

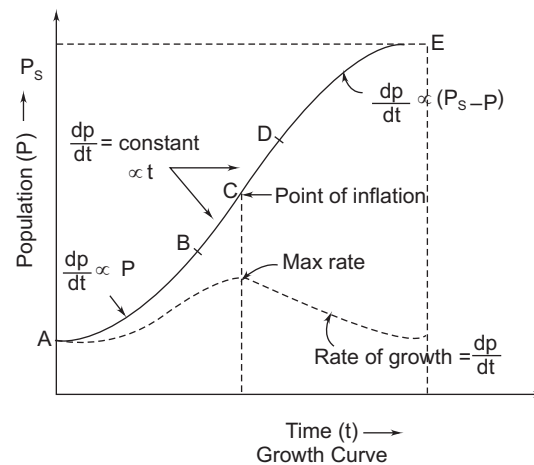
# Water Demand, Its Source and Conveyance

# 1

**Design Period:** The number of years for which a provision is made in designing the capacities of various components of the water supply scheme.

Units	Design Period
Water treatment units	15 years
Service Reservoirs (overhead or ground level)	15 years
Pipe Connections to the several treatment units	30 years
Distribution system	30 years

## Population Forecasting Methods:



where  $P_s$  = Saturation Population

## 9.4 CIVIL ENGINEERING

(i) Arithmetic Increase Method:

$$P_n = P_o + n\bar{x}$$

$P_n$  = Population after n decades from present.

$P_o$  = Present population

$n$  = No. of decades

$\bar{x}$  = Arithmetic mean of population Increase in known decades.

(ii) Geometric Increase Method:

$$P_n = P_c \left( 1 + \frac{r}{100} \right)^n$$

$P_o$  = Population at the end of last known census

$r$  = Assumed growth rate (%)

$$r = \frac{r_1 + r_2 + \dots + r_n}{n} \text{ or } r = (r_1 \times r_2 \times \dots \times r_n)^{1/n}$$

(iii) Incremental Increase method (or method of varying Increment)

$$P_n = P_o + n\bar{x} + \frac{n(n+1)}{2}\bar{y}$$

$\bar{x}$  = Average Increase of population of known decades

$\bar{y}$  = Average of incremental increases of the known decades

(iv) The logistic curve method

$$P = \frac{P_s}{1 + m \log_e^{-1}(nt)}$$

$P_s$  = Saherahen population

$m$  = constant

(v) *Decreasing rate of growth*: Applicable only when the rate of growth shows downward trend. In this method, the average decrease in percentage is worked out, and is then subtracted from the latest percentage increase for each successive decade.

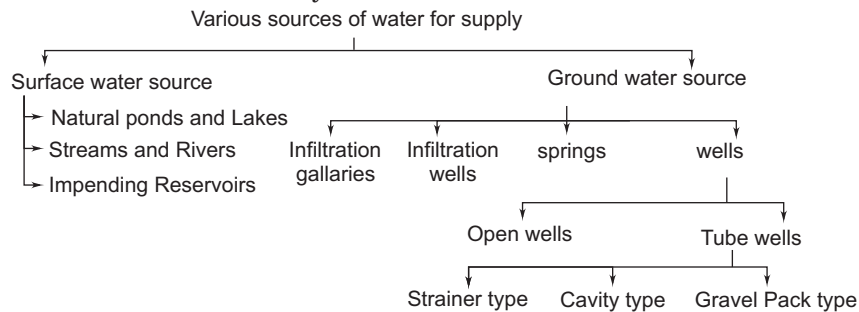
(vi) *Comparative graphical method*: Cities of similar characteristics and conditions are selected which have grown in similar fashion in the past as that of city under consideration and their graph is plotted and then mean graph is plotted.



**9.6 CIVIL ENGINEERING**

**Design capacity of various components of water supply scheme.**

- (i) Source of supply, pipe mains, pumps are to be designed for maximum daily.
- (ii) Distribution system (sensitive reservoir to water taps) for maximum hourly.



**Joint in Water Supply Piping:**

- (i) Spigot and socket joint: Also known as Bell-spigot joint. Where spigot end is inserted into the bell end.
- (ii) Collar joint: Recommended for joining R.C.C pipes and asbestos cement pipes.
- (iii) Expansion joint: Provided at suitable intervals to take into account the change in pipe length due to temperature variations.
- (iv) Flanged joint: Recommended for temporary work where the pipe line is to be dismantled after work or to be shifted.
- (v) Flexible joint: Where Settlement of pipe line can occur.
- (vi) Threaded joint: Recommended for connecting the GI pipes.
- (vii) Simplex joint: For joining asbestos cement pipes.

**Pipe Appurtenances:**

- (i) *Sluice Valve*: Placed at summits, and are provided to regulate the flow of water through the pipe and are essential to divide main line into several sections.
- (ii) *Air Valve*: Provided at summits to release air pressure.
- (iii) *Check valve or Reflux valve or Non-returning valve* : Provided in the pipe line which draws water from the pumps.
- (iv) *Relief valve or cut-off valve or Safety valve*: Helps in regulating the water hammer pressure.

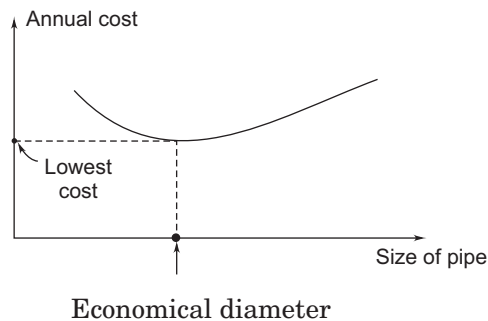
- (v) *Scour Valve or Blow-off valve or Drain valve*: Provided at dead end of the pipe line.
- (vi) *Foot Valve*: Prevent entry of debris into the pumping system and prevent back flow.
- (vii) *Butterfly Valve*: Regulate and Stop the flow specially in large size conduits.
- (viii) *Globe Valve*: Direction of Flow changes by 90° twice.
- (ix) *Ball valvs or Ball Float Valves*: Used to maintain constant level in a service reservoir or elevated tank.
- (x) *Bib Cocks*: Used in small sized taps.
- (xi) *Fire hydrants*: Its an outlet provided in main water line for tapping water in case of fire.
- (xii) *Water Meter*: Device by which quantity of water flowing through a particular point is measured. It is of two types.
  - (a) *Displacement type or Positive displacement Meter*: For small flows
  - (b) *Velocity type or Interential meter*: For high flows.

**Economical diameter of the pumping main:**

$$D = (0.97 \text{ to } 1.22) \sqrt{Q}$$

$D$  = Economical diameter (in meters)

$Q$  = Discharge to be pumped (in m<sup>3</sup>/sec)



## Quality Parameters of Water

# 2

Water impurities are classified as physical, chemical and biological impurities.

### PHYSICAL WATER QUALITY PARAMETER

**1. Suspended Solids:** These are called as physical parameters where as dissolved solids are considered as chemical parameters.

Inorganic solids are non-biodegradable solids.

**Note:** Problem of SS comes only in surface water not in ground water.

Gravimetric SS are calculated by weighing them.

Total solids i.e., all solids (suspended or dissolved). are calculated by evaporating the sample and measuring the residue. Heating temperature is 104°C.

Dissolved solids (*DS*) = Total solids (*TS*) – Suspended solids (*SS*)

Organic fraction  $\xrightarrow{600^{\circ}C}$  CO<sub>2</sub> + Water + Other Gases

Remaining solids are inorganic solids or fixed solids.

**2. Turbidity:** It is not direct quantitative measure of suspended solids.

Measurement of turbidity is done using the following:

- Turbidity rod
- Jackson's turbidimeter
  - Baylis turbidimeter
  - Nephelometer
  - Turbidity which one milligram of finely divided silica produces in one litre of distilled water is taken as one unit.

**Note:** GOI manual gives turbidity in *NTU* i.e., Nephelometer turbidity unit. Acceptable limit is 1 and cause for rejection is 10.

Turbid raw water of natural source has turbidity greater than 25 ppm.

- Baylis and Nephelometer turbidimeters are based on colour matching techniques.
- Baylis turbidity meter light intensity is measured in the direction of the incident light only where as in nephelometer light intensity is measured at right angles to the incident ray.

NTU is based on **Scattering principle**.

If Formazine, a chemical, is used as base in place of  $\text{SiO}_2$ . The turbidity unit is also sometimes called. FTU

### 3. Colour

- After suspended matter causing colour is removed by centrifugation, the colour obtained is called true colour.
- Water containing oxidised iron and manganese impart characteristic reddish or black colour.
- Organic compounds causing colour may exert chlorine demand.
- Measurement of colour is done by colour matching technique (tintometer).
- 1TCU is equal to colour produced by 1 mg per litre of platinum in the form of chloroplatinate ion.

Acceptable limit is **5 TCU** and cause for rejection is **25 TCU**.

### 3. Taste And Odour

- Taste and odour are caused by dissolved gases
- Algae secretes oily substances that may result in bad taste and odour.
- Odour is measured by an instrument known as **osmoscope**.
- Intensity of taste and odour is measured by **Threshold odour number(TON)**.
- TON allowed is between 1 – 3.
- $\text{TON} = \frac{A + B}{A}$  where A 4 mL is the volume of odorous water in mL B is the volume of odour free water required to produce a mixture in which odour is hardly detectable.

## 9.10 CIVIL ENGINEERING

### 5. Temperature

An increase in 10°C, doubles the biological activity. The temperature should be between 10-25°C and greater than 25°C is objectional.

### CHEMICAL PROPERTIES OF WATER

**1. Total Dissolved Solids (TDS):** TDS is made by determining the electrical conductivity of water.

⇒ (Electrical conductivity in  $\mu\text{MHo/cm}$  at 25°C)  $\times 0.65$  = dissolved solid content in mg/l.

If we add organic matter.

• **Source of Total dissolved solids:**

Major source : Na, Ca, Mg,  $\text{HCO}_3^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{Cl}^-$

Minore source : Fe, K,  $\text{CO}_3^{2-}$ ,  $\text{NO}_3^-$ , Fluoride Boron, Silica

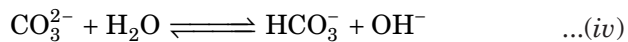
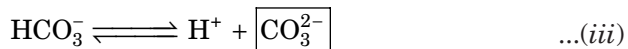
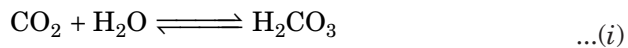
Acceptable limit of **TDS (mg/l) is 500** and cause for rejection is 2000.

### 2. Alkalinity

Quantity of ions in water that will react to neutralize hydrogen ions ( $\text{H}^+$ ).

Common constituents of alkalinity are  $\text{CO}_3^{2-}$ ,  $\text{HCO}_3^-$ ,  $\text{OH}^-$ .

$\text{CO}_3^{2-}$  is carbonate alkalinity,  $\text{HCO}_3^-$  is bicarbonate alkalinity  $\text{OH}^-$  is *caustic alkalinity*.



If algae is present in water, the water becomes alkaline ( $pH = 9$  to  $10$ ).



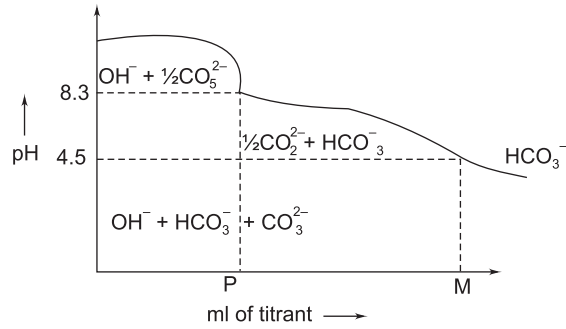
(ppt cause

incaustation of pipes)

- Alkalinity measurements are done by titrating the water with an acid. It is expressed in terms of mg/l as  $\text{CaCO}_3$ .
- If 0.02 N  $\text{H}_2\text{SO}_4$  is used in titration then 1 ml of acid will neutralize 1 mg of alkalinity as  $\text{CaCO}_3$ .



**Relative Quantity of Alkalinity Species are pH Dependent.**



(Titration curve)

- If  $P = M$  all alkalinity is caustic alkalinity.
- If  $P = \frac{M}{2}$ , all alkalinity is carbonate alkalinity
- If  $P < \frac{M}{2}$ , predominant species are carbonate and bicarbonate.
- If  $P > \frac{M}{2}$ , predominant species are carbonate and Hydroxide.
- If  $P = 0$  total alkalinity is bicarbonate alkalinity.

**3. pH**

$pH = -\log_{10} [H^+]$   $[H^+]$  is in moles/litre.

pH is measured by potentiometer

7 – 8.5 is acceptable limit

Methyl orange is an acidic indicator.

Phenolphthalein is a basic indicator.

**Note:** Acidic water causes corrosion and alkaline water causes incrustation of pipe.

**4. Hardness**

Concentration of multivalent metallic cations in solution.

- Hardness can be divided in two parts i.e., carbonate hardness and non-carbonate hardness.
- $HCO_3^-$  and  $CO_3^{2-}$  of calcium and magnesium cause carbonate hardness. It is also called temporary hardness.
- Sulphate, chloride and nitrate of calcium and magnesium gives permanent hardness. It is also called non-carbonate hardness.

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Amount of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  in water is determined by titration with versanate solution (EDTA method). Using **Eriochrome Black T** (EBT) as a in indicator. EBT forms red colour and titration changes the colour to blue .

If  $[\text{Ca}^{2+}]$  and  $[\text{Mg}^{2+}]$  is known in mg/litre, total hardness would be equal to

$$\text{Total Hardness} = \frac{[\text{Mg}^{2+}] \text{ mg/l}}{\text{eq. wt of Mg}} \times \text{eq. wt. of CaCO}_3 + \frac{[\text{Ca}^{2+}] \text{ mg/l}}{\text{eq. wt of Ca}} \times \text{eq. wt. CaCO}_3$$

$$\therefore \text{Total Hardness} = [\text{Ca}^{2+}] \times \frac{50}{20} + [\text{Mg}^{2+}] \times \frac{50}{12}$$

### Alkalinity and Hardness

Acceptable limit of total hardness = 200 mg/l and

Cause for rejection = 600 mg/l

**Note :** Sodium cation imports pseudo-hardness to water.

#### 5. Chloride Content

Estimated by Mohr's method in which raw water is titrated with standard  $\text{AgNO}_3$  Solution using  $\text{K}_2\text{CrO}_4$  (Potassium chromate) as indicator.

#### 6. Nitrogen Content

- It occurs in the form of
  - (a) Free ammonia  $\rightarrow$  Indicates recent pollution
  - (b) Organic ammonia (Albuminoid)  $\rightarrow$  indicates quantity of nitrogen before decomposition has started
  - (c) Nitrite  $\rightarrow$  indicates partly decomposed condition
  - (d) Nitrate  $\rightarrow$  indicates old pollution (fully oxidised)

Free ammonia should not be more than 0.15 mg/l

Organic ammonia should not be more than 0.3mg/l

Free ammonia + organic ammonia = **Kjedahl Nitrogen Ammonia**

- Nitrite permissible limit is zero.
- Nitrate is not harmful as it is fully osidised. But too much of nitret affects infants. Beacuse it caused **blue baby disease or Mathemoglobineming** Nitrate concentration should bot be more than 45mg/l

### 7. Phosphorus

- It facilitates rapid growth of aquatic plants.
- It interferes with water treatment like chemical coagulation.

### 8. Fluorides

- Upto 1 mg/l, it helps to prevent dental cavities
- Excess value (greater than 1.5 to 2 ppm) results in decolouration of teeth called mottling of teeth. (Infants are affected not adults).

### 9. Metals

- Ca, K, Na, Fe, Mn, Zn are non-toxic metals.
- Arsenic, Barium, Cadmium, Chromium, Cyanide, Lead & Mercury are toxic metals.

