Chapter 2

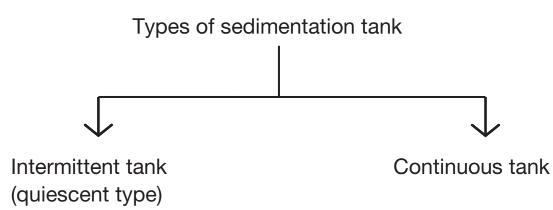
Water Supply Engineering-II

CHAPTER HIGHLIGHTS

- *Plain sedimentation*
- *Sedimentation aided with coagulation*
- *Filtration*
- *Disinfection*
- *Miscellaneous water treatment*
- *Distribution system*

Plain Sedimentation

It is the process which is done after screening in the process of purification of water. This is done to remove suspended coarser particles which tend to settle down when offered storage or flow velocity reduced.

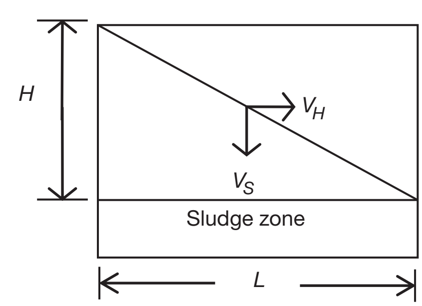


- **Intermittent tank:** Water is completely brought to rest.
- **Continuous tank:** Travel from one end to another end is kept slightly more than time required for settling of a suspended particle in water. It can be rectangular, square, and circular.

Types of Sedimentations

- **Type I—Discrete settling:** It is also known as a free settling. This corresponds to the sedimentation of discrete particles in a suspension of low solids concentration.
- **Type II—Hindered settling:** It refers to dilute suspension of particles that flocculate during sedimentation process. Due to this the mass of the particles increase and rate of settlement is also faster.
- **Type III—Zone settling:** This refers to flocculent suspension of intermediate concentration. Inter-particle forces hold the particles together.
- **Type IV—Compression settling:** This refers to flocculent suspension of so high concentration that particles actually come in contact with each other, resulting in formation of a structure.

Design Concepts of Sedimentation Tank



- Flow velocity, $V_H = \dfrac{Q}{BH}$
- Overflow velocity, $V_0 = \dfrac{Q}{B \cdot L}$

- According to proportionality,

$$\frac{V_H}{V_s} = \frac{L}{H}$$

$$\therefore V_s = V_H \times \frac{H}{L}$$

For settling, $V_s \geq V_0$

- Particles with settling velocity equal to or greater than V_0 will settle down
- Sedimentation efficiency, $\eta = \frac{V_s}{V_0} \times 100$.

Design Parameters

1. **Overflow rate, V_0:** It effects on the efficiency of sediment removal. Efficiency is inversely proportional to the overflow rate and directly proportional to the size of particles to be settled.
   - For sedimentation tank, V_0 = 500 – 750 lit/h/m².
   - For sedimentation tank aided with coagulation, V_0 = 1000 – 1250 lit/hr/m².
2. **Detention time (D_t):** Average time for which water is detained in tank is called detention time.

   For sedimentation tank,

$$D_t = \frac{\text{Volume of tank}}{\text{Rate of flow}}$$

   The detention time is directly proportional to the efficiency of tank.
   - For plain sedimentation tank, D_t = 4–8 hours.
   - For sedimentation aided with coagulation, D_t = 2–4 hours.
3. **Flowing through period:** The average time required for a batch of water to pass through the settling tank. It is always less than the detention period. It is determined by placing sodium chloride in the influent and testing for the chloride content of the effluent.
4. **Displacement efficiency:** It is the ratio of flowing through period to the detention period.

$$\eta_d = \frac{\text{Flowing through period}}{\text{Detention period}}$$

   - Actual detention period = 2 × (Theoritical detention period)
   - η_d varies from 0.25 – 0.5.
5. **Other design values adopted:**
   - Length should not exceed 4 times width ≅ (4B or 5B)

   Flow velocity, 0.3 m/min
   - Amount of flow in 24 hours

     = Maximum daily demand
   - Length of tank = Flow velocity/Detention time

   Sludge storage = 0.8 – 1.2 m
6. **Basin dimensions:**
   - Surface area,

$$A = \frac{\text{Volume of water in liters per hour}}{\text{Surface loading rate in litres per hour/m}^2}$$

   - Settling velocity depends mainly on the diameter of the particles if d < 0.1 mm, then laminar flow condition occurs,

$$V_s = \frac{g}{18}(S-1)\frac{d^2}{\nu} \text{ (or) } 418(S-1)d^2\frac{(3T+70)}{100}$$

   Where

   d = Diameter of particles

   ν = Kinematic viscosity

   S = Specific gravity of particle

   R_e = Reynolds number = $\frac{v_s \cdot d}{\nu}$

   V_s is in mm/s
   - If d lies between 0.1 mm and 1 mm

$$\therefore V_s = 418(S-1)d\frac{(3T+70)}{100}$$

   - If d > 1 mm (or) R_e > 1000. Turbulent conditions occurs

$$V_s = 1.8\sqrt{g \cdot d(S-1)}.$$

SOLVED EXAMPLES

Example 1

A sedimentation tank is designed to capture 0.06 mm diameter particles with specific gravity 2.65. If the sedimentation tank is designed for a surface overflow rate 40 m³/day/m². The efficiency of particle removal is _______.

Take kinematic viscosity of water as 0.01 cm²/s and g = 9.81 m/s².

Solution

Settling velocity, $V_s = \frac{g(s-1)d^2}{18\nu}$

$$= \frac{9.81(2.65-1)\times(0.06\times10^{-3})^2}{18\times0.01\times10^{-4}}$$

$= 3.23 \times 10^{-3}$ m/s

$= 3.23$ mm/s

Efficiency, $\eta = \frac{V_s}{V_0} \times 100$

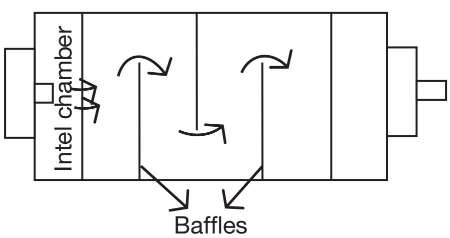
$V_0 = 0.463$ mm/s

$\therefore \eta = \frac{3.23}{0.463} \times 100 = 100\%.$

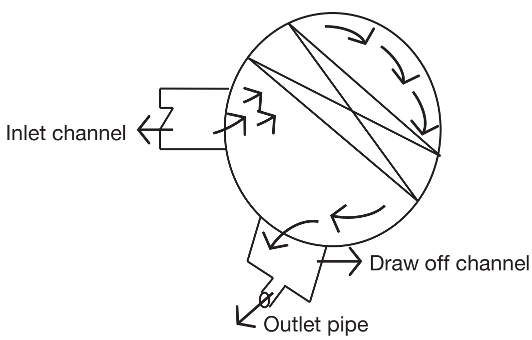
7. **Inlet and outlet arrangements:** The slots should be such that:
   (a) Velocity of flow through slots is about 0.2–0.3 m/s
   (b) Head loss is 1.7 times the velocity head.
   (c) Diameter of the hole not to be larger than the thickness of the diffuser wall.

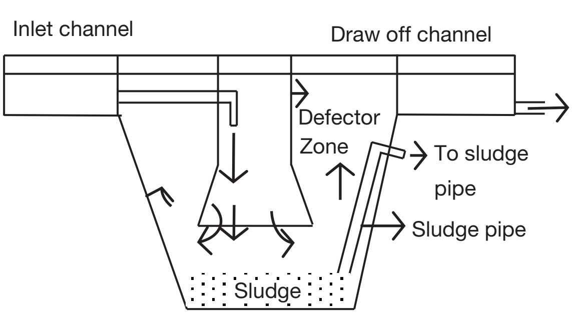
Types of Sedimentation Tanks

1. Rectangular tank with horizontal flow:



2. Circular tank with spiral flow:





Sedimentation Aided with Coagulation

- It is also known as clarification. It is generally done to remove very fine suspended particles and colloidal particles.
- Coagulants are mixed with water to form precipitate called floc which attracts the fine suspended particles.
- Factors affecting coagulation are:
  (a) Type of coagulant
  (b) Quantity (or) dose of coagulant
  (c) Characteristics of water such as
    (i) type and quantity of suspended matter.
    (ii) temperature of water.
    (iii) pH of water.
  (d) Time, violence and method of mixing.
- The commonly used coagulants are:
  (a) Aluminium sulphate (or) alum
  (b) Chlorinated copperas
  (c) Ferrous sulphate and lime
  (d) Magnesium carbonate
  (e) Polyelectrolytes
  (f) sodium aluminates
- Iron salts are used more frequently for treating sewage and alum is used for treating water.

Chemical Reactions

1. **Aluminium sulphate (or) alum:**
   - $Al_2(SO_4)_3 18H_2O + 3Ca(HCO_3)_2 \rightarrow$ $2Al\,(OH)_3 + 3CaSO_4 + 18H_2O + 6CO_2$
   - $Al_2(SO_4)_3 18H_2O + 3Ca(OH)_2 \rightarrow$ $2Al(OH)_3 + 3CaSO_4 + 18H_2O$
   - $Al_2(SO_4)_3 18H_2O + 3Na_2CO_3 \rightarrow$ $2Al(OH)_2 + 3Na_2SO_4 + 3CO_2 + 18H_2O$

   Alum reduces taste and odour apart from turbidity, Alum is effective and cheap. On the other hand it is difficult to dewater the sludge and imparts permanent hardness.

