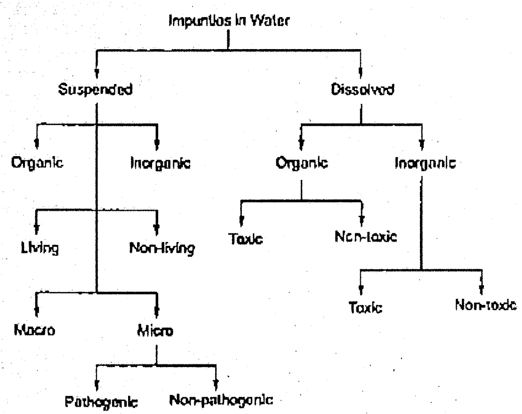
CHAPTER 04

# Treatment of Water

## INTRODUCTION

Absolutely pure water is rarely found in nature, impurities occur in three progressively finer-suspended, colloidal and dissolved. Different methods of treatment are required for their removal or reduction to acceptable limits.



- In most of cases, more than one treatment process is needed to achieve the desired change in quality so that treatment plants usually consist of a chain of processes, which operate in sequence. Each process has a particular area of applicability and it is important that the processes are selected in relation to the nature of the impurities to be removed and the required quality. It is appreciated that most treatment processes do not usually destroy the impurities, which they remove from the liquid phase but simply concentrate them in the form of a sludge or effluent stream.
- This unit describes the types of impurities, which need to be removed from water and outline the main forms of treatment, which are available. The unit describes, in detail the fundamental principles of the main physical treatment processes.

## 4.1 Nature of Impurities in Water

As already pointed out, pure water does not exist in nature so that all water is contaminated to some degree. The impurities in water may be classified as:

1. Floating small and large suspended solids → Leaves, twigs, etc.
2. Colloidal solids → Clay, silt, microorganisms etc.
3. Dissolved solids → Salt, hardness and some organics etc.
4. Dissolved gases, carbon dioxide, hydrogen sulphides etc.

- In number of situation, it becomes necessary to add substances as part of the treatment process e.g. coagulants for removal of turbidity, oxygen for biological oxidation, chlorine for disinfection.

## 4.2 Types of Treatment

Treatment process of water can be divided into three main classes governed by their main principle of operation and the prevailing quality characteristics of the water.

1. Physical treatment process
2. Chemical treatment process
3. Biological treatment process

### 1. Physical Treatment Process

Depends mainly on purely physical characteristics of the impurities to be removed.

- Characteristics such as size, density, viscosity, solubility are of importance in physical treatment operations.
- The chemical nature of impurities and whether they are living organisms or inanimate objects are not relevant in physical treatment.

Treatments, which are physical in nature include:

(a) Screening and straining
(b) Sedimentation
(c) Flocculation
(d) Filtration
(e) Gas transfer

### 2. Chemical Treatment Process

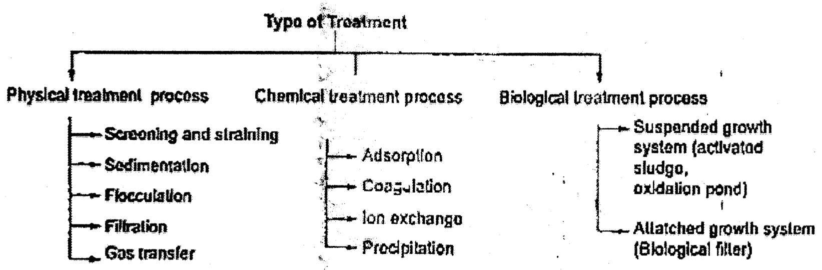
These processes depend on the chemical properties of the impurities, chemical reagents are added to remove the impurities. They include:

(a) Adsorption
(b) Coagulation
(c) Ion Exchange
(d) Precipitation

### 3. Biological Treatment Process

Biological treatment utilizes biological activity to stabilize or remove impurities and they are particularly useful for the removal of organic impurities.

- Biological processes may be aerobic, anaerobic or facultative and are mostly done to purify waste waters. They include
  (a) Suspended growth system – Activated sludge, oxidation pond
  (b) Attached growth systems – Biological filter, trickling filter



- Method of treatment employed depends on the nature of raw water constituents and the desired standard of water quality.
- The unit operation in water treatment includes:

  (a) Screening (b) Aeration
  (c) Flocculation (d) Filtration
  (e) Disinfection (f) Softening
  (g) Deferrization (h) Defluoridation
- The choice of a particular sequence of treatment unit will depend on quality of raw water and treated water desired.
- In case of ground water and surface water with storage having turbidity less than 10 NTU and free from colour, odour, plain disinfection is sufficient for drinking purpose.
- For ground water containing excessive iron, dissolved carbon dioxide and odourous gases, the treatment processes will be

  Aeration → Flocculation and Sedimentation → Rapid sand gravity filter → Disinfection → Supply
- If ground water having only $CO_2$ and odourous gases, aeration and disinfection is sufficient.
- Surface water with turbidity less than 50 NTU and where sufficient land is available, the treatment will be

  Sedimentation + slow sand filter + Disinfection
- Highly polluted surface water laden with algae and other microorganisms, the sequence of treatment will be

  Prechlorination + Aeration + Flocculation and sedimentation + Rapid gravity filtration + Disinfection (Post chlorination) + Supply

**Remember**

1. The last unit of any treatment plant will always be disinfection unit.
2. To kill the algae, we use $CuSO_4$ and $Cl_2$.
3. $NaNO_3$ facilitates the growth of algae.
4. When we use slow sand filter in treatment of water, coagulation and flocculation will never be used prior to it.

## Flow Diagram of Treatment Stages

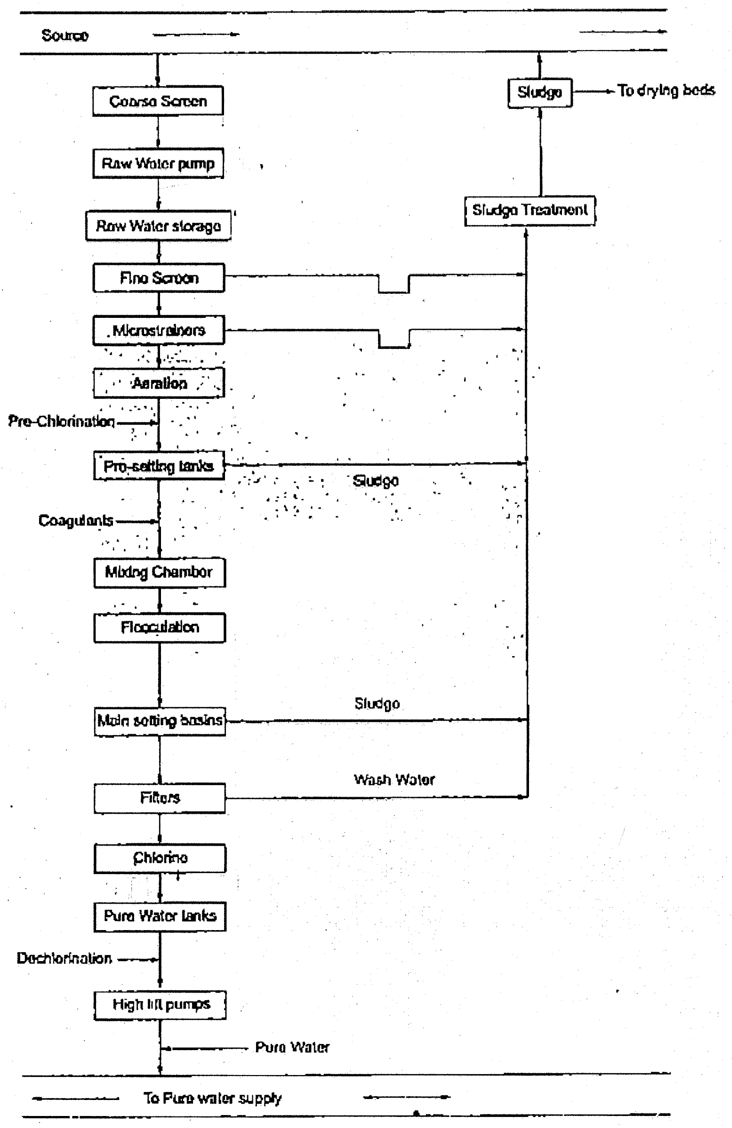


*Fig. 4.1* Flow Diagram Showing Different Treatment Stages

### Typical Treatment Plant for Hard Ground Water

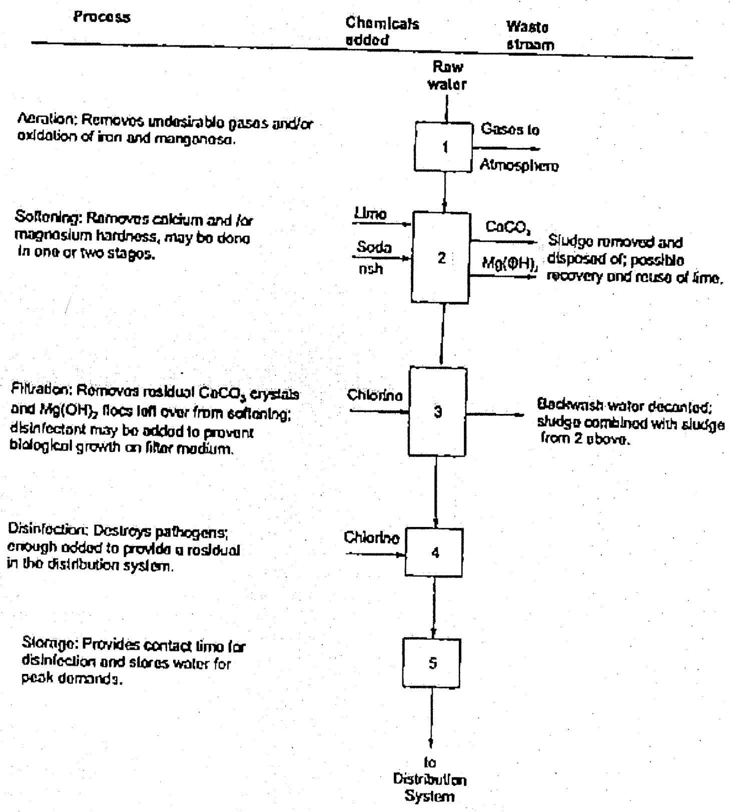


*Fig. 4.2* Typical plant treating hard groundwater

**Example 4.1** Assertion (A): Ozone is not widely used in community water supplies.

Reason (R): It is not possible to maintain residual concentrations of ozone in water after the disinfection process.

(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

Ans. (a)

Ozone is the allotropic form of oxygen.

Ozone is a powerful oxidant which reacts with reduced inorganic compounds and with organic material. It reacts vigorously with bacteria and viruses. It is more effective than chlorine in activating resistant strains of bacteria and viruses. It does not form carcinogenic compounds like chlorine by reacting with organic acids etc.

However it is chemically unstable and so it must be produced on site and used immediately. The cost of ozonation is two to three times higher than the cost of chlorination. Since no residual remains, it will be necessary to use small amounts of chlorine after ozonation to provide continued protection against regrowth of pathogens in the distribution system.

### Typical Treatment Plant for Turbid Surface Water with Organics

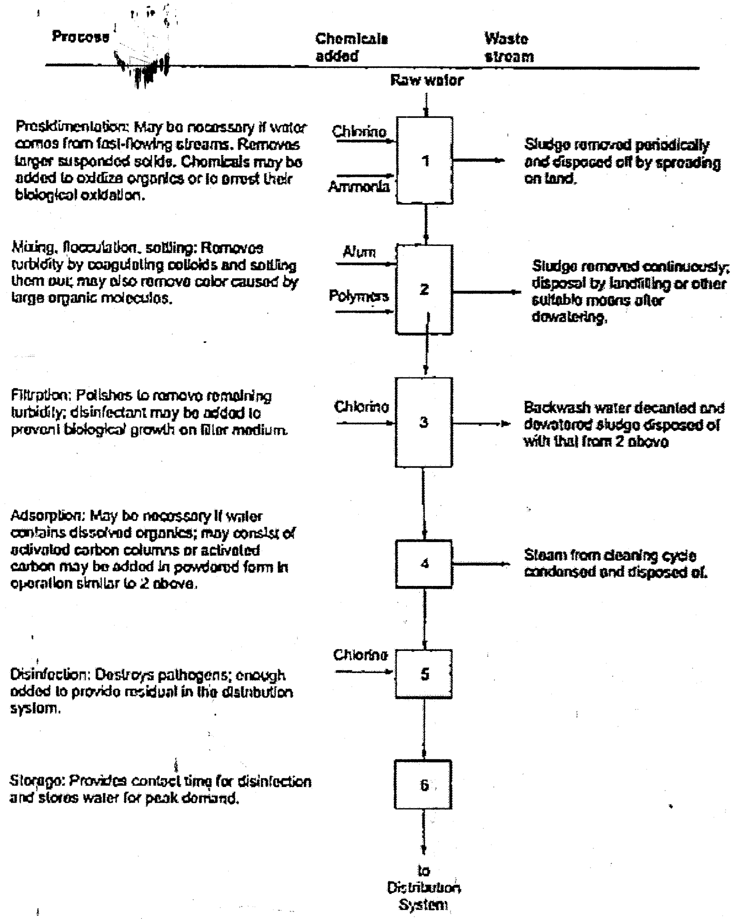


*Fig. 4.3* Typical plant treating turbid surface water with organics

### Function of Water Treatment Units

The function of various treatment units is explained in below table.

Table 4.1: Functions of Water Treatments Units

| Treatment Unit | Function (Removal) |
|---|---|
| Aeration,<br>Use of chemical Coagulation | Colour, odour, taste, Fe, Mn, etc.<br>Suspended matter, a part of colloidal matter and bacterial |
| Disinfection | Pathogenic bacteria, organic matter and reducing substances |
| Filtration | Finer and colloidal dissolved matter, bacteria |
| Screening | Floating matter |
| Sedimentation | Suspended matter |
| Softening | Hardness |

**Example 4.2** **A river is the source of water for water supply to a town. Its water is very turbid and polluted. The correct sequence of steps for treating the river water would be**

**(a) pre-sedimentation → pre-chlorination → coagulation → sedimentation → filtration → post chlorination**

**(b) coagulation → sedimentation → post-chlorination**

**(c) coagulation → filtration → sedimentation → post-chlorination**

**(d) sedimentation → post-chlorination**

**Ans. (a)**

**Example 4.3** **Which of the following treatment(s) will be indicated for a rural water supply from a deep ground water source?**

1. **Sedimentation**
2. **Alum dosage**
3. **Potassium permanganate dosing**
4. **Bleaching powder application**

**Select the correct answer using the codes given below:**

**(a) 1, 2 and 3** **(b) 1, 2 and 4**

**(c) 3 and 4** **(d) 4 alone**

**Ans. (d)**

Ground water sources do not have turbidity so sedimentation, alum doses or oxidant like potassium permanganate is not needed.

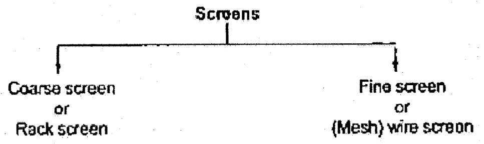
## 4.3 Pre-Treatment

Water from river or streams is not pumped directly to the basins. There are some intermediate processes, which collectively are called pretreatment. They include:

1. Screening
2. Microstrainer
3. Raw water storage
4. Pre-chlorination
5. Aeration
6. Algal control
7. Preliminary settling

Some of the processes may be required at a particular plant, but all are not required at every plant. Each of them perform a particular function, hence, they are provided only when need is there. Otherwise, they can be omitted.

1. **Screens:** Screens are generally provided in front of the pumps or the intake work, so as to exclude the large sized particles, such as debris, animals, trees, branch, bushes etc. the screen are classified as



(i) **Coarse Screen:** Coarse screens (generally called trash rack) are sometimes placed in front of the fine screens.

- Coarse screens are in the form of bars of 25 mm dia size and or spaced at 75 to 100 mm c/c.
- The screen is placed at a slight inclination at 45° to 60° or 3-6 V : 1 H with horizontal to facilitate raking, reducing the flow velocity. Smaller velocity also helps in racking.

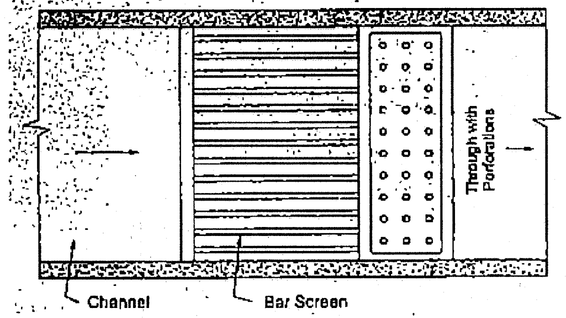


*Fig. 4.4*

(ii) **Fine Screen:** Fine screens are normally fitted immediately after the coarse screens. In case of raw storage is provided, the fine screens are provided at the outlet from the storage reservoir.

- Fine screens are in the form of wire mesh with opening less than 10 mm size.
- Since fine screens get clogged frequently hence, head loss increases, therefore we try to avoid fine screens. Fine particles may be settled in the sedimentation tank.
- The screening is usually undertaken by continuous belt or drum units fitted with a mesh of 4-10 mm. Water are used to remove the collected debris.

2. **Microstrainer:** These are revolving drums of stainless steel wire fabric or other material having very fine mesh.

- Microstrainer are useful for screening stored water, which do not contain a large amount of suspended matter, but contain plankton, algae and other microscopic size particles.
- When used in the purification or treatment system, they lighten the load on the filters i.e. reduce the load on filter.

- The ideal water for a microstrainer is a lake supply or a large storage reservoir.
- The ideal position for a microstrainer is earlier to rapid gravity or slow sand filters whose output is increased by as much as 50%.

3. **Raw Water Storage:** Raw water storage has been regarded as an almost essential "first line of defence" against the transmission of water borne diseases.
   - Prolonged storage of raw water sometimes causes growth in large numbers of various, forms of algae, which increase difficulties in treatment.
   - In reservoirs, in temperate climates having depth around 10 m or deep thermal stratification occurs on a seasonal basis.
   - It is recommended that storage provided purely to improve quality should atleast be equivalent to 7-15 days of average water demand. This is sufficient to reduce pathogenic bacteria and river algae.

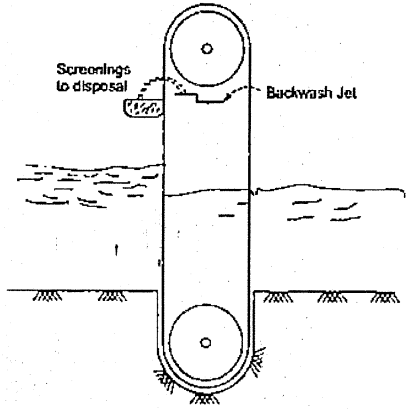


*Fig. 4.5* Belt Screen

4. **Pre-Chlorination:** It refers to the practice of injecting chlorine into the raw water when it is not so turbid but has a high bacteria count.
   - Fairly high dose of chlorine (2-5 *mg/l*) is used.
   - During the lengthy period spent by water in settling basins, this oxidizes and precipitates iron and manganese.
   - It also kills algae and bacteria, reduces colour and slime formation and assists in settlement.
   - If excessive silt is present in suspension, then prechlorination is not so effective, because silt absorbs chlorine without settling. Hence, in case of heavily turbid water, it is not very effective.
   - In case of clear water with high ammonia content, it is effective.
   - A drawback of using pre-chlorination is that raw water has a high chlorine demand and more quantity of chlorine is absorbed than in later chlorination. It is not a substitute for post-chlorination. It is most advantageous when extremely polluted clear raw water has to be used.

5. **Aeration:** Aeration is the process of providing oxygen from the atmosphere to have beneficial changes in the raw water.
   - Water is brought in intimate contact with air so that to create renewing interface between air and water. Aeration help in removal of :

   (*i*) Bad taste and odour caused by dissolved gases like $H_2S$ and organic compounds.
   (*ii*) It increases DO content in water.
   (*iii*) Reduces corrosive property of water by removal of $CO_2$.
   (*iv*) Helps in increasing biological activities hence bacteria early completion of oxidation and some of bacteria may be removed.
   (*v*) Removal of volatile liquids such as phenols, humic acids.

**NOTE:** Aeration is more often used for ground water because surface water is already in contact with atmosphere.

(*vi*) It removes iron and manganese. Iron and manganese are soluble in $Fe^{2+}$ and $Mn^{2+}$ form. They are oxidised to $Fe(OH)_3$ and $MnO_2$ which precipitates.

$$4\,Fe^{2+} + O_2 + 10\,H_2O \longrightarrow 4\,Fe(OH)_3\downarrow + 8\,H^+$$
$$2\,Mn^{2+} + O_2 + 2\,H_2 \longrightarrow 2\,MnO_2\downarrow + 4\,H^+$$

- These processes increases the acidity of water.

**Type of Aerators**

There are mainly four type of aerators.

1. Gravity aerator or tray tower or trickling bed
2. Spray tower or nozzles
3. Air diffusers
4. Cascade aerators

1. **Gravity Aerator or Tray Tower or Trickling Bed**
   - This is used mostly for Fe and Mn removal.
   - To help oxidation, $KMnO_4$ may be mixed.
   - Manganese precipitates very slowly above pH of about 9. Hence to speed up reaction, pH may be increased, by adding $KMnO_4$ or lime.
   - This method is one of the most efficient method for removal of $CO_2$.

2. **Spray Tower or Nozzle**

   Aeration is effected by specially designed nozzles, which direct thin jets of water against metal plates to produce a fine spray which exposes countless droplets of the water to the atmosphere.
   - Nozzle type aerator are very efficient and are commonly used in the removal of carbon dioxide and iron.
   - The nozzle are 2.5 to 4 cm dia and discharge about 5 to 10 *l*/sec.
   - To aerate 10,000 $m^3$/day about 20 nozzles are arranged within an area of 25 $m^2$.
   - Removes 90% $CO_2$ and 99% $H_2S$.

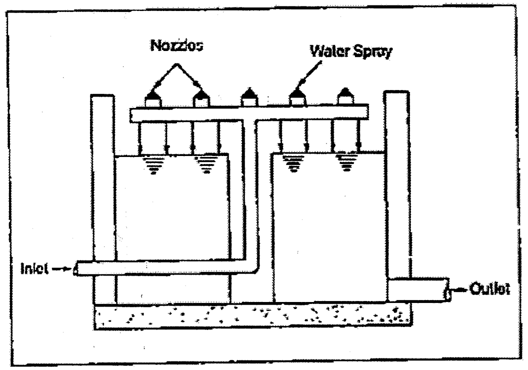


*Fig. 4.6* Spray Nozzle

3. **Air Diffuser**

   Diffused air aerators consist of tank in which air is bubbled upwards from diffuser pipe laid on floor.
   - The air holes in the diffusers pipes are sufficiently fine and are numerous in number to promote a cloud of small bubbles.
   - This type of aerator is efficient because bubbles tend to attain a constant terminal velocity whereas falling droplets tend to accelerate and, therefore, for a given depth, the air water contact in a diffused air plant is longer.
   - The amount of air used can also be regulated as per need.

- Aeration tanks are commonly about 4 m deep and have a retention time of about 15 minute.
- Water absorbs oxygen from compressed air and colour, odour and taste are removed.

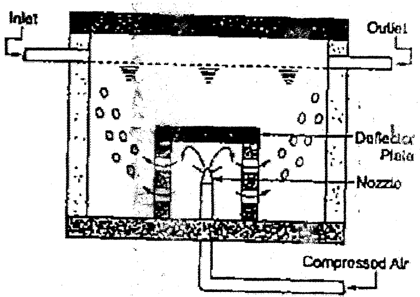


*Fig. 4.7* Air Diffuser

**4. Cascade Aerator**

Cascade type aerators depend on the turbulence created in thin stream of water flowing swiftly down an incline and impinging against fixed upstate.

- The surface area of liquid exposed is rather limited and there is a loss of efficiency.
- Removes 20-45% $CO_2$ and 35% $H_2S$. Cheap compared to others.

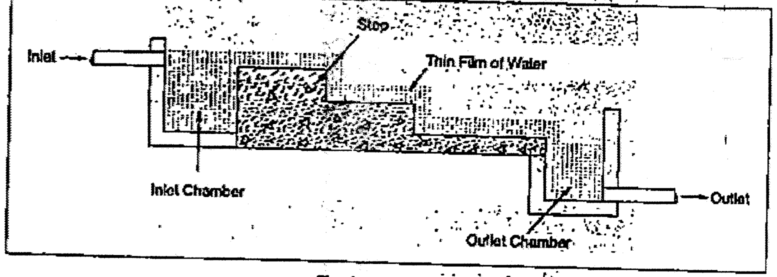
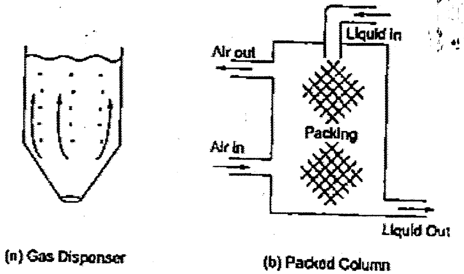


*Fig. 4.8* Cascades

**Various Water Treatment Aeration Devices**

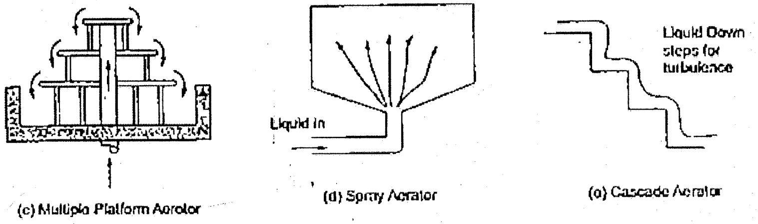
These are:



(a) Gas Dispenser

(b) Packed Column

*Fig. 4.9(I)* Water Treatment Aeration Devices



(c) Multiple Platform Aerator

(d) Spray Aerator

(e) Cascade Aerator

*Fig. 4.9(II)* Water Treatment Aeration Devices

**Limitations of Aeration**

- Not very efficient in removal of taste and odour caused by non-volatile substances like oil and gases.
- Not efficient in removal of taste and odour caused by chemical such as due to individual waste.
- Fe and Mn can be precipitated only when organic matter are not present.
- Possibility of air borne contamination.

**5. Algae Control**

Algae are minute organisms classified as plants and proliferate in rivers and reservoirs.

- The building of an impounding reservoir on an stream encourage their growth, mostly in the upper layers of water.
- Fairly alkaline water containing more concentration of nitrates and phosphates promote to algae growth.
- Algae tend to float and are not easy to remove by means of settling basins.
- The best way to kill algae is by pre-chlorination before reaching the basins with a dose of 1 mg/*l*.
- Where organisms are more, a heavier dose of copper sulphate (2 mg/*l*) or chlorine (3-5 mg/*l*) may be necessary and again this high dose has to be removed before water is allowed to use.
- Strainers are widely used to remove algae either in the form of rapid sand filters running without coagulants or as microstrainers.
- Microstrainers are effective if water is silt free and have been found to reduce the algae problems to the extent of 80% to 90%.

**6. Pre-Settlement Basins**

They are included in the treatment system to reduce the silt load on basins, which are difficult to clean.

- The requirement for pre-settlement basins are there where water reaching main settling basins has suspended solids concentration more than 1000 mg/*l* by dry weight.
- Although 3 hours detention period is more than sufficient, pre-settlement basins with 1 hour detention period have been found to be effective.

## 4.4 Sedimentation

Sedimentation is a natural process by which solids with higher density than the fluid in which they are suspended, settles under the action of gravity.

- Sedimentation tanks are designed to reduce velocity of flow so as to reduce turbulence.
- The purpose of sedimentation is to remove suspended solids.

- The process of sedimentation takes place in a tank or basin circular or rectangular known as sedimentation tank, settling tank or settling basin.
- The process has been used to remove:
  (i) Grit in grit chamber
  (ii) Particulate matter in primary settling and secondary settling basins.
  (iii) Destabilized floc in clariflocculators
  (iv) Biological floc in activated sludge, and
  (v) Solids concentration in the secondary settling tanks

### 4.4.1 Classification of Sedimentation

Sedimentation is classified into two categories:

(a) Plain sedimentation (Type-I sedimentation)
(b) Sedimentation with coagulation (Type-II sedimentation)

**(a) Plain Sedimentation (Type-I Sedimentation)**

In plain sedimentation, impurities are separated from the suspended fluid by gravitational force and natural aggregation.

**(b) Sedimentation with Coagulation (Type-II Sedimentation)**

In sedimentation with coagulation, the addition of chemical substances known as coagulants, increases the aggregation and finely divided and suspended and colloidal matter are made to settle.

- Depending upon the concentration of suspended matter and the characteristics of particles, sedimentation process can be classified in following four categories:

(i) **First type:** In this, particle have little or no tendency to flocculate in a dilute suspension. Such particles are known as discrete particles.

- They settle as individual entities and there is no significant interaction with neighbouring particles.
- The process is as in case of inorganic sand particles.

(ii) **Second type:** In the second type, there is settling of flocculent particles in a dilute suspension.

- Particles agglomerate during settling which causes increase in size, shape and density resulting in settlement at faster rate.

(iii) **Third type:** The third type of sedimentation occurs when flocculent suspensions settle in an intermediate concentration.

- Due to proximity of particles with each other, they tend to remain in fixed positions with respect to each other and settle as a large mass rather than as individuals.

(iv) **Fourth type:** The fourth type is settlement of flocculent particles in a very high concentration.

- Due to high concentration, particles come into physical contact and form a structure and further settling occur due to compression of the structure.
- The process is also known as compression settling.

### 4.4.2 Theory of Sedimentation

The settlement of a particle in water brought to rest, is opposed by the following factors:

(i) The velocity of flow which carries the particles horizontally. The greater the flow area, the lesser is the velocity, and hence more easily the particle will settle down.

(ii) The viscosity of water in which the particle is travelling. The viscosity vanish with temperature. Warm water is less viscous and, therefore, offer less resistance to settlement.

- However, the temperature of water cannot be controlled to any appreciable extent in "Water purification processes" and hence this factor is ignored.

(iii) **The size, shapes and specific gravity of the particle:** The greater is the specific gravity, more readily the particle will settle.

- The size and shape of the particle also affect the settling rate.
- For example, the weight and volume of the spherically shaped particles varies with the cube of its diameter $\left(V = \frac{\pi d^3}{6}\right)$ or its size; and its area varies with square of diameter $\left(A = \frac{\pi d^2}{4}\right)$.
- Hence, very small rod particles will settle very slowly. It, therefore, clearly shows that the shape and size of the particles do affect their settling velocities.
- The settling velocity of a spherical particle is expressed by Stoke's law, which takes the above three factor into account. The final Stoke's equation, is expressed as

$$\boxed{V_s = \frac{g}{18}(G-1)\frac{d^2}{\nu}}$$

For $d \leq 0.1$ mm.

For viscous flow and small sized particles, represented by $Re < 1$.

where,
$V_s$ = settling velocity of particle (m/sec)
$d$ = diameter of particle in (m)
$G$ = specific gravity of the particle = $\frac{\rho_s}{\rho_w} = \frac{\text{density of particle}}{\text{density of water}}$
$\nu$ = kinematic viscosity of water is m²/sec.

### Derivation of Stoke's Law

When a solid particle settles down in water, its downward settlement is opposed by the drag force offered by the water. The effective weight of the particles (i.e. actual weight-buoyancy) causes the particle to accelerate in the beginning, till it attains a sufficient velocity ($V_s$) at which the drag force becomes equal to the effective weight of the particle. After attaining that velocity, the particle falls down with that constant velocity ($V_s$).

Now, the drag force offered by the fluid is given by Newton's law, as

$$\text{Drag force} = C_D \cdot A \cdot \rho_w \cdot \frac{V^2}{2} \qquad ...(i)$$

where,
$C_D$ = Coefficient of drag ; $A$ = Area of particle
$\rho_w$ = Density of water ; $V$ = Velocity of fall

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**NOTE:** This drag force increases with the increasing velocity, till it becomes equal to the effective weight of the particle, at that time, $V$ becomes equal to $V_s$.

The effective weight of the particle

$$= \text{Total weight} - \text{Buoyancy} = \frac{4}{3}\pi r^3 \cdot \gamma_s - \frac{4}{3}\pi r^3 \gamma_w$$

$$= \frac{4}{3}\pi r^3[\gamma_s - \gamma_w] \qquad ...(ii)$$

[∵ Weight = Volume × Unit weight]

where, $r$ = radius of particle, $\gamma_s$ = unit weight of particle, $\gamma_w$ = unit weight of water

Equation (i) and (ii) will become equal when $V$ becomes equal to $V_s$ in equation (i).

$$\therefore \quad C_D \cdot A \cdot \rho_w \cdot \frac{V_s^2}{2} = \frac{4}{3}\pi r^3 [\gamma_s - \gamma_w]$$

But,
$$A = \pi r^2$$

$$\therefore \quad C_D \cdot \pi r^2 \cdot \rho_w \cdot \frac{V_s^2}{2} = \frac{4}{3}\pi r^3 (\gamma_s - \gamma_w)$$

$$V_s^2 = \frac{4}{3} \cdot \frac{(\gamma_s - \gamma_w)}{\rho_w \cdot D} \qquad \text{...(iii)}$$

Now,
$$\gamma_s = \rho_s \cdot g$$
$$\gamma_w = \rho_w \cdot g$$

$$\gamma_s - \gamma_w = g(\rho_s - \rho_w) = g \cdot \rho_w \left(\frac{\rho_s}{\rho_w} - 1\right)$$

$$\therefore \quad \gamma_s - \gamma_w = g \cdot \rho_w (G-1)$$

Equation (*iii*) then becomes,

$$V_s^2 = \frac{4}{3} \cdot \frac{g\rho_w (G-1) \cdot d}{\rho_w \cdot C_D} \quad \text{or} \quad V_s = \left[\frac{\frac{4}{3} \cdot gd(G-1)}{C_D}\right]^{1/2}$$

The drag coefficient $C_D$ changes and depends upon the flow regime surrounding the particle.

The drag coefficient ($C_D$) has been empirically connected with Reynold's number (*Re*) by Thomas Camp by a curve.

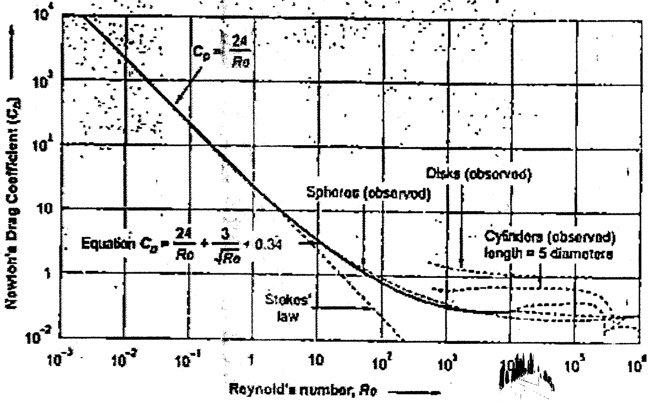

***Fig.4.10*** Curve showing relation between $C_D$ and *Re*

The value of $C_D$ is calculated by

(*i*) If $Re < 1$, $C_D = \frac{24}{Re}$

(*ii*) If $1 < Re < 1000$, $C_D = \frac{24}{Re} + \frac{3}{\sqrt{Re}} + 0.34$

(*iii*) If $Re > 10^4$, $C_D = 0.4$ (constant)

where,
$$Re = \frac{V \cdot d}{\nu}$$

*Re* = Reynold number
*d* = Spherical diameter of the particle
*V* = Velocity of sphere (m/sec)
ν = Kinematic viscosity of water (m²/sec)

So, settling velocity for small particle falling under laminar (quiescent) condition

$$V_s = \left[\frac{\frac{4}{3} \cdot g(G-1) \cdot d}{\frac{24}{Re}}\right]^{1/2}$$

$$V_s^2 = \frac{4}{3} g(G-1) \cdot d \cdot \frac{Re}{24} = \frac{g}{18}(G-1) \cdot d \cdot \frac{V_s \cdot d}{\nu}$$

$$\boxed{V_s = \frac{g}{18}(G-1) \cdot \frac{d^2}{\nu}}$$

- Since the viscosity (ν) is dependent upon the temperature, the above equation can be further modified and written as

$$\boxed{V_s = 418(G-1) \cdot d^2 \left(\frac{3T+70}{100}\right)} \quad \text{for } d < 0.1 \text{ mm}$$

where, $T$ = Temperature of water in °C; $V_s$ = is in mm/sec,
*d* is in mm.