### 10. Dissolved Gas

- $\text{CH}_4$  explosive tendency
- $\text{H}_2\text{S}$  bad taste and odour
- $\text{CO}_2$  biological activity, imparts bad taste and water becomes corrosive
- To determine oxygen deficiency of water 10% solution  $\text{KMnO}_4$  is exposed to  $27^\circ\text{C}$  for 4 hours and the amount of oxygen absorbed is calculated.

### Organics

Classified as biodegradable and non-biodegradable organics.

#### (a) Biodegradable

Reaction in the presence of oxygen is called **aerobic reaction** and reaction in the absence of oxygen is called **anaerobic reaction**

Amount of oxygen consumed during microbial utilization of organics is called BOD (biochemical Oxygen demand)

BOD after 5 days at  $20^\circ\text{C}$  is taken as standard BOD.

$\text{BOD}_5 = (\text{Initial Dissolved oxygen} - \text{Final dissolved oxygen}) \times \text{Dilution factor}$

$$\text{Where, Dilution factor} = \frac{\text{final volume}}{\text{Sample volume}}$$

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(b) **Non-biodegradable**

- These organics decompose so slowly that they are called non-biodegradable.
- Measurement of non-biodegradable organics is done by COD i.e., chemical oxygen demand and also TOC i.e., total organic carbon

$$\text{Non-biodegradable organic} = \text{COD} - \text{BOD}_u$$

$$\text{BOD}_u = \text{ultimate BOD}$$

- The usual routine tests are generally conducted to detect and count the presence of **coliforms** which in themselves are harmless aerobic lactose fermenters organisms.
- Coliform called bacteria coli (B-Coli, E-Coli)
- The tests for coliforms are :

- (a) Membrane filter technique
- (b) MPN test (Most Probable Number)
- (c) Coliform index

**Membrane Filter Technique**

- Membrane is put in contact with nutrients (M-endo medium) that permits the growth of only **Coliform colony**. After incubation for 20 hrs number of visible colonies are counted. No visible colonies should be detectable in any 100 ml sample.

**Most Probable Number (by Multiple Tube Fermentation Test)**

- The presence of **acid** or **Carbon Dioxide** in the test tube will indicate presence of coliform bacteria.

Thomas equation

MPN/100 ml

$$= \frac{\text{Number of positive tube} \times 100}{\sqrt{(\text{ml of sample in negative tube}) \times (\text{ml of sample in all tube})}}$$

**Coliform Index**

It is defined as the reciprocal of smallest quantity of a sample which will give positive B-coli test MPN and B-Coli index are now obsolete.

**Water Borne Diseases**

Bacteria – Typhoid fever, Cholera, Bacillary Dysentery etc.,

Virus – Jaundice, Poliomyelitis,

Protozoa – Amoebic dysentery

**Nuisance Bacteria :** Iron Bacteria, Sulphur Bacteria

## Treatment of Water

# 3

- Plain disinfection is sufficient for drinking purposes.
- For ground water containing excessive iron, dissolved carbon dioxide and odourous gases.

Aeration → Flocculation + Sedimentation → Rapid gravity → Disinfection → Supply

- If ground water contains only CO<sub>2</sub> and odourous gases, aeration and disinfection is sufficient.
- Surface water with turbidity less than 50 NTU  
Plain Sedimentation + Slow sand filter + Disinfection
- Highly polluted surface water laden with algae

Prechlorination + Aeration + Flocculation and Sedimentation + Rapid gravity filtration + Disinfection (postchlorination) + Supply.

### Screening

- Classified as **Coarse screen and fine screen.**
- In the form of bars spaced at 20 – 100 mm c/c.
- Kept inclined 3-6V : 1 H racking.

### Microstrainer

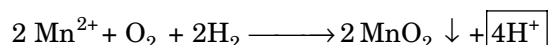
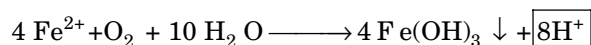
- Usefull for screening stored water, which do not contain a large amount of suspended matter.
- Ideal position of micro-strainer is earlier to rapid gravity or slow sand filters.

### Pre-chlorination

- Practice of injecting chlorine into the raw water.
- Fairly high dose of chlorine (2-5 mg/l) is used.
- Kills algae and bacteria, reduces colour and slime formation.
- In case of clear ground water with high ammonia content, it is effective.
- Most advantageous when *extremely polluted clear raw water*.

### AERATION

- Remove undesirable gases.
- It can also remove volatile liquid like phenols and humic acids.
- It removes iron and manganese.



- Increases the **acidity** of water.

### Process of Aeration

- Spray nozzle** → removes 90% CO<sub>2</sub> and 99% H<sub>2</sub>S.
- Cascade aerator** → Removes 20 – 45% CO<sub>2</sub> and 35% H<sub>2</sub>S.
- Diffused air aerator** → Water absorbs oxygen from compressed air and colour, odour and taste are removed.
- Trickling bed or Tray tower:** Fe, Mn
  - To help oxidation, KMnO<sub>4</sub> may be mixed.

### Algal Control

- Fairly alkaline water containing more concentration of nitrates and phosphates are prone to algal growth.
- Where organisms are more, a heavier dose of copper sulphate (2mg/l) or chlorine (3-5 mg/l) may be necessary.
- Rapid sand filters running without coagulants.

### Pre-settlement Basins

Where water reaching main settling basins has suspended solids concentration more than 1000 mg/l by dry weight.

### SEDIMENTATION

- To remove suspended solids.
- Classified into two categories:
  - Plain sedimentation,
  - Sedimentation with coagulation
- Sedimentation tanks are classified as **Quiescent type** (fill and draw type) and **continuous type**.

**9.18 CIVIL ENGINEERING**

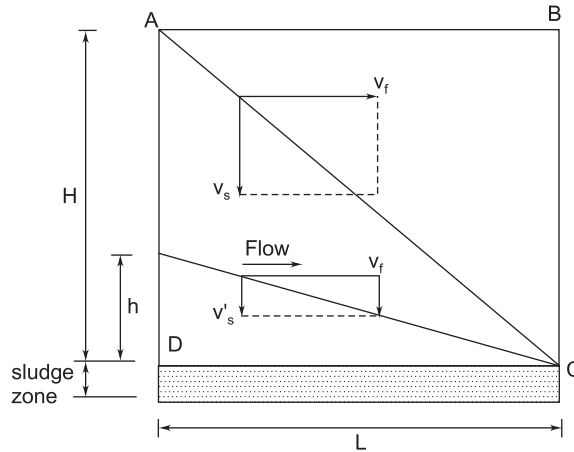
**Quiescent type tank**

- Detention time = 24 hr
- Period of cleaning = 8-12 hr. Minimum 3 numbers of tank, max. daily flow max daily flow = 1.8 × av. daily flow.
- Settling velocity

$$V_s = \frac{(\gamma_s - \gamma_w)d^2}{18\mu} \dots \text{applicable for } Re < 1 \text{ (stoke's law)}$$

$$d < 0.2 \text{ mm}$$

Discrete particle settling not for merging of particle i.e, not used in sedimentation with coagulation only for plain sedimentation.



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

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

$$t_D = \frac{\text{Volume of tank}}{\text{Discharge}}$$

$$V_s = \frac{Q}{BL} \text{ Over/flow rate.}$$

- *Surface overflow rate can be thought of as settling velocity of that particle which if introduced at the top most point at inlet will reach the bottom most point at outlet.*



- Percentage removal of these particle will be is given by

$$\frac{h}{H} = \frac{V_s'}{V_s}$$

Percentage removal of particle having settling velocity  $V_s' = \frac{V_s'}{V_s} \times 100$ .

### Short Circuiting in Sedimentation Tank

- The deviation of actual flow of tank from the flow pattern of ideal tank.

Displacement efficiency ( $\eta_d$ )

$$= \frac{\text{Flow through period actual time needed to cross}}{\text{Theoretical Detention Time}} \times 100$$

### Tube Settlers

- Settling efficiency of the sedimentation tank is primarily dependent upon the surface area of the tank and independent of its depth.
- Divide the tank height into compartments, to reduce the depth and to provide multiple surface area.

### Data for Sedimentation Tanks

- Overflow rate: 15,000 – 30,000 litre/m<sup>2</sup>/day for plain sedimentation, 30,000 – 40,000 litre/m<sup>2</sup>/day for sedimentation with coagulation.

- Detention time is 3-4 hours for plain sedimentation tank and 2-2.5 hrs for sedimentation with coagulation.

$Q \times \text{detention time} = \text{volume of tank}$

$(V_f) = 0.3 \text{ m/minute.}$

$V_f \times \text{detention time} = \text{length of tank}$

- Width 10 to 12 m.

- Length

4 times the width.

Maximum daily flow = 1.8 × average daily flow.

- Depth of tank 3 m.

**CIRCULAR SEDIMENTATION TANK**
**Volume of Circular tank**

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

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

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

$$\bullet \text{ Weir loading Rate} = \frac{Q}{\pi D}$$

**SEDIMENTATION WITH COAGULATION**

- A colloidal dispersion is defined as stable when the dispersion shows little or no tendency to aggregate.
- Aggregation of colloidal particles requires:
  - (a) particle destabilisation
  - (b) agglomeration
- “Zeta potential” is a measure of the stability of particle and indicates the potential, which would be required to penetrate the layer of ions surrounding the particle for destabilisation.
- The choice of the best coagulant for any particular water **Jar Test**.

**Mechanism of Coagulation**

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

(b) **Adsorption and Charge Neutralisation:** Nature rather than quantity of iron is of prime importance.

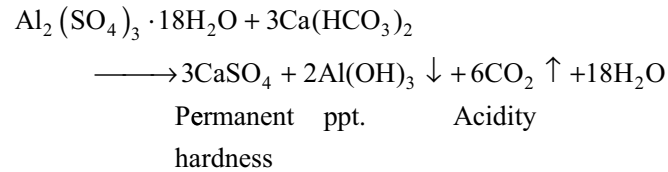
(c) **Sweep Coagulation:** The aluminium hydroxide ( $\text{Al}(\text{OH})_3$ ) formed when alum is added to water. Colloids become entrapped in the flocs as the flocs settle down.

(d) **Inter Particle Bridging:** Large molecules may be formed when Al or ferric sulphate dissociate in water (like  $\text{Al}_7 (\text{OH})_{17}^{4+}$ ).

### Common Coagulants added in Water

#### (a) Alum

- $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$ .

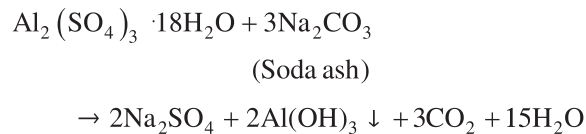
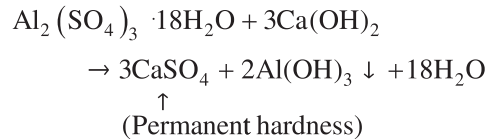


- Reaction introduces permanent hardness in water and water becomes corrosive.
- Normal dose is 10 – 30 mg/litre of water
- pH 6.5 to 8.5.

∴ 1 gm of alum gives = 0.234g = 0.24 gm of  $\text{Al}(\text{OH})_3$  ppt

#### Alkalinity-Coagulation Relationships

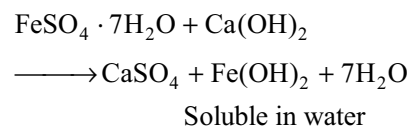
Alkalinity is sufficient in water, lime  $[\text{Ca}(\text{OH})_2]$  or soda ash ( $\text{Na}_2\text{CO}_3$ ) may be added in water.



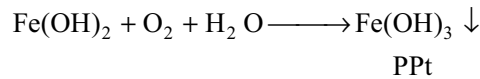
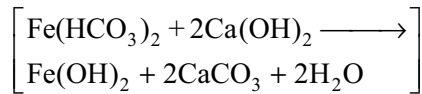
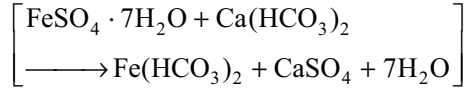
#### (b) Copperas

- $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$

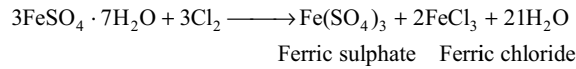
When lime is added first,



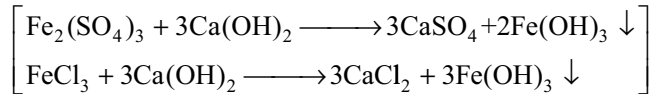
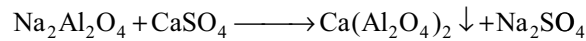
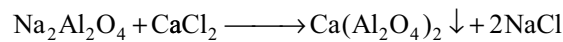
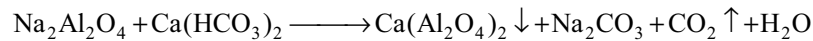
Copperas is added first,

**9.22 CIVIL ENGINEERING**


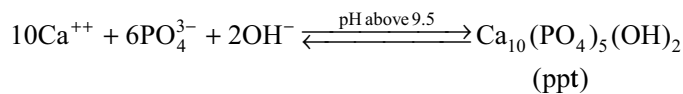
- pH : 8.5 and above
- Quantity 10 – 30 mg/litre

**(c) Chlorinated Copperas**


- Works in large pH range.
- Chlorinated copperas with lime


**(d) Sodium Aluminate [ $\text{Na}_2(\text{Al}_2\text{O}_4)$ ]**


- Reduces the temporary and permanent hardness.
- Costlier than alum.
- pH range is 6 – 8.5.

**(e) Lime** where phosphorus removal is desired.


**Coagulation Aids**

Finally divided clay, bentonites and activated carbon.

**1. High Turbidity Low, Alkalinity of Water**

Low doses of cagulants

**2. High Turbidity – High, Alkalinity of Water**

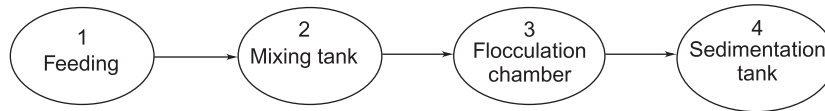
Higher coagulant dosage

**3. Low Turbidity – High, Alkalinity of Water**

High coagulant dosages

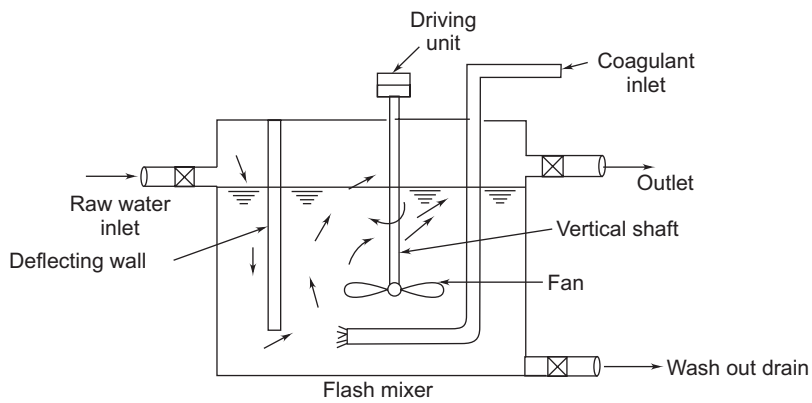
**4. Low Turbidity – Low Alkalinity Water**

Add both turbidity and alkalinity

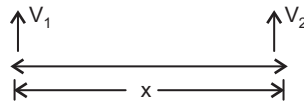


**MIXING**

**Mechanical Mixer**



- Temporal mean velocity gradient (G).



$$G = \frac{V_2 - V_1}{x} = f\left(\frac{P}{V}, \mu\right)$$

## 9.24 CIVIL ENGINEERING

- Unit of  $G$  is  $\text{sec}^{-1}$

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

where,  $P$  is power in watts

$\mu$  is dynamic viscosity

$V$  is volume of tank in  $\text{m}^3$

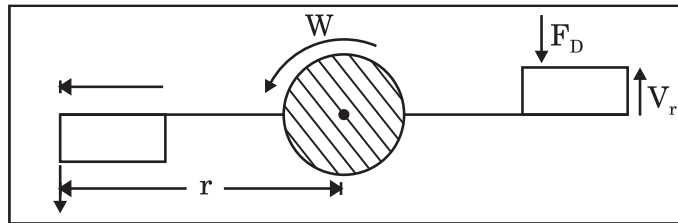
- Detention time 30 to 60 seconds.
- $G$  is kept 300 per second or more.

