

## Design of Water Treatment Plants, Course #405

**Presented by:**

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The course covers fundamentals of the various processes involved such as coagulation, flocculation, sedimentation, filtration and disinfection. It also describes the methodology for the removal of undesirable items such as hardness, iron and manganese, and taste and odor. In addition, it describes the handling and feeding of chemicals and management of wastes produced in the treatment plant.

To receive credit for this course, each student must pass an online quiz consisting of twenty-five (25) questions. A passing score is 70% or better. Completion of this course and successfully passing the quiz will qualify the student for **four (4)** hours of continuing education credit.

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## **I. INTRODUCTION**

Evidence of man's desire to improve the quality of water is found in the earliest recordings of knowledge. In 1804, the first known filter to serve an entire city was completed at Paisley, Scotland. In 1832, the first water purification plant for an American city was built for Richmond Virginia. The half century beginning in 1913 has been described as one distinguished for its consolidation and expansion of existing water treatment knowledge. During that span, the number of water treatment plants on public water supplies in the United States increased from several hundred to more than 10,000.

In the design of water treatment plants, the provision of safe water is the prime goal. Water treatment plants have demonstrated the ability to produce safe water under adverse conditions. They must also produce water which is appealing to the consumer. Ideally, appealing water is one that is clear and colorless, pleasant to the taste, and cool. It is non-staining, and is neither corrosive nor scale forming. The consumer is principally interested in the quality of water delivered to the tap in his home or place of business, as opposed to the quality at the treatment plant. Therefore, water utility operations should be such that quality is not impaired as water flows from the treatment plant through the distribution system to the consumer. Another objective of water treatment is to build facilities that are reasonable with respect to capital and operating costs. To accomplish this, various alternatives must be investigated, including performance and cost studies, and an optimum design is evolved based upon sound engineering principles and in full consideration of the abilities of operating and maintenance personnel.

Typical water sources for municipal supplies are deep wells, shallow wells, rivers, natural lakes, and impounding reservoirs. Water treatment processes selected must consider the raw water quality. Deep well source satisfies the municipal water quality factors such as safety, temperature, appearance, taste and odor, and chemical balance. It has relatively uniform quality of water and hence the treatment processes employed are the simplest. Excessive concentrations of iron, manganese, hardness, hydrogen sulfide, chlorides, sulfates, and carbonates exist in well waters. Quantity of the well water depends upon aquifer permeability, well spacing and depth, seasonal changes in river flow, and pumping rates. About 1/4<sup>th</sup> of the nation's population is served by well water source.

Larger cities are dependent on surface supplies. Water quality in rivers depends on the character of the water shed; pollution caused by municipalities, industries, and agricultural practices; river development such as dams; the season of the year; and climatic conditions. A river water treatment plant must be capable of handling day-to-day variations in quality and the anticipated quality changes likely to occur within its useful life. The quality of water in a lake or reservoir depends on the physical, chemical, and biological characteristics. Size, depth, climate, watershed, and degree of eutrophication, influence the nature of an impoundment.

Treatment process used depends on the raw water source and the quality of finished water desired. Many chemicals are employed in the treatment. The specific chemicals selected for treatment are based on their effectiveness to perform the desired reaction and cost. The most important consideration in designing water treatment plant is to provide flexibility.

Chemical residues from water treatment, (mainly sludge from the settling basins following chemical coagulation, or precipitation softening, and wash water from backwashing filters) are wastes and require to be processed. These wastes are relatively non- putrescible and high in mineral content.

Natural water polluted either by human activity or by nature, is likely to contain dissolved organic and inorganic substances; biological forms, such as bacteria and plankton; and suspended inorganic material. The principal water treatment unit processes employed to remove these substances are as follows:

- Rapid mix,
- Coagulation and flocculation,
- Sedimentation,
- Filtration,
- Disinfection,
- Softening,
- Ion exchange.
- Adsorption,
- Reverse osmosis,
- Aeration,
- Chemical feeding and handling, and
- Sludge handling.

A schematic flow diagram of a typical treatment process is shown in Figure I.1 and the various process units shown above are described below in Section II.

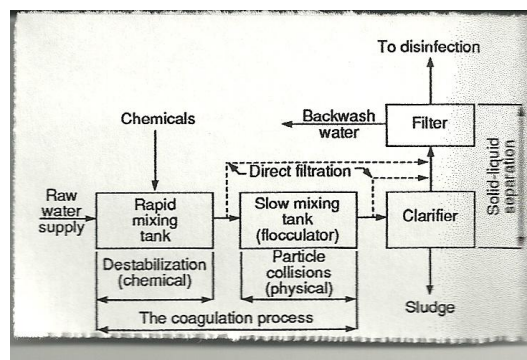


Figure I.1 Schematic Diagram of Coagulation Process

## II. RAPID MIX, COAGULATION AND FLOCCULATION

**II.1. Rapid mix** – Rapid mix, or flash mix or quick mix is the process by which a coagulant is rapidly and uniformly dispersed through the mass of the water. The process usually occurs in a small basin immediately preceding or at the head end of the ‘coagulation basin’. This process is used to generate a homogeneous mixture of raw water and coagulants which result in the destabilization of the colloidal particles in the raw water to enable coagulation. Mixing is provided by pumps, venturi flumes, air jets or rotating impellers (paddles, turbines, or propellers). Where possible, the rapid mix should be a two-compartment unit. Design parameters for rapid mix are as follows:

|                       |                            |
|-----------------------|----------------------------|
| Mixing intensity..... | 700 – 1000 s <sup>-1</sup> |
| Detention time.....   | 10 – 30 sec                |
| Power.....            | 0.25 – 1.0 hp/MGD          |
| Basin dimensions..... | 3 – 10 ft                  |

Three arrangements for rapid mixing are shown in Figure II.1 below.

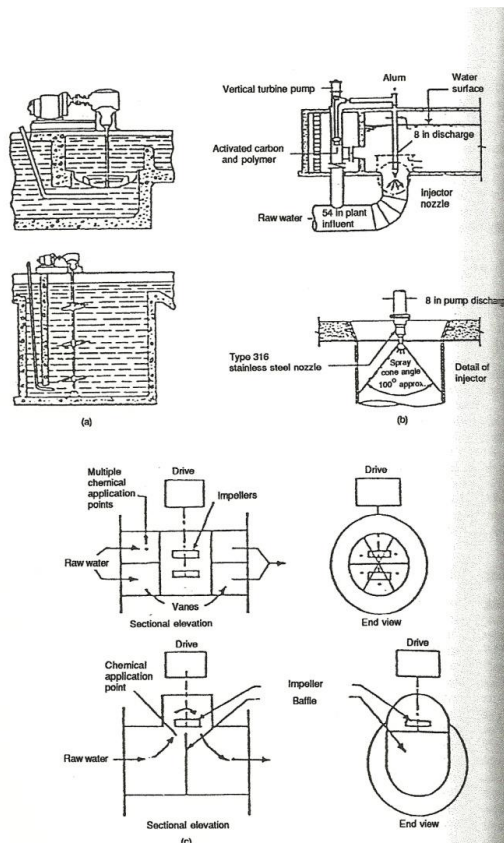


Figure II.1 Rapid Mixers: (a) Mechanical, (b) Injection, (c) In-line Blender

**II.2. Coagulation** – Coagulation is the widely used process to remove the substances producing turbidity in water. Coagulation is a chemical process in which particle charge is satisfied while flocculation is a physical process which agglomerates particles that are too small for gravity settling so that they may be successfully removed during the sedimentation process. Coarser components such as sand and silt can be removed from water by simple sedimentation. Finer particles such as colloidal matter and finely divided suspended matter cannot be removed from water by plain sedimentation in tanks having ordinary dimensions. So they must be flocculated to produce larger particles that are settleable. The process of coagulation may find use in the softening of hard water with lime or lime and soda ash and removal of color producing substances such as colloidal metallic hydroxides or organic compounds having a much smaller particle size. Coagulation treatment depends upon many factors such as pH, turbidity, chemical composition of the water, type of coagulant, temperature, and mixing conditions. Of these, pH is the most important factor. Coagulation should be carried out within the optimum pH range for the particular water. For certain waters it may be necessary to adjust the pH with acid, or lime, or soda ash, etc. The selection of type and dosage of the chemical coagulant must be made by experimentation, most commonly with jar tests. Commonly used coagulants include those which are iron or aluminum-based, lime, and polymers. Aluminum sulfate, commonly known as alum, is effective for pH values of 5.5 to 8.0. Sodium aluminate is used in special cases or as an aid for secondary coagulation of highly colored surface waters and in lime soda softening to improve settling. Ferrous sulfate in conjunction with lime is effective in the clarification of turbid waters and other reactions which have a high pH, such as lime softening. Ferric sulfate reacts with alkalinity and is effective over a wide pH range. It removes color at a low pH and iron and manganese at a high pH. Ferric chloride also reacts with alkalinity but has limited use in water treatment.

**II.2.1. Coagulant Aids** - Many coagulant aids are available to help with difficulties encountered with slow-settling flocs. Polymers act well by producing floc. Polyelectrolytes are synthetic polymers of varying charge which, when applied in dosage from 0.1 to 1.0 mg/L, can reduce primary coagulant doses and make sludge easier to handle. Activated silica increases the rate of chemical reactions occurring during coagulation, reduces coagulant dose, extends optimum pH range, induces faster settling, and produces tougher floc. Bentonite clay treats high-color, low turbidity, and low mineral waters. Wetting agents, to speed up floc settling include powdered silica, limestone, and activated carbon.

**II.3. Flocculation** – During flocculation, slow-moving paddle mixers gently stir a mixture of water and coagulant to generate floc. A series of flocculation chambers is usually employed rather than a single basin. The chambers are designed to enhance laminar flow conditions to prevent floc destruction. A stepped-down mixing intensity is utilized in each successive chamber. Flocculation time is also a governing factor in floc formation. Inlet and outlet design must be such as to prevent short-circuiting and destruction of floc. The flow-through velocity shall not be less than 0.5 and not greater than 1.5 ft/min with a detention time of at least 30 minutes. Mixing devices are driven by variable speed drives with the peripheral speed of paddles ranging from 0.5 to 2.0 ft/sec. Allowances must be made to minimize turbulence at bends and changes in direction. The common mechanical mixing devices are paddle flocculators, flat-bed turbines, and vertical-turbine mixers. These mixing devices are shown in

Figure II.2. Flocculation chamber is built as close to sedimentation tank as possible. A super structure over the flocculation basins may be required.

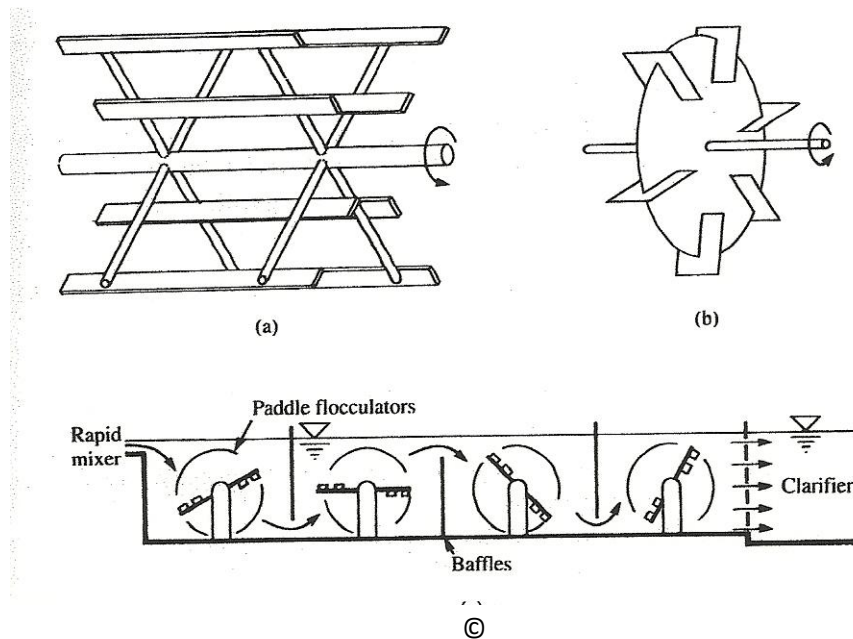


Figure II.2 Common Mixing Devices – (a) Paddle flocculator (b) Flat-blade turbine (c) Multiple tanks

### III. SEDIMENTATION

Sedimentation or clarification is the removal of particulate matter, chemical floc, and precipitates from suspension through gravity settling. The removal of particulate matter is accomplished in settling tanks (also called sedimentation tanks or sedimentation basins, or settling basins or clarifiers). Water clarification is a vitally important step in the treatment of surface waters. Poor design of the sedimentation basin will result in reduced treatment efficiency that may subsequently upset other operations. Sedimentation usually finds application in two principal ways in water treatment: plain sedimentation and sedimentation following coagulation and flocculation or softening. Plain sedimentation is used to remove settleable solids that occur naturally in surface waters. These solids settle without any previous treatment. Plain sedimentation is usually used as a preliminary process to reduce heavy sediment loads prior to subsequent treatment processes such as coagulation. This preliminary sedimentation is often also referred to as pre-sedimentation. Sedimentation following chemical coagulation and flocculation is used to remove settleable solids that have been rendered more settleable by chemical treatment, such as the addition of coagulants to remove color and turbidity and the addition of lime and soda ash to remove hardness. This type of sedimentation follows pre-sedimentation (if used) and aeration and precedes filtration.

