

CHAPTER 7 . WATER TREATMENT

7.1 METHODS OF TREATMENT AND FLOW SHEETS

The aim of water treatment is to produce and maintain water that is hygienically safe, aesthetically attractive and palatable, in an economical manner. Though the treatment of water would achieve the desired quality, the evaluation of its quality should not be confined to the end of the treatment facilities but should be extended to the point of consumer use.

The method of treatment to be employed depends on the nature of raw water constituents and the desired standards of water quality. The unit operations in water treatment include aeration, flocculation (rapid and slow mixing) and clarification, filtration, disinfection, softening, deferrization, defluoridation and water conditioning and many different combinations of these to suit these requirements. Sketches of flow sheets are presented in Fig. 7. 1. The choice of any particular sequence of treatment units will depend not only on the qualities of the raw water available and treated water desired but also on the comparative economics of alternative treatment steps applicable.

In the case of ground waters and surface waters with storage which are well protected, where the water has turbidity below 10 NTU and they are free from odour and colour, plain disinfection by chlorination is adopted before supply as shown in Fig. 7.1 (a) and (b).

Where ground water contains excessive iron, dissolved carbon dioxide and odorous gases, aeration followed by flocculation (rapid and slow mixing) and sedimentation, rapid gravity or pressure filtration and disinfection may be necessary as in Fig. 7.1 (c). In case it contains only carbon dioxide or odorous gases, aeration followed by disinfection may be sufficient. In surface waters with turbidities not exceeding 50 NTU and where sufficient area is available, plain sedimentation followed by slow sand filtration and disinfection are practised.

Conventional treatment including prechlorination, aeration, flocculation (rapid and slow mixing) and sedimentation, rapid gravity filtration and post chlorination are adopted for highly polluted surface waters laden with algae or other microorganisms.

Sometimes, unconventional flow sheets may be adopted for waters of low turbidity (below 10 to 15 NTU) and containing low concentration of suspended matter (less than 50 mg/l) as in Fig 7. 1. (f). Such raw waters are applied to the rapid sand filters with alum addition which may or may not be accompanied by slow mixing for a short period (10 minutes).

Slow sand filters can also be used to polish the filtrate from rapid sand filtration plant. Water with excessive hardness needs softening as in Fig. 7.1 (g). For removal of dissolved

solids, demineralisation by ion-exchange may form a part of the domestic or industrial water treatment units as in Fig. 7.1 (h).

7.2 AERATION

Aeration is necessary to promote the exchange of gases between the water and the atmosphere. In water treatment, aeration is practised for three purposes:

- a) To add oxygen to water for imparting freshness e.g:- water from underground sources devoid of or deficient in oxygen.
- b) Expulsion of carbon dioxide, hydrogen sulphide and other volatile substances causing taste and odour e.g. water from deeper layers of an impounding reservoir; and
- c) To precipitate impurities like iron and manganese in certain forms e.g. water from some underground sources.

7.2.1 LIMITATIONS OF AERATION

The unit operation of aeration requires significant head of water. The water is rendered more corrosive after aeration when the dissolved oxygen content is increased though in certain circumstances it may be otherwise due to removal of aggressive carbon dioxide. The designer should carefully consider the merits of other alternatives because of the additional cost of lifting which may be involved in aeration. For taste and odour removal, aeration is not highly effective but can be used in combination with chlorine or activated carbon to reduce their doses.

