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CIVIL ENGINEERING

For

UPSC Engineering Services Examination, GATE,

State Engineering Service Examination & Public Sector Examination.

(BHEL, NTPC, NHPC, DRDO, SAIL, HAL, BSNL, BPCL, NPCL, etc.)

ENVIRONMENTAL ENGINEERING-II
(WASTE WATER ENGINEERING)

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CHAPTER

1

Waste Water Characteristics

INTRODUCTION

- Waste waters are usually classified as industrial waste water or municipal waste water.
- Industrial waste water with characteristics compatible with municipal waste water is often discharged to the municipal sewers.
- Many industrial waste waters require pretreatment to remove non-compatible substances prior to discharge into the municipal system.
- Water collected in municipal waste water system contains a wide variety of contaminants. Commonly found contaminants with their source and environmental significance are given below:

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 wastes	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

Hence, it is very necessary to study the characteristics and behaviour of sewage, for its safe disposal. This study will also help us in determining the type of treatment required.

PHYSICAL CHARACTERISTICS

The most important physical characteristics of waste water is its turbidity, colour, odour and temperature.

Turbidity

Waste water is normally turbid, containing wastes from baths, faecal matter, pieces of papers, greases, vegetable debris, fruit skins, etc.

Colour

- The colour of waste water can normally be detected by the naked eye, and it refers to the age of waste water.
- Fresh waste water is usually gray or light brown; however, as organic compounds are broken down by bacteria. the dissolved oxygen in the waste water is reduced to zero and colour changes to black, this condition of waste water is said to be septic or stale.
- Some indutrial waste waters may also add colours to the domestic waste water.
- The common method of colour removal is by coagulation followed by sedimentation.

Odour

Anaerobic

- Odours in waste water usually are caused by gases produced by the decomposition of organic matter.
- The most characteristics odour of stale or septic waste water is that of hydrogen sulphide, which is produced by anaerobic microorganisms that reduce sulphates to sulphides.

Temperature

The average temperatures of sewage in India is 20°C, which is near about the ideal temperature for the biological activities.

CHEMICAL CHARACTERISTICS

Important chemical characteristics of waste water are listed below:

(i) Total solids, suspended solids and settleable solids.
(ii) pH value.
(iii) Chloride content.
(iv) Nitrogen content.
(v) Presence of fats, greases, and oils.
(vi) Sulphides, sulphates and H_2S gas.
(vii) Dissolved oxygen.
(viii) Chemical oxygen demand (COD).
(ix) Bio-chemical oxygen demand (BOD).
(x) Total organic carbon (TOC).
(xi) Theoretical oxygen demand (ThOD).

pH

small size

Total Solids, Suspended Solids and Settleable Solids

Solids present in waste water may be in four forms : suspended solids, dissolved solids, colloidal solids and settleable solids.

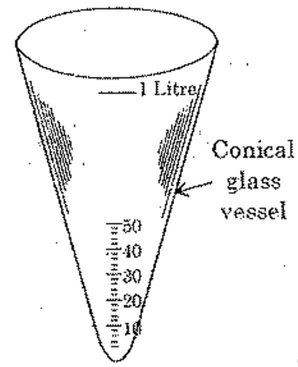
- Suspended solids, are those which remain floating in water.
- Dissolved solids are those which dissolve in waste water.
- Colloidal solids are finely divided solids remaining either in suspension or in solution.
- Settleable solids are that portion of solid matter which settles out, if the waste water is allowed to remain undisturbed for a period of 2 hours.
- The solids in waste water has organic solids as well as inorganic solids, which is about 45 and 55 per cent of total solids respectively.
- Inorganic matter consists of sand, gravel, debris, chlorides, sulphates etc, whereas organic matter consist of:
  (i) carbohydrates such as cellulose, cotton, fibre, sugar etc.
  (ii) fats and oils from kitchens, garages, shops etc.
  (iii) nitrogenous compounds like proteins, urea, fatty acids etc.

The amount of various kinds of solids present in waste water can be determined as follows:

(a) Total amount of solids can be determined by evaporating a known volume of waste water sample, and weighing the dry residue left. The mass of residue left divided by the volume of sample is total solids in mg/l.

(b) The suspended solids, also called non-filtrable solids, as they are retained on a filter of 1 μm pores. Thus weighing the dry residue left and dividing by volume of sample filtered will give suspended solids in mg/l.

(c) The quantity of settleable solids can be determined using Imhoff cone (figure). Waste water is allowed to stand in the cone for two hours and the quantity of solids settled down in the bottom is directly read out, which gives an approximate amount of settleable solids.



Imhoff cone

pH Value

- The determination of pH value is very important, as it gives an idea about certain treatments which depends upon pH value.
- The pH value can be measured by the help of potentiometer which measure the electrical potential exerted by the hydrogen ions, and thus indicating their concentrations.
- The alkalinity of fresh waste water sample is alkaline but as time passes it becomes acidic, because of the bacterial action in anaerobic or nitrification processes.

Chloride Content

- These are derived from the kitchen wastes, human faeces, and urinary discharges etc. The normal chloride content of domestic waste water is 120 mg/1, however, large amount of chlorides may enter from industries like ice-cream plants, meat salting etc., thus increasing the chloride content of waste water.
- The chloride content can be measured by titrating the sample of waste water with standard silver nitrate solution, using potassium chromate as an indicator.

Nitrogen Content

- The presence of nitrogen in waste water indicates the presence of organic matter, and may be found in the following forms.

(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]

Presence of Fats, Oils and Greases

- Fats and oils are compounds of alcohol or glycerol with fatty acids.
- Such matter form scum on the top of the sedimentation tanks and clog the voids of the filtering media. Therefore, they interferes with the normal treatment methods, and hence need proper detection and removal.
- The amount of fats and greases in waste water sample can be determined by evaporating it and then mixing the residual solids left, with ether (hexane). The solution is then poured off and evaporated, leaving behind the fats and greases as residue, which can be easily weighed.

Sulphides, Sulphates and Hydrogen Sulphide Gas

- Sulphides and sulphates are formed due to the decomposition of various sulphur containing substances present in waste water.
- This decomposition also leads to evolution of hydrogen sulphide gas, causing bad smells and odours, besides causing corrosion of concrete sewer pipes.
- The aerobic and facultative bacteria, oxidise the sulphur and its compounds present in sewage to initially form sulphides, which ultimately breakdown to form sulphate ions (SO_4^{--}), which is a stable and unobjectionable end product.
- The initial decompositions is associated with formation of H_2S gas, which also ultimately gets oxidised to form sulphate ions.

Dissolved Oxygen

- Dissolved oxygen is required for the respiration of aerobic micro-organisms as well as all other aerobic life forms.
- The dissolved oxygen in fresh waste water depends upon temperature. If the temperature of sewage is more, the 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*.
- Dissolved oxygen less than 4 ppm is detrimental to the survival of fish.
- The D.O. content of waste water is determined by the ***Winkler's Method***.

Chemical Oxygen Demand (COD)

- The COD test is used to measure the content of organic matter of waste water. Both biodegradable and non biodegradable.
- The oxygen equivalent of organic matter that can be oxidised is measured by using a strong chemical oxidising agent in an acidic medium.
- Potassium dichromate has been found to be excellent for this purpose.
- This test is also sometimes called dichromate-oxygen demand test.
- $(COD-BOD_u) \equiv$ Nonbiodegradable organics.

Theoretical Oxygen Demand (ThOD)

If the chemical formula and the quantity of all organic matter present in the sewage is known, the exact amount of oxygen required to oxidise then can be calculated stoichiometrically. This is called theoretical oxygen demand (ThOD).

For most practical cases, COD = ThOD (taken) $\left[\begin{array}{l}\text{However, generally} \\ \text{ThOD} > \text{COD} > \text{BOD} > \text{TOC}\end{array}\right]$

COD = 0.8 ThOD for domestic sewage

Total Organic Carbon (TOC)

It is another method of expressing the organic matter in terms of carbon content. The following example will illustrate it.

Example 1

Calculate theoretical oxygen demand and organic carbon concentration of water that contains 200 mg/l of glucose ($C_6H_{12}O_6$) and 25 mg/l of benzene (C_6H_6).

Sol.

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$

$$C_6H_6 + 7.5\ O_2 \longrightarrow 6CO_2 + 3H_2O$$

$$\text{ThOD} = \frac{192}{180}\times 200 + \frac{240}{78}\times 25 = 290.2 \text{ mg/l}$$

$$\text{TOC} = \frac{72}{180}\times 200 + \frac{72}{78}\times 25 = 80 + 23.08 = 103.08 \text{ mg/l.}$$

BIO-CHEMICAL OXYGEN DEMAND

Bio-chemical oxygen demand is used as a 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:

(a) Carbonaceous organic materials.

(b) Oxidisable nitrogen derived from nitrite, ammonia and other organic nitrogen compounds which serves as food for specific bacteria (Nitrosomonas and nitrobacter).

(c) Chemical reducing compounds e.g. Fe^{2+}, SO_3^{2-} (sulfites), S^{2-} (sulfide) which are oxydised by dissolved oxygen.

For domestic sewage, nearly all oxygen demand is due to carbonaceous organic material and is determined by BOD test.

Note: When nitrogeneous matter is also to be removed in treatment process. Nitrogeneous demand is also found out. This is called N-BOD (i.e. O_2 required for conversion of nitrogeneous matter to nitrate). Removal of nitrogen from the system is achieved by 1st oxydising the nitrogeneous organic matter to nitrate (i.e. nitrification) and then denitrifying the nitrate to release nitrogen gas (N_2) which goes out of the waste water.

The BOD can be determined by diluting a known volume of a sample of waste water with a known volume of aerated pure water, and then calculating the D.O. of this diluted sample. The diluted sample is then incubated for 5 days at 20°C. The D.O. of the diluted sample, after this period of incubation, is again calculated. The difference between the initial D.O. value and the final D.O. value will indicate the oxygen consumed by the diluted sewage sample in 5 days. The BOD in ppm is then calculated by using the equation:

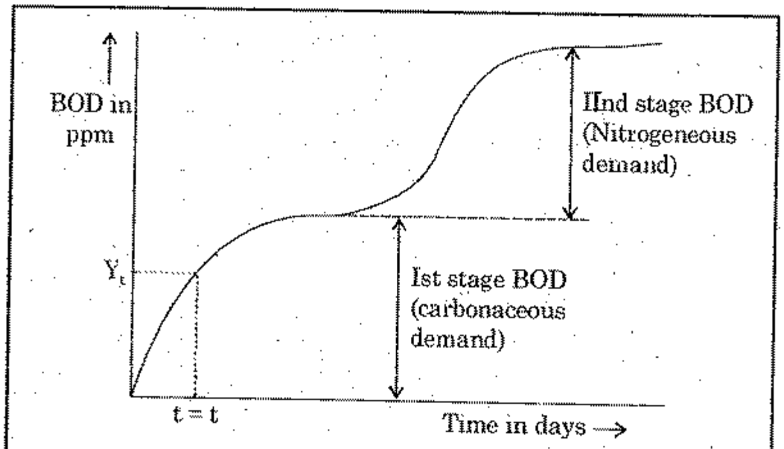
$$\text{BOD or BOD}_5 = \text{D.O. consumed in the test by diluted sample} \times \left[\frac{\text{Vol. of the diluted sample}}{\text{Vol. of the undiluted sewage sample}}\right]$$

= [D.O$_i$ − D.O$_f$] × Dilution factor

The above factor in the bracket is called dilution factor.

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

- The first demand occurs due to oxidation of organic matter and is called **carbonaceous demand** or first stage demand, and later demand occurs due to biological oxidation of ammonia, and is called **nitrogeneous demand** or second stage demand.
- However, the term BOD usually mean the first stage BOD.

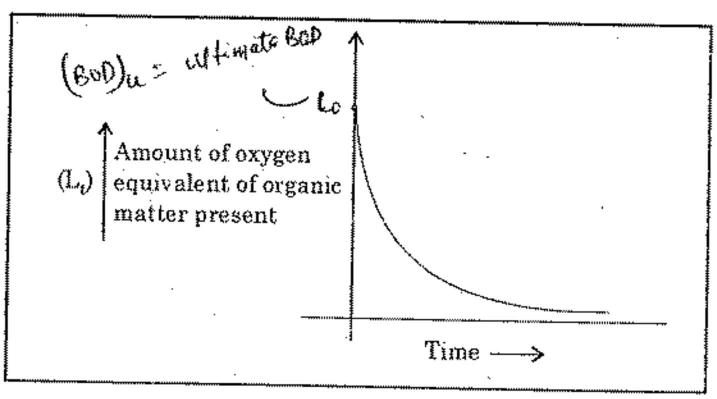


BOD curve

Nitrogenous demand starts only after 5–8 days because the reproduction rate of nitrification bacteria is slow.

Note: Nitrification bacteria are autotropes. They derive carbon for their growth from CO_2. Hence they have to spend energy in reducing 'CO_2' to 'C'. Thus energy available for their reproduction is less thereby growth rate is less. Carbonaceous matter oxidising bacteria are *hetrotropes*. They derive carbon from organic matter directly. Hence energy is not spent in getting carbon. Thereby their reproduction rate is more.

Reaction Kinetics



L_t = amount of organic matter present at time t

$$\boxed{\frac{dL_t}{dt} = -kL_t}$$ ← 1st order reaction

where, k = reaction constant

$$\int_{L_0}^{L_t} \frac{dL_t}{L_t} = \int_0^t -k\,dt$$

$$\Rightarrow \quad \log_e L_t - \log_e L_0 = -k\,(t - 0)$$

$$\log_e \left(\frac{L_t}{L_0}\right) = -kt$$

$$\Rightarrow \quad \boxed{L_t = L_0 e^{-kt}} \qquad \ldots\ldots \text{(i)}$$

From (i) we have
$$2.303 \log_{10}\left(\frac{L_t}{L_0}\right) = -kt$$

$$\Rightarrow \quad \log_{10}\left(\frac{L_t}{L_0}\right) = \frac{-kt}{2.303}$$

$$\Rightarrow \quad \boxed{L_t = L_0 10^{-k_D t}}$$

where
$$\boxed{K_D = \frac{K}{2.303} = 0.434\,k}$$

• k depends upon type of organic matter and temp.

$$\therefore \quad BOD_t = L_0 - L_t$$

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

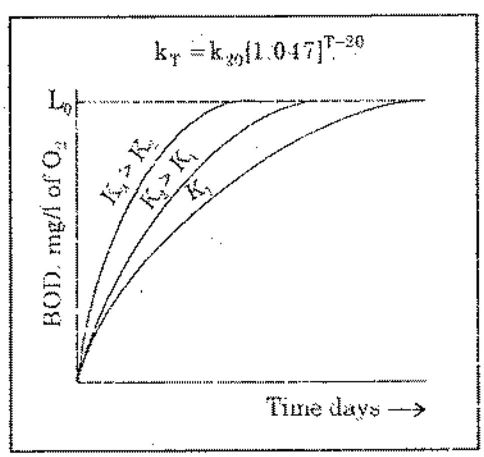
$$\boxed{BOD_t = L_0(1 - 10^{-k_D t})}$$

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

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

- k_D is also sometimes called deoxygenation constant.

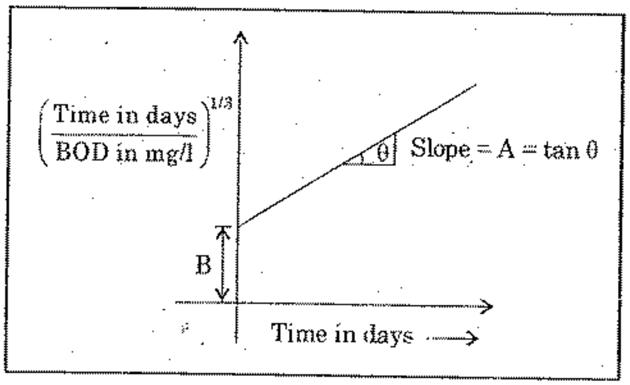
Water type All data in 20°C	**k_D value**
Tap water	< 0.05 per day
Surface water	0.05 – 0.1 per day
Municipal sewage	0.1 – 0.15 per day
Treated sewage	0.05 – 0.1 per day



If the value of constant is given more than the normal range, it is understood that it is given in terms of base 'e'.

- The normal range of BOD for municipal sewage is 200 – 500 mg/l.

Estimation of k_D



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

Population Equivalent

- Average standard BOD of domestic sewage is 80 gms per person per day.
- The number of person which produce the amount of BOD at the rate of 80 gms per person per day equal to that produced by industrial sewage is called population equivalent of industrial sewage.

Relative Stability (S)

- Relative stability (S) is calculated as:

$$S = \frac{O_2 \text{ available in effluent}}{\text{Total } O_2 \text{ required for Ist stage BOD (i.e. BOD ultimate)}}$$

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

Where t_{20}/t_{37} = time in days for a sewage sample to decolourise a sample of methylene blue solution when incubated at 20° and 37° respectively.

- Decolourisation is caused by enzymes produced by anaerobic bacteria.
- The sooner the decolourisation takes place, the earlier the anaerobic condition develops which means lessers availability of oxygen.
- The decolourisation takes place in less than a day at 20°C, the effluent may be treated as unstable. If sample does not decolourise in 4 days it will be taken as stable and thus the effluent can be discharged into the river.
- This relative stability check is a performance check test for the treatment process.

Note: If BOD of domestic sewage is to be found out, we collect samples.
(i) To prevent biological action from taking place preservatives like chloroform, formaldehyde, H_2SO_4 are added in the bottle. (ii) The samples collected at different times have different BOD and all such samples are mixed in poroportion to the rate of flow at the time of collection. This is done to get a representative sample. (iii) Physical and chemical characteristics of sewage vary from top to bottom depth of sewage. So, a representative sample from a point where turbulence is thoroughly mixing up the sewage is called grab sample.

Example 1

Following observations were made on a 3% dilution of waste water:

DO of aerated water used for dilution = 3 mg/l

DO of diluted sample after 5 days of incubation = 0.8 mg/l

DO of original sample = 0.6 mg/l.

Calculate 5-day BOD and ultimate BOD, take $k_D = 0.1$ day^{-1}.

Sol. 3% dilution means 3 ml of sample is mixed with 97 ml of pure water.

$$\text{DO of diluted sample} = \frac{3 \times 0.6 + 97 \times 3}{100} = 2.928 \text{ mg}/l$$

$$BOD_5 = (2.928 - 0.8) \times \frac{100}{3} = 70.9 \text{ mg}/l$$

$$L_0 = \frac{L_t}{1 - 10^{-k_D t}} = \frac{70.93}{1 - 10^{-0.1 \times 5}} = 103.7 \text{ mg}/l$$

Example 2

Determine the maximum upper limit of BOD of a glucose solution of concentration 300 mg/l.

Sol. $\underset{180\text{ gm}}{C_6H_{12}O_6} + \underset{192\text{ gm}}{6O_2} \longrightarrow 6CO_2 + 6H_2O + \text{energy}$

$$\text{ThOD per 300 mg of glucose} = \frac{192}{180} \times 300 = 321 \text{ mg}/l$$

$$\text{ThOD} = \text{max upper limit of BOD}$$

Example 3

The average daily waste flow from a factory in an industrial estate is 75 m^3 of stearic acid ($C_{17}H_{35}COOH$) of concentration 150 mg/l and 9 m^3 of capric acid ($C_9H_{19}COOH$) of concentration 500 mg/l. Calculate the theoretical oxygen demand and 5 day BOD of the combined wastes. Calculate the minimum amount of nitrogen and phosphorus required in the waste stream for it to be amenable to biological oxidation treatment. Assume that BOD = 0.7 ThOD and Atomic weights : H = 1, C = 12, N = 14, O = 16 and P = 32. BOD_5 : N : P ratio of 100 : 5 : 1 is required in waste water for it to be amenable to biological oxydation treatment.

Sol. Stearic acid oxidation

$$\underset{284}{C_{18}H_{36}O_2} + \underset{832}{26O_2} \rightarrow \underset{792}{16CO_2} + \underset{324}{18H_2O}$$

1 part of stearic acid requires $\frac{832}{284}$ of oxygen for oxidation to carbon dioxide and water.

$$\text{Quantity of stearic acid} = \text{flow} \times \text{concentration}$$

$$= 75000 \times 150 \times 10^{-3} \text{ g} = 11250 \text{ gm}$$

Therefore, 11250 grams of stearic acid will require $11250 \times \frac{832}{284}$ oxygen = 32962.5 gm

∴ Theoretical oxygen demand (ThOD) = 32962.5 gm

BOD_5 = 0.7 ThOD = 0.7 × 32962.5 gm = 23073.8 gm

Capric acid oxidation:

$$\underset{172}{C_{10}H_{20}O_2} + \underset{448}{14O_2} \rightarrow \underset{440}{10CO_2} + \underset{180}{10H_2O}$$

1 part of capric acid required $\frac{448}{172}$ of oxygen for oxidation

Quantity of capric acid = 9000 × 500 × 10^{-3} grams

4500 grams of capric acid will require 4500 × $\frac{448}{172}$ grams = 11745 gm

BOD of capric acid = 11745 × 0.7 = 8221.5 gm

Total BOD of waste in kg = 23.07 + 8.22 = 31.29 kg

Total ThoD of waste in kg = 33.96 + 11.75 = 45.71 kg

Biological degradation of organic matter can only occur if a minimum ratio of BOD_5 : N : P of 100 : 5 : 1 is satisfied. From this condition,

The required amount of nitrogen = $\frac{5}{100}$ × 31.29 kg = 1.57 kg

The required amount of phosphorus = $\frac{1}{100}$ × 31.29 kg = 0.31 kg

Example 4

The quantity and strength of biological treatable wastewaters are usually related to the number of persons that would be required to contribute an equivalent quantity of wastewater and are expressed as hydraulic and BOD_5 population equivalents respectively. If a dairy processing factory produces an average of 246 m^3/d of wastewater with a BOD_5 of 1400 mg/l and assuming that per capita daily sewage flow is 110 litre, and that the per capita daily BOD_5 contribution is 40 grams, calculate the BOD_5 equivalent population and the hydraulic equivalent population.

Sol. BOD equivalent population = $\frac{246 \times 1400 \times 1000}{40 \times 1000}$ = 8610

Hydraulic equivalent population = $\frac{246 \times 1000}{110}$ = 2236 persons

Note: Sometimes seeded water is used for dilution in BOD test. The seeded water is the water with seeding of mixed bacterial culture.

In that case, for a seeded sample:

$$BOD_5 = \frac{(D_1 - D_2) - (B_1 - B_2)(1 - P)}{P}$$

where, D_1 = DO of diluted sample immediately after dilution mg/l

D_2 = DO of diluted sample after 5 days (120 hours) mg/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

= Volume of undiluted sample/volume of diluted sample

• Generally used for Chlorinated waste

Note : 20 ml of waste and 280 ml of water

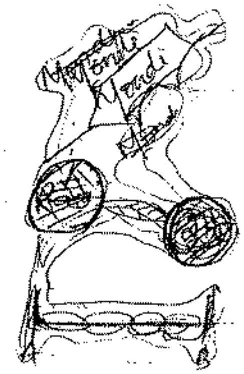
Let initial DO of waste = x mg/l

and initial DO of water = y mg/l

$$\text{dissolved oxygen of (waste + water)} = \frac{x \times 20 + y \times 280}{300}$$

Let finally it is x′ and y′

$$\frac{x' \times 20 + y' \times 280}{380} \text{ mg/l}$$



$$\text{DO differ} = \frac{(x - x') \times 20 + (y - y') \times 280}{300}$$

$$\boxed{BOD_5 = (x - x')}$$

$$\frac{(\text{DO differ}) \times 300 - (y - y') \times 280}{20} = (x - x')$$

$$\frac{(\text{DO diff.})_{mix} - (y - y')(1 - P)}{P}$$

Example 5

A control sample bottle containing seeded dilution water has a drop of 1.5 mg/l in its DO over 5 days incubation. The BOD bottle (300 ml with 20.0 ml of waste water and the remaining seeded water) has a DO drop of 6.8mg/*l*. Compute the BOD_5 of the sample.

Sol.

$$BOD_5(\text{at } 20°C) = \frac{(D_1 - D_2) - (B_1 - B_2)(1 - P)}{P}$$

$$= \frac{6.8 - 1.5\left(1 - \frac{20}{300}\right)}{\frac{20}{300}} = 81 \text{ mg/l}$$

Example 6

For a waste water the BOD_5 at 20°C is found to be 200 mg/l. For same waste BOD_5 at 30°C will be? The reaction constant 'K' (to the base *e*) is 0.2 per day.