**III.1. Zones in Settling Tanks** – Settling tanks have been traditionally divided into four zones for purposes of discussion, each zone having its characteristic function. See Figure III.1

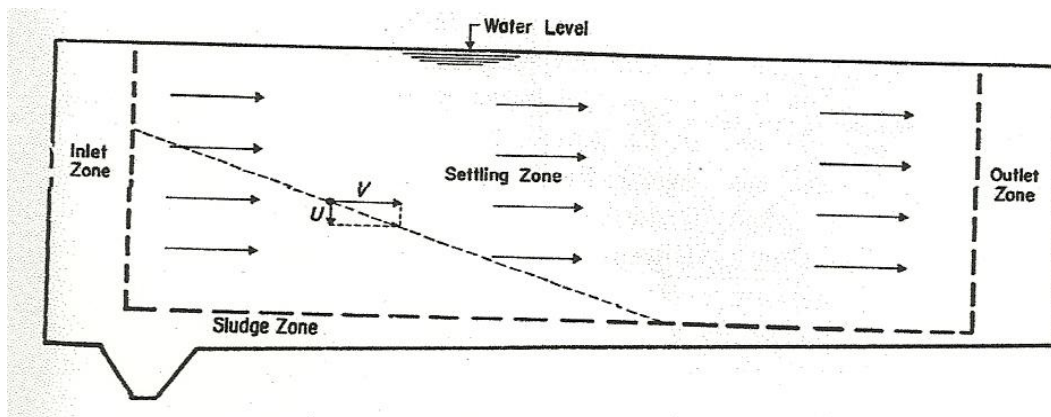


Figure III.1 Rectangular Settling Tank Profile

Inlet zone provides a smooth transition from the influent flow to the uniform and steady flow desired in the settling zone. Outlet zone provides a smooth transition from the settling zone to the effluent flow. Sludge zone receives the settled material and prevents it from interfering with the sedimentation of particles in the settling zone. Settling zone provides tank volume for settling, free from interference from the other three zones.

**III.2. Types of Sedimentation Tanks** – The effectiveness of a sedimentation tank depends on the settling characteristics of the suspended solids that are to be removed and on the hydraulic characteristics of the sedimentation tank. The hydraulic characteristics depend on both the geometry of the tank and the flow through the tank. Most sedimentation tanks are of the horizontal-flow type which may be either rectangular or circular in plan and are constructed of reinforced concrete. The depth varies from 8 to 16 ft. Unless sludge is removed continuously, allowance must be made in the basin volume for sludge accumulation between cleanings. The time between cleanings varies from a few weeks to a year.

**III.3. Sludge Collection** - Most sedimentation tanks are provided with sloping bottoms to facilitate the removal of deposited sludge. Sedimentation basins may be equipped with sludge collection and removal mechanisms to maintain volumetric efficiency and reduce the need to shut down for cleaning. Circular tanks may be provided with rotating mechanisms driven by motors mounted at the center of the tank. The rotating apparatus (equipped with rakes or blades that travel slowly around an axis just above the floor of the basin) is designed to push the sediment to the center to facilitate the movement of the sludge. See Figure III.2 below.

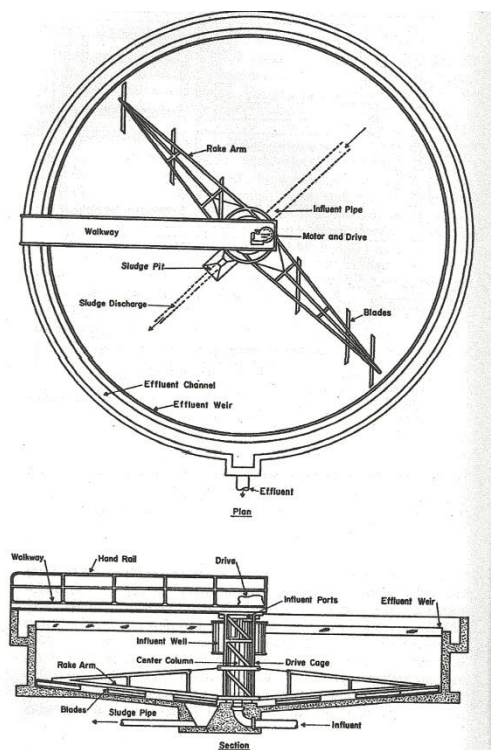


Figure III.2 Circular Center-feed Clarifier

Square tanks may be equipped with a similar mechanism, except that two of the arms are often provided with outriggers which sweep into the corners of the tank outside of the radius of the circular area and convey the solids in those corners into the region of the main arms.

For rectangular tanks, the bottoms are usually designed to slope from the effluent end of the tank to a sludge hopper located at the tank inlet. The main collector will include a drive unit which motivates a set of continuously moving scrapers or squeegees that serve to move the sludge to the hopper. The scrapers are connected in a long belt by means of two drive chains and are moved down the floor slope toward the sludge hopper and around drive sprockets back to the far end of the tank suspended in water. Two channels or tee rails are usually mounted in the floor of the tank to provide a wearing surface for the squeegees. See Figures III.3 below.

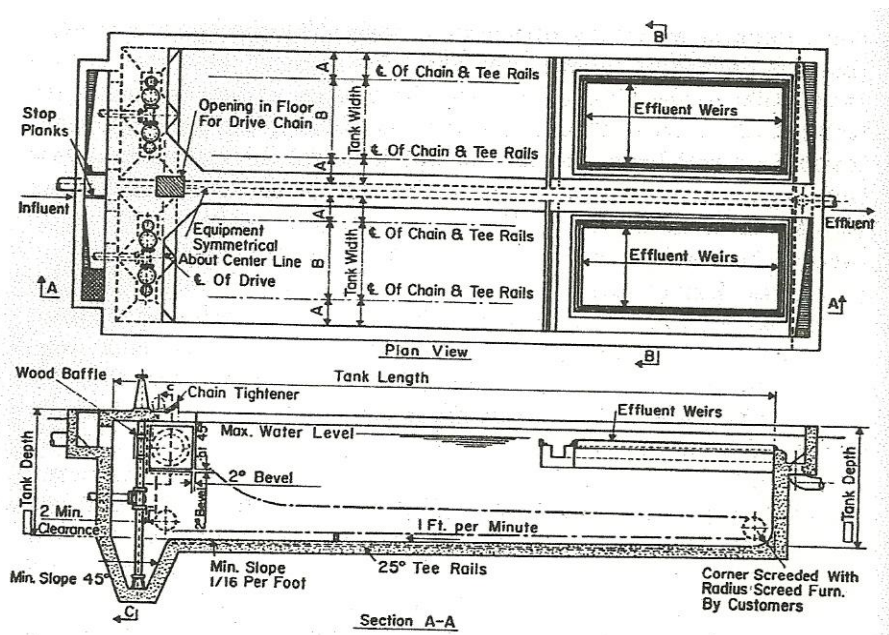


Figure III.3 Rectangular Settling Tank with Mechanical Sludge Collectors

Circular horizontal-flow tanks may be either center feed with radial flow (most common), or peripheral feed with radial flow, or peripheral feed with spiral flow. Figures III.2 and III.4 respectively show a typical center-feed clarifier and peripheral feed clarifier both with radial flow.

In a rectangular tank, the flow essentially is rectilinear, or the flow lines are parallel and all in one direction (see Figure III.1). A minimum of two basins must be provided.

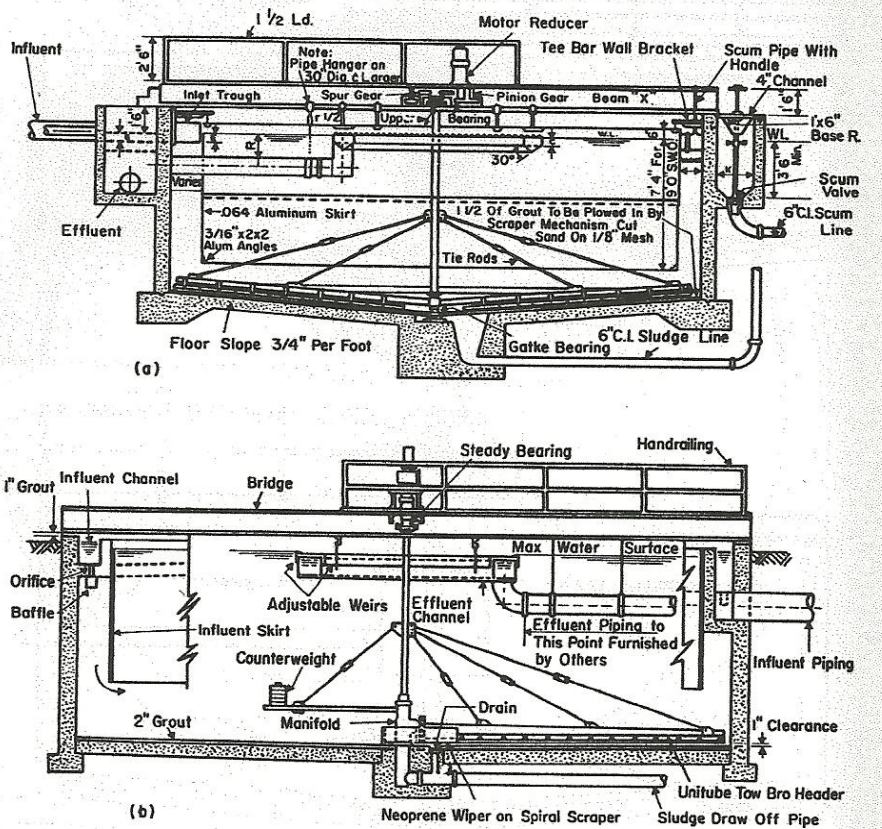


Figure III.4 Circular Peripheral Feed Clarifier

**III.4. Design Criteria** – The design criteria for the sedimentation tank, as recommended by the *Recommended Standard for Water works, Great Lakes Upper Mississippi River Board of State Public Health & Environmental Managers* (Ten State Standards), are given below:

- Detention time – Detention time shall provide a minimum of four hours of settling time. This may be reduced to two hours for lime-soda softening facilities treating only ground water.
- Inlet devices – Inlets shall be designed to distribute the water equally and at uniform velocities. Open ports, submerged ports, and similar entrance arrangements are required. A baffle should be constructed across the basin close to the inlet end and should project several feet below the water surface to dissipate water velocities and provide uniform flows across the basin.
- Outlet devices – Outlet devices shall be designed to maintain velocities suitable for settling in the basin and to minimize short-circuiting. Submerged orifices may be used to provide a volume above the orifices for storage when there are fluctuations in flow.

- Weir overflow –Rate of flow over the outlet weir (weir loading rate) shall not exceed 20,000 GPD /ft of weir length. Where submerged orifices are used as an alternate for over-flow weirs, they should not be lower than three feet below the flow line with flow rate equivalent to weir loadings.
- Velocity – The velocity through settling basins shall not exceed 0.5 ft/min. The basins must be designed to minimize short-circuiting. Baffles must be provided as necessary.
- Surface overflow – The surface overflow rate for plain sedimentation of surface waters is between 350 and 600gal/day/ft<sup>2</sup>. An overflow weir (or pipe) should be installed which will establish the maximum water level desired on top of the filters. It shall discharge with a free fall at a location where the discharge will be noted.
- Sludge collection – Mechanical sludge collection equipment must be provided.
- Drainage – Basins must be provided with a means for dewatering. Basin bottoms should slope toward the drain not less than one foot in twelve feet where mechanical sludge collection equipment is not required.
- Flushing lines or hydrants shall be provided and must be equipped with backflow prevention devices.
- Safety – Permanent ladders or hand -holds should be provided on the side walls of basins above water level. Guard rail should be included.
- Sludge disposal – Facilities are required for disposal of sludge. Provisions shall be made for the operator to observe or sample sludge being withdrawn from the unit.

The following example illustrates calculations for detention time, horizontal velocity, overflow rate, and weir loading.

Example:

Two rectangular clarifiers each 90 ft long, 16 ft wide, and 12 ft deep are used to settle 0.5 million gallons of water in an 8-hour operational period. Calculate (1) detention time, (2) horizontal velocity, (3)

overflow rate, and (4) weir loading, assuming multiple effluent weirs with a total length equal to three tank widths.

Solution:

$$\text{Flow} = 0.50 \text{ mil gal/8 hr} = 1.5 \text{ mil gal/day} = (1.5 \times 1,000,000)/(7.48 \times 24) = 8,356 \text{ ft}^3/\text{hr} = 139 \text{ ft}^3/\text{min}$$

$$(1) \text{ Detention time} = (2 \times 90 \times 16 \times 12)/(8356) = 4.1 \text{ hr}$$

$$(2) \text{ Horizontal velocity} = (139)/(2 \times 16 \times 12) = 0.36 \text{ ft/min}$$

$$(3) \text{ Overflow rate} = (3 \times 500,000)/(2 \times 90 \times 16) = 521 \text{ gal/day/ft}^2$$

$$(4) \text{ Weir loading} = (3 \times 500,000)/(3 \times 2 \times 16) = 15,625 \text{ gal/day/ft}$$

## IV. FILTRATION

Water filtration is a physical and chemical process for separating suspended and colloidal impurities from water by passage through a porous medium, usually a bed of sand or other granular material. Water fills the pores of the medium, and the impurities are left behind in the openings or upon the medium itself. The filtration removal mechanisms include, in general order of importance, adsorption, flocculation, sedimentation, and straining. For effective filtration, pretreatment producing floc particles that are small enough to penetrate the bed is necessary.