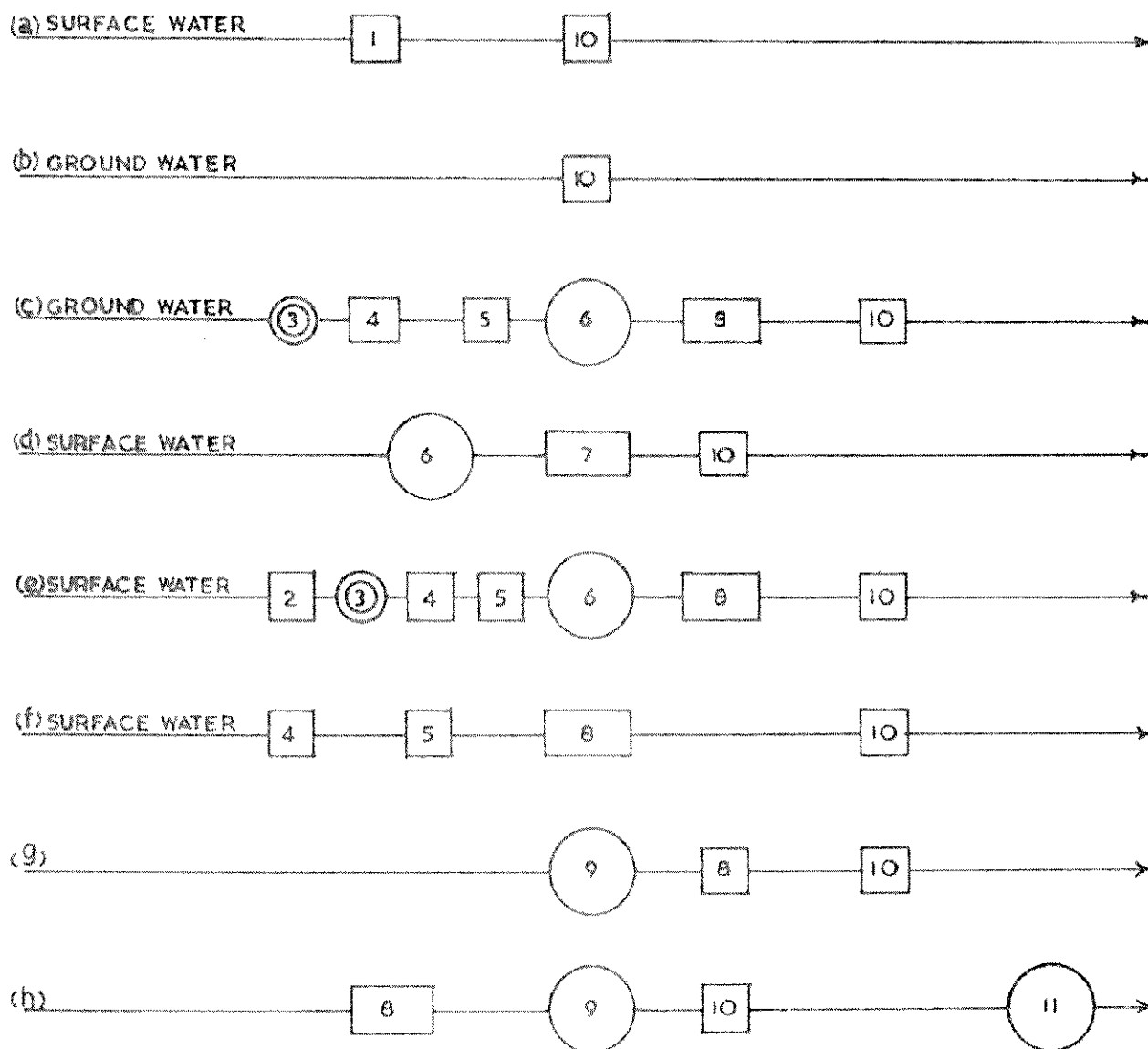
7.2.2 AERATION PROCESS

Gases are dissolved in or liberated from water until the concentration of the gas in the water has reached its saturation value. The concentration of gases in a liquid generally obeys Henry's law which states that the concentration of each gas in water is directly proportional to the partial pressure (product of the volume per cent of the gas and the total pressure of the atmosphere) or concentration of gas in the atmosphere in contact with water. The saturation concentration of a gas decreases with temperature and dissolved salts in water. Aeration tends to accelerate the gas exchange.

The rate of exchange of a gas is governed by the area of interface between the gas and the liquid, the thickness of the interlayers, time of contact, the partial pressure of the gas in the overlaying atmosphere and the degree of under-saturation or oversaturation of the gas in the liquid.

To ensure proper aeration, it is necessary:

- a) To increase the area of water in contact with the air i.e. if the water is sprayed, the smaller the droplets produced, the greater will be the area available. Similarly, if the water is being made to fall as a film over packing material in a tower, the smaller the size of the packing material, the greater will be the area available.



1. STORAGE

2. CHLORINATION (PRE)

3. AERATION

4. RAPID MIXING

5. FLOCCULATION — SLOW MIXING

6. SEDIMENTATION

7. SLOW SAND FILTRATION

8. RAPID SAND FILTRATION

9. SOFTENING

10. CHLORINATION (POST)

11. DEMINERALISATION

FIG. 7.1 : UNIT OPERATIONS IN WATER TREATMENT

- b) To keep the surface of the liquid constantly agitated so as to reduce the thickness of the liquid film which would govern the resistance offered to the rate of exchange of the gas; and
- c) To increase the time of contact of water droplets with air or to increase the time of flow which can be achieved by increasing the height of jet in spray aerator and increasing the height of bed in the case of packed media.

Where oxygen is to be dissolved in water the concentration or partial pressure of the oxygen may be increased by increasing the total pressure of the gases in contact with water. For this reason air injected into a main under pressure is a reasonably efficient method of increasing the amount of dissolved oxygen.

The exchange of gases from water to air or from air to water which takes place at the air water interface can be described by the following formulae:

$$C_t = C_s - (C_s - C_o) \exp\left(-\left(k \frac{A}{V} t\right)\right) \quad (7.1)$$

(Gas absorption)

and

$$C_t = C_s + (C_s - C_o) \exp\left(-\left(k \frac{A}{V} t\right)\right) \quad (7.2)$$

(Gas release)

Where,

- C_t = actual concentration of the gas in the water after a given period 't';
- A/V = ratio of exposed area to the volume of water;
- C_s = gas saturation concentration;
- k = gas transfer coefficient (having dimension of velocity);
- C_o = concentration of gas initially present in the water; and
- t = aeration period.

The gas saturation values of H_2S and CO_2 are generally 0 and 0.5 mg/l when exposed to normal atmosphere having partial pressures of the gases of 0 and 0.03 percent respectively. Because of the low saturation values, removal of H_2S and CO_2 by aeration is practicable.

If the initial concentration of the gas to be removed from water is much above the saturation limit, sizeable reduction in the concentration of the gas by aeration is possible.

7.2.3 TYPES OF AERATORS

There are two main types of aerators depending upon the mechanics of aeration:

- a) those forming drops or thin sheets of water exposed to the atmosphere i.e. water is exposed to come in contact with the ambient air; and
- b) those forming small bubbles of air which rise in the water i.e. air is brought in contact with the water.

Spray, water-fall or multiple tray, cascade and mechanical aerators can be considered under type (a), while diffusion aerators fall under type (b).

7.2.3.1 Spray Aerators

Water is sprayed through nozzles upward into the atmosphere and broken up into either a mist or droplets. Water is directed vertically or at a slight inclination to the vertical. The installation consists of trays and fixed nozzles on a pipe grid with necessary outlet arrangements.

Nozzles usually have diameters varying from 10 to 40 mm spaced in the pipe at intervals of 0.5 to 1 m or more. Special (patented) types of corrosion resistant nozzles and sometimes plain openings in pipes, serving as orifices, are used. The pressure required at the nozzle head is usually 7 m of water but practice varies from 2 to 9 m and the discharge ratings per nozzle vary from 18 to 36 m³/hr. Usually aerator area of 0.03 to 0.09 m²/m³/hr of design flow is provided.

The time of exposure of the droplets, the head required and the flow from each nozzle can be calculated from the following formulae:

$$v = C_v \sqrt{2gh} \quad (7.3)$$

$$q = C_d a \sqrt{2gh} \quad (7.4)$$

$$t = 2C_v \frac{\sqrt{2h}}{g} \sin x \quad (7.5)$$

where,

- h = Total head of water at the nozzle;
- g = Acceleration due to gravity;
- v = Initial velocity of drop emerging from the nozzle;
- C_v = Coefficient of velocity,
- C_d = Coefficient of discharge;
- q = Discharge rate from each nozzle;

a = Area of cross-section of nozzle opening; and
 t = Time of travel or exposure and α is the angle of inclination of the spray from the horizontal.