- The above stokes equation are valid for particles size less than 0.1 mm; in which the viscous force is predominant over the inertial force. This is called stream line settling.
- If however, the settling particles are larger than 1.0 mm, the nature of settling becomes turbulent settling, and is governed by Newton's equation given by

$$\boxed{V_s = 1.8\sqrt{g \cdot d(G-1)}} \quad \text{for } d > 1.0 \text{ mm.}$$

- For particle size between 0.1 mm and 1 mm lie in the transition zone, settling velocity given as

$$\boxed{V_s = 418(G-1)\frac{3T+70}{100}} \quad \text{for } 0.1 \text{ mm} < d < 1 \text{ mm}$$

**Example 4.4** Match List-I (Equation/Law) with List-II (Related Application) and select the correct answer using the codes given below the lists:

| List-I | List-II |
|---|---|
| A. Chick's law | 1. Discrete particle settling |
| B. Darcy-Weisbach equation | 2. Head loss in a pipe |
| C. Stoke's equation | 3. Head loss in filters |
| D. Carmen-kozeny equation | 4. Rate of bacterial kill |

Codes:

| | A | B | C | D |
|---|---|---|---|---|
| (a) | 4 | 2 | 1 | 3 |
| (b) | 3 | 1 | 2 | 4 |
| (c) | 4 | 1 | 2 | 3 |
| (d) | 3 | 2 | 1 | 4 |

Ans. (a)

One of the most important variables in the disinfection is contact time. Harriet Chick observed that for a given concentration of disinfectant, the longer the contact time, the greater the kill. In differential form, Chick's law is

$$\frac{dN_t}{dt} = -kN_t$$

$\frac{dN_t}{dt}$ is rate of kill of pathogens with time

k is inactivation rate constant

$N_t$ is number of pathogens at time t.

Karman-Cozeny equation for head loss in filter is

$$h_f = \frac{f'L(1-e)V_a^2}{n^3 g d_p}$$

$h_f$ is frictional head loss through bed of particles of uniform size $d_p$ in metre.

$n$ is porosity of bed

$V_s$ is filtering velocity $= \frac{Q}{A_s}$ m/s

$d_p$ is diameter of filter media grains, $m$

Friction factor, $$f' = 150\frac{(1-n)}{Re} + 1.75$$

$$Re = \frac{\phi\rho_w V_s d_p}{\mu}$$ where $\phi$ is the shape factor

**NOTE:** The actual settling velocities in the sedimentation basin will be much less than the those calculated from theoretical formulae, because of

(i) Non-sphericity of the particles

(ii) Upward displacement of fluid caused by the settling of other particles.

(iii) Convection currents

**Example 4.5** **Which one of the following types of settling phenomenon can be analyzed by the classic sedimentation laws of Newton and Stokes?**

**(a) Discrete settling** **(b) Flocculent settling**

**(c) Hindered settling** **(d) Compression settling**

Ans. (a)

**Example 4.6** **Find the settling velocity of a discrete particle in water under conditions when Ryenold's number is less than 0.5. The diameter and specific gravity of the particle is 5 × $10^{-3}$ cm and 2.65, respectively. Water temperature is 20°C(Kinematic viscosity v of water at 20°C =1.01 × $10^{-2}$ cm²/sec )**

***Solution:***

Using Stoke's equation

$$V_s = \frac{g}{18}(G-1)\frac{d^2}{\nu} \text{ when } d < 0.1\text{mm}$$

and c.g.s.units, we have

$$V_s = \text{settling velocity in cm/sec} = \frac{g}{18}(G-1).\frac{d^2}{\nu} \text{ when } d < 0.1\text{mm}$$

where

$G = 2.65$

$d = 5 \times 10^{-3}$ cm = 0.05 mm, which is < 0.1 mm

$\nu = 1.01 \times 10^{-2}$ cm²/sec

$g = 981$ cm²/sec

$$\therefore \quad V_s = \frac{981}{18}(2.65-1)\cdot\frac{\left(5\times10^{-3}\right)^2}{1.01\times10^{-2}} \text{ cm/sec}$$

$$= \frac{981}{18}\times\frac{1.65\times25\times10^{-6}}{1.01\times10^{-2}} \text{ cm/sec} = \mathbf{0.2226 \text{ cm/sec}} \quad \ldots(i)$$

Also, $$V_s = 418(G-1)\cdot d^2\cdot\left(\frac{3T+70}{100}\right) \text{for } d < 0.1\text{mm}$$

where,

$G = 2.65$

$d = 5 \times 10^{-3}$ cm = 5 × $10^{-2}$ mm

$T = 20$°C

$$\therefore \quad V_s(\text{in mm/sec}) = 418(2.65-1)(5\times10^{-2})^2\left(\frac{3\times20+70}{100}\right)$$

$$= 418 \times 1.65 \times 25 \times 10^{-4} \times 1.3$$

or $$V_s = 2.24 \text{ mm/sec} = 0.224 \text{ cm/sec} \quad \ldots(ii)$$

$$\therefore \quad V_s = 0.224 \text{ cm/sec (maximum of } (i) \text{ and } (ii))$$

**Example 4.7** **Find the terminal settling velocity of a spherical particle with diameter 0.5 mm and specific gravity of 2.65 settling through water at 20°C.**

***Solution:***

1. Assume laminar flow from equation, $Re = \frac{\phi V_s \rho_{w\times d}}{\nu}$ with $\rho_w = 998.2$ kg/m³ and $\mu = 1.002 \times 10^{-3}$ N.s/m² at 20°C

$$V_s = \frac{9.81 \text{ m/s}(2650-998.2)\text{kg/m}^3 \times \left(5.0\times10^{-4}\right)\text{m}^2}{18\times1.002\times10^{-3} \text{ N}\cdot\text{s/m}^2}$$

(Recall that the units of $N$ are kg-m/s²)

$V_s = 0.22$ m/s

2. Check Reynold's number:

$$Re = \frac{0.22 \text{ m/s} \times 5\times10^{-4} \text{ m} \times 998.2 \text{ kg/m}^3}{1.002\times10^{-3} \text{ N}\cdot\text{s/m}^2} = 112, \text{ which indicates transitional flow}$$

3. $$C_D = \frac{24}{112} + \frac{3}{112^{1/2}} + 0.34 = 0.84$$

4. $$V_s^2 = \frac{4}{3}\times9.81\times\frac{(2650-998.2)}{0.84\times998.2}5\times10^{-4}$$

$V_s = 0.11$ m/s

5. With $V_s = 0.11$, repeat steps 2, 3 and 4

$Re = 55$

$C_D = 1.18$

$V_s = 0.10 \text{ m/s} \simeq 0.11 \text{ m/s}$

6. Also, for 0.1 mm < d < 1 mm

$$V_s = 418(G-1)d\frac{3T+70}{100} = 418(2.65-1)\times 0.5\times\frac{3\times 20+70}{100}$$

$$= 418\times 1.65\times 0.5\times 1.3 = 448.305 \text{ mm/s} = 0.448 \text{ m/s} \quad ...(ii)$$

from (i) and (ii)

$$V_s = 0.448 \text{ m/s}$$

**Example 4.8** Calculate the settling velocity of water of a spherical discrete particle of 0.05 mm diameter and specific gravity 2.5. The kinematic viscosity is 1.02 × $10^{-6}$ $m^2$/sec at 19°C. You should also check if the equation used for calculating settling velocity is valid for the case.

***Solution:***

From equation

$$V_s = \frac{gd^2}{18\,\nu}(G_s-1)$$

$$V_s = \frac{981\times(0.005)^2}{18\times(1.02\times 10^{-6})(10^{-4})}\times(2.5-1)$$

$$V_s = 0.2004 \text{ cm/sec}$$

$$V_s = 0.002 \text{ m/sec} \quad ...(i)$$

The above equation is valid for laminar flow condition i.e. when Reynold's Number is less than 0.5. Hence, we should check whether Reynold's Number is less than 0.5 for the given condition.

$$\text{Reynold's Number, } Re = \frac{V_s d^2}{\nu} = \frac{0.002\times(5\times 10^{-5})^2}{1.02\times 10^{-6}} = 49\times 10^{-7} < 0.5$$

i.e the flow is laminar and equation is applicable.

Also, for $d < 0.1$ mm,

$$V_s = 418(G_s-1)d^2\frac{3T+70}{100} = 418(2.5-1)\times(0.5)^2\times\frac{3\times 19+70}{100}$$

$$= 1.99 \text{ mm/sec}$$

$$= 0.00199 \text{ m/sec} \quad ...(ii)$$

from (i) and (ii)

$$V_s = 0.002 \text{ m/sec}$$

### 4.4.3 Type of Sedimentation Tanks

There are two types of sedimentation tank:

(a) Quiescent type (b) Continuous type

**(a) Quiescent Type (Fill and Draw Type):** Tank is filled with incoming water and is allowed to rest for detention period.

- Generally, 24 hrs detention period is provided and 6 to 12 hrs required for sludge removal (i.e. cleaning the tank), therefore total cyclic operation need 30 to 36 Hrs.
- Hence, minimum three tanks are required to maintain constant supply.

**Remember:** Tanks are designed to treat maximum daily demand i.e. 1.8 times of average daily demand.

These are obsolete nowadays:

**(b) Continuous Flow Type:** The aim of design is to achieve ideal condition of equal velocity at all the points.

Continuous types are most popular. Depending on their shape, they are classified as:

(a) Circular (b) Rectangular (c) Square

Depending on type of flow, thy may be of following two types:

(i) Horizontal flow or Radial flow (ii) Vertical flow or Circular (Upward flow)

**Detention time:** This is the theoretical time that the water is detained in settling basin.

- It is evaluated or the volume of the tank divided by the rate of flow and is denoted as $t_d = \frac{V}{Q}$.
- Thus, it is that time which would be required by the flow of water to fill the tank if there where no outflow.

∴ Detention time '$t_d$' for a rectangular tank $= \frac{\text{Volume of tank}}{\text{Rate of flow}} = \frac{V}{Q}$

$$\boxed{t_d = \frac{BLH}{Q}}$$

Also, detention time for a circular tank

$$\boxed{t_d = \frac{D^2(0.011D+0.785H)}{Q}}$$

where, $D$ = Diameter of the tank
$H$ = Vertical depth at wall or side water depth
$B$ or $L$ = Width and length of the rectanguler tank respectively

**Horizontal Flow Rectangular Sedimentation Tank**

Rectangular horizontel flow type provide the most effective use of land area because of their configuration which posses hydraulic problems at inlet and outlet section in relation to establishing quiescent condition in the settling zone.

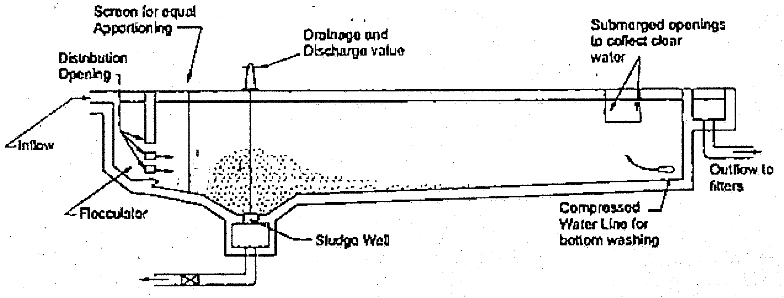

*Fig. 4.11* Horizontal Flow Sedimentation Tank

### Assumption in Horizontal Flow Rectangular Sedimentation Tank

1. Settling of particles is same as in case of quiescent type of equal depth.
2. The flow is horizontal and steady and settling velocity is uniform.

3. The concentration of suspended particle of each size is same at points of the vertical cross-section at inlet end.
4. A particle is removed when it reaches the bottom of settling (sludge) zone.
5. Incoming flow is uniformly distributed over the cross-sectional area of the tank.

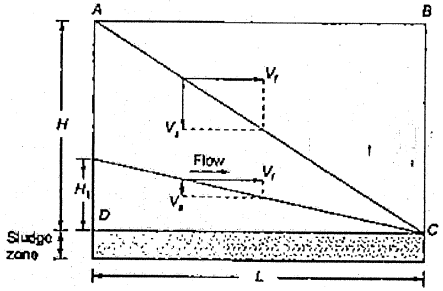

*Fig. 4.12* Rectangular Sedimentation Tank (Elevation)

## Surface Loading/Overflow Velocity

In figure, line diagram of a rectangular tank has been shown. The water containing uniformly distributed sediment entering the rectangular tank with a uniform velocity $V_f$. Let $Q$ is the discharge entering the basin

$$\text{Time of horizontal flow} = \frac{\text{Length of tank}}{\text{Velocity of flow}} = \frac{L}{V_f}$$

and $$\text{Velocity of flow } V_f = \frac{Q}{BH}$$

∴ Time of horizontal flow i.e. detention time

$$t_d = \frac{L}{Q/BH} = \frac{LBH}{Q} = \frac{\text{Volume of tank}}{\text{Discharge}}$$

$$\text{Time of falling through height } (H) = \frac{H}{V_s}$$

If a particle of settling velocity $V_s$ is introduced at the top most inlet point, it will be assumed to be removed if time of falling through it is equal to detention time.

$$\Rightarrow \qquad \frac{H}{V_s} = \frac{LBH}{Q}$$

$$\Rightarrow \qquad \boxed{V_s = \frac{Q}{BL}}$$

- This quantity, $V_s = \frac{Q}{BL}$ is called surface overflow rate.
- Hence, surface overflow rate can be thought of as settling velocity of that particle which if particle introduced at the top most point at inlet will reach the bottom most of point at outlet.

In figure, line diagram of a rectangular tank has been shown. The water containing uniformly distributed sediment enters the rectangular tank with a uniform velocity $V$. Let $Q$ is the discharge entering the basin.

$$\therefore \qquad \text{Flow velocity} = V_f = \frac{Q}{BH} \qquad \text{...(i)}$$

where, $B$ = width of basin
and $H$ = depth of water in the tank

Each discrete particle is moving with a horizontal velocity $V_f$ and a downward velocity $V_s$. The resultant path is given by the vector sum of its flow velocity $V_f$ and settling velocity $V_s$.

Assuming that all particles whose path of travel are above the line AC will pass through the basin, from geometric considerations, it can be said that:

$$\frac{V_f}{V_s} = \frac{L}{H} \qquad \text{...(ii)}$$

or $$V_s = \frac{V_H \cdot H}{L} \qquad \text{...(iii)}$$

Putting value of $V_f$ in equation (iii) from equation (i), we get

$$V_s = \frac{Q}{BH} \cdot \frac{H}{L} = \frac{Q}{BL} \qquad \text{...(iv)}$$

- This shows that all particle having a settling velocity equal or greater than $Q/BL$, will settle down and be removed and hence, no particle having a settling velocity more than or equal to $Q/BL$ will remain suspended in the tank.
- Some particles having settling velocities lower than ($Q/BL$) will also settle down, if they enter at some other height $H_1$ of the tank.
- In that case, when particles enter at some other height $H_1$ of the tank, all particles having their settling velocities $\geq \left(\frac{H_1}{H}\right) \cdot \left(\frac{Q}{BL}\right)$ will settle down.
- If $N_0$ is the number of particles of a given size that have settled out and N being the total number of particles at that size, then percentage of that particular sized particles, which will be removed is $N_0/N$ and is equal to $H_1/H$ for an uniform distribution of particles.
- If 75% of particles of a particular size are proposed to be removed in the settling tank, then the settling velocity of that sized particles must be kept $\geq \left(\frac{75}{100}\right)\left(\frac{Q}{BL}\right)$ i.e. $Q/BL$ at that tank should be kept less than or equal to $\frac{100}{75}$ × settling velocity of that sized particles.
- Hence, it is inferred that quantity $Q/BL$ i.e. the discharge per unit plan area is a very important term for the design of continuously flow type of settling tanks and is known as overflow rate or surface loading or critical settling velocity or overflow velocity.
- Normal volume of surface loading or overflow ranges between 500 – 750 litre/hr/m$^2$ of plan area for horizontal plain sedimentation tanks and between 1000 – 1250 litres/hr/m$^2$ of plan area after coagulants aided tanks.
- The smaller particles will also settle down if the overflow rate is reduced.
- For a given value of a overflow, the rate can be reduced by increasing the plan area of the basin.

---

**Remember:** Theoretically depth does not have any effect on the efficiency of sediment removal.

Weight of particles size such that its settling velocity is less than overflow rate which gets removed.

$$= \left(0.857 \times \frac{15}{100} + 0.7142 \times \frac{20}{100} + 0.5714 \times \frac{10}{100}\right) \times 1000$$

$= 328.545$ grams

$\therefore$ Total removal $= 550 + 328.545 = 878.545$

$\therefore$ Efficiency of sedimentations tank

$$= \frac{878.545}{1000} \times 100 = 87.8545\%$$

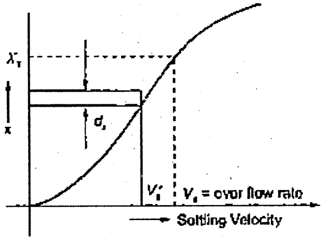

*Fig. 4.13*

**NOTE**

Efficiency of sedimentation tank indicates the overall percentage removal of suspended matter at a given overflow rate.

When the particles in the water are of all possible sizes, we use cumulative frequency distribution curve to find out overall efficiency of settling tank.

where,

$x$ = fraction of particles having settling velocity less than stated velocity

$x_s$ = fraction of particle having velocity less than over flow rate.

$(1 - x_s)$ = fraction of particle having settling velocity greater than over flow rate

(These particles are removed to the extent of 100%)

Weight fraction removal of particles having setting velocity less than overflow rate.

$$= \int_0^{x_s} \frac{V_s'}{V_s} \times dx$$

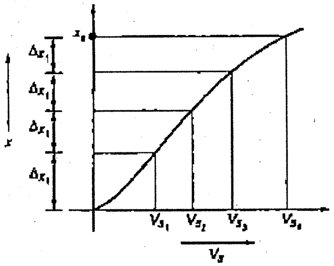

*Fig. 4.14*

$$\text{Overall percentage removal} = (1 - x_s) + \int_0^{x_s} \frac{V_s'}{V_s} \times dx$$

$$(1 - x_s) + \int_0^{x_s} \frac{V_s'}{V_s} \times dx = (1 - x_s) + \frac{\Sigma V_s \Delta x}{V_s}$$

**NOTE:** For a given particle size distribution efficiency will increase if overflow rate is decreased.

As per the ideal conditions each batch of water is supposed to remain in the tank for detention time i.e. the time to reach from the inlet to outlet.

where, Detention $(t_d) = \frac{V}{Q}$ $V$ = Volume of tank ; $Q$ = Rate of flow

- In actual working tanks, these ideal flow conditions do not exist due to currents induced by the inertia of incoming fluids, turbulent flow, wind stress, density and temperature gradient.
- The deviation at actual flow of tank from the pattern of ideal tank is called short-circuiting.
- So, in short-circuiting condition, top layers of water has detention time ($t$) which far less than the detention time of bottom layer.
- The degree of short-circuiting is the deviation of actual flow pattern to the ideal flow pattern. Hence

$$\text{Displacement efficiency} = (\eta_d) = \frac{\text{Flow through period}}{\text{Theoretical detention time}} \times 100$$

- Generally, the displacement efficiency is greater than 30%.

**NOTE:** If the overflow rate is increased, the efficiency of sedimentation tank is decreased and vice-versa.

### 4.4.4 Tube Settlers

In general, the particles settling efficiency of the sedimentation tank is primarily dependent upon the surface area of the tank and independent of its depth.

- Due to this reason, the sedimentation basin should be made as shallow as possible.
- Attempt have, therefore, been made to place horizontal trays in the tank, to divide the tank height into compartment, to reduce the depth and to provide multiple surface area (i.e. increased surface area).
- By doing so, reducing the surface overflow rate and hence causing more particle settlement. But due to clogging and biological growth, these arrangements are obsolete now a days.
- However, very small diameter tubes having high wetted perimeter relative to wetted area, providing laminar flow condition and low surface loading rate, have shown good clarification.
- Such tube settling devices called tube settlers, whose detention time is less than or equal to 10 minutes.

### 4.4.5 Common Design Criteria for Sedimentation Tank

While designing a sedimentation tank, following guidelines should be observed for its satisfactory performance.

**Table 4.2**

| Type | Q/A, (m³/day per m²) | | |
|---|---|---|---|
| | **Normal Condition** | **Easy Condition** | **Very Bad Condition** |
| Without Coagulant | 18 | 24 | 9 |
| With Coagulant | 27 | 36 | 18 |

1. **Velocity of flow:** Not greater than 30 cm/min for horizontal flow tanks.
2. **Detention period:** For plain sedimentation 3 to 4 hours and for coagulated sedimentation 2 to $2\frac{1}{2}$ hours.
3. **Surface loading or Overflow rate or Surface overflow rate (SOR):**
   (a) For plain sedimentation for normal water = 12000 to 18000 l/d/m² of tank area.
   (b) For thoroughly flocculated water 24,000 to 30,000 l/d/m² of tank area.
   (c) For horizontal flow circular tank 30,000 to 40,000 l/d/m² of tank area.
4. **Tank dimensions:** $L : B$ should be 3 to 5 : 1. If $L/B$ is more, chance of short circuiting is less. Generally length provided is 30 m and in extreme case, it may be take as 100 m. Breadth 6 m to 10 m.
   **Circular tank:** Diameter not greater than 60 m. Common size is 20 m to 40 m.
5. **Depth:** 2.5 m to 5 m (Generally, 3 m are more common). Depth of tank does not affect the efficiency of tank.
6. **Slope:** 1% towards inlet and circular 8%.

**Example 4.13** **The average daily demand of a town has been estimated as 8 million litres per day. Design a suitable sedimentation, tank assuming a detention period of 5 hours and velocity of flow as 22 cm per minute.**

***Solution:***

∴ Average daily demand = 8 million litres

∴ Maximum daily demand = 1.8 × 8 = 14.4 million litres = $14.4 \times 10^6$ litres

Quantity of water to be treated during the detention period of 5 hours

$$= \frac{14.4 \times 10^6}{24} \times 5 \text{ litres} = 3 \times 10^6 = 3 \times 10^3 \text{ cubic meters} = 3000 \text{ cubic meters}$$

∴ Capacity of tank = 3000 cubic meters

Velocity of flow to be maintained through the tank = 22 cm/min = 0.22 m/minute

The length of tank required = Velocity of flow × Detention period = 0.22 × (5 × 60) = 66 m

Cross-sectional area of the tank required

$$\therefore = \frac{\text{Capacity of the tank}}{\text{Length of the tank}} = \frac{3000}{66} = 45.45 \text{ m}^2, \text{ say } 45.5 \text{ m}^2$$

Assuming water depth in the tank as 4 m, the width of the tank $= \frac{45.5}{4} = 11.37$ m = Say 11.5 m

Hence, size of the tank = 66 m × 11.5 m × 4 m

**NOTE:** For tank without mechanical sludge removal equipment, additional 0.8 to 1.2 m depth is provided for storage of sludge. It is called sludge zone.

**Do you know?** Sedimentation tank should be designed for maximum daily flow.
Maximum daily flow = 1.8 × Average daily flow

### 4.4.6 Sludge Removal from Sedimentation Tank

The suspended material with raw water settle down at the bottom of the sedimentation tank and it has to be removed periodically because retention of sludge beyond limit reduces the capacity of the tank and detention period.

- In addition, it leads to formation and evolution of certain foul gases due to the deposition of the settled organic matter.
- They are cleaned from time to time either manually or by the mechanical arrangements provided in the tank for cleaning.
- For annual cleaning, tank is first put out of service and the supply of raw water is discontinued and another clean tank is put in service for sedimentation. The contained water of the tank to be cleared is drained off till the depth remains around 30 cm. The sludge is stirred and removed through a separate pipe provided with a gate valve at the bottom of the tank.
- In the mechanical process, sludge is scrapped and brought to the hopper at the outlet end and is removed daily or periodically depending upon the sludge deposition.

### 4.4.7 Circular Sedimentation Tank

In circular tank, horizontal flow velocity of water is continuously decreasing as the distance from the centre increases.

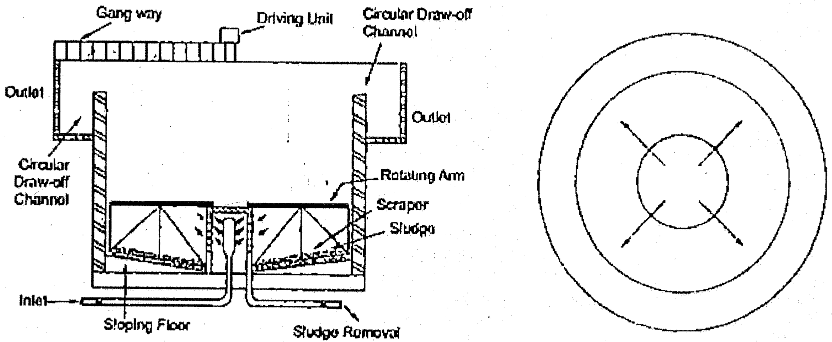

*Fig. 4.15* Circular Sedimentation Tank

Hence, particle path will be parabolic as opposite to straight line path in case of horizontal flow tank.

**NOTE:** This statement is valid only for discrete particle settling.

Volume of circular tank is given by

$$V = D^2(0.785\,H + 0.011\,D)$$

$$Q \times t_d = \text{Volume}$$

where, $H$ = Height of tank in (m); $D$ = Dia in (m); $t_d$ = Detention time

$$\text{Over flow rate} = \frac{Q}{\frac{\pi D^2}{4}}$$

- Weir loading rate $= \frac{Q}{\pi D}$
- Basically, weir, rate affects lighter particle (flocs) clarification.
- Weir loading rate is normally taken as 300 $m^3/d/m$ but when settling tank are properly design its value goes upto 1500 $m^3/d/m$.

**NOTE:** In discrete particle settling, particle maintains their identity i.e. the shape, size and specific gravity of particles do not changes while it is going to settle.

**Example 4.14** **A circular sedimentation tank fitted with mechanical sludge removal unit is to treat 4.0 million litres of water per day. The detention period of the tank is 5 hour. If depth of the tank is to be restricted to 3 m, calculated the diameter of the tank.**

***Solution:***

Quantity of raw water to be treated per day = 4 million litres = $4 \times 10^6$ litres

Quantity of raw water to be treated during the detention period i.e. capacity of tank $= \frac{4 \times 10^6 \times 5}{24}$

$= 833 \times 10^3$ litres = 833 cubic meters

The capacity of a circular tank of depth $H$ and Dia $D$ is given by

$$\text{Volume} = D^2(0.011D + 0.785H)$$

$$\therefore \quad 833 = D^2(0.011D + 0.785 \times 3) = D^2(0.011D + 2.355)$$

Solving by trial $D = 18.06$ m

Hence, diameter of the tank = 18.06 m

### 4.4.8 Multi-storey Tank

Where space is limited, as for structural cheapness, multi-storey tanks are made.

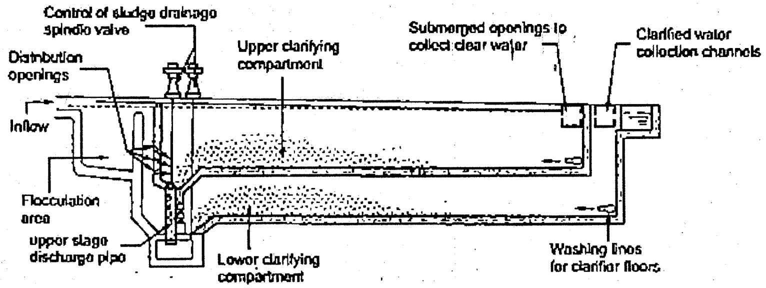

*Fig. 4.16* Multi-storey basin (Storeys working in parallel)

- It has been found that output from a basin has doubled by the construction of a floor at mid-depth in a conventional tank because of doubling the effective area (and halving the effective depth).
- As area is an important factor in settling, multi-storey tanks are found to be cheaper and effective.
- A typical example of such tank designed to treat 7500 $m^3$/day has following criteria.
  Flocculators – detention time 20 min
  Settling tanks – detention time 105 min – total capacity 585 $m^3$.

### 4.4.9 Upward-flow Basin

These are two types:

(a) Hopper-bottomed sludge blanket basins (b) The pulsator

**(a) Hopper-Bottomed Sludge Blanket Basins**

A typical cross-section of a hopper bottomed sludge basin has been shown in figure.

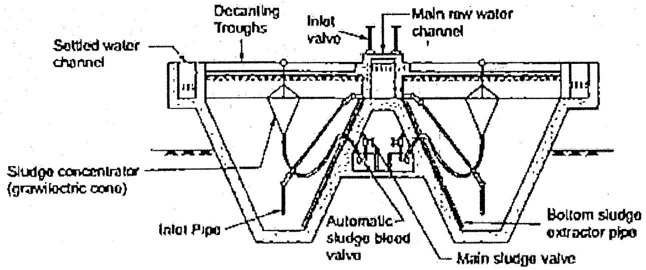

*Fig. 4.17* Hopper Type Settling Tank

The raw water commonly with coagulants is admitted. After flash mixing at the bottom of inverted pyramidal base it passes slowly upward through a zone of previously deposited sludge.

- This acts to flocculate and entropy the floc particles and greatly improves clarification.
- They are also used as water softening plants.
- The permissible maximum upflow rate is kept around 4-4.5 m/h.
- The hopper-bottomed upward flow tanks are more suitable for small works less than 45,000 $m^3$/day.

**(b) The Pulsator**

The pulsator is another type of upward flow tank, which depends on a sludge blanket for its effectiveness.

- It also combines the merit of having a flat bottom with the operating simplicity of the hopper bottom tanks.
- Water in the tank is admitted at varying rates of inflow. The sludge blanket expands during the period of maximum upflow and contracts as soon as inflow diminishes.
- A pulsator in which piston spring effect is obtained by the pulsing movement induced by the variation in flow is shown in figure.

**Basin Failure**

When the silt content in the river becomes excessively high, upward flow basins are more prone to failure than those working on horizontal flow principle.

A basin fails due to any of the following reasons:

(*i*) Suspended solids are not precipitating

(*ii*) The precipitated solids are not ejected fast enough due to which the tank becomes silt-logged.

### 4.4.10 Decrease in Efficiency of Sedimentation Tank

There is decreases in efficiency or effectiveness of sedimentation, when one or more of the following conditions is present:

(a) Excessive suspended solids

(b) Coincidence of peak output with peak turbidity

(c) Low coefficient of fineness

(d) Liability of streaming

(e) Overrun of water in the basin

## 4.5 Sedimentation with Coagulation

- When the suspended particles are very fine, the efficiency of sedimentation tank is very low.
- Coarse solids are effectively removed by sedimentation process because their size makes capable them to settle by gravity.
- Solids, which are not coarse, more so if they are colloidal than it pass alongwith the effluents of the settling basins.
- The colloidal dispersion is defined as stable when the dispersion shows little or no tendency to aggregate.
- For settlement of colloidal particles aggregation is essential. The aggregation of colloidal particles requires:
  - (a) Particle destabilisation to permit attachment when contact occurs
  - (b) Agglomeration of the destabilized particles.
- Colloidal particles are small in size, therefore, the ratio of surface area to mass is high.

- **Coagulation is defined as the addition of a chemical to a colloidal dispersion which result in particle destabilization by the reduction in force, which tend to keep particles apart.**
- **The chemical added is called the** COAGULANT.
- **Coagulation results** in the reduction of surface charges and the formation of precipitable complex hydrous oxides.
- The process involves the agitated addition of the coagulant and the forming of either flocculent suspensions of compounds, which entrap undesired constituents and carry them out of solution or the formation of insoluble precipitate of the undesired constituents themselves.
- Example of the former include organic suspended and colloidal matter and while the latter include precipitates of phosphorus and heavy metals.
- Most microscopic and colloidal particles are stabilized by the formation of layers of ions, which tend to collect around the particle and form a protective barriers for stabilization.
- These ionic layers tend to act or part of the particle and travel with it through solution, inhibiting the close approach of respective particles to each other.
- Both the thickness of the ionic layers and the surface charge density are sensitive to the concentration and the valence of ions in solution.
- So, the stability of a suspension may be markedly affected or altered by adding suitable ions with large positive charge (i.e. aluminium and iron salts) into the solution.
- The "Zeta potential" is a measure of the stability of particle and indicate the potential which would be required to penetrate the layer of ions surrounding the particle for destabilization. Hence, the higher the zeta potential, the more stable the particle.
- Main purpose of coagulation is to reduce the zeta potential by adding agglomerate.
- The suitable ions are generally provided by aluminium salts, iron salts, lime and various polymers which are common coagulants.
- Where floc formation is poor, coagulate aids are added.
- By producing a heavier, faster settling floc, this allows smaller basins to be used and smaller doses of the main coagulants may also be possible.
- The choice of the best coagulant and its dose for any particular water is determined by an experiment known as Jar test which will be described subsequently.

### Diffused Double Layer Theory

As per this, theory of stability of colloids depends on the electrical charge that they posses.

- The primary charge of the colloids are mostly due to charged groups within the particle surface or due to adsorption of a layer of ions from the surrounding medium.
- A colloidal dispersion (solid and aqueous phase) as a whole does not have a net electrical charge so the primary charge on the particle must be counter balanced by ions of opposite charge in the aqueous phase (water phase).
- An electrical double-layer theory is formed at the interface between solid and water as shown in figure 4.18.

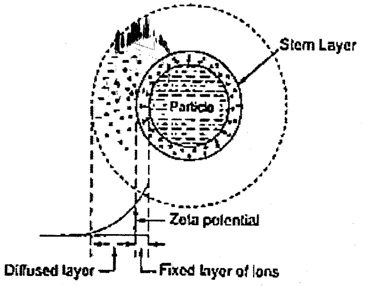

*Fig. 4.18* Diffused Double Layer Theory

- The double layer consists of
  - (*i*) The charged particle
  - (*ii*) An equivalent excess of oppositively charged counter ions which accumulate in the water near the surface of the particle.
- The counter ions are attached to the solid surface. There concentration is high at the solid surface, diffuse and decrease towards the bulk solution.
- This explanation of the stability of colloids is called the "diffused-double layer" theory.
- An electrical potential exists between the surface of the particle and the bulk of the solution due to the primary charge on the particle.
- A fixed covering of positive ions is formed over the negative charged particle by electrostatic attraction.
- This stationary zone of positive ions is referred to as the stem layer and is surrounded by a movable diffused layer of positive ions.
- The "Zeta potential" is the magnitude of the charge at the surface of stem as shown in figure.
- The Zeta potential is defined as

$$\xi = \frac{4\pi\delta q}{D}$$

where, $q$ = charge of particle,

$\delta$ = thickness of the zone of influence of the charge of particle

$D$ = dielectric constant of the medium.

## 4.6 Mechanism of Coagulation

The mechanism of destabilization (Removal of "little or no tendency of colloids to aggregate") of colloids are classified in four types:

| | |
|---|---|
| (a) Ionic layer compression | (b) Adsorption and charge neutralization |
| (c) Sweep coagulation | (d) Interparticle bridging |

(a) **Ionic Layer Compression:** Total quantity of ions in water surrounding a colloid has an effect on reducing the repulsive force.

- A high ion concentration compresses the layer composed predominantly of (+ve) charge ions towards the surface of colloid. But if this layer is sufficiently compressed, then attractive forces (Vander waal force) will be predominant. Thus the particles will grow in size. Thus they will be removed in sedimentation tank.

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**NOTE:** This mechanism generally does not occur in water, generally, this occur in case of delta formation.

(b) Adsorption and Charge Neutralization:

- Nature rather than quantity of ion is of prime importance in the theory of adsorption and charge neutralization. If alum is added in water, then it will form $Al^{3+}$ and $SO_4^{2-}$. The sulphate ion ($SO_4^{2-}$) may remain in this form or may combined with other cations like $Na^+$, $Mg^{2+}$.
- However, $Al^{3+}$ ion will react immediately with water to form various aquometallic cations like $Al(OH)^{2+}$, $Al(OH)_2^+$, $Al_7(OH)_{17}^{4+}$, $Al(OH)_3$ ppt, $H^+$.

These cations surrounds the clouds of (–ve) charge and as they have an affinity for surface, they are adsorbed on to the surface.

- Finally, when the charge is neutralize, free contact can occur. Thus, size increases and settling takes place.

- This shows that electrostatic forces are not the only driving forces for destabilisation but also adsorption. Otherwise, restabilisation would have been produced.

(c) Sweep Coagulation

- $Al(OH)_3$ formed when alum is added to water is a amporphous (shapeless) and gelatinous (sticky) precipitate.
- These are heavier than water and settle down by gravity.
- Colloids may become entrapped in the flocs as the flocs settle down.
- This process by which colloids are swept away from the system in this manner is called sweep coagulation.

(d) Inter-Particle Bridging

- Large molecules may be formed when aluminum or ferric sulphate dissociate in water like $Al_7(OH)_{17}^{4+}$.
- Several colloids may become attached to one molecular or various molecules may get enmeshed resulting in settleable mass.
- Polymer may also be used either alone or in combination with alum or iron salts.

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**NOTE:** Selection of optimum doses of coagulents is determined experimentally by Jar test.

They study of relationship among pH, colloidal concentration of water and optimum coagulant dose is necessary for satisfactory operation of a coagulation process.

1. High turbidity – Low alkalinity of water
2. High turbidity – High alkalinity of water
3. Low turbidity – High alkalinity of water
4. Low turbidity – Low alkalinity of water

1. **High Turbidity-Low Alkalinity of Water:** This type of water is coagulated with low doses of coagulants. The optimum coagulant dosage has to be estimated for destabilization of colloids.
   - Reduction of pH (4 to 6) can occur by ionization of coagulants, which gives hydroxometal polymers ($Al(OH)_3$) or aquometallic ions [$Al(OH)_2^+ + Al(OH)^{2+}$].
   - These metal ions adsorb on the colloids because they have or great affinity for surfaces where they neutralize the surface charge.
2. **High Turbidity-High Alkalinity of Water:** This type of water is unaffected by the addition of coagulants. The reduction of pH is less and remain in the neutral religion.
   - Hence, adsorption and charge neutralization will be less effective than in low turbidity water.
   - Higher coagulant dosage should be used to ensure sweep coagulation.
3. **Low Turbidity-High Alkelinity of Water:** Due to low colloidal concentration, the low dose coagulation is less effective.
   - Hence, high coagulant dosages will enmesh the colloidal particles and form "Sweep floc".
   - Addition of coagulant aid (e.g. Bentonites clay) will help to reduce the high coagulant dosage.
4. **Low Turbidity-Low Alkalinity of Water:** Because of low colloidal concentration is the most difficult and low alkalinity permits the effective formulation of $Al(OH)_3$ floc.
   - It may be useful to add both turbidity and alkalinity.