### FLOCCULATION

Slow mixing or agitation process in which destabilized colloidal particles are brought into intimate contact.

- $Gt_d$  = It is the measure of conjugation opportunity.
- $Gt_d$  adopted for alum is  $(2 - 6) \times 10^4$  for  $\text{FeCl}_3$  is  $(1 - 1.5) \times 10^5$ .
- Larger  $G$  and Smaller  $t_d$  will make Small and dense floc.
- Smaller  $G$  and larger  $t_d$  will make large and light floc.

### Calculation of $G$



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

$$V_r = V_p - V_w$$

$$F_D = \frac{C_D P_w A_p V_r^2}{2}$$

$$G = \sqrt{\frac{C_D P_w A_p V_r^3}{2\mu V}}$$

### Design Criteria

- Depth of tank 3 to 5 m.
- Detention time taken is 10 – 30 min.
- Peripheral velocity ( $V_p$ ) 0.2 – 0.6 meter per sec.
- $Gt_d$  adopted is 10,000 – 100,000.

### FILTRATION

- Effective in controlling guinea worm disease.
- Filters are classified as:
  - (a) Slow sand filter
  - (b) Rapid sand filter
  - (c) Pressure filter

### Theory of Filtration

#### (a) Mechanical Straining:

Particles are removed in upper layers.

**(b) Sedimentation:** Particles finer than voids are removed by sedimentation.

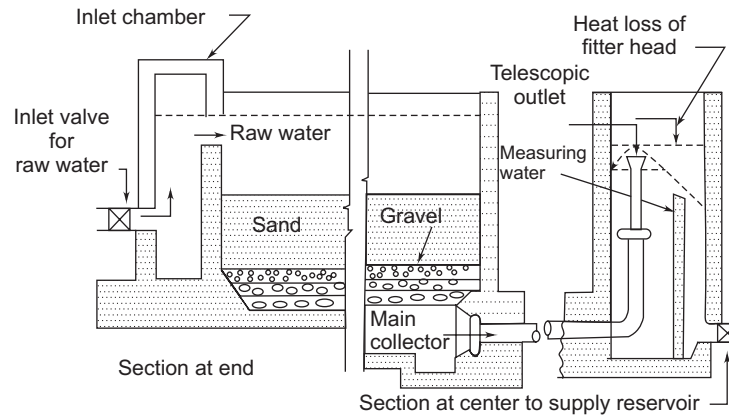
#### (c) Biological Metabolism: Three zones of purification.

- The surface coating is known as “schmutzdecke”.
- The ‘autotropic’ zone existing a few millimeters.
- The “heterotrophic” zone, which extends around 300 mm into the bed.

#### (d) Electrolytic Changes

• Sand grains in filter and impurities in water carry opposite charges. Thus because of their interaction, chemical characteristics of water changes and it becomes pure.

**SLOW SAND FILTER**



- Utilizes the effluent from plain sedimentation tank only.
- Depth of tank is 2.5 to 3.5m.
- Plan area required is 100 – 2000 m<sup>2</sup>.
- $D_{10}$  (of filter medium) = 0.2 – 0.3 mm.
- $\frac{D_{60}}{D_{10}} = 5$
- Depth of sand is 90 – 110 cm  $\approx$  1 m.
- Top 15 cm of sand layer would be finer.
- Top layer size — 3 — 6 mm
- Middle layer — 20 — 40 mm
- Bottom layer — 40 — 65 mm
- Design period of slow sand filter is 10 years.

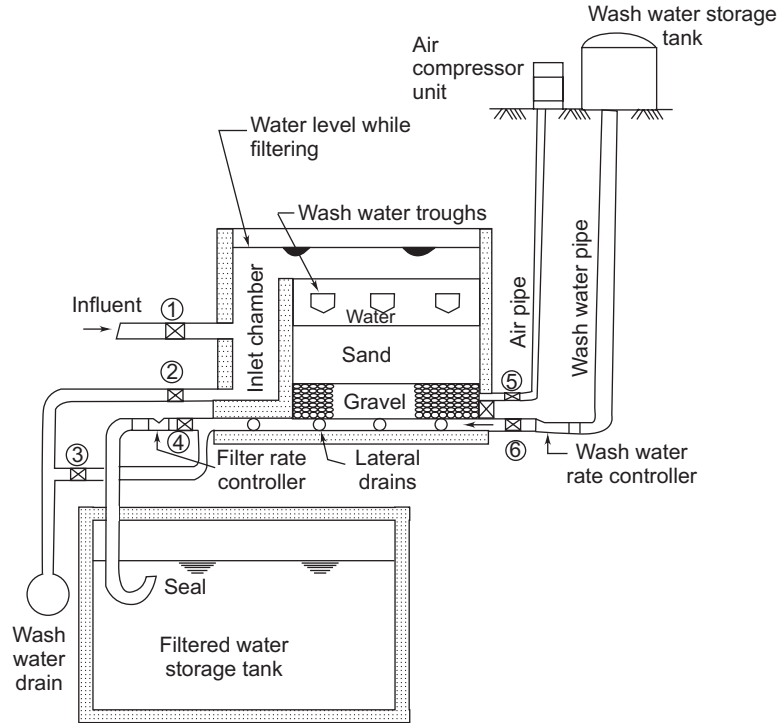
**Cleaning of Filter**

- Top layer of sand is scraped and 1.5 to 3 cm of sand is removed
- Frequency of cleaning is 1 – 3 months.
- Rate of filtration is 100–200 l/hr/m<sup>2</sup> of filter area.
- Bacteria removal is 97-98%.
- Filter cannot be used if turbidity is greater than 50 ppm.
- Used for smaller plants in villages.
- Designed for maximum daily demand.



### RAPID GRAVITY FILTER

- Particle more than and less than 1  $\mu$  m dia are efficiently removed.
- Removes suspended and colloidal matter.
- Remove microorganisms.



#### Back Washing

- Process takes 15 minutes
- Washing period is 24 – 48 hrs.
- Rate of washing is 15 to 90 cm rise per minutes
- Area of tank is 10 – 100 m<sup>2</sup>/unit
- Number of units required  

$$n = 1.22\sqrt{Q}$$
 , Q is plant capacity in MLD.
- Sand layer is 60 – 75 cm deep and D<sub>10</sub> of sand is 0.45 – 0.7 mm.
- Depth of water over sand layer = 1 – 2m.
- Length/width = 1.25 to 1.33.

**9.28** CIVIL ENGINEERING

- $\frac{D_{60}}{D_{10}} = 1.3$  to 1.7
- Max. loss of head = 2.5 to 3.0 meters.

Flow rate in rapid gravity filter 2-20 m/hr

∴ Head loss during back wash  $h$

$$h = \frac{L \times (1 - n)(\gamma_s - \gamma_w)}{\gamma_w}$$

For the expanded length of bed.

$$h = \frac{L_{ex}(1 - n_{ex})(\gamma_s - \gamma_w)}{\gamma_w}$$

Porosity in the expanded condition

$$n_{ex} = \left( \frac{V_B}{V_t} \right)^{0.22}$$

$V_B$  = Back wash velocity → 45 cm/min

$V_t$  = Terminal settling velocity of the particle

**Operational Troubles in Rapid Sand Filter**

- (a) Air binding
- (b) Mud balls formations
- (c) Cracking of filter

Rapid sand filter is highly efficient in colour removal when used with coagulation sedimentation. Efficiency w.r.t. bacteria removal is 80 – 90%.

**DUAL MEDIA FILTER AND MUTLI MEDIA FILTERS**

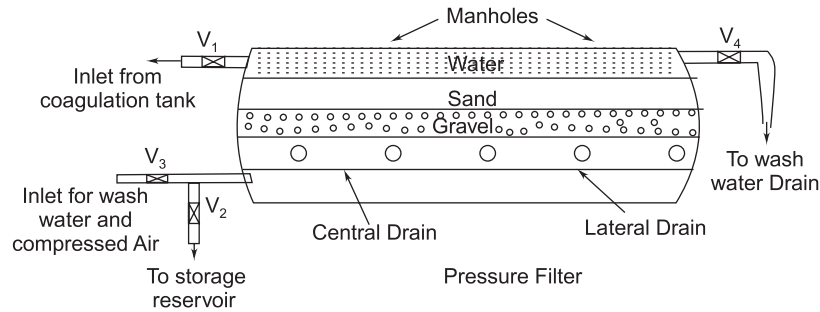
Larger anthracite grain (Sp. gr. 1.55) is provided is 30 – 60 cm depth of filter media and below this smaller sand grain (Sp. gr. 2.65) is provided.

• **Multi Media Filters (MMF<sub>s</sub>)**

Use three or more materials for filter layers.

Multi-media filters are improved dual-media filters, with increased filter run times and better water quality.

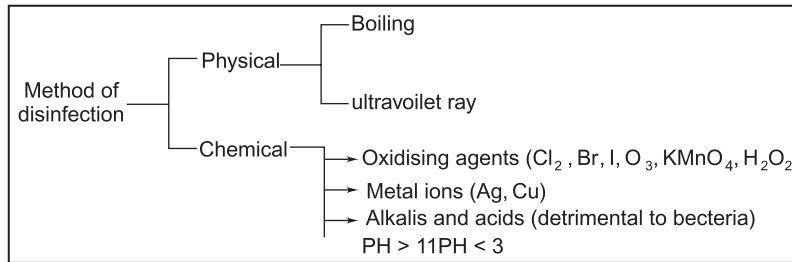
### PRESSURE FILTERS



- Diameter of the tank is 1.5 – 3.0 m.
- Height or length is 3.5 to 8.0 m.
- Rate of filtration 6000 – 15000 lit/m<sup>2</sup>/hr.
- Used for clarifying softened water at industrial plants.

### DISINFECTION

- Process of destruction or inactivation of harmful micro-organism in water either by physical process or chemical process.
- Sterilization process, all organism are killed by a physical phenomenon.



#### 1. Minor Methods

(a) Treatment with excess lime : 14 – 40 ppm

(b) Treatment with ozone : 2-3 ppm

- Residual ozone is measured by orthotolidine test.
- It is less efficient than chlorine in killing bacteria.

**9.30** CIVIL ENGINEERING

**(c) Treatment with F and Br**

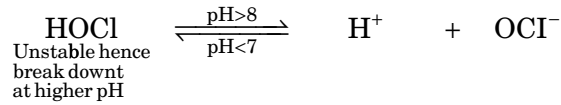
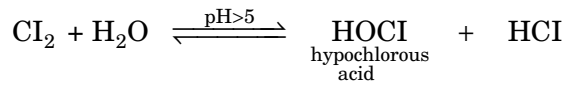
In the form of pills.

**(d) Treatment with  $\text{KMnO}_4$**

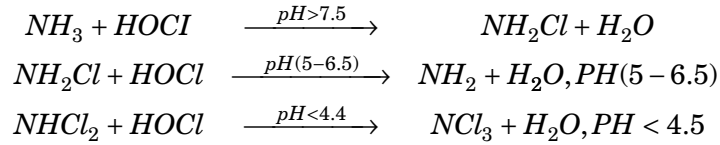
•  $\text{KMnO}_4$  is mixed with water in a bucket and added to well. Pink colour forms because of this. If pink colour disappears, this implies that organic matter is present.

**Major Methods**

**(a) Chlorination**



HOCl is most destructive. It is 80% more effective than the  $\text{OCI}^-$  ion.



**Forms in which Chlorine is Added**

- (a) As free chlorine (liquid or gaseous form)
- (b) Hypochlorites (Bleaching powder)
- (c) Chloramines (ammonia + chlorine)
- (d) Chlorine dioxide ( $\text{ClO}_2$ )

**Types of Chlorination**

**(a) Plain chlorination**

- turbidity b/w 20-30 mg/l
- Dose is 0.5 mg/l

**(b) Pre Chlorination**

- Chlorine is added before filtration or rather before sedimentation and coagulation
- Doses required 0.1 to 0.5 mg/l

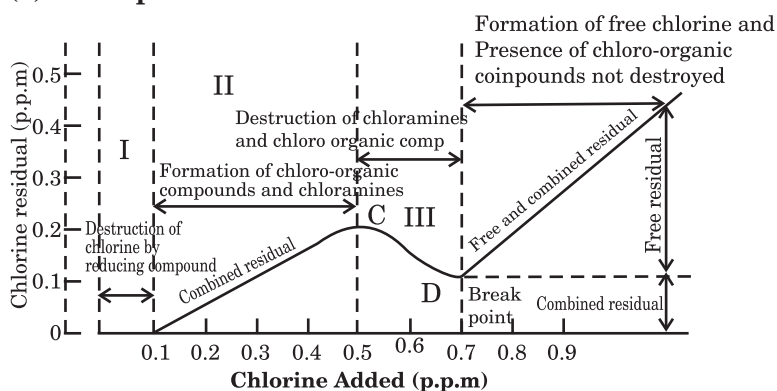
**(c) Post Chlorination**

- Dose of 0.1 to 0.2 mg/lit contact period of 20 min.

**(d) Double Chlorination**

- Prechlorination and post-chlorination combinedly.

**(e) Breakpoint Chlorination**



- Chlorine residue is tested by **DPD** test
- Chlorine is added beyond break point to ensure a residual of 0.2 – 0.3 mg/litre as free chlorine
- The difference of applied chlorine and residual chlorine beyond break point is called chlorine demand of water.

**(f) Super Chlorination**

- Excess chlorine (5 to 15 mg/l) is added in water during epidemic
- Dechlorinating agents are :

**Sodium thiosulphate ( $\text{Na}_2\text{S}_2\text{O}_3$ ) - cheapest of all**

**Activated carbon**

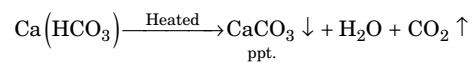
**Sulphur dioxide ( $\text{SO}_2$ )**

**Testing of Chlorine Residue**

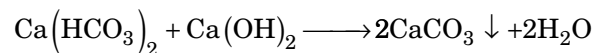
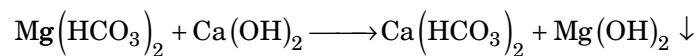
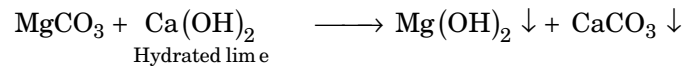
- Orthotolidence test
- DPD test
- Chlorotex test
- Starch iodide test

**WATER SOFTENING**
**Removal of Temporary Hardness**

By simple boiling



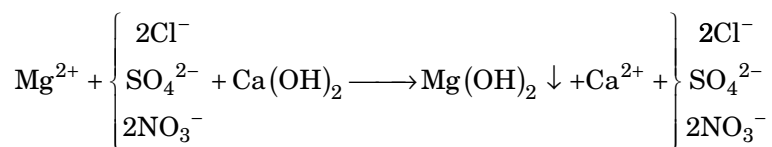
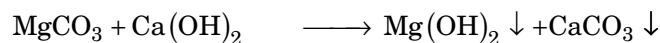
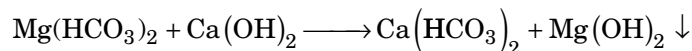
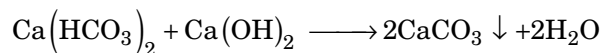
by **addition of lime.**



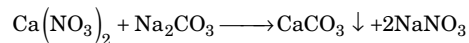
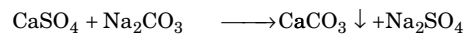
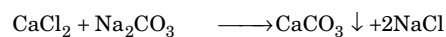
1 mole of  $\text{MgCO}_3$  requires 1 mole of hydrated lime, whereas 1 mole of  $\text{Mg}(\text{HCO}_3)_2$  requires 2 moles of lime.