Sol: BOD_5 at 20°C $= L_0[1 - e^{-K \times 5}]$

BOD_5 at 30° $= L_0[1 - e^{-K'5}]$

$L_0 = BOD_u$ (Remain constant)

$200 = L_0[1 - e^{-5K}]$ ...(i)

$BOD_5 = L_0[1 - e^{-5K'}]$ ...(ii)

From (i) and (ii)

$$\frac{200}{1 - e^{-5K}} = \frac{BOD_5}{1 - e^{-5K'}}$$

$$\frac{1-e^{-5K'}}{1-e^{-5K}} = \frac{BOD_5}{200}$$

But $K' = K(1.047)^{30-20} = 0.2\,[1.047]^{10}$

$K' = 0.316$

$$\Rightarrow \quad BOD_5 = 200\left[\frac{1-2.72^{-5\times 0.316}}{1-2.72^{-5\times 0.2}}\right]$$

$$BOD_5 = \frac{0.794}{0.632}\times 200$$

$BOD_5 = 251.26$ mg/l

OBJECTIVE QUESTIONS

1. Which of the following pairs is not correctly matched?

   (a) BOD : Strength of sewage

   (b) Methane : Product of anaerobic decomposition

   (c) COD : Biodegradability of waste-water

   (d) Nitrate : Methaemoglobinemia

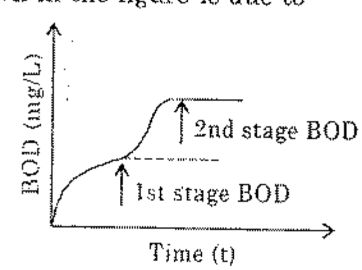
2. The following data pertain to a sewage sample:
   Initial DO = 10 mg/L
   Final DO = 2 mg/L
   Dilution to 1%

   The BOD of the given sewage sample is

   (a) 8 mg/L (b) 10 mg/L

   (c) 100 mg/L (d) 800 mg/L

3. The second stage BOD as shown in the figure is due to



   (a) experimental error (b) increased activity of bacteria

   (c) nitrification demand (d) interference by certain chemical reactions

4. The purpose of proportional weir at the effluent end of a channel type grit removal unit is to

   (a) provide easy passage of solid particles

   (b) measure the rate of flow in the channel

   (c) keep the depth of flow in the channel above a certain value

   (d) maintain constant mean velocity in the channel

5. A 2% solution of a sewage sample is kept at an incubation temperature of 20°C. If initial DO (Dissolved Oxygen) and final DO values after 5 days' incubation period are 8.5 mg/L and 5.5 mg/L respectively, then the BOD will be

(a) 50 mg/L (b) 150 mg/L
(c) 250 mg/L (d) 350 mg/L

6. Consider the following pairs of treatment units and impurities removed:

1. Grit chamber : Sand and silt
2. Detritus tank : Organic matter
3. Primary sedimentation : Suspended tank impurifier
4. Aeration tank of grease : Oil and activated sludge process plant

Which of these pairs are correctly matched?

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

7. For a waste, the 5-day BOD at 20°C is found to be 200 mg/L. For the same waste, 5-day BOD at 30°C will be

(a) less than 200 mg/L (b) more than 200 mg/L
(c) 200 mg/L (d) zero, as the bacteria cannot withstand such a high temperature

8. The ultimate BOD value of a waste

(a) increases with temperature
(b) decreases with temperature
(c) remains the same at all temperatures
(d) doubles with every 10°C rise in temperature

9. A certain waste has a BOD of 162 mg/L and its flow is 1000 cubic metres per day. If the domestic sewage has a BOD of 80 gram per capita, then the population equivalent of the waste would be

(a) 20.25 (b) 1296
(c) 2025 (d) 12960

10. The correct statement of comparison of ultimate BOD, COD, Theoretical Oxygen Demand (ThOD) and 5-day BOD (BOD_5) is

(a) $BOD_u > COD > ThOD > BOD_5$ (b) $COD > ThOD > BOD_u > BOD_5$
(c) $ThOD > COD > BOD_u > BOD_5$ (d) $COD > BOD_u > BOD_5 > ThOD$

11. Match **List-I** (Different forms of nitrogen in water) with **List-II** (Inferences) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Nitrate nitrogen	1. Unsatisfactory microbial activity
B. Total nitrogen	2. Satisfactory microbial activity
C. Nitrite nitrogen	3. Eutrophication may result
D. Ammonia nitrogen	4. Recent organic pollution

Codes:

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

12. Which one of the following pairs is not correctly matched?
   (a) BOD/COD = 0 : Waste-water is toxic
   (b) BOD/COD $\leq$ 0.2 : Acclimatization of seed is necessary
   (c) BOD/COD $\geq$ 0.6 : Waste-water is non biodegradable
   (d) BOD = COD = 0 : Waste-water is devoid of organic matter

13. In aerobic conditions, the microbial decomposition of organics results in the formation of which one of the following?
   (a) Stable and objectionable end products
   (b) Unstable and objectionable end products
   (c) Unstable and acceptable end products
   (d) Stable and unobjectionable end products

14. A waste water sample of 2 mL is made upto 300 mL in BOD bottle with distilled water. Initial DO of the sample is 8 mg/L and after 5 days it is 2 mg/L. What is its BOD?
   (a) 894 mg/L (b) 900 mg/L
   (c) 300 mg/L (d) 1200 mg/L

15. Presence of nitrogen in a waste water sample is due to the decomposition of
   (a) carbohydrates (b) proteins
   (c) fats (d) vitamins

16. Match **List-I** with **List-II** and select the correct answer using the codes given below the lists:

List-I	List-II
A. Suspended solids	**1.** May cause eutrophication
B. Nutrients	**2.** Toxic, may interfere with effulent reuse
C. Heavy metals	**3.** May interfere with effluent reuse
D. Dissolved inorganic solids	**4.** Cause sludge deposits

Codes:

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

17. A heterotroph is an organism that obtains
   (a) its cell carbon from an inorganic source
   (b) its energy from the oxidation of simple inorganic compounds
   (c) its cell carbon as well as its energy from organic matter
   (d) its energy from a natural ecosystem

18. Which one of the following can fix atmospheric nitrogen?

(a) Green algae (b) Blue green algae
(c) Red algae (d) Brown algae

19. What is the theoretical oxygen demand of 300 mg/L glucose solution?

(a) 300 mg/L (b) 320 mg/L
(c) 350 mg/L (d) 400 mg/L

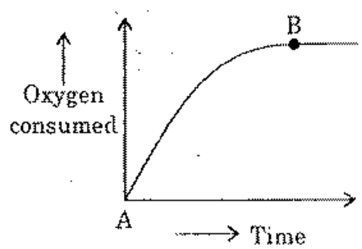
20. Which one of the following types of samples is relevantly employed for the design of wastewater treatment plant?

(a) Grab sample (b) Composite sample
(c) Integrated sample (d) Any sample

21. A 12.5 mL sample of treated waste-water requires 187.5 mL of odor-free distilled water to reduce the odor to a level that is just perceptible. What is the threshold odor number (TON) for the wastewater sample?

(a) 0.07 (b) 1.07
(c) 15 (d) 16

22. The figure below shows, BOD curve when the experiment was conducted at 20°C. If the experiment is conducted at 30°C, then the portion AB of the curve



(a) shifts to the left (b) shifts to the right
(c) remains unchanged (d) shrinks

23. Consider the following parameters:

1. Fixed solids
2. Volatile solids
3. Chemical oxygen demand
4. Biochemical oxygen demand
5. Dissolved oxygen

Which of these parameters are taken into consideration for determining organic strength of a waste?

(a) 1, 2 and 3 (b) 2, 3 and 4
(c) 3, 4 and 5 (d) 1, 4 and 5

24. The five-day BOD of a waste water sample is 150 mg/*l* at 20°C. The reaction constant 'k' (to the base 'e') is 0.2 per day. The ultimate first stage BOD is (e' = 2.72)

(a) 225.5 mg/*l* (b) 237.2 mg/*l*
(c) 240 mg/*l* (d) 245.5 mg/*l*

25. The dissolved oxygen sag curve manifests

(a) BOD demand
(b) BOD deficit
(c) variation of dissolved oxygen saturation
(d) dissolved oxygen deficit

26. What is the zone where fish life might tend to progressively dwindle when was the water is discharged into a river, called?

(a) Zone of degradation
(b) Zone of active decomposition
(c) Zone of mixing
(d) Zone of recovery

27. **Assertion (A):** One of the major differences between the water supply treatment and waste water treatment is the biological treatment given to the waste water and not to the normal water.

Reason (R): Biodegradable organic mater concentration in waste water is very high while it is nearly nil in case of normal water.

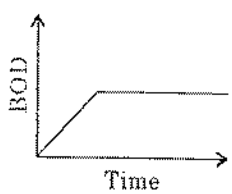
28. **Assertion (A):** For any waste water, to ascertain its polluting capacity, estimation of BOD is more relevant than that of COD.

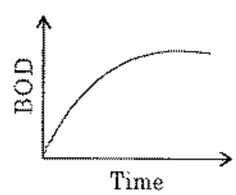
Reason (R): BOD gives the oxygen demand at the stated temperature condition.

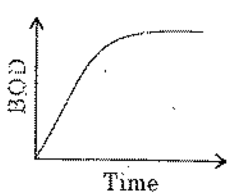
29. The measurement of non-biodegradable organic content is usually carried out in the terms of

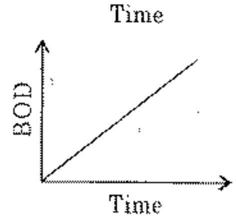
(a) BOD
(b) DO
(c) TOC
(d) COD

30. Which of the following is the correct representation of BOD in mg/*l* exerted against time in days?

(a) 

(b) 

(c) 

(d) 

31. Which one of the following is not biodegradable organic matter?

(a) Carbohydrates
(b) Fats
(c) Alcohols
(d) Petrol

32. What does high COD to BOD ratio of an organic pollutant represent?

(a) High biodegradability of the pollutant
(b) Low biodegradability of the pollutant
(c) Presence of free oxygen for aerobic decomposition
(d) Presence of toxic material in the pollutants

33. What is the BOD_5 at 20°C of a waste that yields an oxygen consumption of 2 mg/l from a 0.5% diluted sample?

(a) 50 mg/l (b) 400 mg/l
(c) 200 mg/l (d) 250 mg/l

34. What are the values of the permissible BOD_5 at 20°C, 'oil and grease' and per cent sodium respectively of treated municipal sewage for land irrigation?

(a) 10 mg/l, 20 mg/l, 60 (b) 60 mg/l, 20 mg/l, 100
(c) 20 mg/l, 100 mg/l, 60 (d) 20 mg/l, 60 mg/l, 100

35. Biochemical oxygen demand (BOD) is quoted at which temperature?

(a) 25°C (b) 20°C
(c) 15°C (d) 10°C

36. Match **List-I** (Characteristics of sewage discharged into inland waters) with **List-II** (Allowable limt, mg/L) and select the correct answer using the codes given below the lists:

List-I	**List-II**
A. BOD_5	1. 250
B. COD	2. 30
C. Oil and Grease	3. 20
D. Total Suspdended Solids	4. 10
	5. 5
	6. 3

Codes:

	A	B	C	D
(a)	2	5	4	2
(b)	4	1	6	4
(c)	3	1	4	2
(d)	2	1	6	3

37. Water samples (X and Y) from two different sources were brought to the laboratory for the measurement of dissolved oxygen (DO) using modified Winkler method. Samples were transferred to 300 mL BOD bottles. 2 mL of $MnSO_4$ solution and 2 mL of alkaliodideazide reagent were added to the bottles and mixed. Samples X developed a brown precipitate, whereas sample Y developed a white precipitate. In reference to these observations, the correct statement is

(a) both the samples were devoid of DO
(b) sample X was devoid of DO while sample Y contained DO
(c) sample X contained DO while sample Y was devoid of DO
(d) both the samples contained DO

38. A portion of waste water sample was subjected to standard BOD test (5 days, 20°C), yielding a value of 180 mg/L. The reaction rate constant (to the base 'e') at 20°C was taken as 0.18 per day. The reaction rate constant at other temperature may be estimated by $k_T = k_{20}\,(1.047)^{T-20}$. The temperature at which the other portion of the sample should be tested, to exert the same BOD in 2.5 days, is

(a) 4.9°C (b) 24.9°C
(c) 31.7°C (d) 35.0°C

39. Total Kjeldahl nitrogen is a measure of
   (a) total organic nitrogen
   (b) total organic and ammonia nitrogen
   (c) total ammonia nitrogen
   (d) total inorganic and ammonia nitrogen

40. In aerobic environment, nitrosomonas convert
   (a) NH_3 to NO_2
   (b) NO_2^- to NO_3^-
   (c) NH_3 to N_2O
   (d) NO_2^- to HNO_3

41. **List-I** contains some properties of water/waste water and **List-II** contains list of some tests on water/waste water. Match **List-I** with **List-II** and select the correct answer using the codes given below the lists:

	List-I		List-II
A.	Suspended solids concentration	**1.**	BOD
B.	Metabolism of biodegradable organics	**2.**	MPN
C.	Bacterial concentration	**3.**	Jar test
D.	Coagulant dose	**4.**	Turbidity

Codes:

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

42. To determine the BOD_5 of a waste water sample, 5, 10 and 50 mL aliquots of the waste water were diluted to 300 mL and incubated at 20°C in BOD bottles for 5 days. The results were as follows.

S.No.	Waste - water volume, mL	Initial DO, mg/L	DO after 5 days, mg/L
1.	5	9.2	6.9
2	10	9.1	4.4
3.	50	8.4	0.0

Based on the data, the average BOD_5 of the waste water is equal to
   (a) 139.5 mg/L
   (b) 126.5 mg/L
   (c) 109.8 mg/L
   (d) 72.2 mg/L

43. A wastewater sample contains $10^{-5.6}$ mmol/L of OH^- ions at 25°C. The pH of this sample is
   (a) 8.6
   (b) 8.4
   (c) 5.6
   (d) 5.4

44. The 5-day BOD of a wastewater sample is obtained as 190 mg/L (with $k = 0.01\ h^{-1}$). The ultimate oxygen demand (mg/L) of the sample will be
   (a) 3800
   (b) 475
   (c) 271
   (d) 190

45. Consider the following statements :

1. Domestic wastewater can be inclusive of marginal inputs from industry.
2. Population equivalent is the term used to compare the pollution potential of different industries.
3. Sullage is the waste water needed to be treated by biological waste water treatment units.
4. Sanitary sewage includes both domestic and industrial sewage.

Which of these statement is/are correct?

(a) 1 and 2 (b) 2 and 4

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

46. A sample of sewage is estimated to have a 5 day 20°C BOD of 250 mg/l. If the test temperature be 30°C, in how many days will the same value of BOD be obtained?

(a) 1.5 days (b) 2.5 days

(c) 3.3 days (d) 7.5 days

47. Statement I : The BOD test is conducted for 5 day at 20°C.

Statement II : The amount of oxygen utilized by micro-organisms anaerobically is called BOD.

ANSWERS

1. (c)	**13. (d)**	**25. (d)**	**37. (c)**
2. (d)	**14. (b)**	**26. (a)**	**38. (d)**
3. (c)	**15. (b)**	**27. (a)**	**39. (b)**
4. (d)	**16. (a)**	**28. (b)**	**40. (a)**
5. (b)	**17. (c)**	**29. (d)**	**41. (b)**
6. (d)	**18. (b)**	**30. (b)**	**42. (c)**
7. (b)	**19. (b)**	**31. (d)**	**43. (d)**
8. (c)	**20. (a)**	**32. (b)**	**44. (c)**
9. (c)	**21. (d)**	**33. (b)**	**45. (b)**
10. (c)	**22. (a)**	**34. (a)**	**46. (c)**
11. (a)	**23. (c)**	**35. (b)**	**47. (c)**
12. (c)	**24. (b)**	**36. (c)**	

CHAPTER

2

Biochemical Reactions in Treatment of Waste Water

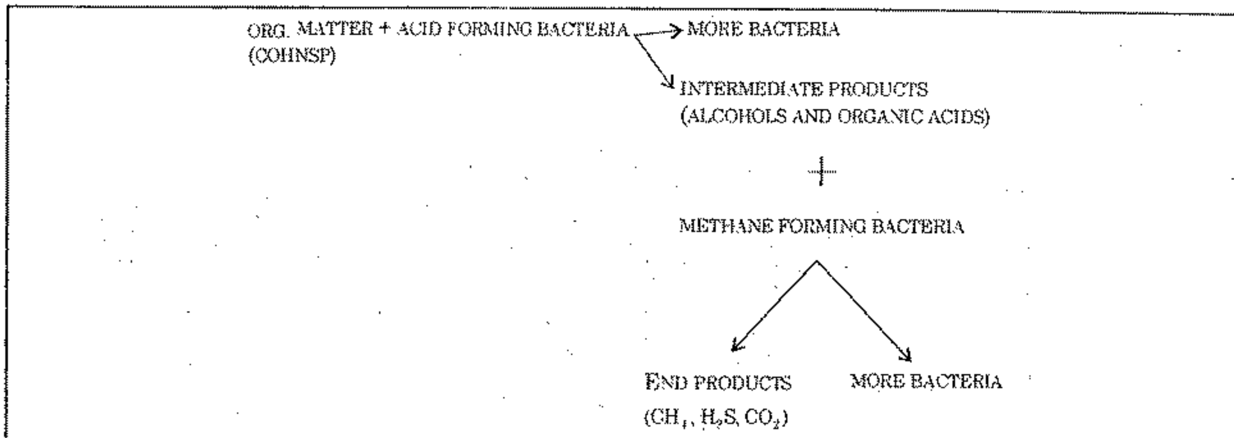
AEROBIC AND ANAEROBIC REACTIONS

- The Aerobic and Anaerobic are the two basic forms of biological stabilisation reactions whose occurrence is dependent upon the availability or otherwise of dissolved oxygen.
- *Aerobic reactions* take place in the presence of free oxygen and produce reasonably stable inorganic end products with relatively low energy contents.
- A considerable portion of the organic matter is synthesised to new microbial cells.
- The reaction provides high degree of stabilisation although the synthesised microorganisms result in the formation of large volumes of sludge which require further treatment.
- *Anaerobic reactions* occur only in the absence of free oxygen.
- They are more complex because they occur in two stages carried out by different species of bacteria.
- Acid-forming bacteria initially convert complex organics into organic acids and alcohols. At this point methane-forming bacteria convert the acids and alcohols into methane and other end products such as hydrogen sulphide.
- The end products of anaerobic reactions still contain considerable amounts of energy, notably in the methane.
- Because of the lower release of energy in anaerobic reactions, the synthesis of new cells is very much less than in aerobic reactions.
- This means that there is less sludge from anaerobic stabilisation of a wastewater than from aerobic stabilisation of the same wastewater.
- Anaerobic reactions are much slower than aerobic reactions and do not usually remove the organic content of the food to such a low level as is possible in an aerobic reaction.

Note: *In anaerobic process, bounded O_2 is removed from the molecules and thus energy released in anaerobic process is less and hence synthesis of new cell is less.*

ORG. MATTER + O_2 + BACTERIA → MORE BACTERIA
(COHNSP) → END PRODUCTS (CO_2, NO_3^-, SO_4^{2-}, PO_4^{3-})

Aerobic Reaction



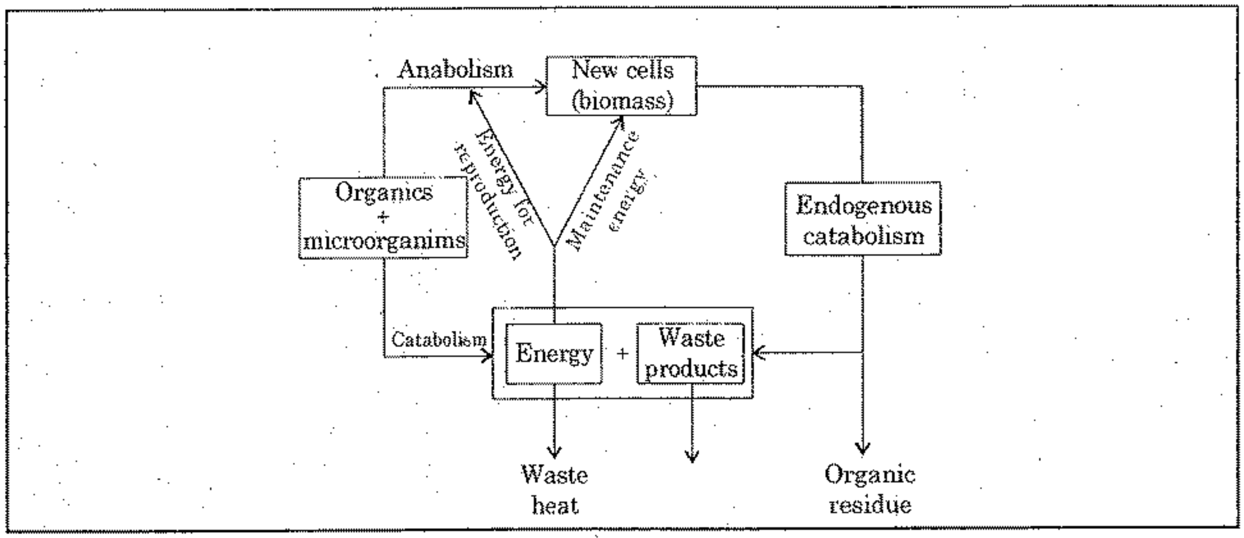
Anaerobic Reaction

Biological Growth

1. In biological treatment processes, the material to be stabilised provides the basic nutritional and energy requirements for its conversion into end products and new microorganisms.
2. Catabolic reactions are those in which food is broken down to release energy.
3. Reactions which provides material for synthesis of new microbial cells are termed anabolic.
4. In the absence of organic matter, microorganisms can exist for sometime because of the existence of auto-oxidation or endogeneous respiration. In endegeneous respiration which takes place continuously in biological system, cell die and lyse to release organic matter and nutrients back into the system where they can be reused.

Parameter	Aerobic oxidation	Anaerobic digestion
Oxygen requirement	Abundant	Nil
Areas of application	Commonly dilute liquid waste and solid waste composting	Commonly sludges
Energy release (per gram-mole glucose)	484-674 Kcal	26 Kcal
Stages required for process completion	1	2
Decomposition and products	CO_2, H_2O, NO_3^-	NH_3, H_2S, CO_2, CH_4
BOD_5 of effluent	Low (less than 60 mg/l)	High (upto 5000 mg/l)
Operative bacterial species	Mesophillic and Thermophillic	Generally mesophillic
Process responsible for bacterial inactivation (composting included)	High heat release during bio-oxidation	Mainly acidic and unfavourable reaction

Anaerobic system will be discussed in detail in sludge digestion topic.



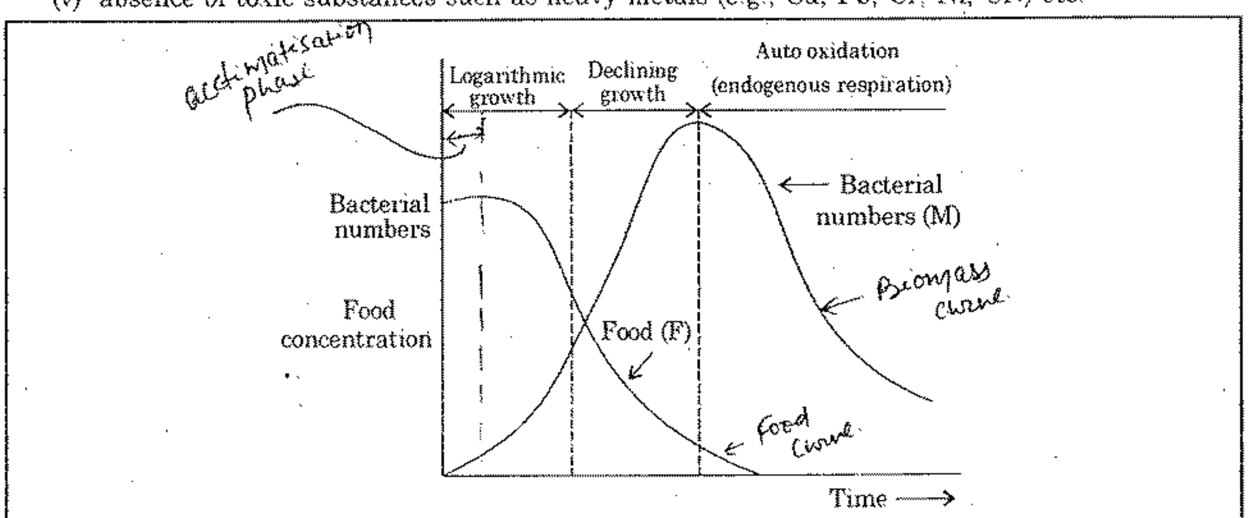
Note: The end products of aerobic catabolism are low-energy, stable compounds, with most of the energy being stored in the cellular material. By contrast, most of the energy released in anaerobic catabolism remains in the waste products.

- Biological growth in the oxidation system assumes the following:
  - (i) ample supplies of carbon, nitrogen and phosphorous so as to enable the synthesis of new cells, the empirical formula for which is

$$C_{60}H_{87}O_{23}N_{12}P$$

(***BOD_5 : N : P ratio of 100 : 5 : 1*** or C : N : P ratio of 100 : 15 : 3);

  - (ii) sufficient energy is available in the organic matter;
  - (iii) inorganic growth nutrients – such as calcium, cobalt, iron, maganese, potassium, etc., are present in the small amounts necessary;
  - (iv) appropriate growth nutrients are present; and
  - (v) absence of toxic substances such as heavy metals (e.g., Cd, Pb, Cr, Ni, CN) etc.



Biological Growth Curve

- Domestic sewage satisfies all of these requirements and, it has an exces of nitrogen and phosphorous.
- Industrial wastewaters may be lacking in some essential components and nutrient supplementation may be needed for effective biological treatment.
- It is also important to reduce the concentrations of toxic substances to innocuous levels when industrial wastewaters are to be treated; thus the need for the pretreatment of industrial wastewaters before discharge into municipal sewage systems arises.