### Commonly Used Coagulatnts

- The most commonly used water treatment coagulant is based primarily on Aluminium and Iron salts. Lime is used as a secondary coagulant in drinking water treatment but as a primary coagulant in waste water treatment.
- Natural polyelectrolytes have been used for many years in several developing countries for clarifying water.
- For instance John (1979) reports that in several African countries (Chad, Nigeria, Sudan) indigenous plants are added to drinking water by rural villages to remove turbidity, taste and odour.
- The common coagulants added in water:
  - (a) Alum
  - (b) Copperas
  - (c) Chlorinated copperas
  - (d) Sodium aluminate
  - (e) Lime

(a) Alum: Chemical formula of alum is $Al_2(SO_4)_3 \cdot 18H_2O$

- Alum react with $HCO_3^-$ alkalinity to form gelatinous precipitate of $Al(OH)_3$.
- This attracts other fine particles and suspended matter, thus grow in size and finally settle.

$$Al_2(SO_4)_3 \cdot 18H_2O + 3Ca(HCO_3)_2 \longrightarrow \underset{\text{Permanent Hardness}}{3\,CaSO_4} + 2\underset{\text{ppt}}{Al(OH)_3} \downarrow + 6CO_2 \uparrow + 18\,H_2O$$

So, this reaction introduces permanent hardness in water and makes water corrosive.

- The turbidity and colour of raw water determines the dose of coagulant (alum) and this amount is estimated.
- By Jar test in laboratory to form a gelatinous precipitate (floc) of aluminium hydroxide.
- Normal alum dose is 10-30 mg/litre of water and is very effective in the pH range of 6.5 to 8.5.
- Alum coagulant is cheap and the flocs formed are very stable.
- Alum also reduces colour, taste and odour but only disadvantage is that it is difficult to dewater the sludge formed.

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**NOTE:**
- 1 mole of alum gives 2 moles of $Al(OH)_3$.
- 666 gm of alum gives 2 × 78 gm of $Al(OH)_3$.

### Alkalinity Coagulation Relationship

The coagulation of metallic salts release hydrogen ion ($H^+$). These $H^+$ neutralise alkalinity and if initial alkalinity of a water is low, coagulation will result in further reduction of pH.

- Proper pH values must be maintained for best coagulation and since alkalinity must be present for hydroxide floc formation, low alkalinity water must be added with lime [$Ca(OH)_2$] or soda ash [$Na_2CO_3$] to increase the alkalinity.
- If alkalinity is insufficient in water, lime [$Ca(OH)_2$] or soda ash ($Na_2CO_3$) may be added in water.

$$Al_2(SO_4)_3 \cdot 18H_2O + 3Ca(OH)_2 \longrightarrow \underset{\text{Permanent Hardness}}{3\,CaSO_4} + 2\underset{\text{ppt}}{Al(OH)_3} \downarrow + 18\,H_2O$$

$$Al_2(SO_4)_3 \cdot 18H_2O + 3Na_2CO_3 \longrightarrow 3\,Na_2SO_4 + 2\underset{\text{ppt}}{Al(OH)_3} \downarrow + 3CO_2 + 15\,H_2O$$

(b) Copperas: Copperas is the name given to ferrous sulphate with its chemical formula as $FeSO_4 \cdot 7H_2O$.

- Copperas is generally added to raw water in conjunction with lime. Lime may be added either to copperas or vice-versa.

- When lime is added first, the following reaction takes place:

$$(i)\ \underset{\text{Copperas}}{FeSO_4 \cdot 7H_2O} + \underset{\text{Hydrated lime}}{Ca(OH)_2} \longrightarrow CaSO_4 + \underset{\substack{\text{Ferrous}\\ \text{hydroxide}}}{Fe(OH)_2} + 7\,H_2O$$

Similarly, when copperas is added earlier to lime, the reaction that takes place is

$$(ii)\ FeSO_4 \cdot 7H_2O + \underset{\substack{\text{Alkalinity present}\\ \text{in raw water}}}{Ca(HCO_3)_2} \longrightarrow Fe(HCO_3)_2 + CaSO_4 + 7\,H_2O$$

$$\text{and } Fe(HCO_3)_2 + \underset{\text{Hydrated lime}}{2Ca(OH)_2} \longrightarrow \underset{\substack{\text{Ferrous}\\ \text{hydroxide}}}{Fe(OH)_2} + 2\,CaCO_3 + 2\,H_2O$$

The ferrous hydroxide formed in either case, further gets oxidised forming hydroxide as given below:

$$4Fe(HCO_3)_2 + O_2 + 2H_2O \longrightarrow 4Fe(OH)_3$$

The ferric hydroxide forms the floc, and thus helps in sedimentation.

- Copperas is extensively used as a coagulant for raw waters that are not coloured. It is generally cheaper than alum, and functions effectively in the pH range of 8.5 and above.
- For coloured raw waters, it is however not used, as its dose not give satisfactory results.

**Do You Know** The quantity of copperas as coagulant, required is almost the same as that of alum but cheaper than alum and more commonly used in industrial softening plants and industrial waste water treatment.

**(c) Use of Chlorinated Copperas as Coagulant :** When chlorine is added to a solution of copperas (i.e. ferrous sulphate), the two react chemically, so as to form ferric sulphate and ferric chloride.

- The chemical equation is as follows:

$$6(FeSO_4 \cdot 7H_2O) + 3\,Cl_2 \longrightarrow \underset{\text{Ferric sulphate}}{2Fe_2(SO_4)_3} + \underset{\text{Ferric chloride}}{2FeCl_3} + 2H_2O$$

The resultant combination of ferric sulphate and ferric chloride is known as chlorinated copperas and is a valuable coagulant for removing colours, especially whose raw water has a low pH value.

- Both the constituents of the chlorinated copperas along with lime are effective coagulants and their combination is often quite effective.
- The chemical reactions that take place are given below.

$$Fe(SO_4) + 3Ca(OH)_2 \longrightarrow 3\,CaSO_4 + \underset{\substack{\text{Ferric hydroxide}\\ \text{ppt}}}{2Fe(OH)_3} \downarrow$$

The resulting ferric hydroxide forms the floc, and helps in sedimentation.

- Ferric sulphate is quite effective in the pH range of 4 to 7 and above 9, whereas ferric chloride is quite effective in the pH range of 3.5 to 6.5 and above 8.5.
- The combination has, therefore, proved to be a very effective coagulant for treating low pH waters.

**(d) Use of Sodium Aluminate as a Coagulant:** Besides alum and iron salts, sodium aluminate ($Na_2Al_2O_4$) is also sometimes used as coagulant.

- This chemical when dissolved and mixed with water, reacts with the salts of calcium and magnesium present in raw water, resulting in the formation of precipitate of calcium or magnesium aluminate.
- The chemical reactions that are involved are

$$Na_2Al_2O_4 + Ca(HCO_3)_2 \longrightarrow \underset{\text{Cal. aluminate}}{CaAl_2O_4} + Na_2CO_3 + CO_2 \uparrow + H_2O$$

$$Na_2Al_2O_4 + CaCl_2 \longrightarrow CaAl_2O_4 + 2\,NaCl$$
$$Na_2Al_2O_4 + CaSO_4 \longrightarrow CaAl_2O_4 + Na_2SO_4$$

**Remember** This coagulant is about $1\frac{1}{2}$ times costlier than alum, and is therefore, generally avoided for treating ordinary public supplies, but however, it is very useful for treating water which do not have the natural desired alkalinity, and thus cannot be treated with pure alum.

**NOTE:** This coagulant is widely used for treating boiler feed waters, which permit very low values of hardness.

## Comparison of Alum and Iron Salts as Coagulant

The alum and the iron salts are having their own advantages and disadvantages as summarized below:

1. Iron salts produce heavy floc and can, therefore, remove much more suspended matter than the alum.
2. Iron salts, being good oxidising agents, can remove hydrogen sulphide and its corresponding tastes and odours from water.
3. Iron salts can be used over a wider range of pH values.
4. Iron salts cause staining and promote the growth of iron bacteria in the distribution system.
5. Iron salts impart more corrosiveness to water than that which is imparted by alum.
6. The handling and storing of iron salts require more skill and control, as they are corrosive and deliquescent. Whereas, no such skilled supervision is required for handling alum.

**Do you know?** Iron salts are used as coagulants more frequently for treating sewage, and alum is used more frequently for treating raw water.

**Example 4.15** A dose of 60 mg/*l* of alum is used in coagulating a turbid raw water.
(a) Calculate the natural alkalinity consumed.
(b) What are the changes in the ionic character of water?
(c) What concentration of aluminium hydroxide is produced?

***Solution:***

The equation for the reaction is

$$\underset{666\text{ g}}{Al_2(SO_4)_3 . 18H_2O} + \underset{3 \times 100\text{ g}}{3Ca(HCO_3)_2} \rightarrow \underset{\text{ppt}}{2Al(OH)_3} + 3CaSO_4 + 6CO_2 + 18H_2O$$

(a) From above equation 666.7 g commercial alum reacts with 300 g alkalinity as $CaCO_3$.

∴ 1 mg/*l* alum will require 300/666.7 alkalinity = 0.45 mg/*l*

∴ 60 mg/*l* will require 0.45 × 60 mg/*l* alkalinity = 27 mg/*l* as $CaCO_3$

(b) 60 mg/*l* of sulphate is added to the water as $CaSO_4$. The aluminium ions precipitate out of solution the calcium content is unaffected and 0.60 meq/*l* of bicarbonate is converted to carbon dioxide.

(c) From the equation above

666.7 grams of commercial alum reacts to produce 156 gms of aluminium hydroxide.

$$\therefore \frac{156 \times 60}{666.7} \text{ mg}/l \text{ of } Al(OH)_3 \text{ produced} = 14.04 \text{ mg}/l \; Al(OH)_3$$

**Example 4.16** **A surface water flow 25000 m³/d is coagulated by adding 50 mg/*l* of ferrous sulphate and an equivalent dose of lime. How much lime is required at a purity of 85% CaO?**

***Solution:***

$$\text{Ferrous sulphate consumption} = \frac{50 \text{ mg}/l \times 25000 \text{ m}^3/\text{d}}{1000} = 1250 \text{ kg/d}$$

An equivalent of $FeSO_4$ (139) would react with an equivalent of 85% CaO which is

$$\frac{28}{0.85} = 32.941$$

$$\therefore \quad \text{Lime dose} = 1250 \times \frac{32.941}{139} = 296.23 \text{ kg/day}$$

**Example 4.17** **Determine the quantity of alum required in order to treat 13 million litres of water per day at a treatment plant, where 12 ppm of alum dose is required. Also, determine the amount of carbon dioxide gas which will be released per litre of water treatment.**

***Solution:***

Quantity of water to be treated = $13 \times 10^6$ litres/day

Alum dose required = 12 ppm, i.e., 12 mg/*l*

Amount of alum required per day = $(13 \times 10^6 \times 12)$mg = 156 kg

The chemical reaction which is involved in treating water with alum is given by

$$Al_2(SO_4)_3 \cdot 18H_2O + Ca(HCO_3)_2 \rightarrow 2Al(OH)_3 \downarrow + 3CaSO_4 + 18H_2O + \underset{\text{carbon dioxide}}{6CO_2} \uparrow$$

Now, the molecular weight of alum

$$= 2[26.97] + 3[32.066 + 4\ 16] + 18[2 \times 1.008 + 16]$$
$$= 666.426 \simeq 666 \text{ (say)}$$

The molecular weight of carbon dioxide = $(12.01) + 2(16) = 44.01 = 44$(say)

Now, it means that 666 mg of alum, if used, will release = $6 \times 44$ mg of $CO_2$

$\therefore$ 12 mg of alum will release

$$= \frac{6 \times 44}{666} \times 12 \text{ mg of } CO_2 = 4.76 \text{ mg}$$

Since 12 mg of alum is required for treating 1 litre of water, the quantity of $CO_2$ evolved per litre of water = 4.76 mg

**Example 4.18** **8 mg of copperas is consumed with lime at a coagulation basin, per litre water. Determine the quantity of copperas and the quick lime required to treat 10 million litres of water.**

***Solution:***

Quantity of copperas required per litre of water = 8 mg

Quantity of copperas required per 10 million litres of water.

$$= 8 \times 10 \times 10^6 \text{ mg} = 80 \text{ kg}$$

The chemical reactions that are involved are

$$\underset{\text{Quick lime or lime}}{CaO} + H_2O \rightarrow \underset{\text{Hydrated lime}}{Ca(OH)_2}$$

$$\underset{\text{Copperas}}{FeSO_4 \cdot 7H_2O} + \underset{\text{Hydrated lime}}{Ca(OH)_2} \rightarrow Fe(OH)_2 + CaSO_4 + 7H_2O$$

Now, molecular weight of copperas

$$= [55.85 + 32.066 + 4 \times 16 + 7(2 \times 1.008 + 16)]$$
$$= 278.028 \simeq 278 \text{ (say)}$$

Since one molecule of copperas requires one molecule of lime 278 mg of copperas will require 56 mg quick lime.

$\therefore$ 278 mg of copperas need = 56 mg quicklime

or 1 mg of copperas need = $\frac{56}{278}$ mg quick-lime

or 80 kg of copperas need = $\frac{56}{278} \times 80$ kg quick-lime = 16.12 kg of quick lime

Hence, the quantity of quick lime required at the plant = **16.12 kg**

**Example 4.19** **A coagulation treatment plant with a flow of 0.5 m³/sec is dosing alum at 23 mg/L. No other chemical is being added. The raw water suspended solids concentration is 37 mg/L. The effluent suspended solids concentration is measured as 12 mg/L. The sludge content is 1 percent and the specific gravity of sludge solids is 3.01. What volume of sludge must be disposed of each day? Based on your result, remark with reference to water treatment process.**

***Solution:***

(a), Alum added = 23 mg/L

Alum reacts with alkali in raw water to produce $Al(OH)_3$ solid precipitate, by the equations.

$$\text{(i) } \underset{\text{(Alum)}}{Al_2(SO_4)_3 \cdot 18H_2O} + Ca(OH)_2 \rightarrow CaSO_4 + 2Al(OH)_3 \downarrow + 18H_2O \text{ and}$$

$$\text{(ii) } \underset{\text{(Alum)}}{Al_2(SO_4)_3 \cdot 18H_2O} + 3NaCO_3 \rightarrow 3NaSO_4 + 2Al(OH)_3 \downarrow + 3CO_2 + 15H_2O$$

It eventually means that 1 mole of Alum produces 2 moles of $Al(OH)_3$. The molecular weight of Alum is 666 gm and that of $Al(OH)_3$ is 78 gm.

Hence,

666 gm of alum produces = $2 \times 78$ gm of $Al(OH) \downarrow$ as solid sludge

$$\therefore \quad 1 \text{ gm of alum will produced} = \frac{2 \times 78}{666} = 0.24 \text{ gm of } Al(OH)_3 \downarrow$$

Hence, 23 mg/*l* of Alum will produce

$$= 23 \times 0.234 \text{ mg}/l \text{ of solid sludge}$$
$$= 5.382 \text{ mg}/l \text{ of solid sludge} \qquad \text{...(i)}$$

(b) Suspended solids (turbidity) removed

$$= 37 \text{ mg}/l - 12 \text{ mg}/l = 25 \text{ mg}/l \qquad \text{...(ii)}$$

∴ Total dry sludge (solids) removed = (i) + (ii)

$$= 5.52 + 25 = 30.52 \text{ mg}/l$$

Total flow in the plant $= 0.5 \text{ m}^3/\text{s} = 0.5 \times 24 \times 60 \times 60 \text{ m}^3/\text{day} = 43200 \text{ m}^3/\text{day}$

Total dry sludge solids produced per day

$$= 43200 \text{ m}^3/\text{d} \times 30.52 \text{ mg}/l = 43200 \text{ m}^3/\text{d} \times 30.52 \text{ gm/m}^3$$

$$= 1318464 \text{ gm/day} = 1.318 \text{ t/day} \qquad \ldots\text{(iii)}$$

∴ Volume of sludge solids produced

$$= \frac{1318 \text{ t/d}}{\text{Unit weight of sludge solids}} = \frac{1.318 \text{ t/d}}{3.01 \text{ t/m}^3}$$

(sp. gr. of sludge solids = 3.01, given)

$$= 0.44 \text{ m}^3/\text{day} \qquad \ldots\text{(iv)}$$

Since the sludge content is stated to be 1%, the produced wet sludge will contain 1% solids and 99% water, by weight. It means that 1 tonne of sludge solids will contain 99 tonnes of water and hence 1.318 t/day × 99 = 130.48 t/day.

∴ Volume of water contained in the wet sludge

$$= \frac{130.48 \text{ t/day}}{1.0 \text{ t/m}^3}$$

(∵ unit of weight of water = 1 t/m$^3$)

$$= 130.48 \text{ m}^3/\text{day} \qquad \ldots\text{(v)}$$

Total volume of wet sludge = (iv) + (v)

$$= (0.44 + 130.48) \text{m}^3/\text{day} = 130.92 \text{ m}^3/\text{day}$$

Disposal of such a heavy quantity of water sludge daily will be a difficult task, and hence it would be advisable to take this sludge to the clarifier thickener. The thickend sludge can then be dewatered and disposed of with or without chemical recovery.

It may also be mentioned here that 12 mg/L of suspended solids (about 30%) are still left in the effluent from the clariflocculators and hence it must be subjected to filtration. The filter waste sludge can also be taken to the clarifier thickener along with the sludge of clariflocculator.

The filtered water shall finally be chlorinated for disinfection, before supplying to the public.

**NOTE** It can be seen from the above computation that the solid account for a negligible fraction of the total volume of sludge and that is why sludge dewatering and drying becomes an important requirement for the safe disposal of the sludge from a water treatment plant.

## 4.7 Mixing Device

After the addition of the coagulant to the raw water, the mixture is thoroughly and vigorously mixed, so that coagulant gets fully dispersed into the entire mass of water.

This violent agitation of water can be achieved by mass mixing devices, such as:

1. Centrifugal pumps
2. Compressed air
3. Mixing basins

Out of these, mixing basins are most important and normally adopted.

There are two types of mixing basin, viz.

(a) Mixing basin with baffle walls; and (b) Mixing basin equipped with mechanical devices

**(a) Mixing Basin with Baffle Walls:** The Baffle type mixing basins are rectangular tanks which are divided by baffle walls.

- The baffle may either be provided in such a way as the water flows horizontally around their ends or they may be provided as to make the water move vertically over and under the baffle.

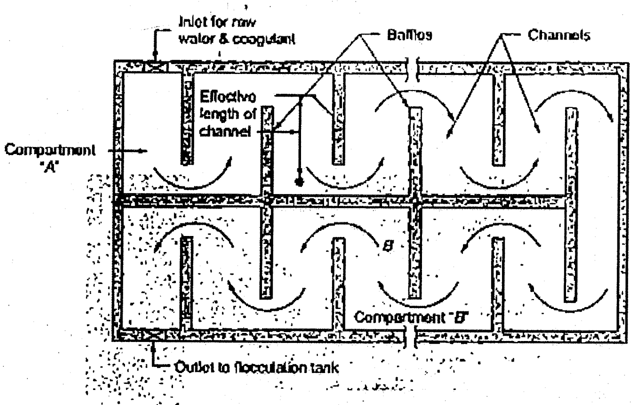


*Fig. 4.19* Plan of "Around the end baffle type" and elevation of "Over and under the baffle type" (i.e. Horizontal flow type) mixing basin.

**NOTE:** Horizontal flow baffle basins are preferred due to ease of clearing.

- The only advantage of the baffle basins is their simplicity, because there is no moving equipment and near plug flow conditions occur with low short-circuiting.
- The head loss through such basin is much greater than that in the basin equipped with mechanical mixer. Therefore baffle type mixing basins are not used in modern days or especially in large plants.

**(b) Mixing Basins Equipped with Mechanical Devices:** Mixing is done in mixing basin or by mechanical mixer. The mechanically agitated mixing basins provide the best type of mixing as also the flocculating devices.

- The chemical added to raw water is vigorously mixed and agitated by a flash mixer for its rapid dispersion in raw water and the water is then transferred to a flocculation tank provided with a slow mixer.

### 4.7.1 Flash Mixture

It consists of a rectangular tank which is provided with an impeller fixed to an impeller shaft. The impeller is driven by an electric motor, and it revolves at high speed inside the tank.

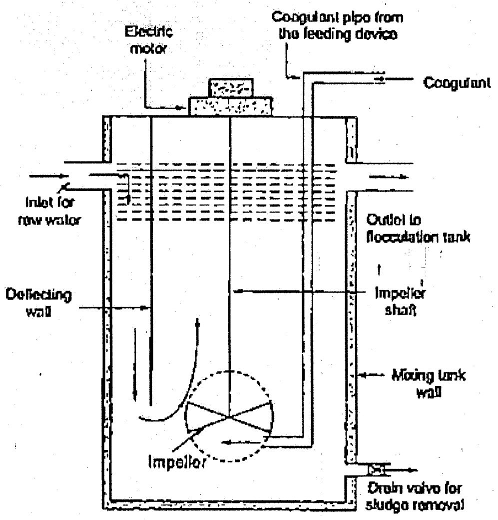
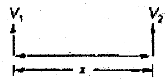


*Fig. 4.20* Mixing basin with a flash mixer

- The coagulant is brought by the coagulant pipe and is discharged just under the rotating fan.
- The impeller's speed is generally kept between 100 to 120 rpm, the usual values of detention period may vary between 1/2 to 2 minutes.
- The raw water and the coagulants are agitated vigorously. The intensity of mixing depends upon temporal mean velocity ($G$). $G$ is a measure of relative velocity of two particles of fluid and distance between them:



$$G = \frac{V_2 - V_1}{x}$$

- Units of $G$ is $\text{sec}^{-1}$.
- Turbulence and the resultant intensity of mixing is based on the rate of power input to the water

$$\boxed{G = \sqrt{\frac{P}{\mu V}}}$$

where, $P$ is power in watts
$m$ is dynamic viscosity in $Ns/m^2$
$V$ is volume of tank in $m^3$

- Propeller type impeller is now mostly used in flash mixer.
- Deep circular or square tank is used.
- $\frac{H}{D \text{ or } B} = 1:1$ to $3:1$, where $D$ is diameter of tank and $B$ is width of tank.
- In this case power requirement is 2-5 watt/m³/hr of flow.
- $\frac{\text{Impeller diameter}}{\text{Tank diameter}} = 0.2 - 0.4$
- Shaft speed is so kept that the tangential velocity greater than 3 m/sec is imparted at the tip of the blade.

**NOTE** The unit of $G$ will evidently be

$$\sqrt{\frac{N \cdot m}{s} \times \frac{m^2}{N \cdot s} \times \frac{1}{m^3}} = \frac{1}{s} \text{ i.e. per second}$$

- For common coagulant of aluminium and iron salts, the value of $G$ for flocculation is usually in the range of 20 to 75 $\text{sec}^{-1}$ with retention time in flocculation chambers varying from about 10 to 60 minutes. the value of $G \cdot t_d$ comes in the range of 12,000 to 27,000.

**Flocculation:** Flocculation is basically slow mixing or agitation process in which destabilized colloidal particles are brought into intimate contact in order to promote agglomeration.

- The ratio of flocculation depend on
  (a) Turbidity (b) Type of coagulant and its dose (c) Temporal mean velocity gradient
- The temporal mean velocity gradient, $G = \sqrt{\frac{P}{\mu V}}$ and

  $G \cdot t_d$ = It is a parameter which is a measure of conjugation opportunity.
- For design $G = 20$ to $75\ \text{sec}^{-1}$ is adopted and $G \cdot t_d$ adopted for alum is $(2 \text{ to } 6) \times 10^4$ and for $FeCl_3$ is $(1 \text{ to } 1.5) \times 10^5$. where $t_d$ is 10 to 30 minutes.

**NOTE:** Larger $G$ and smaller $t_d$ will make small and dence floc, and smaller $G$ and larger $t_d$ will make large and light floc.

- Since large dence flocs are easily removed in the tank it is advantages to vary the G value over the length of flocculation tank.

## Calculation of G

We know that, Power = Drag force × relative velocity of impeller and fluid

$$\text{Power} = F_D \times V_r$$

$$V_r = V_p - V_W$$

where, $$F_D = \frac{C_D \cdot \rho_w \cdot A_p \cdot V_r^2}{2}$$

where, coefficient of drag, $C_D = 1.8$ for paddle with flat plate; $\rho_w$ = density of water; $A_p$ = area of plate

$V_r$ = relative velocity $= V_p - V_w = V_p - KV_p = V_p(1-K)$,

$K = 0.25$ (Normally),

$$\boxed{G = \sqrt{\frac{C_D \cdot \rho_w \cdot A_p \cdot V_r^3}{2 \mu V}}},$$ where $V$ = volume of tank

This equation is also applicable for mixers.

### Design Criteria

- Depth of tank is 3 to 5 m.
- Detention time is 10 to 30 min.
- Total area of paddle is taken as 10 to 25% of the cross-sectional area of tank.
- Peripheral velocity ($V_p$) of plate is taken 0.2 to 0.6 m/sec.
- $G$, temporal mean velocity gradient is 10 - 75 per second for flocculation.
- $G \cdot t_d$ is adopted is 10,000 - 100,000.

**Example 4.20** A flash mixer of 2.0 m³, with a velocity gradient of mixing mechanism equal to 600 $s^{-1}$, and fluid absolute viscosity of $1.0 \times 10^{-3}$ N-s/m² is continuously operated. What is the power input per unit volume?

(a) 360 W (b) 720 W (c) 1440 W (d) 300 W

Ans. (a)

Velocity gradient, $G = \sqrt{\frac{P}{\mu V}}$

Power input per unit volume, $P = \mu G^2 V = 1 \times 10^{-3} \times (600)^2 \times 1 = 360$ W

**Example 4.21** A flocculation chamber 30 m long, 12 m wide and 4.5 deep is to treat 75 MLD of water. It is equipped with 12 m long, 0.3 m wide paddles supported parallel to and moved by four horizontal shafts which rotate at a speed of 2.5 rpm. The centre line of paddle is 1.6 m from the shaft which is at mid. depth of tank. Two paddles are mounted on each shaft one opposite to other. If the mean velocity of water is $\frac{1}{4}$ the velocity of paddle find.

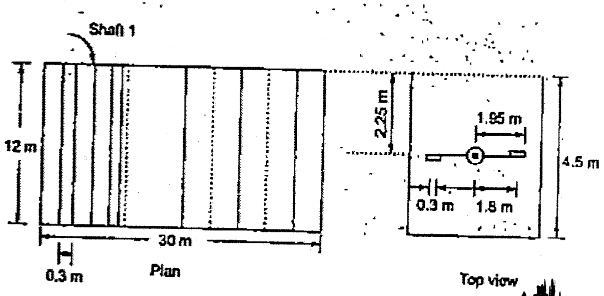
(a) Power consumption (b) Time of flocculation

(c) Value of G

Kinematic viscosity, $\nu = 1.31 \times 10^{-6}$ m²/s

*Solution:*

(a) Assume $C_D = 1.8$



$$V_r = V_p(1-k) = V_p\left(1-\frac{1}{4}\right) = V_p \times 0.75$$

If the value of $V_p$ is taken corresponding to the velocity of outside tip, power consumption will come out to be more and we will be on safer side. The above approach would be used in design. In our calculation of power, we use the velocity at the centre of blade as $V_p$.

$$V_p = w \times r = \frac{2.5 \times 2\pi}{60} \times 1.8 = 0.471 \text{ m/sec}$$

$$V_r = 0.75 \times 0.471 = 0.353 \text{ m/s}$$

Power. $$P = \frac{1}{2} C_d \rho_w A_p V_r^3 = \frac{1}{2} \times 1.8 \times 1000 \times 8 \times 0.3 \times 12 \times (0.353)^3 = 1.14 \text{ kW}$$

(b) $$t_d = \frac{\text{Volume}}{\text{Discharge}} = \frac{30 \times 12 \times 4.5 \times 24 \times 60 \times 60}{75 \times 10^6 \times 10^{-3}} = 1866.24 \text{ sec} = 31.102 \text{ min}$$

(c) $$G = \sqrt{\frac{P}{\mu V}} = \sqrt{\frac{1.14 \times 10^3}{\mu \times V}} = \sqrt{\frac{1.14 \times 10^3}{1.31 \times 10^{-6} \times 10^3 \times 12 \times 30 \times 4.5}} = 23.17 \text{ per sec}$$

**Example 4.22** Determine the surface area of settling tank for 0.5 m³/sec design flow. Using design overflow rate as 32.5 m³/m²/d. Find the depth of clarifier for the overflow rate and detention time of 95 min. Adopt L/B between 2 : 1 and 5 : 1 $L \ngtr 100$ m.

*Solution:*

$$Q = 0.5 \text{ m}^3/\text{sec}$$

$$\frac{Q}{\text{Surface area}} = \text{Overflow rate}$$

$$\Rightarrow \quad \text{Surface area} = \frac{0.5}{32.5/86400} = 1329 \text{ m}^2$$

$$\text{Volume of tank} = Q \times t_d = 0.5 \times 95 \times 60 = 2850 \text{ m}^3$$

$$\text{Depth} = \frac{\text{Volume}}{\text{Surface area}} = \frac{2850}{1329} = 2.15 \text{ m}$$

Assume, $\frac{L}{B} = 2 \quad \Rightarrow \quad L = 2B$

$\Rightarrow \quad B^2 = \frac{1329}{2} \quad \Rightarrow \quad B = 25.77$ m

$\therefore \quad L = 2 \times 25.77 = 51.55 \text{ m} \ngtr 100$ m (ok).

Adopt, $L = 52$ m, $B = 26$ m, $W = 2.15 +$ free board $= 2.15 + 0.3 = 2.45$ m

**Example 4.23** A continuous flow sedimentation tank is 3.5 m deep and 65 m long. The flow velocity observed is 1.22 cm/s. What size of the particle of S.G. 2.65 may be effectively removed. Assume $T = 25°C$ and $\nu = 0.01$ cm²/s.

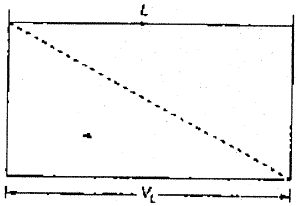
*Solution:* If overflow rate is equated to settling velocity, then

$$V_s = \frac{g(G-1)d^2}{18\nu} \quad \text{...(i)}$$

Particle of size greater than $d$ will be removed to the extent of 100%

$$\frac{L}{V_f} = t_d = \frac{H}{V_s}$$

$$\Rightarrow \quad V_s = \frac{H}{L} \times V_f = \frac{3.5}{65} \times 1.22$$
$$= 0.0656 \text{ cm/sec}$$



put value of $V_s$ in equation (i)

$$\therefore \quad 0.0656 \times 10^{-2} = \frac{(2.65-1) \times 1000 \times 9.81 d^2}{18 \times 1000 \times 0.01 \times 10^{-4}}$$

$$\Rightarrow \quad d = 2.7028 \times 10^{-5} \text{ m}$$

$$\Rightarrow \quad d = 0.027 \text{ mm} \quad \text{...(ii)}$$

Also, $V_s = 418(4-1)d^2\dfrac{3T+70}{100}$ for $d < 0.1$ mm

$\therefore$ $0.0656 \times 10 = 418(2.65-1)\times d^2 \times \dfrac{3\times 25+70}{100}$

$\therefore$ $d = 0.0256$ mm ...(iii)

$\therefore$ $d = 0.027$ mm maximum of (ii) and (iii)

**Example 4.24** A rectangular settling tank without mechanical equipment is to treat 1 MLD of raw water. Data given $t_d =$ 2.5 hr, $V_f = 8$ cm/min and Depth of water + Sediment = 4.5 m

Find length tank, the width of tank. If an allowance of 1.5 m is to be made for sediment, overflow rate of the tank.

***Solution:***

(a) Length of tank $L = V_f \times t_d = 8 \times 10^{-2} \times 2.5 \times 60 = 12$ m

(b) $\text{Volume} = L \times B \times H = Q \times t_d$

$H = 4.5 - 1.5 = 3$ m

$\text{Volume} = 12 \times B \times 3 = \dfrac{1\times 10^6 \times 10^{-3}}{24}\times 2.5$

$\Rightarrow$ $B = 2.89$ m

(c) $\text{Overflow rate} = \dfrac{Q}{BL} = \dfrac{1\times 10^6\times 10^{-3}}{2.89\times 12} = 28.83$ m³/m²/day

**Example 4.25** Design a coagulation-cum-sedimentation tank with continuous flow for a population of 50,000 with a daily per capita consumption of 135 litres.

*Solution:* First design the settling tank and then the floc chamber.

Settling Tank

Average daily consumption = $50{,}000 \times 135 = 6.75 \times 10^6$ litres

Maximum daily demand = $1.8 \times 6.75 \times 10^6$ litres $= 12.15 \times 10^6$ litres

Assume detention period as 4 hours

$\therefore$ Quantity of water to be treated during the detention period

$$= \frac{12.15\times 10^6}{24}\times 4 = 2.025 \times 106 \text{ litres} = 2.025 \times 10^3 \text{ m}^3$$

Assume an overflow rate of 1000 litres/hr/m²:

$$\frac{Q}{BL} = 1000$$

$$Q = \frac{12.15\times 10^6}{24} = 506.25 \times 10^3 \text{ litres/hr}$$

$\therefore$ $\text{Plan area} = B.L. = \dfrac{506.25\times 10^3}{1000} = 506.25$ m²

Keeping length of the tank 3 times that of width

$\therefore$ $3B \times B = 506.25$

$\therefore$ $B = \sqrt{506.25/3} = 12.99 \approx 13$ m

$\text{Length} = 13 \times 3 = 39$ m

Hence, tank size may be taken as 39 m × 13 m × 4 m. Provide 0.5 m extra depth for sludge and 0.5 of free board.

$\therefore$ Size of the tank = 39 m × 13 m × 5 m.

Floc Chamber

The length of floc chamber which will be provided at entry will be extra in addition to 39 m length of settling tank. Assume effective depth in the floc chamber as half the depth in the tank near the floc chamber.

$\therefore$ Depth of flock chamber $= \dfrac{4.5}{2} = 2.25$ m

Assume detention period as 15 minutes

$\therefore$ Capacity of the chamber $= \dfrac{12.15\times 10^3}{24}\times\dfrac{15}{60} = 126.6$ cu.m

$\therefore$ Plan area $= 126.6/2.25 = 56.3$ m²

Using same width of 13 m, length of flocculation chamber

$= 56.3/13 = 4.33$ m $= 4.5$ m (say)

**Example 4.26** **Design a circular clariflocculator for treating water required for a population of 65,000 with a daily per capita consumption of 135 litres. Assume surface loading rate as 1000 l/hr/m².**

***Solution:***

Average daily consumption = $65{,}000 \times 135 = 8.775 \times 10^6$ litres

Maximum daily demand = $1.8 \times 8.775 \times 10^6 = 15.795 \times 10^6$ litres

$\therefore$ (i) Surface area of tanks $= \dfrac{15.795\times 10^6}{24\times 1000} = 653.125$ m²

Take two tanks

$\therefore$ Area of each tank $= 658.125/2 = 329.06 \approx 330$ m²

Assume detention period = 3 h

Volume of tanks $= \dfrac{15.796\times 10^6\times 3}{24\times 1000} = 1974.5$ m³

$\therefore$ Water depth in tank $= \dfrac{\text{Volume}}{\text{Area}} = \dfrac{1974.5}{660} = 2.99 \approx 3.0$ m

Provide 0.5 m for sludge and 0.5 m as free board.

Total depth of tank = 3.0 + 0.5 + 0.5 = 4.0 m

Clariflocculator surface Area $= \dfrac{\pi}{4}\left(D^2 - D_1^2\right) = 330$

$\therefore$ $D^2 = \dfrac{330\times 4}{\pi}\times 7^2 = 469.2$

$D_1$ = Dia of flocculator = 7 m (as calculated at II)

$\therefore$ $D = \sqrt{469.2} = 21.66 \approx 22$ m

(ii) Design of flocculator

Assume detention period for floc formation = 20 minutes

Volume of flocculation $= \dfrac{15.795\times 10^6\times 20}{1000\times 60\times 24} = 219.4$ m³

Assume depth of flocculation zone = 3 m

$\therefore$ Area of flocculation zone $= 219.4/3 = 73.133$ m²

Provide two tanks

∴ Area of each tank = 73.133/2 = 36.56 m²

∴ Dia of flocculator

$$D_i = \sqrt{(4\times36.6)/\pi} = 7\text{ m (say)}$$

**Example 4.27** **Design a mechanical flocculator for treatment of water for a population of 70,000 with a daily per capita consumption of 135 litre. Assume data suitably for the design. Average temperature in the locality may be taken as 30°C and Kinematic viscosity at 30°C = 0.8039 x 10⁻² cm²/s**

***Solution:*** Let us assume paddle speed as 3 rpm at 30°C

Daily average water demand = 70,000 × 135 = 9.45 × 10⁶ litres

∴ Maximum daily demand = 1.8 × 9.45 × 10⁶ = 17.01 × 10⁶ litres

$$\text{Rate of flow in m}^3\text{ per second} = \frac{17.01\times10^6}{24\times60\times60\times1000} = 0.1967 = 0.197$$

Assume detention period as 30 minutes.