2. **Chlorinated copperas:** Hydrated ferrous sulphate ($FeSO_4.7H_2O$) is traditionally referred to as copperas.

$$6FeSO_4\,7H_2O + 3Cl_2 \rightarrow 2Fe_2(SO_4)_3 + 2FeCl_3 + 7H_2O$$

$$Fe_2(SO_4)_3 + 3Ca(OH)_2 \rightarrow 3CaSO_4 + 2Fe(OH)_3$$

$$2FeCl_3 + 3Ca(OH)_2 \rightarrow 3CaCl_2 + 2Fe(OH)_3$$

   Effective pH range is 3.5 to 6.5 and above 8.5

3. **Ferrous sulphate and lime:**

$$FeSO_4\,7H_2O + Ca(OH)_2 \rightarrow Fe(OH)_2 + CaSO_4 + 7H_2O$$

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

Ferric hydroxide thus formed is a satisfactory gelatinous floc, which is heavier than the one formed by alum. The effective pH range for this is 8.5 and above.

4. **Magnesium carbonate and lime:** $MgCO_3 + Ca(OH)_2 \rightarrow Mg(OH)_2 = CaCO_3$ It is useful in removing organic colour, iron and manganese.
5. **Sodium aluminate:**

$$Na_2Al_2O_4 + Ca(HCO_3)_2 \rightarrow CaAl_2O_4 + Na_2CO_3 + CO_2 + H_2O$$

$$Na_2Al_2O_4 + CaCl_2 \rightarrow CaAl_2O_4 + 2NaCl$$

$$Na_2Al_2O_4 + CaSO_4 \rightarrow CaAl_2O_4 + Na_2SO_4$$

The effective pH range is 6 to 8.5. It is used to remove temporary and permanent hardness.

Example 2

At a water treatment plant 14 million liters of water is treated daily using alum dosage of 20 mg per litre. The total quantity of alum used daily is

Solution

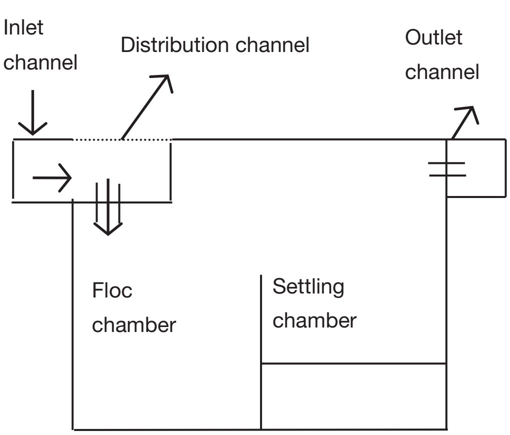
Total quantity of alum per day

$= Q(\text{MLD}) \times \text{Alum dose}$

$= 14 \times 20$

$= 280$ kg.

Process



1. **Floc chamber:** The process of slow mixing which promotes agglomeration of particles is known as flocculation. This flocculation and coagulation are done in this floc chamber. The detention time of floc chamber is 15–40 min. Depth of floc chamber is half the depth of settling chamber.
2. **Dosage of coagulant:** Dosage of coagulant depends on the amount of turbidity present in water. Average dosage of the coagulant in normal water is generally 14 mg/lit. The pH value lies between 6.5 and 8.5. Optimum alum dosage may be determined by jar test.

Filtration

Filtration is the process of removal of fine suspended particles, colloidal matter, bacteria, odour, taste and colour by means of filtering-water through filter media.

Actions of Filtration

1. Mechanical straining
2. Sedimentation
3. Biological action
4. Electrolytic action

Mechanical Straining

The suspended particles are usually larger than the pore space of filter media and hence they are arrested and removed when water passes through the filter media. Major removal takes place only in the upper few centimeters of the filter media.

Sedimentation

Finer particles which are not filtered in mechanical straining are done using sedimentation action. The voids between the sand grains act as minute sedimentation tanks in which particles will settle and adhere to the sides of sand grains. Also colloidal particles held in voids and on the surfaces act as gelatinous material and attracts the other fine particles.

Biological Action

The bacteria, algae, etc., exist on the upper most layer of the sand film. A thin layer of reddish brown colour is formed on the sand which is known as Schumtzdecke or dirty skin which acts as an extremely fine meshed straining mat.

Electrolytic Action

The charge of filter medium neutralizes the charge of the floc, thereby permitting the floc to be removed. When the particles of suspended and dissolved matter having electricity of opposite polarity come into contact with sand grains, they neutralize each other and result in changing the chemical characteristic of water.

Filter Troubles

Some of the filter troubles which are encountered in their operation are

1. **Formation of mud balls:** These are the conglomerations of coagulated turbidity, floc, sand and other binders and are formed near the top of filter media. Mud is accumulated on the sand surface and during washing some lateral pressure between the points where the water breaks through, and the stick mud is pushed into lumps or balls of small size upto 2–5 cm diameter. These balls are removed by breaking them, washing with sand, washing with solutions like caustic soda, sulphuric acid, etc.

Type of Filters

Slow Sand Filters	Rapid Sand Filters
Size of the filter bed varies from 100 m^2 to 2000 m^2 or more.	Size of the filter bed varies from 10 m^2 to 50 m^2.
Filter media of sand has (a) Finer sand grains (b) Effective size of 0.2 to 0.35 mm (c) Uniformity coefficient: 1.8 to 3.0 (d) Thickness: 90 to 110 cm reduced to not less than 40 cm by scrapping.	Filter media or sand has (a) Sand grains are slightly coarser (b) Effective size: 0.35 to 0.55 mm (c) Uniformity coefficient: 1.3 to 1.7 (d) Thickness: 60 to 75 cm, not reduced by washing.
Base material of gravel (a) size: 3 to 65 mm (b) thickness: 30 to 75 cm	Base material of gravel (a) size: 2 to 50 mm (b) thickness: 45 to 60 cm
Coagulation is not required	Coagulation is essential
under drainage system is provided only to receive filtered water	Under drainage system is provided to receive filtered water and also to supply water for back washing of filter
Rate of filtration is 100 to 200 lit/h/m^2	Rate of filtration is 3000 to 6000 lit/h/m^2
Method of cleaning is scrapping of top layer of 15 to 30 cm thickness	Method of cleaning is agitation and back washing with (or) without compressed air
Amount of wash water is 0.2 to 0.6% of filtered water	Amount of wash water is 2 to 5% of filtered water
Period of cleaning is 1 to 3 months	Period of cleaning is 1 to 3 days
It is very efficient in removing bacteria but less efficient in removing colour and turbidity	It is less efficient in removal of bacteria more efficient in the removal of colour and turbidity

2. **Cracking and clogging of bed:** Shrinkage of filter bed causes cracks and develop pulling away of sand from side walls.
3. **Air binding:** When negative pressure exceeds the water tends to release dissolved gasses in the form of bubbles which seriously affect the working of filter such phenomena is called air binding. It occurs due to negative head, increase in temperature of water, release of oxygen by algae.
4. **Sand incrustation:** It is caused either due to the deposition of sticky material such as floc from influent water or due to presence of calcium carbonates. It can be minimized by carbonating the influent.
5. **Jetting and sand boils:** it is due to back washing of filter.
6. **Sand leakage:** It is downward migration and escape of fitness. It can be minimized by proportioning sand and gravel layers.

Pressure Filters

- Similar to rapid sand filters.
- Rate of filtration is 6000 to 15000 lit/h/m^2.
- Installed for colonies of few houses, industries, swimming pools, railway stations, etc.

Filter Hydraulics

1. **Carmen–Kozney equation:**

$$h_f = \frac{fLv_s^2}{g \cdot d}\frac{(1-n)}{n^3\phi}$$

Where, $f = 150\frac{(1-n)}{R_e} + 1.75$

$$R_e = \frac{\rho V_s d}{\mu}\phi$$

Where

d = Grain size

f = Friction factor

L = Depth of filter bed

n = Porosity of filter media

ϕ = Particle shape factor

V_s = Superficial or approach filtration velocity

g = Acceleration due to gravity

r = Density of liquid

μ = Dynamic viscocity of water

R_e = Reynold number

2. **Flow through expanded beds:**

$$\frac{L_e}{L} = \frac{(1-n)}{(1-n_e)}$$

$$V_b = V_s \times n_e^{4.5}$$

Where

L_e = Expanded bed thickness

V_b = Velocity of back wash water

L = Original bed thickness

V_s = Terminal velocity of settling particle

n_e = Expanded bed porosity

n = Porosity of original bed.

3. **Head loss due to backwashing:**

$$h_{fb} = L(1-n)(S-1) \text{ or } L_e(1-n_e)(S-1)$$

Where, S = Specific gravity of filter particle.

Disinfection

Disinfection is the process of killing micro-organisms in water. Disinfection either destroys or inactivates the micro-organism, by way of the following mechanisms:

1. Damage to cell wall of micro-organisms
2. Alternation of cell permeability
3. Changing the colloidal nature of the cell protoplasm
4. Inactivation of critical enzyme systems responsible for metabolic activities.

Methods of Disinfection

1. **Boiling of water:** It is generally used only for domestic purpose. It is most effective method of disinfection of water. It cannot be used for huge quantities of public water supplies.
2. **Treatment with excess lime:** It is added to water to raise its value of pH to 9.50 or more. Thus most of the bacteria will be killed. It kills the bacteria but not safe, thus it is sent for recarbonation and is supplied to public.
3. **Ozone:** Ozone is more powerful than chlorine. It is used for disinfection of water on small scale such as for swimming pool waters. But it is more costly than chlorine.
4. **Iodine and bromine pills:** Iodine provides longer lasting protection against pathogens and reduced offensive tastes and odours. It is used for water supply of army troops and private plants. But it cannot be used for public water supply as it is too costly.
5. **Ultra violet rays:** It is very costly and effective method of disinfection. It is adopted for water supply installations of private buildings, treating small quantities of water in hospitals, etc.
6. **Potassium permanganate:** It is used for disinfecting well water supplies which are generally contaminated with lesser amounts of bacteria. It can remove 100% organisms and it oxidizes organic matter.
7. **Silver or electro-katadyn process:** It removes algae but it is costly.
8. **Chlorination:** Addition of chlorine does not produce any change in pH. The residual disinfecting effects lasts for long periods. It takes care of any possible future contamination.