**Removal of Permanent Hardness (Water Softening)**

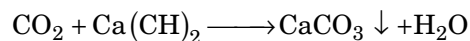
1. Lime Soda Process



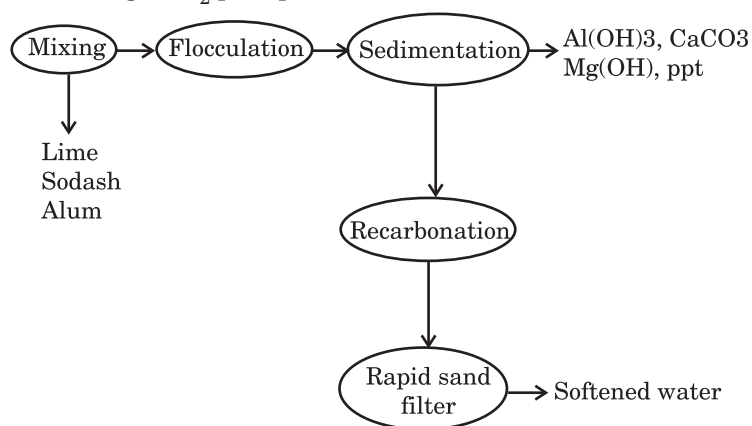
Further



Lastly

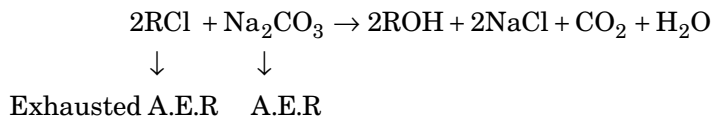


Optimum pH for  $\text{CaCO}_3$  precipitation by lime addition is from 9 – 9.5 and for  $\text{Mg}(\text{OH})_2$  precipitation is 11.0.









### Minor Treatments

**(a) With activated carbon**

**(b) Treatment with Copper Sulphate ( $CaSO_4 \cdot 7H_2O$ )**

**(c) Removal of Iron and Manganese**

**(d) Fluoridation (Addition of Fluorine)**

**(e) Defluoridation (Removal of Fluorine)**

(i) Absorption by activated alumina (AA), commonly known as Prashanti Technology.

(ii) Nalgonda technique.

(iii) Ion exchange adsorption method.

(iv) Reverse osmosis process.

**(f) Desalination**

**(h) Removal of Toxic Metals**

# Distribution System

4

**METHOD OF DISTRIBUTION**

- (i) Gravitational system
- (ii) Direct pumping
- (iii) Combined system

**System of Supply**

- (i) Continuous supply
- (ii) Intermittent supply

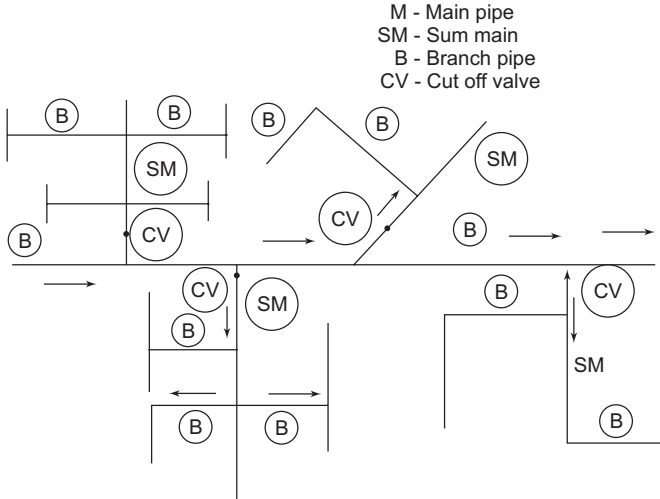
**LAYOUTS OF DISTRIBUTION SYSTEM**

• Pipes except the service connections are usually made of cast iron with some type of coating to avoid rusting where as for service connections galvanised iron pipes are used.

- (i) Dead end or tree system
- (ii) Grid system or reticular system
- (iii) Ring or circular system
- (iv) Radial system

**Dead End System**

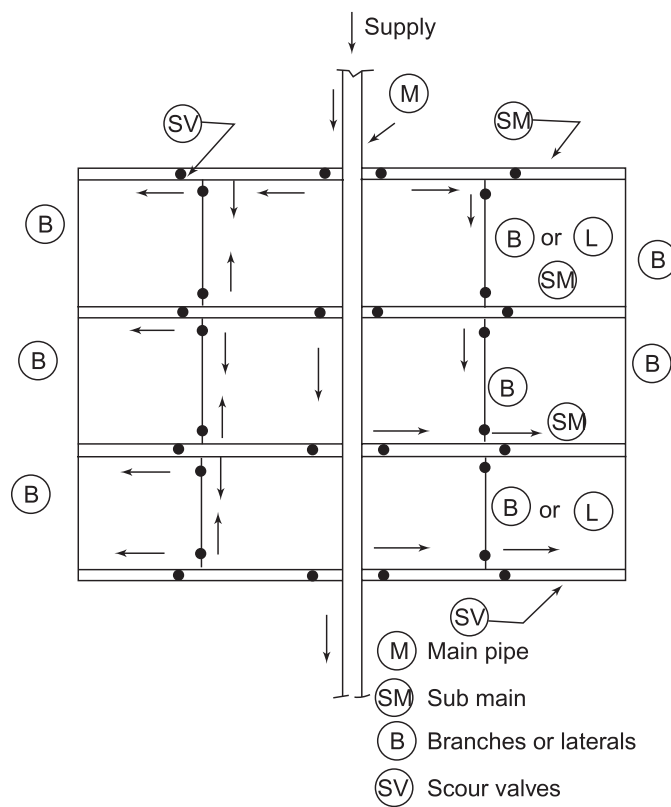
Also known as tree system.



- Water can reach at a particular point only through one route.
- Many dead ends which prevent free circulation of water.
- Stagnant water has to be removed periodically by providing scour valves

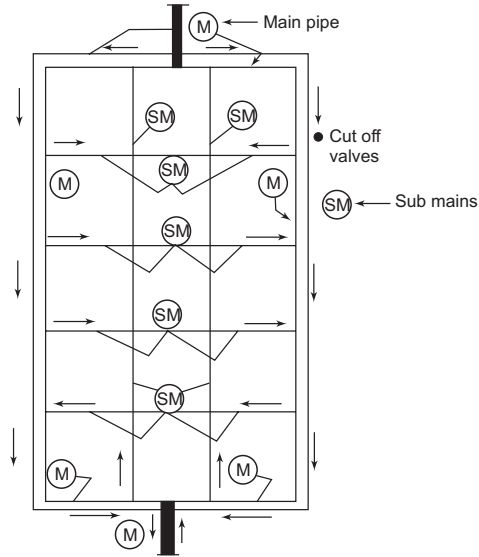
**Grid System**

- Also known as reticular system.



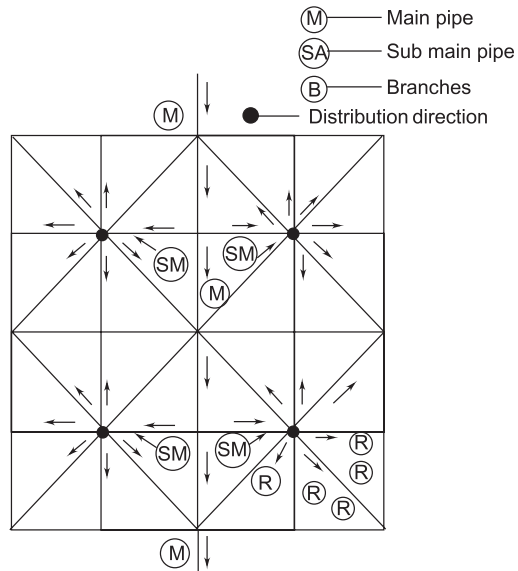
- At the time of fire, water can be diverted to the affected area by closing cut-off valves of other area.
  - Design is a bit difficult.
- Requires more length of pipe lines and a large number of sluice valve.

**Ring System**



- Also known as circular system.
- Consists of a main pipe all round the area.

**Radial System**



This method gives higher service head and efficient water distribution.

### DETECTION OF LEAKAGE IN DISTRIBUTION SYSTEM

- (i) By direct observations.
- (ii) By using sounding rod: Stethoscope type instrument is used, also called aquaphone or a sonoscope.
- (iii) By plotting hydraulic gradient line and
- (iv) By using waste detecting meters.

### PRESSURE IN THE DISTRIBUTION SYSTEM

- Single storey buildings – 7m above ground level.
- Two storey buildings – 12 m above ground level.
- Three storey buildings – 17 m above ground level.

### ANALYSIS OF NETWORK OF PIPES

• The Hazen– Williams is mostly used for computation of flow through pipes and following, two methods are used for analysis:

- (i) Equivalent pipe method.
- (ii) Hardy cross method.

#### Equivalent Pipe Method

- In this method different small loops are replaced by an imaginary single equivalent pipes having same discharge capacities and causing same head loss.
- Used in solving large network of pipes.

#### Hardy-Cross Method

A distribution of flow in the network is assumed and resulting head losses are balanced. In pipe network following two conditions are to be satisfied.

- (i) The algebraic sum of the pressure drops around a closed loop must be zero.
- (ii) The flow entering a junction must be equal to the flow leaving the same junction

Loss of head is  $h_f = rQ^n$ .

#### Steps

- Assume flow in each pipe satisfying continuity eq.
- Take clockwise flow as (+) ve  
Anti clockwise flow as (-) ve

- Modification in discharge  $\Delta Q = \frac{(-)\Sigma rQ^n}{\Sigma |rnQ^{n-1}|}$ .
- $\Delta Q$  is added algebraically.

**APPURTENANCES IN PLUMBING SYSTEM**

1. Ferrules
2. Goose Neck
3. Service Pipe
4. Stop Cock
5. Water Meter

There are two types of meters

- (i) Velocity or inferential meters
- (ii) Positive or displacement meters

Velocity or Inferential Meters : Measure the horizontal velocity

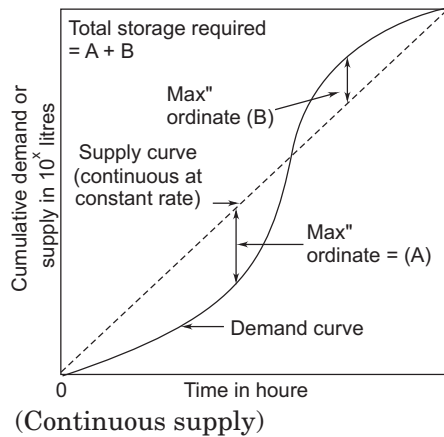
Measure large flow : Positive or Displacement Meters

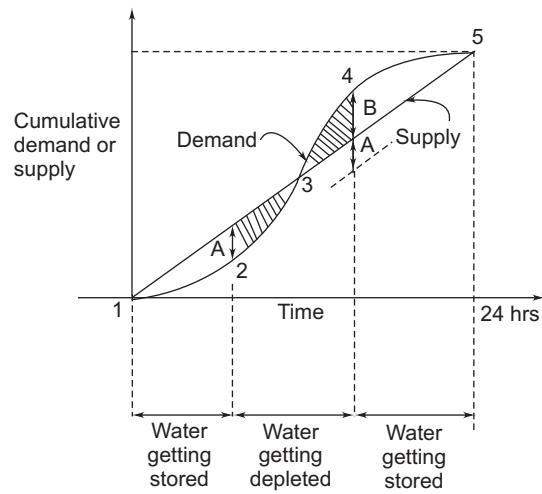
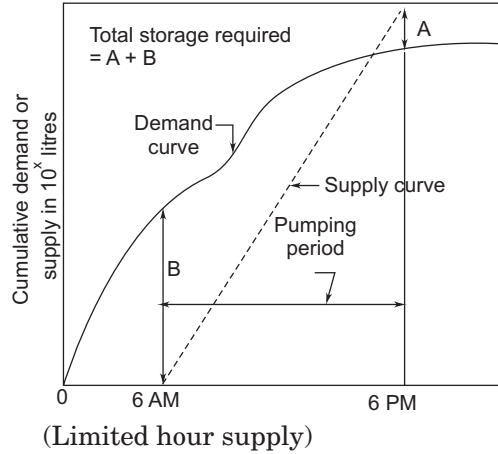
They work by the flow of water causing a piston to reciprocate within a cylinder

**Design of Balancing Reservoir**

**(a) Mass Curve Method**

A mass diagram is the plot of accumulated supply or demand versus time.





- From (2 - 4) → Demand rate > Supply rate  
→ Water getting depleted.
- From (4 - 5 - 1 - 2) → Demand rate < Supply rate  
→ Water getting stored.
- From (4 - 5) → accumulation = B
- From (1 - 2) → accumulation = A
- From (2 - 3) → depletion = A
- From (3 - 4) → depletion = B

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⇒ Max. water that would be stored =  $A + B$  (i.e., From 4 – 2)

⇒ Max. water that would be depleted =  $A + B$  (i.e., From 2 – 4).

(b) **Analytical method:** In this method cumulative hourly demand and cumulative hourly supply are tabulated for all 24 hours.



# Waste Water Characteristics

5

- Classified as industrial waste water or municipal waste water.

## Important Waste Water Contaminants

Sl.No.	Contaminant	Source	Environmental significance
1.	Suspended solids	Domestic use, industrial wastes	Cause sludge deposits and anaerobic condition in aquatic environment
2.	Biodegradable organics	Domestic use, industrial waste	Cause biological degradation
3.	Pathogens	Domestic water	Transmit communicable diseases
4.	Nutrients	Domestic and industrial waste	Cause eutrophication
5.	Refractory organics	Industrial waste	Cause taste and odour problems

## Physical Characteristics

**Turbidity:** Normally turbid.

**Colour:**

- Fresh waste water is gray or light brown and as organic compounds are broken down by bacteria, the dissolved oxygen in the waste water is reduced to zero and colour changes to black.

**Odour:**

- Caused by gases produced by the anaerobic decomposition of organic matter.

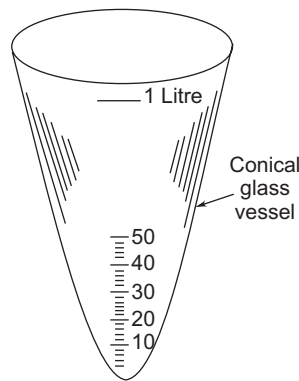
**Temperature:**

Average temperatures of sewage in India is 20°C.

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**Chemical Characteristics**

- Suspended solids, are those which remain floating in water.
- Dissolved solids are those which dissolve in waste water.
- Colloidal solids are finely divided solids remaining either in suspension or in solution.
- Settleable solids are that portion of solid matter which settles out, if the waste water is allowed to remain undisturbed for a period of 2 hours in imhoff cone.



Imhoff cone

**2. pH Value**

- The alkalinity of fresh waste water sample is alkaline but as time passes it becomes acidic.

**3. Chloride Content**

- Normal chloride content of domestic waste water is 120 mg/l.
- Measured by titrating the sample of waste water with standard silver nitrate solution, using potassium chromate as an indicator.

**4. Nitrogen Content**

- (a) Free ammonia or ammonia nitrogen (indicates recent pollution).
- (b) Albuminoid nitrogen or organic nitrogen (indicates quantity of nitrogen before decomposition has started).
- (c) Nitrites (indicates partly decomposed condition).
- (d) Nitrates [indicates old pollution (fully oxidised)].

**5. Presence of Fats, Oils and Greases**

- Determined by evaporating it and then mixing the residual solids left, with ether (hexane).

**6. Sulphides, Sulphates and Hydrogen Sulphide Gas**

- Formed due to the decomposition of various sulphur containing substances.

**7. Dissolved Oxygen**

- Temperature of sewage is more, than D.O. content will be less. Max quantity of D.O. that can remain mixed in water at a particular temperature is called *Saturation Dissolved Oxygen*.

- D.O. content of waste water is determined by the *Winkler's Method*.