Volume of flocculation tank = 0.197 × 30 × 60 = 354.6 m³

Assume depth as 3 m

∴ Surface area of tank = 354.6/3 = 118.2 m²

Assuming horizontal velocity of flow = 1 m/min.

Length of tank = 30 × 1 = 30 m

∴ Width of tank = 118.2/30 = 3.94 = 4.0 m

Hence, adopt size of 30 m x 4 m

Assume distance from paddle to paddle = 3.0 m (Shaft centre to centre distance)

∴ Number of shafts = 30/3 − 1 = 9

∴ Cross-sectional area of tank = 4 × 3 = 12 m²

Assume area of the paddle to be 45% of cross-sectional area of the tank

= 0.45 × 12 = 5.4 m²

Total length of flanks = 2 × 9 × 3 = 54 m

Width of flank = 5.4/54 = 0.1 m = 10 cm.

*L/B* of flank = 300/100 = 30 > 20

$$\text{Velocity gradient } G = \sqrt{1/2\left(C_D A_S U_r^3\right)/\eta V}$$

Where, $C_D$ = Coefficient of drag of paddle depending on shape of paddle and its is 1.8 for flat blade.

$A_S$ = Area of the impeller blade in m²

$U_r$ = Relative velocity of impeller and the surrounding fluid in m/s

= (taken at 25% of fluid velocity at the point without starter blades and 50% with starter blade)

$\eta$ = Viscosity of water (kinematic)

$V$ = Volume in m³

$$\text{Paddle velocity } U_p = \frac{\pi DN}{60} = \frac{3.14\times3\times3}{60}$$

$D$ = Diameter of circular path of paddle flank = 3.0 m

Velocity differential

$$U_r = (1-K)U_p = (1-1/4)0.471 = 0.353\text{ m/s}$$

$$\therefore \quad G = \sqrt{\frac{1/2\times\left[1.8\times5.4\times(0.353)^3\right]}{\left[0.80039\times10^{-6}\times(30\times4\times3)\right]}}$$

[∴ η at 30°C = 0.8039 ×10⁻² cm²/sec = 0.8039 × 10⁻⁶ m²/s]

= 27.24 s⁻¹ (and it is between 20 s⁻¹ to 75 s⁻¹)

*GQ* = 27.244 × 30 × 60

(where *Q* is detention period in seconds)

= 4.9 × 10⁴ (And it is between 1 × 10⁴ to 10 × 10⁴ )

Hence, our design is acceptable.

## 4.8 Filtration

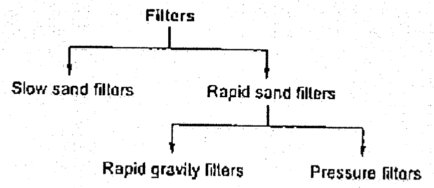
As practiced in modern water treatment plants, filtration is most often a polishing step to remove small flocs or precipitant particles not removed in the settling of coagulated or softened waters.

- Filtration removes fine particles, colour, dissolved minerals and micro-ogranisms.
- It also removes the suspended solids that does not get removed in sedimentation.
- Under certain conditions, filtration may serve as the primary turbidity removal process e.g. in direct filtration of raw water.
- Although filtration removes many pathogenic organisms from water, filtration should not be relied upon for complete health protection.
- It is economically effective in controlling guinea warm diseases.

Filters are classified as:

(a) Slow sand filters

(b) Rapid sand filters



However, when classified on the basis of the rate of their filtrations, the filters can be divided as follows:

Similarly, their classification, when based upon the considerations of gravity and pressure, is indicated below:

- In gravity filters, the head required to flow through sand will be provided by the head of water over the sand medium but in pressure filtration, the necessary head would be provided by pressure applied from outside. Hence, the pressure filter should be inside a closed container.

**Do you know?** Slow sand filter removes larger percentage of impurities as compared to rapid sand filters but has very slow rate of filtration, about 1/30th of the rapid sand filter.

### Theory of Filtration

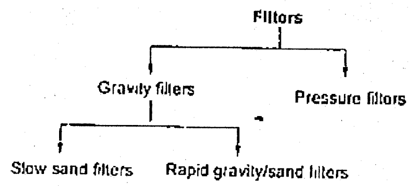
There are four type of filtration theory:

(a) Mechanical straining

(b) Sedimentation and Flocculation

(c) Biological action

(d) Electrolytic charges



**(a) Mechanical Straining:** The suspended particles, which are bigger than the size of the voids in the sand of filter, get arrested in voids. The water passing the voids will be free from such particles.

- Most of the particles are removed in upper layer. Arrested impurities including the coagulated floc forms a mat on top which further helps in straining.

**(b) Sedimentation and Flocculation:** Infact filters remove particles of size smaller than the size of voids present in the filter. These voids infact act like tiny coagulation-sedimentation units.

- The colloidal matter arrested in these voids is a gelatinous mass and hence, attracts other finer particles as well.
- These finer particles, thus, settle down in the voids and get removed.

**(c) Biological Metabolism:** The sand bed has been identified as three zones of purification.

(i) The surface coating is known a "Schmutzdecke"

(ii) The 'autotrophic' zone existing a few millimeters below the zone 'Schmutzdecke'

(iii) The 'heterotrophic' zone, which extends around 300 mm into the bed. When a new filter is put in commission and raw water is passed, during the first two weeks the upper layers of sand grains gets coated with a reddish brown sticky deposit of partly decomposed organic matter together with iron, manganese, aluminium and silica. This coating tend to absorb organic matter existing in the colloidal state. After two or three weeks, there exists in the upper most layer of the sand a film of algae, bacteria and protozoa to which are added the finely divided suspended material, plankton and other organic matter deposited by the raw water. This skin is called the "Schmutzdecke" and it acts on extremely fine meshed straining mat.

- A few millimeters below the schmutzdecke zone is known as autotrophic zone. In this zone, the growing plant life breaks down organic matter, decomposes the plankton and use available nitrogen, phosphates and carbon dioxide providing oxygen in their place. The filtrate becomes oxidized at this stage.
- A few millimeters below the autotrophic zone, the heterotrophic zone extends around 300 mm into the bed. In this zone, the bacteria multiply to very large numbers and the breakdown of organic matter is completed and the resulting effluent consists of simple inorganic substances and unobjectionable salts. The bacteria act not only to breakdown organic matter but also to destroy each other and so tend to maintain a balance of life native to the filter so that the resulting filtrate is uniform. This process is predominant in slow sand filters.

**(d) Electrolytic Charges:** The filter helps in purifying the water by changing the chemical characteristics of water.

- Sand grains of filter media and the impurities in the water carry electrical charges of opposite nature. Thus because of their interaction, chemical characteristics of water changes and it becomes pure.
- During washing process of filter, neutralized material is removed.

### Flow Through Filter Media

Bed of sand are mostly used in the water treatment in the form of deep bed filters. The main purpose of the bed is to remove fine suspended solids. Other forms of porous uncompacted solids in deep beds are also used to provide adsorption and ion exchange process.

### Porous Bed Hydraulics

The hydraulics of flow through porous beds, which applies to clean filters and to granular activated carbon and ion exchange beds is usually described by empirical relationship given by Karman Cozeny as discussed earlier

$$\boxed{\frac{h}{l}=\left[\frac{E(1-n)}{F^3}\right]\times\frac{V^2}{gdS}}$$

where, $\frac{h}{l}$ = head loss per unit depth of bed

$n$ = porosity of bed

$S$ = particle shape factor = $\frac{A_0}{A}$; $A_0$ = surface area of sphere volume, $V_0$; $A$ = surface area of bed grain volume, V; $S$ = 1 for sphere; $S$ = 0.70 to 0.90 for sand grains; $V$ = filtration rate m/sec

$E=\left[\frac{150(1-n)}{R}\right]+1.75$; $R$ = Reynold's number = $\frac{\rho vd}{\mu}$; $\mu$ = Kinematic viscosity of fluid

If all the suspended particles are retained by the bed, the overall head loss ($H$) for a unit size medium is thus made up of the "Cle[illegible]ed head loss" ($h$) as calculated from equation plug on additional head loss caused by the reduction in porosity due to deposition

$$\boxed{H=h+\frac{kv\cdot C_0\cdot t}{(1-n)}}$$

where, $C_0$ = Influent suspended particle concentration

$t$ = duration of filter run

$k$ = a constant depending upon bed and solids

The build up of head loss with time can be shown in figure, which illustrates the way in which negative pressure can be produced in a bed with detrimental effects on the rate of flow.

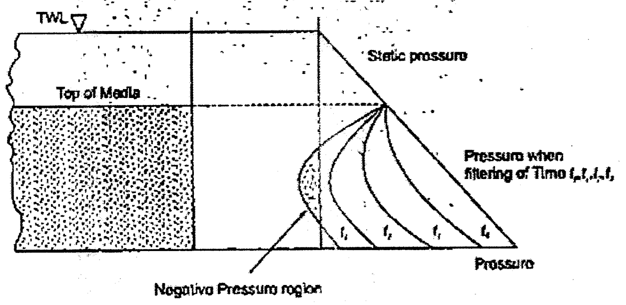


*Fig. 4.21* Head Loss Build up in a Deep Bed Filter

**Example 4.28** A filter bed is composed of 800 mm of unit-size spherical sand of 0.5 mm diameter with a porosity of 45%. Calculate the head loss when the clean bed is operated at rate of 145 m/d. Kinematic viscosity of water at 20°C is $1.01\times10^{-6}$ m²/s.

***Solution:***

Filtration rate 145 m/d $= 145/(24\times60\times60)$ m/s $= 1.68\times10^{-3}$ m/s

Reynold's number $= (1.68\times10^{-3}\times5\times10^{-4})/1.01\times10^{-6} = 0.832$

$E = [150(1-n)/R] + 1.75 = [150(1-0.45)/0.832] + 1.75 = 100.91$

$S$ = 1 for spherical particles

Head loss/unit depth as per Equation

$= [E(1-n)/n^3]v^2/gds$

$= [100.91(1-0.45)/0.45^3](1.68\times10^{-3})^2/(9.81\times0.5\times10^{-3}\times1)$

$= (1.719\times10^{-3})/(4.905\times10^{-3}) = 0.35$

$\therefore$ Head loss/unit depth = 0.350

$\therefore$ Head loss in 800 mm deep bed $\frac{0.35}{1000} \times 800 = 0.28$ m

**Filter Material**

The media used for filtration is mostly natural silica sand. In addition to this, crushed anthracite (hard) coal, earth, powered or granular activated carbon, plastic spheres, rings and grounds and metal fabrics are also used as filter media.

- The filter sand obtained from rocks or rivers based are to have following properties for smooth functioning. The sand should be
  - (*i*) Free from dirt and other impurities
  - (*ii*) Uniform in nature and size
  - (*iii*) Hard and resistant
  - (*iv*) Such as not to loose more than 5% of its weight after being placed in hydraulic acid for 24 hours.

### 4.8.1 Slow Sand Filter

The first filters to be used on a widespread basis for water purification were slow sand filters. These filters were constructed of fine sand with an effective size of about 0.2 mm. (Fig. 4.22)

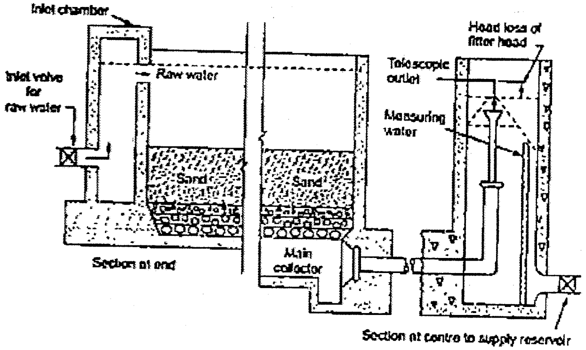


*Fig.4.22* Slow Sand Filter

- The effective size is the size of the openings of the sieve that retains 10 percent of the medium.
- Slow sand filters utilizes the effluent from plain sedimentation tank only, which are relatively clearer.
- The depth of tank is 2.5 to 3.5 m.
- Plan area required is 100 - 2000 $m^2$.
- Filter medium is sand or anthracite or garnet.
- $D_{10}$ i.e. effective size and filter medium is 0.2 - 0.3 mm.
- Here, $D_{60}/D_{10}$ = uniformity coefficient = 5 (as per GOI manual).
- The depth of sand is 90 to 110 cm $\simeq$ 1 m.
- Depth of water over sand medium would be approximately the same as the depth of sand medium.
- Top 15 cm of sand layer would be finer remaining may be of uniform size.
- The base material is gravel, which is in 3 layers.
  - (a) Top layer size – 3-6 mm
  - (b) Middle layer size – 20-40 mm
  - (c) Bottom layer size – 40-65 mm
- The design period of slow sand filter is 10 years.

#### 4.8.1.1 Operation

Filtering action mostly takes place at the surface of the sand. As the surface of a mat (Schmutzdecke) rapidly builds up. the filter become ready and filtration continues for a period of about a month before cleaning. As the rate of flow is low, the loss of head is small varying between 5 cm when the filter is clear to about 90 cm when it is dirty. The increased head required or provided by adjusting the outlets as or to raise the head available over the sand.

- When the filter lose around 90 cm of head, it is taken out of service and drained and the top 15 mm of sand is scrapping off and removed and washed.
- The filter is then returned to service slowly in order to permit the schmutzdecke to re-form. After several scrapping, the sand bed becomes too thin (around 60 cm) and it has to be restored to its original thickness of 90 cm by replacement of the sand removed.
- This is generally the same as sand that is removed after getting dirty and washed and stored near the filter. After a period of several years of use, the bottom sand in the filter tends to turn black and septic and the bed is dug out and removed.

**NOTE:** As clearing is a lengthy process, not less than three filter beds should be made, as they are mostly out of service for clearing.

#### 4.8.1.2 Under-Drainage Condition

The base of sand bed consisting of gravels is laid on the top of an under-drainage system. This consists of a central drain connected with lateral drain as shown in figure.

The laterals are open jointed pipe drains placed 3 to 5 m apart at the floor sloping towards the main central drain. These laterals collect the filtered water and discharge it into the main drain which leads the water to the filtered water reservoirs.

- An inlet chamber is constructed for admitting the effluent from the sedimentation tank without disturbing the sand layers of the filter, and distributing over the filter bed.
- At the outlet the filtered water is coming out of the under-drain. For maintaining a constant discharge through the filter an adjustable telescopic tube is provided. Inlet and outlet are generally governed by automatic valves as per requirement.
- Precaution is taken that coagulant treated water should not be allowed to enter the slow sand filters.

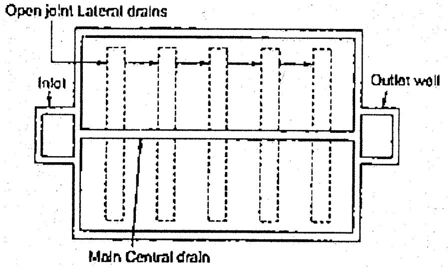


*Fig. 4.23* Plan View of an Over Drainage System

#### 4.8.1.3 Cleaning of Filter

Only water passing through plain sedimentation tank is allowed to enter the filter. The cleaning of slow sand filters is not done by back washing.

- Cleaning is done by scrapping and removing the top 1.5 to 3 cm of sand layers.

- Filters is washed with good water i.e. filter scrapping and cleaning the surface is washed with good water. After each cleaning, the filter is again used and raw water admitted into it.
- Washed filter is than loaded with raw water but effluent is not used.
- After 24-36 hrs. a film of arrested impurities forms and the filter become ready for operation.
- The frequency of cleaning is 1-3 months.
- The rate of filtration is 100-200 $l/hr/m^2$ of filter area.
- Efficiency of slow sand filter in bacteria removal is 97 - 98%.
- If the water is prechlorinated, efficiency can go upto 99.5 - 99.9%.
- The filter cannot be used if turbidity is greater than 50 ppm.
- It is less effective in removing colour but better in removing algae than coagulation + rapid sand filters.
- The effluent from slow sand filter contains less nutrients (nitrogen and phosphorous) and has reduced possibility of after growth of organisms in distribution system.
- It is designed for maximum daily demand.
- Number of beds of filter required depends on area i.e.

Upto:

$20\ m^2$ are ⇒ 2 numbers (1 + 1) stand by
$20\ m^2 - 249\ m^2$ ⇒ 3 numbers (2 + 1)
$250 - 649\ m^2$ ⇒ 4 numbers (3 + 1)
$650 - 1200\ m^2$ ⇒ 5 numbers (4 + 1)
1201 onwards ⇒ 6 numbers (5 + 1)

For example:

If area = 300 $m^2$ then,

Number of filters = (3 + 1) this is for stand-by, number of active filter

$$\therefore \quad \text{Area of one filter} = \frac{300}{3} = 100\ m^2 \text{ per filter bed}$$

**Example 4.29** **Design slow sand filters for a population of 40000 with an average rate of water supply of 150 *l*pcd.**

***Solution:***

Average daily demand = population x per capita demand = 40000 x 150
= $6 \times 10^6$ litres per day

Assuming maximum demand as 1.8 times the average daily demand

∴ Maximum daily demand = 1.8 x average daily demand
= $1.8 \times 6 \times 10^6 = 10.8 \times 10^6$ litres/day

$$\therefore \text{Total surface area of filters required} = \frac{\text{Maximum daily demand}}{\text{Rate of filtration per day}}$$

$$\text{Surface Area} = \frac{10.8 \times 10^6}{150 \times 24} \text{[Assuming rate of filtration} = 150\ l/hr/m^2]$$

Surface Area = 3000 $m^2$

When surface area is more than 1200 $m^2$, then six slow sand filters are designed and one unit out of them will be kept as stand by

$$\therefore \quad \text{Area of each filter unit} = \frac{3000}{5} = 600\ m^2$$

Assuming $L = 2B$

$2B \times B = 600\ m^2$

⇒ $B = 17.32$ m

Adopt $B = 18$ m

$L = 2 \times 18 = 36$ m

Hence each unit will be of size 36 x 18 m.

**Example 4.30** **Design slow sand filter beds for a population of 60,000 persons with per capita demand of 135 litres/head/day. Rate of filtration may be taken as 170 litres/ *hr*/ sq. Assume maximum demand as 1.8 times the average daily demand.**

***Solution:***

Average daily demand = Population x per capita demand
= 60,000 x 135 *l*/day = $8.1 \times 10^6$ litres per day.

∴ Maximum daily demand = $1.8 \times 8.1 \times 10^6 = 14.58 \times 10^6$ litres/day

Rate of filtration = 170 litres/$m^2$/hr = (170 x 24) litres/$m^2$/day

$$\therefore \quad \text{Total surface area of filters required} = \frac{\text{Max.daily demand}}{\text{Rate of filtration per day}} = \frac{14.58 \times 10^6}{170 \times 24} \text{sq m}$$

= 3573.5 sq.m

Let us assume that there will be six units out of them one will be kept as stand-by.

∴ The area of each filter unit = 1/5 x 3573.5 = 714.7 sq.m.

Let $L$ be the length and $B$ is the breadth of each unit and $L = 3B$

∴ $3B \times B = 714.7$, or $B^2 = 238.23\ m^2$

∴ $B = 15.4$ m, say 16 m

∴ $L = 3 \times 16 = 48$ m

Hence, provide 6 filter units with one unit as standby, each unit of size 48 m x 16 m arranged in series with 3 units on either side.

### 4.8.2 Rapid Gravity Filter

A rapid gravity filter is basically a bed of sand supported in a bed of gravel embedded in which there is a system of underdrains. The whole is enclosed in an open concrete chamber.

- The sand layer has a thickness of around 0.45 to 0.75 m. The sand grains are fairy uniform in size lying between 0.4 mm and 1.2 mm.
- The coefficient of uniformity should vary between 1.2 and 1.7 and the sand should be sharp, hard, clean and silicious.
- Particle more than and less than 1 μm diameter are effectively removed.
- It also removes suspended and colloidal matter with microorganisms (i.e. bacteria and helminths etc.)

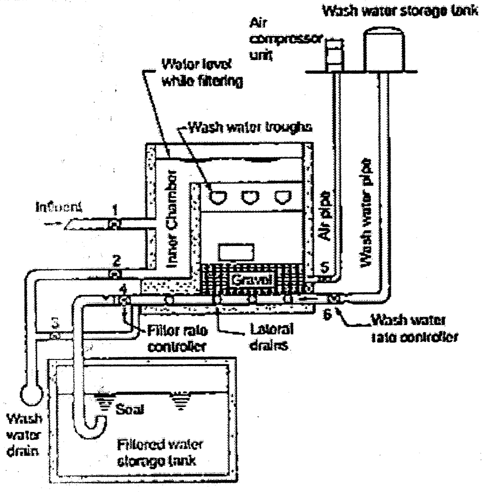


*Fig. 4.25* **Rapid Gravity Filter**

### 4.8.2.1 Operation

The working of a rapid gravity filter is explained below with various valves have been numbered as enumerated in table.

Table 4.3

| Value No. | Name of Valve |
|---|---|
| 1 | Inlet Valve |
| 2 | Waste water valve to drain water from inlet chamber. |
| 3 | Waste water valve to drain water from main drain. |
| 4 | Filtered water supply valve. |
| 5 | Compressed air valve. |
| 6 | Wash water supply valve |

Valve is first of all, upward, which loads the effluents of the coagulation sedimentation basin, to enter the inlet chamber of the filter.

- This water gets filtered through the filter beds and the filtered water can be taken out from the main drain by opening valve 4.
- This filtered water can be taken to disinfection unit.
- Thus, when filter is in working condition, only these two valves (i.e. valves 1 and 4) shall be kept open, all other valves kept closed.

### 4.8.2.2 Back Washing

The dirty sand is indicated by excessive head loss.

- For back washing (1) and (4) are closed and (5) and (6) are open. Thus, wash water and air forces its way upward from the under drain through gravel and sand bed thereby loosening up the sand and washing the accumulated solid in the sand. The dirty water goes in wash water through and is removed by opening valve (2).
- In the case of rapid sand filter, size of particles are large. Hence, impurity can penetrate deep inside the sand layer. Thus, surface washing alone will not be effective. In this case we go for back washing.
- Back washing is necessary so that the bed of sand is expandud and the granules are thus having better chance to come in contact with the wash water because porosity of the bed is increased due to expansion.
- After opening valve (5) and (6), the dirty water goes into wash water through which is then removed by opening valve (2). Once washing is complete, valve (2) (5) and (6) are closed and valve (1) and (3) are opened. It removes the remains of wash water and makes a mat on the sand. Finally, valve (3) is closed and valve (4) is opened.
- The entire process takes 15 minutes.

### 4.8.2.3 Design Criteria of Rapid Sand Filters

1. The number of units at a filter plant is roughly estimated as

   $\boxed{N = 1.22\sqrt{Q}}$ where, $N$ = number of filters,; $Q$ = plant capacity in million litre per day.

2. **Length/Width:** 1.25 to 1.33. Usually size may be upto 9 m wide and 12 m long.
3. **Rate of filtration:** About 100 litres/m²/min of the surface area of sand bed.
4. Maximum loss of head = 2.5 to 3.0 meters.
5. **Under drains:**

   (a) $\dfrac{\text{Length of lateral}}{\text{Diameter of lateral}} \ngtr 60$

   (b) Diameter of perforation is 6 mm to 13 mm at spacing of 7.5 to 20 cm respectively.

   (c) Total area of perforation = 0.2% total of filter area

   (d) $\dfrac{\text{Total area of perforation}}{\text{Total area of laterals}} = 0.25$ to 0.3 for diameter of perforation as 6 mm and 13 mm respectively.

   (e) Spacing of laterals = 30 cm maximum

   (f) Total area of manifold = 1.75 to 2 times the area of laterals.

6. **Rate of washing:** 15 to 90 cm/minute, a figure of 45 cm/min is quite acceptable. The rate can be provided by a flow of 500 litres/m² of bed area per minute.
7. **Amount of wash water:** 2 to 4% of the total water filtered.
8. Time of washing: 10 to 15 minutes, time between washing 24 to 28 hours.
9. Pressure at which wash water is supplied = 1 kg/m².
10. Maximum permissible velocity in manifold to provide the required amount of wash water = 1.8 to 2.5 m per second.
11. Capacity of unit in even multiple of a fraction of $4.5 \times 10^6$ litres/day to $22.5 \times 10^6$ litres/day. It is necessary to have minimum of two units so that one of them may act as a standby unit.

- Base material is gravel. It is provided in five to six layers. Depth of gravel = 45 cm
  1. Layer-I → 3 - 6 mm
  2. Layer-II → 6 - 12 mm
  3. Layer-III → 12 - 20 mm
  4. Layer-IV → 20 - 40 mm
- In rapid sand filter, better gradation of gravel is required because distribution of wash water in this case is critical function.

### 4.8.2.4 Under-Drainage System

In slow sand filters, the under-drainage system was provided only to receive and deliver the filtered water. Whereas, in rapid gravity filters, the under drainage system serves two purposes:

1. To receive and collect the filtered water.
2. To allow to back washing for cleaning of filter.

- Length of each lateral/diameter of lateral < 60.
- Rate of application of wash water is approximately 6-16 times the rate of filtration.
- The rate of filtration is 3000-6000 $l/m^2/hr$.
- The under drainage should be capable of passing wash water upward at high rates. We adopt manifold and lateral system of under drainage.

  If dia of hole = 5 mm, spacing between holes = 8 cm c/c.

  If dia of hole = 12 mm, spacing between holes = 20 cm c/c.

  In under drainage system, two type of laterals can be used:

1. Perforated pipe type: Used for high velocity wash
2. Strainer type: Used for slow velocity wash
   - When perforated pipe is used the washing is called high velocity wash and in this case compressed air is not used.
   - When strainer is used, backwashing using water is accompanied by compressed air. This washing is called slow velocity wash.

#### 4.8.2.5 Size of Pipe Determination

In this, the recommendation are as follows:

1. The total cross-sectional area of perforation = 0.3% of total filter area.
2. Cross-sectional area of each lateral is 2 to 4 times the cross-sectional area of perforation in it.
3. If hole diameter is 12 mm, then adopt 2 times.
   If hole diameter is 5 mm, then adopt 4 times.

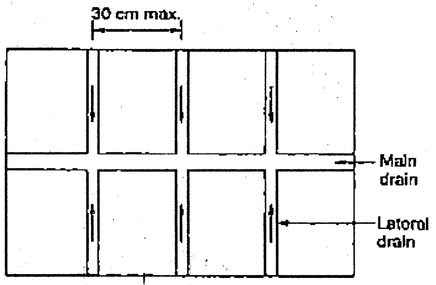


*Fig. 4.26*

4. The cross-sectional area of manifold is 2 times the cross-sectional area of lateral drains.
5. If depth of sand layer is *D*, the top of water should be *D*/2 from the top of sand layer approximately because the sand is likely to expand by maximum of 50% during back washing.

- The maximum permissible velocity through the manifold is 1.8 to 2.4 m/sec.
- The rate of application of wash water should not be more than settling velocity of smallest particle to be retained in the filter.
- The force created due to head loss must be equal to the buoyant weight of particles in the fluid.

where,

$V_s$ = Volume of solids

$V$ = Volume of sand bed

we know that,

$$\text{Porosity } (n) = \frac{V_v}{V_1} = \frac{\text{Volume of void}}{\text{Volume of sand bed}}$$

$$1 - n = 1 - \frac{V_v}{V}$$

$$1 - n = \frac{V - V_v}{V}$$

$$V_s = V(1 - n)$$

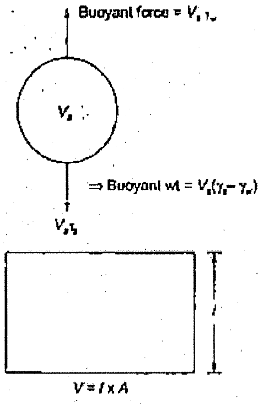


*Fig. 4.27*

The head loss ($h$) per unit depth ($l_o$) after expanded bed during back washing is

$$\boxed{\frac{h}{l_e} = (G_a - 1)(1 - n_o)}$$

where,

$l_a$ = expanded depth of bed

$n_o$ = expanded bed porosity, and

$G_a$ = specific gravity of particles

The expansion produced by a given back wash rate is a function of velocity of the bed grains and bed porosity

$$\frac{l_o}{l} = \frac{(1-n)}{\left[1 - \left(\frac{V_b}{V_s}\right)^c\right]}$$

where, $V_b$ = back wash rate; $V_s$ = bed grains settling velocity; $n$ = porosity of unexpanded bed; $l$ = unexpanded depth of bed; $c$ = an experiment constant (commonly taken as 0.22)

**Example 4.31** **Which of the following remedial measures are taken to avoid negative head and air binding in a rapid sand filter?**

1. **Avoiding the occurrence of excessive negative head**
2. **Pumping in air**
3. **Avoiding increase in water temperature**
4. **Control of algae growth**

**Select the correct answer using the codes given below:**

**(a) 1, 3 and 4 (b) 2, 3 and 4 (c) 1 and 2 (d) 1, 2, 3 and 4**

**Ans. (d)**

**Do you know?** Flow of water during filtration is laminar flow and flow of water in case of back washing is generally in transition.

- Cleaning of filter can also be done using surface wash but it should always be accompanied by back wash. Surface wash helps in cleaning the top layer which otherwise may remain backwash, as the backwashing pressure may not be available sufficiently to clean the top layers.
- Initial head loss in filter is 15-30 cm. Loss goes on increasing as more and more impurities are trapped. A stage comes when the frictional resistance by the media exceeds the static head of water over filter bed. The bottom sand then acts like a vacuum. Hence water gets sucked in filter media without getting filtered. The negative pressure so developed releases dissolved gases. Thus making bubbles which sticks to sand grains, thereby seriously affecting the operation. This phenomenon is called air binding.
- This is an operation trouble. To avoid it, filter is cleaned when the head loss is more than the static head of water over sand bed.
- The depth of water during filtration may also be increased by 15-20 cm as compared to the normal depth to increase static head (to compensate the lost head) and there by reducing the negative head.
- So, the remedial measure to avoid air binding are:
  (*i*) By avoiding development of excessive negative head.
  (*ii*) By controlling the growth of algae.
  (*iii*) By remedying conditions that supersaturate the water with air.
  (*iv*) By taking precaution, if possible the water getting warmed as it passes through plant.

#### 4.8.2.6 Operational of Trouble in Rapid Gravity Filter

Besides air binding, the two other common troubles which are generally encountered during the operation of rapid gravity filters are:

1. Formation of mud balls 2. Cracking of filters

1. **Formation of Mud Balls:** Mud from the atmosphere get deposited on the sand surface and during inadequate washing, they may sink down in sand bed. This mud sticks to sand grain and other arrested impurities, thereby forming mud balls.
   - The mud balls go on increasing in size and may sink down in gravel layers.
   - This interferes with upward movement of water during backwashing causes turbulence around them and gravel are displaced.

- Thus, improper washing leads to accumulation of mud.
- Once mud ball formation starts, it goes on increasing in numbers and ultimately entire space is filled with them.
- To avoid it, scouring with compressed air along with backwashing for 4 minutes supported by manual surface racking and surface washing with caustic soda or sodium thiosulphate is adopted.

2. **Cracking of Filter:** Fine sand in top layers shrinks which results in shrinkage cracks.
   - The crack is widened by pressure applied on filter due to loss of head which increases the crack width further.
   - This flocs, mud and other impurities penetrate deep into the filter, thereby reducing the efficiency.

**Example 4.32** **Match List-I (Operational problems in rapid gravity filter) with List-II (Methods to overcome the problems) and select the correct answer using the codes given below the lists:**

**List-I**

**A. Incrustation of filter sand media**
**B. Air binding and development of negative head**
**C. Mud ball formation**
**D. Slime growth on filter**

**List-II**

**1. Compressed air scouring for about 4 minutes at the time of backwashing and manual surface raking**
**2. Washing the filter with sodium hydroxide or bleaching powder occasionally**
**3. Thorough backwashing with salt solution after soaking the filter in it**
**4. Increasing the depth of water during filter operation by about 15-20 cm as compared to the normal depth maintained during daily operation and more frequent backwashing**

**Codes:**

| | A | B | C | D |
|---|---|---|---|---|
| (a) | 2 | 4 | 3 | 1 |
| (b) | 4 | 2 | 1 | 3 |
| (c) | 2 | 4 | 1 | 3 |
| (d) | 4 | 2 | 3 | 1 |

Ans. (a)

**Example 4.33** Which of the following are the common problems associated with the operation of rapid sand-filter?

1. Air binding
2. Cracking of sand beds
3. Bumping of filter beds
4. Mud balls

Select the correct answer using the codes given below:

(a) 1 and 2 (b) 2 and 3 (c) 2, 3 and 4 (d) 1, 2, 3 and 4

Ans. (d)

Common problems associated with filtration of waste water are:

(i) Air binding
(ii) Turbidity break through cracking of sand bed
(iii) Mudball formation
(iv) Buildup of emulsified grease
(v) Loss of filter medium due to backwashing
(vi) Gravel moulding or bumping of filter beds

#### 4.8.2.7 Efficiency and Performance of Rapid Gravity Filters

Rapid gravity filters, compared to slow sand filters, are less efficient in removing bacteria and turbidities.

- Rapid sand filter is highly efficient in colour removal when used with coagulation sedimentation.
- Efficiency with respect to bacteria removal is 80 - 90% the remaining bacteria are removed in disinfection units.

#### 4.8.2.8 Dual Media Filter and Multi-Media Filter

**Dual Media Filters:** To increase the rate of filtration, we use Dual Media Filter (DMF) in which larger anthracite grain (specific gravity = 1.55) is provided in 30 to 60 cm depth of filter media and below this smaller sand grain (Sp. Gravity = 2.65) is provided.

- In this filter top layer removes the larger sized impurities as well as to some extent smaller one; while bottom sand, captures the smaller impurities.
- As a consequences, more depth of filter is utilized for removal of solids than in rapid sand filter which utilize a single material i.e. well graded sand.

**Multi-Media Filters (MMF):** Multimedia filters is also called mixed-media filters, are similar to dual media filters, except that they use three or more materials for filter layers.

- The multimedia filters are basically improved dual-media filters, with increased filter run times and better water quality. The rate of filtration however, are not much improved.

**Example 4.34** Assertion (A): In the case of dual media filter, the rate of filtration is more than that of rapid sand filter.
Reason (R): The direction of flow is from fine medium to coarse medium.
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

Ans. (c)

**Example 4.35** Design a rapid gravity sand filter system for 5 million litres per day of supply. Any data required for design may suitably be assumed.

***Solution:***

Assume that daily 4% of filtered water is required for washing of the filter

$\therefore$ Total filtered water requirement = 5 × 1.04 = 5.2 million litres per day

Assume that 30 minutes is lost everyday in washing the filter

$\therefore$ Filtered water requirement per hour = 5.2/23.5 = 0.221 million litres/hr.

Next assume that the rate of filtration be 6000 litres/hr/sq.m.

$$\therefore \quad \text{Area of filter required} = \frac{0.221\times10^6}{6000} = 36.83\ \text{m}^2$$

Assuming the length of the filter bed ($L$) as 2 times the width of the filter bed. Provide two beds.

$$\therefore \quad 2\times L.B = 36.83$$
$$\text{or} \quad 2\times 2B\times B = 36.83$$
$$\text{or} \quad B = 3.03\ \text{m}$$
$$\therefore \quad L = 2B = 6.06\ \text{m say } 6\ \text{m}$$

Use the length of the filter as 6.0 m

$$\therefore \quad B = \frac{36.83}{2\times 6} = 3.07 \approx 3.1 \text{ m}$$

Here, provide 2 filter units, each of dimension = 6 × 3.1 m

Under-drainage system

The under drainage system will consists of central manifold pipe with laterals having perforations at their bottom.

Assume area of perforations to be 0.2 % of the total filter area

$\therefore$ Area of perforations = $0.2/100 \times (6 \times 3.1)\text{m}^2 = 0.0372 \text{ m}^2$

Assume the area of each lateral = 2 times the area of preformation in it.

$\therefore$ Total area of laterals = $2 \times 0.0372 = 0.0744 \text{ m}^2$

Next assume that the area of manifold be around twice the area of laterals

$\therefore$ Area of manifold = $2 \times 0.0744 = 0.1488 \text{ m}^2$

$\therefore$ Dia of manifold: $(\pi/4)d^2 = 0.1488$

$$\therefore \quad d = \sqrt{\frac{0.1488\times 4}{\pi}} = 0.435 \text{ m say } 0.45 \text{ m}$$

Hence 45 cm dia manifold pipe will be laid lengthwise at the centre of the filter bottom. Laterals will run perpendicular to the manifold at spacing of (say) 20 cm.

$$\therefore \quad \text{Number of laterals} = \frac{6\times 100}{20} = 30 \text{ on either side of the manifold}$$

$\therefore$ No. of laterals in each unit = $30 \times 2 = 60$

$$\text{Length of each lateral} = \frac{\text{Width of filter}}{2} - \frac{\text{Dia of mainfold}}{2}$$

$$= \frac{3.1}{2} - \frac{0.45}{2} = 1.325\text{m}$$

Adopt 15 mm dia perforations in the laterals

Total area of perforation = $0.0372 \text{ m}^2 = 372 \text{ cm}^2 = n \times \pi/4(1.5)^2$

($n$ = No. of perforation in all 60 laterals),

$$\therefore \quad n = 372 \times \frac{4}{\pi}\frac{1}{(1.5)^2} = 210.5 \text{ say } 211$$

$\therefore$ No. of perforations in each laterals = $211/60 = 3.52$ say 4.