**IV.1. Type of Filters** – The following type of filters are in use:

**IV.1.1 Slow Sand Filters** – This type of filters was the one used first in water treatment. One of the principal drawbacks is the large land areas required. These filters are usually covered to protect against freezing in winter and algae growth in summer. Very few slow sand filters have been built in the United States since 1915. The rate of filtration varies from 1 – 10 mgd per acre, with 3 - 6 mgd per acre the usual range. Slow sand filters operate with a water depth of 3 to 5 ft. Removal of contaminants occurs in the upper inches of the sand. The sand depth ranges up to 42 in., which is reduced to 24 in. by scraping for cleaning before new sand is added. Cleaning of the filter is accomplished by removing the *Schmutzdecke*, upper layer of dirty sand, and cleaning it before replacement. The *Schmutzdecke* formed on the sand surfaces has filtration properties of its own and desirable biological properties which may improve filter efficiency. The sand has an effective size of 0.25 to 0.35 mm, and a uniform coefficient of 2 to 3. Slow sand filters remove most suspended solids and reduce bacteria in excess of 98 percent. The under drainage system is constructed from split tile, with laterals laid in coarse stone and discharging into a tile or concrete main drain. The loss of head is about 0.2 ft initial and 4 ft final. The length of run between cleanings is 20 – 60 days. Many slow sand filters have no pretreatment and others are preceded by coagulation, settling, or roughing filters. Slow sand filters are cleaned by scraping a surface layer of sand and washing the removed sand, or washing the surface sand in place by a traveling washer. Figure IV.1 shows a typical slow sand filter.

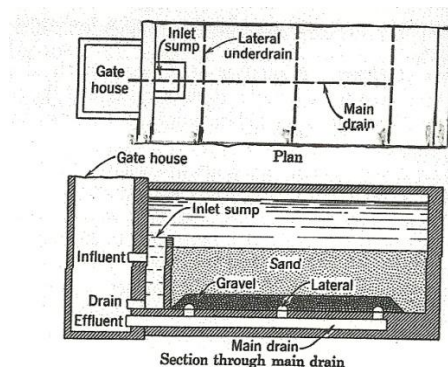


Figure IV.1 Slow Sand Filter

**IV.1.2. Gravity Rapid Sand Filters** – The vast majority of present-day water treatment plants use the gravity rapid sand filter. This filter is normally a single-media, down flow, fine-to-coarse filter. Natural silica sand is the common filtering medium, but crushed anthracite coal is also widely used. The size and depth of sand used must be decided initially in the design of gravity rapid filters as these parameters affect a number of important features of plant design. The size of the sand and the depth of the bed determine the velocity of applied wash water and the height of the gutter edge above the sand surface. Filters containing coarse sand must be deeper than those containing fine sand, and require a greater velocity of applied wash water to lift the sand and clean the bed properly. The best method of selecting the filter media for a particular plant is by pilot plant tests on the water to be treated. The sand should have an effective size between 0.35 and 0.50 mm and the uniform coefficient lies between 1.3 and 1.7. Typically, the sand depth is 18 to 30 in supported by gravel and under drains. These filters are effective for raw or coagulated waters with turbidities as high as 10 NTU and are approximately 90 percent efficient in the removal of applied bacteria. Disadvantages of rapid sand filters as compared to slow sand filters include surface blockage, breakthrough due to coarse media, and loss of biological treatment due to high-rate backwashes. Figure IV.2 shows a typical section of a rapid sand filter.

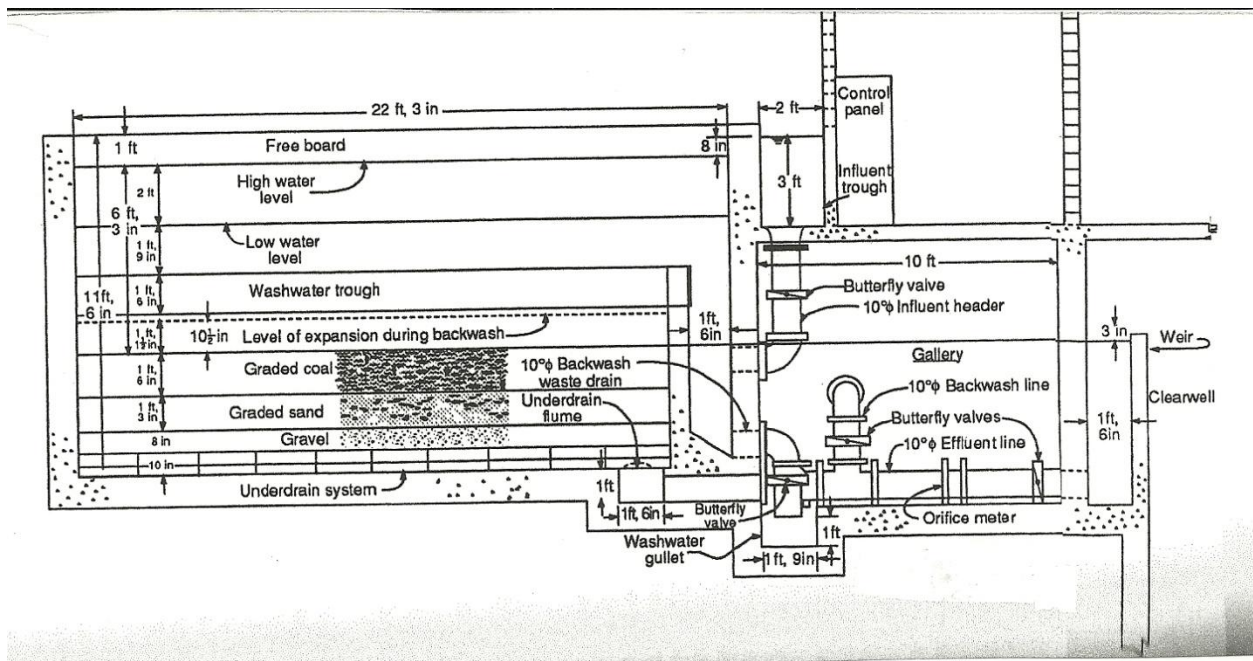


Figure IV.2 Section Through a Rapid Sand Filter

**IV.1.2.1. Dual or Mixed-media Filters** - In recent years, sand filters have been replaced, in many cases, by dual or mixed-media filters. These filters consist of different density media of varying sizes in an attempt to approximate reverse graduation. Two of the most commonly applied schemes in mixed media filtration are:

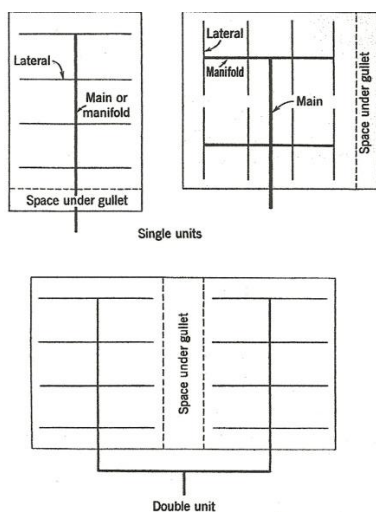
- (1) Dual media, composed of a coarse anthracite coal approximately 12 in deep;
- (2) Mixed-media configuration which utilizes coal, silica sand, and garnet sand.

Both of these filters attempt to create a more ideal filtration mechanism by providing media in which the largest particles are on the top and the smallest particles on the bottom.

**IV.1.2.2. Granular Media Filters** -These filters may be used with or without pretreatment (by coagulation and sedimentation) for removal of solids, by lime-softening for precipitating hardness, or by precipitation of iron and manganese in well water supplies.

**IV.1.2.3. Septum or Diatomaceous Earth Filters** – These filters are used mainly for small community potable water treatment systems. Common rates of filtration range from 1 to 5 gpm/ft<sup>2</sup>. Diatomaceous earth filtration is a low-capital-cost system.

**IV.1.2.4. Filter Underdrains** – The most important function of the filter underdrain is to provide uniform distribution of backwash water. It also serves to collect the filtered water. Ideally, the underdrain would also provide direct support for the fine filter media which is accomplished in the porous-plate bottom type. Most other type of underdrains requires the use of gravel to keep the fine media out of the underdrains and to assist in wash water distribution. Perforated pipe underdrains are commonly used. They consist of a manifold and laterals. Underdrains should be made of corrosion and scale-resistant materials or properly protected against corrosion. Typical arrangements of perforated pipe under drains are shown in Figure IV.3 below.



**Figure IV.3 Perforated Pipe Underdrains**

**IV.1.2.5. Wash Water Troughs** – To equalize the static head on the underdrainage system during backwashing of the filter, and thus to aid in uniform distribution of the wash water, a system of weirs and troughs is ordinarily used at the top of the filter to collect the backwash water after it emerges from the sand and to conduct it to the wash water gullet or drain. The bottom of the trough should be above the top of the expanded sand to prevent possible loss of sand during backwashing. The clear horizontal distance between troughs is usually 5 to 7 ft. The trough usually has a semicircle bottom. Troughs may be made of concrete, fiberglass-reinforced plastic, or other structurally adequate and corrosion-resistant materials. The dimensions of a filter trough may be determined by use of the following equation:

$$Q = 2.49 bh^{3/2} \dots\dots\dots (iv.1)$$

Where     Q = rate of discharge, ft<sup>3</sup>/sec  
               b = width of trough, ft.  
               h = maximum water depth in trough, ft.

Some free board should be allowed in the wash water troughs.

The use of the above formula is illustrated in the following example:

Example:

Rectangular troughs 24 ft long, 18 in wide and 7 ft on centers are to serve a filter that is washed at a rate of 30 in. per minute. Determine: (a) the depth of the troughs if their invert is to be kept level and they are to discharge freely into the gutter, and (b) the height of the top of the trough above the sand if a 30-in. bed is to be expanded by 50 percent.

Solution:

$$\begin{aligned} \text{Rate of discharge } Q &= 24 \times 7 \times [30 / (12 \times 60)] \\ &= 7 \text{ ft}^3/\text{sec} \\ b &= 18 / 12 = 1.5 \text{ ft} \end{aligned}$$

Applying the above data in Equation (IV.1),

$$\begin{aligned} 7 &= 2.49 \times 1.5 \times h^{3/2} \\ h^{3/2} &= 7 / (2.49 \times 1.5) \\ h &= [7 / (2.49 \times 1.5)]^{2/3} \\ &= 1.52 \text{ ft} \dots\dots\dots (a) \end{aligned}$$

$$\text{Expansion of sand} = 0.5 \times 30 = 0.5 \times (30 / 12) = 1.25 \text{ ft}$$

$$\begin{aligned} \text{Height of trough top above sand} &= 1.52 + 1.25 \\ &= 2.77 \text{ ft plus some free board} \dots\dots\dots (b) \end{aligned}$$

Typical arrangement of wash water troughs is shown in Figure IV.4 below.

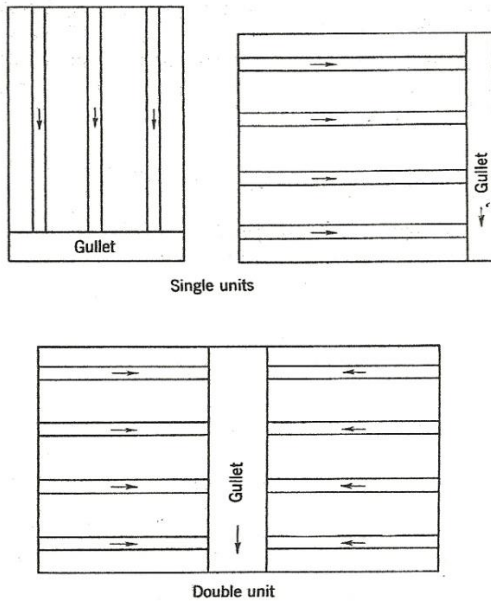


Figure IV.4 Wash-water Troughs

**IV.1.2.6. – Filter Appurtenances** – Filter appurtenances include the following:

1. Manually, hydraulically, or electrically operated gates on the influent, effluent, drain, and wash-water lines;
2. Measuring devices such as Venturi meters;
3. Rate controllers activated by the measuring device;
4. Loss of head and rate of flow gages;
5. Sand-expansion indicators;
6. Operating tables and water-sampling devices; and
7. Wash water pumps and tanks.

The larger the plant and higher the rate of filtration, the greater is the justification for the inclusion of mechanical and automatic aids to operation. Figure IV.5 shows rapid filter with accessory equipment.