**8. Chemical Oxygen Demand (COD)**

- Measure the content of organic matter of waste water, both biodegradable and non-biodegradable.

- Measured by using a strong chemical oxidising agent in an acidic medium.

- $COD - BOD_5 =$  Nonbiodegradable organics.

**9. Theoretical Oxygen Demand (ThOD)**

For most practical cases,  $COD = ThOD$  (taken)

However, generally

$ThOD > COD > BOD > TOC$

**10. Total Organic Carbon (TOC)**

Method of expressing the organic matter in terms of carbon content.

**Bio-chemical Oxygen Demand**

Measure of the quantity of oxygen required for oxidation of bio-degradable organic matter present in water sample by aerobic biochemical action.

Oxygen demand of waste water is exerted by three classes of materials:

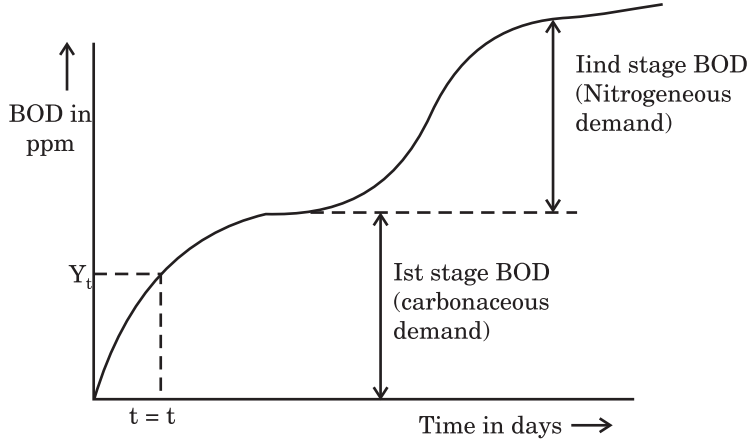
- Carbonaceous organic materials.
- Oxidisable nitrogen.
- Chemical reducing compounds.

$BOD$  or  $BOD_5 =$  D.O. consumed in the test by diluted sample

$$\times \left[ \frac{\text{Vol. of the diluted sample}}{\text{Vol. of the undiluted sewage sample}} \right]$$

**Note:** Sample is diluted with dilution water so that sufficient oxygen is available during the incubation period of 5-days.

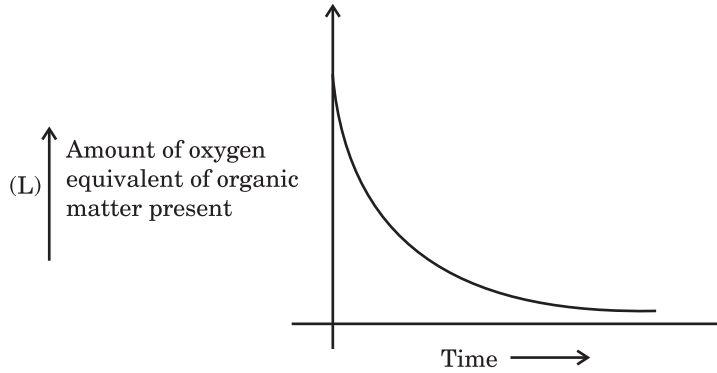
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BOD Curve

Nitrification bacteria are autotrophs. Carbonaceous matter oxidising bacteria are hetrotropes.

Reaction Kinetics 1st order Reaction



$L_t$  = amount of organic matter present at time t

$$\frac{dL_t}{dt} = -kL_t$$

$$L_t = L_0 e^{-kt}$$

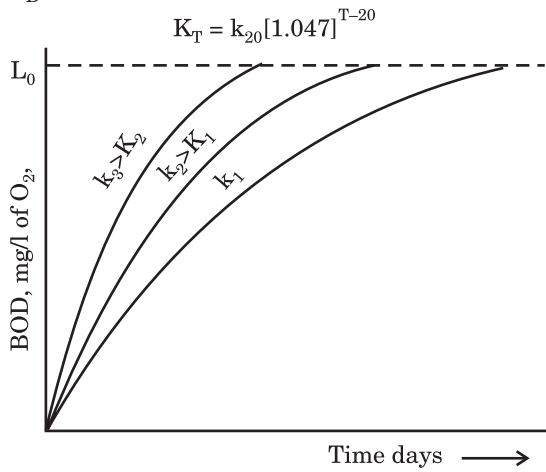
$$L_t = L_0 10^{-k_D t}$$

$$BOD_t = L_0(1 - 10^{-k_D t})$$

Unit of  $k_D$  is in terms of per day and it is temperature dependent.

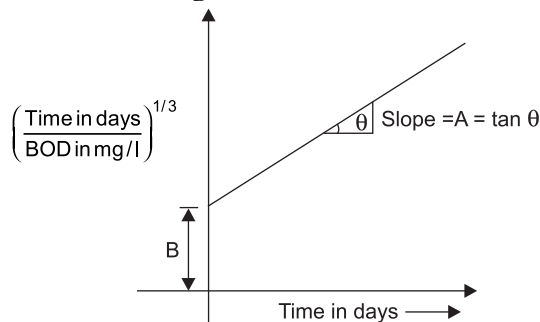
$$k_{D(T^\circ)} = k_{D_{20^\circ}} [1.047]^{T-20^\circ} \quad (\text{Vanthoff-Arrhenius equation})$$

$k_D$  is also sometimes called deoxygenation constant.



BOD for municipal sewage is 200 – 500 mg/l.

Estimation of  $k_D$



$$k_D = 2.61 \frac{A}{B} \text{ per day}$$

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**Population Equivalent**

Average standard BOD of domestic sewage is 80 gms per person per day.

**Relative Stability (S)**

$$S = \frac{\text{O}_2 \text{ available in treated effluent}}{\text{Total O}_2 \text{ required for 1st stage BOD (i.e. BOD ultimate)}}$$

$$S = 100[1 - (0.794)^{t_{20}}] = 100[1 - (0.63)^{t_{37}}]$$

**Note:** A representative sample from a point where turbulence is thoroughly mixing up the sewage is called grab sample.  
 The seeded water is the water with seedign of mixed bacterial culture.

$$\text{BOD}_5 = \frac{(D_1 - D_2) - (B_1 - B_2)(1 - P)}{P}$$

where,  $D_1$  = DO of diluted sample immediately after dilution mg/l  
 $D_2$  = DO of diluted sample after 5 days (120 hours) g/l  
 $B_1$  = DO of seeded control sample before incubation, mg/l  
 $B_2$  = DO of seeded control sample after 5 days incubation, mg/l  
 $P$  = Decimal volumetric fraction of sample used  
 = Volumme of undiluted sample/volume of diluted sample

# Disposal of Sewage Waste

# 6

## BIS Standard for Disposal of Sewage

Parameter	Domestic sewage If discharge into surface water source	Industrial sewage**	
		Surface water	Public sewer
BOD <sub>5</sub>	20 mg/l	30 mg/l	500 mg/l
pH	—	5.5–9.0	5.5–9.0
Suspended solids	30 mg/l	100 mg/l*	600 mg/ml
Phenolic compounds	—	1 mg/l	5 mg/l
Cyanides	—	0.2 mg/l	2 mg/l

\* Suspended organic matter contains least carbon so relaxation in norms.

\*\* Contains refractory organics, which retard backval process here industrial sewage not mixed directly into public sewer.

## Mechanism of Self Purification

### 1. Dilution and Dispersion

It is not a self-purification method.

$$C_{mix} = \frac{C_s Q_S + C_R Q_R}{Q_S + Q_R}$$

$C_s$  = Concentration of material of sewage

$C_R$  = Concentration of same material in river

$Q_S$  and  $Q_R$  are discharges of sewage and river.

### 2. Sedimentation

- The suspended solid in the sewage will settle down at the bottom of the river and in due course they will be stabilized.

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**3. Sunlight**

- Due to sunlight, in the process of photosynthesis, oxygen is released.

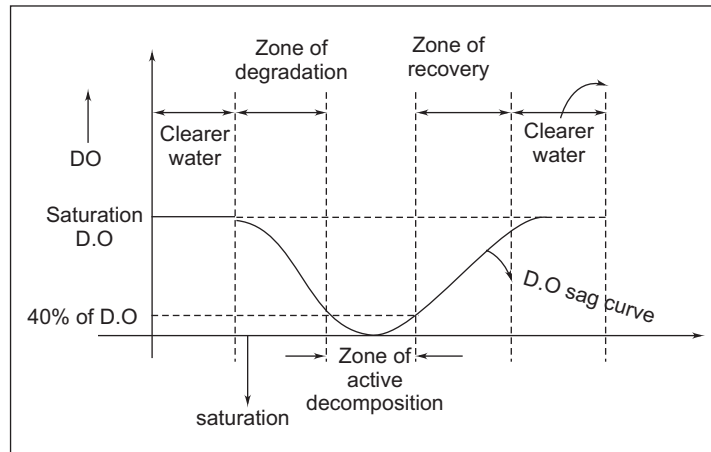
**4. Oxidation**

- Oxidation of organic matter occurs due to oxygen mixed in the river water.

**5. Reduction**

- By hydrolysis of organic matters settled at the bottom either chemically or biologically, the organic matters are stabilized.

**Zone of Pollution in River Stream**



**Zone of Degradation**

- In this algae dies but the fish survives.
- DO reduces to upto 40% of saturation.

**Zone of Active Decomposition**

- It is a zone of heavy pollution.
- DO may even fall to zero.

**Zone of Recovery**

- D.O. content rises above 40% of the saturation value.

**Zone of Clear Water**

- DO will rise upto its saturation value, but the pathogens may remain.



**Oxygen Deficit of a Polluted River Stream**

Two mechanisms are known to contribute oxygen to surface water.

- (a) Reaeration
- (b) production of oxygen by algae photosynthesis

**Reaeration**

Oxygen deficit (D) = [Saturation D.O.] – [Actual D.O. (C)]

$$D = C_s - C$$

if  $r_g$  = rate of reaeration (Rate of oxygen addition)

$$r_g = K_r D \text{ (1st order reaction)}$$

$K_r$  = Re oxygenation constant at base 'e'.

**Rate of Oxygen Removal**

y = BOD of stream added with sewage

$$\frac{dy}{dt} = \frac{dD}{dt}$$

$$y = L_0 - L_t$$

$L_0$  = ultimate BOD of mix.

$L_t$  = oxygen equivalent of organic matter present at any time 't'

$$\frac{dy}{dt} = -\frac{dL_t}{dt}$$

$K_d$  = Deoxygenation constant at base 'e'

$r_d$  = Rate of de-oxygenation

$$r_d = K_d \cdot L_t$$

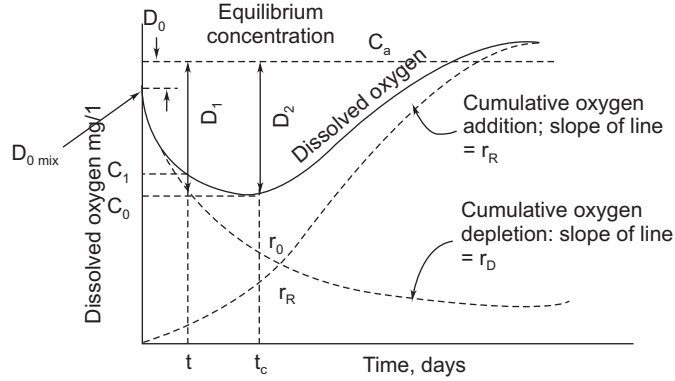
**The Oxygen Sag Curve**

Net rate of oxygen deficit = Rate of re-aeration + Rate of de-oxygenation

$$\frac{dD}{dt} = K_r D - K_d L_t$$

Deficit is max. when rate of re-aeration = rate of de-oxygenation

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Characteristics of the oxygen sag curve

$D_0$  = initial oxygen deficit

$$D = \frac{K_d L_0}{K_r - K_d} [e^{-K_d t} - e^{-K_r t}] + D_0 e^{-K_r t}$$

**Streeter-Phelps equation.**

$$D = \frac{K_D L_0}{K_R - K_D} [10^{-K_D t} - 10^{-K_R t}] + D_0 10^{-K_R t}$$

...(i)

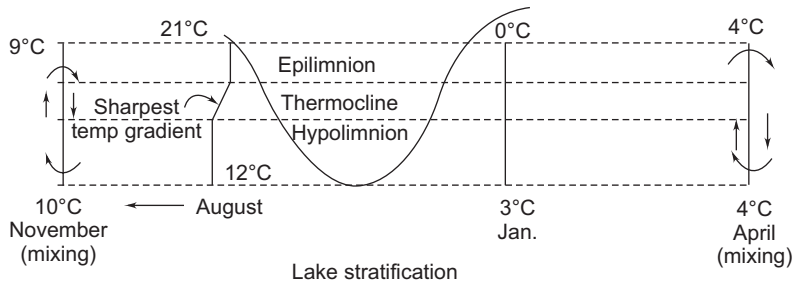
$D_C$  = critical oxygen deficit

$$D_C = \frac{K_D L_0}{K_R} 10^{-K_D t_c}$$

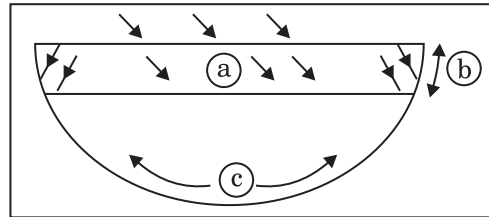
$$\left( \frac{L_0}{D_C f} \right)^{(f-1)} = f \left[ 1 - (f-1) \frac{D_0}{L_0} \right]$$

$f = \frac{K_R}{K_D}$  = self purification constant.

**Lake Stratification**



**Biological Zones in Lakes**



(a) **Euphotic zone:** Layer of lake through which sunlight can penetrate.

(b) **Littoral zone:** Near the shore where rooted plants grow is called littoral zone.

(c) **Benthic zone:** The bottom sediments in lake which contains bacteria.

**Productivity of Lake**

- Is a measure of algal growth.
- **Oligotrophic:** low level of productivity.
- **Mesotrophic:** Medium algal growth (medium productivity).
- **Eutrophic:** High productivity and algal growth.
- **Senescent:** Marshy, lake.

**Eutrophication of Lake**

- Natural process under which lakes get infested with algae and silt up gradually to become shallow and more productive.

**Note:** Once phosphorus is mixed in lake, only solution is to add lime to it and to dredge out the sediment at the bottom of lake.

BIS standard for waste water effluent to be discharged into sea.

BOD	-100 mg/l
COD	-250 mg/l
pH	-5.5 – 9.0 mg/l
SS	-100 mg/l
Fluoride	-15 mg/l
Oil and grease	-20 mg/l

**Sewage farming**

In case of sewage farming, stress is laid upon the use of sewage effluents for irrigating crops and increasing fertility of soil.

# Design of Sewerage System and Sewer Appurtenances

# 7

## Laying of Sewer

It consists of the following steps:

1. Marking of the Alignment
  - (a) By Reference Line
  - (b) By Sight Rail
2. Excavation of Trench
3. Bracing of the Trench
4. Dewatering of Trench
5. Laying and Joining of Pipes
6. Testing of Leakage
  - (a) By Water Test
  - (b) By Air Test

## Assumptions in Sewer Design

- (i) The flow of waste water in sewer is steady and uniform.
- (ii) Design of sewer is based on peak flow discharge.
  - Manning's formula.

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

V = velocity of flow  
 R = hydraulic radius  
 S = slope of sewer

- Hazen William's formula.

$$V = 0.849 CR^{0.63} S^{0.54}$$

[C = Hazen-William coefficient]

**Design Data**

- Self cleansing velocity is the minimum velocity at which no solid gets deposited at the bottom of sewer.