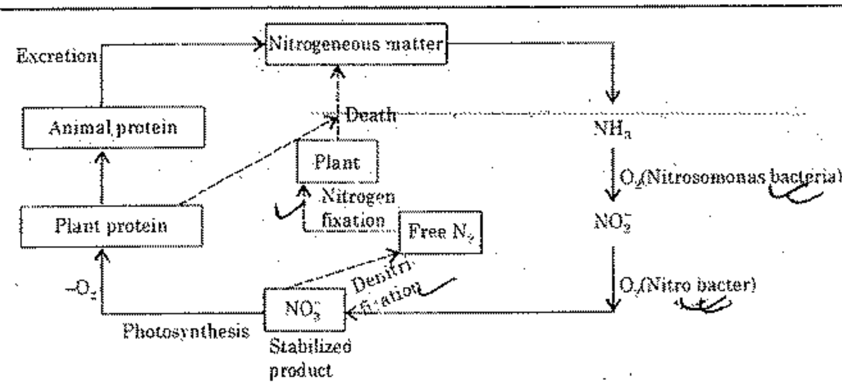
VARIOUS NATURAL CYCLES

(1) Aerobic cycle

(2) Anaerobic cycle

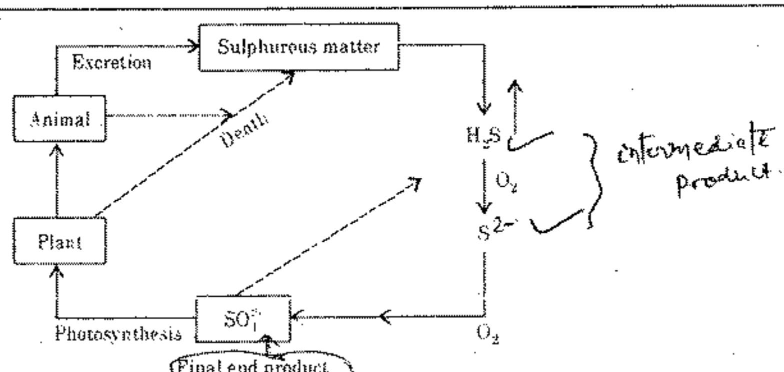
Aerobic Cycle

(i) Nitrogen Cycle



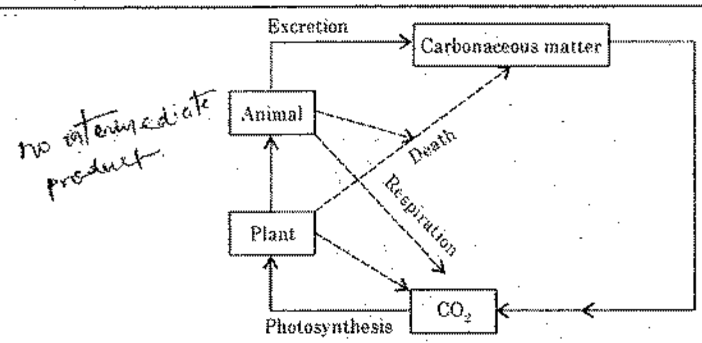
Nitrogen cycle (Aerobic cycle)

(ii) Sulphur Cycle



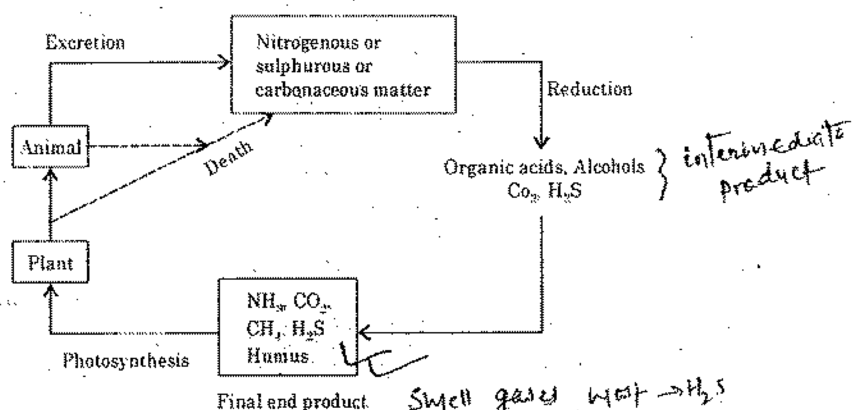
Sulphur Aerobic cycle

(iii) Carbon Cycle



Carbon Aerobic cycle

Anaerobic Cycle



Anaerobic cycle

VARIOUS TYPES OF BACTERIA

- Bacteria are primary decomposers of organic material. They utilize soluble food.
- Bacteria requires energy and material for growth and reproduction.
- Energy for bacteria is derived from bio-chemical oxidation or reduction of inorganic or organic compounds.
- Material is derived from inorganic and organic compounds.

Bacteria are classified according to the energy or material source they require:

Autotrophs: They derive both enough and material from inorganic substance.

Heterotropbs: They derive both energy and material from organic compounds.

Phototrophs: Utilise sunlight as energy source and inorganic substance for material source.

Heterotrophic bateria are the most important species in the degradation of organic matter:

Aerobic heterotrophs: Aerobic bacteria (normally called) utilises organics in the presence of oxygen.

Anaerobic heterotrophs: Anaerobic bacteria utilises organic in the absence of oxygen.

Facultative heterotrophs: Facultative bacteria is capable of functioning both in the presence as well as absence of oxygen.

CHAPTER

3

Disposal of Sewage Effluent

There are two general methods of disposing of the sewage effluents.

(a) Dilution *i.e.* disposal in water

(b) Disposal on land.

Disposal by dilution is more common of these two methods.

Disposal by Dilution

Disposal by dilution is the process where by the treated sewage or the effluent from sewage treatment plant is discharged into a river stream; or a large body of water, such as a lake or sea.

STANDARDS OF DILUTION FOR DISCHARGE OF WASTEWATERS INTO RIVERS

The ratio of the quantity of the diluting water to that of the sewage is known as the dilution factor; and depending upon this factor; the *Royal Commission Report on Sewage Disposal* has laid down the following standards and degree of treatment required to be given to a particular sewage.

Dilution Factor	Standards of Purification Required
Above 500	No treatment is required. Raw sewage can be directly discharged into the volume of water.
Between 300 to 500	Primary treatment such as *plain sedimentation* should be given to sewage. and the effluents should not contain suspended solids more than 150 ppm.
Between 150 to 300	Treatments such as *sedimentation*, *screening* and essentially *chemical precipitation* are required. The sewage effluent should not contain suspended solids more than 60 ppm.
Less than 150	Complete thorough treatment should be given to sewage. The sewage effuent should not contain suspended solids more than 30 ppm. and its 5 days B.O.D. should not exceed 20 ppm.

BIS Standard for Disposal of Sewage

Parameter	Domestic sewage	Industrial sewage	
	If discharged into surface water source	surface water	Public sewer
BOD_5	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/*l*
Phenolic compounds	—	1 mg/*l*	5 mg/*l*
Cyanides	—	0.2 mg/*l*	2 mg/*l*

MECHANISM OF SELF PURIFICATION

When sewage is disposed of in a river, self purification by natural agents takes place. This self purification occurs by various mechanisms. They are:

(a) Dilution and dispersion.
(b) Sedimentation
(c) Sunlight
(d) Biological oxidation
(e) Reduction

Dilution and Dispersion

- Dilution only reduces the potential nuisance due to sewage. 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 in sewage

C_R = Concentration of same material in river

Q_S and Q_R are discharges of sewage and river.

- This formula is also applicable for concentration, like BOD, DO, temperature, etc.

Sedimentation

- The suspended solid in the sewage (inorganic as well as organic) will settle down at the bottom of the river and in due course they will be stabilized. Thus, the river, water will have no suspended solid and it can be thought of as a purification method.
- Primarily the settled organic solid at bottom will be stabilized by anaerobic bacteria.

Sunlight

- Due to sunlight, in the process of photosyntheis, oxygen is released. This oxygen helps in the oxidation of organic matter, thereby forming a stable product which is not a potential hazard.

Oxidation

- Oxidation of organic matter occurs due to oxygen mixed in the river water. The oxygen in river water is due to photosynthesis and due to atmospheric oxygen getting mixed in river water.

Reduction

- By hydrolysis of organic matters settled at the bottom either chemically or biologically, the organic matters are stabilized. The process is a reduction process.

Anaerobic bacteria at the bottom helps in splitting complex organic matters of sewage into simple compounds and gases. These simple compounds can come in contact with oxygen during thorough mixing of river water, hence they will be stabilized eventually.

VARIOUS FACTORS ON WHICH NATURAL FORCE OF PURIFICATION DEPENDS

1. Temperature

Increase in temperature leads to decrease inD.O. and increase in rate of reaction. Hence, oxygen will quickly get depleted and anaerobic conditions may set in.

2. Turbulence

Turbulence will lead to increase in the oxygen mixed in water.

3. Amount and Type of organic matter

Some compounds can be easily oxidised and some will take time, thereby purification will be slow or fast depending on the type of organic matter.

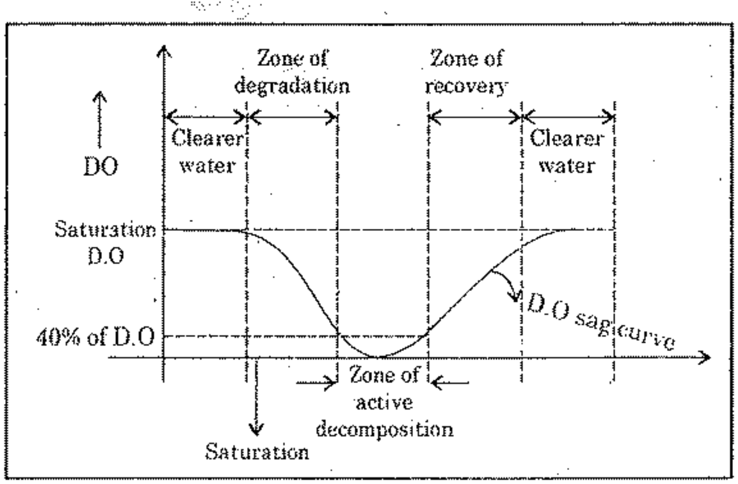
4. Hydrography of river stream

Higher velocity and larger surface area leads to greater turbulence and greater dilution of sewage added. This helps in self purification.

5. Rate of reaeration.

More is the rate of reaeration, faster will be the self purification. Higher the deficiency of O_2 more is the rate of Reaeration.

ZONE OF POLLUTION IN RIVER STREAM



Short notes in exam.

Zones of pollution in river stream are :

(a) Zone of degradation.

(b) Zone of active decomposition.

(c) Zone of recovery.

(d) Zone of clear water.

Zone of Degradation

- It is found upto certain distance downstream of the point at which sewage is discharged into the river.
- In this algae dies but the fish may survives.

- Water becomes dark and turbid.
- DO reduces to upto 40% of saturation.

Zone of Active Decomposition

- It is a zone of heavy pollution.
- Water becomes darker than zone of degradation.
- DO may even fall to zero.
- Fish will disappears.
- At upper ends, anaerobic bacteria will replace aerobic bacteria. Hence, anaerobic conditions set in and thus gases like CH_4, H_2S, CO_2 will be evolved and ugly scum forms on the surface.
- At the end of this zone DO concentration will reach upto 40% of the saturation DO.

Zone of Recovery

- BOD falls down.
- Organic matter will produce nitrate, sulphate, phosphate, carbonate, etc.
- 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

- When biodegradable organics are discharged into a stream containing D.O., micro-organism begin the metabolic process that convert the organics along with D.O. into new cells and oxidised waste products.
- The rate at which the D.O. is used will depend on the quantity of the organics, the ease with which they are biodegraded and the dilution capacity of stream.

  The D.O. that is used from the stream must be replenished as otherwise anaerobic condition will develop.

  Two mechanisms are known to contribute oxygen to surface water.

  (a) dissolution of oxygen from atmosphere (Reaeration)

  (b) production of oxygen by algae photosynthesis

Reaeration

At a particular temperature there is a max value of D.O. that remains mixed in the water. ThisD.O. is called *saturation* D.O. (C_S)

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

$$\boxed{D = C_S - C}$$

Dissolved oxygen deficit is the driving force for reaeration. The greater the deficit, the greater is the rate of reaeration.

if r_R = rate of reaeration (Rate of oxygen addition)

$$\boxed{r_R = -K_r D} \text{ (1st order reation)}$$

(–) ve sign indicates that as rate of reaeration increases, oxygen deficit fall down.

K_r = Re oxygenation constant at base 'e'.

Note: Oxygen contribution of algae photosynthesis has been neglected because algae will produce oxygen during day light but may consume oxygen in night. At night, algae catabolizes stored food for energy and use oxygen in the process. Thus, there is diurnal variation in the oxygen due to algae. On account of this reaeration is considered as most dependable source ofD.O..

Rate of Oxygen Removal

If y = BOD of stream added with sewage [i.e. diluted BOD]

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

but $D = C_S - C$

$$\Rightarrow \quad \frac{dD}{dt} = -\frac{dC}{dt} \qquad [C_S = \text{constant}]$$

$$\Rightarrow \quad \boxed{\frac{dy}{dt} = \frac{dD}{dt}} \qquad \text{... (1)}$$

$$y = L_0 - L_t$$

L_0 = ultimate BOD of mix,

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

$$\Rightarrow \quad \boxed{\frac{dy}{dt} = \frac{-dL_t}{dt}} \qquad \text{... (2)}$$

but $\frac{dL_t}{dt} = -K_d L_t$

K_d = Deoxygenation constant at base 'e'

$$\Rightarrow \quad -\frac{dL_t}{dt} = K_d L_t = \frac{dy}{dt} = \frac{dD}{dt}, \quad \text{[from (2) and (1)]}$$

$\Rightarrow$ r_d = Rate of de-oxygination

$$\boxed{r_d = K_d \cdot L_t}$$

The Oxygen Sag Curve

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

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

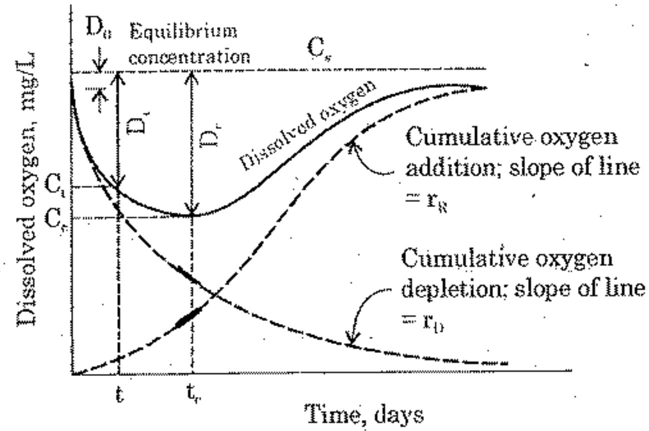
$$\boxed{\frac{dD}{dt} = K_d L_t - K_r D} \qquad \text{... (3)}$$

Note: deficit is max, when rate of re-aeration = rate of de-oxygenation

Integration of equation (3) gives D.O. deficit at any time 't' i.e. D_t.

From D_t one can calculate D.O. (C) in river stream at any time 't'

$$\boxed{C = (C_S - D)}$$



Characteristics of the oxygen sag curve.

c → critical O_2 deficit

From equation (3)

$$\frac{dD}{dt} + K_r \cdot D = K_d \cdot L_t = K_d L_0 e^{-K_d t}$$

$$e^{K_r t} \cdot \frac{dD}{dt} + K_r e^{K_r t} \cdot D = K_d \cdot L_0 e^{(K_r - K_d)t}$$

$$\frac{d}{dt}\left(D \times e^{K_r t}\right) = K_d L_0 e^{(K_r - K_d)t}$$

$$\int d(De^{K_r t}) = \int K_d L_0 e^{(K_r - K_d)t} \cdot dt$$

$$\Rightarrow \quad De^{K_r t} = \frac{K_d L_0}{(K_r - K_d)} e^{(K_r - K_d)t} + C'$$

C' = constant of integration

at t = 0, $D = D_0$ = initial oxygen deficit

$$D_0 - \frac{K_d L_0}{K_r - K_d} = C'$$

$$\Rightarrow \quad De^{K_r t} = \frac{K_d L_0}{(K_r - K_d)} e^{(K_r - K_d)t} - \frac{K_d L_0}{K_r - K_d} + D_0$$

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

$$\boxed{D = \frac{K_D L_0}{K_R - K_D}\left[10^{-K_D t} - 10^{-K_R t}\right] + D_0 10^{-K_R t}} \quad \text{.................. (1)}$$

where K_R and K_D are on base 10. This equation is called *Streeter-Phelps* equation.

K_D → deoxygenation rate const.

K_R → reaeration rate const.

Note: $e^{-K_d t} = x$

$\ln x = -K_d t$

$2.303 \log_{10} x = -K_d t$

$\log_{10} x = -K_D t \Rightarrow 10^{-K_D t} = x = e^{-K_d t}$

Note: Saturation D.O. at

$0°C = 14.6$ mg/l

$20°C = 9.2$ mg/l

$30°C = 7.6$ mg/l

K_D at $T°C = K_D$ at $20°C(1.047)^{T-20}$

K_R at $T°C = K_R$ at $20°C(1.016)^{T-20}$

Critical time at which DO is minimum is given by

$$t_C = \frac{1}{K_R - K_D}\log_{10}\left[\left\{\frac{K_D L_0 - (K_R - K_D) D_0}{K_D L_0}\right\}\frac{K_R}{K_D}\right] \quad \text{.......... (2)}$$

Note: This is obtained from $\frac{dD}{dt} = 0$

D_C = critical oxygen deficit i.e. maximum oxygen deficit

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

The above equation can also be re-arranged as

$$\left(\frac{L_0}{D_C f}\right)^{(f-1)} = f\left[1-(f-1)\frac{D_0}{L_0}\right] \quad \text{.......... (3)}$$

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

Example 1

125 m³/s of a sewage is discharged in a river which is fully saturated with O_2 and flow at a minimum rate = 1600 m³/s with a minimum velocity of 0.12 m/s. If the 5 day BOD of the sewage is 300 mg/l. Find out where the critical DO will occur in the river.

Assume coefficient of purification of river = 4.0

k_D = 0.11/day

$BOD_u = 1.25\ BOD_5$

Assume sat DO at 20° = 9.2 mg/l

Sol. The location where critical $DO_{occurs} = (0.12 \times t_c)$ downstream from the point of addition

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

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

$$D_0 = \text{Saturation DO} - \text{DO of mix.}$$

$$\text{DO of mix} = \frac{C_S Q_S + C_R Q_R}{Q_S + Q_R}$$

Assuming temperature of river water = 20°C, saturation DO = 9.2 mg/l. DO of sewage should be taken as 0.

$$\text{DO of mix} = 8.53 \text{ mg/l}$$

$$D_0 = 9.2 - 8.53 = 0.67 \text{ mg/l.}$$

$$BOD_5 \text{ of mix} = \frac{300 \times 125 + 0 \times 1600}{1600 + 125} = 21.74 \text{ mg/l.}$$

$$L_0 = 1.25 \times 21.74 = 27.17 \text{ mg/l.}$$

$$\left[\frac{27.17}{D_C \times 4}\right]^3 = 4\left[1 - 3 \times \frac{0.67}{27.17}\right]$$

$$\Rightarrow \quad D_C = 4.39 \text{ mg/l}$$

$$\Rightarrow \quad t_C = 1.723 \text{ days}$$

Location of critical DO = $\frac{0.12 \times 86400 \times 1.723}{1000}$ km = 17.86 km D/S of the point of application of sewage into river.

DISPOSAL OF WASTE WATERS IN LAKES AND MANAGMENT OF LAKE WATERS

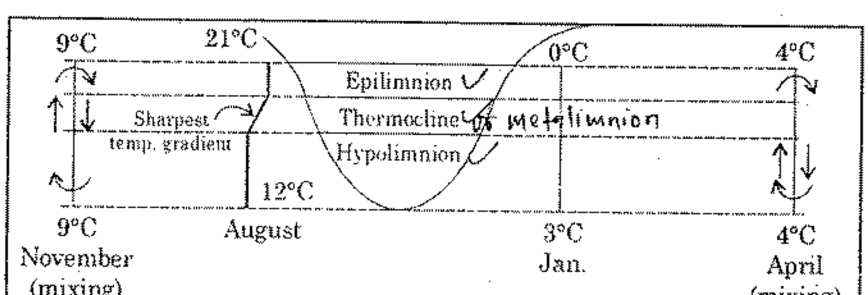
Treated or untreated sewage can be disposed of in a river, lake, land or sea.

Disposal in Lakes

Phosphorous present in the sewage is a prime lake pollutant.

Study of Lake System

Lake Stratification



Lake Stratification

- In temperate zones, heat transfer in reservoirs and lakes, where the influence of turbulence and current is negligible, is controlled by a phenomenon known as *thermal stratification*.
- The fresh water reaches their maximum density at 4°C with density declining as water moves towards freezing point or grows warmer. Thus, during warm season water divides into upper layers of warm water known as epilimnion.
- In this zone (epilimnion) water is well mixed and sufficient oxygen is present.
- The lower layer is cool and unmixed, it is known as hypoliminion. In this zone there is deficiency of oxygen. These two layers are separated by thermocline or metalimnion. This is a region of sharp temperature gradient.
- This stratification is interrupted in winter and spring (when complete mixing takes place).

Note : Maximum killing of aquatic plant and animal will occur during mixing as they are not be accustomed to such temperature changes.

- Epilimnion is smaller in small lakes and larger in large lakes.

Biological Zones in Lakes

(a) Euphotic zone
(b) Littoral zone
(c) Benthic zone

Euphotic Zone: The upper layer of lake through which sunlight can penetrate is called euphotic zone. The depth of the euphotic zone is reduced by the turbidity, which blocks sunlight penetration.

Littoral Zone : The zone near the shore where rooted plants grow is called littoral zone. This zone never extends beyond euphotic zone.

Benthic Zone : The bottom sediments in lake which contains bacteria. Living organism when die settles down to the bottom which are decomposed by bacteria present in benthic zone.

Productivity of Lake

- Productivity is a measure of its ability to support food chain. It is a measure of algal growth.
- Higher algal growth leads to decreased water quality. Depending upon the increasing level of productivity, the lakes can be classified as :

(a) Oligotrophic lake
(b) Mesotrophic lake
(c) Eutrophic lake
(d) Senescent lake

Productivity increasing order

- **Oligotrophic** : Oligotrophic lakes have a low level of productivity due to a severely limited supply of nutrients to support algal growth. Euphotic zones extends to hypolimnion which in this case becomes aerobic. Algal growth is negligible.
- **Mesotrophic** : It has medium algal growth (i.e., medium productivity) hypolimnion remains aerobic although substantial depletion of oxygen occurs.
- **Eutrophic** : It has fairly high productivity and algal growth. Euphotic zone will partially extent into epilimnion. Hypolimnion will be anaerobic.
- **Senescent** : It represents a very old lake which has almost becomes marshy.

Short note if asked

Eutrophication of Lake

- It is a natural process under which lakes get infested with algae and silt up gradually to become shallow and more productive through the entry and cycling of nutrients like carbon, nitrogen and phosphorus.

- The increased phosphate in lake water accentuate eutrophication of lake and this is called cultural eutrophication.
- 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.
- To avoid eutrophication lakes should not be used for disposal of even the treated sewage.

Note: Autotrophism and Heterotrophism represent the oxidation (aerobic) or degradation (anaerobic) of inorganic and organic matter by bacteria (micro-organisms) respectively. Bacteria that oxidise inorganic matter are termed as autotrophic and those that oxidise organic matter are called heterotrophic.

DISPOSAL OF WASTE WATER IN SEA

- Sea water contains 20% less oxygen than the fresh water of river stream. But as the dilution is more in sea water it can be considered as source for disposal.
- Sewage when disposed in sea may form sludge banks. It is formed due to the reaction of sewage solids and dissolved matter of sea. the sulphate rich sea water may give H_2S if sewage is disposed in it.
- BIS standard for waste water effluent to be discharged into sea.

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

- Sewage will be disposed during low tides only.

In this method, the sewage effluent (treated or diluted) is generally disposed of by applying it on land.

DISPOSAL ON LAND

Most solids contained in wastewater applied on land are retained in the top 5 cm, while dissolved solids flow through. During the mean residence time in a soil layer, the removal of organic matter occurs. In intermittently aerated soils, the biological degradation is aerobic, while in waterlogged soils, the degradation may be anaerobic. BOD removal with soil depth follows first-order kinetics.

More organic load can be placed on a sandy soil than a clayey one. Overloaded soils develop anaerobicity, clogging and ponding of wastewater reduction in soil permeability is referred to as a *sewage sick soil.*

Effluent irrigation

In this type, chief consideration is successful disposal of sewage.

Sewage farming

In this type, chief consideration is successful growing of crops. Incase of sewage farming, stress is laid upon the use of sewage effluents for irrigating crops and increasing fertility of soil.

Pre-treatment of effluent to remove substances which are harmful to crop is necessary in this case.

BIS Standards of Wastewater Effluents to be Discharged on Land for Irrigation

Characteristic/constituent of effluent wastewater	Tolerance limit
1. BOD_5 at 20°C	500 mg/l
3. Total dissolved solids (TDS)	2100 mg/l
4. Oil and grease	30 ml/l
5. Chlorides (as Cl)	600 mg/l
7. Sulphates	1000 mg/l
8. Percentage of sodium with respect to total content of sodium, Calcium, Magnesium and Potassium.	60%

Example 2

Calculate the population equivalent of a city given that average sewage from the city is 95×10^6 litre/day and the average 5-day BOD is 300mg/l.