The vertical jet gives the longest exposure time for a given value of h (2 seconds for a head of 6 m), while the inclined jets can have less interference between falling drops. Wind can influence the path of the trajectory of each drop and allowance must be made for its effect. The dimensions of the tray must take into account the velocity and direction of the wind to ensure that no water is lost by carry-away. The size, number and spacing of nozzles, aeration time and interference between adjacent sprays, as already explained are also factors governing the aeration efficiency. Spray aerators are usually quite efficient with respect to gas transfer and can be expected to remove 70 to 90% of CO_2 and 90 to 99% H_2S and add to the appearance of a water treatment plant. They require large area and consequently difficult to be housed readily and pose operating problems due to corrosion and choking of the nozzles particularly during freezing weather.

The diameters of the pipe grid and orifices should be so designed as to ensure a uniform discharge (with a maximum variation of 5 percent) through all the nozzles in the grid. The loss of head in the pipe is kept low compared to the loss of head in the nozzle. Theoretically numerous small nozzles capable of producing atomised water could be used. Practically, however extremely small nozzles are to be avoided because of clogging and consequent excessive maintenance needed. Common friction formulae are used in the estimation of loss of head, excepting that the pipe with nozzles has to be considered to be carrying uniformly decreasing flow.

7.2.3.2 Waterfall Or Multiple Tray Aerators

Water is discharged through a riser pipe and distributed on to a series of trays or steps from which the water falls either through small openings to the bottom or over the edges of the trays. Water is caused to fall into a collection basin at the base. In most aerators, coarse media such as coke, stone or ceramic balls, ranging from 50 to 150 mm in diameter are placed in the trays to increase the efficiency. For iron removal (see 9.5.2) this may be beneficial. The trays about 4 to 9 in number (with a spacing of 300 mm to 750 mm) are arranged in a structure 1 m to 3 m high. With the media, good turbulence is created and large water surface is exposed to the atmosphere. By the addition of more trays, the time of contact can be increased. The space requirements vary from 0.013 to 0.042 m^2 per m^3/hr of flow. Natural ventilation or forced draft is provided. Removal efficiencies varying from 65 to 90 percent for CO_2 and 60 to 70 percent for H_2S have been reported.

7.2.3.3 Cascade Aerators

In cascade aerators water is allowed to flow downwards after spreading over inclined surface in thin sheets and the turbulence is secured by allowing the water to pass through a series of steps or baffles. The number of steps is usually 4 to 6. Exposure time can be increased by increasing the number of steps and the area to volume ratio improved by adding baffles to produce turbulence. Head requirements vary from 0.5 to 3.0 metres and the space requirements vary from 0.015 to 0.045 $\text{m}^2/\text{m}^3/\text{hr}$. In cold climates, these aerators must be

housed with adequate provision for ventilation. Corrosion and slime problems may be encountered. The gas transfer efficiency is less compared to the spray type. Removal of gas varies from 20 to 45 percent for CO_2 and upto 35 percent for H_2S .

7.2.3.4 Diffused Air Aerators

This is an obverse of waterfall type aerator. This type of aerator consists of a basin in which perforated pipes, porous tubes or plates are used for release of fine bubbles of compressed air which then rise through the water being aerated. As the rising bubbles of air have a lower average velocity than the falling drops, a diffused air type provides a longer aeration time than the water fall type for the same power consumed. These have higher initial costs and require greater recurring expenditure. Tanks are commonly 3 to 4.5 m deep and 3 to 9 m wide. Compressed air is injected through the system to produce fine bubbles which on rising through the water produce turbulence resulting in a continual change of exposed surface. Ratios of width to depth should not exceed 2:1 for effective mixing and the desired detention period varies from 10 to 30 minutes. The amount of air required ranges from 0.06 to 1 m^3 of air per m^3 of water treated. The air diffusers are located on one side of the tank. The power requirements of blower vary from 3 to 13 $\text{w/m}^3/\text{hr}$.

The air should be filtered before passing through porous diffusers. Oil trap is also provided before diffusers. Diffused aerators require less space than spray aerators but more than tray aerators. Cold weather operating problems are not encountered. The aerators can also be used for mixing of chemicals.

Compressor power requirements may be estimated from the air flow, discharge and inlet pressures and air temperatures, using the following equation, which is based upon the assumption of adiabatic conditions:

$$P = \frac{wRT_1}{(8.41)e} \left[\left(\frac{p_2}{p_1} \right)^{0.283} - 1 \right] \quad (7.6)$$

where,

- P = Power required in KW;
- p_1 = Absolute inlet pressure in atm. (normally 1 atm);
- p_2 = Absolute outlet pressure in atm.;
- R = Gas constant ($8.314 \text{ J/mole, } ^\circ\text{K}$);
- w = Air mass flow in Kg/s ;
- e = Efficiency of the machine, (usually 0.7 to 0.8); and
- T_1 = Inlet temperature in degrees $^\circ\text{K}$

7.2.3.5 Mechanical Aerators

These are not normally used in water treatment because of the availability of more economical alternatives but find application in waste water treatment.

7.3 CHEMICALS HANDLING HANDLING AND FEEDING

The chemicals are introduced into the water for the purposes of coagulation and flocculation, disinfection, softening, corrosion control, algae control and fluoridation. In general, chemicals are added as solutions or dilute suspensions. As the treatment is a continuous process, the flow of chemicals is regulated and measured continuously through chemical feeders which can be either solution feed type or the dry feed type. The installation of chemical feeders obviously promotes the uniform distribution of chemicals and eliminates wastage. Every chemical feeder should be arranged and positioned in such a way that checking of dosing rate can be made at regular intervals to verify the discharge rate.

7.3.1 SOLUTION FEED

Preparation of the solution of the chemical in water in desired strength is the first step and is done in the solution tanks. This solution is fed to the raw water through controlled feeders which are of gravity or pressure type. The selection of the proper type of feeders and the point of application are important. For example, when mixing is done in a channel, it should be at a number of points in the cross-section of maximum turbulence. Also as different chemicals are to be fed at different points, the location at which the chemicals are fed is important to derive maximum efficiency.

7.3.1.1 Solution Tanks

There should be at least two tanks for each chemical feed. The capacity of each tank should generally be such as to hold 8 hours requirement at the maximum demand of chemical at the design flow. A minimum free board of 0.3 m is necessary. Dissolving trays or boxes and also adequate facilities for draining the solution tanks should be provided.