Max hourly discharge = 3 × average daily discharge  
 Max daily discharge = 2 × average daily discharge  
 Min hourly discharge =  $\frac{1}{3}$  × average daily discharge  
 Min daily discharge =  $\frac{2}{3}$  × average daily discharge

Self cleansing velocity is given by **Shields formula**

$$V = \frac{1}{n} R^{1/6} [K_s (G_s - 1) d_p]^{1/2}$$

$d_p$  = particle size

$K_s$  = a dimension less constant

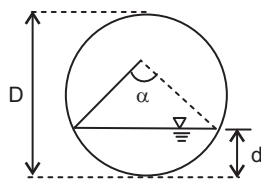
R = hydraulic radius of sewer

- Slope of sewer should be designed for min. permissible velocity at min flow.

**Partial Flow Characteristics of Circular Sewer**

Small letter : hydraulic elements under partial flow

Capital letter : the hydraulic elements under full flow condition then for a circular sewer.



$$\frac{d}{D} = \frac{1}{2} \left( 1 - \cos \frac{\alpha}{2} \right)$$

$$\frac{a}{A} = \frac{\alpha}{360} - \frac{\sin \alpha}{2\pi}$$

$$\frac{p}{P} = \frac{\alpha}{360}$$

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$$\frac{r}{R} = 1 - \frac{360 \sin \alpha}{2\pi\alpha} = \frac{a/A}{p/P}$$

$$\frac{v}{V} = \frac{N}{n} \left( \frac{r}{R} \right)^{2/3}$$

$$\frac{q}{Q} = \frac{v}{V} \times \frac{a}{A}$$

By knowing the conditions under which sewer runs full and by knowing two ratios of hydraulic elements, under partial and full flow conditions, third can be calculated analytically.

**Note:** 1. If Manning's coefficient 'n' is assumed constant with depth, then

$$\frac{v}{V} = \left( \frac{r}{R} \right)^{2/3}$$

2. For constant 'n', velocity of flow is max when  $d/D = 0.81$ .

3. For constant 'n', discharge is max when  $\frac{d}{D} = 0.95$

4.  $\frac{v}{V}$  decreases less sharply than  $\frac{d}{D}$  below  $\frac{1}{2}$  full depth (for constant  $n$ ).

5.  $\frac{q}{Q} = \frac{1}{2}$  at  $\frac{1}{2}$  full flow

6. If  $\frac{d}{D} \geq 0.5$ , then  $\frac{v}{V} \geq 1$

## SEWER APPURTENANCES

### (1) Manholes

#### Components of Manhole

##### (a) Access Shaft

##### (b) Working Chamber

- Hight of chamber = 2m
- Size (rectangular) = 1.2 × 1.5 m
- If chamber is circular diameter = 1.2 m

#### Types of Manholes

##### (i) Straight – Trough Manholes

Where there is a change in the size of sewer, the soffit or crown level of the two sewers should be the same.

##### (ii) Junction Manholes

Built at every junction of two or more seweres.

**(iii) Drop Manholes:** To connect the high level branch sewer to the low level main sewer by vertical dropping pipe.

**(iv) Flushing Manhole:** Where it is not possible to obtain self-cleansing velocities due to flatness of the gradient. It is essential that some form of flushing device be incorporated.

**(2) Lamp Hole:** Opening which is provided in a sewer line for lowering a lamp inside.

##### (3) Grease and Oil Trap

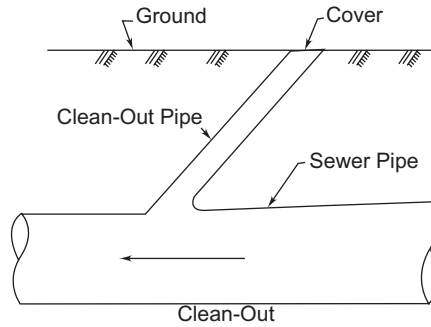
##### (4) Catch basin

To allow the strom water to enter the sewer by eliminating the silt, grit, etc. at the bottom of the basin.

**(5) Storm Water Inlet:** Meant to admit the surface run off to the sewers storm water inlets having vertical openings.

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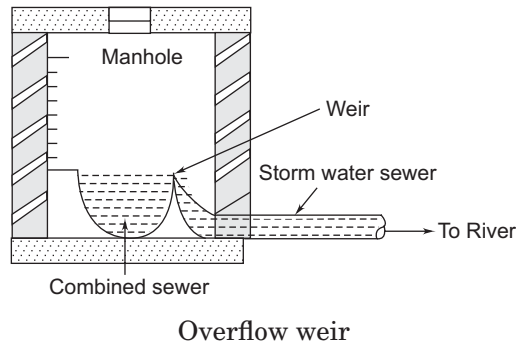
**(6) Clean Outs:**



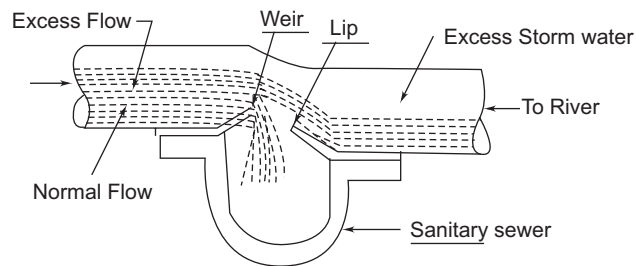
**(7) Inverted Siphons:** Whenever a sewer pipe has to be dropped below the hydraulic gradient line for passing it beneath a valley. Any depression in the earth's surface or where it passes beneath some other obstructions in its path, it is known as an inverted siphon.

**(8) Storm Water Regulator or Overflow Device**

**(i) Side Flow Weir**

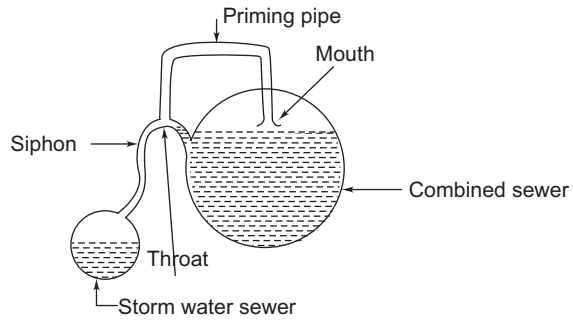


**(ii) Leaping Weir**





(iii) **Siphon Spillway:** It is an automatic process, and works on the principle of siphonic action.



Siphon Spillway

# Sewage Treatment

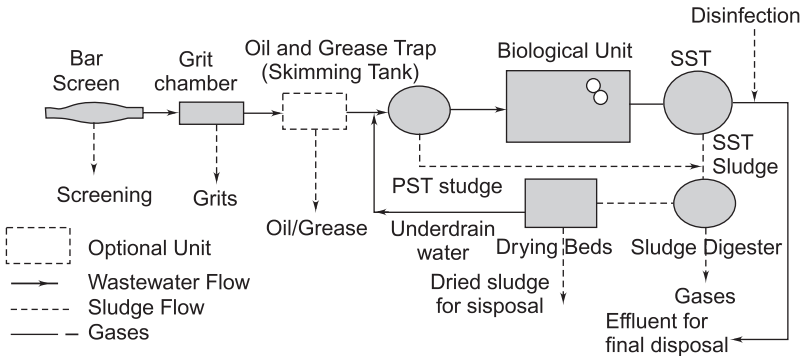
## 1. Treatment Methods

### Unit Operations

The means of treatment in which the application of physical forces predominates are known as unit operations.

### Unit process

The types of treatment in which the removal of contaminants is brought about by the addition of chemicals or the use of biological mass or microbial activities.



PST–Primary Settling Tank, SST–Secondary Settling Tank

Schematic flow diagram of a typical conventional treatment plant

## Primary Treatments

### 1. Screening:

- Primary purpose of screen is to protect pumps and other mechanical equipments.
- Head loss through screen.

$$h_L \text{ (m)} = 0.0729 (V^2 - v^2)$$

V = velocity through opening of bar screen (in m/s)

v = approach velocity in upstream channel (in m/s)

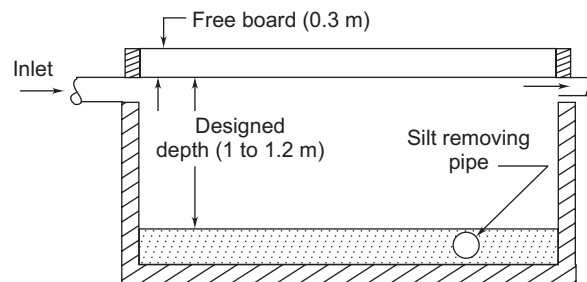
## 2. Comminution and Maceration

They are installed before fine screen.

## 3. Grit Chamber

Located either before or after sewage pumps. Separate non-decaying heavy inorganic material from sewage.

- Should not allow settlement of organic materials.
- Two channels are provided one for normal flow and other for peak flow.
- Only one section (channel) is required if velocity control devices has been used.



### Design Criteria

- Removes particles of size  $\geq 0.2$  mm
- For 0.2 mm particle setting velocity = 0.025 m/s
- Surface over flow rate = 2160 m<sup>3</sup>/m<sup>2</sup>/day
- Horizontal critical flow velocity  $V_C = K_C \sqrt{g(G_s - 1)d}$   
 $K_C = 3$  to 4.5
- Detention time is 40 – 60 sec.
- Depth is 1 – 1.5 m
- Free board is 0.3 m

## 4. Detritus Tank

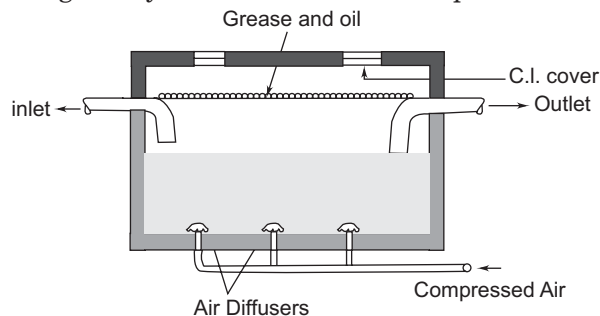
- To remove finer and inorganic particles.

## 5. Skimming Tank

- Removal of soaps, oil and greases.
- Provided before sedimentation tank.
- Compressed air is blown from below.

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- Chlorine gas may also be blown with compressed air.



**Sedimentation**

In primary sedimentation, organic suspended solids are settled.

**Types of Settling**

- Type 1. Discrete settling
- Type 2. Flocculent settling
- Type 3. Hindered or zone settling
- Type 4. Compression settling.

	PST	Over flowrate (m <sup>3</sup> /m <sup>2</sup> /day)		Depth	Detention time
		Avt.	Peak		
1.	1°-settling only	25-30	50-60	2.5-3.5 m	2-2.5 hr
2.	1°-settling followed by secondary treatment	35-50	80-120	2.5-3.5 m	2-2.5 hr
3.	1°-settling with SAP	25-35	50-60	3.5-4.5	2-2.5 hr

$$\text{Surface area from average flow} = \frac{\text{Average discharge}}{\text{Average over flow rate}}$$

$$\text{Surface area from peak flow} = \frac{\text{Peak discharge}}{\text{peak overflow rate}}$$

**Note:** Sedimentation with Coagulation is not used generally in sewage treatment.

**Secondary Treatment (Biological Treatment)**

Secondary treatment is generally carried out aerobically.

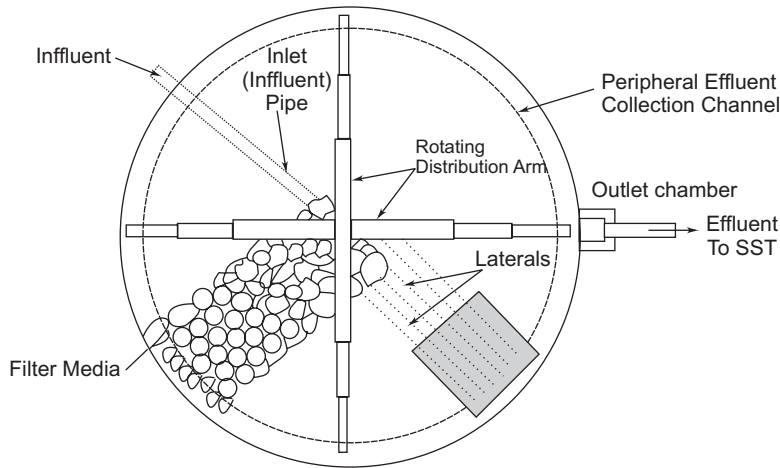
Units based on aerobic treatment are:

- Trickling filter
- Activated sludge process
- Oxidation pond etc.

Units based on annerobic treatments are:

- Septic tank
- Imhoff tank
- UASB Reactor (Upflow Anaerobic Sludge Blanket)

**Standard Rate Trickling Filter**



- 2 m deep circular bed, angular stone about 50 mm in size, supported on a tile floor
- Discharge under a head of 0.5-0.8 m

**Operational Trouble in Standard Rate Filter**

- (a) Filter media ponding and clogging
- (b) Excessive fly breeding
- (c) Odour

	Standard	High rate	Super high rate
Hydraulic loading (in $m^3/m^2/day$ )	1 – 4	10–40 (including recirculation)	40 – 200 (including recirculation)
Organic loading (in $kg BOD_5/m^3/day$ )	– 0.08 – 0.32	0.32 – 1.0 (excluding recirculation)	06 – 0.8 (excluding recirculation)
Depth (m)	1.8 – 3.0	0.9 – 2.5 m	4.5 – 12 m
Recirculation ratio ( $Q_R/Q_0$ )	0	0.5 – 3.0	1 – 4

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Standard rate trickling filter, removes BOD upto 80-90%.

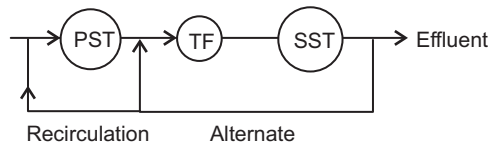
$$\eta = \frac{100}{1 + 0.0044\sqrt{u}}$$

$u$  = organic loading in kg/hac-m/day

- Design of TF is done for average flow.

**High Rate Trickling Filter**

Recirculation is done by pumping the effluent of trickling filter to influent of trickling filter or to the primary sedimentation tank.



**Design of High Rate TF**

Surface area of trickling filter

$$= \frac{(Q_0 + Q_R)}{\text{Hydraulic loading (including recirculation)}}$$

$$\text{Volume of trickling filter} = \frac{Q_0 Y_1}{\text{Organic loading (excluding recirculation)}}$$

$Q_0$  = discharge from PST

$Q_R$  = Recycled discharge

$Y_0$  = BOD of waste water

$Y_1$  = BOD of PST effluent

$Y_2$  = BOD of TF effluent

**Efficiency of High Rate Trickling Filter**

$$\eta_1 = \frac{100}{1 + 0.41\sqrt{\frac{W_1}{V_1 F_1}}}$$

$W_1$  = BOD<sub>5</sub> applied to trickling filter in kg/day

$W_1 = Q_0 Y_1$  (excluding recirculation)

$V_1$  = Volume of trickling filter in m<sup>3</sup>

$F_1$  = Recirculation factor

$$F_1 = \frac{1 + R}{[1 + (1 - f)R]^2}, [R = \text{recirculation ratio} = \frac{Q_R}{Q_0}]$$

$f$  = Treatability factor

$f = 0.9$  for sewage

$$F_1 = \frac{1 + R}{(1 + 0.1R)^2}$$

Efficiency of 2nd stage ( $\eta_2$ ) is

$$\eta_2 = \frac{100}{1 + \frac{0.44}{1 - \eta_1} \sqrt{\frac{W_2}{V_2 F_2}}}$$

$W_2$  = BOD<sub>5</sub> applied on 2nd stage TF (excluding recirculation in kg/day)

$V_2$  = Volume of 2nd stage filter

$F_2$  = Recirculation factor for 2nd stage

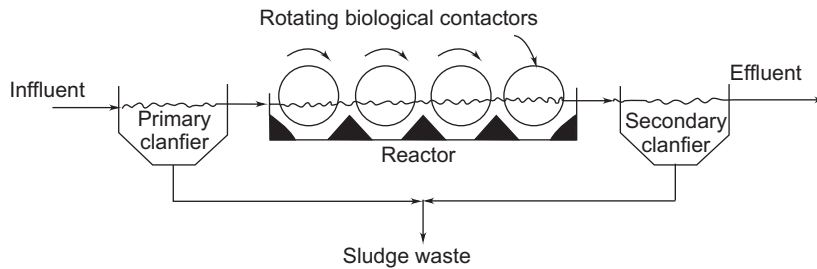
$$W_2 = \frac{W_1(100 - \eta_1)}{100}$$

**Overall Efficiency in Terms of  $\eta_1$  and  $\eta_2$**

$$\eta = \frac{W_1 - W_1 \left(1 - \frac{\eta_1}{100}\right) \left(1 - \frac{\eta_2}{100}\right)}{W_1} \times 100$$

**Rotating Biological Contractor (RBC)**

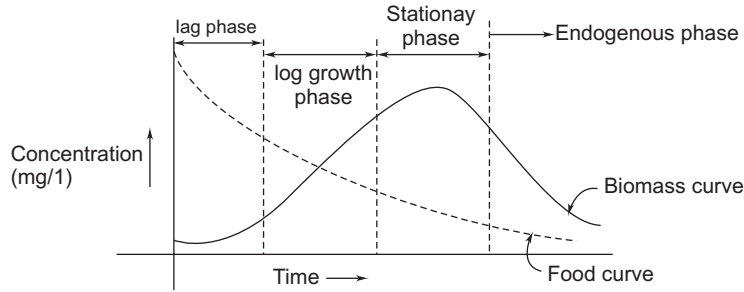
- It is based on attached growth system.