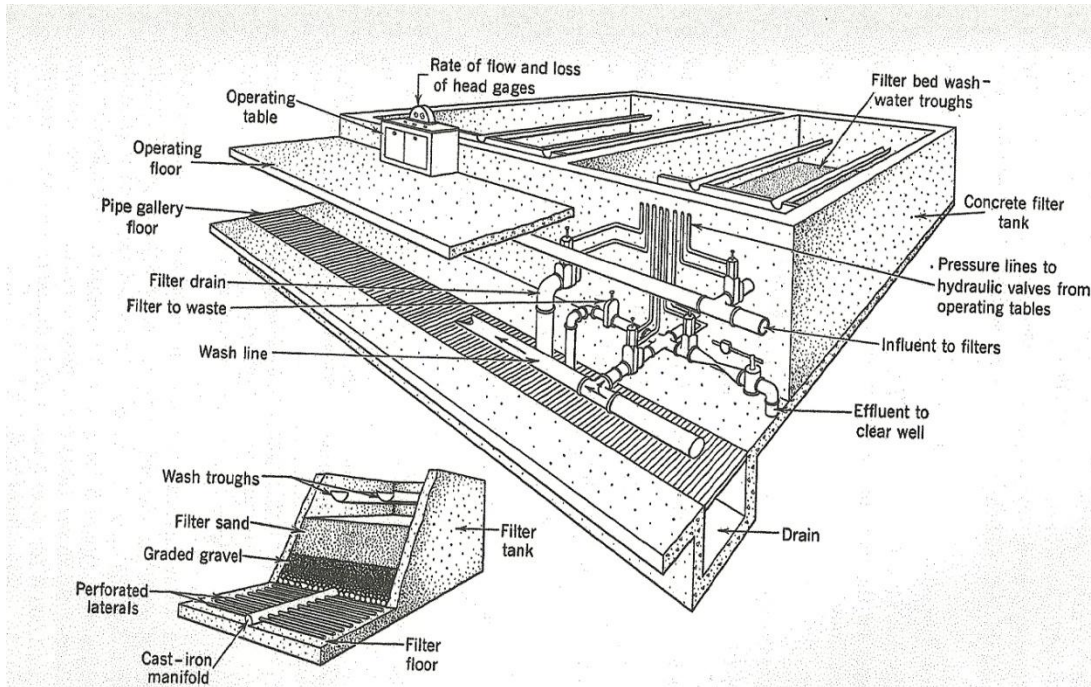


Figure IV.5 Rapid Filter and Accessory Equipment

**IV.1.2.7. Design Criteria** - The design criteria for rapid sand gravity filters as recommended by the *Recommended Standard for Water works, Great Lakes Upper Mississippi River Board of State Public Health & Environmental Managers* (Ten State Standards) are given below:

1. At least two units shall be provided. Where only two units are provided, each shall be capable of meeting the plant design capacity of the projected maximum daily demand at the approved filtration rate. Where more than two filter units are provided, the filters shall be capable of meeting the plant design capacity at the approved filtration rate with one filter removed from service.
2. The filter structure shall be designed to provide for vertical walls within the filter.
3. Filter walls shall not protrude into the filter media.
4. A cover shall be provided by superstructure.
5. Minimum depth of filter box shall be 8.5 feet.
6. Minimum water depth over the surface of the filter media shall be 3 ft.
7. Floor drainage to the filter shall be prevented with a minimum of 4-inch curb around the filters.
8. Flooding shall be prevented by providing overflow.
9. The velocity of treated water in pipe and conduits shall be limited to 2 ft/sec.
10. Cleanouts and straight alignment shall be provided for influent pipes or conduits where solids loading is heavy, or following lime-soda softening.
11. Wash water drain shall have adequate capacity to carry maximum flow.
12. Walkways around filters shall not be less than 24-inch wide.
13. Safety hand rails or walls around filter areas adjacent to normal walkways shall be provided.

14. The bottom of wash water troughs shall be above the expanded media during washing.
15. A free board of 2 in shall be provided at the maximum rate of wash.
16. The top edge of the trough shall be level.
17. The spacing of troughs shall be such as to each trough serves the same filter area.
18. Maximum horizontal travel of suspended particles to reach the trough shall be restricted to 3 ft.
19. Provision shall be made for influent and effluent sampling taps, an indicating loss of head gauge, and an indicating rate-of-flow meter.
20. For backwash, a minimum rate of 15 gpm/ft<sup>2</sup> shall be provided.
21. Duplicate wash water pumps shall be installed.
22. Each filter shall be backwashed for not less than 15 min at the design rate of wash.
23. Provision shall be made for a wash water regulator and a rate of flow indicator.
24. Roof drains shall not discharge into the filters or basins and conduits preceding the filters.

**IV.1.3. Pressure Filters** – Pressure filters are based on the same principles as rapid sand gravity filters, except that the filter is contained in a pressure vessel, usually a cylindrical steel tank. Granular filter media is used. Water is pumped under pressure through the filter, and the media are washed by reversing flow through the bed, flushing out the impurities. Filtration rates are comparable to those in gravity rapid sand filters; however, the maximum head loss can be significantly greater since it is a function of the input pump pressure rather than static water level. Air binding rarely occurs in these filters. Careless operation is a problem because of the fact that the bed cannot be seen, and excess pressure can be applied to force water through the filter. Pressure filters are commonly installed in small municipal softening and iron-removal plants, and in industrial water treatment processes. Figure IV.6 illustrates a typical pressure filter.

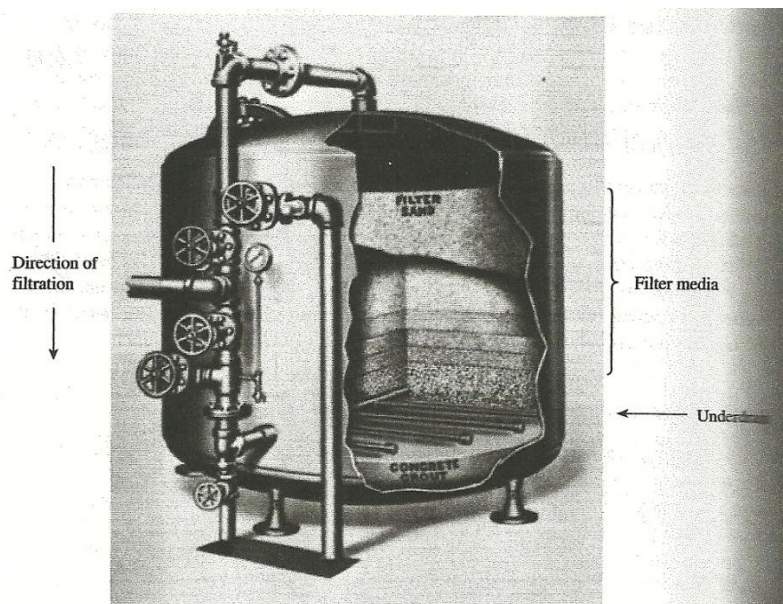


Figure IV.6 Pressure Filter

## V. DISINFECTION

Disinfection of water involves specialized treatment for the destruction of harmful (pathogenic) and otherwise objectionable organisms. Disinfection has been practiced for destruction of pathogenic organisms, more particularly, bacteria of intestinal origin. The survival time of pathogenic organisms depends upon temperature, pH, oxygen and nutrient supply, dilution, competition with other organisms, resistance to toxic influences, ability to form spores, and others. Water disinfection does not necessarily imply sterilization (complete destruction) of all living organisms. Elemental chlorine is commonly employed in municipal treatment applications. Water disinfection is also practiced by means of storage or by the application of heat, irradiation by ultraviolet rays, applying metal ions such as copper and silver, and oxidants such as halogens, and ozone etc.

Chlorine is shipped in liquid form, in pressurized steel cylinders ranging in size from 100 lb to 1 ton. One volume of chlorine liquid yields 450 volumes of chlorine vapor. The moist gas is corrosive and so all piping and dosing equipment must be nonmetal or resistant to corrosion.

Chlorine gas is drawn from the pressurized cylinder through a solution feeder which controls the rate of application. The injector, in a solution feed chlorinator, dissolves the gas into the feed water. The concentrated solution is then applied to the process water. See Figure V.1 for a chlorination flow diagram.

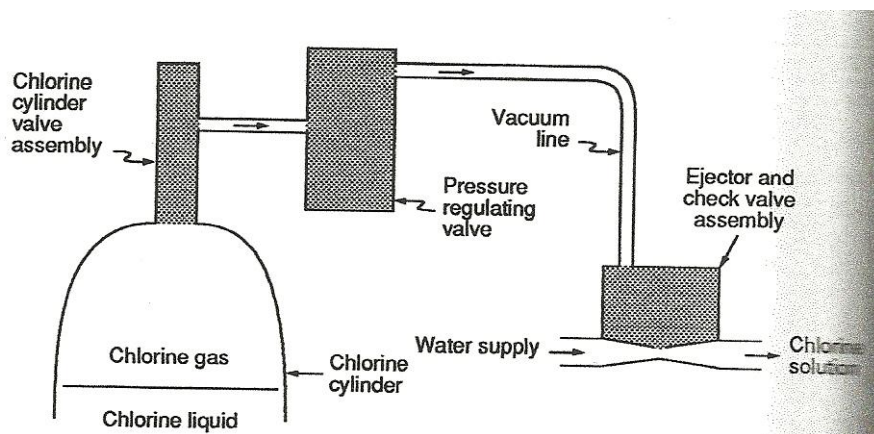


Figure V.1 Chlorination Flow Diagram

**V.1. Points of Chlorine Application** – Use of chlorine in various stages of treatment, and even in raw water collection and potable water distribution system, is common practice. Multiple or split-chlorination schemes frequently enhance the efficiency of many other unit water treatment processes, such as flocculation. In practice, the terms *plain-chlorination (simple chlorination)*, *pre-chlorination*, *post-chlorination*, and *re-chlorination* are commonly used to specify the location at which chlorine is applied.

Plain or simple chlorination represents the sole public health safeguard and more than half of all existing water treatment facilities in the United States fall into this category. It involves the application of chlorine to water that receives no other treatment. When applied to impounded or naturally elevated surface supplies, chlorine is usually injected by means of auxiliary pumping equipment into the pipe line leading from such a gravity supply. When applied to water pumped into a system, chlorine is usually added at the pump suction using pressure beyond the pump to operate the chlorine feeders. Pre-chlorination is useful in the following applications:

1. To improve coagulation and to suppress the decomposition of organic matter in sludge deposited in flocculation basins,
2. To control algae and other microorganisms,
3. To destroy taste-, odor- and color-producing materials by oxidation,
4. To retard decomposition in settling basins,
5. To improve filter operation by reduction and equalization of the bacterial and algae load,
6. To control slime and mud ball formation in filters, and
7. To provide a safety factor in disinfecting heavily contaminated waters.

When employed with a gravity feed raw water supply, the chlorine usually is applied to the intake of the gravity feed pipe line or to the water as it enters the mixing chamber or the settling basin. When employed with a pumped water supply, it usually is applied at the suction side of the pump or to the water as it enters the mixing chamber or settling basin.

Post chlorination follows filtration for disinfection and for provision of free or combined residual chlorine in a part or the entire distribution system. Chlorine should be applied either to the filter effluent or to the filter clear well influent.

Re-chlorination is common where the distribution system is long and complex and where the plant effluent residual is insufficient to control bacterial and algal re-growth and red water troubles.

**V.2. Chlorine- dioxide as a Disinfectant** – Chlorine dioxide may be produced from sodium chlorite and acid; from sodium chlorite and gaseous chlorine, or from sodium hypochlorite. After production, chlorine dioxide is fed through PVC pipe using a diaphragm pump. Safety features such as chlorine gas detectors, floor drains, and emergency gas masks should be available at the generation and application site. The major advantage of chlorine dioxide is in its use as a residual disinfectant. It does not produce measurable quantities of by-products such as trihalomethanes, because it does not react with many

chlorine-demanding substances. Other advantages of chlorine dioxide include algae destruction; improvement in taste, color, and odors; iron and manganese removal, and residual and general disinfection properties.

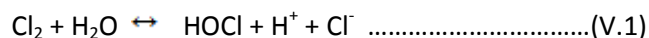
**V.3. Ozone as a Disinfectant** – Ozone is a strong oxidizing gas that reacts with most organic and many inorganic molecules. It is more reactive than chlorine. It does not react with water to produce disinfecting species but decomposes in water to produce oxygen and hydroxyl free radicals. Since it does not produce a disinfecting residual, chlorine is added to treated potable water before distribution for a protective residual. The half-life of ozone in water is approximately 10 to 30 min and shorter if pH is above 8 and hence it must be generated at site. Ozone is rarely applied solely for disinfection because of the high cost relative to chlorine. In most cases its application is for a combination of operations incorporating taste, odor, or color control; oxidation of humic organic substances that are precursors in the formation of trihalomethanes; destabilization of colloids; and inactivation of microorganisms. Ozone does not produce any health-related by-products and for this reason there is increased interest in application of ozone in potable water treatment. The ozonation system consists of four parts as follows:

1. A gas preparation system.
2. An electric power supply.
3. Ozone-generating equipment.
4. Contacting equipment.

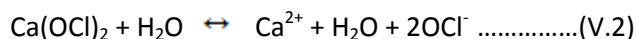
Two systems are available for ozone production – the Otto system and Welsback system. Ozone must be produced at the water treatment plant. Pipes leading from the ozonator are usually stainless steel. Ozone is introduced into the water by injection through a filter head at the base of a column contactor or by jetting into an impeller at the base of a contact column or by diffusion through various media such as ceramic and stainless steel diffusers. Typically, the column provides 5 to 10 min of contact time between the ozone and the water. Ozone has multiple possibilities in water treatment. It oxidizes cyanide, iron, manganese and, organic matter including bacteria and viruses.