The solution tank may be constructed either of masonry, plain or reinforced cement concrete. Coating with bituminous paint may be adequate for alum tanks while for tanks for handling other corrosive chemicals, suitable lining of rubber, PVC or Epoxy resin may be necessary to resist corrosion.

The chemical solution tanks should be located in or as near the chemical storage godown as possible to avoid unnecessary lifting and handling of chemicals. These tanks should preferably be located at a suitable elevation, to facilitate gravity feed of the chemical solution.

A lifting tackle for lifting the chemicals to the elevated tanks should be provided. Each tank should have a platform which should be at least 0.75 m wide to allow the workers sufficient space for handling the chemicals and preparing the solution; wherever necessary, the platforms should have railings upto a minimum height of 0.75 m. The platforms should be located at an elevation to have clear headroom of 2.0 m from the ceiling. The top of the solution tank should not be higher than 1.0 m from the floor of the platforms.

7.3.1.2 Dissolving Trays Or Boxes

The chemicals after being carefully weighed, are placed into the dissolving trays which vary in size to suit the capacity of the treatment plant. The trays or boxes may be constructed

of wood, cast iron or cement or cement concrete with slots or perforations both at the sides and at the bottom. These may be placed either inside or just above the solution tanks.

For small tanks, a pipe perforated with small holes to provide a spray of water to help dissolve the chemicals, may be placed above these trays. For plants of medium and large size, dissolving boxes should preferably be constructed of concrete with a pipe manifold having holes either at bottom or at sides for dissolving chemicals.

7.3.1.3 Preparation Of Solutions

It is essential to ensure that all the chemicals are dissolved before the solution is put into operation and the homogeneity of the prepared chemical solution is maintained. This can be achieved by proper mixing either by compressed air or recirculating the solution or by mechanical agitation. For plants having capacities not exceeding 2500 m³/d manual mixing may be adopted ensuring proper mixing.

A knowledge of the solubility characteristics of the chemical as well as the solution strength that are used in normal practice will facilitate the choice of feed equipment. The solution strength of alum which is the most widely used coagulant shall not be more than 5% for manual operations and 10% for other operations with efficient mixing. It may be desirable to dilute down to 1% prior to addition. For other chemicals, reference may be made to Appendix 7.10 which gives the strengths to be used with mechanical mixing. With manual operation, lower strengths are recommended.

The chemical solution is conveyed from the solution tanks to the point of application by means of chemical feed lines. These should be as short and straight as possible.

Liquid Alum

Liquid alum contains 5.8 to 8.5% water soluble alumina as against 17% for crystalline alum, but is lower priced. Since its use also avoids construction of solution tanks, it may be economical in large plants especially if the waterworks are within a reasonable trucking distance of alum producing works. Acid-proof equipment such as rubber-lined or stainless steel tanks and piping is necessary for transport, handling and storage.

7.3.1.4 Solution Feed Devices

Solution feed devices are used to regulate the doses of chemical fed into water. The rate of flow of the chemical solution of known strength prepared in the solution tank is measured by means of either an orifice rotameter, positive displacement pump or by weirs. The solution feed equipment should be simple in operation and corrosion resistant.

The constant head orifice is the most common device used for measuring the rate of flow of solution. It is usually contained in a unit consisting of corrosion resistant, constant level box with a float valve and an orifice. The orifice can be of either variable size or constant size, the adjustment in the latter being made by using the required size to give the desired rate of flow. The unit should also be capable of adjustment to allow setting for various depths of solution in the box.

In large systems, automatic control of chemical feed could be practiced which assures that the quantity of chemical measured is not prone to human errors. The principle must be

based upon the measurement of some attributes of the water such as the rate of flow, pH, colour, conductivity, chlorine residual.

Since the flow of water can fluctuate, it is necessary to maintain the flow of chemical in a fixed proportion to the flow of water for which a proportional feed device is necessary. Measurement of the water can be done in a number of ways, the simplest possibly being the tipping bucket or a pump with positive meter which provides a positive method of measurement but is applicable to the smaller installations only. The more common measuring device is a weir, venturi tube or orifice plate described in Chapter 4.

Another method is based on the actuation of a flow regulator directly or through a relay from the primary measuring unit. This usually involves the empirical calibration of some link in the system and care must always be taken to see that such arrangements are properly adjusted for they do not depend on a state of equilibrium.

The most satisfactory method of control is one that depends upon the matching of two factors, one of which is associated with the primary measuring unit (control) and the other with the flow of chemical. For example, a venturi tube will produce a differential pressure bearing known relationship to the flow of water through it. If it is desired to control the flow of a chemical solution, then some similar measurement associated with the flow of a chemical solution must be compared with the differential pressure and means provided for adjusting the flow of chemical so that the two factors so compared are mutually in equilibrium. Such a system is basically stable.

7.3.1.5 Solution Feeders

There are several types of solution feeders, some of which are discussed below:

(a) Pot Type chemical Feeders

The pot type chemical feeder is a simple type of equipment for feeding alum or alkali into water. The chemical, in large crystal or lump form, is charged into the feeding pot. A special orifice fitting, placed in the raw water line, contains an orifice plate which creates a pressure differential in pipes which connect the chemical pot into the orifice fitting.

This pressure differential causes a small stream of water to flow from the high pressure side of the orifice plate through a pipe and a regulating valve, into the bottom of the chemical feeding pot and this forms an equivalent stream of the chemical solution, formed in the pot, to flow out of the top of the pot into the raw water line on the low pressure side of the orifice plate.

Since the same pressure differential acts across the regulating valve as across the orifice, the flow through the regulating valve, at any setting, is a definite fraction of the flow through the orifice. Consequently, the rates of flow of the small stream of chemical fed to the raw water are directly proportional to the rates of flow of the raw water. These find use in small plants because they do not permit a uniform feed rate and the feed rate cannot be also checked. Sediment tanks are usually employed with these feeding lines.

(b) Pressure Solution chemical Feeders

Pressure solution chemical feeders are much more accurate than the pot type chemical feeders. In these a chemical solution of a definite strength is made by dissolving a weighed amount of chemical in a specified volume of water in the chemical solution tank. This batch of chemical solution, when required, is charged into the displacement tank through the bottom. As the specific gravity of the chemical solution is higher than that of water, the water in the displacement tank is displaced upwardly to waste through a valve.