- Film is moving (3-6 rpm).
- Sheared off mass is kept in suspension, by the turbulence created due to movement of discs.

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Reaction Kinetics



- MLSS represents both living and dead bacteria.

$$\text{Rate of biomass growth} = \frac{dX}{dt}$$

$$\text{Rate of food consumption} = -\frac{dS}{dt} \quad \left( -\frac{dS}{dt} > \frac{dX}{dt} \right)$$

- During log-growth phase  $\frac{dX}{dt} = kX$  [1st order equation]

$$k = \frac{k_0 S}{k_s + S} \quad (\text{Monod's equation})$$

$k_0$  = maximum growth rate constant  
 $s$  = concentration of limiting food (in mg/l)  
 $k_s$  = Half saturation constant

$$-y \frac{dS}{dt} = \frac{dX}{dt}$$

$y$  is the fraction of food mass converted to biomass.

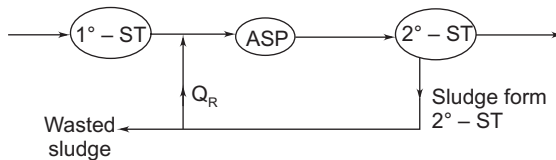
The equation for overall biological growth is

$$\frac{dX}{dt} = \left( \frac{k_0 S}{k_s + S} \right) X - k_d X$$

$k_d$  = endogenous decay rate constant.

$$k_d = 0.06 \text{ per day}$$

Activated Sludge



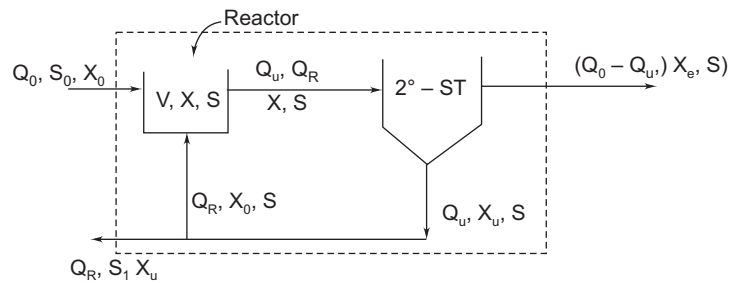


The settled sludge in secondary clarifier containing living micro-organisms is returned to the reactor to increase the available biomass and speed up the reaction.

The process can be:

- (i) completely mix process
- (ii) plug flow process

**Completely Mix Process**



$$\text{Biomass in} + \text{Biomass growth} = \text{Biomass out}$$

$$\text{Food in} - \text{Food consumed} = \text{Food out}$$

$$\frac{Q_u X_u}{VX} = \frac{Q_0 Y (S_0 - S)}{VX} - k_d$$

**Design Parameters**

**1. Hydraulic retention time ( $\theta$ ) or Aeration time or detention time**

$$\theta = \frac{\text{Volume of tank (v)}}{\text{Rate of flow in the tank excluding recirculation (} Q_0 \text{)}}$$

**2. Volumetric BOD loading**

$$= \frac{\text{Mass of BOD applied}}{\text{Volume of aeration tank}}$$

**3. Specific substrate utilization rate (U)**

$$U = \frac{Q_0 (S_0 - S)}{VX}$$

**4. F/M ratio** =  $\frac{Q_0 S_0}{VX} = \frac{\text{Food added}}{\text{Bacteria in system}}$

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**5. Sludge age ( $\theta_c$ )**

$$\theta_c = \frac{\text{Mass of MLSS in the aeration tank}}{\text{Mass of MLSS leaving the system per day}}$$

$$\frac{1}{\theta_c} = UY - k_d$$

$$VX = \frac{YQ_0(S_0 - S)\theta_c}{1 + k_d\theta_c}$$

**6. Sludge Volume Index (SVI)**

- SVI represents the degree of concentration of sludge in the system
- It unit is **ml/gm**

$$\frac{Q_R}{Q_0} = \frac{X}{X_u - X} \quad \text{where } X \text{ is MLSS in tank (mg/l)}$$

$$X_u = \frac{10^6}{SVI}$$

$$\text{Recirculation Ratio} = \frac{Q_R}{Q_0} = \frac{X}{\frac{10^6}{SVI} - X}$$

$$SVI = \frac{V_{ob}(\text{ml/mg})}{X_{ob}(\text{l/mg})} = \frac{V_{ob}}{X_{ob}} \text{ ml/mg}$$

when 1 litre sample of mixed liquor is allowed to settle for 30 minutes and the settled sludge volume ( $V_{ob}$ ) in ml. Concentration of suspended solids in the mixed liquor in mg/l be  $X_{ob}$ .

**Design of Aeration Tank**

Process type	Flow regime	MLLS mg/l	MLVSS MLSS	F/M	H. B. T. (hr.)	$\theta_c$ days	$Q_r/Q$	$\eta$	kg O <sub>2</sub> required kg of BOD removed
Conventional	plug flow	1500-3000	0.8	0.3-0.4	4-6	5-8	0.25-0.5	85-92%	0.8-1.0
Completely mix	Completely mix	3000-4000	0.8	0.3-0.6	4-5	5-8	0.25-0.8	85-92%	0.8-1.0
Extended Aeration	Completely mix	3000-5000	0.8	0.1-0.18	12-24	10-15	0.5-1.0	95-98%	1.0-1.2

**Excess Sludge Wasting**

- Done to maintain steady level of MLSS in the tank and to maintain sludge age.

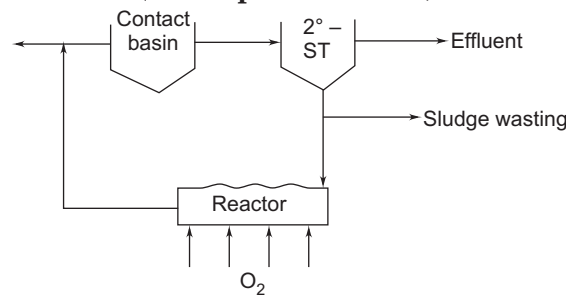
**Nitrification**

- This problem can be overcome by increasing the sludge wasting rate.
- Nitrification can lead to subsequent denitrification ( $N_2 \uparrow$ ) in secondary tank causing sludge rising problem called blanket rising.

**Sludge Bulking**

- Sludge with poor settling characteristics

**Contact Stabilization (Biosorption Process)**



**Completely Mix Process**

- Sewage is maintained in log-growth phase by keeping high F/M ratio

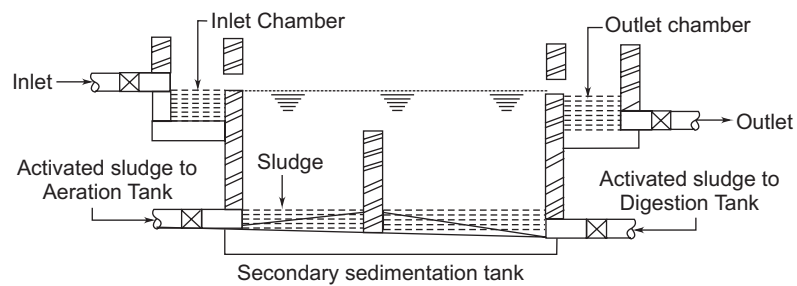
**Extended Aeration**

- F/M ratio is kept lower and detention time is kept more.

**Oxidation Ditch**

- An oxidation ditch is basically an extended aeration system of a modified activated sludge process.

**Secondary Sedimentation Tank**



- It is designed on the basis of:
  - (a) Solid loading rate
  - (b) Over flow rate

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	Overflow rate (m <sup>3</sup> /m <sup>2</sup> /day)		Solid loading rate (kg/m <sup>2</sup> /day)		Depth (m)	Detention time (hr)
	Avg.	Peak	Avg.	Peak		
2° ST for TF	15-25	40-50	70-120	190	2.5-3.5	1.5-2
2° ST for ASP excluding extended aeration	15-35	40-50	70-140	210	3.5-4.5	1.5-2
2° ST for extended aeration	8-15	25-35	25-120	170	3.5-4.5	1.5-2

$$\text{Area (Avg.)} = \frac{Q_0}{\text{Over flow rate}} \text{ (from overflow rate criteria)}$$

$$\text{Area} = \frac{(Q_0 + Q_R)X}{\text{Solid loading rate}}, X = \text{MLSS of aeration tank.}$$

**Sludge Thickener**

- To reduce the volume to be handled in sludge digester, sludge thickener is provided.
- Three types of thickening:
  1. Gravity thickening
  2. Air floating
  3. Centrifugation
- Designed for surface loading, rate of 20 – 25 m<sup>3</sup>/m<sup>2</sup>/day. The solid loading is 25 – 30 kg/m<sup>2</sup>/day.
- Depth is normally 3 to 4 m.
- Detention period is 4 hrs.

**Sludge Digestion**

- The sludge digestion serves both to reduce the volume of thickened sludge still further and to render the remaining solids inert and relatively pathogen free.

**Aerobic Digestion**

- Adopted only for biological sludge (2°-sludge) that does not contain primary sludge.
- An extension of extended aeration process.
- Process is energy consumption

**Anaerobic Digestion**

- The organisms are broadly classified as
  - **Acid formers:** They consist of (facultative) and (anaerobic) bacteria and organisms which solublize the organic acids through hydrolysis.
  - **Methane former:** They are strictly (anaerobic) and convert acids and alcohol along with hydrogen and carbon dioxide to methane.

**Note:**  $V(100 - p) = V_1(100 - P_1)$   
 $V$  = Volume of sludges at moisture content  $P$   
 $V_1$  = Volume of sludge at moisture content  $P_1$

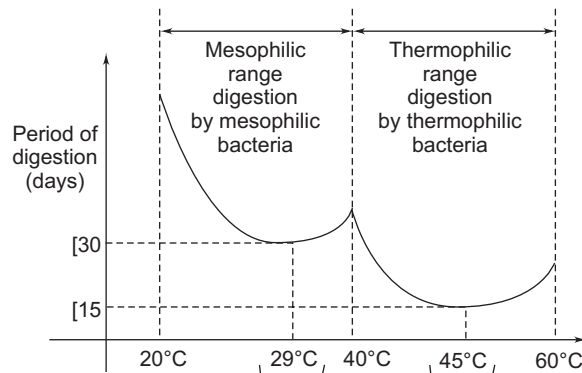
- When sludge is digested anaerobically the volume of original sludge is reduced to apox.  $\frac{1}{3}$  of the original value.

**Stages in Sludge Digestion Process**

- Hydrolysis
- Fermentation (Acidogenesis)
- Methane formation (Methanogenesis)

**Factors Affecting Sludge Digestion and their Control**

**(a) Temperature**



**(b) pH**

- pH decreases due to overdosing of raw sewage, over withdrawal of digested sludge and sudden admission of industrial waste.

**(c) Seeding with Digested Sludge**

Helps in achieving quick balance condition.

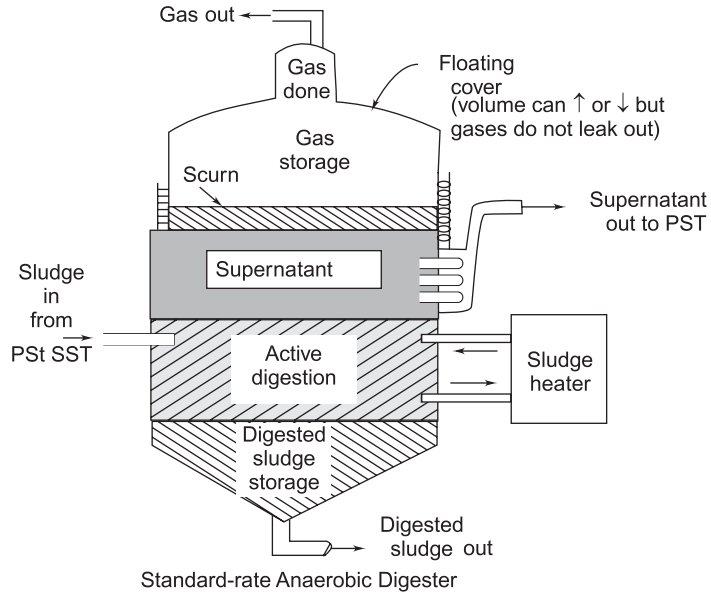
**(d) Mixing and Steering of Raw Sludge**

**(e) Nuisance Organisms**

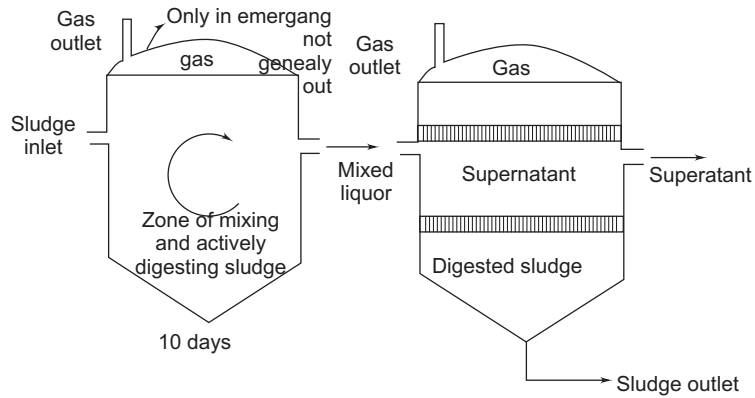
Remedy is to add to precipitate iron sulphide.

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**Reactor for Anaerobic Digestion**



**High rate digestors**



**Design (Standard Rate Digester)**

- Diameter 6 – 38 m
- Depth of tank 6 – 12m
- Lower slope 1 : 1 to 1 : 3
- Volume of digester

$$V = \left[ V_1 - \frac{2}{3}(V_1 - V_2) \right] t$$

V = Volume of digester

$V_1$  = Volume of raw sludge

$V_2$  = Volume of digested sludge. It may be taken equal to volume of digested sludge.

t = digestion period

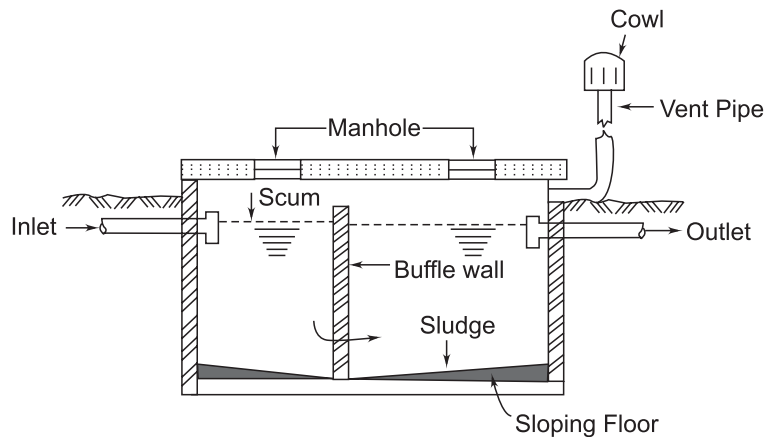
- Digestion period = 30 days

**Design Parameters for Oxidation Pond**

- Depth 1 – 1.5 m
- Detention time 15 – 30 days
- Pathogenic bacteria = 99.9%
- BOD removed = 80 – 90%
- Sludge accumulation is 2 – 5 cm/year
- Minimum depth of water 0.3 m

**Septic Tank**

- Designed as ordinary settling tank.