**V.4. Chemistry of Chlorination** – Chlorine is used in the form of free chlorine or as hypochlorite. In either form it acts as a potent oxidizing agent and often dissipates itself in side reactions so rapidly that little disinfection is accomplished until amounts in excess of the chlorine demand have been added.

Reactions with water - Chlorine combines with water to form hypochlorous and hydrochloric acids as show in the following equation:



Hypochlorous is a weak acid and poorly dissociates at pH levels below 6. In dilute solution and at pH levels above 4, the equilibrium shown above is displaced greatly to the right and very little  $\text{Cl}_2$  exists as such in solution. Hypochlorites are used largely in the form of calcium hypochlorites. When such compounds are dissolved in water, they ionize to yield hypochlorite ion as shown below:



This ion establishes equilibrium with hydrogen ions in accordance with the following equation:



The amounts of  $\text{OCl}^-$  ion and  $\text{HOCl}$  in the solution depend upon the pH as shown in Figure V.2 below.

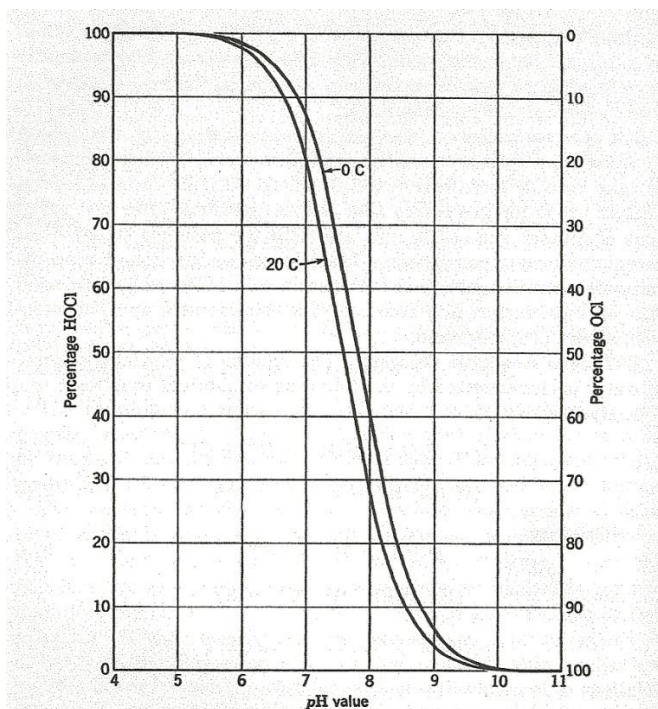
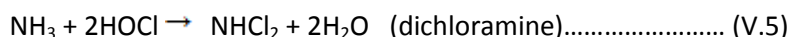
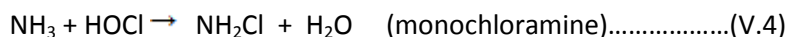
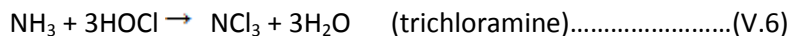


Figure V.2 Distribution of HOCl and OCl at different pH<sub>s</sub> & Temperatures

Natural waters always contain some chloride ions, and so the hypochlorous acid and chloride and hydrogen ions present in water exist in equilibrium with free chlorine as shown in Equation(1). Thus, it can be concluded that the same equilibria are established in water regardless whether chlorine or hypochlorites are added. The significant difference would be in pH effects and the influence of chlorine or hypochlorites on the relative amounts of  $\text{OCl}^-$  and  $\text{HOCl}$  at equilibrium. Chlorine tends to decrease the pH, whereas hypochlorites tend to increase the pH.

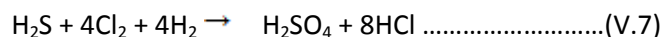
Reactions with Ammonia - Ammonium ions exist in equilibrium with ammonia and hydrogen ions. The ammonia reacts with chlorine or hypochlorous acid to form monochloramines, dichloramines, and trichloramines depending upon the relative amount of each and to some extent on the pH as follows:



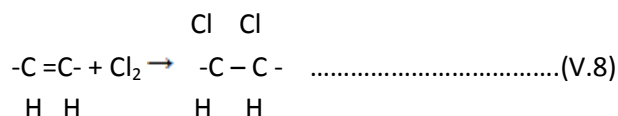


The mono- and dichloramines have significant disinfecting power and are, therefore, of interest in the measurement of chlorine residuals.

Chlorine combines with a wide variety of materials, particularly reducing agents. Many of the reactions are very rapid, while others are much smaller. These side reactions complicate the use of chlorine for disinfecting purposes. Their demand for chlorine must be satisfied before chlorine becomes available to accomplish disinfection. The reaction between hydrogen sulfide and chlorine, as shown below, illustrates the type of reaction that occurs with reducing agents.



$\text{Fe}^{2+}$ ,  $\text{Mn}^{2+}$ , and  $\text{NO}_2^-$  are examples of other inorganic reducing agents present in water supplies. A few organic reducing agents may be present, but their concentrations are very low in potable waters. Organic compounds that possess unsaturated linkages will also need chlorine and increase the chlorine demand.



Chlorine-Ammonia reactions – The reactions of chlorine with ammonia are of great significance in water disinfection. When chlorine is added to water containing natural or added ammonia, the ammonium reacts with HOCl to form various chloramines which, like HOCl, retains the oxidizing power of the chlorine. The reactions between chlorine and ammonia are shown below:



The distribution of reaction products is governed by the rates of formation of monochloramine and dichloramine, which are dependent on pH, temperature, time, and initial  $\text{Cl}_2 : \text{NH}_3$  ratio. In general high  $\text{Cl}_2 : \text{NH}_3$  ratios, low temperatures, and low pH levels favor dichloramine formation. It is evident some dichloramine can be anticipated at pH levels below 7. At pH levels below 7.5 some nitrogen trichloride can be expected. Depending on the free ammonia and organic nitrogen content of the raw water, the level of free residual chlorination applied, contact time, pH, and type of water plant, nitrogen trichloride can pose a considerable problem which may be disposed by various means.

Chlorine Residuals: Time of contact and concentration of the disinfecting agent are extremely important in disinfection. Where other factors remaining constant, the disinfecting action may be represented by

$$\text{Kill} = C \times t$$

Where C = concentration of the disinfecting agent

t = time of contact

Kill = Disinfection effect

With long contact times, a low concentration of disinfectant suffices, whereas short contact times require high concentration to accomplish equivalent kills.

It has become common practice to refer to chlorine, hypochlorous acid, and hypochlorite ion as free chlorine residuals and chloramines are called combined chlorine residuals. The reaction rate between ammonia and hypochlorous acid is most rapid at pH 8.3 and increases rapidly as the pH is decreased or increased. For this reason, it is common to find free chlorine and combined chlorine residuals coexisting after contact periods of 10, 15, or even 60 min.

With mole ratios of chlorine to ammonia up to 1:1, both monochloroamine and dichloroamine are formed, the relative amounts of each being a function of the pH. Further increases in the mole ratio of chlorine to ammonia result in formation of some trichloramine and oxidation of part of the ammonia to nitrogen gas. These reactions are essentially complete when 2 moles of chlorine have been added for each mole of ammonia nitrogen originally present in the water. Chloramines residuals usually reach a maximum when 1 mole of chlorine has been added for each mole of ammonia and then decline to a minimum value of chlorine to-ammonia ratio of 2:1. Further additions of chlorine produce free chlorine residuals. Chlorination of a water to the extent that all the ammonia is converted to trichloramine or oxidized to free nitrogen or other gases is referred to as *break point chlorination* because of the peculiar character of the chlorine residual curve, as illustrated in Figure V.3

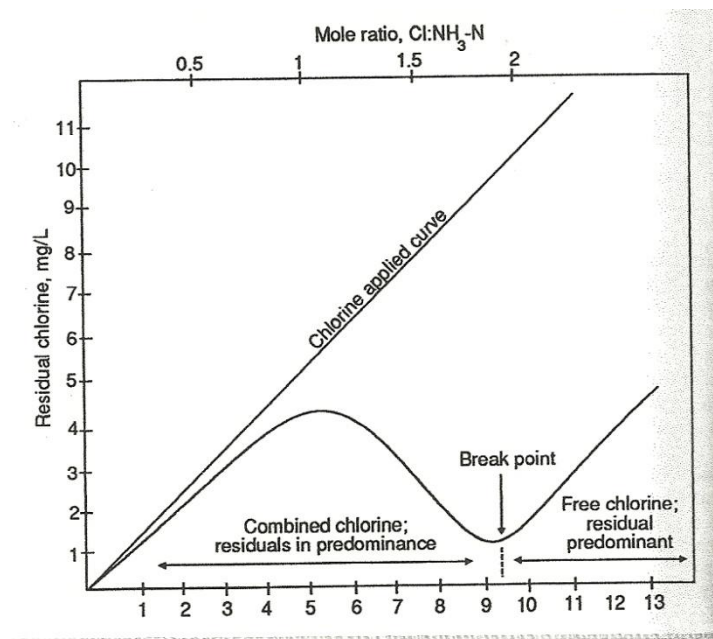
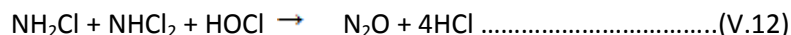


Figure V.3 Residual Chlorine Curve

Theoretically, it should require 3 moles of chlorine for the complete conversion of 1mole of ammonia to nitrogen trichloride (trichloramine). The fact that 2 moles of chlorine are required to reach the break point indicates that some unusual reactions occur. Nitrous oxide, nitrogen, and nitrogen trichloride have been identified among the gaseous products of the breakpoint reaction. The presence of nitrous oxide could be accounted for by the following reaction:



The total chlorine required for formation of monochloroamine, dichloramine, and the hypochlorous acid for the final oxidation step corresponds to 2 moles for each mole of ammonia. This would indicate that nitrous oxide is the major end product when ammonia is oxidized by chlorine in dilute solutions.

**V.5. Design Criteria** – The design criteria, as recommended by *the Recommended Standard for Water works, Great Lakes Upper Mississippi River Board of State Public Health & Environmental Managers* (Ten State Standards), are given below:

1. Solution-feed-gas-type chlorinators or hypochlorite feeders of the positive displacement type must be provided.
2. The chlorinator capacity must be such that a free chlorine residual of at least 2 mg/L can be attained in the water after contact time of at least 30 min when maximum flow rates coincide with anticipated maximum chlorine demands. The equipment must be of such design that it will operate accurately over the desired feeding range.
3. Standby equipment of sufficient capacity must be available to replace the largest unit during shut-down.
4. Automatic proportioning chlorinators must be provided where the rate of flow or chlorine demand is not reasonably constant.
5. Chlorine must be applied at a point which will provide the maximum contact time.
6. At plants treating surface water, provision must be made for applying chlorine to the raw water, settled water, filtered water, and water entering the distribution system. At plants treating ground water, provision should be made for applying chlorine to at least the detention basin inlet and water entering the distribution system.
7. A contact time of 30 min must be provided for ground waters and 2 hours for surface waters.
8. Minimum free residual chlorine at distant point in a water distribution system must be 0.2 to 0.5 mg/L. Combined chlorine residuals must be between 1.0 and 2.0 mg/L at distant points in the distribution system.
9. The chlorinator water supply piping must be designed to prevent contamination of the treated water supply by sources of questionable quality.
10. Adequate housing must be provided for the chlorination equipment and for storing the chlorine.
11. Chlorine residual test equipment must be provided and should be capable of measuring residuals to the nearest 0.1 mg/L. Automatic chlorine residual recorders must be provided where the chlorine demand varies appreciably over a short period of time.

## VI. SOFTENING

Softening is the removal of ions which cause hardness in water. Hardness is derived largely from contact with soil and rock formations and is caused by divalent metallic ions especially by calcium and magnesium ions, and at times by iron, manganese, strontium, and aluminum ions. Hard waters are as satisfactory for human consumption as soft waters but hardness causes excessive soap consumption for washing operations and scale formation in pumps, boilers, and pipes.

Waters are commonly classified, in terms of the degree of hardness, as follows:

|                |                 |
|----------------|-----------------|
| 0 – 75 mg/L    | Soft            |
| 75 – 150 mg/L  | Moderately hard |
| 150 – 300 mg/L | Hard            |
| Above 300 mg/L | Very hard       |

Hardness greater than 150 mg/L is unacceptable for aesthetic considerations. There are two methods to soften water: Lime-Soda process and ion-exchange process.