A sight glass at the side of the feed tank has in it a glass float, which is so constructed that it floats in the heavy chemical solution but sinks in water. This float indicates, at all times, the level of the chemical solution thus notifying the operator when recharging is necessary.

A special orifice fitting, placed in the raw water line, contains an orifice plate which creates a pressure differential in the pipes connecting the displacement feed tank to the orifice fitting. This pressure differential causes a small stream of water to flow from one side of the orifice plate. The greater part of this stream flows through a secondary orifice and the smaller through an adjustable needle valve into the top of the displacement feed tank, where it displaces downwardly an equivalent stream of the heavier chemical solution.

This small stream of chemical solution is diluted when it discharges on the other side of the secondary orifice into the water flowing through this orifice and this diluted chemical solution is fed into the raw water line on the other side of primary orifice. This dilution serves to make the density of the effluent column approach the density of the influent column thus assuring a greater degree of accuracy, at varying flow rates, than is possible with a single orifice control.

Since the same pressure differential acts across the primary orifice as across the needle valve, the flow through the needle valve at each setting, is a constant fraction of the flow through the primary orifice. As the rates of flow of the chemical solution are directly proportional to the rates of flow of the raw water, this type of feed is applicable to water supplies of varying flow rates and pressure. Sediment tanks are usually employed with pressure solution chemical feeders to keep sediment out of the feeding line. In cases, where corrosive chemicals are handled, special pressure solution chemical feeders are employed.

(c) Electro-chemical Feeders

The water flows through an integrating raw water meter causing an electrical circuit to start the feed control unit through a time switch. The feed control unit is a mechanism designed to lower the swing drawoff pipe at a rate which is proportional to the rate of flow of raw water. It consists of a motor, a speed reducing mechanism, two drums on which separate tapes are wound, a manual rewinding mechanism, a switch for operating an alarm for stopping the feed at low level in the solution tank and a dial for indicating directly the depth of solution removed from the tank.

(d) Gravity Orifice chemical feeders

The gravity orifice chemical feeder is limited in application to those cases where the flow rate of the water being treated is constant. The solution from the chemical solution tank flows by gravity, through a strainer and through a float valve, into the orifice box.

The float valve keeps the chemical solution in the orifice box always at the same level so that the adjustable orifice operates under constant head. By gravity, the chemical solution flows from the orifice box through the adjustable orifice to the point of application.

To stop and start the chemical and water simultaneously, a float switch may be used in the settling basin to operate a solenoid-operated valve on the orifice box discharge and an electrically controlled valve on the raw water line. Thus the flows of raw water and chemical solution are stopped whenever the level of the water in the basin has reached a certain height. When the level has fallen a certain distance, the float switch closes an electric circuit thus starting simultaneously the flows of raw water and chemical solution.

Instead of being connected to an electrically controlled valve in the raw water line, the float switch may be connected so as to start or stop a raw water pump simultaneously with the starting or stopping of the chemical feeder.

The amount of chemical solution fed to the raw water may be varied over a wide range by means of the adjustable orifice located in the orifice box.

Instead of the chemical solution flowing by gravity to the point of application, it may be discharged in to a pump suction box from which it is pumped to the point of application.

(e) Reciprocating Pump chemical Feeders

This method of feeding chemical employs a motor-driven reciprocating chemical pump. The pump withdraws a chemical solution, or suspension of suitable strength, from a tank and discharges the solution or suspension to the point of application under any desired pressure. The feeding pump may be designed to treat either a variable or a constant flow of water.

The chemicals to be fed are prepared in solution tanks. If the chemical to be fed is relatively insoluble, a high speed motor-driven agitator maintains uniform suspension throughout the full depth of the tank. If the chemical forms a clear solution, a dissolving basket is furnished and the mechanical agitator is omitted.

(1) Variable rate proportional feeders

If the rate of flow of water being treated varies, proportional feeding of chemicals is necessary. This is carried out by accurately measuring the amount of chemical fed by the pump. This pump is a proportioning and metering device which delivers a definite volume of chemical with each stroke. A water meter with an electrical contactor is placed in the raw water line. The contactor closes a circuit every time a given volume of water flows through the meter. The closing of the circuit energizes the motor of the reciprocating pump, which then operates to deliver a given volume of chemical until an electric time switch breaks the circuit, thereby stopping the pump. The cycle repeats itself approximately every thirty seconds, at maximum flow, with the pump operating for approximately twenty seconds after each contact. The amount of chemical fed is thus accurately proportioned to the flow of water regardless of variations in the rate of flow, because both the volume of water treated between meter contacts and the volume of chemical added to treat the water are accurately measured. However this suffers from the disadvantage that, particularly when used with alum solutions, the water is subject to an overdose and no-dose sequence. It is better to have the

chemical pump run continuously and to modulate the stroke of the pump either manually or with a mechanical device.

For a number of chemicals fed simultaneously, one meter control serves to operate any number of pumps.

(2) Constant rate feeding for uniform flow

If the flow of water being treated is constant, the chemical pump operates continuously at the set dosage. When the flow of water ceases, the chemical pump is stopped automatically so as to shut off the flow of chemicals. When the flow of water begins again, the chemical feeding is automatically resumed.

(3) Adjustment of feeding rates

Two methods are available for adjusting the rate of chemical feeding. Firstly, the length of the pump stroke can be changed to vary the rate of feeding of a given strength of solution over a wide range. Secondly, the strength of the chemical solution or suspension in the chemical tank can be changed when a new chemical charge is made up so as to provide a different chemical dosage for the same setting of the chemical pump.

The method of adjustment of the chemical feeding rate varies with the type of proportioning pump used. The single feed pump varies the feeding rate by a simple screw adjustment, which changes the length of the plunger stroke. The duplex pump varies its feeding rate by screwing the adjusting coupling toward the liquid end of the pump to increase the capacity or away from the end to decrease the capacity.