Sol. Given: Average sewage = 95×10^6 litre/day

$$BOD_5 = 300 \text{ mg/l}$$

$$\text{Total } BOD_5 \text{ sewage} = 300 \text{ mg/l} \times 95 \times 10^6 \text{ litre/day}$$

$$= 28500 \text{ kg/day}$$

Assume the domestic sewage quantity to be 0.08 kg/person/day

$$\therefore \quad \text{Population equivalent} = \frac{\text{Total } BOD_5 \text{ in kg/day}}{0.08}$$

$$BOD_5 \text{ of sewage} = 300 \text{ mg/l}$$

$$= \frac{28500}{0.08} = 356250$$

$= 356250$ **Ans.**

Example 3

The treated domestic sewage of a town is to be the discharged in a natural stream. Calculate the percentage purification required in the treatment plant with the following data:

(i) Population = 50,000
(ii) BOD contribution per capita = 0.07 kg/day
(iii) BOD of stream on U/S side = 3 mg/l
(iv) Permissible maximum BOD of stream on D/S side = 5 mg/l
(v) Dry weather flow of sewage = 140 litres per capita per day
(vi) Minimum flow of stream = 0.13 m^3/s

Explain graphically the process of self purification of natural waters when sewage is discharged there in.

Sol. Given:

$$\text{Population} = 50000$$

$$\text{BOD, percapita} = 0.07 \text{ kg/day}$$

$$\text{Total BOD per day} = 0.07 \times 50000$$

$= 3500$ kg/day

Sewage discharge $= \dfrac{140 \times 50000}{86400}$ l/sec

$= 0.081\ m^3/s$

BOD of the mix = 5 mg/l

BOD of the river = 3 mg/l

Let BOD of treated sewage be C_S

we know that

$$\text{BOD mix} = \frac{C_S \times Q_S + C_R Q_R}{Q_S + Q_R}$$

$$5 = \frac{C_S \times 0.081 + 3 \times 0.13}{0.081 + 0.13}$$

$C_S = 8.21$ mg/l

$$\text{BOD of untreated sewage} = \frac{3500 \times 10^6 \text{ mg/d}}{50000 \times 140 \text{ L/d}}$$

$= 500$ mg/l

Percentage treatment required

$$= \frac{500 - 8.21}{500} = 98.358\%$$

$= 98.36\%$ **Ans.**

Example 4

An environmental survey for a town with population of 30,000 revealed the following Domestic sewage produced at the rate of 240 litres per capita per day. The per capita BOD of the domestic sewage being 72 g/day. Industrial wastes produced were estimated as 4 million litres per day with BOD of 1500 mg/L. The sewage effluents can be discharged into a river with a minimum dry weather flow of 4500 litres/sec and a saturation D.O. content of 7 mg/l. It is necessary to maintain a D.O. content of 4 mg/l in the stream.

For designing a sewage treatment plant, determine the degree of treatment required to be given to the sewage. Assume

K_D = De-oxygenation coefficient = 0.1/day

K_R = Re-oxygenation coefficient = 0.3/day

An overall expansion factor of 10% to be provided.

Sol. Given:

Population = 30000

Sewage = 240 litres/C/day

BOD = 72 g/C/day

Average sewage flow = $30000 \times 240 \times 7.2 \times 10^6$ l/C/day

BOD = 30000×72 g = 2160 kg/day

$$\text{BOD per litre of domestic sewage} = \frac{2160 \times 10^6}{7.2 \times 10^6} = 300 \text{ mg/l}$$

Industrial water = 4 × 10^6 litre/day

BOD = 1500 mg/l

$$\text{Net BOD of mix} = \frac{7.2 \times 10^6 \times 300 + 4 \times 10^6 \times 1500}{7.2 \times 10^6 + 4 \times 10^6}$$

$$= \frac{7.2 \times 300 + 4 \times 1500}{7.2 + 4} = 728.57 \text{ mg/l}$$

$$\text{Total waste water discharge} = \frac{(7.2 + 4) \times 10^6}{864010} = 129.63 \text{ l/sec}$$

Total waste water discharge with 10% expansion

= 1.1 × 129.63 = 142.59 l/sec

River discharge = 4500 l/sec

Now

Initial DO of saturated stream water = 7 mg/l

Assume DO of sewage = 0 mg/l

$$\text{DO of mix} = \frac{0 \times 142.59 + 7 \times 4500}{142.59 + 4500} = 6.785 \text{ mg/l}$$

= 6.785 mg/l

Initial deficit in DO, D_0 = 7 – 6.785

= 0.215 mg/l

Critical deficit in DO, D_C = 7 – 4 = 3 mg/l

$$f = \frac{K_R}{K_D} = \frac{0.3}{0.1} = 3$$

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

$$\left(\frac{L}{3 \times 3}\right)^2 = 3\left[1 - 2 \times \frac{0.215}{L}\right]$$

$$\frac{L^2}{81} = 3 \times \left[1 - \frac{0.43}{L}\right]$$

$$L^3 - 243\ L + 140.49 = 0$$

L = 15.37 mg/l

BOD_5 of mixture

$$Y_5 = L\left(1 - 10^{-K_D t}\right)$$

$$= 15.37\ (1 - 10^{-0.1 \times 5})$$

= 10.51 mg/l

Let BOD of sewage after 5 days = C_s

$$\therefore \quad BOD_{mix} = \frac{C_S Q_S + C_R Q_R}{Q_S + Q_R}$$

$$10.51 = \frac{C_S Q_S + C_R Q_R}{Q_S + Q_R}$$

$$C_S = 342.2 \text{ mg/l}$$

Degree of treatment required (neglecting the expansion factor)

$$= \left(\frac{\text{Initial BOD} - \text{Final BOD}}{\text{Initial BOD}}\right) \times 100$$

$$= \frac{728.57 - 342.2}{728.57} \times 100$$

$$= 53.03\%$$ **Ans.**

Example 5

A river before its entry into a town had a discharge of 100 l/sec and 20 mg/l as the concentration of a conservative parameter. The town's waste water outfall having 200 mg/l (two hundred mg/l) concentration of the same conservative parameter raised the river concentration of 50 mg/l after a complete mix with the river water. Determine the dilution ratio resulting from the discharge of the said waste water outfall.

Sol. Given: River discharge $Q_R = 100$ l/sec

River conservative parameter $C_R = 20$ mg/l

Sewage conservative parameter $C_S = 200$ mg/l

Mixture conservative parameter $C = 50$ mg/l

Let sewage discharge $= Q_S$

$$\therefore \quad C_{mix} = \frac{C_S Q_S + C_R Q_R}{Q_S + Q_R}$$

$$50 = \frac{200 Q_S + 20 \times 100}{Q_S + 100}$$

$$\Rightarrow \quad 50\, Q_S + 5000 = 20\, Q_S + 2000$$

$$150\, Q_S = 3000$$

$$Q_S = 20 \text{ l/sec}$$

$Q_R = 100$ l/s, $C_R = 20$ mg/L, $C_S = 200$ mg/L

$$\text{Dilution ratio} = \frac{Q_R + Q_S}{Q_S}$$

$$= \frac{100 + 20}{20} = \frac{120}{20} = 6$$

Example 6

A large stream has a reoxygenation constant of 0.4 per day. At a velocity of 0.85 m/s; and at the point at which an organic pollutant is discharged, it is saturated with oxygen at 10 mg/L ($D_0 = 0$). Below the outfall, the ultimate demand for oxygen is found to be 20 mg/L and the deoxygenation constant is 0.2 per day. What is theD.O. 48.3 km downstream?

Sol. Given: $K_R = 0.4$/day

Velocity of river V = 0.85 m/s

Saturation DO = 10 mg/l

time required for certain amount of DO 48.3 km downstream is given by

$$t = \frac{\text{Distance downstream}}{\text{Velocity of flow in large stream}}$$

$$= \frac{48.3 \times 10^3}{0.85} = 56823.53 \text{ sec}$$

$$= \frac{56823.53}{86400} = 0.6577 \text{ day}$$

TheD.O. deficit after time t

$$D_t = \frac{K_D L}{K_R - K_D}\left[10^{-K_D t} - 10^{-K_R t}\right] + (D_0 \times 10^{-K_R t}]$$

$$D_t = \frac{0.2 \times 20}{0.4 - 0.2}(10^{-2.0 \times 0.6577} - 10^{-0.4 \times 0.6577}] + (0 \times 10^{-0.4 \times 0.6577})$$

$$= 20 \times 0.1927 + 0$$

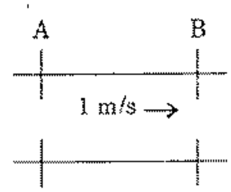
$$= 3.85 \text{ mg/l}$$

DO at 48.3 km down stream = 10 – 3.85

= 6.15 mg/l

Example 7

The BOD rate constant (K) for a river's BOD assimilation was determined to be 2/day (base e). The BOD of this river after leaving a heavily populated town was determined to be 50 mg/l. Determine the distance after which the rivers BOD would become 4 mg/l when the average velocity of river was 1 m/s. What would have been this 'K' value if the distance would have been 300 km and state what K manifests.



Sol.

1. Amount of organic matter at 'A' and B will be different as they will get oxidised while water moves from A to B.

   ⇒ Ultimate BOD at A and B will be different (when BOD is given we infer that BOD_5 is given).

2. $(BOD_5)_A = 50 = L_A(1 - e^{-2\times5})$

   $(BOD_5)_B = 4 = L_B\,(1 - e^{-2\times5})$

   $$\Rightarrow \boxed{\frac{L_A}{L_B} = \frac{50}{4}}$$

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

$\Rightarrow L_B = L_A e^{-2\times t} \Rightarrow t = 1.2628$ days

3. Distance = 109.11 km
4. If distance had been 300 km

$$\ln\left(\frac{4}{50}\right) = -K \times \frac{300 \times 1000}{1 \times 86400} \Rightarrow K = 0.7274/\text{day}$$

Example 8

A municipal wastewater-treatment plant discharges secondary effluent to a surface stream. The worst conditions are known to occur in the summer months when stream flow is low and water temperature is high. Under these conditions, measurements are made in the laboratory and in the field to determine the characteristics of the wastewater and stream flows. The wastewater is found to have a maximum flow rate of 15,000 m^3/day, a BOD_5 (at 20°C standard temperature) of 40 mg/L, a dissolved oxygen concentration of 2 mg/L, and a temperature of 25°C. The stream (upstream from the point of wastewater discharge) is found to have a minimum flow rate of 0.5 m^3/s, a BOD_5 (at 20°C standard temperature) of 3 mg/L, a dissolved oxygen concentration of 8 mg/L, and a temperature of 22°C. complete mixing of the wastewater and stream is almost instantaneous, and the velocity of the mixture is 0.2 m/s. From the flow regime, the reaeration constant is estimated to be 0.4 day^{-1} for 20°C conditions. And deoxygenation constant to be 0.23/day at 20°C. Take the saturation D.O of the mix to be 8.7 mg/*l* at mix temperature. Find where the min D.O will occur.

Sol. 1. Determine characteristics of wastewater-stream mixture.

(a) $Q_w = 15{,}000 \times \frac{1}{24} \times \frac{1}{60} \times \frac{1}{60}$

$= 0.174\ m^3/s$

$Q_{mix} = 0.174 + 0.5 = 0.674\ m^3/s$

(b) BOD

$$BOD_{mix} = \frac{C_s Q_s + C_w Q_w}{Q_s + Q_w}$$

$$= \frac{3.0 \times 0.5 + 40 \times 0.174}{0.674} = 12.552 \text{ mg/L}$$

Convert to ultimate BOD.

$$y_u = L_0 = \frac{L_t}{1 - e^{-k_1 t}}$$

$$= \frac{12.552}{1 - e^{-0.23\times 5}}$$

$= 18.368$ mg/L

(c) Dissolved oxygen:

$$DO_{mix} = \frac{8.0 \times 0.5 + 2.0 \times 0.174}{0.674}$$

= 6.451 mg/L

(d) Temperature:

$$T_{mix} = \frac{22 \times 0.5 + 25 \times 0.174}{0.674}$$

= 22.78°C

≈ 22.8

2. Correct reaction constants for temperature.

(a) BOD reaction rate

$k_{22.8} = k_{20}(1.047^{22.8 - 20})$

= 0.23 × 1.14

$k_{22.8} = 0.26 d^{-1} = k_d$

(b) Stream reaeration rate

$k_{22.8} = k_{20}(1.016^{22.8-20})$

= 0.4 × 1.05

$k_{22.8} = 0.42 d^{-1} = k_r$

3. Determine initial oxygen deficit D_0

(a) At T = 22.8, the saturation concentration of oxygen in fresh water is 8.7; therefore

$D_0 = 8.7 - 6.5 = 2.2$ mg/L

4. Determine the critical deficit and its location

(a) $$t_c = \frac{1}{k_r - k_d} \ln\left[\frac{k_r}{k_d}\left(1 - D_0 \frac{k_r - k_d}{k_d L_0}\right)\right]$$

$$= \frac{1}{0.42 - 0.26} \ln\left[\frac{0.42}{0.26}\left(1 - 22 \frac{0.42 - 0.26}{0.26 \times 18.2}\right)\right]$$

$t_c = 2.5$ d

This condition will occur at a distance of

x = 0.2 × 86,400 × 2.5

= 43.2 km downstream from point of discharge

OBJECTIVE QUESTIONS

1. An industrial waste water enters a stream having a BOD concentration of 10 mg/L and a flow of 20 m^3/s. If the flow of wastewater is 1.5 m^3/s and its BOD concentration is 250 mg/L, then the BOD concentration in the stream at a point downstream of the point of confluence of wastewater with the stream will be

   (a) 2.67 mg/L (b) 12.09 mg/L
   (c) 13.00 mg/L (d) 26.74 mg/L

2. Eutrophication of water bodies is caused by the

   (a) discharge of toxic substances
   (b) excessive discharge of nutrients
   (c) excessive discharge of suspended solids
   (d) excessive discharge of chlorides

3. Self purification of running streams may be due to

   (a) sedimentation, oxidation and coagulation
   (b) dilution, sedimentation and oxidation
   (c) dilution, sedimentation and coagulation
   (d) dilution, oxidation and coagulation

4. The following zones are formed in a polluted river

   1. Zone of clear water
   2. Zone of active decomposition
   3. Zone of recovery
   4. Zone of pollution

   The correct sequence in which these zones occur progressively downstream in a polluted river is

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

5. For fish habitat in a river, the minimum dissolved oxygen required is

   (a) 2 mg/L (b) 4 mg/L
   (c) 8 mg/L (d) 10 mg/L

6. When a sewage is disposed off in a river, the rate of depletion of dissolved oxygen of the river mainly depends on

   (a) biochemical oxygen demand of the sewage
   (b) chemical oxygen demand of the sewage
   (c) total organic carbon present in the sewage
   (d) dissolved oxygen present in the sewage

7. From ecological considerations, the minimum level of Dissolved Oxygen (DO) necessary in the rivers and streams is

   (a) 1 mg/L (b) 2 mg/L
   (c) 4 mg/L (d) 8 mg/L

8. Which one of the following sets of processes is a part of self-purification of streams?
   (a) Settling, bio-degradation and desalination
   (b) Settling, bio-degradation and aeration
   (c) Floatation, ion exchange and desalination
   (d) Desalination, ion exchange and reverse osmosis

9. When sewage enters a flowing river, the rapid depletion of dissolved oxygen is due to
   (a) change in temperature in river water
   (b) the suspended particles in river and waste
   (c) respriatory activity of aquatic plants in the river
   (d) microbial activity

10. Sewage may be disposed of without treatment into a water body if the available dilution is
   (a) less than 150 (b) more than 150
   (c) more than 300 (d) more than 500

11. When wastewater is disposed of into a running stream, four zones are formed. In which one of the following zones will the minimum level of dissolved oxygen be found?
   (a) Zone of degradation (b) Zone of active decomposition
   (c) Zone of recovery (d) Zone of clear water

12. **Assertion (A):** U.K. Royal Commission on Sewage Disposal of 1898-1915 classified British rivers on the basis of 65°F, 5-day BOD.
   Reason (R): British rivers do not have flow time to open sea more than 5 days.

13. A municipal sewage has BOD_5 of 200 mg/L. It is proposed to treat it and dispose off into a marine environment. For what minimum efficiency should the sewage treatment plant be designed?
   (a) 85% (b) 60%
   (c) 50% (d) 33.67%

14. Effluent from a wastewater treatment plant (flow rate = 8640 m^3/d, temperature = 25°C) is discharged to a surface stream (flow rate = 1.2 m^3/s, temperature = 15°C). What is the temperature of the stream after mixing?
   (a) 10°C (b) 15.77°C
   (c) 20°C (d) 24.99°C

15. In a certain situation, waste water discharged into a river mixes with the river water instantaneously and completely. Following is the data available:

Waste water	DO = 2.00 mg/L
	Discharge rate = 1.10 m^3/s
River water	DO = 8.3 mg/L
	Flow rate = 8.70 m^3/s
	Temperature = 20°C

   Initial amount of DO in the mixture of waste and river shall be
   (a) 5.3 mg/L (b) 6.5 mg/L
   (c) 7.6 mg/L (d) 8.4 mg/L

16. **Assertion (A) :** The BOD gets removed at a very fast rate immediately after sewage is discharged into a river.

Reason (R) : A part of the BOD in the sewage is due to settled organic matter therein.

17. Consider the following statements :

The time of BOD assimilation in a stream can be affected by

1. Ratio of stream width to flow depth.
2. Stream BOD value
3. BOD rate constant

Which of these statements are correct?

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

18. Sewage sickness is a term used for

(a) persons who become sick after drinking polluted water
(b) a treatment plant which does not function properly
(c) a stream where the flora and fauna die due to sewage inflow
(d) the condition of land where sewage is applied continuously for a long period

ANSWERS

1. (d)	6. (a)	11. (b)	16. (b)
2. (b)	7. (c)	12. (a)	17. (a)
3. (b)	8. (b)	13. (c)	18. (d)
4. (b)	9. (d)	14. (d)	
5. (b)	10. (d)	15. (c)	

....

CHAPTER

4

Design of Sewerage System and Sewer Appurtenances

DIFFERENCE IN THE DESIGN OF WATER SUPPLY PIPES AND SEWER

The hydraulic design of sewer and drains, which means finding out their sections and gradients, is generally carried out on the same lines as that of the water supply pipes. However, there are two major differences.

These differences are :

(i) The water supply pipes carry pure water without containing any kind of solid particles, either organic or inorganic in nature. The sewage, on the other hand, does contain such particles in suspension; and the heavier of these particles may settle down at the bottom of the sewers, as a result the flow velocity reduces, thus ultimately resulting in the clogging of the sewers. In order to avoid such clogging or silting of sewers, it is necessary that the sewer pipes be of such a size and laid at such a greadient, as to generate self-cleansing velocities at different possible discharges. The sewer materials must also be capable of resisting the wear and tear caused due to abrasion of the solid particles present in the sewage, with the interior of the pipe.

(ii) The water supply pipe carry water under pressure, and hence, within certain limits, they may be carried up and down the hills and the valleys; whereas, the sewer pipes carry sewage as gravity conduits (or open channels), and they must, therefore, be laid at a continuous gradient in the downward direction up to the outfall point, from where it will be lifted up, treated and disposed of.

LAYING OF SEWER

All the sewer pipes are generally laid starting from their outfall ends, towards their starting ends. The advantage gained in starting from the tail end, (i.e. out fall end) is the utilisation of the tail length even during the initial period of its construction, thus ensuring that the functioning of the sewarage scheme has not to wait till the completion of the entire scheme.

The laying of the sewer consists of the following steps:

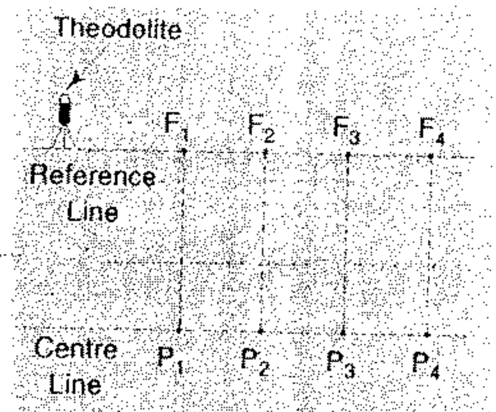
1. Marking of the Alignment

The alignment (i.e., centre line) of the sewer is marked along the road with a theodolite and inver tape. The centre line may be marked according to the following two methods:

(a) By Reference Line

(b) By Sight Rail

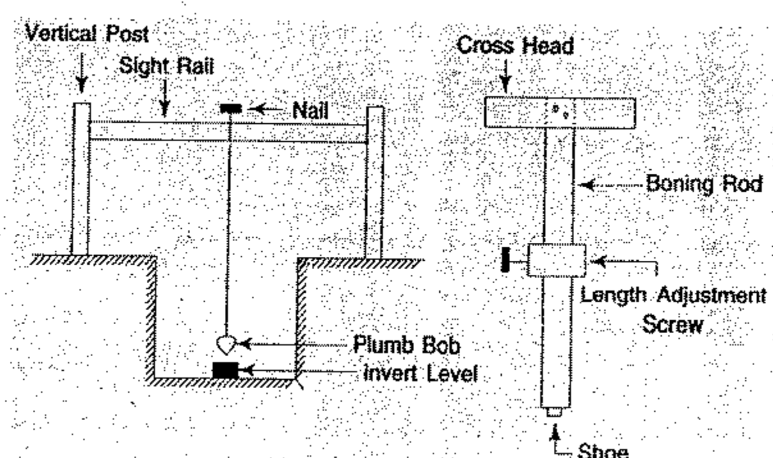
(a) By Reference Line : In this method, a reference line is marked along any side of the busy roads by theodolite and inver tape. The points F_1F_2 ...... are on the reference line. The starting point (P_1) of the centre line is marked with a peg. Then the distance F_1P_1 is with a peg. Then the distance F_1P_1 is measured by inver tape.



Reference Line

Now the other points P_2, P_3, P_4 ...... etc. are marked pegs by taking as $F_1P_1 = F_2P_2 = F_3P_3$ .... etc. Thus, the points P_1, P_2, P_3 ..... etc. Will represent the centre line of the sewer. This centre line may be checked by the theodolite.

(b) By Sight Rail : In this method, two vertical posts are driven at suitable distance apart. Then by ranging through a theodolite the centre line is marked with nail on a sight rail which is fixed on the vertical posts. The sight rail should be fixed such a way so that its upper edge just coincides with the line of sight. The centre line of the sewer is transfered to the ground by plumb bob with respect to the nail.



Sight Rail

The distance between the upper edge of sight rail and the invert level is determiend and noted on the sight rail for finding the exact invert level by boning rod. The length of bonding rod is adjusted according to the height as noted in sight rail. The cross-head is levelled with the upper edge of sight rail and the bottom edge incdicates the invert level.

2. Excavation of Trench

3. Bracing of the Trench

4. Dewatering of Trench

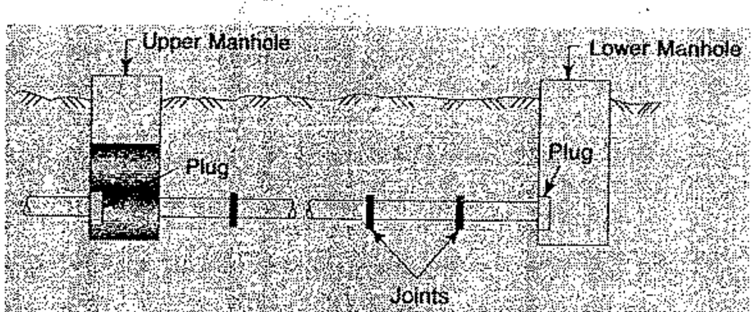
5. Laying and Joining of Pipes

After the preparation of sewer bed the operation of joining is performed in which the sewer pipe lengths are usually laid from the lowest point with their socket ends facing upstream and the spigot of each pipe be easily inserted in the socket of the already laid pipe.

6. Testing of Leakage

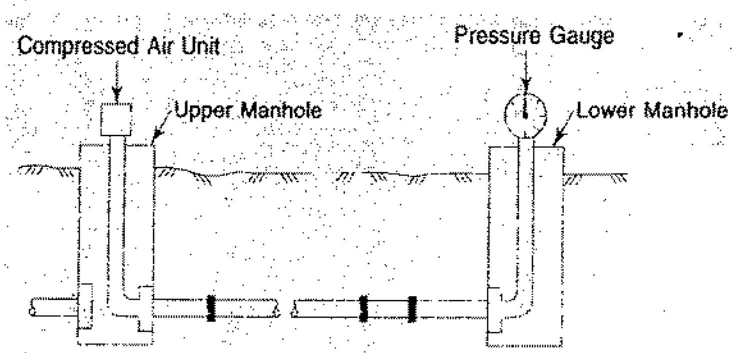
The leakage in the pipe joints or at any point in the pipe line is tested by the following two methods :

(a) By Water Test : This test is carried out between two manholes. In the lower manhole, the end of the sewer is plugged and in the upper manhole, the other end is kept open. The pipe end of previous section is kept plugged. Then the water is allowed to flow in the sewer line from the upper manhole until the sewer is completely filled up. The depth of water in the upper manhole is raised up to 1 m above the sewer line is inspected to detect the leakage by observing any sweating. If the leakage is detected, it is rectified immediately.