Septic Tank

**Design Parameters of Septic Tank**

- Flow of sewage 40 – 70 lpcd.
- Rate of accumulation = 30 lpc per year
- Detention time 12 – 36 hrs.
- Length/width ratio = 2 to 3

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- Depth 1.2 – 1.8 m

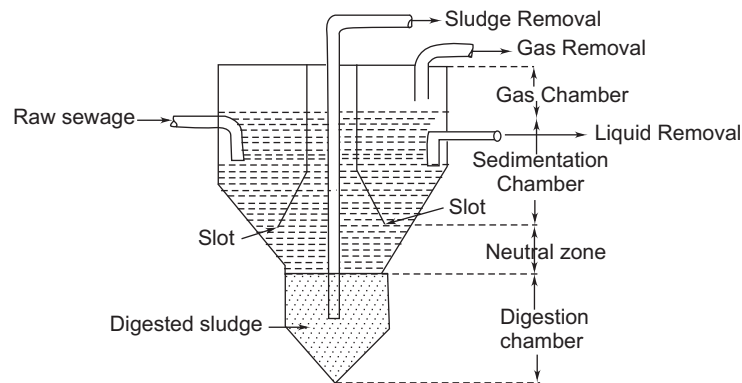
Cleaning period 6 month-1 year

- Volume of septic tank = (Sewage flow × Detention time) + (Sludge accumulation rate × cleaning period).
- Percolation rate is defined as the time in minute required for seepage of water through ground by 2.5 cm.

### Dispersion Trench

$$\text{Absorption area required} = \frac{Q_0 \text{ (l/day)}}{\left(\frac{204}{\sqrt{t}}\right) \text{ l/m}^2 \text{ / day}}$$

### Imhoff Tanks



### High Rate Anaerobic Systems

- Anaerobic Contact (AC) process
- Anaerobic filters (AF)
- Anaerobic fixed films (AFF) reactors
- Upflow Anaerobic Sludge Blanket (UASB) reactor



# Solid Waste Management

## 9

### **Type of solid waste**

- (i) Municipal wastes
- (ii) Industrial wastes
- (iii) Hazardous wastes

### **Disposal of Solid Waste**

Commonly employed methods for solid waste disposal, practised all over the world are:

#### **1. Disposal of Refuse by Open Dumping**

- Not an eco-friendly method
- Method is highly unacceptable

#### **2. Disposal of Refuse by Sanitary Land Filling**

Include: (1) site selection, (2) landfilling methods and operations, (3) occurrence of gases and leachate in landfills, and (4) movement and control of landfill gases and leachate.

#### **3. Leachate in Landfills**

- Leachate may be defined as liquid that has percolated through solid waste and has extracted dissolved or suspended materials from it.

#### **4. Landfilling Method at Sanitary Landfill Sites**

- Area method.
- Trench method.

#### **5. Depression Method**

#### **6. Disposal of Refuse by Composting**

- If the organic material excluding plastics, leather and rubber are separated from the solid wastes and are subjected to decomposition, either aerobically or anaerobically, the remaining end product is called compost and humus. The entire process involving both the separation and bacterial conversion of the organic solid wastes is known as *composting*.

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### Carbon-Nitrogen ratio

- Bacteria use nitrogen for building their cell structures (as proteins) and carbon for food (as energy).
- C/N is higher than the optimum, then nitrogen will be used up and carbon left over, thereby leaving the digestion of organic matter incomplete.
- C/N ratio is lower than the optimum, then the carbon will soon get exhausted and fermentation stop, leaving nitrogen in the digester which will combine with hydrogen to form ammonia ( $\text{NH}_3$ ).
- Optimum C/N ratio is 30-50.

### Indore Method

- Manual turning of piled up mass for its decomposition under **Aerobic** conditions.

### Bangalore Method

- This method is widely adopted by municipal authorities throughout the country. Its an **Anaerobic** method.

### Disposal of Refuse by Pulverization

- Refuse is pulverized in grinding machines, so as to reduce its volume.
- It is further disposed of by filling in trenches, or digested in open windrows or closed digestors.

### Disposal of Refuse by Incineration and Thermal Pyrolysis

#### Incineration

- Most effective methods of reducing the volume and weight.
- Estimation of oxygen requirement and heat balance are very vital.

#### Pyrolysis

- Combination of thermal cracking and condensation reactions in absence of oxygen.
- Also known as destructive distillation.

**Note:** Pyrolysis is an endothermic process – requiring continuous input of heat energy, while incineration is an exothermic process.

# Air Pollution

10

Air pollutants can be classified as follows:

1. Natural contaminants.
2. Aerosols (particulates)
3. Gases and vapours

## **Natural Contaminants**

From weeds, grasses and trees.

## **Aerosols**

• Aerosols refer to the dispersion of solid or liquid particles of microscopic size in gaseous media, such as dust, smoke, or mist.

The following are the various aerosols.

- (i) **Dust**
- (ii) **Smoke**
- (iii) **Mists**
- (iv) **Fog**
- (v) **Fumes**

## **Gases**

- (i) **Sulphur Dioxide**
- (ii) **Hydrogen Sulphide and Mercaptans**
- (iii) **Hydrogen Fluoride**
- (iv) **Oxides of Nitrogen**
- (v) **Carbon Monoxide**
- (vi) **Aldehydes**

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### Primary and Secondary Air Pollutants

Primary air pollutants are those emitted directly from identifiable sources.

**Example :**

1. Finer particles (less than 100  $\mu$ ) in diameter).
2. Coarse particles (greater than 100  $\mu$  in diameter).
3. Sulphur compounds.
4. Oxides of nitrogen.
5. Carbon monoxide.
6. Halogen compounds.
7. Organic compounds.
8. Radioactive compounds.

Secondary air pollutants are produced by the interaction among two or more primary pollutants, or by reaction with normal atmospheric constituents, with or without photoactivation.

**Examples**

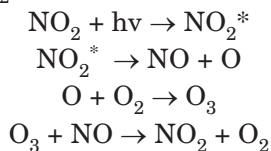
1. Ozone
2. Formaldehyde
3. PAN (peroxy acetyl nitrate)
4. Photochemical smog
5. Formation of acid mists ( $H_2SO_4$ )

Smog = Smoke + Fog
--------------------

**Note:** Mercaptans are often added to natural or manufactured gas supplies so that leakage of gas will be noticed.

### Photochemical Air Pollution

**Nitrogen Dioxide Photochemical Reaction:** Ultraviolet length energy is absorbed by  $NO_2$ .



**Sulphur Dioxide Photochemical Reaction:** Ozone ( $O_3$ ) may be formed in the atmosphere as a by product during photochemical oxidation of sulphur dioxide to sulphuric acid.

**Factors Affecting Photochemical Reactions**

- (i) Light intensity
- (ii) Hydrocarbon reactivity
- (iii) Ratio of hydrocarbons to nitric oxide
- (iv) Presence of light absorbers
- (v) Meteorological variables

**Effects of Photochemical Smog**

1. Eye irritation
2. Vegetation damage
3. Visibility reduction
4. Cracking of rubber
5. Fading of dyes

**Global Implications of Air Pollution**

- (a) Troposphere    00 to 11 km    15 to – 56°C
- (b) Stratosphere    11 to 50 km    – 56 to – 02°C
- (c) Mesosphere    50 to 85 km    – 02 to – 92°C
- (d) Thermosphere    85 to 500 km    – 92 to 1200°C

- 1 percent argon (Ar), 0.03 percent carbon dioxide (CO<sub>2</sub>)
- The layer of greatest interest in pollution control is the

**troposphere**
**Acid Rain**

- Acid rain (or acid deposition) results when gaseous emissions of sulfur oxides (SO<sub>x</sub>) and nitrogen oxides (NO<sub>x</sub>) interact with water vapor and sunlight and are chemically converted to strong acidic compounds (H<sub>2</sub>SO<sub>4</sub> and HNO<sub>3</sub>).

- ‘clean’ rain is slightly acidic. If pH of rain is less than 5.6, it is called acid rain.

**Global Warming**

- The green house gases act like a thermal blanket surrounding the earth as due to the presence of green house gases the heat remains within the atmosphere and does not escape out of it.

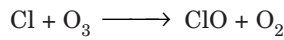
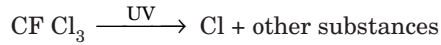
**The major green house gases are**

- (i) Carbon dioxide (CO<sub>2</sub>)
- (ii) Methane (CH<sub>4</sub>)
- (iii) Nitrous oxide (N<sub>2</sub>O)
- (iv) Chloroflouro carbon (CFC)

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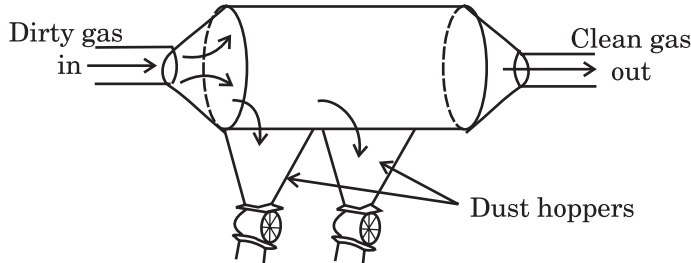
**Ozone Layer Depletion**

- Ozone layer is termed as *ozone umbrella*
- Primary reason for ozone layer depletion is CFC (Chlorofluoro carbon) or freons.
- Ozone is destroyed due to the photolytic reaction of CFC as shown below:



**Control Devices for Particulates**

**(1) Gravitational Settling Chambers**



**Gravitational Settling Chambers**

**(2) Centrifugal Gas Collectors**

**Cyclone Collectors**

- A cyclone collectors consists of a cylindrical shell, conical base, dust hopper, and an inlet where the dust-laden gas enters tangentially.

**Dynamic Precipitators**

**(3) Wet Scrubbers (or Collectors)**

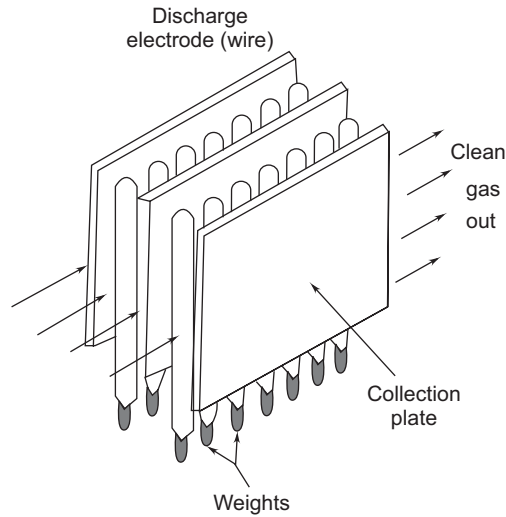
**(a) Spray Towers**

**(b) Wet Cyclone Scrubbers**

**(c) Venturi Scrubbers**

**(4) Electrostatic Precipitators**

- Extensively used in thermal power plants, pulp and paper industries, mining and metallurgical industries, iron and steel plants, chemical industries, etc.



High voltage electrostatic precipitators

**(5) Fabric Filters**

**Control Devices for Gaseous Pollutants**

**1. Adsorption Unit**

- (i) Fixed bed Adsorbers
- (ii) Moving bed Adsorbers
- (iii) Fluidized bed Adsorbers

**2. Absorption Units**

- (i) Spray Towers
- (ii) Plate or Tray Towers
- (iii) Packed Towers

**3. Condensation Units**

**4. Combustion (or Incineration) Units**

**Note:** Soot and carbon monoxide are by-products of combustion at low oxidation, while carbon dioxide is a by product of combustion in the presence of sufficient oxygen.

- (i) Direct-flame Combustion.
- (ii) Thermal Combustion:
- (iii) Catalytic Combustion:

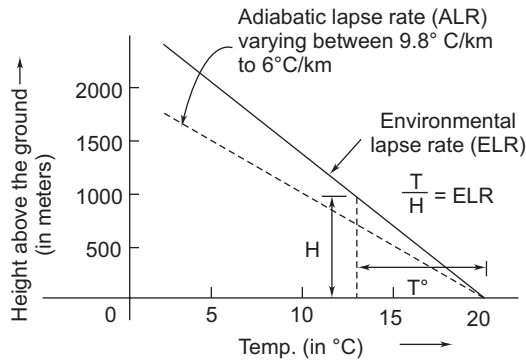
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**Dispersion of Air Pollutants into the Atmosphere**

**Lapse Rate :** In the troposphere, the temperature of the ambient (surrounding) air normally decreases with increase in the altitude (height). This rate of change of temperature is called lapse rate.

**(i) Environmental Lapse Rate/Ambient Lapse Rate (ELR):**

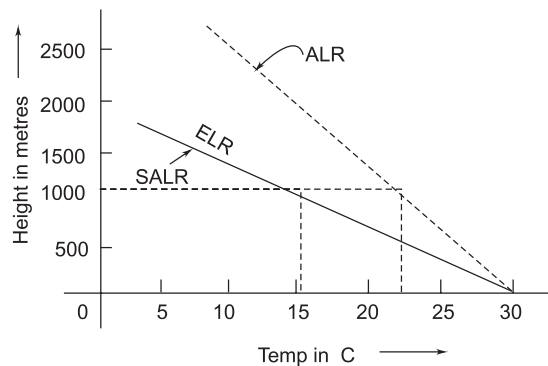
The lapse rate is known as the prevailing lapse rate, or the ambient lapse rate or the environmental lapse rate (ELR).



**(ii) Adiabatic lapse Rate:** Rate of decrease of temperature with height is called adiabatic lapse rate.

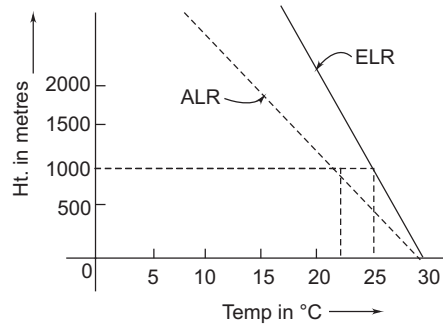
- Dry air expanding and cooling adiabatically cools at rate of 9.8°C per km and it is called dry adiabatic lapse rate.
- In saturated (wet) air, this rate is calculated to be 6°C per km, and is known as wet adiabatic lapse rate (due to release of latent heat or condensation of water vapour within saturated parcel of rising air).

**(a) Super Adiabatic Lapse Rate**



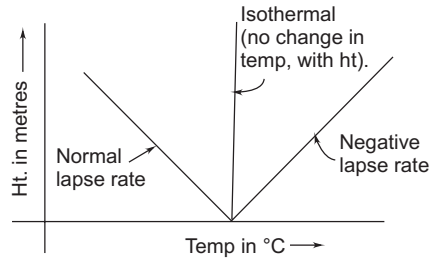


**(b) Sub-adiabatic Lapse Rate**



**(c) Neutral:** ELR and ALR are exactly equal.

**Negative Lapse Rate and Inversion**



There are two types of inversion:

- (i) Radiation inversion
- (ii) Subsidence inversion

**Plume Behaviour**

Plume is defined by the path taken by continuous discharge of gaseous effluents emitted from a stack or chimney.

**(i) Looping plume**