The reciprocating chemical pumps can be provided with ball check valves on both suction and discharge, thus assuring maximum efficiency of displacement, non-clogging and selfcleaning features, elimination of air binding and the minimising of wire drawing of valve seats. The check valves are readily opened, to inspect the ball checks and seats, without disconnecting either suction or discharge piping.

7.3.2 DRY FEED

Dry chemical feeders incorporate a feed hopper which sometimes serves as a storage hopper also mounted above the feeding device. This device may consist of a rotating table and scraper, a vibrating trough or an oscillating displacer or some equivalent method of moving the chemical from the point where it leaves the feed hopper to the point of discharge. The rate of movement of the chemical determine the quantity to be discharged on a volumetric basis. Gravimetric feeders are also available in which the quantity discharged in a unit of time is continuously weighed and the speed of operation automatically controlled to maintain a constant weight. The feeder may be designed for constant rate operation or for feeding chemicals in proportion to the rate of flow of water. The dry feeders with a completely enclosed feeding mechanism have many advantages over the solution feeder like accuracy of feeding, reproducibility of feeding rate for any feeder setting with a stepless adjustment of dosage in a wide feeding range. A single feeder serves as a spare for a group of feeders handling different materials and the height of chemical in standard or extension hopper has no effect on feeding rate. When small rates of chemical feeding are desired, one hopperful of chemical will allow the feeder to operate for several days unattended.

Chemicals stored in a steep-sided hopper feed downward to a discharge opening at the bottom of the hopper. Chemicals which have a tendency to arch or stick, such as lime and soda ash, are made free-flowing by a vibrator mounted on the side of the hopper at a point where it produces the most effective vibration. Exact volumes of chemicals are sliced off and displaced from the bottom of the discharge opening by an endless belt with integral lugs in the form of equally spaced partitions.

Machined guides on both sides and above the lugs insure that each pocket is filled with an exact volume of chemical. As the belt moves forward it passes over a pulley where each pocket is stretched open as the belt goes over and then under this pulley so that all the chemical is dropped into a mixing or dissolving chamber. A jet of water admitted tangentially or power driven paddles in the mixing chamber provides the agitation needed for mixing or dissolving the chemical. This chemical solution, or suspension then overflows or is pumped to service.

Where the quantity to be handled is large a storage hopper is usually constructed above the relatively small fed hopper. The capacity of the storage hopper is usually arranged for recharging once a day or once a shift. Because of the height of such hoppers, it is almost inevitable that storage of chemicals has to be at an elevated place to obviate the need of lifting of the chemicals every time.

7.3.3 CHEMICALS

7.3.3.1 Chemicals Used And Their Properties

Appendix -7.10 gives the list of chemicals commonly used in water treatment and their properties.

7.3.3.2 Chemical Storage

The chemical store should be of damp proof construction, properly drained. Special precautions against flooding should also be taken.

For chemicals purchased in bags, storage by piling on the floor of the store room may be arranged. A height of stack not exceeding 2 m is recommended. Hygroscopic chemicals should be obtained in moisture-proof bags and stored in air-tight containers.

All plants, particularly small ones, should keep on hand at all times, a supply of chemicals sufficient to provide a safety factor. A storage of 3 months is advisable but this again depends upon the location of the plant as well as the source of supply, transport facilities and the arrangement made with the suppliers for the supply of chemicals.

In cases where the major storage is provided at a place away from the feed equipment, a week's storage space should be provided near the plant.

Dampness may cause severe caking even in chemicals such as aluminium sulphate which usually are free from such troubles. Quick lime gradually expands on prolonged storage and may even burst the containers if kept too long.

Chemicals such as powdered activated carbon which are likely to cause dust problems should preferably be stored in separate rooms.

Storage of acid materials near alkalis is undesirable as their contact generates considerable heat resulting in combustion. This is also true of oxidising chemicals such as chloride of lime mixed with activated carbon. Hence they should be isolated. It is advisable to store chlorine cylinders separately as gaseous chlorine in contact with activated carbon leads to severe fire hazards.

7.3.3.3 Handling Of Chemicals

Ordinarily a 50 kg container can be handled by a single person when aided by small hand carts. Heavy containers should be handled with the aid of mechanical contrivances such as trucks, monorail pulley, cranes and other special equipments.

Chemicals such as chlorine, ferric chloride, sodium hydroxide, sulphuric acid, ammonium chloride, ammonia, sulphur dioxide and sodium bisulphite should be handled by equipment, specially designed to reduce the hazards in their handling to a minimum. Care should be taken to prevent the dropping or bumping of the containers of these chemicals. For safe lifting, cranes should be preferred to ropes.

Sufficient space with access should be provided for handling bulk storages allowing for negotiating of vehicles and cranes likely to be used.

Rolling of cylinders, barrels and drums on the floor should be avoided.

Chlorine, ammonia and sulphur dioxide are toxic gases when present even in small concentrations in the air. Hence special care must be exercised in their handling. Sodium bisulphate may give off sulphur dioxide and may cause corrosion when spilled. Ferrous sulphate mixed with lime is likely to generate enough heat to start combustion. When such chemicals are used, special care needs to be given to ventilation arrangements (IS: 3103-1965). In the case of chlorination rooms, ventilation is specially necessary at the bottom and should be provided by exhaust fans.

7.4 COAGULATION AND FLOCCULATION

The terms 'Coagulation' and 'Flocculation' are often used indiscriminately to describe the process of removal of turbidity caused by fine suspensions, colloids and organic colour.

'Coagulation' describes the effect produced by the addition of a chemical to a colloidal dispersion, resulting in particle destabilization. Operationally, this is achieved by the addition of appropriate chemical and rapid intense mixing for obtaining uniform dispersion of the chemical.

'Flocculation' is the second stage of the formation of settleable particles (or flocs) from destabilised colloidal sized particles and is achieved by gentle and prolonged mixing.

In modern terminology, this combination of mixing (rapid) and stirring or agitation (slow mixing) that produces aggregation of particles is designated by the single term 'flocculation'. It is a common practice to provide an initial rapid or flash mixing for dispersal of the coagulant or other chemicals into the water followed by slow mixing where growth of floc takes place.

7.4.1 INFLUENCING FACTORS

Both these states in flocculation are greatly influenced by physical and chemical forces such as electrical charges on particles, exchange capacity, particle size and concentration, pH water temperature, electrolyte concentrations and mixing.