Action of Chlorine

- $Cl_2 + H_2O \leftrightarrow HOCl + HCl$ (Hydrolysis) [reversible reaction]
- $HOCl \underset{\longleftrightarrow}{pH} H^+ + OCl^-$ (Ionization) [reversible reaction]
- At pH < 5.5 $\rightarrow$ 100% HOCl and no OCl^-
- At pH > 9.5 $\rightarrow$ 100% OCl^- and no HOCl
- At pH = 7.5 $\rightarrow$ 50% HOCl and 50% OCl^-
- HOCl $\rightarrow$ Hypochlorous acid
- OCl^- $\rightarrow$ Hypochlorite ion
- HOCl and OCl^- combinedly known as free available chlorine.
- HOCl is 80 to 100 times more powerful than OCl^-

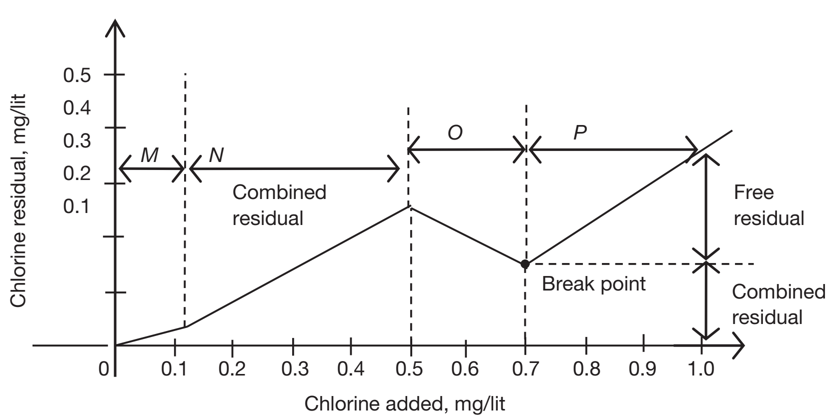
Free chlorine reacts with the compounds such as ammonia, proteins, amino acids and phenol which are generally present in water to form chloramines and chloro-derivatives which are also called combined chlorine.

Residual chlorine = Chlorine dosage – Chlorine demand

Chloramines:

- $NH_3 + HOCl \rightarrow NH_2Cl$ (Monochloramines) + H_2O
- $NH_2Cl + HOCl \rightarrow NHCl_2$ (Dichloramines) + H_2O
- $NHCl_2 + HOCl \rightarrow NCl_3$ (Nitrogen + trichloride) + H_2O (or) Trichloramine
- If pH < 4.4, only trichloramine exists
- For pH : 4.5 to 5.5, only dichloramine exists
- For pH : 5.5 to 8.4, both mono and dichloramines exists
- If pH > 8.4, only monochloramine exist.

Break Point Chlorination



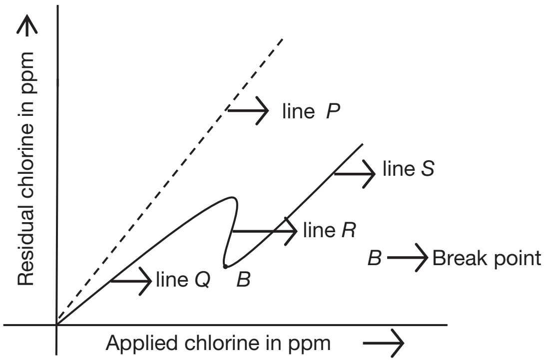
Where

M = Destruction of chlorine residual reducing compounds (Fe, Mn, H_2S)

N = Formation of chloro-organic compound and chloramines

O = Destruction of chloramines and chloro-organic compounds

P = Formation of free chlorine and presence of chloro-organic compounds not destroyed



When chlorine is added to water, some of it is consumed in killing bacteria and oxidizing organic matter to form its compound (chloramines) and the remaining chlorine is available as residual chlorine. This is indicated by line *Q*. The fall of line *R* indicates oxidation of chloro-organic compounds and chloramines indicated by bad odour and taste in water. Any further increase in chlorine dose beyond point *B* will appear as residual chlorine only and this is shown by line *S*.

Factors Affecting Efficiency of Chlorine

1. **Turbidity:** The penetration of chlorine and therefore the destruction of bacteria in particles of suspended matter of a turbid water may be very uncertain. Due to this reason, the application of chlorine is preferred after filtration when water will be free from turbidity.
2. **Presence of metallic compounds:** Presence of metallic compounds is not favorable. Presence of iron and manganese reduce the effectiveness of chlorine.
3. **Ammonia compounds:** The addition of ammonia compounds reduces efficiency.
4. **pH value of water:** If the value of pH increases the effectiveness of chlorine decreases.
5. **Temperature of water:** At low temperature the efficiency will be less and hence requirement of chlorine is more.
6. **Contact time:** Killing of bacteria increases with increase in contact period.

Types of Chlorination

Depending upon the stage at which chlorine is supplied to water, chlorination is done in following types.

1. **Plain chlorination:** It is the application of chlorine to plain or raw water supply before it enters the distribution system. It also includes chlorination of raw water in tanks or reservoirs to check the growth of weeds, organic matter, algae and bacteria. The normal dose is between 0.5–1 ppm.
2. **Pre-chlorination:** It is the application of chlorine to water before its treatment. It reduces the taste and odour of water, controls the growth of algae, prevents putrefaction of sludge in settling tanks. The dosage is generally 0.1–0.5 ppm.
3. **Post chlorination:** It is the application of chlorine to water after its treatment. This is the standard form of chlorination in which chlorine is added to water as it leaves the rapid filters and before it enters the distribution system. The dose of residual chlorine is 0.1–0.2 ppm.
4. **Double or multiple chlorination:** It consists of pre-chlorination and post chlorination. It is adopted when raw water is highly contaminated and contains large amount of life.
5. **Break point chlorination:** When chlorine is applied to water, two actions take place.
   (a) It kills bacteria and disinfection is effected.
   (b) It oxides the organic matter.

   This break point gives an idea of chlorine to be added to water so as to ensure desired amount of residual chlorine. It removes taste and odour, colour due to organic matter and manganese. The break point lies between 3–7 ppm.
6. **Super chlorination:** It is the application of chlorine beyond the stage of break point. It is most commonly added at the end of filtration. When super chlorination is practiced, it becomes necessary to remove excess chlorine by any suitable method of dechlorination before water is supplied to the consumers.
7. **Dechlorination:** The process of removing excess chlorines by dechlorinating agents is known as dechlorination. This is to avoid chlorinous taste from water. The chemicals used in chlorination are sulphur dioxide, sodium thiosulphate, sodium bi-sulphate, activated carbon, potassium permanganate, ammonia.

Various Forms of Chlorine

Chlorine can be applied to water in various forms such as:

1. **Bleaching powder or hypochlorite:** Bleaching powder or hypochlorite $Ca(OCl)_2$ is a chlorinated lime containing $33\frac{1}{3}\%$ of available chlorine when freshly made. The process of chlorination with hypochlorites is known as hypochlorination.

The highest hypochlorites having available chlorine contents of 65–70% are stable, easily soluble and free flowing.

2. **Chloramines:** These are the compounds of ammonia and chlorine. The treatment of ammonia as NH_3 is added to water just before chlorine is applied.
   - $H_2O + Cl_2 \rightarrow HCl + HOCl$
   - $NH_3 + HOCl \rightarrow H_2O + NH_2Cl$
   - $NH_2Cl + HOCl \rightarrow H_2O + NHCl_2$
   - $NHCl_2 + HOCl \rightarrow H_2O + NCl_3$

   Chloromines are much weaker disinfectants as compared to free chlorine.
3. **Free chlorine:** Chlorine is generally applied in gaseous or liquid form. Chlorine in gaseous or liquid form is now-a-days universally adopted as disinfectant for public water supplies. It is a powerful disinfectant and may remain in water as residual for sufficient time. No sludge is formed in its application, as may be formed by using hypochlorites or chloramines.
4. **Chlorine dioxide:** It has an oxidizing capacity $2\frac{1}{2}$ times that of chlorine. Further it is effective in removal of tastes and odours, but due to its high cost of production it is not economical.

Dosage of Chlorine

The dose of chlorine which leaves a residual chlorine of about 0.2 mg/lit at the end of 10 minutes contact period is selected which gives the optimum dose of chlorine for the given water sample.