$\therefore$ Area of perforations per lateral = $4[\pi/4 \times (1.5)^2] = 7.068 \text{ cm}^2$

Area of each lateral = 2 × area of perforations per lateral

$= 2 \times 7.068 = 14.136 \text{ cm}^2$

$\therefore$ Dia of each lateral = $\sqrt{14.136 \times 4/\pi} = 4.24$ cm say 4.3 cm

$\therefore$ use 60 laterals each of 4.3 cm dia @ 20 cm c/c each having 4 perforations of 15 mm size with 45 cm dia manifold.

**Wash water :** Assume the rate of washing of the filter be 0.45 m/minute

$$\therefore \quad \text{The wash water discharge} = \frac{0.45\times(6\times 3.1)}{60} = 0.1395 \text{ m}^3/\text{sec}.$$

$$\therefore \quad \text{Velocity of flow in the lateral for wash water} = \frac{0.1395}{60\left[\frac{\pi}{4}\times\left(4.3\times 10^{-2}\right)^2\right]} = \frac{0.1395}{0.0871} = 1.6 \text{ m/s}$$

$$\text{Velocity flow in the manifold:} = \frac{\text{Discharge}}{\text{Area}} = \frac{0.1395}{\left[\pi/4(0.45)^2\right]} = \frac{0.1395}{0.159}$$

$$= 0.877 \approx 0.88 \text{ m/sec}$$

Velocity of flow is less than 1.8 to 2.4 m/sec (maximum permissible), hence, design is acceptable.

**Design of Troughs**

Wash water troughs are kept around 1.5 to 2 m apart.

$\therefore$ In a length of 6 m of filter bed provide 3 troughs at 6/3 = 2.0 m apart

Total wash water discharge of 0.1395 m$^3$/sec enters in these 3 troughs

$\therefore$ Discharge in each trough = $0.1395/3 = 0.0465 \text{ m}^3/\text{sec}$

Dimension of a flat bottom trough is given by the empirical formula

$Q = 0.76 B' h^{3/2}$

$Q$ = Discharge in litres/min

$B'$ = Width of trough

$h$ = Water depth in the trough

Assume $B'$ = 20 cm

$\therefore \quad 0.0465 \times 1000 \times 60 = 0.76 \times 20 \times h^{3/2}$

$$\text{or} \quad h^{3/2} = \frac{0.0465\times 1000\times 60}{0.76\times 20} = 183.55$$

$h = 183.55^{2/3} = 33.29$ cm

Keep 5 cm freeboard. Hence, depth of trough = 32.29 + 5 = 37.29 cm ≈ 38 cm

Hence, 3 No. wash water troughs of size 38 cm × 20 cm will be used.

**Example 4.36** **Design the approximate dimensions of a set of two rapid gravity filters for treating water required for a population of 50000, the rate of supply being 18 *l*/d/person. The filters are rotated to work 5000 *l*/hr/m$^2$. Assume maximum daily demand to be 1.8 times the average daily demand. Assume any other data, if necessary.**

***Solution:***

Maximum daily demand = Population × 1.8 × average daily demand

= 50000 × 1.8 × 180 = 16.2 MLD

$$\text{Water demand per hour} = \frac{16.2\times 10^6}{24} \text{[neglecting time lost in wasing the filter]} = 675 \times 10^3 \; l/\text{hr}$$

$$\therefore \quad \text{Area of filter beds required} = \frac{\text{Water demand}}{\text{Rate of filtration}} = \frac{675\times 10^3}{5000} = 135 \text{ m}^2$$

Since two units are required to be designed, therefore area of each unit = $\frac{135}{2} = 67.5 \text{ m}^2$

Assuming, $L = 1.3 B$

$\Rightarrow \quad 1.3 B \times B = 67.5$

$\Rightarrow \quad B = 7.2$ m

Adopt $B = 8$ m

And, $L = 1.3 \times 8 = 10.4$

Adopt $L = 10.5$ m

Hence two units of size 10.5 × 8 m are provided

**Example 4.37.** A rapid sand filter is proposed for water supply treatment plant for a town with a population of 75000. The average rate of water supply is 150 *lpcd* and rate of filtration is to be 100 *l/min/m²*. Design

1. Size and number of filter beds.
2. Manifold lateral under drainage system
3. Wash water discharge required, if the rate of washing is 45 cm rise/min

***Solution:***

1. **Size and number of filter beds**

Maximum water demand per day

$= 75000 \times 1.8 \times 150 = 20.25 \times 10^6\ l/day = 20.25$ MLD

Assuming that 4% of filtered water is required for back washing of the filter per day.

Total filtered water required $= 20.25 + 0.04 \times 20.25 = 21.06$ MLD

Also assuming 30 min is lost every day in washing the filter

∴ Filtered water required per hour

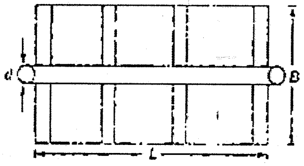
$$= \frac{21.06}{23.5} = 0.896 \text{ ML/hr}$$

$$\text{Area of filter} = \frac{\text{Filtered water required}}{\text{Rate of filtration}}$$

$$\Rightarrow \quad \text{Area} = \frac{0.896 \times 10^6}{100 \times 60} m^2$$

Number of unit (filter units)

$$\therefore \quad \text{Area of each filter unit} = \frac{149.33}{6} = 24.88 \text{ m}^2$$



Assuming $L = 1.3B$

$1.3B \times B = 24.88$

⇒ $B = 4.4$ m

Adopt $B = 4.5$ m

$L = 1.3 \times 4.5 = 5.85$ m

Adopt $L = 6$ m

Hence provide 6 filter units of dimension 6 × 4.5 m

2. **Design of manifold and laterals**

Let us assume area of perforations to be 0.3% of filter area

∴ Total area of perforations $= 0.3 \times 10^{-2} \times 6 \times 4.5$ m²

Cross sectional area of all laterals $= 2 \times$ Area of perforations in it $= 2 \times 0.081 = 0.162$ m²

Cross sectional area of manifold $= 2 \times 0.162 = 0.324$ m²

∴ Diameter of manifold ($d$) is

$$\frac{\pi}{4} d^2 = 0.324$$

⇒ $d = 0.64 \text{ m} \approx 0.65$ m

Adopt $d = 65$ cm

Number of laterals on each side

$$= \frac{\text{Length of filter bed}}{\text{Spacing between laterals}} = \frac{6 \times 100}{15} = 40 \quad \left[\begin{array}{l}\text{Assuming spacing}\\ \text{15 cm (max 30 cm)}\end{array}\right]$$

Hence total number of laterals $= 40 \times 2 = 80$

$$\text{Length of each lateral} = \frac{B - d}{2} = \frac{4.5 - 0.65}{2} = 1.925 \text{ m}$$

Total number of perforations in 80 laterals $= [illegible] \times \left(\frac{12}{1000}\right)^2 = 0.081$ [Assuming dia of perforation 12 mm]

⇒ Total number of perforations in 80 laterals = 716.197 ≈ 720

$$\text{Number of perforation in each lateral} = \frac{720}{80} = 9$$

∴ Area of perforation per lateral $= 9 \times \frac{\pi}{4} \times (1.2)^2 = 10.18$ cm²

Now, area of each lateral = 2 × area of perforation in it = 2 × 10.18 = 20.36 cm²

$$\text{Diameter of each lateral} = \sqrt{\frac{4 \times 20.36}{\pi}} = 5.09 \text{ cm}$$

Hence use 80 laterals each of 5.09 cm dia @ 15 cm c/c each having 9 perforation of 12 mm size with 65 cm diameter manifold.

$$\text{Check} \quad \frac{\text{Length of lateral}}{\text{Diameter of lateral}} = \frac{1.925 \times 100}{5.09} = 37.82 < 60 \text{ (ok)}$$

3. $$\text{Wash water discharge} = \frac{0.45 \times 6 \times 4.5}{60} = 0.2025 \text{ m}^3/\text{s}$$

∴ Velocity of flow in the lateral for wash water (assuming full flow).

$$= \frac{0.2025}{80 \times \frac{\pi}{4}\left(\frac{5.09}{100}\right)^2} = 1.24 \text{ m/sec}$$

$$\text{Velocity of flow in the manifold} = \frac{\text{Wash water discharge}}{\text{Area}} = \frac{0.2025}{\frac{\pi}{4} \times (0.65)^2} = 0.61 \text{ m/sec}$$

According to GOI manual velocity of flow in manifold be 1.8 - 2.4 m/sec

### 4.8.2.9 Comparison of Performance of Slow Sand and Rapid Sand Filters

Table 4.4

| S. No | Item | Slow Sand Filters | Rapid Sand Filters |
|---|---|---|---|
| 1. | Rate of filtration | 3m³/m²/d | 125 m³/m²/d |
| 2. | Size of bed | Large, 200 m² | Small, 200-400 m² |
| 3. | Depth of bed | 0.3 m of gravel, 1.2 m of sand usually reduced to not less than 0.6 m by scraping | 0.5 m of gravel, 0.7 m of sand or less not, reduced by washing. |
| 4. | Size of sand | Effective size 0.25 to 0.3 to 0.35 mm, uniformity coefficient 2 to 2.5 to 3. | 0.45 mm and higher uniformity coefficient 1.5 and lower depending on under-drainage system. |
| 5. | Grain size distribution of sand in filter | Unstratified | Stratified with smallest or lightest grains at top and coarsest or heaviest at bottom. |

| | | | |
|---|---|---|---|
| 6. | Under-drainage system | Split tile laterals laid in coarse stone and discharging into tile of concrete main drain | 1. Perforated pipe laterals discharging into pipe mains.<br>2. Porous plates above inlet box<br>3. Porous blocks with included channels |
| 7. | Loss of head | 0.15 m initial to 1 m final | 0.3 m initial to 2.5 m final |
| 8. | Length of run between cleanings | 20 to 60 days | 12 to 72 hours |
| 9. | Penetration of suspended matter | Superficial | Deep |
| 10. | Method of cleaning | 1. Scraping off surface layer of sand and washing and storing cleaned sand for periodic re-sanding of bed<br>2. Washing surface sand in Place by washer traveling over sand bed. | Dislodging and removing suspended matter by upward flow or backwashing which fluidises the bed. Possible use of water or air jets or mechanical rakers to improve scour. |
| 11. | Amount of wash water used in cleaning sand | 0.2 to 6% of water filtered | 1 to 4 to 6% of water filtered |
| 12. | Preparatory treatment of water | Generally none | Coagulation, flocculation and sedimentation |

### 4.8.3 Pressure Filters

There is no theoretical difference between the operation of a rapid gravity filter and the pressure type rate of flow, criteria for washing and other factors remain similar.

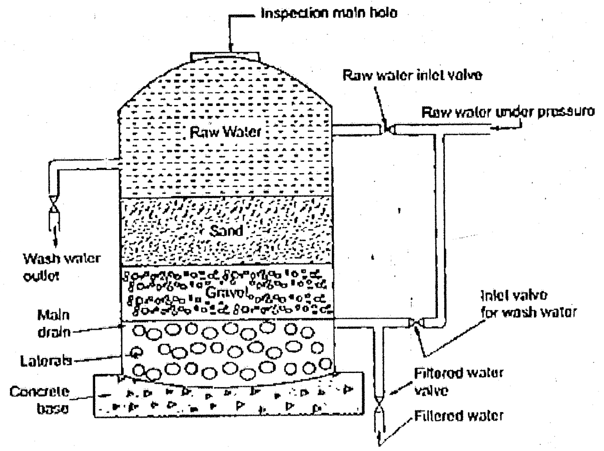


*Fig. 4.28* Vertical Pressure Filter

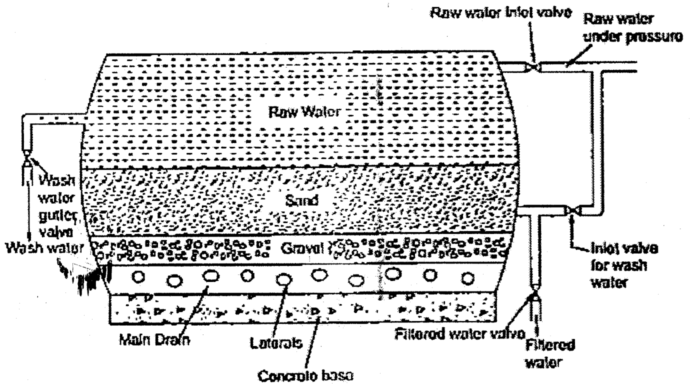


*Fig. 4.29* Horizontal Pressure Filter

The difference between them is that pressure filter unit is completely inside a closed chambers.

- In pressure filter, the flow of water is not under gravity. This implies that water inside the chamber is under pressure.
- Diameter of the tank is 1.5 - 3.0 m and height or length is 3.5 to 8.0 m.
- It is operated like a rapid gravity filter except that raw water is neither flocculated nor sedimented before it enters the filter.
- Rate of filtration in the case is 6000 - 15000 $l/m^2/hr$.
- It is used for clarifying softened water at industrial plants and in treating swimming pool water.

**Pressure Filter Suffers from the following Disadvantages:**

1. Treatment of water under pressure seriously complicates effective feeding, mixing and flocculation of water to the filters.
2. In case of direct supply from the pressure filter, it is not possible to provide adequate contact time for chlorine.
3. Water under filtration and the sand bed are out of sight and it is not possible to observe the effectiveness of the backwash or the degree of agitation during washing process.
4. It is very difficult to inspect, clean and replace the sand, gravel and under-drain of pressure filter.
5. On occasions when the pressure on the discharge main is released suddenly the entire sand bed might be distributed violently with distareous results to the filter efficiency.

## 4.9 Disinfection

Disinfection may be defined as the process of killing or inactivation of harmful micro-organisms in water either by physical process or chemical process. Physical process includes heating, ultraviolet radiation etc. and chemical process includes of disinfectants such as chemicals.

- Physical disinfection such as heating is safe and destroys pathogenic micro-organisms such as virus, bacteria, cysts. However, it can only be applied on a family size or household treatment unit. Ultraviolet light radiation is effective only for clear and low salinity water and is generally not applicable to community water supplies in the developing countries.

- Disinfection can be distinguished from sterilization. In sterilization process, all organisms are usually killed by a physical phenomenon such as boiling for a long period whereas in disinfection disease or illness causing micro-organisms are reduced to such low level that no infection or disease results when the water is used for domestic purposes including drinking water.
- Chemical disinfection is the most widely used method. The chemicals that have been successfully used are.

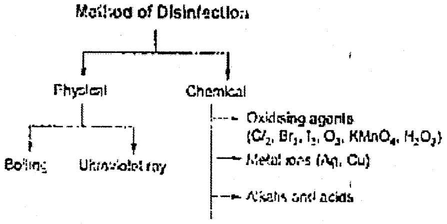
  Chlorine and chlorine compounds, bromine, iodine, ozone, potassium permaganate, hydrogen per oxide, silver and some of the phenolic compounds

  On a plant scale, the following disinfectant are in common use:

  (i) Chlorine (ii) Chloramine (iii) Chlorine dioxide (iv) Ozone

  Other disinfection are used principally for different situation as given below:

  1. Ultraviolet radiation for small public supplies, railway refreshment vehicles, restaurants etc.
  2. Silver for in house "Water supplies"
  3. Iodine for temporary, small scale use in emergencies.
  4. $KMnO_4$ for pre-disinfection of water before other treatment and also for iron and manganese removal.
  5. Boiling for domestic drinking supplies usually in an emergency but some times as a routine precaution.



- Disinfection is an essential minimum treatment requirement for any drinking water and it is the final process in the chain of water purification
- Out of various methods, chlorine and their various compounds are the most widely used disinfectants and the following are the reasons for their most wide use
  (a) ease of killing of pathogens
  (b) cheapness and ready availability
  (c) ease of application due to availability in various forms are high solubility production of desirable residual chlorine to ensure bacteriological purity in the distribution network.
- However, chlorine has some disadvantages which should be kept in mind when using. It is poisonous gas which requires careful handling. As regarding the toxicity of chlorine gas, the concentrations produces various physiological reaction in human being
- Various method of disinfection are classified in two category
  (a) Minor method (b) Major method

### 4.9.1 Minor Method

These are following types

1. **Treatment with Ozone:** Ozone is a gas of $O_3$ which has a powerful oxidising effect causing rapid and effective disinfection of a clean water
   - Ozone is produced by passing a discharge of high voltage alternating current through dry air.

$$\underset{\text{Oxygen molecule}}{3O_2} \xrightarrow{\text{Under high voltage}} \underset{\text{Ozone molecule}}{2O_3}$$

Because of its instability, ozone readily breaks down into normal oxygen and releases nascent oxygen

$$\underset{\text{Ozone}}{O_3} \longrightarrow \underset{\text{Oxygen}}{O_2} + \underset{\text{Nascent oxygen}}{[O]}$$

- Nascent oxygen is powerful oxidising agent and it removes organic matter as well as bacteria from water.
- 2-3 ppm ozone is required to maintain a residual of 0.1 ppm.
- Residual ozone is measured by orthotolidine test
- Ozone is unstable hence nothing remain in water by the time it reaches the distribution system.
- Ozone removes colour, taste and odour also, because it is a strong oxidizing agent and oxidizes everything which causes colour, taste and odour.
- It gives pleasant taste to water, unlike the chlorinated water which becomes bitter.
- It does not ensure safety against future recontamination.
- It is less efficient than chlorine in killing bacteria

**Limitation of Ozone Using as Disinfectant:**

(a) It is costlier than chlorination. Total cost of ozonation is of the order of three times the cost of equivalent chlorination.

(b) No residuals can be maintained as it is highly unstable and its use does not ensure safety against possible future contamination

2. **Treatment with F and Br:** The Fluorine and Bromine are available in the form of pills.
3. **Treatment with Silver:** Silver in the form of colloidal or "Katadyn" silver is also having a disinfecting effect.
4. **Treatment with $KMnO_4$:** Potassium permaganate is a popular disinfectant for well water supplies in villages which is contaminated with lower amounts of bacteria.
   - Besides killing bacteria, it also helps in oxidising the taste producing organic matter, hence it is sometimes added to filtered and chlorinated water.
   - $KMnO_4$ is mixed with water in a bucket and added to well. Pink colour forms because of this.
   - If pink colour disappears, this implies that organic matter is present. Hence, more $KMnO_4$ is added until the pink colour stands. The well is not used for next 48 hours.
   - The dose of $KMnO_4$ is normally 1-2 mg/l and the contact period is 4 to 6 hours.

**Remember**

- $KMnO_4$ removes 98% bacteria but removes 100% bacteria causing cholera.
- Water treated with $KMnO_4$ with passage of time produces dark brown precipitate.
- This agent is mostly used in rural areas

5. **Treatment with Excess Lime:** Excess lime makes water highly alkaline and kills bacteria:
   - Excess lime kills bacteria but excess lime (14 - 40 ppm) has to be removed before supply. For this, recarbonation is done
   - But, it is obsolete now a days

### 4.9.2 Major Method

1. **Chlorination:** Chlorine is powerful oxidising agent, which when dissolved in water yields the following reaction:

$$Cl_2 + H_2O \xrightleftharpoons{\text{[illegible]}} HCl + HOCl$$

which is followed by the secondary reaction:

$$HClO \underset{pH<7}{\overset{pH>8}{\rightleftharpoons}} H^+ + OCl^- \text{ (free residuals)}$$

- At $pH < 5$, chlorine does not react with water remains as free chlorine.
- $(HOCl + OCl^-)$ are combinedly called freely available chlorine.
- Out of these forms of freely available chlorine hypochlorous acid ($HOCl$) is most destructive. It is 80% more effective than $OCl^-$ ion. Hence, pH of water should be maintained slightly below 7.
- Moreover, chlorine will immediately react with ammonia in water to form chloramines.

$$NH_3 + HOCl \xrightarrow{pH>7.5} \underset{\text{Monochloroamine}}{NH_2Cl} + H_2O$$

$$NH_2Cl + HOCl \xrightarrow{pH(5-6.5)} \underset{\text{Dichloroamine}}{NHCl_2} + H_2O$$

$$NHCl_2 + HOCl \xrightarrow{pH<5} \underset{\text{Trichloramine}}{NCl_3} + H_2O$$

- The chloramines are the combined residuals. They are more stable than the free residuals but less effective as disinfectant and remains in water for greater duration.
- In the usual chlorine treatment, in which pH is kept slightly less than 7, dichloramine is most predominant.
- These disinfectant kill those enzymes which are essential for the metabolic process of living organisms.
- Doses of chlorine should be sufficient so as to leave a residue of 0.2 mg/$l$ after 10 minutes of contact period.
- The residual chlorine is tested by Diethyl-paraphenylene diamine (DPD) test.
- Although the primary objective of chlorination of potable water is the destruction or inactivation of bacteria, there are several other important secondary functions achieved by chlorination. These include:
  - (*i*) the oxidation of iron, manganese and hydrogen sulphides.
  - (*ii*) the destruction of some taste and odour producing compounds,
  - (*iii*) control of algae and slime organisms in treatment plants.
  - (*iv*) as an aid to coagulation.

**Factors Affecting Disinfection:**

1. Form of chlorine
2. pH
3. Concentration of $Cl$
4. Type of microbial organisms
5. Temperature
6. Contact time

**Forms in which Chlorine is Added:**

$Cl$ may be applied to the water in any of the following forms:

(a) Bleaching powder (Hypochlorites)
(b) As free chlorine (Liquid or gaseous form)
(c) Chloramines (Ammonia + Chlorine)
(d) Chlorine dioxide ($ClO_2$)

**(a) Bleaching Powder (Hypochlorites):** Powdered chlorine which may be chlorinated lime (bleaching powder) or its more stable variant. Chlorinated lime approximately comprises of :

$$Ca(OCl)_2 \rightleftharpoons Ca^{2+} + \underset{\text{Hypochlorite ion}}{2OCl^-} \qquad OCl^- \underset{pH>8}{\overset{pH<7}{\rightleftharpoons}} \underset{\text{Hypochlorous acid}}{HOCl}$$

- $OCl^-$ and $HOCl$ are disinfectant in this case. This process is called hypochlorination.
- 100% pure hypochlorite should contain free available chlorine equal to $OCl^-$ value of the compound. e.g. 142 gm of $Ca(OCl)^2$ will contain 102 gm of $OCl^-$ i.e. free chlorine in 100% column hychlonite is 70%. But the actual chlorinating ability is lesser because bleaching powder is unstable and goes on loosing its chlorine content when exposed to atmosphere.
- Hypochlorites are generally not used in modern days because they increase pH, which is result of lime content and finally, sludge is formed in this case.
- Hypochlorite contains very low amount of chlorine.

---

**Remember:** Since bleaching powder increases the pH, hence, its use is restricted to swimming pools only.

---

**NOTE:** Bleaching powder [illegible]mula actually is

$$CaCl_2 \cdot Ca(OH)_2 \cdot H_2O + Ca(OCl)_2 \cdot 2\,Ca(OH)_2$$

**(b) As Free Chlorine:**

- Either it may be in gaseous form or liquid form but liquid form is mostly used.
- If temperature is below 10°C, liquid chlorine will froze into ice crystals which will stick and choke the lines of feeding. Hence, liquid cylinder is kept at 32° – 48°C.
- Steel cylinder burns in dry chlorine at temperature greater than 92°C. High temperature is avoided.
- Chlorine gas causes irritation to the lungs and to membranes of the nose and throat.
- Chlorine gas neither burns nor explodes but chlorine forms explosive mixture with carbon monoxides.
- Chlorine is applied to the water to be treated through an instrument called chlorinator or chloroname.
- Free chlorine can be stored for long time without being deteriorated.
- The gaseous form of chlorine gets converted into the liquid form, when subjected to a pressure of about 700 kN/m$^2$.
- Chlorine dose can be easily measured in liquid forms. Hence, underloading and overloading is less frequent. Chlorine is a powerful disinfectant and remains in water for a long time when ammonia is present.

---

**NOTE:** No sludge is formed in its application as it may be produced in Hypochlorites and chloramines.

**(c) Chloramines ($NH_3 + Cl_2$):** Chloramines are the disinfectant compounds, which are formed by the reactions between ammonia and chlorine.

- These compounds are quite stable and can remain in water as residuals for a sufficient time, contrary to the unstable chlorine which evaporates after some time.
- Hence, they can provide a greater safeguard against future pollution.
- The other advantages of using chloramines as disinfectant are:
  1. They do not cause bad tastes and odours when left as residuals.
  2. They are very useful when phenols are present in water.
- Chloramine are weaker disinfectant (25 times less than free chlorine). Hence, either higher dose or longer contact period is used.
- For producing chloramines, ammonia is added to filtered water before adding chlorine.
- Amount of ammonia should be 1/3 to 1/4 of the amount of chlorine. They are added in water and mixed for 20 minutes to 2 hours before adding chlorine. This contact period of ammonia should be higher when phenol is present.

---

**NOTE:** Ammonia adding instrument is called ammoniator.

**(d) Chlorine Dioxide ($ClO_2$):** Chlorine dioxide ($ClO_2$) is a very effective and powerful disinfectant, about $2\frac{1}{2}$ times stronger than free chlorine.

- It is produced by passing chlorine gas through sodium oxychloride, as follows:

$$2\,NaOCl_2 + Cl_2 \longrightarrow 2\,NaCl + \underset{\text{Chlorine dioxide}}{2\,ClO_2} \uparrow$$

- It may also be used when phenol is present and can also remove organic impurities.
- pH range is 8-10.
- Normal dose is 0.5 – 1.5 mg/litre

**Use of Chlorine Tablets:** Chlorine tablets may also sometimes be used to disinfect small quantities of water, but they are costly

- They are available in the market under various trade names such as halazone tablets.

---

**Do you know?** The NEERI (National Environmental Engineering Research Institute), Nagpur has formulated a new type of chlorine tablet which is 15 times better than the ordinary halazone tablets.

**Example 4.36** The following residual chlorine compounds are formed during chlorination of water:

| | |
|---|---|
| 1. $NH_2Cl$ | 2. $NHCl_2$ |
| 3. $HOCl$ | 4. $OCl^-$ |

The correct sequence of formation of these residual chlorine compounds is

| | |
|---|---|
| (a) 2, 1, 3, 4 | (b) 1, 2, 4, 3 |
| (c) 1, 2, 3, 4 | (d) 2, 1, 4, 3 |

Ans. (c)

First chloramines (combined residuals) will form by reaction of ammonia with chlorine. The chloramines are formed first by following reactions of ammonia and chlorine (hypochlorous acid HOCl)

$$NH_3 + HOCl \rightarrow NH_2Cl + H_2O$$
$$NH_2Cl + HOCl \rightarrow NHCl_2 + H_2O$$
$$NHCl_2 + HOCl \rightarrow NCl_3 + H_2O$$

At pH > 6.5 monochloramine will be the predominant species.

Then free residual chlorine compounds ($HOCl$ and $OCl^-$) will form as follows:

$$Cl_2 + H_2O \rightarrow HOCl + H^+$$
$$HOCl \rightleftharpoons H^+ + OCl$$

Thus, correct sequence is $NH_2Cl - NHCl_2 - HOCl - OCl$

**Types of Chlorination and Certain Important Definitions:**

Depending upon the quantity of chlorine added or the stage at which it is added or upon the results of chlorination, various technical terms in relation to the chlorination are used. They are:

(i) Plain chlorination
(ii) Pre-chlorination
(iii) Post chlorination
(iv) Double chlorination
(v) Break point chlorination
(vi) Super chlorination
(vii) Dechlorination

**(i) Plain Chlorination:** This term is used to indicate that only the chlorine treatment and no other treatment has been given to the raw water.

- This helps in removing bacteria, organic matter and colour from the raw water.
- It is used for clean water i.e. turbidity between 20-30 mg/l.
- Dose is 0.5 mg/l.

**(ii) Pre-Chlorination:** Pre-chlorination is the process of applying chlorine to the water before filtration or rather before sedimentation-coagulation.

- Doses required are such that 0.1 to 0.5 mg/l comes to filters.
- Normal dose is 5 to 10 mg/l and prechlorination is always followed by post chlorination to ensure final safety.

**(iii) Post Chlorination:** Post chlorination or sometime simply called chlorination is the normal standard process of applying chlorine in the end, when all other treatments have been completed.

- Applying chlorine at the end when all the treatment is completed is called post chlorination.
- The dose should be such that 0.1 to 0.2 mg/l should be left after a contact period of 10 min.

**(iv) Double Chlorination:** The term double chlorination is used to indicate that the water has been chlorinated twice.

- The pre-chlorination and post-chlorination are generally used in chlorination

**(v) Break-Point Chlorination:** Break point chlorination is a term which gives us an idea of the extent of chlorine added to water.

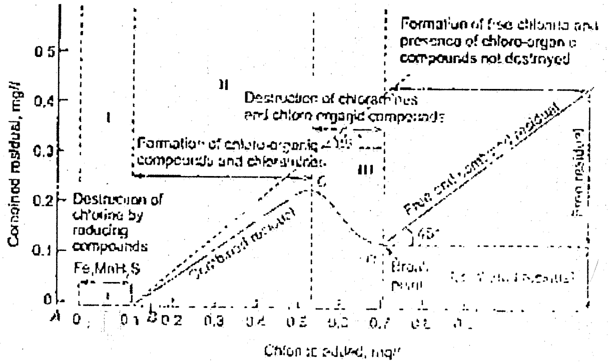


*Fig.4.70* Chlorine Reaction in Water

- Infact, it represents that much dose of chlorination beyond which any further additional chlorine will appear as free residual chlorine.
- During disinfection process, amount of residual chlorine is less in the beginning (Stage-I) during which iron, nitrite etc. are oxidised
- In Stage-II, chloramines and combined residual chlorine forms. Combined residual chlorine gradually increased as demand for disinfection is satisfied
- Actually chlorine residue is tested by DPD test which measures both combined and free chlorine.

- Amount of residual would be slightly less than applied chlorine because some bacteria killing takes place.
- At point *C*, bad smell start coming out. It is due to the fact that oxidation of organic matter starts at point *C*. Hence, residual amount decreases.
- In stage-III, free chlorine breaks down chloramines into nitrogen compounds.

$$2\,NH_3 + 3\,Cl_2 \longrightarrow N_2 + 6\,HCl$$

- Chloro-organic compounds are also destroyed. At point *D*, bad smell suddenly disappear. This implies that oxidation of organic matter is complete.
- Any further chlorine addition simply appears as free chlorine i.e. chlorine breaks away from water. Thus, point *D* is called "Break point".
- In general practice, chlorine is added beyond break point to ensure a residual of 0.2 – 0.3 mg/*l* as free chlorine. This residual takes care of future recontamination.

---

**NOTE:** The difference of applied chlorine and residual chlorine is called chlorine demand of water.

**(vi) Super Chlorination:** When excess chlorine (5 to 15 mg/*l*) is added in water during epidemic such that it gives a residual of 1 to 2 mg/litre beyond break point is called super chlorination.

**(vii) Dechlorination:** When chlorine residue is high excess chlorine will be removed by dechlorinating agent.

- The various dechlorinating agents are:
  - (*i*) Sodium Thiosulphate ($Na_2S_2O_3$) → Cheapest in all
  - (*ii*) Activated carbon
  - (*iii*) Sulphur dioxide ($SO_2$)
  - (*iv*) Sodium bisulphate ($NaHSO_3$)
  - (*v*) Ammonia as $NH_4OH$

**Example 4.39** Assertion (A): Break-point chlorination is required to ensure free chlorine residuals for better disinfection.

Reason (R): Free chlorine residuals have good disinfecting power and they are usually dissipated quickly in the distribution system.

(a) both A and R are true and R is the correct explanation of A

(b) both A and R are true but R is not a correct explanation of A

(c) A is true but R is false

(d) A is false but R is true

Ans. (c)

### Testing of Chlorine Residuals:

The amount of residual chlorine left in the chlorinated water after the required contact period can be experimentally determined by using any of the following tests:

(a) Orthotolidine test
(b) Starch iodide test
(c) Chlorotest; and
(d) D.P.D. test

**(a) Orthotolidine Test:** The main test used for residual chlorine for many years has been that using orthotolidine. However, orthotolidine is not recognized as being among those chemical substances capable of causing cancer.

- 10 m*l* of chlorinated water sample is taken in a test tube after the required contact period. To this, 0.1 m*l* of orthotolidine solution is added.
- Colour will be yellow (free + combined chlorine)
- By comparing this colour, with a colour of known concentration, the amount of chlorine residue is obtained. If free and combined chlorine are to be found out separately. Colour formed in 5 minutes ($R_2$) and colour formed in 5 seconds ($R_1$) is noted.

  $R_1$ → Compared with → Free chlorine

  $R_2$ → Compared with → Combined chlorine + Free chlorine
- In orthotolidine test presence of iron, manganese, nitrite etc. will give false yellow colour thereby indicating increased chlorine residue which is wrong. For such water, orthotolidine arsenite test is performed. In this case, sodium arsenite is added to chlorinated water. This will dechlorinate the sample.
- To this dechlorinated sample, orthotolidine solution is added and colour formed $R_1$ is noted.

  So, $R_1$ → Iron, manganese, nitrite
- Another sample of chlorinated water is taken and colour formed in 5 min ($R_3$) and colour formed in 5 sec ($R_2$) is noted.

  So, $R_2$ → Free chlorine + Iron, manganese, nitrite
  and $R_3$ → (Free + combined chlorine) + Iron, manganese, nitrite
  Free chlorine = $R_2 - R_1$
  Combined chlorine = $R_3 - R_2$
  when chloramine is used as disinfectant, ordinary ortholotidine test is done and colour should be noted in 15 minutes instead of 5 minutes because reaction is slow with chloramines.

**(b) Starch Iodide Test (Iodometric Test):** In the starch iodide tests one litre of water sample is collected in a heat proof earthenware vessel known as casserole. To this, 10 m*l* of potassium iodide solution is added.

- It is used when presence of nitrite, $NO_2^-$, manganese compounds which makes orthotolidene test unsuitable.
- This test is more precise than ortholotidine test particularly when residual chlorine is more than 1 ppm.

  [1 litre water + 10 m*l* of potassium iodide + 5 m*l* starch] → Blue colour is formed titrated with 0.01 N $Na_2S_2O_3$ (Sodium thiosulphate).
  $Cl_2$ in ppm = 0.3546 x number of m*l* of 0.01 N $Na_2S_2O_3$ required to remove the blue colour.

**(c) Chlorotest:** Its based on colour matching technique.

- In this case, BDH (British Drug House Reagent) chlorotex reagent is used.
- 50 m*l* of water + 5 m*l* of chlorotex reagent → developed colour is matched with that of known concentration.
- Corresponding to 0.2 mg/*l* residue, colour formed is pink colour.
- No comparator is used in this method.

**(d) DPD Test (Diethyl-Paraphenylene Diamine):** Due to problem with orthotolidene, the use of ortholotidene for water testing has now been superceded by the plain test using DPD.

- The necessary reagents are supplied as tablets with detailed instruction.
- It is also a colour matching technique.
- The reagent used is Pallian's DPD reagent.

**Important Factors Affecting Bacteriocidal Efficiency of Chlorine**

1. Turbidity↑ – Bacteriocidal Efficiency↓
2. Metallic compound (Iron, Manganese): Chlorine is utilised in oxidizing these metallic compounds. Hence, bacteriocidal efficiency decreases.
3. Ammonia compounds form chloramines which reduces efficiency.
4. pH of water: pH range of 5-7 is most effective. Beyond this range, bacteriocidal efficiency decreases.
5. Temperature: Requirement of chlorine increases with decreases in temperature and increase in pH beyond 7.
6. Time of contact↑ → Efficiency↑

**Example 4.40** A rural water supply scheme serves a population of 10,000 at the rate of 50 litres per capita per day. For the chlorine dose of 2 ppm, the required amount of bleaching powder with 20% available chlorine will be

(a) 0.5 kg (b) 5 kg (c) 10 kg (d) 15 kg

Ans. (b)

**Example 4.41** **The chlorine consumption in the treatment of 10,000 m³/d of a river water is 6 kg/d. The residual chlorine after 30 minutes contact is 0.40 mg/l. Calculate the chlorine dosage in milligram per litre and the chlorine demand of river water.**

***Solution:***

Water treated per day = 10,000 m³ = 10,000 × 10³ litres = 10 × 10⁶ litres = 10 million litres.