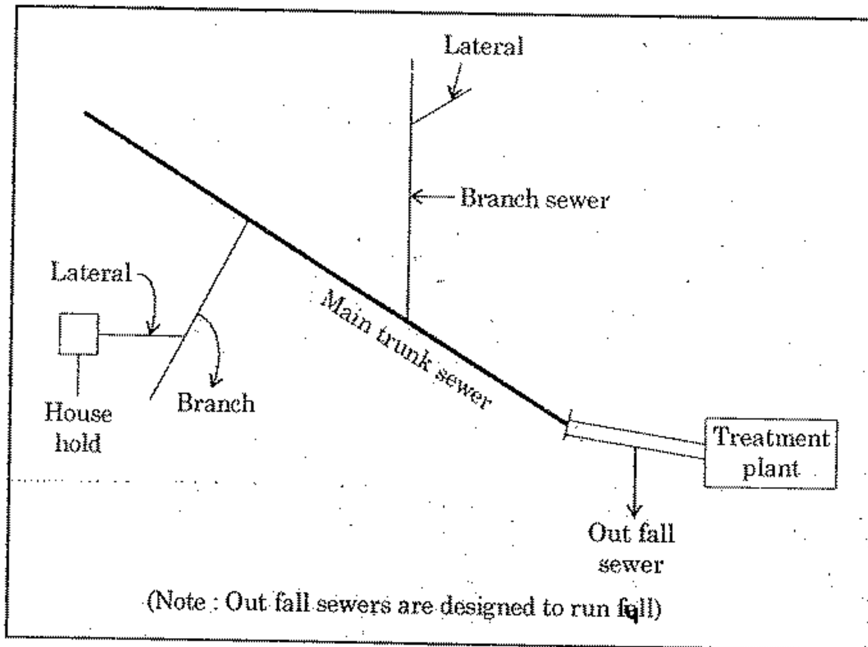
Water Test

(b) By Air Test : This test is carried out for large diameter sewer. The pipe ends of both the manholes are plugged. An air compressor is connected to the plug of upper manhole and pressure gauge is attached with the plug of lower manhole. The pressure exerted by the compressed air is recorded in the pressure gauge. It is left for few hours. If the pressure drops below the permissible limit, then it is an indication of leakage. The exact point of leakage is found out by applying soap solution which will show bubbles at the point of leakage. If leakage is detected, it should be removed immediately.



Air Test

DESIGN OF SEWER



Sewer should be designed so as to transport the entire sewage effectively and efficiently from the houses and upto the point of disposal. The sewer are designed not to flow full under gravity because reserve space in the sewer safeguards against fluctuation in sewage flow.

They should be adequate in size and should have proper slope or they will overflow and cause property damage, danger to health and nuisance.

Sewers
- Sanitary sewers — Collecting discharges from house
- Storm sewers → designed to carry water or ground water excluding domestic and industrial sewage.
- Combined Sewer — designed for domestic, industrial and storm sewage.

Sanitary Sewer

In sanitary sewer system, lateral sewer collects discharges from houses and carry them to branch sewer. Branches or sub-main lines receive waste water from lateral and carry it to mains. A main sewer, also called trunk sewer or outfall sewer (last part of main sewer), carries the discharges from large areas to the treatment plant. Manholes are provided at intersections of sewer lines and also at regular intervals to facilitate regular inspection and cleaning.

Storm Sewer

Designed to carry storm water or ground water excluding domestic and industrial sewage.

Storm sewers carry surface runoff developed during the period of rainfall over concerned area including street wash.

Combined ~~System~~ sewer

Designed for domestic sewage, Industrial sewage and storm sewage.

- This system consists of a single sewer line of large diameter through which the sewage and storm water are allowed to flow and are carried to the treatment plant.
- The storm water dilutes the sewage and hence its strength is reduced.
- The self-cleansing velocity is easily acheived.
- As the single sewer line serves the double function, it becomes economical.

ASSUMPTIONS IN SEWER DESIGN

For the purpose of hydraulic design of sewer following assumptions are made:

(i) The flow of waste water in sewer is steady and uniform. The unsteady and non-uniform waste water flow characteristics are accounted for in the design by proper sizing of manholes.

(ii) Design of sewer is based on peak flow discharge.

Flow Formula

Manning's formula is used for open channel flow (i.e. when sewer is design to run partially full).

Hazen Williams formula is used for closed conduit or pressure flow.

- Manning's formula

$$V = \frac{1}{n} R^{2/3} S^{1/2} \qquad \begin{bmatrix} V = \text{velocity of flow} \\ R = \text{hydraulic radius} \\ S = \text{slope of sewer} \end{bmatrix}$$

- Hazen William's formula

$$V = 0.849 C R^{0.63} S^{0.54}$$

[C = Hazen-William coefficient,
Units are SI units]

DESIGN DATA

- Sanitary sewers are design to run partially full (flow under gravity)

Pipe size	Design condition
D < 0.4 m	$\frac{1}{2}$ full at max discharge
0.4 ≤ D ≤ 0.9 m	$\frac{2}{3}$rd full at max discharge
D > 0.9 m	$\frac{3}{4}$th full at max discharge

- Sewer should be designed to carry peak discharge. i.e. *Max hourly discharge*, and should be checked to ensure that at min discharge, (i.e. min hourly discharge) velocity generated should be greater than *self cleansing velocity*.
- *Self cleansing velocity* is the minimum velocity at which no solid gets deposited at the bottom of sewer.
- Ratio of max discharge to average discharge is max in the laterals and decreases progressively from lateral to branch and to main sewer.
- Unless otherwise given, the following data should be adopted for discharges through 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

- It is assumed that almost 75-80% of accounted water supply goes into sewage.

Self cleansing velocity is given by Shields formula -

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

G_s = sp. gravity of particle

d_p = particle size

K_s = a dimension less constant with a value of about 0.04 to start motion of granular particle and about 0.8 for adequate self cleansing of sewer.

R = hydraulic radius of sewer

n = manning coefficient.

Ensuring self cleansing velocity at min flow ensures that no solid is deposited even at min flow. However, sometimes design is done in such a way that although solid silting may occur at min flow, the same should be flushed out at peak flow.

Note: Minimum self cleansing velocity for 1 mm size inorganic particle and 5 mm size organic particle, which are normally found in sewage is 0.45 m/s. Such a self-cleansing velocity of 0.45 m/s at min hourly flow can be ensured by designing the sewer under design flow (1/2 to 3/4th full), and also ensuring that the velocity at that time is greater than 0.8 m/s.

Max Velocity

- To avoid erosion of pipe surface max velocity should be limited as follows:

  Concrete sewer ⟶ 2.5-3 m/s

  Castiron sewer ⟶ 3.5-4.5 m/s

  Stone ware sewer – 3-4

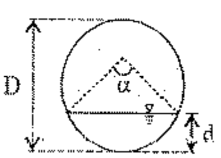
  G_s → 2.65 Inorganic particle
  → 1.2 organic particle

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

Min diameter of public sewer should be 150mm but for hilly [illegible] can be 100mm also.

PARTIAL FLOW CHARACTERISTICS OF CIRCULAR SEWER

If small letter represent hydraulic elements under partial flow and capital letter represents the hydraulic elements under full flow condition then for a circular sewer



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

d = depth of flow

D = Dia of sewer

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

a = area of flow under partial flow condition

A = area of full flow $\left(\frac{\pi D^2}{4}\right)$

α = angle as shown in the figure

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

p = perimeter (wetted) under partial flow

$P = \pi D$

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

r = hydraulic radius under partial flow

R = hydraulic radius under full flow $= \dfrac{D}{4}$

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

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

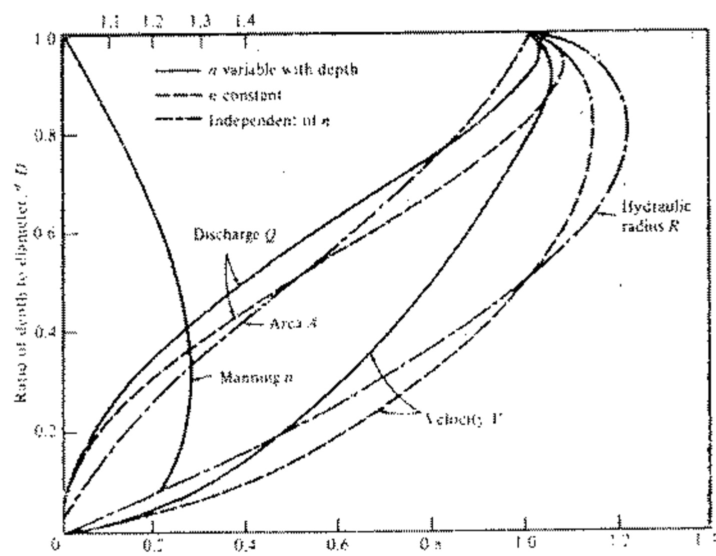
v = velocity under partial flow

V = velocity under full flow

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

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 or by using partial flow diagram.

Values of $\dfrac{n}{n_{full}}$



Hydraulic Elements $\dfrac{V}{V_{full}}, \dfrac{Q}{Q_{full}}, \dfrac{A}{A_{full}}, \dfrac{R}{R_{full}}$

Hydraulic Elements For Circular Sewer

Points to be Noted

- If Manning's coefficient 'n' is assumed constant with depth, then

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

- For constant 'n', velocity of flow is max when $d/D = 0.81$ and this V_{max} is 12.5% greater than when running full.
- For constant 'n', discharge is max when $\frac{d}{D} = 0.95$ and this q_{max} is 7% greater than the discharge at running full.
- $\frac{v}{V}$ decreases less sharply than $\frac{q}{Q}$ below $\frac{1}{2}$ full depth (for constant n) in circular sewer.

Note: As the d/D < 0.5, the velocities and discharges both decline, and become lesser than those at full flow. However, the decline in velocities is not so sharp, as in the decline in discharges, because the area (on which depends discharge) reduces much faster as compared to the hydraulic mean depth (on which depends velocity).

- $\frac{q}{Q} = \frac{1}{2}$ at $\frac{1}{2}$ full flow (n = constant) because $(r = R)$.
- If $\frac{d}{D} \geq 0.5$, then $\frac{v}{V} \geq 1$ (for n = constant)

Equal Degree of Self Cleansing

- If in a particular sewer, drag force under partial flow and drag force under full flow is to be same, then

$$\rho gRS = \rho grS$$

$$\Rightarrow \quad R = r$$

This will happen only at $\frac{1}{2}$ full and full condition. There cannot be any other point where $\frac{r}{R} = 1$.

- Thus degree of self cleansing will be same in a particular sewer only at $\frac{1}{2}$ full and full condition.
- When two sewers kept at different slopes are to be compared for equal degree of self-cleansing (one running full and other partially) then

$$\rho gRS = \rho grs$$

$$\Rightarrow \quad \boxed{RS = rs}$$

Under this condition

$$\frac{v}{V} = \frac{N}{n}\left(\frac{r}{R}\right)^{2/3}\left(\frac{s}{S}\right)^{1/2}$$

$$\frac{v}{V} = \frac{N}{n}\left(\frac{r}{R}\right)^{2/3}\left(\frac{1}{r/R}\right)^{1/2}$$

$$\Rightarrow \quad \boxed{\frac{v}{V} = \frac{N}{n}\left(\frac{r}{R}\right)^{1/6}}$$

Note: When minimum velocity requirement in a sewer is not satisfied option is to

(a) increase the slope

(b) increase the dia of sewer

Example 1

Design a sewer to serve a population of 36000. Daily water supply per capita = 135 *l* of which 80% goes into the sewer. Slope, $S = \frac{1}{625}$ and the sewer would be designed to carry 4 times the average discharge under design condition. What would be the velocity generated if n = 0.012 and it is assumed to be constant.

Sol.

$$Q_{design} = 4\times\left[0.8\times135\times36000\frac{10^{-3}}{86400}\right]$$

$$= 0.18 \text{ m}^3/\text{s} = q$$

$$S = \frac{1}{625}$$

$$\text{Assume } \frac{d}{D} = \frac{3}{4}$$

$$\Rightarrow \quad \frac{d}{D} = \frac{1}{2}\left(1-\cos\frac{\alpha}{2}\right) = 0.75$$

$$\alpha = 240°$$

$$\frac{q}{Q} = \left(\frac{\alpha}{360}-\frac{\sin\alpha}{2\pi}\right)\times\left(1-\frac{360\sin\alpha}{2\pi\alpha}\right)^{2/3}$$

$$\Rightarrow \quad \frac{q}{Q} = (0.804)(1.206)^{2/3}$$

$$= 0.911$$

$$\Rightarrow \quad Q = 0.198 \text{ m}^3/\text{sec}$$

$$Q = \frac{1}{0.012}\times\left(\frac{D}{4}\right)^{2/3}\times\left(\frac{1}{625}\right)^{1/2}\times\frac{\pi D^2}{4} = 0.198 \text{ m}^3/\text{s}$$

$$\Rightarrow \quad D = 0.573 \text{ m} = 537 \text{ mm}$$

$$V = \frac{0.198}{\frac{\pi}{4}(0.537)^2}$$

$$= 0.875$$

$$\frac{v}{V} = \left(\frac{r}{R}\right)^{2/3} = (1.206)^{2/3}$$

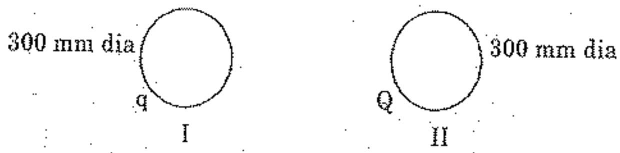
$$\Rightarrow \quad v = 0.99 \text{ m/sec}$$

As the velocity is greater than 0.8 m/s at design flow it will ensure that at minimum flow, the velocity generated will be more than self cleasing velocity.

Example 2

Design a sewer of diameter 300 mm flowing at d/D = 0.3 on a grade ensuring a degree of self cleansing equivalent to that obtained in a sewer of dia 300 mm in which at full flow, velocity is 0.9 m/sec. Find (a) required grade (b) the velocity of flow and discharge (assume n = constant = 0.013).

Sol. (a)



$$\frac{d}{D} = 0.3 \qquad \frac{d}{D} = 1.0$$

$$R = \frac{300}{4} = 75 \text{ mm}$$

$$\frac{r}{R} = 1 - \frac{360 \sin\alpha}{2\pi\alpha}$$

$$\frac{d}{D} = \frac{1}{2}\left(1 - \cos\frac{\alpha}{2}\right) = 0.3$$

$$\Rightarrow \quad \alpha = 132.84°$$

$$\Rightarrow \quad \frac{r}{R} = 0.684$$

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

$$0.9 = \frac{1}{0.013}(0.075)^{2/3}\sqrt{S}$$

$$\Rightarrow \quad S = \frac{1}{231}$$

$$\Rightarrow \quad rs = RS$$

$$s = \frac{R}{r} \times S$$

$$= \frac{1}{0.684} \times \frac{1}{231}$$

$$S = \frac{1}{158}$$

(b) For equal degree of self cleansing

$$\frac{v}{V} = \left(\frac{r}{R}\right)^{1/6}$$

$$v = 0.9 \times (0.684)^{1/6}$$

$$v = 0.845 \text{ m/s}$$

$$\frac{q}{Q} = \left(\frac{r}{R}\right)^{1/6} \times \frac{a}{A} \qquad \left[\frac{a}{A} = \frac{\alpha}{360} - \frac{\sin\alpha}{2\pi} = 0.252\right]$$

$$= (0.684)^{1/6} \times 0.252$$

$$q = 0.2365 \times 0.9 \times \pi \times \frac{0.3^2}{4}$$

$$q = 0.015 \text{ m}^3\text{/sec}$$

Example 3

Determine the size of a circular sewer for a discharge of 500 litres per second running half full. Assume S = 0.0001 and n = 0.015.

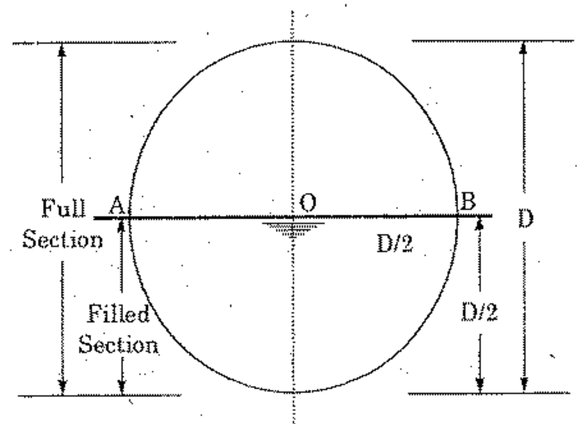
Sol. Given d = 0.5D

When running half full,

$$a = \frac{\pi}{8}D^2$$

$$p = \frac{\pi D}{2}$$

$$\therefore \quad r = \frac{\pi}{8}D^2 \times \frac{2}{\pi D} = \frac{D}{4}$$



Now, $q = \frac{1}{n}a.r^{2/3}S^{1/2}$

Here q = 500 litres/sec = 0.5 cumecs

$$\therefore \quad 0.5 = \frac{1}{0.015} \times \frac{\pi}{8}D^2\left(\frac{D}{4}\right)^{2/3} \times (0.0001)^{1/2}$$

or $D^{8/3} = 4.8128$

From which D ≈ **1.80 m**

Example 4

A town has a population of 100,000 persons with a per capita water supply of 200 litres/day. Design a sewer running 0.7 times full at maximum discharge. Take a constant value of n = 0.013 at all depths of flow. The sewer is to be laid at a slope of 1 in 500. Take a peaking factor of 3. (Take self cleansing velocity = 60 cm/s) and adopt

$\frac{q}{Q}$	$\frac{v}{V}$
0.196	0.776
0.088	0.615

Sol. Water supplied = 100,000 × 200 = 20 × 10^6 litres/day

$$= \frac{20 \times 10^6}{10^3 \times 24 \times 3600} = 0.2315 \text{ cumecs.}$$

Assuming that 80% of the water supplied to the town appears as sewage, we have average discharge in the sewer

= 0.8 × 0.2315 = 0.185 cumecs.

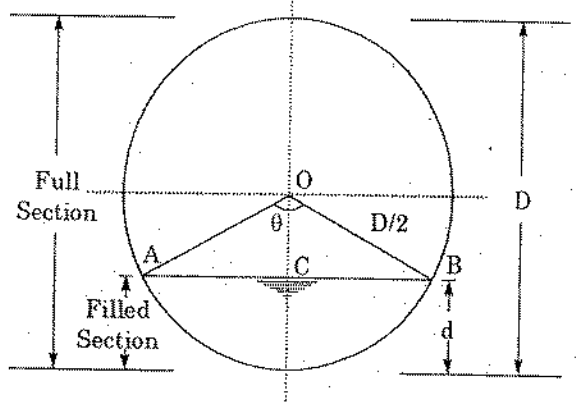
At a peaking factor of 3,

Max. discharge = 3 × 0.185 = 0.556 cumecs

Since the sewer is to be designed as running 0.7 times the full depth, d/D = 0.7

and q = 0.556 cumecs.

For a sewer running partially full



$$\cos\frac{\theta}{2} = 1 - 2\frac{d}{D} = 1 - 2\times 0.7 = -0.4$$

$$\therefore \quad \frac{\theta}{2} = 113.58°; \quad \theta = 227.16°; \quad \sin\theta = -0.7332$$

$$a = \frac{\pi}{4}D^2\left[\frac{\theta}{360} - \frac{\sin\theta}{2\pi}\right] = \frac{\pi}{4}D^2\left[\frac{227.16}{360} + \frac{0.7332}{2\pi}\right]$$

$$= 0.587\ D^2 \qquad \text{.............(i)}$$

$$p = \pi D\frac{\theta}{360} = \pi D\frac{227.16}{360} = 1.982D \qquad \text{.............(ii)}$$

$$r = \frac{a}{p} = \frac{0.587D^2}{1.982D} = 0.296D \qquad \text{.............(iii)}$$

Now, $q = \frac{1}{n}ar^{2/3}S^{1/2}$

$$\therefore \ 0.556 = \frac{1}{0.013}\times 0.587D^2(0.296D)^{2/3}\left(\frac{1}{500}\right)^{1/2}$$

or $\quad D^{8/3} = 0.6190$

From which D = **0.835 m**

Check for self cleansing velocity at max. discharge

r = 0.296 D = 0.296 × 0.835 = 0.247 m

$$\therefore \ v = \frac{1}{n}r^{2/3}S^{1/2} = \frac{1}{0.013}(0.247)^{2/3}\left(\frac{1}{500}\right)^{1/2} = \mathbf{1.356\ m/s}$$

This is much more than the self cleansing velocity of 60 cm/sec.

Check for self cleansing velocity at min. discharge.

Let us assume minimum flow equal to $\frac{1}{3}$ times the average flow.

$\therefore \ q_{min} = (1/3) \times 0.185 = 0.0617\ m^3/s$

$$\text{Full flow discharge} = \frac{1}{n}(D/4)^{2/3}S^{1/2}\cdot\frac{\pi D^2}{4}$$

$$= \frac{1}{0.013}\left(\frac{0.835}{4}\right)^{2/3}\left(\frac{1}{500}\right)^{1/2} \times \frac{\pi}{4}(0.835)^2$$

$= \mathbf{0.6625\ m^3/s}$

$$\frac{q_{min}}{Q} = \frac{0.185}{3 \times 0.6625} = 0.093$$

$$V_{full} = \frac{0.6625}{\frac{\pi}{4}(0.835)^2} = 1.21\ m/s$$

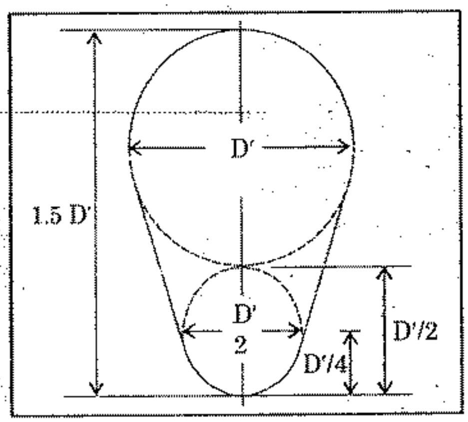
For $\frac{q}{Q} = 0.093$

$$\frac{v}{V} = 0.622$$

$v = 0.753$ m/s > 0.6 m/s

EGG SHAPED SEWER

Short notes.



- Circular sewer sections are mostly used for separate sewage system. But the advantage of circular sewer is obtained only when the section runs atleast half full. When the depth goes below half depth the velocity reduces considerably.
- If a circular sewer is used for combined system it will be effective only during maximum rain water flow but during dry weather flow, velocity generated would be very less. Thus to take advantage of a circular sewer, two such circular sewers are assumed to be combined into one to form an egg shaped sewer in which smaller circular portion will be effective during dry weather and full section is effective during maximum rain water flow.
- Two sewers (of different shape) are hydraulically equivalent when they discharge at same rate "while flowing full" on the same grade. i.e. $\frac{1}{n} AR^{2/3}$ is same under full condition in both the sewer.
- The egg shaped sewer of an equivalent section, whose top diameter D' = 0.84 D : where D = diameter of circular sewer of same cross-sectional area obtained for passing the requisite discharge.

Note: In circular sewers for combined system, fluctuation in discharge could be as large as 25 times. Egg shaped sewer produces 2-15% higher velocity than that provided by hydraulically equivalent circular sewer.

STORM WATER DRAINAGE

- Design of storm sewer requires the estimation of peak runoff rate for design.
- Peak runoff will depend on the intensity of rainfall.
- Intensity of rainfall depends on the reccurrence interval (frequency) and duration of rainfall.

Note: Rain of larger reccurrence interval will have larger intensity. Hence if 5-yr reccurrence interval rain is chosen for design, than it may lead to flooding in every 5-years (because the rainfall has a probability of exceeding the adopted value every 5-years and drainage has not been designed for this large rain fall) if larger frequency of rainfall is adopted in design, larger sewer will be required to carry the runoff safely.

Time of Concentration

- In the starting, the entire catchment will not be contributing to the runoff at the monitoring point. The time after which the entire catchment starts contributing to the runoff is called time of concentration.

Time of concentration = (Overland flow time + Channel flow time)

Water 1st flows overland and than joins a channel in the catchment. Thus total time required to come to the monitoring point is equal to summation of overland flow time and channel flow time.

- The rainfall which continues upto the time of concentration will yield max runoff.
- To estimate the peak runoff, rainfall intensity (*i*) of particular frequency (as specified by the local authorities) and duration equal to time of concentration is adopted.

Peak rate of runoff is calculated using rational formula.

Rational Formula

$$Q = C.i.A$$

where, Q = Peak rate of runoff

$$C = \text{Runoff coefficient}\left(\frac{\text{runoff}}{\text{rainflow}}\right)$$

i = intensity of rainfall

A = drainage basin area = catchment area........

Runoff Coefficient (also called Impermeability Factor)

Runoff coefficient value increases as imperiousness of catchment increases.

When several different types of surfaces comprise the catchment than weighted average value of runoff-coefficient is adopted

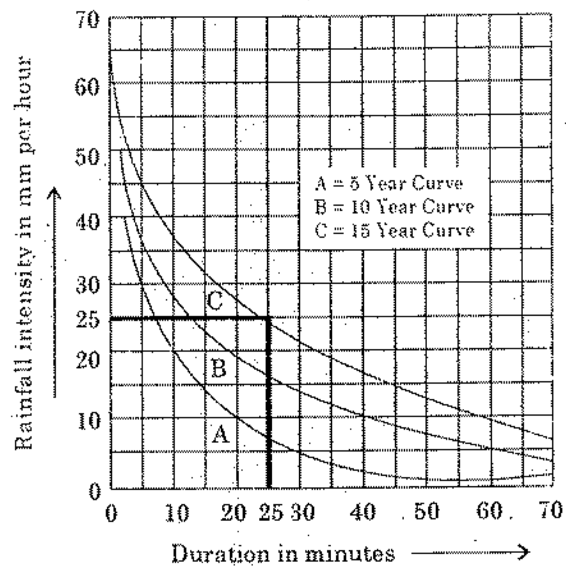
$$C_{av.} = \frac{C_1A_1 + C_2A_2 + C_3A_3 + \ldots\ldots}{A_1 + A_2 + A_3 + \ldots\ldots}$$

A_1 area has runoff coefficient = C_1

A_2 area has runoff coefficient = C_2

A_3 area has runoff coefficient = C_3 etc.