**VI.1. Lime-Soda Process** – Calcium and magnesium compounds cause hardness mostly. The anions with which these calcium and magnesium ions associated are principally the bicarbonate and sulfate ions, although chlorides and nitrates of calcium and magnesium do occur in some natural waters. The softening process consists of removing a part of these salts from the water to reduce the hardness to a predetermined value consistent with the reduction of detergent consumption, the control of scale formation, the prevention of corrosion, and other factors which make quality water. Calcium and magnesium bicarbonates are designated as carbonate hardness, and calcium and magnesium sulfates (or chlorides and nitrates) are called non-carbonate hardness. The above facts are shown diagrammatically in Figure VI.1 below.

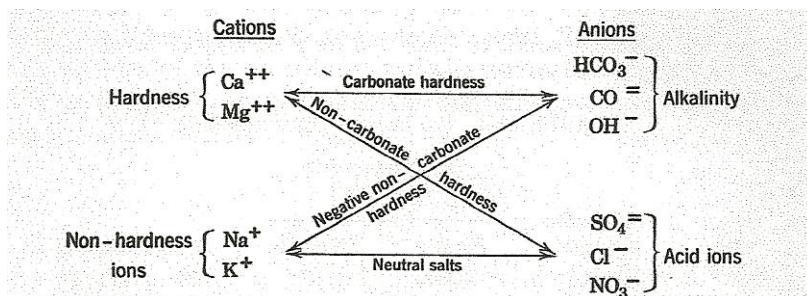
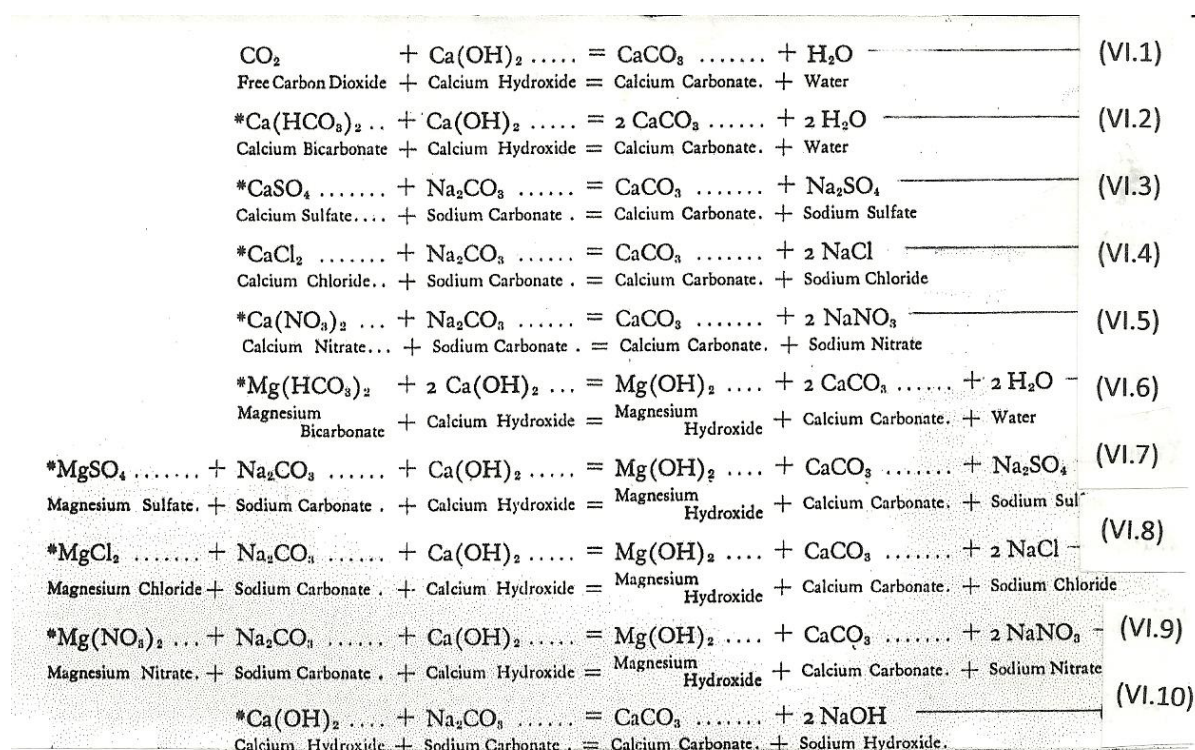


Figure VI.1 Relationship of  $\text{Ca}^{++}$  and  $\text{Mg}^{++}$  to Other Mineral Ions

The alkalinity determination on raw water ordinarily measures the carbonate hardness, but in some raw and softened waters the alkalinity may also include some sodium alkalinity if the total alkalinity exceeds the total hardness. Sodium alkalinity is called *negative non carbonate hardness*, since on reacting with lime, sodium carbonate is formed which is used for removing noncarbonate hardness.

The noncarbonate hardness is measured by the difference between the total hardness and the carbonate hardness, and requires soda ash for its reduction or removal. The sum of the alkalinity plus the non-carbonate hardness equals total hardness if the water contains no sodium alkalinity.

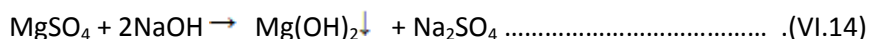
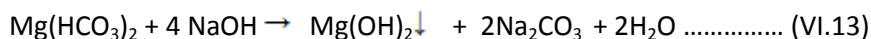
The chemistry of water softening is illustrated by showing the chemical reactions that take place when lime and soda ash are added to water containing calcium and magnesium salts. The reactions are as follows:



These equations show all of the reactions taking place in softening water containing carbonate and non-carbonate hardness by the lime-soda process. It should be noted that in Eq. (VI.1), the carbon dioxide is not hardness as such, but (in proportion to its content in water) will consume lime and so must be considered in calculating the amount of lime required. Equations (VI.2) and (VI.6) show the removal of carbonate hardness by lime. While only one molecule of lime is required for one molecule of calcium bicarbonate as per Eq. (VI.2), two molecules of lime are required for the removal of one molecule of magnesium bicarbonate as per Eq. (VI.6). Equations (VI.3) to (VI.5) show the removal of non carbonate calcium hardness by lime while Equations (VI.7) to (VI.9) show the removal of noncarbonate magnesium hardness by lime and soda ash.

From these equations, it is apparent that the amounts of lime and soda ash required to soften a water may be calculated from the concentrations of free carbon dioxide, carbonate hardness and non carbonate hardness of calcium and magnesium.

An alternative method in the lime-soda ash process that can be adopted for hardness removal is the use of caustic soda instead of soda ash. The reactions of caustic soda with carbonate and noncarbonate hardness are as follows:



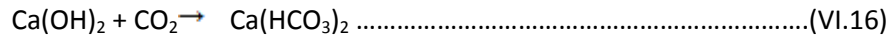
Liquid caustic soda (50 percent NaOH) is usually used. The advantages include ease of handling and feeding, lack of deterioration in storage and the fact that less calcium carbonate sludge is formed. The disadvantage includes increase in the total dissolved solids.

With waters containing more than about 40 mg/L magnesium hardness (as CaCO<sub>3</sub>) it is usually necessary to resort to excess-lime treatment to obtain the desired magnesium reduction. Also the excess lime remaining in solution after settling out the precipitated magnesium hydroxide and calcium carbonate must be neutralized. It has to be converted to calcium carbonate by re-carbonation or by the use of bypassed raw water (split treatment)

Re-carbonation is a process in lime-softening plant where it is used for pH adjustment and for the neutralization and precipitation of the calcium hydroxide in the primary basin effluent in cases where high-magnesium waters are softened by application of excess lime followed by re-carbonation. When a low-magnesium hard water is treated with the amount of lime necessary to react with free CO<sub>2</sub> and bicarbonates, as in the process of selective carbonate removal, the water remains supersaturated with calcium carbonate and may have a pH as high as 10.4 or more. This water would be highly encrusting, and the pH should be adjusted downward before filtration. CO<sub>2</sub> gas is bubbled through the water for this purpose. The CO<sub>2</sub> combines with all or part of the un-precipitated CaCO<sub>3</sub> to form some soluble bicarbonate, the amount depending on the final pH desired. The reaction is as follows:



If enough lime has been added to precipitate some magnesium hydroxide, the hydroxide alkalinity which remains must also be converted to bicarbonate according to the following equation:



If, however, the method of excess lime followed by re-carbonation is used, there is too much calcium hydroxide present after sedimentation, and converting it to the soluble bicarbonate would unduly increase the hardness. It is necessary to precipitate it as  $\text{CaCO}_3$  according to the following reaction:



Sometimes it is possible to add enough additional  $\text{CO}_2$  to convert a portion of the carbonate to the bicarbonate in the re-carbonation basin between the primary and secondary basins, and thus lower the pH to the desired value.

The sludge formed in the precipitation process is gravity- thickened, dewatered using mechanical means, and the cake disposed of in landfills. Dewatering can be accomplished by centrifugation, or pressure filtration, or vacuum filtration, or drying beds. The filtrate and the supernatant from the thickener may be returned to the plant influent or discharged into a nearby sanitary sewer.

**VI.2. Ion-Exchange Softening** – The following ion-exchange methods are in use for hardness removal:

1. Sodium cycle,
2. Split stream, and
3. Demineralization.

The major thrust in softening is the use of sodium cycle operation (cation exchange). Softening of water is obtained by operating on the sodium cycle. All metal ions can be removed by operating on the hydrogen cycle. Regeneration in the sodium cycle is by salt brine ( $\text{NaCl}$ ) and in the hydrogen cycle by sulfuric acid. Hardness removal by ion exchange consists essentially of passing hard water through a bed of ion exchanger. There, the hardness components of the water (calcium and magnesium ions), are removed from solution and replaced by sodium ions. For successful ion exchange, adequate contact of the water with the exchange material must be secured. To secure this contact, experienced correlation of all important influencing factors such as hardness of water, depth of material, rate of flow, and character of the exchanger is required. The following equations illustrate the reactions (sodium cycle) which take place in cation-exchange softening.





7. Type of operation (manual or automatic), and
8. The number of units to be installed.

(1) The volume required of the ion-exchanger is determined by the following formula:

$$E = KQH/G$$

Where E = volume of exchange material to be used, ft<sup>3</sup>

Q = volume of water to be treated between regeneration, ft<sup>3</sup>

H = hardness of water, grains per gallon (gpg) {1 gpg = 17.14 mg/L}

G = hardness to be removed between regenerations/unit of volume of exchange material,  
Grains/gallon

K = a factor dependent on the units (7.48 for US customary units)

- (2) Shell diameter and bed depth should be adjusted to maintain a unit rate in the range of 4 to 8 gpm/ft<sup>2</sup>.
- (3) When regenerating cation exchangers, an applied brine concentration of at least 10 percent NaCl by weight is recommended. The salt dosage may vary from about 5 to 15 lb/cubic foot of exchanger.
- (4) A regeneration procedure that provides a 30-min contact with at least a 10 percent salt solution by weight will produce the optimum exchange capacity for any selected salt dosage.
- (5) When water treatment plants are located near a salt brine source such as a sea, the brine in the sea water may be used for regeneration.
- (6) A bed depth of 24 in. or more is generally recommended when a high quality effluent is desired.
- (7) Waters high in dissolved solids tend to lower the exchange capacity of the exchanger.
- (8) It is desirable that the water going to the exchanger be free from suspended matter.
- (9) The loading of the ion exchanger is 2 gpm/ cu ft.
- (10) The rate of flow of the regenerant is 1 gpm/ per cu ft.
- (11) Rinse water requirements after regeneration ranges from 30 to 100 gal/cu ft.

**VI.3. Plant Design** – The cation exchange softening unit resembles an ordinary mechanical sand filter, with an exchanger substituted for the sand. The softener unit may be a pressure type device or an open gravity type similar to those used in large water purification plants. The pressure softener consists of a closed steel cylinder that may be vertical or horizontal. The diameters of the shells range from about 20 inches to 10 feet. Horizontal units range in diameter from 9 to 10 ft. with length up to 25 ft.

Figure VI.2 shows a cutaway view of a fully automatic vertical pressure type softener.

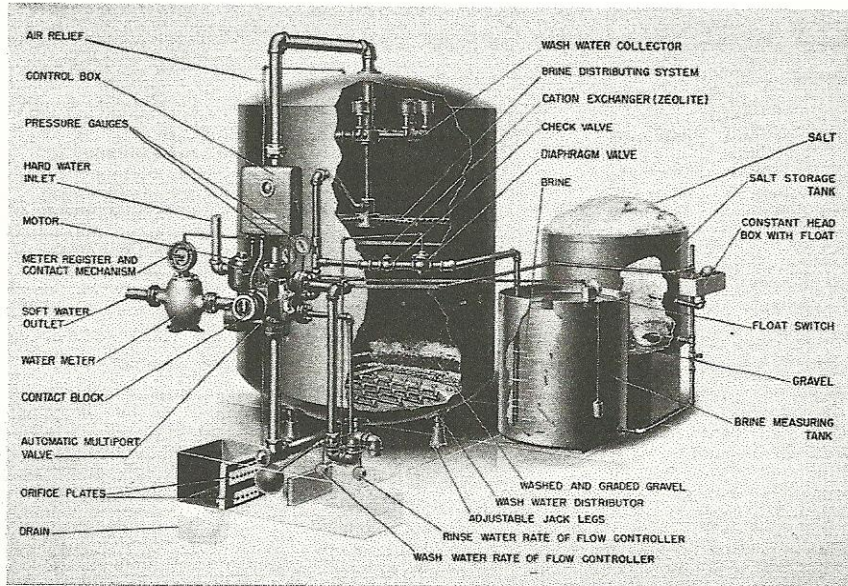


Figure VI.2 A cutaway View of an Automatic Vertical Pressure-t ype Softener.