Chlorine consumed per day = 6 kg = 6 million mg

$\therefore$ Chlorine used per litre of water $= \dfrac{6 \text{ million mg}}{10 \text{ million ltrs}} = 0.6$ mg/l

$\therefore$ Residual chlorine left = 0.4 mg/l (given)

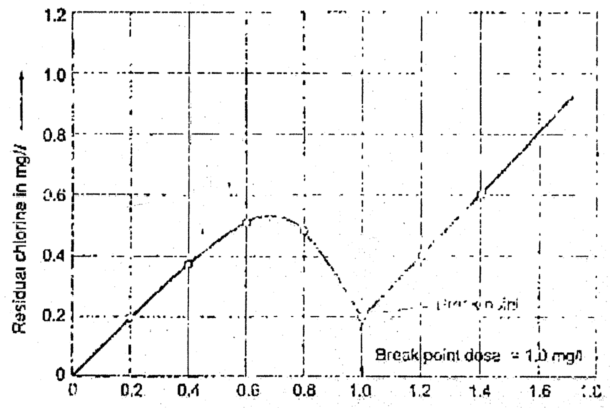
$\therefore$ **Actual chlorine demand** (or chlorine dosage which has reacted in water) = 0.6 – 0.4 = 0.2 mg/l

**Example 4.42** **Result of chlorine demand test on a raw water is as follows:**

| Sample No. | Chlorine Dosage (mg/l) | Residual Chlorine after 10 minutes contact (mg/l) |
|---|---|---|
| 1 | 0.2 | 0.19 |
| 2 | 0.4 | 0.36 |
| 3 | 0.6 | 0.50 |
| 4 | 0.8 | 0.48 |
| 5 | 1.0 | 0.20 |
| 6 | 1.2 | 0.40 |
| 7 | 1.4 | 0.60 |
| 8 | 1.6 | 0.80 |

**Draw the chlorine demand curve and find out the "breakpoint dosage". What is the "chlorine demand" at dosage of 1.3 mg/l.**

***Solution:*** The data has been plotted in graph in figure 4.31



**Applied chlorine (mg/l)**

*Fig.4.31*

The breakpoint is represented by the point B.P. and it is 1.0 mg/l.

Chlorine demand = Applied chlorine – Residual chlorine

= 1.0 – 0.2 = 0.8 mg/l at the breakpoint

This chlorine demand becomes constant and thereafter, all added chlorine appears as free chlorine.

$\therefore$ At any dosage above 1.0 mg/l chlorine demand will remain steady and equal to 0.8 mg/l

Hence, the chlorine demand at a dosage of 1.3 mg/l will be equal to 0.8 mg/l only.

$\therefore$ Residual Chlorine = 1.3 – 0.8 = 0.5 mg/l

## 4.10 Water Hardness and Softening

- The reduction or removal of hardness from water is known as water softening.
- The advantage of softening lies in chiefly in the reduction of soap consumption, lowered cost in maintaining plumbing fixtures, and improved taste of food preparations.
- Salts of calcium and magnesium react with soap and until they have been neutralised, a lather cannot form.
- Therefore, the greater the concentration of calcium and magnesium present in solution, the more soap is needed before a lather will form and it is said that the water is harder.
- There are two type of hardness

(a) Temporary hardness (b) Permanent hardness

### 4.10.1 Removal of Temporary Hardness

The temporary or carbonate hardness, which is caused by carbonates and bicarbonates of Ca and Mg, can be removed by boiling or by adding lime.

By simple boiling:

$$Ca(HCO_3)_2 \xrightarrow{\text{Heated}} \underset{ppt}{CaCO_3} \downarrow + H_2O + CO_2 \uparrow$$

**NOTE:** The boiling does not remove temporary hardness due to magnesium because $MgCO_3$ is fairly soluble in water.

- Hence, this hardness is removed by addition of lime.

$$MgCO_3 + \underset{\text{Hydrated lime}}{Ca(OH)_2} \longrightarrow \underset{\text{ppt}}{Mg(OH)_2\downarrow} + \underset{\text{ppt}}{CaCO_3\downarrow}$$

$$Mg(HCO_3)_2 + \underset{\text{Hydrated lime}}{Ca(OH)_2} \longrightarrow Ca(HCO_3)_2 + \underset{\text{ppt}}{Mg(OH)_2\downarrow}$$

$$Ca(HCO_3)_2 + \underset{\text{Hydrated lime}}{Ca(OH)_2} \longrightarrow \underset{\text{ppt}}{2\,CaCO_3\downarrow} + 2\,H_2O$$

1 mole of $MgCO_3$ requires 1 mole of hydrated lime, whereas 1 mole of $Mg(HCO_3)_2$ requires 2 moles of hydrated lime.

- Precipitate are removed by sedimentation and filtration through rapid gravity filter.

### 4.10.2 Removal of Permanent Hardness (Water Softening)

The permanent or non-carbonate hardness, which is caused by the sulphate, chlorides and nitrates of Ca and Mg are removed by special methods.

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**NOTE:** It is not necessary to remove hardness completely from drinking water rather some degree of hardness is necessary in water because it gives the water palatable taste.

There are following methods to remove permanent hardness:

(a) Lime-soda process (b) Base-exchange process (c) Demineralization

**(a) Lime Soda Process:** It is used for the removal of all forms of calcium hardness.

- In this, soda ash is added and the non-carbonate hardness is converted into the sparingly soluble calcium carbonate.

$$Ca(HCO_3)_2 + Ca(OH)_2 \longrightarrow 2\,CaCO_3\downarrow + 2\,H_2O$$

$$Mg(HCO_3)_2 + Ca(OH)_2 \longrightarrow Ca(HCO_3)_2 + Mg(OH)_2\downarrow$$

$$MgCO_3 + Ca(OH)_2 \longrightarrow Mg(OH)_2\downarrow + CaCO_3\downarrow$$

$$Mg^{2+} + \left\{\begin{matrix} 2\,Cl^- \\ SO_4^{2-} \\ 2NO_3^- \end{matrix}\right. + Ca(OH)_2 \longrightarrow Mg(OH)_2\downarrow + Ca^{2+} + \left\{\begin{matrix} 2\,Cl^- \\ SO_4^{2-} \\ 2NO_3^- \end{matrix}\right.$$

Now further,

$$CaCl_2 + Na_2CO_3 \longrightarrow CaCO_3\downarrow + 2\,NaCl$$

$$CaSO_4 + Na_2CO_3 \longrightarrow CaCO_3\downarrow + Na_2SO_4$$

$$Ca(NO_3)_2 + Na_2CO_3 \longrightarrow CaCO_3\downarrow + 2\,NaNO_3$$

At the end,

$$CO_2 + Ca(OH)_2 \longrightarrow CaCO_3\downarrow + H_2O$$

- Lime removes entire carbonate hardness.
- Lime reacts with non-carbonate hardness of magnesium to convert it to non-carbonate hardness of calcium.
- Non-carbonate hardness of calcium is finally removed by soda ash.
- Lime also helps in removing $CO_2$ from the system. If concentration of $CO_2$ is more, it will consume more amount of lime, thus the amount of lime available for removing carbonate hardness is reduced.
- Thus, if $CO_2$ concentration is more than 10 mg/l, we remove $CO_2$ first by aeration before adding lime.
- Optimum pH for $CaCO_3$ precipitation by lime addition is from 9 – 9.5 and for $Mg(OH)_2$ precipitation is 11.0.
- Normally, water has a pH less than this value, hence for effective precipitation, pH is artificially raised. This can be achieved by addition of excess lime.
- Complete removal of hardness cannot be accomplished by chemical precipitation, under normal condition in treatment plant, 40 mg/l of $CaCO_3$ and 10 mg/l of $Mg(OH)_2$ usually remains in softened water. These remains will precipitate slowly and hence will get accumulated inside the pipe. Hence, it is necessary to make it soluble. This is done by recarbonation.

$$CaCO_3 + CO_2 + H_2O \longrightarrow Ca(HCO_3)_2$$

$$Mg(OH)_2 + CO_2 \longrightarrow MgCO_3 + H_2O$$

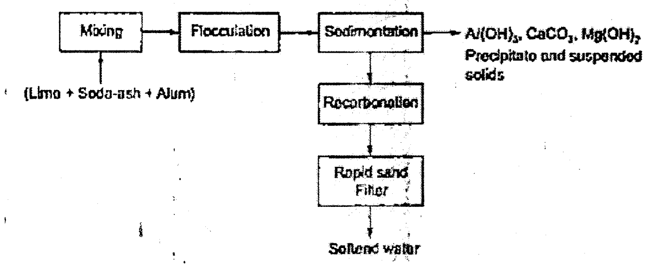
$$MgCO_3 + CO_2 + H_2O \longrightarrow Mg(HCO_3)_2$$

- This process can also be performed by using acids:

$$CaCO_3 + H_2SO_4 \longrightarrow \underset{\text{Soluble}}{2\,Ca(HCO_3)_2}$$

$$Mg(OH)_2 + H_2SO_4 \longrightarrow MgSO_4 + 2\,H_2O$$

- If pH has been raised to facilitate the precipitation of $CaCO_3$ and $Mg(OH)_2$, this pH has to brought under control before stabilization, recarbonation is done.
- So in step-I, we added acid and in step-II, $CO_2$ will be added for recarbonation.



- When softening and coagulation process is combined i.e. when lime soda is added with alum, lesser quantity of coagulant is required.
- Due to increased alkalinity by lime soda process, it reduces the corrosion of pipes.
- Its also help in killing bacteria because of high causticity.
- Its also help in removing upto some extent of Fe and Mn but the process produces huge quantity of sludge.
- 1 mg/l of calcium hardness as $CaCO_3$ removed will produce 1 mg/l of sludge as $CaCO_3$.

- 1 mg/*l* of Mg hardness as $CaCO_3$ removed will produce 0.58 mg/*l* of $Mg(OH)_2$ and 1 mg/*l* added lime as ($CaCO_3$) will produce 1 mg/*l* of sludge as $CaCO_3$.
- Lime soda removes hardness upto about 50 mg/*l*.
- When coagulation and lime soda processes are combined, which results additional sludge (solids) produced, will correspond to the metal coagulant precipitated solids removed.
- Dry sludge produced in mg/*l* [Ca removed + 0.58 Mg removed + Lime added]
- Lime soda process results in reduction of the total dissolved solid of treated water.

---

**Remember:** About 50 - 200 mg/*l* hardness can be left for the consumer. Any hardness above 200 mg/*l* requires water softening.

**NOTE** The greatest disadvantage of the lime-soda process of softening is the large amount of sludge that results in the difficulty of its disposal. However, the following methods may be adopted for disposal.

(*i*) Direct disposal of wet sludge to a running water course or sea.
(*ii*) Drying of the sludge in open lagoons and carrying away dried material to tips e.g. quarries.
(*iii*) Efficient drying of the sludge by mechanical means so that it may be sold as a fertilizers or used in industry.

(b) Base Exchange Process (Cation Exchange Process): In the process, ions of a given species are displaced from an insoluble exchange materials by ions of species from solution.

- The most commonly used exchange materials are zeolites, which are complex sodium alumino-silicates and green sands.
- When used for water softening, the hard water is passed through the bed of natural zeolites, which exchange their sodium ions for the calcium and magnesium ions in water, giving complete removals of hardness:

$$Ca^{++} + Na_2Z \longrightarrow CaZ + 2\,Na^{+} \quad | \quad Mg^{++} + Na_2Z \longrightarrow MgZ + 2\,Na^{+}$$

- When the capacity for the exchanging ions has been depleted a regenerating solution with a high concentration of the original ions is pumped through the bed.
- The process displaces the contaminant ions and rejuvenates the exchangers as given below:

$$\underset{\substack{\uparrow \\ \text{Used} \\ \text{zeolites}}}{CaZ} + \underset{\substack{\downarrow \\ \text{Sodium chloride} \\ \text{solution} \\ \text{(Brine Solution)}}}{2NaCl} \longrightarrow \underset{\text{Regenerated zeolite}}{Na_2Z} + CaCl_2 \quad | \quad MgZ + 2\,NaCl \longrightarrow Na_2Z + MgCl_2$$

- The use of ion exchanges is not limited to water softening.
- Ion exchange can also be used for removal other ions such as ammonia, nitrate, fluoride etc. from water.
- A wide variety of ion exchangers are commercially available. The widest application of ion exchangers is in industrial water supply treatment rather than in domestic water supply treatment.
- The ion-exchange materials used is known as zeolites and are mainly processed green sand and synthetic zeolites made from sulphonated coals and condensation polymers.
- But now a days, they are being superceded by ion-exchange resins.

**Important Points about Zeolite Process:**

- Zeolite process results in zero hardness.
- Sludge formation problem doesn't occur.
- No problem of incrustation of pipe as in lime soda process, but it is not suitable for turbid waters. It also leaves $NaHCO_3$ in water which causes foaming in boilerfeed water.
- The process is costlier for water containing iron and manganese because Fe and Mn zeolites are formed which cannot be regenerated into sodium zeolite.
- Thus zeolite is wasted, if Fe and Mn are present.

## Comparison of Lime-Soda and Zeolite Processes of Softening Water Supplies

Table 4.5

| S.No. (1) | Item (2) | Lime Soda Process (3) | Zeolite Process (4) |
|---|---|---|---|
| 1. | Size of plant | Bulky and large. | Compact and small |
| 2. | Skilled supervision, if required. | Careful and skilled supervision is necessary for obtaining results. | Automatic and easy to operate. |
| 3. | Sludge troubles, if any. | Large quantity of sludge is formed, thereby posing problems for finding out space for its disposal. | No sludge is formed and therefore, there in no problem of sludge disposal. |
| 4. | Post treatment, if needed | Recarbonation is a must after sedimentation and filtration. If recarbonation is not done, incrustation of pipe walls in distribution system may occur. | No such post treatment is required. |
| 5. | Results obtained. | This can produce waters of hardness not less than about 50 mg/*l*. Therefore, useful for public supplies only. | Water of zero hardness can be obtained. Therefore, useful for industrial supplies also. |
| 6. | Removal of colour due to iron and manganese. | Can remove the colour due to iron and manganese, but only to a very small extent. | Can remove the colour due to iron and manganese, although very costly for treating such waters, because the exhausted Mn and iron zeolites cannot be regenerated. |
| 7. | Effects on bacteria. | The increased causticity may help in killing pathogenic bacteria, especially when alkalinity caused by calcium, magnesium or sodium hydroxides of 20 to 50 mg/*l* is maintained for 4 to 5 hours. | No such advantage is offered by this process. |
| 8. | The pH of the treated water. | Increases the pH value of water, which reduces the corrosion of distribution pipes. | The pH value of the water is not affected. |

| | | | |
|---|---|---|---|
| 9. | Care needed in handling materials. | Careful handling is required because the materials i.e. (lime and soda) are corrosive. | Brine solution is required to be handled, which does not require much care. |
| 10. | Economy. | Process is economical and can be easily combined with usual water treatment methods at slight extra cost. | Process is costlier. |
| 11. | Hardness which can be treated. | Excessively hard waters, particularly those which are high in magnesium hardness can be treated. | Raw waters with hardness greater than 800 mg/*l* can not be easily and economically treated. |
| 12. | Allowable turbidities in raw waters. | Highly turbid and acidic waters can be treated. | Highly turbid waters are difficult to be treated, because the suspended impurities deposited around the zeolite particles cause obstruction to the working of the zeolite. |

(c) Demineralisation Process for Removing Hardness: Demineralisation means removing the minerals from the water.

- The process helps us in completely removing or reducing the mineral content to any desired extent.
- This demineralized water, sometimes called de-ionised water, is as pure as distilled water, and is very suitable for industrial purposes, especially for steam raising in high pressure boilers.
- The complete removal is done by first passing the water through cation exchange resins and then through anion exchange resin (*R*).

$$1^{st}\text{ stage}\begin{cases} Ca(HCO_3)_2 + H_2R \longrightarrow CaR + 2H_2O + 2CO_2 \\ CaCl_2 + H_2R \longrightarrow CaR + 2HCl \\ MgSO_4 + H_2R \longrightarrow MgR + H_2SO_4 \\ 2NaCl + \underset{\text{Cation exchange resin}}{H_2R} \longrightarrow \underset{\text{Exhausted cation exchange resin}}{Na_2R} + 2HCl \end{cases}$$

$$2^{nd}\text{ stage}\begin{cases} \underset{\text{Anion exchange resin}}{ROH} + HCl \longrightarrow \underset{\text{Exhausted anion exchange resin}}{RCl} + H_2O \end{cases}$$

- The exhausted cation exchange resin can be regenerated by treating by HCl and anion exchange resin can be regenerated by treating by soda-ash.

$$\underset{\substack{\downarrow \\ \text{Exhausted} \\ \text{CER}}}{\left.\begin{matrix} Ca \\ Mg \\ Na \end{matrix}\right\}} R + 2HCl \longrightarrow \underset{\substack{\uparrow \\ \text{CER}}}{H_2R} + \left.\begin{matrix} Ca \\ Mg \\ Na \end{matrix}\right\} Cl_2$$

$$2RCl + Na_2CO_3 \longrightarrow 2ROH + 2NaCl + CO_2 + H_2O$$

## 4.11 Minor Treatments

**1. Treatment with Activated Carbon**

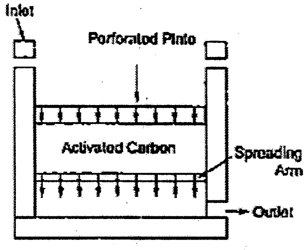


*Fig.4.32*

- This is a specially treated carbon, which possesses the property of absorbing and attracting impurities.
- Due to absorption property it removes taste, colour and odour and also removes phenol type impurity.
- The activated carbon is mostly used in the powered form, and may be added to water either before or after the coagulation but before filtration.
- In split method, a part of activated carbon is mixed in mixing tank and remaining is mixed before it enters the filter.
- The usual dose of activated carbon varies from 5 to 20 mg/*l*.
- When used in powered from before coagulation, it aids in coagulation.
- It reduces the chlorine demand of treated water.
- It removes the organic matter present in water.
- It removes the tastes, odours and colour caused by the presence of iron, manganese, phenols, excess chlorine, hydrogen sulphide etc.
- Its overdoes is not harmful.

**2. Treatment with Copper Sulphate ($CuSO_4 \cdot 7H_2O$)**

- It helps in removing colours, taste and odours from water.
- Its main advantage is obtained by adding it to open reservoirs or lakes.
- When added in reservoirs, it kills the algae or rather check the growth of algae.
- The solution of $CuSO_4$ is added at the entry of water into the distribution pipes.
- Usual dose is 0.5 – 0.75 mg/*l*.

**3. Treatment with Oxidising Agents**

- The colour, odour and taste from the water can be removed.
- The oxidising agents used are potassium permanganate, chlorine, ozone etc.
- Usual dose of potassium permanganate vary between 0.05 to 0.1 mg/*l*.

**4. Removal of Iron and Manganese**

The presence of iron and manganese in water may be in two forms:

(a) Without any organic matter
(b) In combination with organic matter

**(a) Without any organic matter:** When Fe and Mn are present without combination with organic matter, they can be removed by simple aeration, sedimentation and filtration.

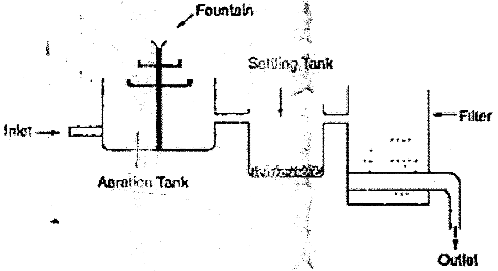


*Fig.4.33(a)* Iron and manganese removal without organic matter

**(b) In combination with organic matter:**

- When Fe and Mn exist in water in combination with organic matter, then the bond is broken by adding lime, chlorine or potassium permanganate ($KMnO_4$).
- The water is agitated thoroughly to break the bond.
- The water is then taken to the settling tank and then to filter unit.

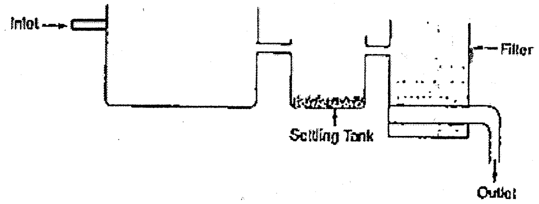


*Fig. 4.33(b)* Iron and manganese removal (with organic matter)

5. **Fluoridation (Addition of Fluorine)**

Agents are NaF (Sodium Fluoride), $Na_2SiF_6$ (Sodium silico fluoride), $H_2SiF_6$ (Hydro silicic acid).

6. **Defluroidation (Removal of Fluorine)**

The following technologies are generally used for removing fluorides from water.

*(i)* Absorption by activated alumina (AA). (commonly known as Prashanti Technology)
*(ii)* Nalgonda technique
*(iii)* Ion exchange absorption method
*(iv)* Reverse osmosis process

***(i)* Absorption by Activated Alumina (Absorption by AA)**

- In this method, the raw water containing high contents of fluoride is passed through the insoluble granular beds of substance like activated alumina (AA) or Bone char or activated carbon or surpentinite or activated bauxite which adsorbs fluoride from the percolating water, giving out defluoridated water.
- Activated alumina is an excellent medium for removal of excess fluoride than other absorption media. Activates alumina is rejuvenated by NaOH solution.
- The absorption process is best carried out under slightly acidic condition (pH = 5 to 7).

***(ii)* Nalgonda Technique (most economical)**

- Mainly used in rural areas for ground water containing excess fluoride.
- Nalgonda technique uses aluminium salt (alum) for removing fluoride.
- The raw water is first mixed with adequate amount of lime (CaO) or sodium carbonate ($Na_2CO_3$) and thoroughly mixed.
- Alum solution is then added and water is stirred slowly for about 10 min, and allowed to settle for nearly one hour in sedimentation tank where bleaching powder is added.
- The precipitated sludge is discarded and the clear supernatant containing permissible amount of fluoride is withdrawn for use.
- Bleaching powder and alum combination is a very effective disinfectant also.

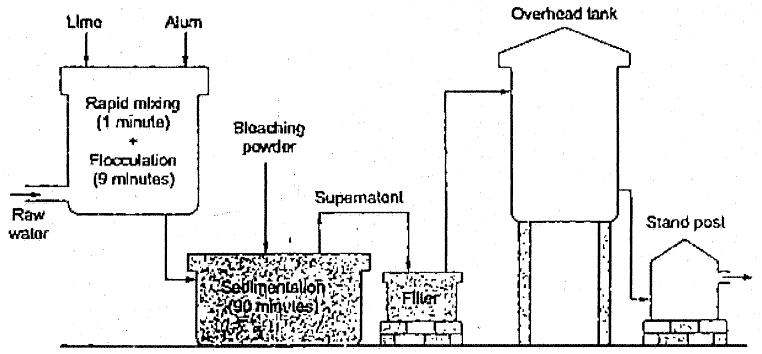


*Fig. 4.34* Line diagram for Nalgonda Technique

***(iii)* Ion Exchange Absorption Method**

- This method is almost similar to that used for removing hardness from water.
- This process uses a strong base anion exchange resin (Zeolite) in the chloride form.

***(iv)* Reverse Osmosis Process**

- In this method, the raw water is passed through a semi permeable membrane barrier, which permits the flow of clear water through itself and blocks the flow of salts including fluorides.

**Table 4.6: Comparative Table of Available Technologies for Defluoridation**

| Name of technology | Developer and process | Advantages | Disadvantages |
|---|---|---|---|
| 1. Absorption by activated Alumina (AA) Commonly known as Prashanti technology. | • Satya Sai University for Higher Learning<br>• Andhra Pradesh : Cost Rs. 35,000 at community level and Rs. 1,300 - 1700 at household level. Recurring cost of AA replenishment.<br>• In this process, raw water is passed through AA which absorbs fluoride, passing out defluoridated water. | • Useful at community and household level.<br>• Filters can be attached with handpumps or stand-posts.<br>• Low sludge formation | • Cost is inhibiting for vilagers<br>• Poor after sales service in villages<br>• Regeneration of AA poses problem |
| 2. Ion Exchange Absorption Method. | • Ion Exchange (India) Ltd.<br>• In this process, resin is used to absorb fluoride from water.<br>• Capacity ranges from 500 litres per hour to 5000 litres per hour. | • Useful at community and household level.<br>• Filters can be attached with handpumps or standposts.<br>• Low sludge formation | • Regular replacement of resin<br>• Large amount of salts are involved in regeneration<br>• Poor after sales service in villages |
| 3. Nalgonda Technique | • National Environmental Engineering and Research Institute, Nagpur in 1975.<br>• In this process, alum and lime is added to raw water and stirred for 10 minutes. Fluoride gets adsorbed by alum, and flocs are formed. These flocs are allowed to settle down for 90 minutes, after which is filtered by addition of bleaching powder. | • Useful at community and household level.<br>• High fluoride removal efficiency. | • Technical expertise required<br>• Time consuming process<br>• Disposal of flocs is a problem<br>• Alum dose needs regular calculation |
| 4. Reverse Osmosis | • In this process, water is passed through a membrane which blocks fluoride flow, allowing only defluoridated water to pass<br>• 60-litre per day filter costs Rs. 20,000<br>• Annual maintenance costs about Rs. 3000 | • Different kind of membranes available<br>• High fluoride removal efficiency. | • Cost inhibitive for villagers<br>• Poor after sales service in villages |

7. **Desalination**
   - It is done by reverse osmosis (RO) process.
   - It is also done by electrodialysis.
   - In electrodialysis treatment process, dissolved salts from water are separated by passing an electric current through the water tank, installed with ion exchange membrane.
8. **Removal of Toxic Metals**
   - They are removed by coagulation sedimentation process. By adding coagulants and maintaining a proper pH value, the toxic metal precipitates and are removed in sedimentation process.

**Example 4.43** **Match List-I (Water quality) with List-II (Method of determination) and select the correct answer using the codes given below the lists:**

| List-I | List-II |
|---|---|
| A. Hardness | 1. Winkler's method |
| B. Chlorine | 2. EDTA method |
| C. DO | 3. Orthotolidine test |
| D. Chloride | 4. Mohr method |

Codes:

| | A | B | C | D | | A | B | C | D |
|---|---|---|---|---|---|---|---|---|---|
| (a) | 2 | 3 | 1 | 4 | (b) | 2 | 4 | 1 | 3 |
| (c) | 1 | 3 | 2 | 4 | (d) | 1 | 4 | 2 | 3 |

Ans. (a)

Chlorine residuals can be tested by orthotolidine test, DPD test, Chlorotex test and Starch-Iodide test. The dissolved oxygen of sewage is generally determined by Winkler's method which is an oxidation reduction process carried out chemically to liberate iodine in amount equivalent to the quantity of DO originally present.

## Illustrative Examples

**Example 4.44** **Design a sedimentation tank rectangular in shape to treat 2 million litres of raw water with detention period of 2 hours and overflow rate less than 45,000 litres per day unit surface area. The water contains 700 mg/l of suspended solids, 35% of which are settleable, calculate the volume of sludge storage of one month cleaning period.**

***Solution:***

$$\therefore \quad \text{Detention} = \frac{\text{Volume}}{\text{Discharge}}$$

$$\therefore \quad \text{Volume} = \text{Detention Period} \times \text{Discharge} = \frac{2}{24} \times \frac{2\times10^6}{1000} = 166.66\ \text{m}^3$$

Assuming depth = 3 m

Surface area = 166.66/3 = 55.55 m²

Providing 2 units of 55.55/2 = 27.78 m² each

$L : B = 3 : 1$

$$\therefore \quad 3B^2 = 27.78$$

$$\therefore \quad B^2 = 9.26$$

$$B = 3.04 \approx 3.0\ \text{m}$$

Hence, $B = 3$ m and $L = 3 \times 3 = 9$ m

$$\frac{Q}{\text{Surface Area}} = \frac{10^6}{3\times9} = 37037.04\ l/\text{d/m}^2$$

which is less than 45000 $l$/d/m²

Hence, satisfying the requirement. The water contains 700 mg/l of suspended solids.

∴ Total suspended solid per tank is = 700 × 10⁶ mg/d and out of this 35% are settleable.

Hence, quantity of settleable suspended solids = 0.35 × 700 × 10⁶ mg/d

Cleaning period = 1 month = 30 days

$$\therefore \text{ For 30 days quantity of settleable solids per tank} = \frac{30\times0.35\times700\times10^6}{1000\times1000} = 7350\ \text{kg/tank}$$

∴ Volume of sludge storage per tank = 7350/1000 = 7.35 m³

**Example 4.45** **For a continuous flow settling tank 3 m deep and 60 m long, what flow velocity of water would you recommend for effective removal of 0.025 mm particles at 25°C. The specific gravity of particles is 2.65 and kinematic viscosity of water may be taken as 0.01 cm²/sec.**

***Solution:***

The settling velocity $v_s$ from Stoke's equation for $d < 0.1$ mm is

$$v_s = \frac{gd^2}{18\nu}(G_s - 1)$$

$$d = 0.025\ \text{mm} = 0.0025\ \text{cm} = \frac{981\times(0.0025)^2}{18\times0.01}(2.65-1)\text{cm/sec.} = 0.562\ \text{mm/s} \quad ...(i)$$

Also,

$$v_s = 418(G-1)\,d^2\,\frac{3T+70}{100}$$

$$= 418\times(2.65-1)\times(0.025)^2\times\frac{3\times25+70}{100} = 0.625\ \text{m/s} \quad ...(ii)$$

from (i) and (ii), $v_s = 0.625$ m/s

From equation

$$\frac{v_f}{v_s} = \frac{L}{H}$$

where, $v_f$ = Flow velocity, $v_s$ = settling velocity, $L$ = length of the tank = 60 m, H = height of water in the tank. Assume 0.6 m free-board out of the total depth 3 m of the tank.

∴ Water depth in the tank = H = 3 − 0.6 = 2.4 m

$$\therefore \quad v_H = 0.625\times\frac{60}{2.4}\ \text{mm/sec} = 15.626\ \text{mm/sec}$$

Therefore, to ensure effective removal of particles upto 0.025 mm, the flow velocity in the settling tank should not be more than 15.626 mm/sec.

**Example 4.46** **Design a flocculator A water-treatment plant is being designed to process 50000 m³/d of water. Jar testing and pilot-plant analysis indicate that an alum dosage of 40 mg/L with flocculation at a *Gt* value of 4.0 x 10⁴ produces optimal results at the expected water temperature of 15°C. Determine**

1. **The monthly alum requirement.**
2. **The flocculation basin dimensions if three cross-flow horizontal paddles are to be used. The flocculator should be a maximum of 12 m wide and 5 m deep in order to connect appropriately with the settling basin.**
3. **The power requirement.**
4. **The paddle configuration.**

***Solution:***

1. Monthly alum requirements

$$40\text{ mg/L} = 0.04\text{ kg/m}^3 \text{ and } \frac{0.04\text{ kg}}{\text{m}^3} \times 50000\frac{\text{m}^3}{\text{d}} \times 30\text{ kg/month}$$
$$= 60000\text{ kg/month}$$

2. Basin dimension

(a) Assume an average $G$ value of 30 s⁻¹

$$G.t. = 4.0 \times 10^4$$
$$t = \frac{4.0 \times 10^4}{30 \times 60}\text{ min} = 22.22\text{ min}$$

(b) Volume of the tank is $V = Qt = 50000\text{ m}^3/\text{d} \times 22.22\text{ min} \times \frac{1\text{ d}}{1440\text{ min}}$
$$= 771.5\text{ m}^3$$

(c) The tank will contain three cross-flow paddles, so its length will be divided into three compartments. For equal distribution of velocity gradients, the end area of each compartment should be square, i.e. depth equals 1/3 length. Assuming maximum depth of 5 m length is

$$3 \times 5 = 15\text{ m}$$

and width is $5 \times 15 \times w = 771.5$
$$w = 10.3\text{ m}$$

(d) The configuration of the tanks and paddles should be as follows.

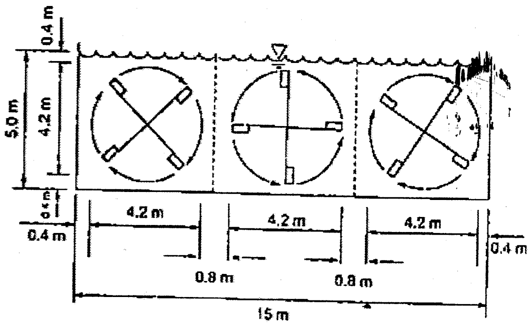


*Fig. 4.35* Profile

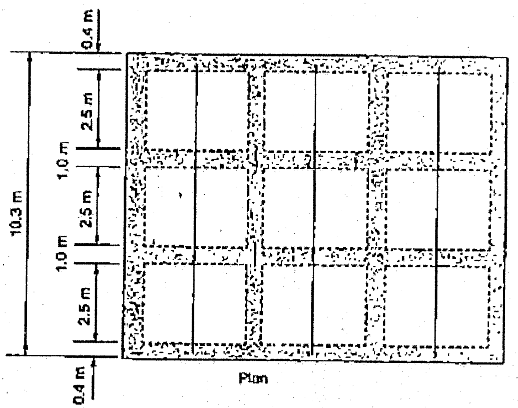


*Fig. 4.36* Plan

3. Power requirements

(a) Assume G value tapered as follows

First compartment, $G = 40\text{ s}^{-1}$
Second compartment, $G = 30\text{ s}^{-1}$
Third compartment, $G = 20\text{ s}^{-1}$

(b) Calculate power requirements for compartments 1, 2, and 3.

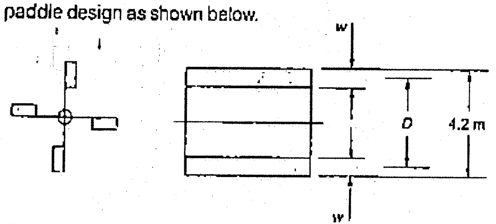
$$P = G^2V\mu$$
$$V = 771.5\text{ m}^3/3 = 257.2\text{ m}^3$$

At 15°C

$$\mu = 1.139 \times 10^{-3}\text{ N·s/m}^2$$
$$P_1 = 40^2/\text{s}^2 \times 257.2\text{ m}^3 \times 1.139 \times 10^{-3}\text{ N·s/m}^2$$
$$= 468.7\text{ N·s/m}^2 \times 10\text{–}3\text{ kW/N·m/s} = 0.47\text{ kW}$$
$$P_2 = 30^2 \times 257.2 \times 1.139 \times 10^{-3} \times 10^{-3} = 0.26\text{ kW}$$
$$P_3 = 20^2 \times 257.2 \times 1.139 \times 10^{-3} \times 10^{-3} = 0.12\text{ kW}$$

4. Paddle configuration

(a) Assume paddle design as shown below.



Each paddle wheel has four boards 2.5 m long and *w* wide - three paddle wheel per compartment.

(b) Calculate *w* from power input and paddle velocity

$$P = \frac{C_D A_p \rho v_p^3}{2}$$

At 15°C, $\rho = 999.1\ \text{kg/m}^3$

Assume $v_p = 0.67\ \text{m/s} \times 0.75 = 0.5\ \text{m/s}$ and $C_D = 1.8$ $\quad (V_r = 0.67\ \text{m/s})$

$$A_p = \text{Length of boards} \times w \times \text{number of boards}$$

3 paddles at 4 boards per paddle = 12 boards

$$12 \times 2.5 \times w = 30w = A_p$$

$$P_1 = 467.7\ \text{N·m/s}$$

$$= (1.8 \times 30w\,\text{m} \times 999.1\ \text{kg/m}^3 \times \text{N·s}^2/\text{kg.m} \times 0.5^3\ \text{m}^3/\text{s}^3)/2$$

$$937.4\ m = 1.8 \times 30 \times 999.1 \times 0.5^3 w$$

$$937.4\ \text{m} = 6744\ w$$

$$w = 0.14\ \text{m}$$

(c) Calculate rotational speed of paddles

First compartment

$$v_r = \pi \frac{DN}{60}$$

$$\therefore \quad N = \frac{0.67 \times 60}{\pi \times 4.2} = 3.05\ \text{rpm}$$

Second compartment

$$P = 0.26\ \text{kW} \times 10^3 \frac{\text{N·m/s}}{\text{kW}} = 260\ \text{N·m/s} = \frac{C_D A_p \rho v_p^3}{2}$$

$$= 1.8(30 \times 0.14)\text{m}^2 \times 999.1\ \text{kg/m}^3 \times \text{N·s/kg·m} \times \frac{v_p^3}{2}$$

$$260\ \text{N·m/s} = 3777\ \text{N·m/s} \times v_p^3$$

$$v_p = \left(260\ \text{N·m/s} \times \frac{1\ \text{m}^2}{377\ \text{N·s}^2}\right)^{\frac{1}{3}} = (0.07\ \text{m}^3/\text{s}^3)1/3 = 0.41\ \text{m/s}$$

$$\text{Actual speed} = \frac{v_p}{0.75} = 0.55\ \text{m/s}$$

$$N = 2.5\ \text{rpm}$$

Third compartment, $P_3 = 120\ \text{N·m/s} = 3777\ \text{N.s}^2/\text{m}^2 \times v_p^3$

$$v_p = \left(120\ \text{N·m/s} \times \frac{1\ \text{m}^2}{3777\ \text{N·s}^2}\right)^{\frac{1}{3}} = (0.03\ \text{m}^3/\text{s}^3)^{1/3} = 0.32\ \text{m/s}$$

$$v_p\,\text{actual} = 0.32\ \text{m/s} \times \frac{1}{0.75} = 0.42\ \text{m/s}$$

$$N = 1.91\ \text{rpm}$$

**Example 4.47** A city must treat about 15000 m³/d of water. Flocculating particles are produced by coagulation, and a column analysis indicates that an overflow rate of 20 m/d will produce satisfactory removal at a depth of 3.5 m. Determine the size of the required settling tank.