Rainfall Intensity



Intensity Duration Frequency Curves

Rainfall intensity depends on the storm recurrence internal and the storm duration.

Note: In the above figure, if 15-hr recurrence interval rain is to be adopted and time of concentration is 25 min then rainfall intensity to be adopted will be 25 mm/hr.

The grapth given as above will be the rainfall intesity measured at a particular rain-gauge station and is termed as point rainfall intensity.

It is therefore necessary to multiply it by a factor called areal dispersion factor, in order to account for non-uniformity of rainfall over the catchment (particuarly for large catchment).

Thus design rainfall intensity = (point rainfall intensity) × (areal dispersion factor).

In the absence of intensity – duration curve, following formula may be adopted for calculation of design rainfall intensity

$$i = i_0\left(\frac{2}{1 + T_C}\right)$$

i_0 = (Point rainfall intensity of a particular frequency) × (area dispersion factor)

i = design (critical) rainfall intensity

This point rainfall intensity is obtained from contour map of max rainfall of a particular frequency.

i_0 is in cm/hr

i is in cm/hr

T_C is in hr = Time of concentration.

The design rainfall can also be obtained from the formula

$$i = \frac{a}{b + T_C}$$

where, i = cm/hr (critical rainfall intensity)

T_C = minutes

Design of storm sewer or combined sewer is done in form of

a and b are constants.

$$i = \frac{75}{T_C + 10}, \quad T_C \text{ is min}, \quad \text{for } 5 \le T_C \le 20$$

$$= \frac{100}{T_C + 20}, \quad T_C \text{ in min}, \quad \text{for } 20 < T_C < 100$$

Example 5

A combined sewer of circular section is to be laid to serve a particular area. Calculate the size of sewer for the following data.

Area of to be served = 120 ha

Population = 100000

Max. velocity of flow = 3 m/s

Time of entry = 10 min

Time of channel flow = 20 min

per capita water supply = 250 lpcd

k = 0.45

Hourly max. rainfall of the area at design frequency = 5 cm.

Sol. The maximum discharge will be assumed to be corresponding to full flow.

$$Q_S = Q_{sewage} = 250 \times 10^5 \times 0.8$$

$$Q_{s\ peak} = 3 \times (250 \times 10^5 \times 0.8) = 60 \times 10^6 \text{ lit/day} = 0.694 \text{ m}^3\text{/sec}$$

$$Q_{rain\ peak} = P_c \times A \times K$$

$$P_c = P_0\left(\frac{2}{1 + t_c}\right)$$

$$= 5\left(\frac{2}{1 + 0.5}\right)$$

$$= 6.67 \text{ cm/hr}$$

$$Q_{p\ rain} = 0.45 \times 120 \times 10^7 \times 6.67 \times 10^{-2}$$

$$= 10 \text{ m}^3\text{/s}$$

$$\text{Total } Q = Q_{p\ rain} + Q_{s\ peak}$$

$$= 10 + 0.694 = 10.694 \text{ m}^3\text{/s}$$

$$\text{max velocity} = 3 \text{ m/s}$$

$$Q = \frac{\pi D^2}{4} \times 3 = 10.694$$

$$\Rightarrow \quad D = 2.13 \text{ m}$$

Example 6

A circular sewer of 45 cm diameter was designed for a town of population 30,000. The sewer was designed to cary 3.5 times of the dry weather flow. What slope should be provided to the sewer when running full? Value of n = 0.012 in Manning's equation. Assume other relevant data suitably.

Sol. Given:

Population = 30,000

Diameter of sewer = 45 cm = 0.45 m

Let water supply = 150 l/p/d

Average water discharge = $\frac{150 \times 30000}{86400} = 52.08\ l/\text{sec}$

Let average sewage discharge is 80% of average water discharge

= 41.667 l/sec

Peak discharge = 145.833 l/sec = 3 × 41.667 l/sec

$$Q = \frac{1}{N} AR^{2/3}S^{1/2}$$

$$\Rightarrow Q = \frac{1}{N} (\pi/4D^2)(D/4)^{2/3} S^{1/2}$$

$$145.83 \times 10^{-3} = \frac{1}{0.012} \times \left[\frac{\pi}{4} \times (0.45)^2\right]\left[\frac{0.45}{4}\right]^{2/3} \times S^{1/2}$$

$$S^{1/2} = 0.0473 \Rightarrow S = \frac{1}{447.46}$$

Example 7

The surface water from airport road side is drained to the longitudinal side drain from across one half of a bituminous pavement surface of total width 7.0 m, shoulder and adjoining land of width 8.0 m on one side of the drain. On the other side of the drain, water flows across from reserve land with average turf and 2% cross slope towards the side drain, the width of this strip of land being 25 m. The inlet time may be assumed to be 10 min for these conditions. The runoff coefficients of the pavement, shoulder and reserve land with turf are 0.8, 0.25 and 0.35 respectively. The length of the stretch of land parallel to the road from where the water is expected to flow to the side drain is 400 m. Estimate the quantity of runoff flowing in the drain assuming 10 year frequency. The side drain will pass through clayey soil with allowable velocity of flow as 1.33 m/s. Intensity-duration chart for 10 year frequency is:

Duration (minutes)	Intensity (mm/hr)
5	160
10	150
15	125
20	110
30	95

Sol. Runoff factor K for the entire area contributing discharge

$$K = \frac{K_1A_1 + K_2A_2 + K_3A_3}{A_1 + A_2 + A_3}$$

$$= \frac{0.8 \times (7 \times 400) + 0.25 \times (8 \times 400) + 0.35 \times (25 \times 400)}{(7 \times 400) + (8 \times 400) + (25 \times 400)}$$

$$= \frac{6540}{2800 + 3200 + 10000} = 0.40875$$

Total area = 16000 m^2 = 1.6 hac.

Time of concentration

$T_C = T_i + T_f$

T_f = channel flow time in drain

$= \frac{400}{1.33} = 300 \text{ sec} = 5 \text{ min}$

$\therefore \quad T_C = 10 + 5 = 15 \text{ min}$

Corresponding to T_C, rainfall intensity = 125 mm/hr

$\Rightarrow \quad P_C = 12.5$ cm/hr

$$\text{Peak discharge } Q_P = \frac{1}{36} K P_C A$$

$$= \frac{1}{36} \times 0.40875 \times 12.5 \times 1.6$$

$$= 0.227 \text{ m}^3/\text{s} \quad \textbf{Ans.}$$

Example 8

Design a sewer to serve a population of 36000; the daily per capita water supply allowance being 135 litres of which 80% finds its way into the sewer. The slope available for the sewer to be laid is 1 in 625 and the sewer should be designed to carry four times the dry weather flow when running full. What would be the velocity of flow in the sewer when running full? Assume n = 0.012 in Manning's formula.

Sol. Given :

Population = 36000

Water supply = 135 l/p/d

Slope = 1/625

n = 0.012

$$\text{Average water discharge} = \frac{36000 \times 135}{86400} \times 10^{-3} = 56.25 \times 10^{-3} \text{ m}^3/\text{sec}$$

Average sewage discharge = $0.8 \times 56.25 \times 10^{-3} = 45 \times 10^{-3}$ m³/s

Design discharge = 4 × average sewer discharge

$= 4 \times 56.25 \times 10^{-3} \times 0.8 = 0.18 \text{ m}^3/\text{s}$

Applying Mannings formula

$$Q = \frac{1}{n}(\pi/4 D^2)(D/4)^{2/3} S^{1/2}$$

$$0.18 = \frac{1}{0.012} \pi/4 \, D^2 \times \frac{D^{2/3}}{4^{2/3}} \left(\frac{1}{625}\right)^{1/2}$$

$$D^{2/3} = 0.17325$$

$$D = 0.518 \text{ m} \quad \textbf{Ans.}$$

Example 9

A combined sewer of circular section is to be laid to serve an area of 100 ha with a population of 90,000 supplied with water at 200 litres per day. Assuming an impermeability factor of 0.50 and time of concentration of rainfall 't' as 20 minutes, calculate the size of the sewer when it has to run full with a velocity of 0.3 m/s. Assume suitable coefficients for 'a' and 'b' in the equation for R, intensity of rainfall relating to 't', the time of concentration.

Sol. Given :

Population = 90,000

Area = 100 ha

Water supply = 200 litres per day

K = 0.50

Time of concentration = 20 minutes

Full velocity = 0.3 m/s

Let critical rainfall intensity $= \dfrac{a}{b + T_C}$

$$a = 75 \text{ and } b = 10$$

$$\therefore \quad R = \frac{75}{T_C + 10}$$

$$= \frac{75}{20+10} = 2.5$$

$$\therefore \quad R = 2.5 \text{ cm/hr}$$

$$\text{Peak discharge, } Q_P = \frac{1}{36} \text{ ki}\cdot\text{A}$$

$$= \frac{1}{36} \times 0.50 \times 2.5 \times 100$$

$$= 3.47 \text{ m}^3\text{/sec}$$

$$\text{Average water discharge} = \frac{90000 \times 200}{86400} \times 10^{-3} = 0.2083 \text{ m}^3\text{/s}$$

Average sewage discharge = 0.8 × 0.2083 = 0.1666 m^3/sec

Peak sewage discharge = 0.1666 × 3 = 0.5 m^3/sec

Total discharge = 3.47 + 0.5 = 3.97 m^3/s

Given full velocity = 0.3 m/s

$$\therefore \quad \text{Area of sewer} = \frac{3.97}{0.3}$$

$$= 13.24 \text{ m}^2$$

Take sewer as circular

$$\frac{\pi}{4} D^2 = 13.233$$

$$\therefore \quad D = 4.1 \text{ m} \quad \textbf{Ans.}$$

Example 10

A combined sewer of circular section is to be designed in a sewage system for a city with a population of 100,000 in an area of 100 hectares. The mean flow of sewage from the city is 250 litre/capita/day. The rainfall intensity in the a rea is 4 cm/hr. The coefficient of runoff of the area is 0.48. The ratio of peak to average sewage flow is 2.0. The Manning's roughness coefficient is 0.012 and the Hazen-William's coefficient is 85. Using Manning's equation and Hazen-William's expression, determine the gradient of the sewer to carry the peak flow with a velocity of 1.2 m/s.

Sol. Given :

Population = 100000

Area = 100 ha

Mean flow of sewage = 250 l/c/day

$P = 4$ cm/hr

$K = 0.48$

$n = 0.012$

Ratio of peak to average sewage flow = 2

$$\text{Discharge } Q_p = \frac{1}{36} KiA$$

$$= \frac{1}{36} \times 0.48 \times 4 \times 100 = 5.33 \text{ m}^3/\text{s}$$

$$= 5.33 \text{ m}^3/\text{s}$$

$$\text{Average sewage discharge} = \frac{100000 \times 250}{86400}$$

$$= 0.29$$

Total average discharge = 5.33 + 0.29

Peak discharge = 5.33 + 2× 0.29 = 5.91 m^3/s

Peak velocity = 1.2 m/s

$$\therefore \quad \text{Area of sewer} = \frac{5.91}{1.2} = 4.925 \text{ m}^2$$

Let dia of sewer is D

$$\therefore \quad \frac{\pi}{4} D^2 = 4.925 \text{ m}^2$$

$$\mathbf{D = 2.505 \text{ m}}$$

According to Manning's formula

$$\therefore \quad V = \frac{1}{N}\left(\frac{D}{4}\right)^{2/3} S^{1/2}$$

$$1.2 = \frac{1}{0.012}\left(\frac{2.505}{4}\right)^{2/3} S^{1/2}$$

$$\therefore \quad S = 3.869 \times 10^{-4}$$

According to William Hazen's formula

$$V = 0.85\ C_H \times r^{0.63}\ S^{0.54}$$

$$\Rightarrow \quad S = 8.739 \times 10^{-4} \quad \textbf{Ans.}$$

Example 11

A 20 cm diameter sewer with invert slope of 1 in 500 is running full. Calculate the rate of flow in the sewer. Compare the velocity with self-cleansing velocity. Assume Manning's n = 0.12.

Sol. Given:

Diameter of sewer = 0.20 m

$$\text{Slope} = \frac{1}{500}$$

$$V_{full} = \frac{1}{n}\left(\frac{D}{4}\right)^{2/3}$$

$$= \frac{1}{0.012}\left(\frac{0.20}{4}\right)^{2/3}\left(\frac{1}{500}\right)^{1/2}$$

$$= 0.506 \text{ m/s}$$

Self cleansing velocity

$$V_S = \frac{1}{n} R^{1/6}\{K_S(G_S-1)\, d_p\}^{1/2}$$

$$= \frac{1}{0.012}\left(\frac{0.2}{4}\right)^{1/6}\sqrt{0.04\times 0.001\,(2.65-1)}$$

$$= \frac{1}{0.012}\left(\frac{.2}{4}\right)^{1/6}\sqrt{0.04\times .001(2.65-1)}$$

$$V_S = 0.41 \text{ m/s } \textbf{Ans.}$$

Example 12

A 1200 m long storm sewer collects wastewater from a catchment area of 50 hectare, where 35% area is covered by roof (I = 0.9), 20% area is covered by pavements (I = 0.8) and 4% area is covered by open land (I = 0.13). Determine the average I, and diameter of storm sewerline assuming

(i) the time of entry = 3 min

(ii) velocity of full flow = 1.5 m/s

(iii) n = 0.013 and slope = 0.001

I = runoff ratio.

Sol. Given:

$$I_1A_1 = 0.35 \times 50 \times 0.9 = 15.75$$
$$I_2A_2 = 0.20 \times 50 \times 0.8 = 8$$
$$I_3A_3 = 0.45 \times 50 \times 0.13 = 2.925$$

$$\text{Average I} = \frac{I_1A_1 + I_2A_2 + I_3A_3}{A}$$
$$= \frac{15.75 + 8 + 2.925}{50}$$
$$= 0.5335$$

Now,

$$V = 1.5 \text{ m/s}$$
$$n = 0.013$$
$$S = 0.001$$
$$R = \frac{D}{4}$$
$$V = \frac{1}{n}\left(\frac{D}{4}\right)^{2/3} (0.001)^{1/2}$$

$\Rightarrow$ $D = 1.937$ m **Ans.**

Example 13

Using n = 0.015 in Manning's formula, design a sewer running half-full at a flow rate of 650 litres per second and laid at an invert slope of 0.0001.

Sol. Given :

Half full discharge = 650 *l*/sec = 0.65 m^3/s

$$n = 0.015$$

Let sewer dia D

$$R = \frac{D}{4}$$

Since sewer in half full

$$\therefore \quad \frac{q}{Q} = 0.5$$

$$\therefore \quad Q = \frac{0.65}{0.5} = 1.3 \text{ m}^3/\text{s}$$

$$\therefore \quad Q = \frac{1}{n}\frac{\pi}{4}D^2\left(\frac{D}{4}\right)^{2/3} S^{1/2}$$

$$1.3 = \frac{1}{0.015}\frac{\pi}{4}\frac{D^{8/3}}{4^{2/3}}(0.0001)^{1/2}$$

$$\therefore \quad D = 1.99 \text{ m}$$

Say $D = 2$ m **Ans.**

SEWER APPURTENANCES

Sewer appurtenances are those structures which are constructed at suitable interval along a sewarage system, and help in its efficient opperation and maintenance. These are as follows.

(1) Manholes

- A manholes is an opening constructed on the aligment of a sewer for facilitating a person access to the sewer for the purpose of inspection, testing, cleaning and removal of obstruction from the sewerline.
- Manholes should be built at every change of aligment, gradient or diameter, at the head of all sewers and branches and at every Junction of two or more sewer.
- The spacing of manholes above 90 to 150 m may be allowed on straight runs for sewers of diameter 0.9 to 1.5 m. Spacing of manholes at 150 to 200m may be allowed on straight runs for seweres of 1.5 to 2m diameter.
- The depth <1m is considered as normal manhole and depth > 1.5m is considered as deep manhole.

Components of Manhole

(a) Access Shaft

It may be rectangular or circular (min^m size 90 × 100 cm or min^m dia 90 cm) serves the purpose of removing the debris from the sewer and acts as a passage for the workers to conduct the maintenance works.

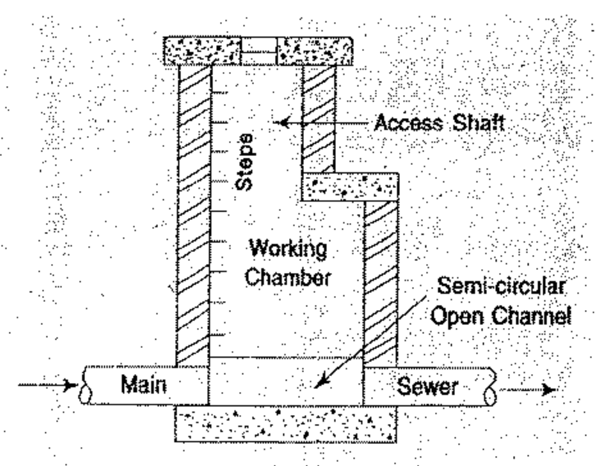
(b) Working Chamber

It provide sufficient space for the workers for cleaning the sewer and for conducting maintenance works.

Height of chamber ≈ 2m.

Size (rectangular) = 1.2 × 1.5 m

If chamber is circular diameter ≈ 1.2 m



Manhole

Types of Manholes

(i) Straight – Trough Manholes

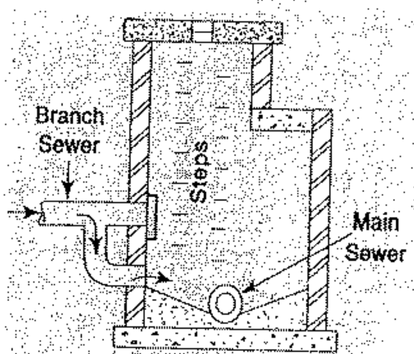
It is a simplest type of manhole that is built on a straight run of sewer with no side Junctions, where there is a change in the size of sewer, the soffit or crown level of the two sewers should be the same.

(ii) Junction Manholes

This manhole should be built at every junction of two or more seweres, and the curved portions of the inverts of tributary sewers should be formed within the manhole. The soffit of the smaller sewer at a junction should be not lower than that of the larger sewer, in order to avoid the surcharging of the former when the latter is running full.

(iii) Drop manholes

A manhole which is constructed to connect the high level branch sewer (> 0.6m) to the low level main sewer by vertical dropping pipe is known as drop manhole. As showin in figure a branch sewer passes at higher level and the main sewer runs at lower level. So the sewage will will fall in the main sewer in the form of a spring. This will cause much inconvenience to the workers at the working chamber. So, the end of the branch pipe is plugged and a verical dropping pipe is taken from the branch pipe and connected to the manhole near the bottom to allow the sewage to fall in main sewer smoothly.



Drop Manhole

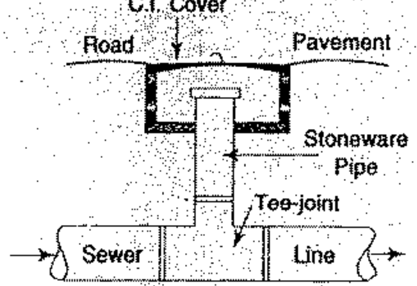
(iv) Flushing Manhole

Where it is not possible to obtain self cleansing velocities due to flatness of the gradient especially at the top ends of branch sewers which receive very little flow, it is essential that some form of flushing device be incorporated in the system. Which imparts sufficient velocity in the flow to wash away the deposited solids.

(2) Lamp Hole

A hole or opening which is provided in a sewer line for lowering a lamp inside is known as Lamp hole. It is a vertical pipe made of stoneware which is connected to the sewer by a Teeth-joint. At the top a box-line compartment is made which carries a cast-iron cover.

Functions of Lamp Hole : An electric lamp is inserted into the sewer for inspection purpose if the sewer is clear, the light will be visible from the adjacent manholes. Then the operation of cleaning will be done accordingly.



Lamp Hole

The construction of lamp hole is advisable for the following conditions :

(i) When the spacings of regular manholes are at longer interval.

(ii) When it is difficult to construct a regular manhole.

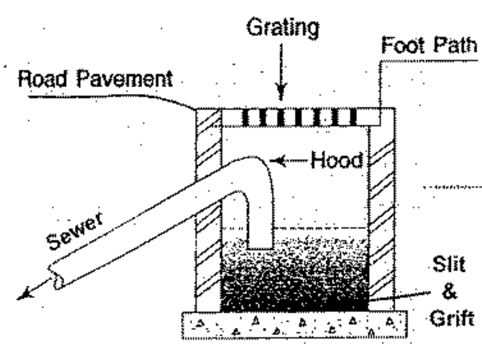
(iii) When a change of direction or change of grade comes in the sewer line.

(3) Grease And Oil Trap

The traps or chambers which are constructed on the sewer line for excluding grease and oil from the sewage are known as grease and oil traps. If sewage contains grease and oil, it sticks to the interior surface of the sewer and decreases the carrying capacity of sewer gradually.

(4) Catch Basin

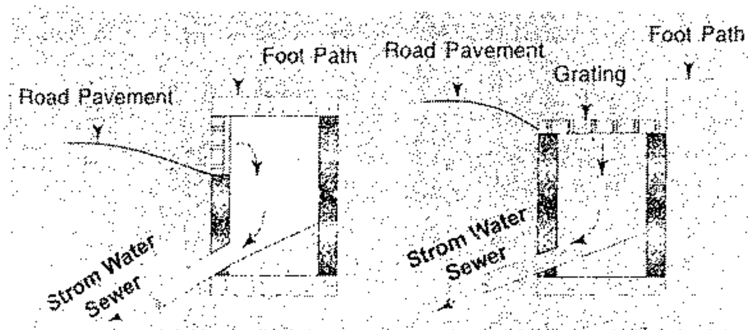
A catch basin is a rectangular chamber constructed along the sewer line to allow the strom water to enter the sewer by eliminating the silt, grit, etc. at the bottom of the basin.



Catch Basin

(5) Storm water Inlet

These are devices meant to admit the surface run off to the sewers storm water inlets having vertical openings is known as the vertical inlet or the curb inlet, and the inlet having horizontal opening is known as the horizontal inlet or Gutter Inlets.



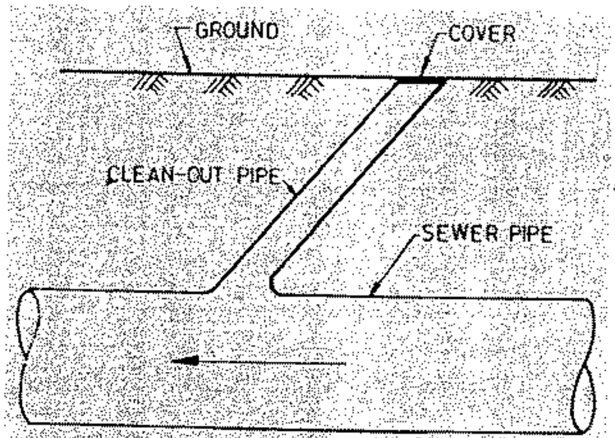
Street Inlet

Maximum spacing of inlets would depends upon various conditions of road surface, size and type of inlet and rainfall. A maximum spacing of 30m is recommended

(6) Clean Outs

A clean out is an inclined pipe extending from the ground and connected to the underground sewer for cleaning sewer pipes.

A clean out is generally provided at the upper ends of lateral sewer in place of manholes.

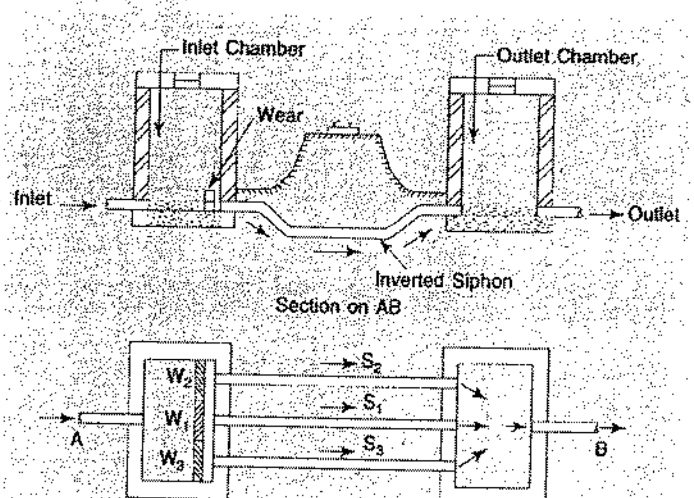


Clean-Out

(7) Inverted Siphons (Depressed Sewers)

Whenever a sewer pipe has to be dropped below the hydraulic gradient line for passing it beneath a valley, a road, a railway, a stream, a tidal estuary or any other depression in the earth's surface or where it passes beneath some other obstructions in its path, it will be known as an inverted siphon or a depressed sewer or a sag pipe. The sewage through such a pipe line will be flowing under pressure (as in the case of water pipe lines)

An inverted siphon is usually made of siphon tubes or pipes made of cast iron or concrete. These pipes are laid between the inlet and the outlet chambers (usually at the same elevation).



To ensure self cleansing velocities (1 m/s) for the wide variation in flows, generally two or more pipes not less than 20 cm dia are provided in parallel so that upon the average flows, the pipe is used and when the flow exceeds the average flow, the balance flow is taken by the second and subsequent pipes.

