity for corrosion retardation. On the other hand, excessive calcium and alkalinity will often result in objectionable scale formation. It is, therefore, necessary to seek a compromise between corrosion on the one hand and scale formation on the other.

2.12.1.6 Based on the corrosion accelerating effects of chloride and sulfate and the corrosion inhibiting effects of alkalinity, the following ration, termed the "Corrosion Index," has been developed. For a pH range of about 7 to 8, and in the presence of dissolved oxygen, an index below about 0.1 indicated probable general freedom from corrosion. An index higher than 0.1 is indicative of corrosion tendencies. The higher the index, the greater the probability of corrosion.

2.12.2 Scale. Scale problems in distribution systems are caused principally by calcium carbonate, magnesium hydroxide, aluminum hydroxide, and the oxides and hydroxides of manganese and iron.

2.12.2.1 Aluminum. Aluminum hydroxide deposits can result from excessive alum use for coagulation and/or improper coagulation practice, such as poor mixing and

flocculation and incorrect coagulation pH. Aluminum hydroxide can create a soft white deposit having a rippled surface which will produce reductions in pipe carrying capacity as measured by the Hazen-Williams "C" value. The problem is one of "after precipitation" of aluminum hydroxide; i.e., aluminum remains in solution until after filtration. Chlorination, which often follows filtration, will reduce the pH slightly and the chemical nature of aluminum is such that a slight reduction in pH will result in a significant reduction insolubility.

2.12.2.2 Magnesium. Magnesium hydroxide deposits have caused serious difficulties in distribution systems and hot water heaters. Magnesium volubility is highly sensitive to pH and temperature and failure to exercise careful control over its stabilization following softening will usually lead to deposition problems. In the absence of detailed information regarding the scaling tendencies of a given water, it is advisable to maintain magnesium hardness below 40 mg/L and pH below 9.8. Hot water heaters should be operated so that water temperatures will not exceed 140° F.

2.12.2.3 Iron and manganese. Hydrous oxide deposits of iron and manganese are inevitable in distribution systems handling water containing more than about 0,3 mg/L of iron and 0.05 mg/L of manganese. The severity of the problem is directly related to the concentration of iron and manganese and the best solution is to remove them at the source. A less satisfactory procedure is to attempt to prevent their precipitation by polyphosphate treatment at the source. Iron deposits may also be caused by corrosion reactions which form loose scale or tubercles. In severe cases, cleaning and lining of the pipe may be required. Tubercle formation can be minimized through corrosion control.

QUIZ

AN INTRODUCTION TO WATER TREATMENT

1. _____ is/are not considered a preliminary treatment.

    a. Coarse screens
    b. Fine screens
    c. Aeration
    d. Racks

2. _____ has been used to overcome ice accumulation problems on screens in northern locales.

    a. Diffusion aeration
    b. Sedimentation
    c. Sand filtration
    d. Reverse osmosis

3. Water flow rate measurement in open channels can be done using a/an _____.

    a. Venturi meter
    b. Parshall flume
    c. magnetic flow meter
    d. magnetometer

4. Flow division or flow splitting is important to _____ .

    a. control manganese and iron
    b. control corrosion and scale
    c. provide for pretreatment
    d. insure continuity of operation during major maintenance

5. Plain sedimentation or presedimentation is accomplished _____.

    a. without the use of coagulating chemicals
    b. after aeration
    c. after sand filtration
    d. before intake screening

6. Detention time in a plain sedimentation basin should be about _____ hours.

   a. 2
   b. 3
   c. 4
   d. 5

7. Aeration is frequently employed at plants treating ground water for _____.

   a. scale control
   b. corrosion control
   c. iron and manganese removal
   d. flocculant removal

8. Which of the following is not a common type of aerator?

   a. Waterfall
   b. Diffusion
   c. Mechanical
   d. Flume

9. In a multiple-tray aerator the vertical opening between trays usually ranges from 12 inches to _____ inches.

   a. 18
   b. 24
   c. 30
   d. 48

10. A counter-current packed column aerator is particularly efficient at the removal of _____ through air-stripping.

   a. volatile organic compounds
   b. sand
   c. manganese
   d. iron

11. In a diffusion aerator, _____ is/are injected into the water as it flows through a rectangular basin.

   a. flocculants
   b. compressed air
   c. coagulants
   d. softening chemicals

12. With a mechanical aerator, the basin depth usually varies from 5 to _____ feet in depth.

    1. 10
    2. 12
    3. 17
    4. 20

13. Trihalomethane is a/an _____.

    a. volatile organic compound
    b. petroleum-oil-lubricant
    c. coagulant
    d. sediment

14. "Coagulation" means a/an _____.

    a. joining together of small particles into larger particles
    b. reduction in the forces which tend to keep suspended particles apart
    c. breaking large particles into smaller particles
    d. increasing the forces which tend to keep suspended particles apart

15. "Flocculation" means a/an _____.

    a. joining together of small particles into larger particles
    b. reduction in the forces which tend to keep suspended particles apart
    c. breaking large particles into smaller particles
    d. increasing the forces which tend to keep suspended particles apart

16. The most frequently used chemical coagulant is _____.

    a. aluminum hydroxide
    b. calcium chloride
    c. sodium hypochlorite
    d. aluminum sulfate

17. Sedimentation _____ flocculation.

    a. precedes
    b. follows
    c. accelerates
    d. retards

18. In design of a rectangular sedimentation tank the length/width ratio is typically 3:1 to _____.

        a. 7:1
        b. 6:1
        c. 5:1
        d. 4:1

19. In design of a circular sedimentation tank the diameter is typically 10 to _____ feet.

        a. 150
        b. 100
        c. 50
        d. 25

20. In filtration using sand, granular coal or granular activated coal, the suspended particles removed during filtration range in diameter from about 0.001 to _____ microns and larger.

        a. 0.1
        b. 1
        c. 10
        d. 50

21. Rapid sand filters commonly operate at rates between approximately 2 and _____ gpm per square foot.

        a. 5
        b. 8
        c. 15
        d. 18

22. Silica sand is the most commonly used filter medium and its depth should be at least 24 inches and not more than _____ inches.

        a. 30
        b. 36
        c. 42
        d. 48

23. In a rapid sand filter, the influent water design velocity should range from about 1 to _____ feet/second.

      a. 2
      b. 4
      c. 6
      d. 8

24. In a rapid sand filter, the effluent water design velocity should range from about 3 to _____ feet/second.

      a. 4
      b. 5
      c. 6
      d. 7

25. The application of _____ to water is the preferred method of disinfecting water supplies.

      a. fluorine
      b. chlorine
      c. bromine
      d. manganese