- Normal dosage = 0.3–1.1 mg/lit
- Residual chlorine = 0.1–0.2 mg/lit

Chlorine dose must be generally increased during rainy season

$$Cl_2 \text{ dosage} = Cl_2 \text{ demand} + Cl_2 \text{ residual}$$

Kinetics of Disinfection

Various factors of disinfection are:

1. Time of contact
2. Concentration of disinfectant
3. Concentration of organisms
4. Temperature of disinfection

Chick's Law of Disinfection

Chick's law states that the number organisms (y) destroyed in unit time is proportional to number of organisms (N) remaining.

$$\frac{dy}{dt} = KN = KC(N_0 - y)$$

Where

N_0 = Number of organisms, initially present

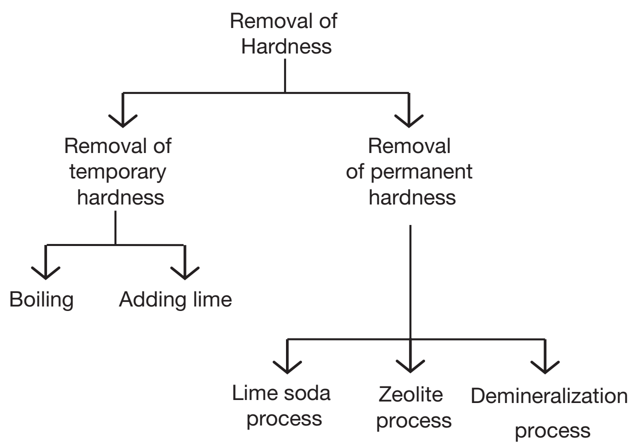
y = Number of organisms remaining at any time = $N_0 - y$

K = coefficient of proportionality, known as rate Constant with dimension t^{-1}.

Miscellaneous Water Treatment

Water Softening

Water softening is the process of removal of hardness of water. The removal of hardness involves various methods based on the type of hardness.



Boiling

In boiling the following reactions denote the methodology of removal of hardness

- $Ca(HCO_3)_2 + \text{Heat} \rightarrow CaCO_3\downarrow + 2H_2O + CO_2$
- $Mg(HCO_3)_2 + Ca(OH)_2 \rightarrow CaCO_3\downarrow + MgCO_3 + 2H_2O + CO_2$

Heat converts bicarbonates to carbonates.

Addition of Lime

The following reactions take place when lime is added

- $Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3\downarrow + 2H_2O$
- $Mg(HCO_3)_2 + Ca(OH)_2 \rightarrow CaCO_3\downarrow + MgCO_3 + 2H_2O$

The calcium carbonate and magnesium carbonate so formed can be removed in the sedimentation tanks since these are insoluble in water.

Lime Soda Process

It is the process of removal of permanent hardness of water. The aim of the lime soda process is to make the calcium and magnesium content of the hard water take their insoluble form so that they precipitate out.

The following reactions take place:

- $CO_2 + Ca(OH)_2 \rightarrow CaCO_3 \downarrow + H_2O$
- $Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3 \downarrow + 2H_2O$
- $Mg(HCO_3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3 \downarrow + 2H_2O + MgCO_3$
- $MgCO_3 + Ca(OH)_2 \rightarrow Mg(OH)_2 + CaCO_3 \downarrow$
- $MgSO_4 + Ca(OH)_2 \rightarrow Mg(OH)_3 \downarrow + CaSO_4$
- $CaSO_4 + Na_2CO_3 \rightarrow CaCO_3 \downarrow + Na_2SO_4$
- $CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 + NaCl$
- $MgCl_2 + C(OH)_2 \rightarrow Mg(OH)_2 + CaCl_2$

The lime soda water softening plant consists of following units:

1. **Feeding and mixing devices:** These are used for mixing which will be done in coagulation process also.
2. **Settling basin:** It is similar to coagulation-sedimentation, but the retention period is 2–4 hours to obtain larger clarification.
3. **Recarbonation or stabilization plant:** The effluent from the settling basin is super saturated with calcium carbonate. If this is not prevented it will precipitate on sand filters and cause enlargement of sand grains, incrustation of mains and stoppage of water meters. The carbonate balance may be partly or completely restored by recarbonation of water. This is usually accomplished by diffusing carbon dioxide gas through the water or by underwater combustion.
   - $CaCO_3 + CO_2 + H_2O \rightarrow Ca(HCO_3)_2$

Advantage of Lime Soda Process

1. It is economical.
2. The pH value increases and corrosion of the distribution system decreases.
3. The process is suitable for turbid and acid waters for which zeolite process cannot be used.
4. Less quantity of coagulant will be required.
5. Removal of iron and manganese to some extent.
6. There is likelihood of killing of pathogenic bacteria in this process.
7. Better for excessively hard waters.

Disadvantages of Lime Soda Process

1. Large quantity of sludge is formed in this process which needs to be disposed-off by suitable method.
2. In this process recarbonation is required.

Zeolite Process

Zeolite is the complex compound of aluminum, silica, soda, some forms of which are synthetic and others are naturally occurring. Natural zeolites are mainly processed from green sand (glauconite). Zeolite has larger grains of white colour. It has chemical formula $SlO_2Al_2O_3Na_2O$. Calcium and magnesium are removed by sodium ion-exchange process. When water is passed through the zeolite and the following reactions taken place.

- $2SiO_2Al_2O_3Na_2O + Ca(O)CHCO_3)_2$
  $\rightarrow 2SiO_2 \rightarrow Al_2O_3CaO + 2NaHCO_3$
- $2SiO_2Al_2O_3Na_2O + CaSO_4$
  $\rightarrow 2SiO_2Al_2O_3CaO + Na_2SO_4$
- $2SiO_2Al_2O_3Na_2O + CaCl_2 \rightarrow$
  $2SiO_2Al_2O_3CaO + 2NaCl$

By zeolite process the resulting hardness will almost be reduced to zero.

Advantages of Zeolite Process

1. No sludge is formed hence no problem of sludge disposal.
2. The unit is compact and small space is required.
3. No skilled supervision is required.
4. It is possible to reduce the hardnesscompletely to zero. Hence the water can be used for boilers.

Disadvantages of Zeolite Process

1. It is not suitable for highly turbid water and water containing iron and manganese.
2. The process is not suitable for acid waters which irreversibly substitute hydrogen for sodium in zeolite.
3. There are chance of growth of bacteria on bed of zeolite.

Demineralization or Dionization Process

It is similar to zeolite process with the difference that in demineralization process the metallic ions like calcium, magnesium, etc., are exchanged for hydrogen ions. The ion exchanger is prepared with carbonaceous mineral or resin. The effluent obtained in this process is free from minerals and has quality.

Desalination

It is the process of converting saline water to fresh water. Different methods of desalination are as follows:

1. Distillation
2. Revere osmosis
3. Electrodialysis
4. Freezing
5. Demineralization
6. Solar evaporation

- **Distillation:** In this process saline water is boiled or evaporated. The vapours re-conducted which gives fresh water.

- **Reverse osmosis:** In this process water is forced across a semi-permeable membrane by mechanical force.
- **Electrodialysis:** In this process salt ions are removed from saline water under the impetus of an electric current.
- **Demineralization:** In this process salts are removed from water through the use of ion exchangers.

Removal of Colour, Odour and Taste

This can be done by following ways:

1. **Aeration:** It is applicable to the removal of tastes resulting from dissolved gases, whereas chloramines or lime is applicable in removal of phenol tastes. Carbon dioxide, hydrogen sulphide and other volatile substances imparting taste and odour to water are easily expelled. Iron and manganese present in water are oxidixed to certain extent by aeration.
2. **Treatment by activated carbon:** Activated carbon is used for the control of tastes and odour of water, resulting from the presence of dissolved gases. It has also valuable colour removal properties. Activated carbon removes organic contaminants from water by the process of adsorption. In adsorption high surface area is the prime consideration. Activated carbon can be applied for treatment of water in two ways:
   (a) as filter media,
   (b) as fine powder feed.
3. **Use of copper sulphate:** Copper sulphate $CuSO_4$ is used for:
   (a) removal of colour, odour and taste from water.
   (b) control the growth of algae, bacteria and some types of aquatic weeds. It can be applied either in the distribution pipes (or) in open reservoirs.

Iron and Manganese

Iron and manganese are generally present in water supplies, either suspension as hydrated oxides or in solution as bicarbonates. If water containing iron and manganese is used in a laundry, it will develop reddish or brownish stains on the clothes. If deposited in distribution pipes, it leads to the blocking of pipes, meters, etc., the water is coloured either red or brown. Iron and manganese can be removed by aeration followed by coagulation, sedimentation and filtration.

Fluoridation

The process of raising the fluoride content of water is known as fluoridation. Fluoride compounds that are adopted for fluoridation are: sodium fluoride (NaF), sodium silicon fluoride (Na_2SiF_6) and hydrofluosilicic acid (H_2SiF_6). It is best to apply fluoride after other treatments, but at point where thorough mixing of fluoride with water can take place before water leaves the treatment works.

Defluoridation

It is the process of reducing the fluoride concentration of water. There are different methods of deflouridation namely:

1. Calcium phosphates
2. Bone charcoal
3. Synthetic tricalcium phosphate
4. Fluroex
5. Ion-exchanger
6. Lime
7. Aluminium compounds
8. Activated carbon
9. Nalgonda technique

Nalgonda Technique Nalgonda techniques is a new technique for defluoridation. In this technique sodium aluminate or lime, bleaching power and filter alum are added to fluoride water in sequence. Water is stirred and then withdrawn without disturbing the sediments. Sodium aluminate or lime accelerates settlement of precipitate and bleaching power ensures disinfection.

Distribution System

Introduction

Water is conveyed or transported from the source to the community through various types of conduits. This chapter deals with the method of distribution and the components of distribution system.