***Solution:***

1. Compute surface area (provide two tanks at 7500 m³/d each)

$$Q = V_s A_s$$

$$7500\ \text{m}^3/\text{d} = A_s \times 20\ \text{m/d}$$

$$A_s = \frac{7500}{20} = 375\ \text{m}^2$$

2. Selecting a length to width ratio of 3/1, calculate surface dimensions

$$w \times 3w = 375\ \text{m}^2$$

$$\text{Width} = 11.18,\ \text{say } 11\ \text{m}$$

$$\text{Length} = 33.54,\ \text{say } 34\ \text{m}$$

3. Check retention time.

$$t = \frac{\text{Volume}}{\text{flow rate}} = \frac{11\ \text{m} \times 34\ \text{m} \times 3.5\ \text{m}}{7500\ \text{m/d} \times \frac{1\ \text{d}}{24\ \text{h}}} = 4.19\ \text{h}$$

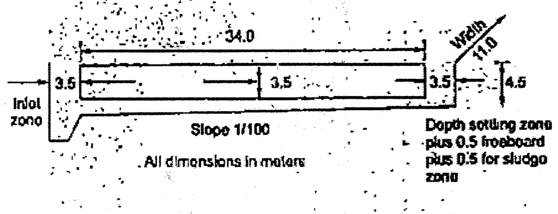
4. Check horizontal velocity, $v_f = \frac{Q}{A}\frac{7500\ \text{m}^3/\text{d} \times \frac{d}{24\ h}}{11\text{m} \times 3.5\ \text{m}} = 8.1\ \text{m/h}$

5. Check weir overflow rate. If simple weir is placed across end of tank, overflow length will be 11 m and overflow rate will be

$$7500\frac{\text{m}^3}{\text{d}} \times \frac{1\text{d}}{24\text{h}} \times \frac{1}{11\text{m}} = 28.4\frac{\text{m}^3}{\text{h·m}}$$

Five times this length will be needed. Design weir as shown in figure

6. Add inlet and outlet zones equal to depth of tank and sludge zones as shown in the accompanying figure



**Example 4.48** A new water main is disinfected using a 100 mg/l chlorine dosage by applying 50% hypochlorite solution. Calculate:

(a) how many kilograms of dry hypochlorite powder containing 72% available chlorine should be dissolved in 100 litres of water to make a 50% (50, 000 mg/l) solution.

(b) the rate at which this solution should be applied to the water entering the main to provide a concentration of 100 mg/l.

(c) If 35000 litres of water is used to fill the main at a dosage of 100 mg/l how many litres of hypchlorite solution is used.

Solution:

(a) $\quad \text{Kilograms of hypochlorite powder} = \frac{100\,\text{litre} \times 0.1\,\text{kg/litre} \times 0.5}{0.72} = 6.94\ \text{kg per 100 litre}$

(b) $\quad \text{Feed rate for 100 mg/l} = \frac{100\ \text{mg/l}}{50,000\ \text{mg/l}} = \frac{1 \times \text{volume of 50\% solution}}{500 \times \text{volume of water}}$

(c) $\quad \text{Solution usage for 35,000 litre} = 35,000 \times \frac{100}{50,000} = 70\ \text{litres}$

**Example 4.49** **An analysis on a surface water sample gave following result:**
**Calcium = 70 mg/l, Magnesium = 50 mg/l, Sodium = 10 mg/l,**
**Bicarbonate = 300 mg/l, Sulphate = 135 mg/l, Chloride = 7.0 mg/l,**
**Calculate**

**(i) Number of milli-equivalents per litre (meq/l) for each substance.**

**(ii) Total hardness, carbonate and non-carbonate hardness and alkalinity expressed as mg/l $CaCO_3$.**

***Solution:***

(i) Concentration in meq/l can be calculated by the equation:

$$\text{meq}/l = \frac{\text{mg}/l}{\text{Equivalent weight}}$$

Concentration expressed as mg/l $CaCO_3$ is expressed by the equation:

$$\text{mg}/l\ CaCO_3 = \text{mg}/l \times \frac{50}{\text{Eqv. weight}}$$

The result is tabulated below:

| Component | mg/l | Equiv. Wt. | meq/l | mg/l as $CaCO_3$ |
|---|---|---|---|---|
| Calcium | 70.0 | 20.0 | 3.5 | 175 |
| Magnesium | 50.0 | 12.2 | 4.1 | 204.9 |
| Sodium | 10. | 23.0 | 0.43 | 21.74 |
| Bicarbonate | 300.0 | 61.0 | 4.92 | 245.9 |
| Sulphate | 135.0 | 48.0 | 2.81 | 140.63 |
| Chloride | 7.0 | 35.5 | 0.197 | 9.86 |

(ii) Alkalinity = Bicarbonate alkalinity
= 245.9 mg/l as $CaCO_3$ [as calculated in part (i) in the equation]
Total Hardness = 175 + 204.9 = 379.9 as mg/l as $CaCO_3$.
Carbonate Hardness = Alkalinity = 245.9 mg/l as $CaCO_3$.
∴ Non-carbonate Hardness = Total hardness − Carbonate hardness
= 379.9 − 245.9 = 134 mg/l as $CaCO_3$.

**Example 4.50** **The analysis of a hard water shows the following compositions :**

**Free carbon dioxide = 3 mg/l**
**Alkalinity = 68 mg/l**
**Non-carbonate hardness = 92 mg/l**
**Total magnesium = 15 mg/l**

**Assume that it is possible to remove all but 35 mg/l of carbonate hardness with lime, and that the treated water is to have a total hardness of 80 mg/l. Determine the amount of hydrated lime and soda required for treatment per million litre of raw water.**

***Solution:***

Total hardness to be left = 80 mg/l
Carbonate hardness to be left = 35 mg/l
∴ Non-carbonate harness to be left = 80 − 35 = 45 mg/l
Non-carbonate hardness of raw water = 92 mg/l
∴ Non-carbonate hardness to be removed from raw water = (92 − 45) mg/l = 47 mg/l

Now, we know that the lime is required to remove carbonate hardness, free carbon dioxide and magnesium present in water, whereas soda is required to remove non-carbonate hardness. Their quantities are computed as below :

**Lime requirement:** Lime is required for three reactions, as computed below :

(i) Lime required for free carbon dioxide. Since the molecular weight of $CO_2$ is 44, and that of lime (CaO) as 56, we have

44 mg/l of $CO_2$ requires = 56 mg/l of CaO

$$\therefore\quad 3\ \text{mg}/l \text{ of } CO_2 \text{ will required} = \frac{56}{44} \times 3\ \text{mg}/l \text{ of CaO}$$

∴ CaO required for 1 Ml of water = 3.82 kg ...(i)

(ii) Lime required for carbonate hardness, which equals to the alkalinity of 68 mg/l.
Since the molecular weight of $CaCO_3$ is 40 + 12 + 48 = 100 gm, and that of CaO is 40 + 16 = 56 gm, we have

NCH of 100 mg/l of CaCO3 will requires = 56 mg/l of CaO

$$\therefore\quad \text{NCH of 68 mg}/l \text{ of } CaCO_3 \text{ will requires} = \frac{56}{100} \times 68\ \text{mg}/l \text{ of CaO}$$

∴ CaO required for 1 Ml of water = 38.08 kg ...(ii)

(iii) Lime required for magnesium. Since 24 mg/l of magnesium (in magnesium salt) reacts with 56 mg/l of pure lime (CaO), we have

24 mg/l of Mg requires = 56 mg/l of CaO

$$\therefore\quad 15\ \text{mg}/l \text{ of Mg will require} = \frac{56}{24} \times 15\ \text{mg}/l \text{ of CaO} = 35\ \text{mg}/l \text{ of CaO}$$

∴ Lime required for 1 Ml of water = 35 kg...(iii)

Hence, total pure lime (CaO) required = (i) + (ii) + (iii)
= 3.82 + 38.08 + 35 = 77.90 kg

Also, 56 kg of pure lime (CaO) is equivalent to 74 kg of hydrated lime i.e., $Ca(OH)_2$, we have
Hydrated lime (Impure lime) required per M.l. of raw water

$$= 77.90 \times \frac{74}{56} = 102.94\ \text{kg}$$

**Quantity of Soda Required:** Soda ($Na_2CO_3$), is required for non-carbonate hardness, as follows :

Non-carbonate hardness to be removed = 47 mg/l (as $CaCO_3$)

Now, 100 mg/l of $CaCO_3$ requires = 106 mg/l of $Na_2CO_3$

$$\therefore\quad 47\ \text{mg}/l \text{ of } CaCO_3 \text{ will require} = \frac{106}{100} \times 47\ \text{mg}/l \text{ of } Na_2CO_3 = 49.8\ \text{mg}/l$$

∴ Soda required for 1 Ml of water = 49.8 kg

**Example 4.51** The result of chemical analysis of sample of raw water is given below:

$Ca^{++}$ = 80 mg/*l*
$Na^{+}$ = 2.5 m.eq./*l*
Total alkalinity = 80 mg/*l* as $CaCO_3$
Total hardness = 120 mg/*l* as $CaCO_3$
$SO_4^{--}$ = 20 mg/*l* as $CaCO_3$
$Cl^{-}$ = 140 mg/*l* as $CaCO_3$
$NO_3^{-}$ = 5 mg/*l* as $CaCO_3$

(i) Prepare a bar diagram for the raw water.

(ii) Estimate the quantity in kg/day of CaO (90% pure) and Soda ash (95% pure) required to soften 4 million litres per day of this water.

***Solution:*** A bar chart of water analysis is the graphical presentation of the water analysis and is generally obtained by plotting milli equivalent per litre value of various radicals, to a scale. In order to plot such a chart, it is therefore necessary to compute milli equivalent/litre (m.eq./*l*) values for all the cations (positive radicals) as well as anions (negative radicals).

The sum of the m.eq./*l* values for cations must be equal to the sum of the m.eq./*l* values for anions. In perfect evaluation, they would exactly be the same, because water in equilibrium is electrically balanced. The given values of different radical in mg/*l* are therefore to be converted into a m.eq./*l* values, except for $Na^{+}$, where concentration is directly given in m.eq./*l*. The visual inspection of the given data also reflects that the concentration of different radical are given in mg/*l* as $CaCO_3$, whose equivalent mass is 50. Hence, the given in mg/*l* $CaCO_3$ will have to be divided by this equivalent mass of $CaCO_3$ in order to obtain their concentration in m.eq./*l*.

However, the concentration of $Ca^{++}$ is given as 80 mg.eq./*l* which cannot be its concentration as $Ca^{++}$, since that total hardness. as $CaCO_3 = \left(Ca^{++} \times \frac{52}{20} + Mg^{++} \times \frac{50}{12}\right)$ is given to be 120 mg/*l*. Had $Ca^{++}$ been equal to 80 mg/*l*, then eventually, the total hardness would have been something more than $80 \times \frac{50}{20}$ = 200 mg/*l*. (as against the given value of 120 mg/*l*). It, therefore, transpires that $Ca^{++}$ present in water also equals to 80 mg/*l* as $CaCO_3$.

$Mg^{++}$ present in this water (as $CaCO_3$) can then be computed as :

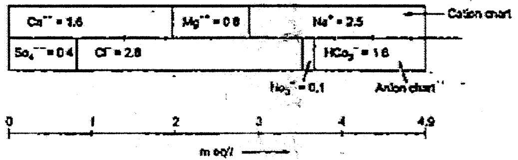
= Total hardness − $Ca^{++}$ (as $CaCO_3$)
= (120 − 80) mg/*l* (as $CaCO_3$)
= 40 mg/*l* (as $CaCO_3$).

Hence, $Mg^{++}$ = 40 mg/*l* as $CaCO_3$

Since, the alkalinity of 80 mg/*l* is lesser than the total hardness of 120 mg/*l*, it transpires that the carbonate hardness is 80 mg/*l* (being lesser of the two values). Hence, the entire alkalinity can be considered to be bicarbonate alkalinity, causing carbonate hardness.

All the given value of radicals (as $CaCO_3$) are now listed in Col (3) of given below table. These values are converted into m.eq./*l* values by dividing mg/*l* (as $CaCO_3$) by 50 (i.e. eq. mass of $CaCO_3$), as shown in Col (4) of this table.

| S.No. | Name of radical | mg/*l* as $CaCO_3$ | m.eq/*l* = $\frac{\text{mg/l as } CaCO_3}{\text{Eq. mass of } CaCO_3 \text{ in gm}} = \frac{\text{col. (3)}}{50}$ | Remarks |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| 1. | $Ca^{++}$ | 80 | 1.6 | Water analysis is perfect, as it is getting balanced |
| 2. | $Mg^{++}$ | 40 | 0.8 | |
| 3. | Na+ | – | 2.5 (directly given) | |
| | | | Total for cations = 4.9 | |
| 4. | $SO_4^{--}$ | 20 | 0.4 | |
| 5. | $Cl^{-}$ | 140 | 2.8 | |
| 6. | $NO_3^{-}$ | 5 | 0.1 | |
| 7. | $HCO_3^{-}$ (Alkalinity) | 80 | 1.6 | |
| | | | Total for anions 4.9 | |



**Bar Chart for the raw water**

**(a) Computing Quantity of lime (CaO) required for Softening.** Lime is required for neutralising the carbonate hardness (i.e. alkalinity) plus $Mg^{++}$, and hence is given by

= [m.eq/*l* of $HCO_3^{-}$ + m.eq/*l* of $Mg^{++}$] × [Eq. mass of CaO]
= (1.6 + 0.8) 28 mg/*l* = 67.2 mg/*l*

Quantity of impure lime required = $\frac{67.2}{0.90}$ mg/*l* (∵ Purity = 90%)
= 74.67 mg/*l*

Total quantity of lime required to treat 4 Ml/day of raw water
= 74.67 × 4 × $10^6$ mg/day = 74.67 × 4 kg/day = 298.67 kg/day

**(b) Computing Quantity of Soda required for softening.** Soda ash ($Na_2CO_3$) is required to neutralise non-carbonate hardness, which equals $\underbrace{Ca^{++} + Mg^{++}}_{TH} - \underbrace{HCO_3^{-}}_{CH}$.

Hence, Soda required = [m/eq/*l* of $Ca^{++}$ + m.eq/*l* of $Mg^{++}$ − m.eq/*l* $HCO_3^{-}$]
× (Eq. mass of $Na_2CO_3$)
= (1.6 + 0.8 − 1.6) 53 mg/*l* = 42.4 mg/*l*

Quantity of Impure Soda required = $\frac{42.4}{0.95}$ mg/*l* = 44.63 mg/*l* (∵ Purity = 95%)

Total quantity of Soda required to treat 4 Ml/day of raw water
= 44.63 × (4 × $10^6$) mg/day = 178.5 kg/day

## Important Expressions

1. Settling velocity, $V_s = \frac{gd^2}{18\eta}(G_s - 1)$

$d$ = dia of particle
$G_s$ = Sp. gravity
$\eta$ = kinematic viscosity

2. Drag force on particle,

$$F_d = \frac{1}{2} C_d \rho_w A V_s^2$$

where,
$C_d$ = Newton drag coefficient
$A$ = Area (Projected)
$V_s$ = Settling velocity
$\rho_w$ = Density of water

3. Detention time,

$$t_d = \frac{V}{Q} = \frac{BLH.}{Q} \quad \text{for rectangular tank}$$

$$t_d = \frac{D^2(0.011D + 0.785H)}{Q} \quad \text{for circular tank}$$

4. Overflow or surface loading or critical settling velocity,

$$V = \frac{Q}{BL}$$

5. Magnitude short circuiting

$$= \frac{\text{Flow through period}}{\text{Theoretical detention time}}$$

6. Efficiency of displacement = Magnitude of short-circuiting × 100

7. Zeta potential,

$$\varepsilon = \frac{4\pi \delta q}{D}$$

where,
$q$ = charge of particle
$\delta$ = thickness of zone
$D$ = dielectric constant of medium

8. Temporal mean velocity gradient,

$$G = \sqrt{P/\mu V}$$

$P$ = Power (in water)
$V$ = Volume ($m^3$)
$\mu$ = dynamic viscosity

9. Head loss per unit depth by Karman Cozeny

$$\frac{h}{l} = \left[E\frac{(1-F)}{F^3}\right]\frac{V^2}{gdS}$$

$$E = \left[\frac{150(1-F)}{R}\right] + 1.75$$

where,
$V$ = Filtration rate (m/s)
$F$ = Porosity of bed
$S$ = Particle shape factor
$R$ = Reynold's number

10. Number of unit in a filter plant,

$$N = 1.22\sqrt{Q}$$

where, $Q$ = Capacity in million litres/day

11. Chlorine designed =
Applied chlorine – Residual chlorine

## Summary

- If excessive silt is present in suspension, pre-chlorination is not so effective because silt absorbs chlorine without settling.
- Fairly alkaline water containing more concentration of nitrates and phosphates are prone to algae growth.
- Theoretically, depth does not have any effect on the efficiency of tank.
- Higher the zeta potential, more stable the particle.
- Coagulation aids, divided clay, bentonites and activated carbon are the most commonly used material as nucleus to floc formation.
- Larger $G$ and smaller $t_d$ will make small and dense floc.
- Efficiency of slow sand filter in bacteria removal is 97-98% which is greater than rapid gravity filter.
- The biggest advantage of zeolite process is achieving zero hardness with no sludge formation.

## Objective Brain Teasers

**Q.1** Match List-I (Type of water source) with List-II (Treatment to be given) and select the correct answer using the codes given below the lists:

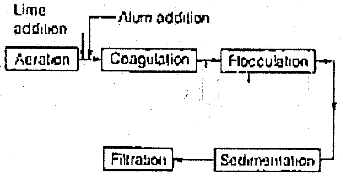
List-I
A. Surface water (river or canal)
B. Water from infiltration gallery
C. Lake/pond water
D. Tube well water

List-II
1. Aeration, coagulation, sedimentation and disinfection
2. Disinfection
3. $CuSO_4$ treatment, coagulation, sedimentation, filtration and disinfection
4. Coagulation, flocculation, sedimentation, filtration and disinfection

Codes:

| | A | B | C | D |
|---|---|---|---|---|
| (a) | 4 | 1 | 3 | 2 |
| (b) | 1 | 4 | 3 | 2 |
| (c) | 1 | 4 | 2 | 3 |
| (d) | 4 | 1 | 2 | 3 |

**Q.2** The flow chart of water treatment plant is shown in the following figure. If it is proposed to defluoridate the water using 'Nalgonda treatment' then it should be done



(a) after adjusting the dose of lime and alum
(b) after sedimentation
(c) after filtration
(d) before aeration

**Q.3** Which of the following treatment reduce salinity of water?
1. Flash mixing and sedimentation
2. Electrodialysis
3. Reverse osmosis
4. Freezing
5. Filtration

Select the correct answer using the codes given below:
(a) 1, 2, 3, 4 and 5
(b) 2, 3 and 4
(c) 1, 3 and 5
(d) 1, 2 and 4

**Q.4** The cleaning of slow sand filter is done by
(a) reversing the direction of flow of water
(b) passing air through the filter
(c) passing a solution of alum and lime through the filter
(d) scraping off top layers of sand and admitting water

**Q.5** Match List-I (Name of impurity in water) with List-II (Removed by) and select the correct answer using the codes given below the lists:

| List-I | List-II |
|---|---|
| A. Fluorides | 1. Activated carbon |
| B. Manganese | 2. Activated alumina |
| C. Taste and odour | 3. Manganese zeolite |

Codes:

| | A | B | C |
|---|---|---|---|
| (a) | 1 | 2 | 3 |
| (b) | 2 | 3 | 1 |
| (c) | 2 | 1 | 3 |
| (d) | 3 | 2 | 1 |

**Q.6** Which of the following statements about design period are true?
1. It is concerned with economy of investments.
2. It takes into account aspects like life and durability and ease or difficulty in capacity increase of installations.
3. It considers the frequency of occurrence of extremes of river flow.
4. It is concerned with estimating future requirements.

Select the correct answer using the codes given below.
(a) 1, 2, 3 and 4
(b) 2 and 3
(c) 1, 2, and 4
(d) 1, 3 and 4

Q.7 Uniformity coefficient of filter sand is given by

(a) $\frac{D_{50}}{D_5}$ (b) $\frac{D_{50}}{D_{10}}$

(c) $\frac{D_{60}}{D_5}$ (d) $\frac{D_{60}}{D_{10}}$

Q.8 Which of the following statement is/are true in relation to the term 'detention period' in a settling tank?

1. It may be determined by introducing a dye in the inlet and timing its appearance at the outlet.
2. Greater the detention period, greater the efficiency of removal of settleable matter.
3. It is the time taken for any unit of water to pass through the settling basin.
4. It is usually more than the flow through period.

Select the correct answer using the codes given below:

(a) 1, 2, 3 and 4 (b) 2, 3 and 4

(c) 1 and 3 (d) 4 alone

Q.9 Which of the following pairs is/are correctly matched?

1. Eutrophication...Nutrient accumulation leading to ecosystem change occurring in impounded water
2. Autotrophism...Utilization, rearrangement and decomposition of complex materials predominate
3. Heterotrophism...Predominance of fixation of light energy, use of simple inorganic substances and built-up of complex substances

Select the correct answer using the codes given below:

(a) 1, 2 and 3 (b) 1 alone

(c) 2 and 3 (d) 1 and 3

Q.10 Air-binding in rapid sand filters is encountered when

(a) there is excessive negative head

(b) the water is subjected to prolonged aeration

(c) the raw water contains dissolved gases

(d) the filter bed comprises largely of coarse sand

Q.11 In a water treatment plant, dissolved iron and manganese can be removed from the water by

(a) aeration

(b) aeration and coagulation

(c) aeration and flocculation

(d) aeration and sedimentation

Q.12 The various treatment processes in a water treatment plant are listed below:

1. Filtration 2. Chlorination

3. Sedimentation 4. Coagulation

5. Flocculation

The correct sequence of processes in water treatment is

(a) 1, 2, 3, 4, 5 (b) 4, 5, 3, 1, 2

(c) 2, 3, 1, 5, 4 (d) 1, 2, 5, 3, 4

Q.13 The effective size (ES) of sand and its uniformity coefficient (*UC*) are the usually specified parameters for sand filters. In slow sand filters, as compared to rapid sand filters,

(a) ES is less but UC is more

(b) ES is more but UC is less

(c) both ES and UC are more

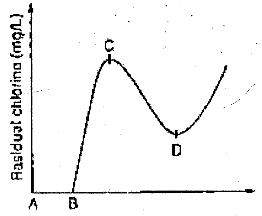
(d) both ES and UC are less

Q.14 For proper slow mixing in the flocculator of a water treatment plant, the temporal mean velocity gradient G needs to be of the order of

(a) 5 to 10 $s^{-1}$ (b) 20 to 80 $s^{-1}$

(c) 100 to 200 $s^{-1}$ (d) 250 to 350 $s^{-1}$

Q.15 If only ammonia was present in water, the only change in the diagram below would have been that the curve would



(a) be a straight line

(b) become parallel to *Y*-axis

(c) become parallel to *X*-axis after *D*

(d) be passing through the origin

Q.16 Match **List-I** (Water treatment units) with **List-II** (Detention time) and select the correct answer using the codes given below the lists:

| List-I | | List-II | |
|---|---|---|---|
| A. | Rapid mixing unit | 1. | 1.5 hours |
| B. | Flocculator | 2. | 10 seconds |
| C. | Propeller mixing unit | 3. | 30 seconds |
| D. | Sedimentation tank | 4. | 30 minutes |

**Codes:**

| | A | B | C | D |
|---|---|---|---|---|
| (a) | 3 | 4 | 2 | 1 |
| (b) | 4 | 3 | [illegible] | 2 |
| (c) | 4 | 3 | 2 | 1 |
| (d) | 3 | 4 | 1 | 2 |

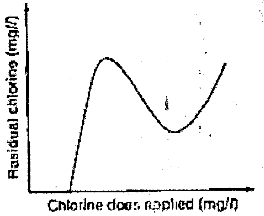
Q.17 Match List-I (Nature of the solids) with List-II (Unit operation or process connected with its removal) and select the correct answer using the codes given below the lists:

| List-I | List-II |
|---|---|
| A. Dissolved solids | 1. Sedimentation |
| B. Colloidal solids | 2. Reverse osmosis |
| C. Volatile solids | 3. Coagulation |
| D. Settleable solids | 4. Digestion |

Codes:

| | A | B | C | D |
|---|---|---|---|---|
| (a) | 2 | 3 | 4 | 1 |
| (b) | 3 | 2 | 4 | 1 |
| (c) | 2 | 3 | 1 | 4 |
| (d) | 3 | 2 | 1 | 4 |

Q.18 In the plot of residual chlorine dose applied shown in the figure below, the curve will not have any (0, 0) point because



(a) of experimental error

(b) chlorine escapes into the atmosphere

(c) chlorine requires some contact time

(d) chlorine is consumed for disinfection

Q.19 The correct sequence of processes in a water treatment plant for rural water supply is

(a) chlorination, aeration, sedimentation, rapid sand filter

(b) coagulation, sedimentation, slow sand filter, chlorination

(c) coagulation, flocculation, clarification, pressure filter

(d) aeration, plain sedimentation, slow sand filter, chlorination

Q.20 The role of the bed material in a "packed tower" used for removing particulate matter from gaseous emissions is to

(a) act as a filter bed to capture the particulates within the pores

(b) provide a large surface area on which the particulate matter can be collected

(c) reduce the flow of gas

(d) uniformly distribute the spray of water

Q.21 The raw water entering an ideal horizontal settling tank contains following two types of particles:

| Particle type | Settling velocity (m/h) | Concentration (mg/L) |
|---|---|---|
| I | 3 | 200 |
| II | 1 | 300 |

When the surface overflow rate of the settling tank is 3 $m^3/m^2/h$, the concentration of the particles in the settled water will be

(a) 100 mg/L (b) 200 mg/L

(c) 300 mg/L (d) 400 mg/L

Q.22 Which one of the following filters will produce water of higher bacteriological quality?

(a) Slow sand filter (b) Rapid sand filter

(c) Pressure filter (d) Dual media filter

Q.23 Match List-I (Unit in water treatment plant) with List-II (Impurities removed) and select the correct answer using the codes given below the lists:

List-I

A. Aerator

B. Rapid sand filter

C. Slow sand filter

D. Sedimentation tank (after coagulation and flocculation)

List-II
1. Excess $CO_2$ and $H_2S$
2. Settleable and colloidal matter
3. Suspended matter
4. Suspended, colloidal and bacterio-logical matter

Codes:

| | A | B | C | D |
|---|---|---|---|---|
| (a) | 1 | 3 | 2 | 4 |
| (b) | 3 | 1 | 2 | 4 |
| (c) | 3 | 1 | 4 | 2 |
| (d) | 1 | 3 | 4 | 2 |

Q.24 Which of the following statements are correct?
1. Groundwater is generally free from suspended and dissolved impurities.
2. Suspended matters often contain pathogenic bacteria.
3. Rain water is soft and tasteless.
4. Lake water may contain microscopic organisms.

Select the correct answer using the codes given below:
(a) 1, 2, 3 and 4 (b) 1 and 2
(c) 2, 3 and 4 (d) 1, 3 and 4

Q.25 Consider the following impurities:
1. $CO_2$ and $H_2S$
2. Finely-divided suspended matter
3. Disease causing bacteria
4. Excess alkalinity

The correct sequence of the removal of these impurities in a water treatment plant is
(a) 1, 2, 3, 4 (b) 1, 4, 3, 2
(c) 1, 4, 2, 3 (d) 4, 1, 3, 2

Q.26 Match List-I (Impurities) with List-II (Effects) and select the correct answer using the codes given below the lists:

List-I
A. Dissolved sulphates and chlorides of Ca and Mg
B. Dissolved bicarbonates of Ca and Mg
C. Dissolved fluorides of Na
D. Dissolved organic matter

List-II
1. Hardness and corrosion
2. Bacterial infection
3. Alkalinity and softness
4. Impairment of dental health

Codes:

| | A | B | C | D |
|---|---|---|---|---|
| (a) | 2 | 3 | 4 | 1 |
| (b) | 1 | 4 | 3 | 2 |
| (c) | 2 | 4 | 3 | 1 |
| (d) | 1 | 3 | 4 | 2 |

Q.27 Which of the following statements regarding industrial water supply is/are correct?
1. Industrial water supplies need not be disinfected.
2. Water for industrial use requires chemical treatment.
3. Standards of purity and methods of treatment of water for industrial use are often different from those for domestic water supplies.
4. It is more economical to use water from surface sources than groundwater sources for industrial water supplies.

Select the correct answer using the codes given below:
(a) 1, 2 and 4 (b) 2, 3 and 4
(c) 3 and 4 (d) 3 only

Q.28 Match List-I (Different forms of nitrogen in water) with List-II (Inferences) and select the correct answer using the codes given below the lists:

List-I
A. Nitrate nitrogen
B. Total nitrogen
C. Nitrite nitrogen
D. Ammonia nitrogen

List-II
1. Unsatisfactory microbial activity
2. Satisfactory microbial activity
3. Eutrophication may result
4. Recent organic pollution

Codes:

| | A | B | C | D |
|---|---|---|---|---|
| (a) | 3 | 2 | 1 | 4 |
| (b) | 1 | 4 | 3 | 2 |
| (c) | 3 | 4 | 1 | 2 |
| (d) | 1 | 2 | 3 | 4 |

Q.29 Air binding' may occur in
(a) Sewers (b) Artesian well
(c) Aerator (d) Filter

Q.30 The purpose of recarbonation after lime-soda process of water softening is the
(a) removal of excess soda from water
(b) removal of non-carbonate hardness
(c) recovery of lime
(d) conversion of precipitates to soluble form

Q.31 Which of the following treatment processes are necessary for removing suspended solids from water?
1. Coagulation 2. Flocculation
3. Sedimentation 4. Disinfection

Select the correct answer using the codes given below:
(a) 1 and 2 (b) 1, 2 and 3
(c) 2 and 4 (d) 1 and 4

Q.32 Match List-I (Filter operating problems) with List-II (Effects) and select the correct answer using the codes given below the lists:

List-I
A. Air binding
B. Mud deposition
C. Cracking of bed
D. Sand incrustation

List-II
1. Changes effective size of sand
2. Mud penetrates deeper inside the bed
3. Mounds and balls of mud are formed in the bed
4. Air and gases get locked in the bed

Codes:

| | A | B | C | D |
|---|---|---|---|---|
| (a) | 4 | 3 | 2 | 1 |
| (b) | 3 | 4 | 1 | 2 |
| (c) | 4 | 3 | 1 | 2 |
| (d) | 3 | 4 | 2 | 1 |

Q.33 Which of the following are removed by rapid sand filter from water?
1. Dissolved solids 2. Suspended solids
3. Bacteria 4. Helminths

Select the correct answer using the codes given below:
(a) 1 and 2 (b) 2 and 3
(c) 1 and 3 (d) 2, 3 and 4

Q.34 If the specific gravity of a suspended particle is increased from 2 to 3, the settling velocity will
(a) not change
(b) get doubled
(c) get increased by 1.5 times
(d) get increased by 2.25 times

Q.35 Which one of the following filters should be recommended for protected rural water supply project?
(a) pressure filter
(b) slow sand filter
(c) diatomaceous earth filter
(d) rapid sand filter

Q.36 Which one of the following is a not a specific criterion for calculating surface overflow rate in sedimentation tank design?
(a) Total quantity of water to be treated
(b) Total surface area available in the tank
(c) Total length of the tank
(d) Total depth of the tank

Q.37 A town having a water demand 20 MLD is to be supplied with water having a residual chlorine concentration of 0.2 ppm. If the chlorine demand in raw water is 0.6 ppm and the available chlorine in bleaching power is 27% the amount of bleaching powder per day is
(a) 4.32 kg (b) 44.4 kg
(c) 59.3 kg (d) 21.92 kg

Q.38 Match List-I (Treatment process) with List-II (Removed matter) and select the correct answer using the codes given below the lists:

List-I
A. Plain sedimentation
B. Chemical precipitation
C. Slow Sand Filtration
D. Aeration

List-II
1. Dissolved gases
2. Dissolved solids
3. Suspended solids with specific gravity more than 1.0.
4. Floating solids
5. Bacterial cells

Codes:

| | A | B | C | D |
|---|---|---|---|---|
| (a) | 5 | 1 | 4 | 2 |
| (b) | 3 | 2 | 5 | 1 |
| (c) | 5 | 2 | 4 | 1 |
| (d) | 3 | 1 | 5 | 2 |

**Q.39** Among the following, which is/are not pre-treatment unit(s)?

(a) Bar-screen and grit chamber
(b) Flow equalization and proportioning tank
(c) Neutralization for pH adjustment tank
(d) Nutrient removal tank

**Q.40** According to the theory of filtration in water treatment, which of the following mechanisms come into play when water is filtered through a filter bed?

1. Mechanical straining
2. Capillary action
3. Centrifugal force
4. Electro-kinetic phenomenon
5. Osmotic force
6. Bacteriological action

Select the correct answer using the codes given below:

(a) 1, 2, 4 and 6 (b) 2, 3 and 5
(c) 3, 4, 5 and 6 (d) 1, 3, 4 and 6

**Q.41** In which treatment unit is Schmutzdecke formed?

(a) Sedimentation tank
(b) Rapid sand filter
(c) Coagulation tank
(d) Slow sand filter

**Q.42** Which one of the following chemicals is employed for dechlorination of water?

(a) Sodium sulphite
(b) Sodium bicarbonate
(c) Calcium carbonate
(d) Hydrogen peroxide

**Q.43** Match List-I (Parameter) with List-II (Impact) and select the correct answer using the codes given below the lists:

List-I
A. Excess sulphates
B. Lack of iodide
C. Excess hardness
D. Excess dissolved oxygen

List-II
1. Greater soap consumption
2. Laxative effect
3. Goitre
4. Corrosion of pipes

Codes:

| | A | B | C | D |
|---|---|---|---|---|
| (a) | 2 | 1 | 3 | 4 |
| (b) | 4 | 3 | 1 | 2 |
| (c) | 2 | 3 | 1 | 4 |
| (d) | 4 | 1 | 3 | 2 |

**Q.44** The concentration of hardness producing cations may be estimated using which one of the following?

(a) Conductivity meter
(b) pH meter
(c) Spectrophotometer
(d) Flame photometer

**Q.45** Which one of the following treatments is economically effective in the control of guinea worm disease?

(a) Chlorination (b) Filtration
(c) Ozonation (d) Sedimentation

**Q.46** Match List-I (Disinfectant) with List-II (Property) and select the correct answer using the codes given below the lists:

List-I
A. Chlorine
B. Ozone
C. Iodine
D. Ultraviolet rays

List-II
1. No carcinogenics results
2. Ineffective in the presence of suspended solids
3. Not affected by the Ammonium ion
4. Feasible residual oxygen

Codes:

| | A | B | C | D |
|---|---|---|---|---|
| (a) | 4 | 3 | 1 | 2 |
| (b) | 1 | 2 | 4 | 3 |
| (c) | 4 | 2 | 1 | 3 |
| (d) | 1 | 3 | 4 | 2 |

**Q.47** What is the predominating coagulation mechanism for raw water having high turbidity and high alkalinity?

(a) Ionic layer compression
(b) Adsorption and charge neutralization
(c) Sweep coagulation
(d) Inter particle bridging

**Q.48** Match List-I (Predominance of compounds) with List-II (pH range) and select the correct answer using the codes given below the lists:

| List-I | List-II |
|---|---|
| A. Monochloramine | 1. Below pH 4.4 |
| B. Dichloramine | 2. Over pH 7.5 |
| C. Nitrogen trichloride | 3. Between pH5 to 6.5 |

Codes:

| | A | B | C |
|---|---|---|---|
| (a) | 1 | 2 | 3 |
| (b) | 2 | 3 | 1 |
| (c) | 3 | 1 | 2 |
| (d) | 3 | 2 | 1 |

**Q.49** Which one of the following can fix atmospheric nitrogen?

(a) Green algae (b) Blue green algae
(c) Red algae (d) Brown algae

**Q.50** What is the most important design parameter used in designing a continuous flow rectangular sedimentation tank for removal of discrete particles?

(a) Length of the tank
(b) Surface overflow rate
(c) Depth of the tank
(d) Temperature of the water to be treated

**Q.51** Which combination of surface water quality parameters will indicate sweep coagulation as the preferred mechanism of coagulation?

(a) High turbidity-low alkalinity
(b) High turbidity-high alkalinity
(c) Low turbidity-high alkalinity
(d) Low turbidity-low alkalinity

**Q.52** Which one of the following processes of water softening requires recarbonation?

(a) Lime-soda ash process
(b) Hydrogen-cation exchanger process
(c) Sodium-cation exchanger process
(d) Demineralization

**Q.53** Consider the following treatment process units in a water treatment plant:

1. Coagulation
2. Disinfection
3. Sedimentation
4. Filtration

Which is the correct sequence of the process units in the water treatment plant?

(a) 2-4-3-1 (b) 1-4-3-2
(c) 2-3-4-1 (d) 1-3-4-2

**Q.54** Which one of the following tests of water/wastewater employs Erichrome Black T as an indicator?

(a) Hardness (b) COD
(c) Residual chlorine (d) DO

**Q.55** Consider the following statements:

The appropriate method(s) for removal of fluorides from water comprise

1. addition of alum and lime followed by clarification.
2. passing through beds of activated alumina.