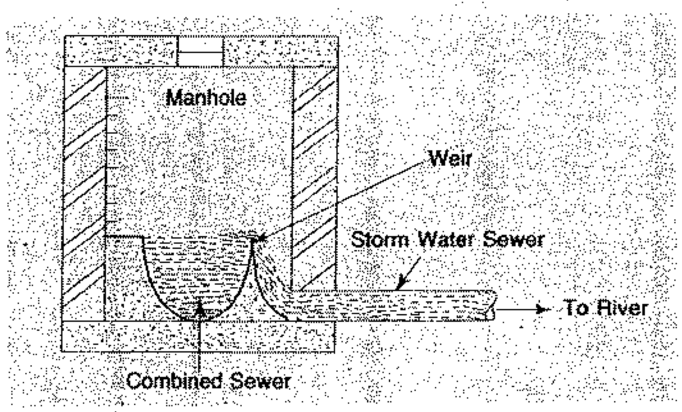
(8) Storm Water Regulator or Overflow Device

These are used for preventing over loading of sewers pumping stations, treatment plants by diverting the excess flow to relief sewers.

The overflow devices may be side flow or leaping weirs according to the position of the weir, siphon spillway or float actuated gates and valves.

(i) Side Flow Weir

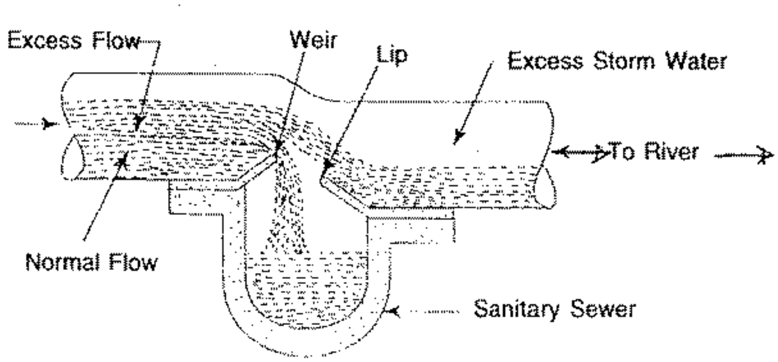
A side flow weir constructed along one or both sides of a combined sewer delivers excess flows during the storm periods to relief sewers or natural drainage courses. The crest of the weir is set at an elevation corresponding to the desired depth of flow in the sewer.



Overflow Weir

The length of the side flow weir is given by the formula devised by **Babbitt**.

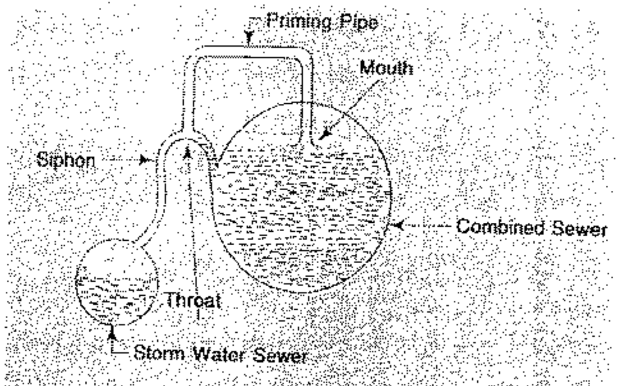
(ii) Leaping Weir



This arrangement is done within a manhole. It consists of an adjustable weir and lip which are adjusted in such a way so that the permissible discharge of sewage is allowed to flow over the crest of the weir and directly fall in the sanitary sewer. When the discharge is increased enormously due to heavy rainfall, the excess storm water jumps over the the crest of the weir and falls on the lip which carries the strom water to the river or stream.

(iii) Siphon Spillway

The siphon spillway arrangement used for diverting excess sewage discharge from the combined sewer. It is an automatic process, and works on the principle of shiphonic action. The shiphonic action starts when the sewage in the combined sewer rises above a fixed level (i.e. the crest level of the siphon) and stop as soon as the sewage falls below this level.



Siphon Spillway

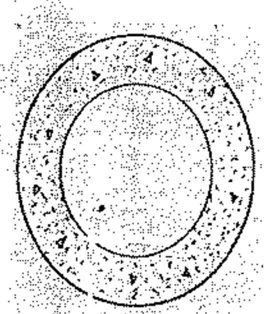
VENTILATION OF SEWERS

The sewers must be properly ventilated or the following reason:

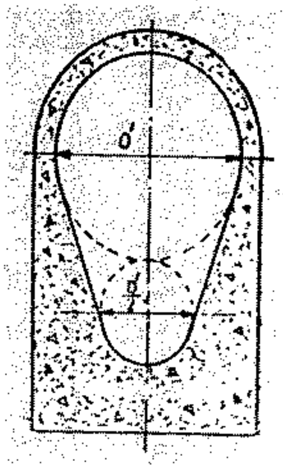
The decomposition and putrefaction of sewage inside the sewers may result in the production of various sewer gases, such as H_2S, CO_2, CH_4, CO, NH_3, N_2. These gases are disposed of into the atmosphere by exposing the sewage to the outside atmosphere by suitable methods of ventilation. Methane gas being highly explosive, if not removed, may even below off the manhole covers. To ensure a continuous flow of sewage inside the sewer is achieved by ventilation by keeping the surface of sewage in contact with free air and thus preventing the formation of air locks in these sewage.

SHAPE OF SEWER PIPES

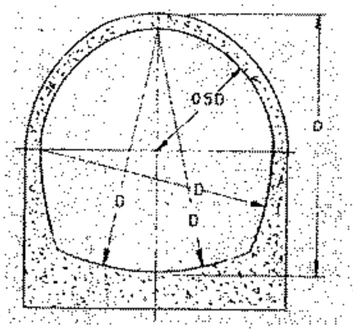
(a) Circular Shaped Sewer (Most Widely Used for all Types of Sewers)



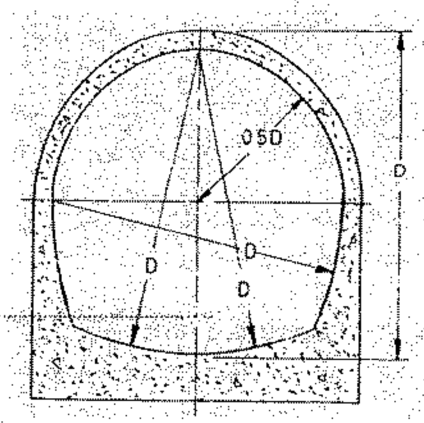
(b) Standard Egg-shaped Sewer (May be Preferred for Combined Sewers)



(c) Horse Shoe Shaped Sewer (May be Used for Large Sewers with Heavy Discharges, such as Trunk and Outfall Sewers)



(d) Parabolic Shaped Sewer (May be used for Carrying Comparatively Smaller Quantities of Sewage)



CORROSION OF CONCRETE SEWERS DUE TO BIOLOGICAL REACTION

- H_2S in sewer is usually produced by bacteriological reduction of sulphates.
- H_2S gas by itself is not injurious to cement concrete. It gets readily oxidised by dissolved oxygen or by several bacterial species.
- In the presence of air, H_2S gets oxidised to H_2SO_4 and this sulphuric acid reacts with the cement constituents of concrete.
- Actually, it reacts with the lime in the cement concrete to form $CaSO_4$ which in turn, reacts with the calucium aluminates in the cement to form calcium sulpho-aluminates which occupy a greater volume than the compound they replace. This leads to expansion and disruption of concrete sewer.

Note: (i) *Stoneware pipes are highly resistant to sulphide corrosion, and therefore, preferred for carrying polluted sewage and industrial wastes.*

(ii) *The usual practice is to use vitrified clay (or stoneware or salt-glazed sewers) pipes of smaller diameter and cement concrete pipes for larger diameter for carrying sewage.*

OBJECTIVE QUESTIONS

1. The slope of a 1.0 m diameter concrete sewer laid at a slope of 1 in 1000, develops a velocity of 1 m/s, when flowing full. When it is flowing half-full, the velocity of flow through the sewer will be

(a) 0.5 m/s (b) 1.0 m/s
(c) 2 m/s (d) 2.0 m/s

2. Self-cleansing velocity is

(a) the minimum velocity of flow required to maintain a certain amount of solids in the flow
(b) the maximum velocity of flow required to maintain a certain amount of solids in the flow
(c) such flow velocity as would be sufficient to flush out any deposited solids in the sewer
(d) such flow velocity as would be sufficient to ensure that sewage does not remain in the sewer

3. In the design of storm sewers, "time of concentration" is relevant to determine the

(a) rainfall intensity (b) velocity in the sewer
(c) time of travel (d) area served by the sewer

4. The maximum flow occurs in an egg shaped sewer when the ratio of flow to vertical diameter is

(a) 0.33 (b) 0.50
(c) 0.95 (d) 1.00

5. **Assertion (A):** The design of all non-circular sections is based upon getting a "hydraulically equivalent section".
Reason (R): The chart of hydraulic elements is very useful in sewer design.

6. A sewer is commonly designed to attain self-cleansing velocity is

(a) peak hourly rate of flow
(b) average hourly rate of flow
(c) minimum hourly rate of flow
(d) sewer running half full

7. If a sewer X is to be designed to generate equivalent self-cleansing action as in sewer Y, then

(a) velocity in sewer X must be equal to velocity in sewer Y
(b) slope of sewer X must be equal to slope of sewer Y
(c) tractive force intensity generated in sewer X must be same as that in sewer Y
(d) the roughness coefficient of X sewer material should be same as that of Y sewer material.

8. Which of the following statements is correct?
A combined sewer is one which transports domestic sewage and

(a) storm water (b) industrial waste
(c) overhead flow (d) industrial wastes and storm water

9. Match **List-I** (Equation/Method) with **List-II** (Application) and select the correct answer using the codes given below the lists:

	List-I		List-II
A.	Manning's Equation	1.	Frictional head loss estimation in pipe flow
B.	Darcy-Weisbach	2.	Sanitary sewer design
C.	Hardy Cross Method	3.	Storm sewer design
D.	Rational Method	4.	Water distribution system design

Codes:

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

10. In the design consideration of sewerage system, the sewers must have which one of the following?
    (a) Maximum velocity of flow
    (b) Only 50 per cent of maximum velocity of flow
    (c) Minimum velocity of not less than cleansing velocity of flow
    (d) High pressure at all times

11. A 600 mm diameter RCC sewer is laid at a slope to develop a velocity of flow of 0.6 m/s when sewer is running exactly half-full, the velocity of fullflow taking Manning's constant to be equal to 0.013, is nearly
    (a) 0.3 m/s (b) 0.6 m/s
    (c) 0.9 m/s (d) 1.2 m/s

12. The ventilation in sewers is needed to avoid the
    (a) development of explosive mixtures of sewer gases
    (b) build up of odorous gases
    (c) danger of asphyxiation of sewer maintenance employees
    (d) anaerobic decomposition of organics

13. Which one of the following statements is not correct?
    (a) In combined sewerage system, one set of sewer is laid for both sanitary sewage and storm water.
    (b) In separate system, the design of sewage system is economical.
    (c) In separate system, self-cleansing velocities are not available and occasional flushing is required.
    (d) As the sewage is diluted by storm water in combined sewage system, cost of treatment is low.

14. For combined sewerage systems, why are egg-shaped sewers preferred?
    (a) Their construction is economical
    (b) Their maintenance is easier
    (c) They perform satisfactorily during dry weather flow
    (d) They are structurally more stable than other shapes

15. Determine the correctness or otherwise of the following Assertion [A] and the Reason [R]:
    Assertion: The crown of the outgoing larger diameter sewer is always matched with the crown of incoming smaller diameter sewer.

Reason: It eliminates backing up of sewage in the incoming smaller diameter sewer.

(a) Both [A] and [R] are true and [R] is the correct reason for [A]
(b) Both [A] and [R] are true but [R] is not the correct reason for [A]
(c) Both [A] and [R] are false
(d) [A] is true but [R] is false

16. For the design of a storm sewer in a drainage area, if the time of concentration is 20 min, then the duration of rainfall will be taken as

(a) 10 min (b) 20 min
(c) 30 min (d) 40 min

17. A sewer has a diameter of 300 mm and slope of 1 in 400. While running full it has a mean velocity of 0.7 m/s. If both the diameter and slope are doubled (to respectively be 600 mm and 1 in 200), what will be the changed mean velocity when running half-full? Use Manning's formula.

(a) 1.59 m/s (b) 2.8 m/s
(c) 0.9 m/s (d) 1 m/s

18. Consider the following statements :

1. The velocity of flow in the rising main should be less than 0.8 m/s at any time.
2. Maximum velocity of flow generally limited to 1.8 m/s and never allowed to exceed 3 m/s. IN the design of large sewage pumping stations, which of the above conditions must be satisfied?

(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2

19. Consider the following statements :

Ventilation of sewer lines is necessary to

1. avoid building up of sewer gases
2. ensure atmospheric pressure in the waste water surface
3. ensure the safety of sewer maintenance people
4. provide oxidation facility to sewage

Which of these statements are correct?

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

20. In a design of storm sewers, if the time taken by rain-water to flow from the farthest point of the watershed to the sewer inlet is 't_i' and the time of flow of water from the sewer inlet to the point in the sewer that is under consideration is 't_f' then the time of concentration will be

(a) t_i (b) t_f
(c) $t_i + t_f$ (d) t_i or t_f whichever is greater

21. A circular sewer of diameter 1 m carries storm water to a depth of 0.75. The hydraulic radius is approximately

(a) 0.3 m (b) 0.4 m
(c) 0.5 m (d) 0.6 m

22. In transition of sewers from smaller diameter sewers to larger diameter sewers, the continuity of sewers is maintained at the

(a) bottom of the concrete bed of sewers (b) inverts of the sewers
(c) crowns of the sewers (d) hydraulic gradients of the sewers

23. **Assertion (A):** While laying a sewer line, the socket end of a sewer is kept facing the downward slope in the trench.

    Reason (R): The socket end being heavy will slide down the slope if it faces the downward slope.

24. The following steps are involved in laying a sewer in a trench:

    1. Transferring the centre line of the sewer to the bottom of a trench.
    2. Setting sight rails over the trench.
    3. Driving pegs to the level of the invert line of the sewer.
    4. Placing the sewer in the trench.

    The correct sequence of these steps is

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

25. Consider the following statements:
    Ventilation of sewer lines is necessary to

    1. avoid building up of sewer gases
    2. ensure atmospheric pressure in the waste water surface
    3. ensure the safety of sewer maintenance people
    4. provide oxidation facility to sewage

    Which of these statements are correct?

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

26. Match **List-I** (Unit) with **List-II** (Purpose) and select the correct answer using the codes given below the lists:

    List-I

    A. Leaping weir
    B. Gutter inlet
    C. Inverted syphon
    D. Catch basin

    List-II

    1. To prevent grit, sand, debris, etc. from entering the storm sewer.
    2. To carry the sewer below a stream or railway line
    3. To drain rain water from roads to the storm sewer
    4. To separate storm water and the sanitary sewage

    Codes:

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

27. Which of the following are storm water regulators?

1. Slide weir
2. Leaping weir
3. Syphonic spillway
4. Float actuated gates or valves
5. Inverted syphon

Select the correct answer using the codes given below:

(a) 1, 2, 3 and 4 (b) 1, 3 and 5

(c) 2, 3, 4 and 5 (d) 1, 2, 4 and 5

28. Consider the following statements:

Assertion (A): Most important activity in sewer line construction is to start constructing it from the tail end and to check levels with a boning rod.

Reason (R): Construction of sewer line from tail end is recommended because required number of pumping stations may be incorporated in sewer network design.

Of these statements:

(a) both A and R are true and R is the correct explanation of A

(b) both A and R are true but R is not a correct explanation of A

(c) A is true but R is false

(d) A is false but R is true

29. Consider the following statement regarding building manholes:

1. They must be provided at every change of alignment, gradient or diameter.
2. They must be provided at the head of all sewers.
3. They must be provided at every junction of two or more sewers.
4. They must be provided at every 100 m along straight runs of sewers.

Which of these statements are correct?

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

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

30. Consider the following statements:

The basic difference between water pipes and sewer pipes is

1. in the material used for the pipes
2. in the pressure of the liquid flow
3. in the suspended solids they carry

Which of these statements is/are correct?

(a) 1 and 3 (b) 1 only

(c) 2 and 3 (d) 1, 2 and 3

31. Match **List-I** (Appurtenance) with **List-II** (Function in water supply) and select the correct answer using the codes given below the lists:

List-I

A. Drop Manhole
B. Inverted Siphon
C. Manhole
D. Air Ejector

List-II

1. Carrying sewage flow below depressions
2. Connecting higher level branch sewer to lower level main sewer
3. Transporting sewage from basements to higher level sewer
4. Connecting branch sewer to lower level main sewer

Codes:

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

32. Which is the best sewer material to resist hydrogen sulphide corrosion?

(a) Glazed stoneware (b) Glazed earthenware
(c) RCC (d) Brick masonry

33. When are drop manholes provided in a sewerage system?

(a) There is change from gravity system to pressure system.
(b) There is change in the elevation of the ground level.
(c) There is change in the diameter of the sewer.
(d) There is change in the direction of the sewerline.

34. Match **List-I** (Test) with **List-II** (Purpose) and select the correct answer using the codes given below the lists:

List-I

A. Inverted siphon
B. Drop Manhole
C. Clean out
D. Leaping weir

List-II

1. Maintenance of sewer
2. Sewer crossing a river/road way
3. Storm water regulation
4. Connecting between sewers at different invert levels

Codes:

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

35. **Assertion (A) :** Sewers are not allowed to flow full.

Reason (R) : Reserve space in the sewer takes care of fluctuations in sewage flow.

ANSWERS

1. (b)	10. (c)	19. (d)	28. (b)
2. (c)	11. (b)	20. (c)	29. (a)
3. (a)	12. (a)	21. (a)	30. (c)
4. (c)	13. (b)	22. (d)	31. (b)
5. (b)	14. (c)	23. (d)	32. (a)
6. (c)	15. (a)	24. (d)	33. (b)
7. (c)	16. (b)	25. (d)	34. (a)
8. (a)	17. (a)	26. (b)	35. (a)
9. (a)	18. (c)	27. (a)	

CHAPTER 5

Sewage Treatment

Wastewater can be defined as any water or liquid that contains impurities or pollutants in the form of solids, liquid or gases or their combinations in such a concentration that is harmful if disposed into the environment.

TREATMENT METHODS

Usually, Physical, Chemical or Biological means are applied for wastwater to carry out specific function on the principles of either one or a combination of the means employed. Based on the means used, treatment methods have been broadly classified as unit operations and unit processes.

Unit Operations

The means of treatment in which the application of physical forces predominates are known as unit operations. Major treatment methods falling under this category are screening, mixing, sedimentation, etc.

Unit Process

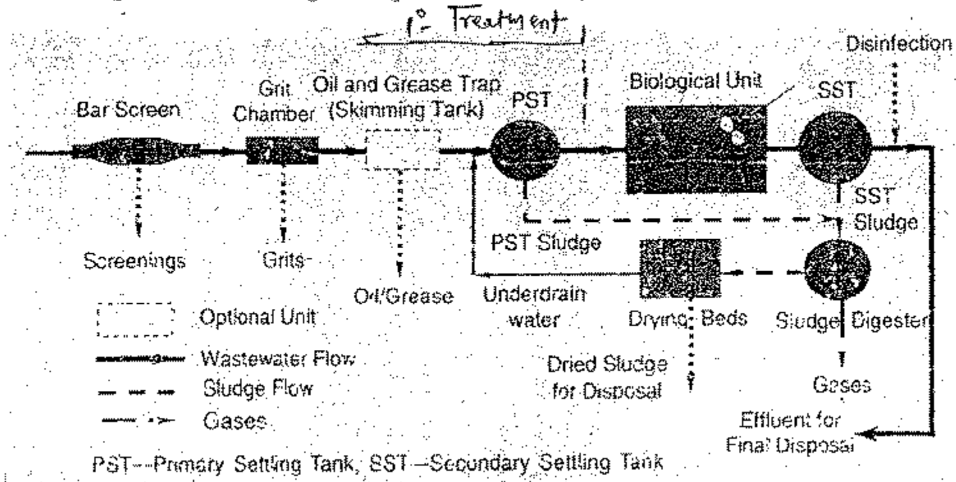
The types of treatment in which the removal of contaminants is brought about by the addition of chemicals or the use of biological mass or microbial activities are known as unit process. Based on the type of agent used biological unit process are

(i) Suspended growth process.

Example: Activated Sludge Process, Aerated Lagoon, Oxidation Pond, Aerobic & Anaerobic Digester etc

(ii) Attached growth process

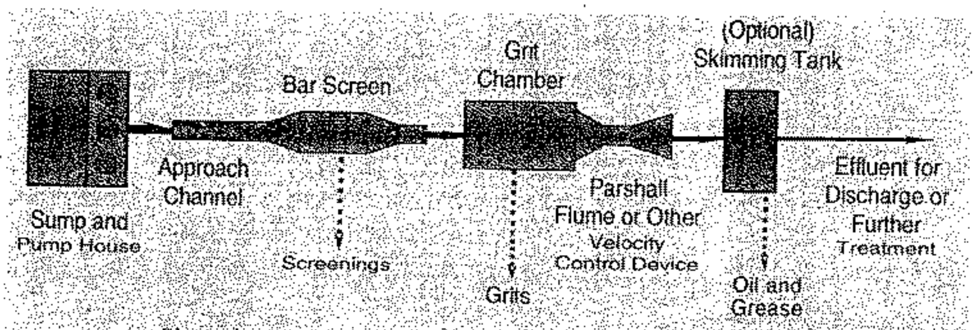
Example ; Trickling Filter, Rotating Biological contactors, Bio-Towers etc.



Schematic flow diagram of a typical conventional treatment plant

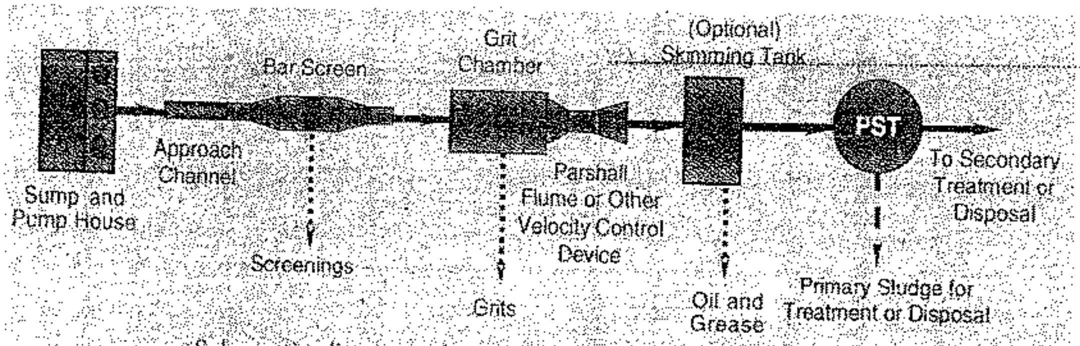
The type of combinations used from the available unit operations and process for treatment of a particular wastewater is known as the treatment system. A wastewater treatment plant is designed for either of the following treatment system.

(1) **Preliminary Treatment System :** The Preliminary Treatement System is mainly selected to remove floating materials and large inorganic particulate contents of wastewater. The preliminary treatment systems are screen chamber, grit chamber and skimming tank (oil and grease traps) A flow diagram of a typical preliminary treatment system is given below



Flow diagram of a typical preliminary treatment system

(2) **Primary Treatment System :** The primary treatment system includes all the units of the preliminary treatment system and primary sedimentation tank (PST), also known as primary clarifier.



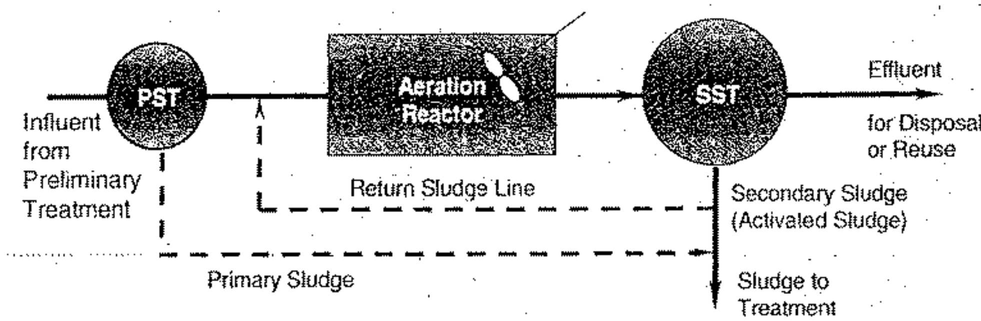
Schematic diagram of a typical primary treatment system

- The purpose of primary treatment is to remove suspended solid materials from the incoming waste water.
- It will not remove the collodial and soluble (dissolved) organic content of waste water.
- Large debris are removed by screen or may be reduced in size by grinding devices.
- Inorganic solids are removed in grit channels.
- Organic suspended solids are removed in sedimentation tank.
- Disposal of inorganic matter is convenient because it does not decompose. But, disposal of organic matter is difficult because if it is disposed untreated, it will create nuisance. Hence it is desired that inorganic and organic matters are removed in two different units.
- Primary treatment removes approx. 60-70% of suspended solid.
- The BOD associated with these solids account for approx. 30% of influent BOD. Hence 30% of influent BOD is removed in 1° treatment.