Components of Distribution System

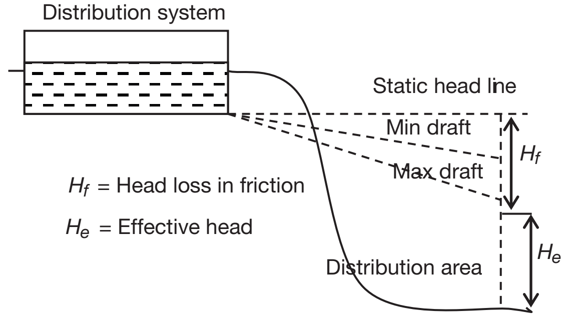
1. Pipes—Main, sub-mains, branches and laterals
2. Valves—For controlling flow
3. Hydrants—For releasing water during fire break outs
4. Meters—For measuring discharges
5. Pumps—For lifting water
6. Service reservoir—For storing the treated water and stabilizing pressures
   - Pressure for single-storey building is 7 m of water.
   - Pressure for two-storey building is 12 m of water
   - Pressure for three-storey building is 17 m of water

System of Distribution

The method of distribution depend on topographic area. The following methods are adopted for distribution:

1. Gravity system
2. Combined gravity and pumping system
3. Pumping system

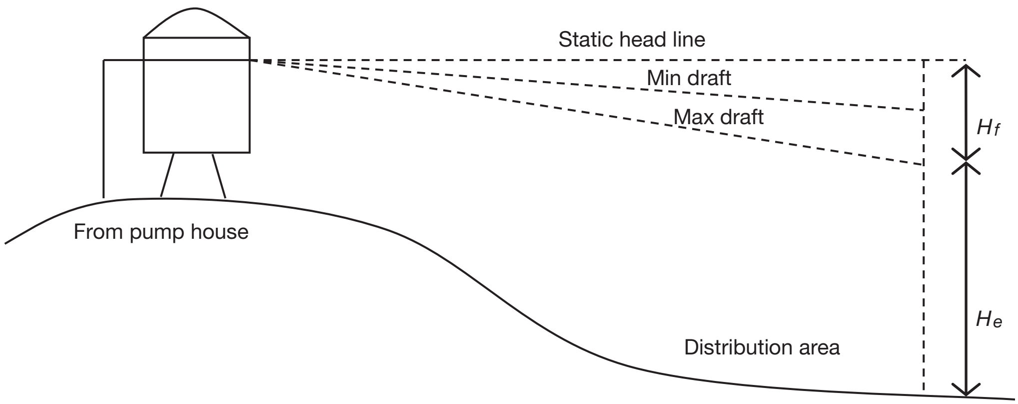
Gravity System



In this system the source of water supply is so located with respect to the area of distribution that water is available with sufficient pressure at various points of the area.

Combined Gravity and Pumping System

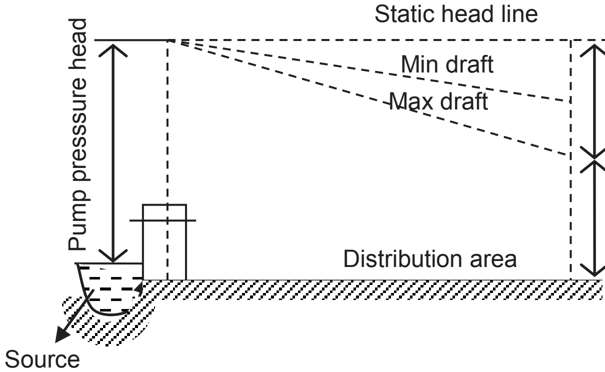
It is the most common system adopted in most of the cases. Generally the water purification works are located almost at the same level as the area of distribution—especially when source of raw water supply is a river or a reservoir formed behind a dam. In order to obtain sufficient distribution pressure, filtered water is pumped into clear water reservoir located on a high ground or elevated on a tower.



Combined gravity and pumping system

Pumping System

In this system, water is pumped directly into the distribution system to achieve the required pressure, as shown in the figure such a system is not desirable. Generally double pumping is required. First to pump raw water from the source to the treatment works and then to pump the purified water direct into distribution mains.

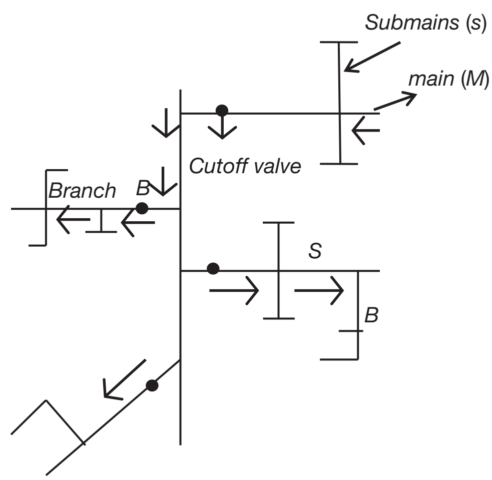


Pumping system

Layout of Distribution System

There are different layouts of distribution system.

Dead End System

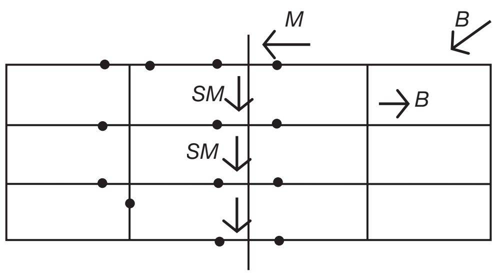


- **Suitability:** For old towns and cities with irregular and unplanned development.
- **Advantages:** Quite simple design; lesser number of cut-off valves; easier expansions; short pipe lengths are required, cheap and economical.
- **Limitation:** Considerable area gets affected during repairs, water stagnation at dead ends leads to

the pollution. It is less successful in maintaining satisfactory pressures in remote parts.

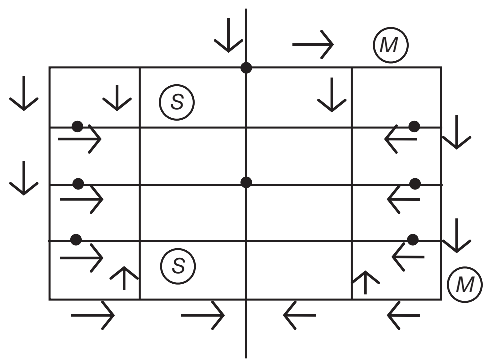
Grid Iron System

Mains, sub-mains and branches are interconnected with each other.



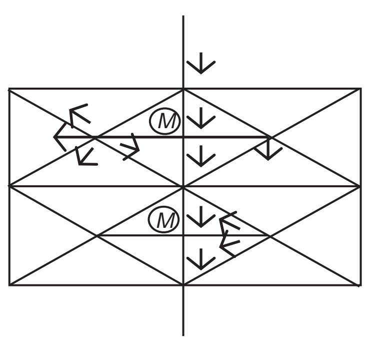
- **Suitability:** It is suitable for well-planned cities.
- **Advantages:** Size of pipes get reduced. A very small area gets affected in case of repairs. Water cannot be polluted. More water is diverted for fire break out.
- **Disadvantages:** More the lengths of pipes, larger the number of valves.

Ring System



Main pipe is laid peripherally. Laying of mains peripherally increase pressure at farthest point. Suitable for towns and cities having well planned roads.

Radial System



The area is divided into small distribution zones and in the center of each zone a distribution reservoir is provided. Water from these reservoirs is supplied through radially laid distribution pipes running towards periphery of zone. It ensures high pressure and efficient water distribution.

Storage Capacity of Distribution Reservoir

The storage capacity of reservoir is based on the following requirements

1. **Balancing storage:** It is the quantity of water required to be stored in the reservoir for balancing and equalizing the variable demand of water.
2. **Breakdown storage:** It is the storage required to be provided in the distribution reservoir to take care of emergencies which may arise due to failure of pumps, failure of electric supply. It is 25% of total storage.
3. **Fire storage:** It is a provision for fire storage in a distribution reservoir which is required to be made to provide water for firefighting purposes.

Total capacity of distribution .reservoir = Balancing storage + Breakdown storage + Fire storage.

Appurtenances in Distribution System

Valves

These are provided in the pipelines to control the flow of water, to isolate and drain sections for test, inspection and cleaning.

1. **Gate valve:** It is used in pipelines for convenience in manually closing the pipes. The gate valve has advantage over the globe valve and offers less resistance to flow. It is therefore used in preference to globe valve where resistance to flow of water is to be kept at minimum.

   Head loss due to fitting = $\dfrac{K\cdot(\bar{v})^2}{2g}$

   $K = 0.3$–0.4 for gate valve

   $K = 10$ for globe valve.
2. **Globe valve:** It is used in pipelines for convenience in manually closing the pipes to control the flow of water. The globe valve has advantage of quicker opening.
3. **Butterfly valves:** They are used to regulate and stop the flow in large size conduits.
4. **Check valves:** They are also known reflux valves or non-return valves. A check valve allows water to flow in one direction only and the flow in the reverse direction is automatically stopped by it.
5. **Air valve or air-relief valve:** The air valve helps to admit air into the pipe when the pipe is being emptied or when negative or vacuum pressure is created in the pipe. Air valve operates automatically while allowing air to escape from or to enter a pipe.

6. **Scour valve or blow off valve or drain valve:** They are provided for completely emptying or draining of the pipe for removing sand or silt deposited in the pipe and for inspection, repair, etc.
7. **Pressure-relief valves:** It is also called overflow towers, are provided to keep the pressure in a pipeline below a predetermined valve, and thus protect it against the possible danger of bursting due to excessive pressure. Thus these valves are often placed at low points where the pressures are high. Further a pressure relief valve is usually provided on the upstream side of the valve is relieved of water hammer pressure resulting from the sudden closure of sluice valve.

Manholes

They are provided at suitable intervals along the pipeline for inspection and repairs. Usually spaced 300–600 m apart on large pipelines.

Water Meters

These are installed in pipeline to measure the quantity of water flowing in them.

1. **Inferential or velocity meters:** These are used to measure the velocity of flow. For example, rotary and turbine meters.
2. **Displacement meters:** They are primarily used for flow rate and commonly used for residential buildings. The quantity of water actually passing through it is measured by filling and emptying the chamber of known capacity.