7.4.1.1 Coagulant Dosage

Although there is some relation between turbidity of the raw water and the proper coagulant dosage, the exact quantity can be determined only by trial. Even thus determined, the amount will vary with other factors such as time of mixing and water temperature. The use of the minimum quantity of coagulant determined to be effective in producing good flocculation in any given water, will usually require a fairly long stirring periods varying from 15 to 30 minutes in summer and 30 to 60 minutes in the colder months, as water temperatures approach the freezing point.

Addition of coagulants in excess of the determined minimum quantity may increase bactericidal efficiency. It is, however, usually more economical to use the minimum quantity of coagulant and to depend on disinfectant for bacterial safety.

Very finely divided suspended matter is more difficult to coagulate than coarse particles, necessitating a larger quantity of coagulant for a given turbidity. The cation-exchange capacity of the particles of turbidity bears a significant relationship to the success of flocculation.

7.4.1.2 Characteristics of Water

The characteristics of water especially pH have considerable influence on the satisfactory formation of flocs. Some natural waters need certain adjustments in acidity or alkalinity of water.

7.4.1.2.1 Optimum pH Zone

There is at least one pH zone for any given water in which good flocculation occurs in the shortest time with a given dose of coagulant, or in a given time with the required minimum dose of coagulant. Coagulation should be carried out within this optimum zone using alkalis and acids for correction of pH wherever necessary. For many waters, usually those which are low in colours and well buffered and having pH in the optimum zone, no adjustment of pH is necessary. However, in waters of low mineral content, or in the presence of interfering organic matter, constant attention is needed for pH adjustment. Failure to operate within the optimum zone, may be a waste of chemicals and may be reflected in the lowered quality of the plant effluent. As a result of studies of the effect of pH on coagulation, it has been found that "the more dilute the water in total dissolved solid and the less the alum added, the narrower becomes the pH zone".

In the case of coagulation with alum, the control over the alkalinity is very important. Not only should the water contain sufficient alkalinity to completely react with the aluminium sulphate but there should be a sufficient residual to ensure that the treated water is not corrosive. A consideration of the reaction involved shows that one molecule of "filter alum"

(molecular weight of $\text{Al}_2 (\text{SO}_4)_3 \cdot 18 \text{H}_2\text{O} = 666$ requires three molecules of calcium bicarbonate $[\text{Ca} (\text{HCO}_3)_2] \times 3 = 486$ for complete reaction.

If the alkalinity is expressed in terms of calcium carbonate, the theoretical requirement of 666 parts of "filter alum" works out to 300 parts of alkalinity, i.e. approximately in the ratio of 2:1. This reduction of alkalinity should be taken into consideration and sufficient alkalinity should be added to the water, if necessary. For this purpose, hydrated lime $\text{Ca}(\text{OH})_2$ is usually added, or "soda ash" (Na_2CO_3) may be used when the increase of hardness is to be avoided.

When ferrous sulphate is used as a coagulant, the pH should be maintained above 9.5 to ensure complete precipitation of the iron. This is done by the addition of hydrated lime. For this reason, the process is sometimes known as "iron and lime process".

7.4.1.3 Coagulant Aids

Coagulant aid is a chemical, which when used along with main coagulant, improves or accelerates the process of coagulation and flocculation by producing quick-forming, dense and rapid-settling flocs.

Finely divided clay, fuller's earth, bentonites and activated carbon are the most commonly used materials as nuclei to floc formation. The particles may become negatively charged making them subject to attraction by the positively charged aluminium ion.

Activated silica, i.e. sodium silicate activated with aluminium sulphate, sulphuric acid, carbon dioxide or chlorine, when applied to water, produces a stable solution having a high negative charge which unites with the positively charged alum or other floc to make it denser and tougher. It is especially useful for clear water that do not coagulate well with the usual processes. It has a wider range of use in water softening.

Polyelectrolytes which are polymers containing ionisable units have been used successfully as both coagulant aids and coagulants but care should be taken to guard against their toxicity. They are soluble in water, conduct electricity and are affected by the electrostatic forces between their charges. Cationic, anionic and ampholytic polyelectrolytes have been used; the cationic being able to serve as both a coagulant and coagulant aid while the other two as coagulant aids primarily. Polyelectrolytes create extraordinarily slippery surfaces when spilled on floor and are difficult to clean up.

Toxicity of any polyelectrolyte has to be checked before it can be used as coagulant or coagulant aid.

7.4.1.4 Choice of Coagulant

In selecting the best coagulant for any specific treatment problem, a choice has to be made from among various chemicals, each of which may offer specified advantages under different conditions. The common coagulants used in water works practice are salts of aluminium viz. filter alum, sodium aluminate and liquid alum and iron salts like ferrous sulphate (Copperas), ferric sulphate, ferric chloride and chlorinated copperas which is an equimolecular mixture of ferrous sulphate and ferric chloride being obtained by chlorinating

ferrous sulphate. Some coagulants derived from natural products such as Nirmali seeds have also been used.

Selection of aluminium or iron coagulants is largely decided by the suitability of either type and its easy availability. Both filter alum and ferric sulphate have certain specific advantages. Alum does not cause the unsightly reddish brown staining of floors, walls and equipment which may result when iron salts are used; nor is its solution as corrosive as the ferric form of iron salts. The dissolving of ferric sulphate also offers difficulties not encountered with alum. The trivalent aluminium ion is not reduced to a more soluble bivalent iron, as may be the case when ferric salts are used with waters high in organic matter. On the other hand, ferric floc is denser than alum floc and is more completely precipitated over a wider pH range. Also good flocculation with alum is not possible in some waters.

The choice of the coagulant to be used for any particular water should preferably be based upon a series of jar tests, so planned that it will permit accurate comparison of the materials being studied under identical experimental conditions. The coagulant dose in the field should be judiciously controlled in the light of the jar test values.

A few of the many substances used in coagulation of water are listed in Appendix 7.10

7.4.2 RAPID MIXING

Rapid mixing is an operation by which the coagulant is rapidly and uniformly dispersed throughout the volume of water, to create a more or less homogeneous single or multiphase system. This helps in the formation of microflocs (Perikinetic flocculation) and results in proper utilisation of chemical coagulant preventing localisation of concentration and premature formation of hydroxides which lead to less effective utilisation of the coagulant. The chemical coagulant is normally introduced at some point of high turbulence in the water. The source of power for rapid mixing to create the desired intense turbulence are gravitational, mechanical and pneumatic.