Which of these statements is/are correct?

(a) Neither 1 nor 2 (b) Both 1 and 2
(c) 1 only (d) 2 only

**Q.56** Consider the following statements:

In water treatment, the addition of chlorine inactivates the cells of pathogenic bacteria through

1. penetration of the chlorine species through the cell walls.
2. suffocation of the cells.
3. reaction of the chlorine species with the enzyme system of the cells.

Which of these statements are correct?

(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

**Q.57** In a water treatment, the optimum time of flocculation is usually given as 30 minutes. In case the time of flocculation is increased beyond this value, the flocs will

(a) become heavy and settle down in flocculation itself
(b) entrap air and will float in the sedimentation tank
(c) break up and defeat the purpose of flocculation
(d) stick to the paddles

**Q.58** If organic sources of carcinogenic compounds in water persist even after chlorination, then what is the correct sequence among treatment processes listed below if all these are considered compulsory?
1. Coagulation
2. Sedimentation
3. Filtration in general
4. Activated carbon bed filtration
5. Flocculation
6. Chlorination

(a) 4-5-3-2-6 and 1 (b) 1-2-3-4-5 and 6
(c) 4-2-3-1-5 and 6 (d) 1-5-2-3-4 and 6

**Q.59** Match List-I with List-II and select the correct answer using the code given below the lists:

List-I
A. Viruses in water
B. Depletion of oxygen
C. Excess nitrates in water
D. Excess fluorides in water

List-II
1. Parasite-based disease
2. Fish extinction
3. Methemeglobinemia
4. Mottling of teeth

Codes:

| | A | B | C | D |
|---|---|---|---|---|
| (a) | 1 | 2 | 3 | 4 |
| (b) | 4 | 2 | 3 | 1 |
| (c) | 1 | 3 | 2 | 4 |
| (d) | 4 | 3 | 2 | 1 |

**Q.60** Consider the following statements:
The role of the gravel bed in a rapid sand filter is
1. To filter out large suspended matter.
2. To support the sand bed above it.
3. To prevent the escape of sand particles.
4. To uniformly distribute the backwash water.
5. To prevent algae growth.

Which of these statements are correct?
(a) 1, 2, 3, 4 and 5 (b) 2, 3 and 4 only
(c) 3, 4 and 5 only (d) 1, 2 and 3 only

**Q.61** Consider the following statements:
The following factors relate to the process of coagulation
1. Percentage removal is higher when turbidity is more.
2. Addition of activated silica aids in the process of coagulation.
3. pH of water is an important consideration for selecting a coagulant.

Which of these statements are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

**Q.62** Which of the following methods are employed for determination of free and combined chlorine residuals in water?
1. Starch-iodide method
2. Orthotolidine method
3. Amperometric titration method
4. SNORT method
5. DPD method

(a) 1, 2, 4 and 5 (b) 1, 2 and 3 only
(c) 3, 4 and 5 only (d) 2, 3 and 4 only

**Q.63** Match List-I with List-II and select the correct answer using the code given below the lists:

List-I
A. Primary sedimentation
B. Coagulation
C. Flocculation
D. Secondary sedimentation

List-II
1. Differential settling
2. Hindered settling
3. Charge neutralization
4. Growth of flocs
5. Flow-through velocity

Codes:

| | A | B | C | D |
|---|---|---|---|---|
| (a) | 2 | 5 | 4 | 1 |
| (b) | 1 | 3 | 4 | 2 |
| (c) | 2 | 4 | 3 | 1 |
| (d) | 5 | 4 | 3 | 2 |

**Q.64** Which of the following operational problems relate to the functioning of rapid gravity filter?
1. Inadequate media comprising filter bed
2. Sludge bulking
3. Mud balls
4. Negative head
5. Incrustation of media

(a) 3, 4 & 5 only (b) 1, 2, 3 and 4 only
(c) 2, 3, 4 & 5 only (d) 1, 3, 4 and 5

**Q.65** Which one of the following tests employs ferroin indicator?
(a) Chemical oxygen demand
(b) Ammonia nitrogen
(c) Nitrate nitrogen
(d) Fluoride

**Q.66** EDTA titration method of hardness determination of water sample uses an indicator which combines with hardness-causing divalent cations and forms a coloured complex. The name of the indicator and the colour of the formed complex respectively are
(a) Ferroin & dark blue (b) Ferroin & wine red
(c) Eriochrome Black T and dark blue
(d) Eriochrome Black T and wine red

**Q.67** Consider the following statements:
1. Carbonate hardness is due to bicarbonates.
2. Non-carbonate hardness is due to sulphates and chlorides of Ca and Mg.
3. Both the hardnesses can be removed by lime-soda method.
4. Both the hardnesses can be removed by ion-exchange method.

Which of these statements are correct.
(a) 1, 2 and 3 only (b) 1, 2 and 4 only
(c) 2, 3 and 4 only (d) 1, 2, 3 and 4

**Q.68** The most common constituents of alkalinity in natural water are measured by titrating the water sample with 0.02 N $H_2SO_4$ using.
(a) Eriochrome Black *T* and Ferroin indicators
(b) Ferroin and Phenolphthalein indicators
(c) Phenolphthalein and Methyl Orange indicators
(d) Methyl Orange and Eriochrome Black *T* indicators.

**Q.69** Consider the following statements:
1. Particulates have irregular shapes
2. Size can be determined by an equivalent aerodynamic diameter by comparing with a perfect sphere.
3. Particulates larger than 10 mm are said to settle relatively quickly since their settling velocity is not less than 10 cm/min.
4. The particles roughly the size of bacteria have aerodynamic diameter of 0.1 mm to 10 mm.

(a) 1, 2, 3 and 4 (b) 1 and 3 only
(c) 1, 2 and 4 only (d) 2, 3 and 4 only

**Q.70** An approximate estimation of total dissolved solids of a given water sample is often made by measuring
(a) Electrical conductivity of the water sample
(b) Electromagnetic conductivity of the water sample
(c) Sound conductivity of the water sample
(d) Thermal conductivity of the water sample

**Q.71** Which of the following statements are the important characteristics of a slow sand filter?
1. Cleaning of filter is done by scraping and sand removal.
2. Lack of pretreatment.
3. Greater efficiency of bacterial removal as compared to rapid sand filter.
4. Efficient in colour, taste and odour removal.

(a) 1, 2, 3 and 4 (b) 1, 2 and 4 only
(c) 2, 3 and 4 only (d) 1, 2 and 3 only

**Q.72** Which of the reasons given below favour the use of cast iron pipe for city water supply?
1. Strong in tension; and pipe of large diameter (up to 6 m) can be made.
2. Easy to make joints
3. Durable
4. Corrosion-resistant

(a) 1, 2, 3 and 4 (b) 2, 3 and 4 only
(c) 1, 2, and 4 only (d) 1, 3 and 4 only

**Q.73** In what interval are rapid sand filter to be cleaned by back washing?
(a) 24 - 48 hours (b) 10 - 15 days
(c) 1 - 2 months (d) 1 week

Q.74 Consider the following statements
Aeration in water treatment helps
1. killing pathogens
2. correcting pH
3. precipitating dissolved iron and manganese
4. expelling excess $CO_2$ and $H_2S$
5. expelling volatile oils

Which of these statements are correct?
(a) 2, 4 and 5
(b) 3, 4 and 5
(c) 1, 2, 3 and 5
(d) 1, 2, 3 and 4

Q.75 A flash mixer of 2.0 $m^3$, with a velocity gradient of mixing mechanism equal to 600 $s^{-1}$, and fluid absolute viscosity of 1.0 x $10^{-3}$ N-s/$m^2$ is continuously operated. What is the power input per unit volume?
(a) 360 W
(b) 720 W
(c) 1440 W
(d) 300 W

Q.76 Which one of the following types of settling phenomenon can be analyzed by the classic sedimentation laws of Newton and Stokes?
(a) Discrete settling
(b) Flocculent settling
(c) Hindered settling
(d) Compression settling

Q.77 Which of the following are associated with alum coagulation?
1. A decrease in alkalinity of treated water
2. Formation of hydroxide flocs of aluminium
3. A slight decrease in pH of treated water
4. An increase in permanent hardness

Select the correct answer using the codes given below
(a) 1, 2 and 3
(b) 1, 3 and 4
(c) 1, 2, 3 and 4
(d) 2 and 4

Q.78 In which treatment units is Schmutzdecke formed?
(a) Sedimentatin tank
(b) Rapid sand filter
(c) Coagulation tank
(d) Slow sand filter

Q.79 Which one of the following is the correct sequence of slow sand filter (SSF), rapid sand filter (RSF), dual media filter (DMF) and mixed media filter (MMF) in the decreasing order of their filtration rates?
(a) MMF > DMF > RSF > SSF
(b) DMF > RSF > SSF > MMF
(c) RSF > SSF > MMF > DMF
(d) SSF > MMF > DMF > RSF

Q.80 After which of the following treatment units, the turbidity is maximum?
(a) Chlorination
(b) Primary sedimentation
(c) Flocculation basin
(d) Secondary sedimentation

Q.81 Which one of the following describes the short-circuiting occurring in a sedimentation tank?
(a) Detention time
(b) Recirculation ratio
(c) Surface loading
(d) Displacement efficiency

Q.82 Consider the following statements:
1. In a continuous flow type sedimentation tank, the particles to be removed, should have their settling velocity more than the surface loading rate.
2. In a continuous flow type sedimentation tank, the particles which are settling, move vertically down to the bottom.
3. Coagulant added to the water containing alkalinity results in the formation of its hydroxide compound.

Which of these statements are correct?
(a) 1 only
(b) 1 and 2
(c) 2 and 3
(d) 1 and 3

Q.83 Match List-I (Water treatments units) with List-II (Normal detention time) and select the correct answer using the codes given below the lists.

List-I
A. Rapid mixing device
B. Flocculator
C. Plain sedimentation tank
D. Tube settlers

List-II
1. 5 to 10 minutes
2. 30 seconds
3. 30 minutes
4. 2 and 3 hours

Codes:

| | A | B | C | D |
|---|---|---|---|---|
| (a) | 3 | 2 | 4 | 1 |
| (b) | 3 | 2 | 1 | 4 |
| (c) | 2 | 3 | 1 | 4 |
| (d) | 2 | 3 | 4 | 1 |

Q.84 Consider the following valves used in rapid sand filter unit
1. Influent valve
2. Filtered water outlet valve
3. Backwash water inlet valve
4. Wash water drain valve

Which of these valves should be closed while back-washing the rapid sand filter?
(a) 2 and 3
(b) 1 and 2
(c) 1 and 4
(d) 3 and 4

Q.85 An ideal settling basin has a plan area of 100 $m^2$. If a flow of 24 $m^3$/day has removing the discrete particle completely from the basin, the terminal settling velocity is, nearly
(a) 0.01 m/hour
(b) 0.5 m/hour
(c) 0.1 m/hour
(d) 0.05 m/hour

Q.86 Iron and manganese can be removed from water by
(a) boiling
(b) aeration followed by coagulation
(c) chlorination
(d) activated carbon treatment

Q.87 An ideal settling basin is designed with surface overflow rate (SOR) of 1 $m^3/m^2/h$. Particles have their discrete settling velocities and concentration as follows.

| Particle Type | Settling velocity (m/h) | Concentration (mg/L) |
|---|---|---|
| 1. | 1.0 | 100 |
| 2. | 0.5 | 100 |
| 3. | 0.1 | 100 |
| 4. | 0.05 | 100 |

Which one of the following gives correct estimate of the overall removal of particles per hour?
(a) 65 mg/l
(b) 165 mg/l
(c) 265 mg/l
(d) 365 mg/l

Q.88 Consider the following characteristics
1. Effective size : 0.5 mm
2. Uniformity coefficient : 2.5
3. Filtration rate : 5.0 $m^3/m^2/h$

Which of the above values are correct in respect of rapid sand filter?
(a) 1 and 2
(b) 2 and 3
(c) 1 and 3
(d) 1, 2 and 3

Q.89 Match List-I (Process) with List-II (Description) and select the correct answer using the codes given below the lists:

List-I
A. Absorption
B. Adsorption
C. Agglomeration
D. Dilution

List-II
1. Colloidal of finely divided solids on the surface of solid bodies
2. The coalescence of dispersed suspended matter into larger flocs
3. Artificial augmentation of the volume of the environment used to assimilate waste
4. Taking up one substance into the body of another

Codes:

| | A | B | C | D |
|---|---|---|---|---|
| (a) | 4 | 2 | 1 | 3 |
| (b) | 3 | 1 | 2 | 4 |
| (c) | 4 | 1 | 2 | 3 |
| (d) | 3 | 2 | 1 | 4 |

Q.90 In water treatment process, the chemical used for defluoridation is
(a) alum
(b) lime
(c) potassium permanganate
(d) sodium aluminate

Q.91 Consider the following processes involved in filtration
1. Sedimentation
2. Flocculation
3. Biological action
4. Straining

The correct sequence of these processes in filtration is
(a) 2 - 3 - 4 - 1
(b) 4 - 3 - 2 - 1
(c) 4 - 2 - 1 - 3
(d) 2 - 4 - 1 - 3

**Q.92** **Which of the following processes can be combine to arrive at an appropriate water treatment scheme for a large city with envisaged maximum population of 500000? Maximum turbidity in the nearby river may reach 3000 NTU in monsoon season. The area for location of treatment plant is limited.**

1. **Aeration**
2. **Chemical coagulation, flocculation and settling**
3. **Slow sand filtration**
4. **Rapid sand filtration**
5. **Pressure filtration**
6. **Chlorination**

**Select the correct answer using the codes given below:**

(a) 1, 2 and 3
(b) 2, 5 and 6
(c) 1, 3 and 5
(d) 2, 4 and 6

**Q.93** **Which of the following reactions take place when chlorine is added to water containing ammonia?**

1. $NH_3 + HOCl \rightarrow NH_2Cl + H_2O$
2. $NH_2Cl + HOCl \rightarrow NHCl_2 + H_2O$
3. $NHCl_2 + HOCl \rightarrow NCl_3 + H_2O$
4. $NCl_2 + 2HOCl \rightarrow NCl_4 + H_2O$

**Select the correct answer using the codes given below:**

(a) 2 and 4
(b) 1, 2 and 3
(c) 1, 3 and 4
(d) 1, 2, 3 and 4

**Q.94** **Match List-I (Type of settling) with List-II (Description of process) and select the correct answer using the codes given below the lists:**

**List-I**

A. Type 1
B. Type 2
C. Type 3
D. Type 4

**List-II**

1. **Compression settling:** Particle concentration increases during settling
2. **Zone settling:** Particle concentration do not change during settling
3. **Flocculent settling:** Particle settling velocity increases with time
4. **Discrete settling:** Particle velocity remains constant

**Codes:**

| | A | B | C | D |
|---|---|---|---|---|
| (a) | 4 | 3 | 1 | 2 |
| (b) | 3 | 2 | 4 | 1 |
| (c) | 4 | 3 | 2 | 1 |
| (d) | 3 | 1 | 4 | 2 |

**Q.95** The most commonly used adsorbent for water purification is

(a) groundnut husk carbon
(b) activated carbon
(c) coconut shell carbon
(d) neem bark carbon

**Q.96** Match List-I with List-II and select the correct answer using the codes given below the lists:

**List-I**

A. High turbidity low alkalinity
B. Low turbidity high alkalinity
C. High turbidity high alkalinity
D. Low turbidity low alkalinity

**List-II**

1. Small number of colloids makes coagulation difficult sweep coagulation is more effective
2. Prevents formation of $Al(OH)_3$
3. Reduced pH makes small dosages of coagulant more effective
4. pH is relatively not affected when coagulant is added

**Codes:**

| | A | B | C | D |
|---|---|---|---|---|
| (a) | 4 | 1 | 3 | 2 |
| (b) | 3 | 2 | 4 | 1 |
| (c) | 4 | 2 | 3 | 1 |
| (d) | 3 | 1 | 4 | 2 |

**Q.97** Match List-I (Treatment unit) with List-II (Function) and select the correct answer using the codes given below the lists:

| List-I | List-II |
|---|---|
| A. Aeration | 1. Suspended matter |
| B. Softening | 2. Colour, odour, taste |
| C. Coagulation | 3. Colloidal dissolved matter, bacteria |
| D. Filtration | 4. Hardness |

Codes:

| | A | B | C | D |
|---|---|---|---|---|
| (a) | 3 | 4 | 1 | 2 |
| (b) | 2 | 1 | 4 | 3 |
| (c) | 3 | 1 | 4 | 2 |
| (d) | 2 | 4 | 1 | 3 |

**Q.98** Match List-I (Type of filter) with List-II (Filtering characteristic) and select the correct answer using the codes given below the lists.

List-I

A. Slow sand filter
B. Rapid sand filter
C. Pressure filter

List-II

1. Filtered water comes out under pressure sand no lifting device is necessary to lift water
2. Removes 98.99% bacteria
3. Rate of filtration is 4500 $l/m^2/hr$

Codes:

| | A | B | C |
|---|---|---|---|
| (a) | 2 | 1 | 3 |
| (b) | 3 | 1 | 2 |
| (c) | 2 | 3 | 1 |
| (d) | 3 | 2 | 1 |

**Q.99** Consider the following statements

1. Most colloidal particles in water are negatively charged.
2. The surface charge on colloidal particles is the major contributor to their long term stability

Which of these statements are correct?

(a) 1 only
(b) 2 only
(c) Both 1 and 2
(d) Neither 1 nor 2

**Q.100** What is the ratio of rate of back-washing to that of filtration in a typical rapid sand filter?

(a) 2
(b) 4
(c) 6
(d) 10

**Q.101** Match List-I with List-II and select the correct answer using the codes given below the lists:

| List-1 | List-II |
|---|---|
| A. Fluorides | 1. Aluminium oxide |
| B. Hexavalent chromium | 2. Reduction and precipitation |
| C. Iron and manganese | 3. Oxidation and precipitation |
| D. Toxic organics treatment | 4. Activated carbon |

Codes:

| | A | B | C | D |
|---|---|---|---|---|
| (a) | 1 | 4 | 3 | 2 |
| (b) | 3 | 2 | 1 | 4 |
| (c) | 3 | 4 | 1 | 2 |
| (d) | 1 | 2 | 3 | 4 |

**Q.102** In the lime-soda process of water softening

(a) lime reduces carbonate hardness while soda removes non-carbonate hardness
(b) only carbonate hardness is removed
(c) lime reduces non-carbonate hardness while soda removes carbonate hardness
(d) only non-carbonate hardness is removed

**Q.103** Plain sedimentation tanks are designed for what value of surface loading rate (in $m^3/m^2/day$)?

(a) 2 to 10
(b) 15 to 30
(c) 50 to 80
(d) 100 to 500

**Q.104** Which one of the following is not reduced by chlorination of water?

(a) Ammonia content
(b) Organic matter content
(c) BOD
(d) Dissolved oxygen content

**Q.105** The results of analysis of a raw water sample are given below:

Turbidity : 5 mg/L, pH : 7.4
Fluorides : 2.5 mg/L, Total Hardness : 300 mg/L
Iron : 3.0 mg/L, MPN : 50 per 100 mL

From the data given above, it can be inferred that water needs removal of

(a) turbidity followed by disinfection
(b) fluorides and hardness
(c) iron, followed by disinfection
(d) fluorides, hardness and iron followed by disinfection

**Q.106** An ideal horizontal flow settling basin is 3 m deep having surface area 900 $m^2$. Water flows at the rate of 8000 $m^3/d$ at water temperature 20°C ($m = 10^{-3}$ kg/m-s and $r = 1000$ kg/$m^3$).

Assuming Stoke's law to be valid, the proportion (percentage) of spherical sand particles (0.01 mm in diameter with specific gravity 2.65), that will be removed, is
(a) 32.5 (b) 67
(c) 87.5 (d) 95.5

**Q.107** The design parameter for flocculation is given by a dimensionless number Gt, where G is the velocity gradient and t is the detention time. Valves of Gt ranging from $10^4$ to $10^5$ are commonly used with t ranging from 10 to 30 min. The most preferred combination of G and t to produce smaller and denser flocs is
(a) large G values with short t
(b) larger G values with long t
(c) small G values with long t
(d) small G values with long t

**Q.108** How are particles of approximately 1 micron size best removed?
(a) filtration
(b) plain sedimentation
(c) chemical coagulation
(d) chemical precipitation

**Q.109** Match List-I (Disinfection) with List-II (Characteristic) and select the correct answer using the codes given below the List.

| List-I | List-II |
|---|---|
| A. Chlorine | 1. Post-treatment required |
| B. UV rays | 2. Residual concentration for some duration |
| C. Ozone | 3. Physical disinfectant |
| D. Excess lime | 4. Costlier |

Codes:

| | A | B | C | D |
|---|---|---|---|---|
| (a) | 2 | 3 | 4 | 1 |
| (b) | 1 | 3 | 4 | 2 |
| (c) | 2 | 4 | 3 | 1 |
| (d) | 1 | 4 | 3 | 2 |

**Q.110** What is the condition of the raw water when coagulants used in water treatment functions more effectively?
(a) slightly acidic (b) slightly alkaline
(c) nearly neutral (d) minimally turbid

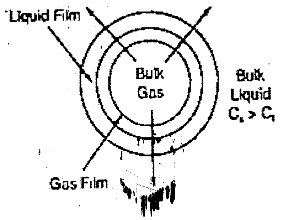
**Q.111** Which reaction is indicative of break point chlorination?
(a) chloramines and chloro-organic compounds get destroyed
(b) destruction of chlorine by reducing compounds
(c) free chlorine and remnants of chloro-organic compounds
(d) ammonia plus chlorine producing chloramines

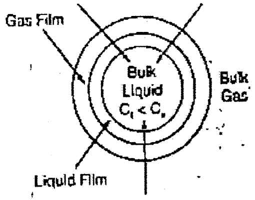
**Q.112** Which of the following reasons are responsible for adoption of post-chlorination of water?
1. chlorine demand is reduced
2. possibility of taste and odour formation is reduced
3. possibility of carcinogenic compounds is reduced
4. chloramines are formed
(a) 1, 2, 3 and 4 (b) 1, 2 and 3 only
(c) 1 and 4 only (d) 2, 3 and 4 only

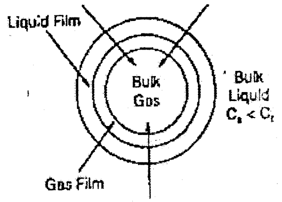
**Q.113** Consider the following statements
The following factors relate to the process of coagulation
1. Percentage removal is higher when turbidity is more
2. Addition of activated silica aids in the process of coagulation
3. pH of water is an important consideration for selecting a coagulant
Which of these statements are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

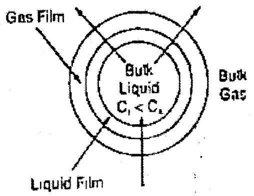
**Q.114** Water treated by conventional treatment system comprising screening, plain sedimentation, sedimentation by coagulation, filtration and super-chlorination units, need to be further analyzed for detecting the presence of bacterial cells. Which is the simplest test to be conducted for this?
(a) Residual chlorine test
(b) Membrane filter technique
(c) MPN test
(d) Biological analysis of water

**Q.115** In a liquid-gas system, when the water is dispersed in air, the absorption of gas is represented by

(a)


(b)


(c)


(d)


**Q.116** Match List-I (Disinfectant) with List-II (Characteristic) and select the correct answer using the codes given below the List.

| List-I | List-II |
|---|---|
| A. Ozonation | 1. Complete sterilization |
| B. U-V radiation | 2. Residual concentration |
| C. Chlorination | 3. Effective in killing bacterial spores also |
| D. Adequal duration of boiling | 4. High cost |

Codes:

| | A | B | C | D |
|---|---|---|---|---|
| (a) | 4 | 3 | 2 | 1 |
| (b) | 3 | 4 | 2 | 1 |
| (c) | 1 | 2 | 3 | 4 |
| (d) | 4 | 2 | 3 | 1 |

**Directions:** The following items consists of two statements; one labelled as **'Statement (I)'** and the other as **'Statement (II)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:
Codes:
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

**Q.117** **Statement (I):** A small quantity of ammonia is added to water before carrying out disinfection using chlorine.
**Statement (II):** Chloramines are persistent disinfectants, which provide continued protection against regrowth of micro-organisms in a water distribution system.

**Q.118** **Statement (I):** Chlorides are added to kill pathogens as a disinfection process in the treatment of water.
**Statement (II):** It forms hypochlorous acid to oxidize the organic compounds including bacteria.

**Q.119** **Statement (I):** An epidemic of infective hepatitis is transmitted by drinking contaminated water.
**Statement (II):** Since infective hepatitis is transmitted by bacteria, it can be controlled by filtration and disinfection of water.

**Q.120** **Statement (I):** Chlorophyll-bearing plants take water and carbondioxide to synthesize carbohydrates.
**Statement (II):** Wasted food ultimately leads to production of various natural resources like water and sunlight energy.

**Q.121** **Statement (I):** Rapid sand filters consisting of carefully sieved sand on top of a bed of gravel will only filter particles larger than its pore size.
**Statement (II):** In addition to staining, adsorption, continued flocculation and sedimentation in the pore spaces help in particles removal mechanism.

**Q.122** **Statement (I):** Large weir overflow rates will result in excessive velocities at the outlet of a settling basin.
**Statement (II):** These excessive velocities will extend backward into the settling zone, causing particles and flocs which would otherwise be removed as sludge to be drawn into the outlet.

**Q.123** **Statement (I):** The fluoride content in drinking water should neither be too low nor too high.
**Statement (II):** Deficiency of fluoride content causes motling of teeth and its excess causes dental cavities in children.

**Q.124** **Statement (I):** The settling velocity of a discrete particle will become five times when its diameter doubles.
**Statement (II):** The settling velocity of a discrete particle is almost proportional to the square of the particle diameter.

**Q.125** **Statement (I):** Chlorides should be absent in drinking water.
**Statement (II):** Chlorides give salty taste to water.

**Q.126** **Statement (I):** Tapered flocculation is more efficient when compared to the conventional process of flocculation.
**Statement (II):** In tapered flocculation, velocity gradient at the inlet is less than that at the outlet of the flocculation unit.

## Answers

| | | | | |
|---|---|---|---|---|
| 1 (a) | 2 (a) | 3 (b) | 4 (d) | 5 (b) |
| 6 (c) | 7 (d) | 8 (a) | 9 (b) | 10 (a) |
| 11 (d) | 12 (b) | 13 (a) | 14 (b) | 15 (d) |
| 16 (a) | 17 (a) | 18 (d) | 19 (d) | 20 (b) |
| 21 (b) | 22 (a) | 23 (d) | 24 (c) | 25 (c) |
| 26 (d) | 27 (b) | 28 (a) | 29 (d) | 30 (d) |
| 31 (b) | 32 (a) | 33 (d) | 34 (b) | 35 (b) |
| 36 (d) | 37 (c) | 38 (b) | 39 (d) | 40 (d) |
| 41 (d) | 42 (a) | 43 (c) | 44 (c) | 45 (a) |
| 46 (a) | 47 (c) | 48 (b) | 49 (b) | 50 (b) |
| 51 (b) | 52 (a) | 53 (d) | 54 (a) | 55 (b) |
| 56 (d) | 57 (b) | 58 (d) | 59 (a) | 60 (b) |
| 61 (a) | 62 (a) | 63 (b) | 64 (a) | 65 (a) |
| 66 (d) | 67 (d) | 68 (c) | 69 (a) | 70 (a) |
| 71 (a) | 72 (b) | 73 (a) | 74 (b) | 75 (a) |
| 76 (a) | 77 (d) | 78 (d) | 79 (a) | 80 (c) |
| 81 (d) | 82 (d) | 83 (d) | 84 (b) | 85 (a) |
| 86 (b) | 87 (b) | 88 (c) | 89 (c) | 90 (a) |
| 91 (c) | 92 (d) | 93 (b) | 94 (c) | 95 (b) |
| 96 (d) | 97 (d) | 98 (c) | 99 (c) | 100 (d) |
| 101 (d) | 102 (a) | 103 (b) | 104 (d) | 105 (d) |
| 106 (c) | 107 (a) | 108 (a) | 109 (a) | 110 (b) |
| 111 (c) | 112 (b) | 113 (a) | 114 (b) | 115 (b) |
| 116 (a) | 117 (a) | 118 (d) | 119 (c) | 120 (c) |
| 121 (d) | 122 (b) | 123 (c) | 124 (d) | 125 (d) |
| 126 (c) | | | | |

## Hints and Explanations:

**Ans.1** (a)

Surface water contains inorganic suspended matter, organic suspended matter and pathogens mainly. They are generally soft and less corrosive than ground water. So coagulation, flocculation, sedimentation, filtration and disinfection shall be the treatment. Ground water has no suspended matter and it can be used after disinfection.

Lake water will have odour, taste and colour due to heavy algal growth. Some turbidity will also be there due to mixing of layers. So $CuSO_4$ treatment for colour, odour and taste followed by coagulation, sedimentation, filtration and disinfection is needed.

**Ans.2** (a)

Defluoridation using Nalgonda technique uses alum with prior mixing of lime (CaO) or sodium carbonate ($Na_2CO_3$). The added lime helps to ensure adequate alkalinity required for effective hydrolysis of alum, so that residual alum does not remain in the treated water.

**Ans.3** (b)

Chlorides are generally present in water in the form of sodium chloride and may be due to leaching of marine sedimentary deposits, pollution from sea water, brine or industrial and domestic wastes, etc. Their concentrations above 250 mg/L produce brackish taste which is objectionable. It is measured by potentiometric method using titration with silver nitrate solution. In Argentometric method, of chloride measurement, silver nitrate titration in the presence of potassium chromate indicator is used. The red precipitate of silver chromate indicates end of titration.

Brackish taste of chlorides can be removed by:
(i) Evaporation and distillation
(ii) Electrodialysis method
(iii) Reverse osmosis method
(iv) Freezing process
(v) Solar distillation method.

Lime soda process and cation exchange process are used for hardness removal. Chemical coagulation is used for colloidal particle removal.

**Ans.5** (b)

Fluoride can be removed by:
(i) Nalgonda technique
(ii) Activated alumina
(iii) Bone char

Nalgonda technique uses aluminium salt (alum) for removing fluoride.

Manganese and iron can be removed by aeration or manganese zeolite (a natural green sand coated with manganese dioxide).

Taste and odour can be removed by:
(i) Aeration
(ii) Activated carbon
(iii) Copper sulphate

Copper sulphate is an algicide also.

**Ans.6** (c)

Design period considers the useful life of any structure. Further hydrological analysis for design of the structure considers the frequency of occurrence of extremes of river flow.

**Ans.8** (a)

The flow through period (actual average time for batch of water) is always less than the detention period.

Tracer analysis using dyes can be used to measure residence time distribution curves and short circuiting in sedimentation tank.

**Ans.9** (b)

Organisms that use organic carbon for the formation of new biomass are called heterotrophs, while organisms that derive cell carbon from carbon dioxide are called autotrophs. The conversion of $CO_2$ to cellular complex compounds requires a reductive process, which requires a net input of energy. Therefore, autotrophic organisms must spend more of their energy for synthesis than heterotrophs, resulting in generally lower yield of cell mass and growth rates. Eutrophication is caused by nutrients like carbon, nitrogen and phosphorous. It is a natural process of algal production and siltation of water body. The water body becomes shallower.

**Ans.11** (d)

Aeration will oxidize the iron and manganese and then they can be separated by sedimentation.

**Ans.13 (a)**

| | Slow sand filter | Rapid sand filter |
|---|---|---|
| Effective Size | 0.2 mm to 0.4 mm | 0.35 to 0.55 mm |
| Uniformity Coefficient | 1.8 to 2.5 | 1.2 to 1.8 |

Thus in slow sand filters ES is less but UC is more than that in rapid sand filters.

**Ans.15 (d)**

If only ammonia is present then first chloramines will be formed. Thus there will be no destruction of chlorine residual by reducing compounds, which is represented by *AB*. So curve will pass through origin.

**Ans.18 (d)**

In the initial dose of chlorine there is no residual because chlorine, being a strong oxidant, reacts with almost any matter in a reduced state such as $Fe^{2+}$, $Mn^{2+}$, $H_2S$ and organics. Thus there is no exact answer but closest answer will be (d).

**Ans.19 (d)**

Disinfection using chlorine is necessary part of water treatment for rural water supply. Therefore (a) and (c) can not be the answer. Before slow sand filter, coagulation is not suitable. Therefore (b) is not possible.

**Ans.20 (b)**

In the packed tower, packing material (bed material) is used to increase the contact time between vapour and liquid. The material chosen for packing has a large surface to volume ratio and a large void ratio that offers minimum resistance to gas flow.

**Ans.21 (b)**

All particles having settling velocity equal to or greater than surface overflow rate will be completely removed while particles having settling velocity lower than SOR will be partially removed.

$$\text{Total removal} = 200 + \frac{1}{3} \times 300 = 300 \text{ mg/L}$$

The concentration of particles in settled water $= (200 + 300) - 300 = 200$ mg/L

**Ans.22 (a)**

Slow sand filter can remove 98-99% bacteria. It has maximum bacteria removal efficiency.

**Ans.24 (c)**

Ground water is free from suspended impurities. However dissolved gases, salts and minerals are found in groundwater.

**Ans.25 (c)**

First aeration is done to remove gases $CO_2$ and $H_2S$ and pathogens (disease causing bacteria) will be removed in the last.

**Ans.27 (b)**

The disinfection of industrial water supplies is necessary in food processing, distillery (alcohol), etc.

**Ans.30 (d)**

Lime-soda process converts all types of hardness into precipitate of $CaCO_3$ and $Mg(OH)_2$. These precipitate may not be removed completely and will continue settling slowly resulting in deposits in water lines and storage facilities. It is therefore necessary to 'stabilize' the water by converting the supersaturated $CaCO_3$ back to the soluble form. This can be done by recarbonation.

**Ans.33 (d)**

Dissolved solids cannot be removed in rapid sand filter.

**Ans.35 (b)**

Slow sand filter will be able to remove suspended particles and up to 99% pathogenic organisms. So small amount of supplies for rural areas can be ensured by slow sand filters.

**Ans.36 (d)**

$$\text{Surface overflow rate} = \frac{Q}{A_s} = \frac{Q}{LB}$$

$A_s$ is surface area

SOR does not depend upon total depth of the tank.

**Ans.39 (d)**

Nutrient (Phophorus and nitrogen) removal comes under secondary treatment.

**Ans.40 (d)**

Principal mechanisms and phenomenon contributing to removal of material within a granular medium depth filter are:

(i) Straining (mechanical and chance contact)
(ii) Sedimentation
(iii) Impaction
(iv) Interception
(v) Adhesion
(vi) Flocculation
(vii) Chemical adsorption (bonding and chemical interaction)
(viii) Physical adsorption (electrostatic forces, electrokinetic forces and vander Waals forces)
(ix) Biological growth
(x) Centrifugal force in disc filter.

**Ans.41 (d)**

The biological layer formed by microbial decomposition of harmless compounds is called schmutzdecke or dirty skin. This helps in absorbing and straining out impurities. This layer is formed in slow sand filter.

**Ans.42 (a)**

Dechlorination means removing the chlorine from water. This is generally required when super-chlorination has been practised. The common dechlorinating agents are:

(i) $SO_2$ gas
(ii) Sodium thiosulphate ($Na_2S_2O_3$)
(iii) Activated carbon
(iv) Sodium metabisulphate ($Na_2S_2O_5$)
(v) Ammonia as $NH_4OH$
(vi) Sodium sulphite ($Na_2SO_3$)
(vi) Sodium bisulphite ($NaHSO_3$)

**Ans.44 (c)**

Hardness is defined as the concentration of multivalent metallic cations in solution. The multivalent metallic ions most abundant in natural waters are calcium and magnesium. Hardness can be measured by using spectrophotometric techniques or chemical titration to determine the quantity of calcium and magnesium ions in a given sample. Hardness can be measured directly by titration with ethylenediamine tetracetic acid (EDTA) using Eriochrome Black T (EBT) as an indicator.

**Ans.47 (c)**

The coagulation of metallic salts releases hydrogen ions as well as coagulant species. These hydrogen ions neutralize alkalinity. In water with high turbidity and high alkalinity the pH will be relatively unaffected by coagulant addition. Because of the high alkalinity, absorption and charge neutralization will be less effective than in waters of low alkalinity. Higher coagulant dosage should be used to ensure sweep coagulation.

**Ans.50 (b)**

Surface overflow rate is the most important design parameter in designing a continuous flow rectangular sedimentation tank. If the discharge through the tank is Q, width of tank is B and length of the tank is L, then surface overflow rate is given by $v_0 = Q/BL$

The surface overflow rate can be said to be representing the settling velocity of the slowest settling particles which are 100% removed. Thus, particles having settling velocity greater than or equal to surface overflow rate are 100% removed. Particles having settling velocity less than surface overflow rate are not 100% removed. If a particle enters the tank at a height '*h*' with a settling velocity *v* which is less than $v_0$, then it will be removed if

$$v = \frac{h}{H} \times v_0 \quad \text{where } H \text{ is the height of the tank}$$

**Ans.56 (d)**

At low concentrations, chlorine probably kills micro-organisms by penetrating the cell and reacting with the enzymes and protoplasm. At higher concentrations, oxidation of the cell wall will destroy the organism.

**Ans.58 (d)**

Filtration is employed after coagulation, flocculation and sedimentation to remove the