Fire Hydrants

Hydrant is an outlet provided in a pipeline for tapping water mainly for the purpose of fire fighting. Also be used for withdrawing water for certain other purposes such as sprinkling on roads, flushing streets, etc. Generally hydrants are placed at all important road junctions and at intervals not exceeding about 300 m.

Design of Distribution System

Head loss by Hazen–Williams formula:

$$h_f = 10.70 \times \left(\frac{Q}{C_H}\right)^{1.852} \times \frac{L}{D^{4.87}}$$

Where, C_H = Roughness coefficient

There are different methods of analysis of pipe networks:

Equivalent Pipe Method

For the purpose of analysis the entire network of pipes is considered to be split up into two portions.

1. Pipes in series
2. Pipes in parallel

Hardy Cross Method

It is a method of successive approximations which involves a trial and error process. Hardy Cross method may be carried out in the following two ways.

1. Balancing heads by correcting assumed flow; and
2. Balancing flows by correcting assumed heads

In this method three laws are applicable:

1. In each separate pipe or element comprising the system there will be a relation between the head loss in the element and the quantity of water flowing through it.
2. At each junction, the algebraic sum of the quantities of water entering and leaving the junction is zero, i.e., $\Sigma Q = 0$.
3. In any closed path or circuit, the algebraic sum of head loss in individual element is zero, i.e., $\Sigma h = 0$.

Storage and Distribution Reservoir

Storage and distribution reservoirs are important units in a modern distribution system. Clear water storage reservoirs are required for storage of filtered water until it pumped into the service reservoirs or distribution reservoirs.

Types of storage and distribution reservoirs:

1. Surface reservoirs
2. Elevated reservoirs
3. Stand pipes

Surface Reservoirs

These are made mostly of masonry or concrete. These are the reservoirs which are built underground. These are the reservoirs which should be located at high points in distribution system.

Elevated Reservoirs

These are commonly known as overhead tanks. They may be constructed at an elevation from ground level. It is also called overhead tanks.

Stand Pipes

These stand pipes are normally employed where the construction of a surface reservoir would not provide sufficient head. A stand pipe is essentially a tall cylindrical tank whose storage volume includes an upper portion, which is above the entrance to the discharge.

Exercises

1. For a flow of 5.7 MLD (million litres per day) and a detention time of 2 hours, the surface area of a rectangular sedimentation tank to remove all particles have settling velocity of 0.33 mm/s is
(A) 20 m^2 (B) 100 m^2
(C) 200 m^2 (D) 400 m^2

2. A town has an existing horizontal flow sedimentation tank with an overflow rate of 17 $m^3/day/m^2$, and it is desirable to remove particles that having settling velocity of 0.1 mm/s. Assuming the tank is an ideal sedimentation tank, the percentage of particles removal is approximately equal to
(A) 30% (B) 50%
(C) 70% (D) 90%

3. For a water treatment plant having a flow rate of 432 m^3/h, what is the required plan area of a type I settling tank to remove 90% of the particles having a settling velocity of 0.12 cm/s?
(A) 120 m^2 (B) 111 m^2
(C) 90 m^2 (D) 100 m^2

4. 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/ms) and p = 1000 kg/ m^2). Assuming Stokes 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

5. Flocculation is a process
(A) that removes algae from stabilization pond effluent.
(B) that promotes the aggregation of small particles into larger particles to enhance their removal by gravity.
(C) that mixes the coagulant in water.
(D) None of these

6. Design parameters for rapid mixing units are
(A) velocity gradient and the volume of mixing basin.
(B) viscosity and velocity gradient.
(C) viscosity, velocity gradient and the volume of the mixing basin.
(D) detention time and viscosity of water.

7. Coagulation–flocculation with alum is performed
(A) immediately before chlorination.
(B) immediately after chlorination.
(C) after rapid sand filtration.
(D) before rapid sand filtration.

8. Use of coagulants such as alum
(A) results in reduction of pH of the treated water.
(B) results in increase of pH of the treated water.
(C) results in no change in pH of the treated water.
(D) may cause an increase or decrease of pH of the treated water.

9. The following chemical is used for coagulation.
(A) Ammonium chloride
(B) Aluminium chloride
(C) Aluminium sulphate
(D) Copper sulphate

Direction for questions 10 and 11:

A water treatment plant treating 10 MLD of water requires 20 mg/lit of filter alum, $Al_2(SO_4)_3$ $18H_2O$. The water has 6 mg/lit of alkalinity as $CaCO_3$ (Al = 26.97, S = 32, O = 16, H = 1, Ca = 40 and C = 12).

10. Total alkalinity requirement (10^6 mg per day as $CaCO_3$) matching filter Alum, shall be
(A) 180 (B) 120
(C) 90 (D) 60

11. Quantity of quick lime required (10^6 mg per year as CaO) shall be
(A) 2132 (B) 3000
(C) 4132 (D) 6132

12. The design parameter for flocculation is given by a dimensionless number Gt, where G is the velocity gradient and t is the detention time. Values 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) large G values with long t.
(C) small G values with short t.
(D) small G values with long t.

13. The following characteristics pertain to the sand filters used in water industry.
I. Filtration rate is 1 to 4 $m^3/(m^2 day)$.
II. Typical duration of operation in one run is 24 to 72 hours.
III. Operation cost is low.

Which of the above characteristics pertain to slow sand filters?
(A) I, II and III (B) I and II
(C) II and III (D) I and III

14. The cleaning of slow sand filter is done by
(A) reversing the directions of flow of water.
(B) passing air through the filter.
(C) passing a solution of alum and lime through the filter.
(D) scrapping off top layers of sand and admitting water.

15. Match List I (Water treatment units) with List II (Detention time) and select the correct answer using the codes given in 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	b	c	d
(A)	3	4	2	1	(B)	4	3	1	2
(C)	4	3	2	1	(D)	3	4	1	2

16. **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 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.

17. Chlorides from water are removed by
(A) lime soda process.
(B) reverse osmosis.
(C) cation exchange process.
(D) chemical coagulation.

18. What is the rapid sand filter surface area required for filtering of 10 MLD water assuming a filtration rate of 100000 $l/m^2/day$?
(A) 100 m^2 (B) 10 m^2
(C) 1 m^2 (D) 1000 m^2

Direction for questions 19 and 20:

A city is going to install the rapid sand filter after the sedimentation tanks. Use the following data:
Design loading rate to the filter : 200 m^3/m^2d
Design flow rate : 0.5 m^3/s
Surface area per filter box : 50 m^2

19. The surface area required for the rapid sand filter will be
(A) 210 m^2 (B) 215 m^2
(C) 216 m^2 (D) 218 m^2

20. The number of filters required shall be
(A) 3 (B) 4
(C) 6 (D) 8

21. In order to test a filtration process, clear water is made to pass through a bed of uniform sand at a filtering velocity of 3.0 m/h. Sand bed has the following properties:
Depth of bed : 0.6 m
Sand grain specific gravity: 0.5 mm
Sand grain specific gravity: 2.65
Sand grain shape factor used to calculate filtration Reynolds number: $\phi = 0.80$
Porosity of sand bed: $e = 0.40$
Kinematic viscosity of water: $\nu = 1.0 \times 10^{-6}$ m^2/s calculate the loss of head in filtration.

22. A dual media rapid sand filter plant is to be constructed for treatment of 72 million litres of water per day. A pilot plant study indicated that a filtration rate of 15 m/h would be acceptable. Allowing one unit out of service for back washing, how many 5 m × 8 m filter units will be required? Determine the net production in million liters per day of each filter unit if back washing is done at 36 m/h for 20 minutes and the water is wasted for the first 10 minutes of each filter run.

23. Pathogens are usually removed by
(A) chemical precipitation
(B) sedimentation
(C) activated sludge process
(D) chlorination

24. Among the following disinfectant of waste water, the one that is most commonly used is
(A) chlorine dioxide
(B) chlorine
(C) ozone
(D) UV-radiation

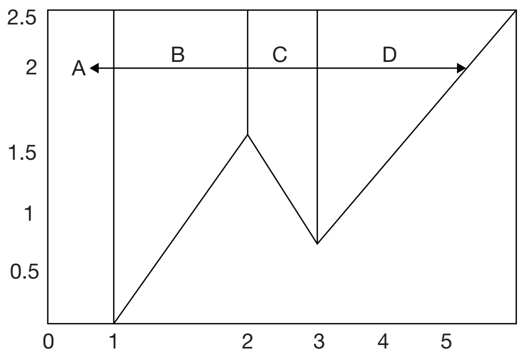
25. The disinfection efficiency of chlorine in water treatment
(A) is not dependent on pH value.
(B) is increase by increased pH value.
(C) remains constant at all pH values.
(D) is reduced by increased pH value.

26. In disinfection, which of the following forms of chlorine is most effective in killing the pathogenic bacteria?
(A) Cl
(B) OCl
(C) NH_2Cl
(D) HOCl

27. Chlorine gas used for disinfection combines with water to form hypochlorous acid (HOCl). The HOCI ionizes to hypochlorite OCl^- in a reversible reaction:

$HOCl \Leftrightarrow H^+ + OCl^-$ ($K = 2.7 \times 10^{-8}$ at 20°C), the equilibrium of which is governed by pH. The sum of HOCI and OCI is known as free chlorine residual and HOCI is the more effective disinfectant. The 90% fraction of HOCl in the free chlorine residual is available at a pH value
(A) 4.8
(B) 6.6
(C) 7.5
(D) 9.4

28. The following is a chlorination curve for a water sample:



(a) Explain what chlorine does in regions A, B, C and D?

(b) If your are to design a chlorination facility for this water, what minimum chlorine dose will you choose?