The intensity of mixing is dependent upon the temporal mean velocity gradient, 'G'. This is defined as the rate of change of velocity per unit distance normal to a section (or relative velocity of two flow lines divided by the perpendicular distance between them) and has the dimensions of s^{-1} and generally expressed as s^{-1} . The turbulence and resultant intensity of mixing is based on the rate of power input to the water and G can be measured or calculated in terms of power input by the following expression:

$$G = \sqrt{P / \mu(\text{vol})} \quad (7.7)$$

Where,

G = Temporal mean Velocity gradient, s^{-1} ;

P = Total input of power in water, watts;

μ = Absolute viscosity of water, $N.s/m^2$; and

Vol = Volume of water to which power is applied, m^3 .

Where head loss through the plant is to be conserved as much as possible and where the flow exceeds $300 \text{ m}^3/\text{hr}$, mechanical mixing also known as flash mixing, is desirable. Multiple units may be provided for large plants. Normally a detention time of 30 to 60 seconds is adopted in the flash mixer. Head loss of 0.2 to 0.6 m of water, which is approximately equivalent to 1 to 3 watts per m^3 of flow per hour is usually required for efficient flash mixing. Gravitational or hydraulic devices are simple but not flexible, while mechanical or pneumatic devices are flexible, but require external power.

7.4.2.1 Gravitational Or Hydraulic Devices

In these devices, the required turbulence is obtained from the flow of water under gravity or pressure. Some of the more common devices are described below.

(a) Hydraulic jump Mixing

This is achieved by a combination of a chute followed by a channel with or without a sill. The chute creates super critical flow (velocity 3 to 4 m/s), the sill defining the location of the hydraulic jump and the gently sloping channel induces the jump. Standing wave flumes specially constructed for measurement of flow can also be used in which the hydraulic jump takes place at the throat of the flume. In the hydraulic jump mixing, loss of head is appreciable (0.3 m or more) and the detention time is brief. This device though relatively inflexible, is simple and free from moving parts. This can be used as a standby in large plants to the mechanical mixers while for small plants, this can serve directly as the main unit. Typical residence time of 2 seconds and G value of 800 s^{-1} have been reported. overflow weirs have also been used for rapid mixing. A head loss of 0.3 to 0.6 m across the weir has been reported.

(b) Baffled Channel Mixing

In this method, the channel section (neglecting the baffle) is normally designed for a velocity of 0.6 m/s.

The angle subtended by the baffle in the channel is between 40° to 90° with the channel wall. This angle should ensure a minimum velocity of 1.5 m/s while negotiating the baffle.

The main walls of the channels are constructed of brick masonry, stone masonry or reinforced cement concrete finished smooth to avoid growing of weed etc. The baffles are made of concrete or brick, finished in the same manner as the channel. A minimum free board of 150 mm is normally provided.

(c) Other Type of Hydraulic Mixing

Sudden drop in hydraulic level of water over a weir can cause turbulence and chemicals can be added at this "plunge" point with the aid of diffusers. Similarly in pressure conduits, the chemicals can be added at the throat of a venturi or just upstream of orifice located within the pipe. In this system, no effective control is possible even though mixing takes place. Rapid mixing can also be obtained by injection of chemicals preferably, in the suction end or delivery end of low lift pumps where the turbulence is maximum. In this system also, the detention time is brief while the cost is low.

7.4.2.2 Mechanical Devices

There are two devices, the usual one being the rapid rotation of impellers or blades in water and the other mixing with the aid of a jet or impingement over a plate. Propeller type impellers are commonly employed in flash mixers, with high revolving speeds ranging from 400 to 1400 rpm or more. The blades are mounted on vertical or inclined shaft and generate strong axial currents. Turbine types and paddle types are also used. In the design of a mechanical flash mixer unit, a detention time of 30 to 60, sec. is provided. The relatively high powered mixing devices should be capable of creating velocity gradients of 300 s^{-1} or more. Power requirements are ordinarily 1 to 3 watts per m^3/hr of flow. Usually, the flash mixers are deep, circular or square tanks. The usual ratio of impeller diameter to tank diameter is 0.2 to 0.4 and the shaft speed of propeller greater than 100 rpm imparting a tangential velocity greater than 3 m/s at the tip of the blade. The ratio of tank height to diameter of 1: 1 to 3: 1 is preferred for proper dispersal.

Vertical strips or baffles, projecting $1/10$ to $1/12$ tank diameter, at minimum of four places, along the walls of the tank should be provided to reduce vortex formation or rotational movement of water about the impeller shaft. The mixing chamber can be placed below the chemical feed floor ensuring short chemical feedlines. The usual mechanical agitator drive is an electric motor with continuous duty, operating through a reduction gear. Good results are achieved by adding the chemical just near the tip of the blade or the propeller in the tank. Mechanical type consumes very little head of water and permits flexibility of operation. When there is possibility of short circuiting in the tank, one more compartment may be provided. This requires more external power input and needs constant attention and maintenance.

In the impingement type, water is forced as jet through a nozzle, impinging on a plate where the chemical is added. An auxiliary pump is used to create the jet action. The rapid mixing takes place at the point of impingement where turbulence occurs. The power requirement of the auxiliary pump should be worked out in accordance with Table 7.1. Rapid mixing channels may be obviated by pipe mixing preferably with orifice (instead of venturi) or with a mechanical impeller through a stuffing box into a pipe.

7.4.2.3 Pneumatic Devices

When air is injected or diffused into water after suitable compression, it normally expands isothermally and the resultant work done by the air can be used for necessary agitation. They are not common in water works practice. The typical range of velocity gradients and contact times are in the range of 3000 to 5000 s^{-1} and 0.5 to 0.4 sec. respectively.

Taking into account the various types of rapid mixing devices velocity gradients and the detention times, the following equation is proposed:

$$G = 2790 t^{-0.35} \quad (7.8)$$

where,

G = Velocity gradient, s^{-1}

t = Detention time, S