Gravity or open type softeners are usually built of concrete and are rectangular in shape usually. With the pressure type, it is possible to pump the water to be softened directly from the source of supply through the softener into the distribution system. With gravity softeners, it is possible to observe their condition readily, to see whether or not there is any channeling of the water or brine through the bed, and to observe the condition of the exchanger and determine if any exchanger is being washed out. In general, pressure units are used for softening plants of small capacity, and gravity units for plants of large capacity. The factors affecting the hydraulic design of softening units are the same as those pertaining to the design of rapid sand filters. In general, each softening unit must be provided with the following:

1. Hard-water inlet,
2. Soft-water outlet,
3. Wash water inlet and outlet (for down flow type),
4. Salt solution inlet,
5. Salt solution and rinse water outlet,
6. Method of controlling rates of flow,
7. Sampling cocks,

8. Under drainage system, and
9. Graded gravel or other suitable support for the exchanger.

The various inlet and outlet devices may be designed to be controlled either manually or automatically. The under drainage system must be designed such that it will drain the unit completely. In a conventional under drainage system, the total area of the holes in the system should be 0.16 to 0.18 percent of the total area of the softener. This is about half that is required for a sand filter. The holes should be placed on centers not to exceed 12 in. each way. The rate of backwash should be such as to give a bed expansion of 50 percent. The amount of water required to rinse out the brine after regeneration of the exchanger will range from 25 to 35 gallons per cubic foot.

Sampling taps must be provided at the following locations:

1. Softener influent, raw water,
2. Softener effluent, softened water,
3. Blended-water line or reservoir,
4. Brine-dissolving tank effluent,
5. Brine-measuring tank effluent,
6. Dilute brine line, and
7. Softener unit waste brine line.

**VI.4. Blending** – Under normal operating conditions, the water produced by cation exchange softening has a nominal hardness of zero. For municipalities it is economically inadvisable to soften an entire supply to zero hardness. Zero hard water is not only expensive to produce but also may cause health related problems. They are devoid of all minerals needed for human body and also contain sodium in large amount which is not good for people requiring low sodium diet. For these reasons, the water that is supplied in the distribution system must not be softened below 80 to 85 parts of hardness. So a part of the softened water with zero hardness is mixed with the raw water without softening in such proportions as to produce a hardness of about 80 to 85 parts in the blended water.

## **VII. TASTE AND ODOR CONTROL**

Taste and odor problems are more intense and more frequent in surface water sources because these are more subject to contamination by both natural and man-made organic wastes. A threshold level varying from 3 to 5 is tolerable for most people. Odors and tastes are often caused by:

1. Dissolved gases such as hydrogen sulfide, and methane,
2. Organic matter derived directly from algae and other microorganisms living in the supply,
3. Other decomposing matter in general, such as weeds, grasses, or trees,
4. Industrial wastes, of which phenols and cresols are probably the most troublesome,
5. Chlorine, either the residual chlorine alone, or a combination of chlorine with phenol compounds in the water,
6. Detergents that find their way into surface water supplies, and
7. Agricultural chemicals such as insecticides.

Odors are classified as aromatic, musty, swampy, moldy, or septic. The varied nature of the odor-producing compounds precludes any single treatment for control. Normally, these compounds are in solution and hence removed only slightly by coagulation and flocculation. The operation of a public water supply needs to be concerned with prevention of the formation of tastes and odors in the raw water supply and removal of odors within the treatment plant itself as apart of the treatment program.

**VII.1. Preventive Measures** – Any activity that prevents or inhibits the growth and multiplication of algae in the water will preserve good water quality. Materials that are used for destroying algae growths are activated carbon, copper sulfate, potassium permanganate, and chlorine compounds. The cost of activated carbon precludes its use as a routine measure except in small holding basins. Copper sulfate is probably the most common chemical used in algae growth prevention. It is relatively inexpensive and very small amounts are required. Potassium permanganate is used to provide complete algae kills. This is more expensive than copper sulfate. Chlorine compounds may be used but their cost is relatively high. The only effective preventive measure within the plant to prevent algae growth is the use of copper sulfate or chlorine products on settling basin walls, weirs, and filter troughs. Pre chlorination also may be used as a preventive measure.

**VII.2. Plant Control Measures** – In the removal of existing odors in the water, there are three basic approaches: (1) mechanically by aeration, (2) chemically by means of chlorine, chlorine products, or permanganate, and (3) adsorptive approach by means of activated carbon, floc, clays, and similar materials.

Aeration provides a direct approach when the objectionable compounds are quite volatile. It is particularly effective on dissolved gases such as hydrogen sulfide and methane.

Chlorination at the reservoir will prevent the growth of slimes and microorganisms in the supply line, thereby, preventing possible stagnation and the introduction of septic type odors. Where chlorine is applied at the entrance to the treatment plant, and suitable chlorine residual is maintained throughout the sedimentation basins, it prevents the growth of algae on the basin weirs and the walls of basins and filters. Chlorine may be introduced into the water on top of the filters to oxidize any organic material remaining in the sand filters after backwashing. It will also prevent the growth of slimes within the filter sands themselves where backwashing is incomplete. Simple chlorination, either at the reservoir outlet or at the treatment plant inlet, is effective where taste and odor in the raw water is of a fishy or grassy type resulting from the decay of vegetation. It is more economical to use chlorine dioxide for taste and odor control applying it at the first stage of the treatment plant. Potassium permanganate has been used for destruction of taste and odor producing compounds.

Activated carbon is well known for removal of taste and odor compounds by adsorption. It accomplishes its mission by physical adsorption and not by chemical reaction. Activated carbon is useful in the removal of materials such as gasoline, kerosene, and other organics present in an already oxidized form.

As a rough guide, the following dosages are suggested for activated carbon application:

1. For routine, continuation .....2 - 8 ppm
2. For intermittent severe problems ..... 5 – 20 ppm
3. For emergency treatment .....20 – 100 ppm

## VIII. IRON AND MANGANESE REMOVAL

Iron and manganese, in objectionable concentrations, are present in many water supply sources. Alone or in combination with the other, they can cause serious impairment of water quality. They cause staining of clothes and plumbing fixtures, and impart color and turbidity. Both iron and manganese are natural constituents of soil and rocks. Iron is more abundant than manganese. They are found normally in ground water rather than in surface waters.

Iron exists in two levels of oxidation: (1) as a bivalent, ferrous ( $\text{Fe}^{++}$ ) iron and (2) as a trivalent, ferric ( $\text{Fe}^{+++}$ ) iron. In clear ground waters, the iron present is all ferrous iron. The ferrous compounds are unstable in the presence of air and oxygen and are usually converted to insoluble ferric salts through aeration, and then can be removed in the subsequent treatment processes. Manganese is also found naturally in two oxidation states: (1) as a bivalent, manganous ( $\text{Mn}^{++}$ ) and as a quadrivalent ( $\text{Mn}^{++++}$ ) manganic. The higher valence form is very insoluble.

**VIII.1. Removal methods** – The reduction of iron and manganese to acceptable levels by water treatment may be accomplished by: (1) conversion to insoluble ferric and manganic compounds and mechanical removal (sedimentation and filtration or filtration alone) of these precipitates, or (2) removal by substitution in the reduced soluble form (ion exchange). The actual mechanics of removal of these compounds involves the use of conventional water treatment procedures.

Passage of water through a bed of filter media is necessary in all cases of iron and manganese removal. These filters may be of gravity or pressure type. Filter rates may be 3 to 4 gpm/ft<sup>2</sup> of surface area. Wash water application rate may be about 10 to 12 gpm/ft<sup>2</sup>. The filter media for either gravity or pressure units may be either filter sand, anthracite coal, or a mixture of the two. Bed depths of 30 in. are commonly used. Diatomaceous earth filters are also sometimes used.

When iron alone is present, simple aeration followed by direct filtration may be effective. Iron oxidation rates are rapid at pH values above 7.5. Under certain conditions a 5-min reaction period may be sufficient. Pre chlorination ahead of chlorination, sedimentation, and filtration at pH values between 6.7 and 8.4 will usually insure removal of iron to acceptable limits.

Chlorine and chlorine compounds are usually effective manganese oxidizing agents.

Potassium permanganate that is fed continuously to water being supplied to manganese green sand, a manganese-containing media, anthracite coal, or sand filters, may be effective for waters that do not respond to conventional procedures.

Manganese and iron may be removed in softening plants using lime. Both ferrous iron and manganous manganese can be removed by ion exchange method. Either a sodium resin or hydrogen cation exchange material may be used. This method is limited for economic reasons, to waters with low hardness and low dissolved solids. Both pressure and gravity type ion exchange units may be employed with pressure units generally more readily adaptable.

## IX. CHEMICAL FEEDING AND HANDLING

Chemicals are in use in almost all process units in potable water treatment. The process units and the chemicals used therein are explained below:

### IX.1. Coagulation

1. Aluminum sulfate  $\{Al_2(SO_4)_3\} \cdot 14 H_2O$  commonly called alum, or filter alum, or sulfate of alumina - This is by far the most important coagulant agent. This is available in lump, ground or liquid form. Ground aluminum sulfate is grayish, crystalline solid completely soluble in water. Protective clothing, neck cloths, gloves, goggles, and respirators should be provided for the workers. Liquid aluminum sulfate is clear and amber in color. Liquid alum may be stored in tanks that are lead, plastic, or rubber-lined. It may be transmitted through lines of similar material. Stainless steel of Formula 316 may also be used. Protective clothing, gloves, goggles, and face shields should be provided where necessary.
2. Ferrous sulfate ( $FeSO_4 \cdot 7H_2O$ ) commonly called copperos - This, in combination with lime, is an effective coagulant for the clarification of turbid water. This is a greenish-white crystalline solid that is obtained as a byproduct of other chemical processes. Ferrous sulfate is available also in liquid form. Hazards of handling this chemical are similar to those for alum.
3. Ferric Sulfate  $\{Fe_2(SO_4)_3 \cdot 9H_2O\}$  commonly called "ferrifloc" - This is produced to some degree when ferrous sulfate is chlorinated. It is available as a reddish brown deliquescent solid. Ferric sulfate can be fed in dry-chemical feeders, constructed so as to be reasonably resistant to corrosion. This is soluble in water producing an acidic solution. Because of the acidic nature of the material, the user must be careful to provide more adequate protection than is necessary with alum or ferrous sulfate.
4. Ferric chloride ( $FeCl_3 \cdot 6H_2O$ ) commonly known as "ferrichlor" - This chemical is primarily used in the coagulation of sewage and industrial wastes. It is sometimes used in the coagulation of water. It is one of the end products of the reaction produced by the chlorination of ferrous sulfate. It is an orange-yellow, very deliquescent crystalline solid. It is highly soluble in water and, in the presence of moist air or light, decomposes to yield hydrochloric acid. It must be shipped, stored, and fed in equipment and devices that are corrosion-resistant. The hazards are those of highly acidic chemical compound.
5. Sodium aluminate ( $Na_2Al_2O_4$ ) commonly called soda alum - This chemical is sometimes used as an auxiliary coagulant for the removal of fine turbidity and/or other bodies in soft low-pH waters. The solid form is a white or brown powder containing 70 to 80 percent of  $Na_2Al_2O_4$ . The solution form is a concentrated solution containing approximately 32 % of  $Na_2Al_2O_4$ . The material is readily soluble in water producing a noncorrosive solution. It may be shipped, stored, and fed in the devices that are standard in the water works industry.
6. Aluminum ammonium sulfate  $\{Al_2(SO_4)_3 \cdot (NH_4)_2 \cdot SO_4 \cdot 24H_2O\}$  commonly called ammonia alum - This chemical is occasionally used in water coagulation. Since it is a comparatively expensive

material, its use is limited to small installations, such as swimming pools and boiler feed-water make up tanks. It is a non corrosive material and may be shipped in multiwall paper bags or drums.

7. Potassium aluminum sulfate  $\{K_2SO_4 \cdot Al_2(SO_4)_3 \cdot 24H_2O\}$  commonly known as potash alum - This material exists in the form of white crystals with an astringent taste. Its properties and use are similar to those described for ammonium alum. It is equally expensive, and its use in water treatment is restricted to swimming pools and boiler feed waters.
8. Bentonite – It is a form of clay that swells on absorbing moisture, is often used as a coagulant aid in waters of very low turbidity. It may be shipped in burlap bags or in bulk by hopper rail road cars or trucks. It should be stored in a dry place and may be fed with a conventional dry feed machine.
9. Calcium carbonate ( $CaCO_3$ ) also known as “precipitated chalk” - This is available in a number of forms, both prepared and occurring naturally. It is an inert material only slightly soluble in water and may be handled in standard material-handling equipment. There is slight dust hazard in handling this material.
10. Carbon dioxide ( $CO_2$ ) – The function of carbon dioxide as a coagulant aid is primarily that of adjusting the pH or solubilities so that proper coagulation is obtained.
11. Sodium silicate ( $Na_2SiO_3$ ) known as “activated silica” or “water glass” - The chief advantage of this material is its ability to toughen the floc. This material is shipped in ordinary tank cars, trucks, or drums, and may be stored in ordinary steel tanks.