29. The absorbent most commonly used in water and waste treatment is

(A) sand of grain size from 0.1 to 2 mm.
(B) activated carbon granules of size 0.1 to 2 mm.
(C) ordinary wood pieces of fine size.
(D) coal-tar.

30. Aeration of water is done to remove

(A) suspended impurities
(B) colour
(C) dissolved salts
(D) dissolved gases

31. Zero hardness of water is achieved by

(A) lime soda process.
(B) excess lime treatment.
(C) ion exchange treatment.
(D) excess alum and lime treatment.

32. Match the following:

	List I (Type of water impurity)		List II (Method of treatment)
P.	Hardness	**1.**	Reverse osmosis
Q.	Brackish water from sea	**2.**	Chlorination
R.	Residual MPN from filters	**3.**	Zeollite treatment
S.	Turbidity	**4.**	Coagulation and flocculation
		5.	Coagulation, flocculation, and filtration

Codes:

	P	Q	R	S		P	Q	R	S
(A)	1	2	3	5	(B)	3	2	2	4
(C)	2	1	3	5	(D)	3	1	2	5

33. Match the following

	List I		List II
P.	Release valve	**1.**	Reduce high inlet pressure to lower outlet pressure
Q.	Check valve	**2.**	Limit the flow of water to single direction
R.	Gate valve	**3.**	Remove air from the pipeline
S.	Pilot valve	**4.**	Stopping the flow of water in the pipeline

Codes:

	P	Q	R	S		P	Q	R	S
(A)	3	2	4	1	(B)	4	2	1	3
(C)	3	4	2	1	(D)	1	2	4	3

34. If the Cl demand of water is 0.5 mg/lit to have a residual Cl of 0.1 mg/lit. What dose of bleaching powder is added to the water if bleaching powder contains 32% of available chlorine?

(A) 1.875 mg/lit (B) 1.25 mg/lit
(C) 1.562 mg/lit (D) 2.188 mg/lit

35. If the methyl orange alkalinity of water equals or exceeds total hardness, all of the hardness is

(A) non-carbonate hardness.
(B) carbonate hardness.
(C) pseudo hardness.
(D) negative non-carbonate hardness.

36. Which of the following are removed by rapid sand filter from water?

I. Dissolved solids
II. Suspended solids
III. Bacteria
IV. Helminths

(A) I and II (B) II and III
(C) I and III (D) II, III and IV

37. The yield of a well depends upon

(A) permeability.
(B) area of aquifer opening into the wells.
(C) actual flow velocity.
(D) All of these

Direction for questions 38 and 39:

In a slow sand filter, water is supplied at the rate of 24 million litres per day and rate of filtration is 5 $m^3/h/m^2$. If backwashing is done for 15 minutes at the rate of 5 times of rate of filtration for every 24 hours (Let L: B = 2:1), then:

38. Find the volume of water filtered between backwashing in m^3.

(A) 23,750 m^3 (B) 24,000 m^3
(C) 24,860 m^3 (D) 25,390 m^3

39. Find the volume of water used in backwashing in m^3.

(A) 250 m^3 (B) 500 m^3
(C) 750 m^3 (D) 1250 m^3

40. Calculate the requirement of soda ash or softening 2 MLD of water formed to have the following chemical composition:

CO_2 = 39.6 mg/lit

Ca^{2+} = 44 mg/lit

Mg^{2+} = 18 mg/lit

HCO_3 = 122 mg/lit

(A) 168.4 kg/day (B) 180.2 kg/day
(C) 230.1 kg/day (D) 242.8 kg/day

41. Which among the following are dechlorinating agents?
I. Sulphur dioxide gas
II. Ammonia
III. Sodium sulphate
IV. Sodium sulphite
(A) I and II (B) II, III and IV
(C) I, II and IV (D) All of these

42. The following data are given for a channel type grit chamber of length 8 m:
I. Flow through velocity = 0.4 m/s
II. Depth of waste water at peak flow in the channel = 1 m
III. Specific Gravity of inorganic particles = 2.6
IV. $g = 9.8$ m/s^2, $\mu = 1.002 \times 10^{-3}$ N–s/m^2 at 20°C, ρ_w = 1000 kg/m^3

Assuming that the stokes law is valid, the largest diameter particle that would be removed with 100%. efficiency is.
(A) 0.08 mm (B) 0.12 mm
(C) 0.18 mm (D) 0.24 mm

43. A sedimentation tank is treating 5 million litres of sewage per day containing 300 ppm of suspended solids. The tank removes 60% of suspended solids. Calculate the quantity of sludge produced per day is bulk and weight respectively, if moisture content of sludge is 98% (assume specific gravity of wet sludge = 1.02).
(A) 78.43 m^3 and 80 tonnes
(B) 66.67 m^3 and 68 tonnes
(C) 50.98 m^3 and 52 tonnes
(D) 44.12 m^3 and 45 tonnes

44. Match List I with List II

	List I (Treatment Units)		List II (Types of Processes)
a.	Trickling filter	1.	Symbiotic
b.	Activated sludge	2.	Extended aeration
c.	Oxidation ditch	3.	Suspended growth
d.	Oxidation pond	4.	Attached growth

Codes:

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

Direction for questions 45 and 46:

The sewage is flowing at 6 MLD from a primary clarifier to a standard rate tricking filter. The 5 day BOD of the influent is 150 mg/lit. The adopted organic loading is to be 160 gm/m^3/day and surface loading 2000 l/m^2/day.

45. Determine the volume of the trickling filter.
(A) 4532 m^3
(B) 5138 m^3
(C) 5625 m^3
(D) 6100 m^3

46. Calculate the efficiency of the filter.
(A) 85%
(B) 74%
(C) 61%
(D) 91%

47. The chemical used for coagulation is ______.
(A) ammonium chloride
(B) aluminium chloride
(C) aluminium sulphate
(D) copper sulphate

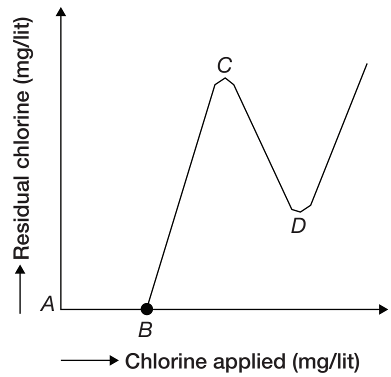
48. Identify the correct sequence of slow sand filter (SSF), rapid sand filter (RSF) and mixed media filter (MMF) in decreasing order of their filtration rates?
(A) MMF > RSF > SSF
(B) RSF > MMF > SSF
(C) RSF > SSF > MMF
(D) MMF > SSF > RSF

49. The process in which the chlorination is done beyond the breakpoint is known as ______.
(A) pre chlorination
(B) post chlorination
(C) super chlorination
(D) break point chlorination

50. Available chlorine in bleaching powder solution is 0.3 mg/ml. To obtain a chlorine dose of 0.1 mg/lit in a 1200 ml water sample, the amount of bleaching powder solution (in ml) to be added is ______.
(A) 0.1 ml
(B) 0.3 ml
(C) 0.4 ml
(D) 0.6 ml

51. The diameter and depth of a circular clarifier for the given conditions is ______.
Flow rate = 10 MLD
Surface loading rate = 25 m^3/day/m^2
Detention time = 2 hours
(A) Dia = 22.6 m, depth = 2.1 m
(B) Dia = 19.4 m, depth = 2.5 m
(C) Dia = 29.7 m, depth = 1.8 m
(D) Dia = 24.3 m, depth = 2.8 m

52. If only ammonia was present in water, the only change in the figure given 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 point *D*
(D) be passing through the origin

53. Match the following:

	List I		List II
a.	Hardness	**1.**	Winkler 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

54. For a water treatment plant having a flow rate of 420 m^3/h, what is the required plan area of type I settling tank to remove 92% of the particles having a settling velocity of 0.12 cm/s?
(A) 90 m^2 (B) 120 m^2
(C) 140 m^2 (D) 180 m^2

55. A chlorine residual of 0.15 mg/lit is required to treat 10 MLD of water, if chlorine demand of water is 0.5 mg/lit. Find the monthly requirement of bleaching power if it contains 30% of available chlorine?
(A) 600 kg (B) 650 kg
(C) 700 kg (D) 750 kg

56. Ozone is used as disinfectant in water purification process. The reaction constant (*K*) is 3×10^{-2} per second. The contact time required to kill 98% of bacteria will be ______.
(A) 2.17 min (B) 6.82 min
(C) 3.42 min (D) 1.29 min

57. Match the List I wish List II:

	List I		List II
P.	Butterfly valve	**1.**	Safeguards pipe against bursting
Q.	Check valve	**2.**	Cleans the pipe
R.	Scour valve	**3.**	Controls flow rate
S.	Pressure – relief valve	**4.**	Allow water in only one direction

(A) P – 2, Q – 3, R – 4, S – 1
(B) P – 4, Q – 3, R – 2, S – 1
(C) P – 3, Q – 2, R – 3, S – 1
(D) P – 3, Q – 4, R – 2, S – 1

58. The amount of CO_2 generated (in kg) while completely oxidizing one kg of CH_4 to the end product is ______.
(A) 1.75 kg (B) 2.25 kg
(C) 2.75 kg (D) 3.25 kg

59. A water treatment plant, having discharge of 1 m^3/s, has 14 filters to treat the water. Each filter has an area of 50 m^2, but due to backwashing activity 3 filters are non-operational. The hydraulic loading rate (in m^3/day. m^2) would be ______.
(A) 157 (B) 147
(C) 137 (D) 127

Previous Years' Questions

Direction for questions 1 and 2:

A plain sedimentation tank with a length of 20 m, width of 10 m, and a depth of 3 m is used in a water treatment plant to treat 4 million litres of water per day (4 MLD). The average temperature of water is 20°C. The dynamic viscocity of water is 1.002×10^{-3} N-s/m^2 at 20°C. Density of water is 998.2 kg/m^3. Average specific gravity of particles is 2.65. **[GATE, 2007]**

1. What is the surface overflow rate in the sedimentation tank?
(A) 20 m^3/ m^2/day
(B) 40 m^3/ m^2/day
(C) 67 m^3/ m^2/day
(D) 133 m^3/ m^2/day

2. What is the minimum diameter of the particle which can be removed with 100% efficiency in the above sedimentation tank?
(A) 11.8×10^{-3} mm
(B) 16.0×10^{-3} mm
(C) 50×10^{-3} mm
(D) 160×10^{-3} mm

3. A water treatment plant is required to process 28800 m^3/d of raw water (density = 1000 kg/m^3, kinematic viscosity = $10^{-6} m^2/s$). The rapid mixing tank imparts a velocity gradient of 900/s to blend 35 mg/lit of alum with the flow for a detention time of 2 minutes. The power input (*W*) required for rapid mixing is **[GATE, 2008]**

(A) 32.4 (B) 36
(C) 324 (D) 32400

4. Match List I (Terminology) with List II (Definition/ Brief description) for waste water treatment systems **[GATE, 2008]**

	List I		List II
P.	Primary treatment	1.	Contaminant removal by physical forces
Q.	Secondary treatment	2.	Involving biological and/or chemical reaction
R.	Unit operation	3.	Conversion of soluble organic matter to business
S.	Unit process	4.	Removal of solid materials from incoming waste water

Codes:
(A) P – 4, Q – 3, R – 1, S – 2
(B) P – 4, Q – 3, R – 2, S – 1
(C) P – 3, Q – 4, R – 2, S – 1
(D) P – 1, Q – 2, R – 3, S – 4

5. A horizontal flow primary clarifier treats waste water in which 10%, 60% and 30% of particles have settling velocities of 0.1 mm/s, 0.2 mm/s, and 1.0 mm/s respectively. What would be the total percentage of particles removed if clarifier operates at a surface over flow rate (SOR) of 43.2 m^3/dm^2? **[GATE, 2009]**
(A) 43% (B) 56%
(C) 86% (D) 100%

6. Anaerobically treated effluent has MPN of total coliform as 10^6/100 ml. After chlorination, the MPN value declines to 10^2/100 ml. The percentage removal (%R) and log removal (log R) of total coliform MPN is **[GATE, 2011]**
(A) % R = 99.90; log R = 4
(B) % R = 99.90; log R = 2
(C) % R = 99.99; log R = 4
(D) % R = 99.90; log R = 2

7. Chlorine gas (8 mg/lit as Cl_2) was added to a drinking water sample. If the free chlorine residual and pH was measured to be 2 mg/lit (as Cl_2) and 7.5, respectively, what is the concentration of residual OCl^- ions water? Assume that the chlorine gas added to the water is completely converted to HOCI and OCl^-. Atomic weight of CI: 35.5, $OCI^- + H^+ \rightleftarrows HOCI$, $K = 10^{7.5}$ **[GATE, 2011]**
(A) 1.408×10^{-5} moles/lit
(B) 2.817×10^{-5} moles/lit
(C) 5.634×10^{-5} moles/lit
(D) 1.127×10^{-5} moles/lit

8. Consider the following unit processes commonly used in water treatment; rapid mixing (RM), flocculation (F), primary sedimentation (PS), secondary sedimentation (SS), chlorination (c) and rapid sand filtration (RSF). The order of these unit processes (first to last) in conventional water treatment plants is **[GATE, 2011]**
(A) PS → RSF → F → RM → SS → C
(B) PS → F → RM → RSF → SS → C
(C) PS → F → SS → RSF → RM → C
(D) PS → RM → F → SS → RSF → C

9. A settling tank in a water treatment plant is designed for a surface overflow rate of $30 \frac{m^3}{day \cdot m^2}$. Assume specific gravity of sediment particles = 2.65, density of water (ρ) = 1000 kg/m^3, dynamic viscosity of water (μ) = 0.001 N · s/m^2, and Stokes' law is valid. The approximate minimum size of particles that would be completely removed is: **[GATE, 2013]**
(A) 0.01 mm (B) 0.02 mm
(C) 0.03 mm (D) 0.04 mm

10. A suspension of sand like particles in water with particles of diameter 0.10 mm and below is flowing into settling tank at 0.10 m^3/s. Assuming g = 9.81 m/s^2, specific gravity of particles –2.65, and kinematic viscosity of water = 1.0105×10^{-2} cm^2/s. The minimum surface area (in m^2) required for this settling tank to remove particles of size 0.06 mm and above with 100% efficiency is ______. **[GATE, 2014]**

11. A surface water treatment plant operates round the clock with a flow rate of 35 m^3/min. The water temperature is 15°C and jar testing indicated an alum dosage of 25 mg/lit with flocculation at a Gt value of 4×10^4 producing optimal results. The alum quantity required for 30 days (in kg) of operation of the plant is ______. **[GATE, 2014]**

12. 16 MLD of water is flowing through a 2.5 km long pipe of diameter 45 cm. The chlorine at the rate of 32 kg/d is applied at the entry of this pipe so that disinfected water is obtained at the exit. There is a proposal to increase the flow through this pipe to 22 MLD from 16 MLD. Assume the dilution coefficient, n = 1. The minimum amount of chlorine (in kg per day) to be applied to achieve the same degree of disinfection for the enhanced flow is **[GATE, 2014]**
(A) 60.50 (B) 44.00
(C) 38.00 (D) 23.27

13. An effluent at a flow rate of 2670 m^3/d from a sewage treatment plant is to be disinfected. The laboratory data of disinfection studies with a chlorine dosage of 15 mg/lit yield the model $N_t = N_0 e^{-0.145t}$, where N_t = Number of micro organisms surviving at time t (in min) and N_0 = number of micro-organisms present initially (at $t = 0$). The volume of disinfection unit (in m^3) required to achieve a 98% kill of micro-organisms is ______. **[GATE, 2014]**

14. Consider a primary sedimentation tank (PST) in a water treatment plant with Surface Overflow Rate (SOR) of 40 $m^3/m^2/d$. The diameter of the spherical particle which will have 90 per cent theoretical removal efficiency in this tank is ______ μm. Assume that settling velocity of the particles in water is described by Stoke's Law. **[GATE, 2015]**

Given: Density of water = 1000 kg/m^3; Density of particle = 2650 kg/m^3; $g = 9.81$ m/s^2; Kinematic viscosity of water (v) = 1.10×10^{-6} m^2/s.

15. A water treatment plant of capacity, 1 m^3/s has filter boxes of dimensions 6 m × 10 m. Loading rate to the filters is 120 $m^3/day/m^2$. When two of the filters are out of service for back washing, the loading rate (in $m^3/day/m^2$) is ______. **[GATE, 2015]**

16. Ultimate BOD of a river water sample is 20 mg/lit. BOD rate constant (natural log) is 0.15 day^{-1}. The respective values of BOD (in %) exerted and remaining after 7 days are **[GATE, 2015]**

(A) 45 and 55 (B) 55 and 45
(C) 65 and 35 (D) 75 and 25

17. It was decided to construct a fabric filter, using bags of 0.45 m diameter and 7.5 m long, for removing industrial stack gas containing particulates. The expected rate of airflow into the filter is 10 m^3/s. If the filtering velocity is 2.0 m/minute, the minimum number of bags (rounded to nearest higher integer) required for continuous cleaning operation is **[GATE, 2016]**

(A) 27 (B) 29
(C) 31 (D) 32

18. A water supply board is responsible for treating 1500 m^3/day of water. A settling column analysis indicates that an overflow rate of 20 m/day will produce satisfactory removal for a depth of 3.1 m. It is decided to have two circular settling tanks in parallel. The required diameter (expressed in m) of the settling tanks is ______. **[GATE, 2016]**

19. The hardness of a ground water sample was found to be 420 mg/lit as $CaCO_3$. A softener containing ion exchange resins was installed to reduce the total hardness to 75 mg/lit as $CaCO_3$ before supplying to 4 households. Each household gets treated water at a rate of 540 lit/day. If the efficiency of the softener is 100%, the bypass flow rate (expressed in lit/day) is ______. **[GATE, 2016]**

Answer Keys

Exercises

1. C	**2.** B	**3.** C	**4.** C	**5.** B	**6.** C	**7.** D	**8.** A	**9.** C	**10.** C
11. D	**12.** A	**13.** D	**14.** D	**15.** A	**16.** C	**17.** B	**18.** A	**19.** C	**20.** C
21. 0.27 m	**22.** 6,13620 m^3/day		**23.** D	**24.** B	**25.** D	**26.** D	**27.** B	**28.** 3.4 mg/lit	
29. B	**30.** D	**31.** C	**32.** D	**33.** D	**34.** A	**35.** B	**36.** D	**37.** A	**38.** A
39. D	**40.** B	**41.** C	**42.** D	**43.** D	**44.** D	**45.** C	**46.** A	**47.** C	**48.** A
49. C	**50.** C	**51.** A	**52.** D	**53.** A	**54.** A	**55.** B	**56.** A	**57.** D	**58.** C
59. A									

Previous Years' Questions

1. A	**2.** B	**3.** D	**4.** A	**5.** B	**6.** C	**7.** A	**8.** D	**9.** B
10. 31.214		**11.** 37800	**12.** A	**13.** 50.02	**14.** 0.075	**15.** 144	**16.** C	**17.** B
18. 6.91	**19.** 385.7							