## **IX.2. Disinfection**

1. Anhydrous ammonia (ammonia) –In the gaseous state, ammonia is colorless and about 0.6 times as heavy as air. The liquid, also colorless, is about 0.68 times as heavy as water. Common metals are not affected by dry ammonia; moist ammonia, however, reacts with copper, brass, silver, zinc, and many alloys. Iron and steel containers and fittings are preferred. Ammonia vapor is not poisonous, but has a very irritating action on the mucous membranes of the eye, nose, throat, and lungs. Contact with the liquid causes severe burns. Ammonia gas- feed equipment is similar to that used for chlorine. The solubility of ammonia in water, though relatively high, decreases as pH increases.
2. Ammonium hydroxide ( $NH_4OH$ ) commonly called aqua ammonium - This material is quite volatile at atmospheric temperatures and pressures. Aqueous solutions of ammonia exert a local irritating action; strong solutions cause tissue destruction on contact with eyes, skin, mucous membranes, gastrointestinal mucosa or pulmonary tissue.
3. Ammonium sulfate  $\{(NH_4)_2SO_4\}$  commonly called sulfate of ammonia - This chemical is used as a source of ammonia in the formation of chloramines. Because it is a byproduct material, it

should be carefully examined for the presence of heavy metals. It is a white, crystalline solid that is readily soluble in water and may be fed in conventional dry-feed machines. It may be shipped in paper bags or in bulk in hopper cars or trucks. Ammonium sulfate solution may be transmitted through piping reasonably resistant to corrosion.

4. Chlorine ( $\text{Cl}_2$ ) – In the gaseous state, chlorine is greenish yellow in color and about 2.48 times heavier than air., the liquid is amber in color and about 1.44 times as heavy as water. Unconfined liquid chlorine rapidly vaporizes to gas; one volume of liquid yields about 450 volumes of gas. Chlorine is slightly soluble in water and because of the low solubility, water is not a very satisfactory vehicle for disposing of chlorine or for use in handling chlorine emergencies. The corrosiveness of chlorine-water solutions creates additional problems in handling. Chlorine contained in a container may exist as gas, as liquid, or as a mixture of both. Under specific conditions, chlorine reacts with most elements, ammonia or nitrogen-containing compounds, and organic materials. Some of these reactions can be explosive. Most common metals are not affected at normal temperatures by dry chlorine as either gas or liquid; moist chlorine, however, is corrosive to these materials. Chlorine gas is a respiratory irritant. It causes varying degrees of irritation of the skin, mucous membranes, and the respiratory system depending on the concentration and duration of exposure. In extreme cases death can occur from suffocation. Liquid chlorine may cause skin and eye burns upon contact with these tissues. Chlorine is shipped in cylinders, tank cars, tank trucks, and barges as a liquefied gas under pressure. It is classified as a nonflammable compressed gas. Chlorine cylinders deliver gas when in an upright position, and liquid when in an inverted position.
5. Sodium chlorite ( $\text{NaClO}_2$ ) – This chemical, a dry flaked salt and orange in color, is shipped in steel drums. It is stable when sealed or in solution, but is very combustible in the presence of organic material. It dissolves easily in water at ordinary temperatures to form an orange-brown solution. No health hazard is involved in handling this material. It should be stored only in an enclosed space. Rubber gloves should be worn while handling the material. Protective clothing should be used, and rinsed with water in case of spillage.
6. Chlorinated lime ( $\text{CaO} \cdot 2\text{CaOCl}_2 \cdot 3\text{H}_2\text{O}$ ) commonly known as bleaching powder – This material is primarily used as a disinfectant. Sometimes it is used in treating swimming pool water supplies. It is a white powder prepared by chlorinating slaked lime. It decomposes in water, releasing the chlorine for disinfecting action. It should be shipped in corrosion-resistant containers.
7. Calcium hypochlorite  $\{\text{Ca}(\text{OCl})_2 \cdot 4\text{H}_2\text{O}\}$  commonly called “perchloron” - This material contains at least 70 percent available chlorine and from 3 to 5 percent lime. Calcium hypochlorite, an off white granular material, is a highly active oxidizer, relatively stable throughout production, packaging, distribution, and storage. The granular form is essentially non hygroscopic and resists moist caking tendencies when properly stored. It is readily soluble in water. Because of its strong oxidizing and reactivity with organic materials, calcium hypochlorite must be segregated or stored in a location separate from other chemicals.

8. Sodium hypochlorite ( $\text{NaOCl}$ ) commonly called liquid bleach – This is available in liquid form only and usually contains 12 to 15 percent available chlorine. Its use is generally limited to small potable water treatment installations and swimming pool water disinfection. It is corrosive to some degree and affects the eyes, skin, and other body tissues they come in contact. So rubber gloves, aprons, goggles, and similar suitable protective apparel should be provided for preparing and handling the solution.
9. Ozone ( $\text{O}_3$ ) – It is a faintly blue gas of pungent odor. It is an unstable form of oxygen with three atoms to the molecule that breaks down readily to normal oxygen and nascent oxygen. The nascent oxygen is a powerful oxidizing agent and has germicidal action. Ozone is usually produced by passing high-voltage electricity through dry atmospheric air between stationary electrodes. A small percent of air is converted to ozone in this process. It is usually injected into the water to be treated in a highly baffled mixing chamber.

### **IX.3 De- chlorination**

1. Activated carbon – This is a form of charcoal that has been treated to make it highly adsorbent of various materials. It is available in powdered and granular forms. It has high affinity for adsorbing chlorine. Granular carbon is used in pressure filters to de chlorinate water that has been heavily chlorinated. In the presence of moisture, it can be corrosive to iron and steel. Rubber-lined pipes, copper or plastic lines are used for transmission.
2. Ion exchange resins – These are sometimes used as de chlorinating agents, but usually on a very small scale.
3. Sodium sulfite ( $\text{Na}_2\text{SO}_3$ ) – This is available in white crystalline powder form and is readily soluble in water and may be applied to water with conventional dry-feed equipment.
4. Sulfur dioxide ( $\text{SO}_2$ ) – this is a colorless gas and is about 2.26 times as heavy as air. The liquid is also colorless and is about 1.44 times as heavy as water. It is slightly soluble in water and not corrosive to steel and other common metals, but if moisture is present in adequate amount, it can be corrosive to most metals. It is neither flammable nor explosive in either the gaseous or liquid state. It is an extremely irritating gas causing varying degrees of irritation of the mucous membranes of the eyes, nose, throat, and lungs.

### **IX .4 Tastes and Odor control**

1. Activated carbon – See discussion under paragraph VII.3, Item No.1
2. Bentonite –See discussion under Paragraph VII.1, Item No.8
3. Chlorine - See discussion under Paragraph VII.2, Item No.4

4. Chlorine dioxide ( $\text{ClO}_2$ ) – Under atmospheric conditions, this is a yellow to red, unpleasant-smelling, and irritating gas that is unstable.
5. Copper sulfate ( $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ ) – This material is available in blue crystalline granules or powder. This chemical and its solution are poisonous and corrosive. The solution is made up in batch form in a definite concentration and distributed as needed.
6. Potassium permanganate ( $\text{KMnO}_4$ ) commonly known as purple salt – This material is in the form of black or purple crystals having a blue metallic sheen and a sweetish astringent taste. It is odorless and highly soluble in water. Large quantities cause fire hazard. It can be fed with conventional dry-feed equipment.

## **IX.5 Softening**

1. Carbon dioxide ( $\text{CO}_2$ ) - Please see discussion under Paragraph VII.1, Item No.10
2. Calcium oxide ( $\text{CaO}$ ) commonly known as quick lime – This is a product resulting from the calcination of limestone. This is available in different particle sizes. It is usually shipped in covered rail road hopper cars or in bulk materials trucks. This is not a corrosive material and may be stored in concrete, steel silos, or bins. Exposure to outside air should be kept to a minimum. The hazards of handling are those of fairly active chemical dust. Severe eye injuries or skin burns may be obtained by contact. Protective clothing, gloves, goggles, and respirators must be worn by the handlers.
3. Calcium hydroxide  $\{\text{Ca}(\text{OH})_2\}$  commonly known as hydrated lime – This material is a very finely divided powder resulting from the hydration of quick lime with enough water. It should have a minimum available calcium oxide content of 90 percent. Hydrated lime has a tendency to absorb carbon dioxide from the atmosphere and so exposure to outside air must be kept to a minimum.
4. Sodium carbonate ( $\text{Na}_2\text{CO}_3$ ) commonly known as soda ash – This is a grayish, white powder containing at least 98 percent of sodium carbonate. It is non corrosive and can be stored in ordinary steel or concrete bins or silos. It may be fed in conventional chemical dry feeder. Its hazards are primarily those of a chemical dust. Protective clothing, gloves, goggles, and respirators must be worn by the handlers.
5. Sodium chloride ( $\text{NaCl}$ ) generally known as common salt – This is granular and available in white, grayish-white, pink, brown, or brownish-white colors. This is available in bags, or bulk containers. It has a tendency to absorb moisture under certain conditions. It is readily soluble in water and the solution may be transmitted through rubber, or bronze lines. Exposure to large

amounts of the dry salt would have a tendency to cause dehydration of the skin. Protective clothing, gloves, goggles, and respirators must be worn by the handlers.

6. Sodium hydroxide (NaOH) commonly known as caustic soda – This material is available in three forms: (1) flake, (2) lump, or (3) liquid. It is shipped in 100-lb and 700-lb drums or bulk in trucks and tank cars. In its solid state it has a tendency to become hygroscopic.

## **X. MANAGEMENT OF WATER TREATMENT PLANT RESIDUES**

A residue is a remnant, a substance which remains after another part has been taken away. In water treatment practice, where suspended and dissolved constituents are separated from water in order to effect purification, a variety of residues remain after the product water is disposed.

**X.1. Sources of Residues** – Occurrence of the following type of residues are common in water treatment plants:

- Residues from chemical coagulation – aluminum and ferric hydroxides are the chief constituents of sludge from water treatment plants practicing chemical coagulation. The residue may also contain particulate matter, both organic and inorganic. The sludge is stable since it does not undergo active decomposition or promote anaerobiasis. Most of the matter entrained in coagulation is inorganic in nature and consists of fine sand, silt, and clay.
- Residues from softening – the residue most frequently consists of calcium carbonate, magnesium hydroxide, and unreacted lime. These residues are generally stable, dense, inert, and relatively pure.
- Residues from backwashing of filters – due to filter washing operations, a large volume of wash water containing a low solids concentration is produced. About 30 to 40 percent of the total solids produced in a water treatment plant appear in the backwash water. When activated carbon is applied directly prior to filtration, the filter backwash water will also contain the bulk of the carbon applied. Hydrous oxides of aluminum, iron, manganese, and magnesium; carbonates of calcium and iron; plus silicate material form the largest fraction of the solids. Organic matter may be present in the form of algae, plankton, slime-forming bacteria, and spent activated carbon.
- Residues from Iron and manganese removal – hydrated ferric and manganic oxides are precipitated in the process of removing iron and manganese. Volume of solids produced is very small.
- Spent diatomaceous earth – the amount of solids accumulated is small. The solids produced are primarily pure silica and are easily dewatered.
- Spent brines from regeneration of Ion-exchange units – the volume of brine residue may range from 3 to 10 percent of the treated water. The residues consist primarily of the regenerant salt, sodium chloride, plus the calcium and magnesium ions displaced from the exchange resin. Approximately 50 percent of the solid residue is sodium chloride and the remainder is entirely calcium and magnesium chloride.

**X.2. Methods of Disposal** – The following methods are in practice:

1. Waste (sludge) from lime soda softening plants, combined with the sludge from sedimentation basins, is gravity- thickened, dewatered using mechanical means, and the cake disposed of in landfills.
2. Dewatering can be accomplished by centrifugation, or pressure filtration, or vacuum filtration, or drying beds. The filtrate and the supernatant from the thickener may be returned to the plant influent or discharged into a nearby sanitary sewer.
3. Dewatered sludge may be applied in pasture or farm land, or in road stabilization or used to fill natural or man-made depressions, such as strip mine areas, borrow pits, and quarries.
4. In large plants with high lime concentration, recovery of coagulants by recalcination may be practiced provided the sludge is of sufficient quality and the process is economically feasible.
5. Filter back wash water is stored in a holding tank and discharged at a controlled and uniform rate to the gravity thickener, mentioned in Item 1, above.
6. The waste from ion-exchange plants may be disposed of by controlled discharge to a stream if adequate stream flow is available. A holding tank of sufficient size is provided to allow the brine to be discharged over a 24-hour period.
7. Brine wastes may be disposed of in deep wells ranging in depth from 400 to 5,000 ft depending upon the fact that there will be no contamination of the water wells in the area.
8. Potable water can be recovered from brine wastes by means of reverse osmosis, or electro-dialysis or multi stage flash distillation if economically feasible. The resulting solids from these operations can be disposed of as mentioned in Item 3, above.