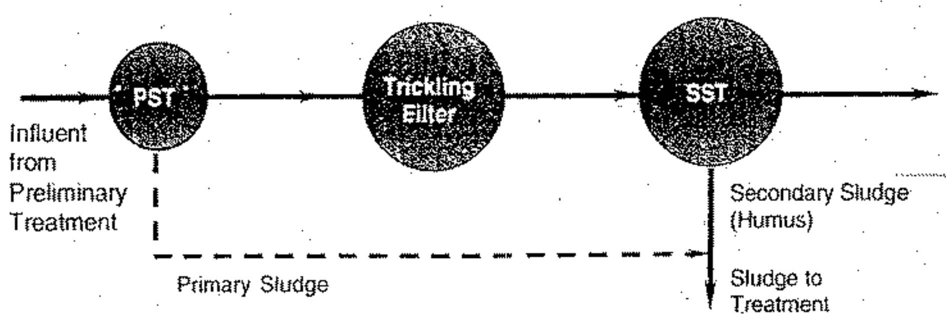
(3) Secondary Treatment System

- After primary treatement, its wastewater is further treated for the removal of colloidal and soluble organic matter present in wastewater, then it is called secondary treatment of wastewater.

- Secondary treatment usually consists of biological conversion of dissolved and colloidal organics into biomass that can subsequently be removed by sedimentation.
- Contact between microorganisms and the organics is optimized by suspending the biomass in the wastewater or by passing the wastewater over a film of biomass attached to solid surfaces.
- The most common suspended biomass system is the activated-sludge process shown in Fig.(a).



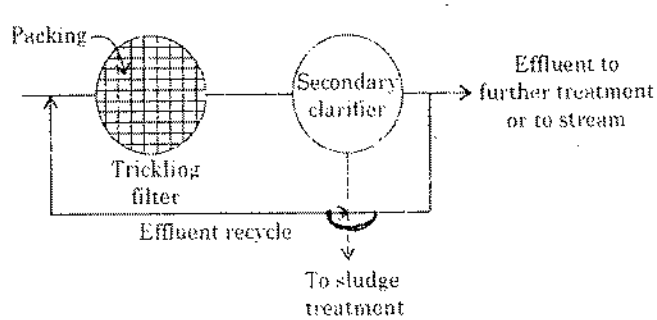
(a) Secondary treatment system with activated sludge process



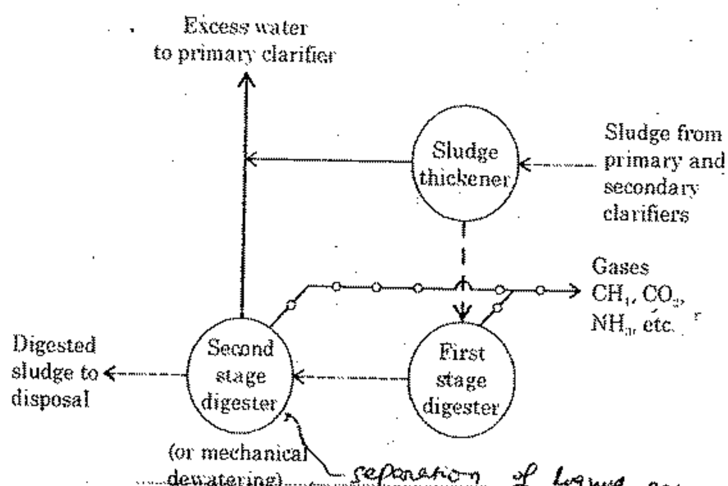
(b) Secondary treatment system with trickling filter

Schematic diagram of biological secondary treatment system.

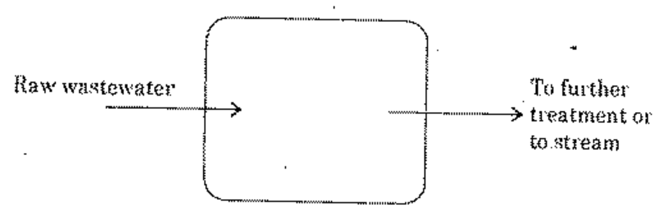
- A part of settled sludge in secondary clarifier is recycled back to aerator.
- Recirculating a portion of the biomass maintains a large number of organisms in contact with the wastewater and speeds up the conversion process.
- The classical attached-biomass system is the trickling filter. Stones or other solid media are used to increase the surface area for biofilm growth. Mature biofilms peel off the surface and are washed out to the settling basin with the liquid underflow. Part of the liquid effluent may be recycled through the system for additional treatment and to maintain optimal hydraulic flow rates.



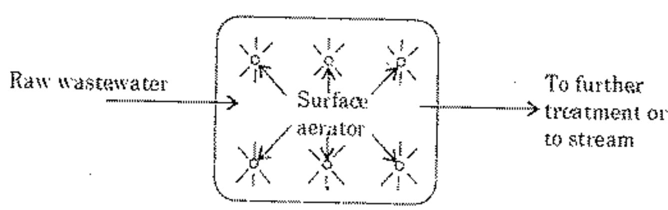
- Secondary systems produce excess biomass that is biodegradable through endogenous catabolism and by other microorganisms.
- Secondary sludges are usually combined with primary sludge for further treatment by anaerobic biological processes. The results are gaseous end products, principally methane (CH_4) and carbon dioxide (CO_2), liquids and inert solids.
- The methane has significant heating value and may be used to meet part of the power requirements of the treatment plant.
- The liquids contain large concentrations of organic compounds and are recycled through the treatment plant.



- The solid residue has a high mineral content and may be used as a soil conditioner and fertilizer on agricultural lands.
- Other means of solids disposal may be by incineration or by landfilling.
- Sometimes primary and secondary treatment can be accomplished together. The oxidation pond most nearly approximates natural systems, with oxygen being supplied by algal photosynthesis and surface reaeration. This oxygen seldom penetrates to the bottom of the pond, and the solids that settle are decomposed anaerobically.



(a) Oxidation pond



(b) Aerated lagoon

In the aerated lagoon system, oxygen is supplied by mechanical aeration, and the entire depth of the pond is aerobic.

- Decomposition of the biomass occurs by aerobic endogenous catabolism.
- The small quantity of excess sludge that is produced is retained in the bottom sediments.

(4) Tertiary Treatment

- In most cases, secondary treatment of municipal wastewater is sufficient to meet effluent standards. In some instances, however, additional treatment may be required.
- Tertiary treatment most often involves further removal of suspended solids and/or the removal of nutrients.
- Solids removal may be accomplished by filtration, and phosphorus and nitrogen compounds may be removed by combinations of physical, chemical, and biological processes.

PRIMARY TREATMENTS

1. SCREENING

It is used for removal of certain materials such as pieces of wood, floating debris, leaves, rags, etc. found in sewage. Primary purpose of screen is to protect pumps and other mechanical equipments. Hence screening is normally the 1st operation performed on the incoming waste water. Depending on the clear spacing, the screens shall be classified as under:

(a) Coarse screens	Above 50 mm
(b) Medium screens	20 to 50 mm
(c) Find screens	Less than 20 mm

- Bars are usually 10 mm thick.

Location

removal equipments

- Screening devices generally precede grit chamber and pumps. Screens shall preferably be installed in open channels.
- For facility of manual cleaning of the screen, inclination shall be between 45° and 60° to the horizontal.
- Head loss through screen (bar screen)

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

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

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

Example 1

A bar screen is installed in a watewater treatment plant receiving a daily peak flow of crude sewage of 50,000 m^3. Estimate the headloss through the screen and also the gross area of the screen (i.e., the screen requirements). Take desired velocity of flow through screen = 0.8 m/s

Also calculate the head loss when $\frac{1}{2}$ of the screen in plugged due to leaves and debris.

Sol. Maximum flow, Q = 50,000 m^3/d = 0.5788 m^3/s

Desired velocity through screen, V, at ultimate flow = 0.8 m/s

Net area of screen, A = 0.5788/0.8 = 0.72 m^2 (since Q = VA)

Adopting screens with bars of 10 mm width (dia) and 50 mm clear opening, the gross area (including bars) would be

$$\frac{0.72 \times 60}{50} = 0.86\ m^2$$

Velocity through screen = 0.8 m/s

Velocity above screen, $u = \frac{0.8 \times 50}{60} = 0.67$ m/s

(using the equation of continuity)

Headloss through screen is usually given as

$$0.0729\,(V^2 - u^2) = 0.0729\,(0.8^2 - 0.67^2)$$

$$= 0.013 \text{ m}$$

If the screen openings are half plugged with screenings, leaves and debris, the velocity through the screen is doubled.

Maximum head loss $= 0.0729\,(1.6^2 - 0.67^2)$

$= 0.0729 \times 2.27 \times 0.93$

$= 0.15$ m

At this maximum head loss, the screen has to be cleaned.

Assuming that the inclination of the screen to the horizontal is at 60°, the gross area of screen needed would be:

$$\frac{0.86}{\sqrt{3}/2} = 0.9931\text{ m}^2 = 1\text{ m}^2$$

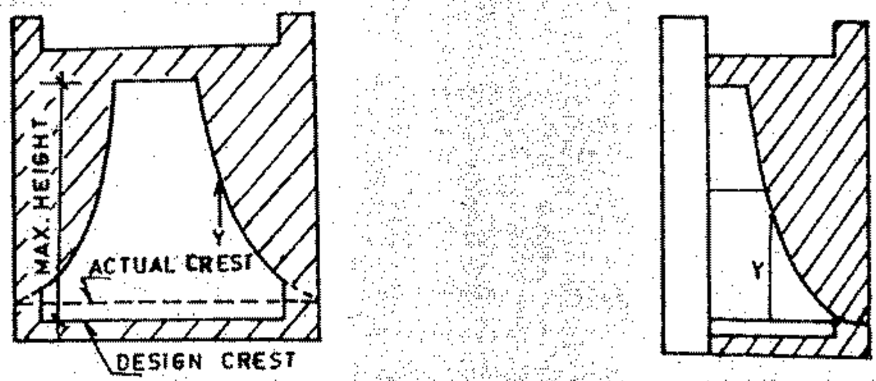
2. COMMINUTION AND MACERATION

They are installed before fine screen. They shed materials to size 6–20 mm. Comminutors has cutting teeth whereas macerator have grinding wheels.

3. GRIT CHAMBER

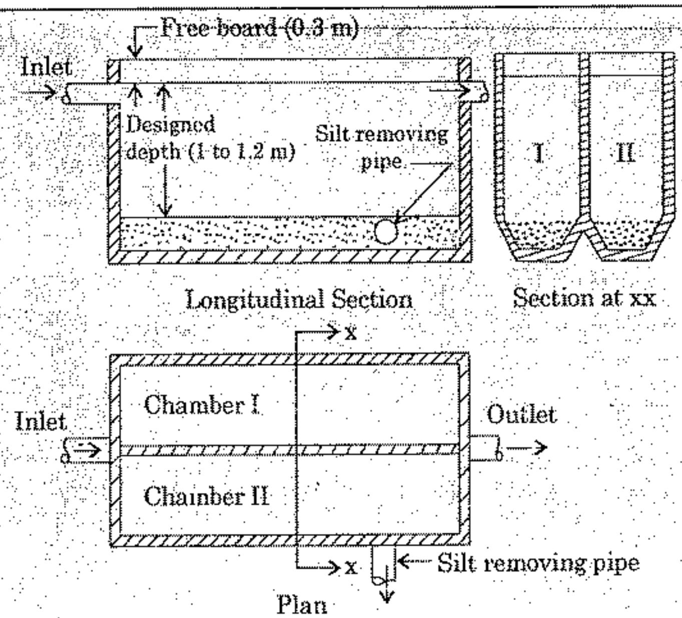
Grit removing devices are located either before or after sewage pumps in sewage treatment plants to prevent clogging of pipelines, channels, etc. due to settlement of grit. They separate non-decaying heavy inorganic material from sewage so that inorganic material may be disposed off without causing nuisance. They also assist in prevention of grit accumulation in digestors and clarifiers, and, in general, in protecting all the machinery used in sewage treatment plant. Removal of grift also reduces the frequency of cleaning of digesters and settling tank.

- Grit chambers are provided in the form of channels of longer length and smaller x-sec. area.
- Grit chamber should not allow settlement of organic materials.
- Velocity in the grit chamber should be such that organic matters do not settle. Or if it has settled, the velocity should be sufficient to scour away the settled organic matter.
- Two channels are provided one for normal flow and other for peak flow, obviously used with normal flow.
- Only one section (channel) is required if velocity control devices has been used e.g., proportional flow weir, or Parshall flume or sutro weir. (is half proportional weir flow)



(a) PROPORTIONAL FLOW WEIR (b) SUTRO WEIR

- If proportional used weir is used, rectangular section is provided and if parshall flume is used, parabolic channel is produced.
- A parshall flume can be used both as a discharge measuring device and also a velocity control device.
- Parshall flume is preferable because head loss is less.
- Velocity control devices are provided at the end of channel.



Sectional Views of a Rectangular Grit Chamber

- Sludge of grit chamber is disposed by burial or burning or filling ditches by dumping.

Design Criteria

- Grit chamber removes particles of size ≥ 0.2 mm. (discrete particle setteling)
- The specific gravity of the grit is usually in the range of 2.4 to 2.65. But for design adopt ≈ 2.65.
- For 0.2 mm particle setting velocity = 0.025 m/s

- Surface over flow rate (Q/A) = 2160 $m^3/m^2/day$.
- Stokes law can not be applied to grit chamber settling because particle size is ≥ 0.2 mm. The settling velocity of discrete particles can be determiend using the appropriate equation depending upon the Reynolds number. For this condition, the transition flow hold when R_e is between 1 and 1000. In this range, C_D can be approximated by $C_D = \frac{18.5}{(Re)^{0.6}}$.

$$V_s^2 = \frac{4}{3}\frac{(\gamma_s - \gamma_w)\,d}{C_D \cdot \rho_w}, \qquad Re = \frac{V_s d}{\nu},\ d = \text{size of particle}\ (0.1\text{mm} \le d \le 1\text{mm})$$

Putting the value of C_D in V_s equation, we get

$V_s = [0.707\,(G_S - 1)d^{1.6}\upsilon^{-0.6}]^{0.714}$ (All data are in SI units)

- Horizontal velocity of flow is 0.15 – 0.3 m/s (for particle size ≥ 0.2 mm).
- Horizontal critical flow velocity is given by $V_C = K_C\sqrt{g(G_s - 1)\,d}$ (units are SI units).

  Where K_C = 3 to 4.5, a value of 4 is usually adopted.
- Detention time is 40 – 60 sec.
- Depth is 1 – 1.5 m.
- Free board is 0.3 m.
- Length of channel is generally increased by 20% as an allowance for inlet and outlet turbulence.
- Loss of head in a grift chamber varies from 6 to 60 cm depending on the device adopted for velocity control.
- $\eta = \frac{V_S}{V_0}$ where, V_S is settling velocity, V_0 is surface overflow rate.
- The settling velocity of grit particles in the transition zone is also caclulated by the Hazen's modified formula.

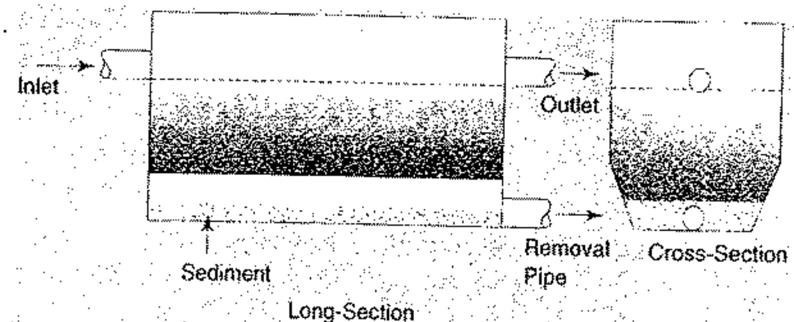
$$V_S = 60.6(G_S - 1)d\,\frac{3T+70}{100} \qquad (\text{for } d \approx 0.2\,\text{mm})$$

where d is in cm. ; T is temperature in degree, C and V_S is in cm/sec.

Note : Particle size < 0.1 mm the flow conditions are laminar where viscous forces dominate over inertial forces.

4. DETRITUS TANK

The function of detritus tank to remove finer organic and inorganic particles. Practically, the detritus tank is similar to grit chamber. The only difference is that the grit chamber is meant for removing the larger particles and detritus tank is meant for removing finer particles.



Detritus Tank

Example 2

Design a grit chamber to remove particles of a diameter 0.2 mm and specific gravity 2.6. Settling velocity of the particles are in the range of 0.0160 to 0.02 m/sec. The proportioning weir will be having a velocity of 0.28 m/sec. The maximum wastewater flow is expected to be 12000 cum/day.

Sol. Provide a rectangular channel section.

$$\text{Horizontal velocity of flow} = 0.28 \text{ m/sec.}$$

$$\text{Average of settling velocity} = \frac{0.016 + 0.02}{2} = 0.018 \text{ m/sec}$$

$$\text{Discharge} = \text{velocity} \times \text{cross-sectional area}$$

$$Q = V_h \times A$$

or $$12000 \text{ cum/day} = \frac{12000}{24 \times 60 \times 60} = 0.139 \text{ m}^3/\text{sec}$$

$$A = 0.139/0.28 = 0.496 \text{ m}^2$$

Assume a depth of 1 m,

$$\text{Width B of the basin} = 0.4961/1 = 0.496 \text{ m} \approx 0.5 \text{ m}$$

$$\text{Settling velocity } V_s = 0.018 \text{ m/sec.}$$

$$\text{Detention time} = \frac{\text{Depth of basin}}{\text{Settling velocity}}$$

$$= 1/0.018 = 55.56 \approx 56 \text{ sec}$$

$$\text{Length of the tank} = V_h \times \text{detention time}$$

$$= 0.28 \times 56 = 56 = 15.68 \approx 16 \text{ m}$$

Providing additional length for the inlet and outlet turbulence, the total length is

$$L_{total} = \text{net length} + 20\% \text{ of net length}$$

$$= 1.2 \times 16 = 19.2 \text{ m} \approx 20\text{m}$$

∴ The rectangular tank will be of size 20 m(L) × 0.5 m (B) × 1 m (D) **Ans.**

Example 3

There is a dry weather flow of 500 litre/sec. Assuming flow velocity through the tank as 0.22 m/sec. and detention period of 2.2 minutes, design a suitable grit chamber-cum-detritus tank. The maximum flow is three times the dry weather flow.

Sol. Length of the tank = Velocity × Detention time = 0.22 × (2.2 × 60) = 29 m

The detritus tank is nothing but a grit chamber designed to flow with a smaller flow velocity and longer detention period so that larger grits are separated with fine sand particle. The discharge passing through tank

$$= 500 \text{ litre/sec.} = 0.5 \text{ m}^3/\text{sec.}$$

$$\text{Cross-sectional area required} = \frac{\text{discharge}}{\text{velocity}} = \frac{1.5}{0.22} = 6.82 \text{ m}^2$$

Assume water depth in the tank to be 1.3 m, the width of the tank

$$= \frac{\text{area of cross-section}}{\text{depth}}$$

$$= \frac{6.82}{1.3} = 5.25 \text{ m, say } 6 \text{ m}$$

Provide a detritus tank of 29 × 6 × 1.3 m size.

Provide a free-board of 0.25 m and at bottom a dead space depth of 0.4 m for collection of detritus.

$\therefore$ Overall depth of the tank $= 1.3 + 0.25 + 0.4 = 1.95 \approx 2.0$ m **Ans.**

Example 4

Design a grit chamber for flow = 40 MLD; $G_s = 2.65$; Size of particles to be removed = 0.2 mm; and $\nu = 1.0 \times 10^{-2}$ cm²/s

1. Find settling velocity of 0.2 mm particle.
2. Critical horizontal flow velocity.
3. Size of grit chamber.

Sol.

$$V_s^2 = \frac{4}{3}\frac{(\gamma_s - \gamma_w)\, d}{C_D \rho_w}$$

$$V_s^2 = \frac{4(G_s - 1)\,\rho_w g d}{3\rho_w \dfrac{18.5}{\left(\dfrac{V_s d}{\nu}\right)^{0.6}}}, \qquad \because R_e = \frac{V_s d}{\nu}$$

$$V_s^2 = \frac{4\,(G_s - 1)\, gd \times (V_s d)^{0.6}}{3 \times 18.5\,(\nu)^{0.6}}$$

$$V_s^{1.4} = \frac{4(G_s - 1)\, gd^{1.6}}{3 \times 18.5\,(\nu)^{0.6}}$$

$$V_s = \left[\frac{4(G_s - 1)\, gd^{1.6}}{3 \times 18.5\,(\nu)^{0.6}}\right]^{1/1.4}$$

$$= \left[\frac{4\,(1.65)\, 9.81 \times (0.2 \times 10^{-3})^{1.6}}{3 \times 18.5\,(10^{-2} \times 10^{-4})^{0.6}}\right]^{1/1.4} \left[\frac{\dfrac{m}{S^2}\, m^{1.6}}{\left(\dfrac{m^2}{S}\right)^{0.6}}\right]^{1/1.4}$$

$$= \left[\frac{7.8138 \times 10^{-5}}{13.94 \times 10^{-3}}\right]^{1/1.4} \text{m/s}, \qquad \left(\frac{m^{2.6} \times S^{0.6}}{S^2 \times m^{1.2}}\right)^{1/1.4} = \left(\frac{m^{1.4}}{S^{1.4}}\right)^{1/1.4} = \text{m/s}$$

$$= 24.7 \text{ mm/s}$$

Critical horizontal flow velocity

$$V_c = 4\sqrt{g\,(G_s - 1)\, d}$$

$$= 4\sqrt{9.81 \times 1.65 \times 0.2 \times 10^{-3}} \text{ m/s}$$

$$V_c = 0.227 \text{ m/s}$$

Let $t_d = 60$ sec

$$L = V_c \times t_d = 13.65 \text{ m}$$

$$L_{total} = 1.2 \times 13.65 = 16.38 \text{ m}$$

Adopt L = 17 m

$$\frac{H}{V_S} = \frac{L}{V_C} = t_d$$

$$\Rightarrow H = t_d V_S = 60 \times 24.7 \times 10^{-3} \text{ m}$$

$$H = 1.48 \text{ m}$$

$$Q = 40 \text{ MLD} = \frac{40 \times 10^3 \text{ m}^3}{86400} = 0.463 \text{ m}^3/\text{s} \quad \text{[Given]}$$

$$Q \times t_d = V = 27.77 \text{ m}^3$$

$$V = Q \times t_d = 27.77 \text{ m}^3$$

$$\Rightarrow L \times B \times H = 27.77$$

$$B = \frac{27.77}{17 \times 1.48} = 1.104 \text{ m}$$

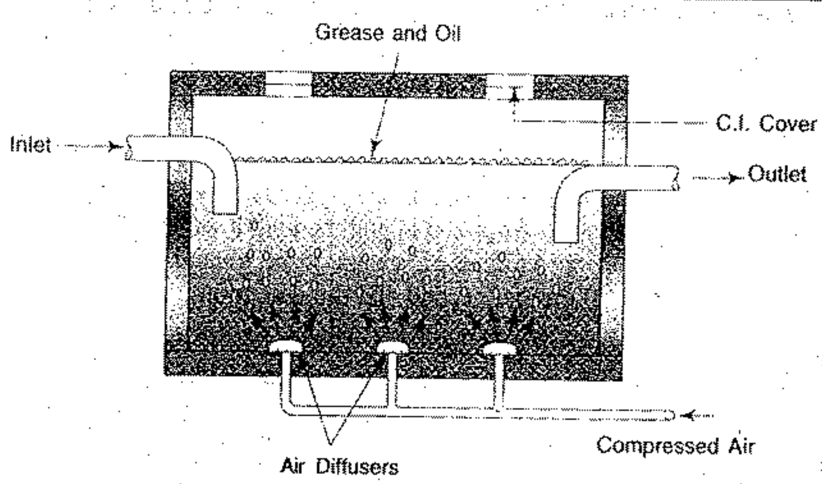
$$\Rightarrow L = 17 \text{ m}$$

$$B = 1.104 \text{ m}$$

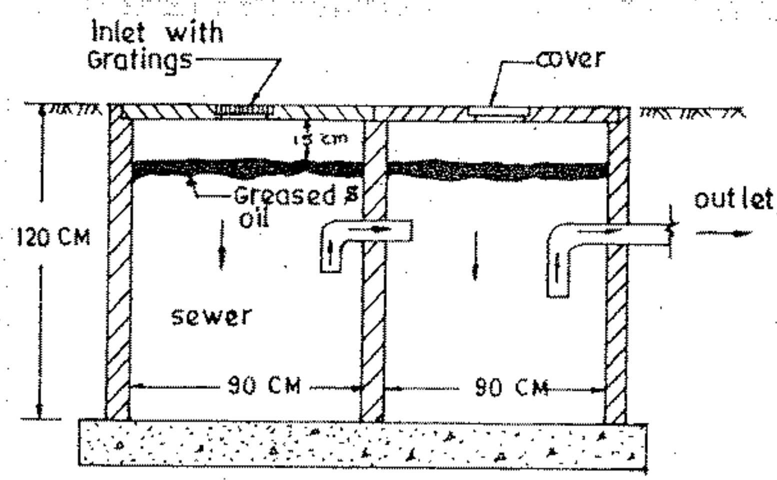
$$H = 1.48 \text{ m}$$

5. SKIMMING TANK

- For removal of oil and greases, soaps, skimming tank is provided.
- Skimming tank is provided before sedimentation tank.
- If above pollutants are not removed, it forms scum on the surface and interfere with activated sludge treatment process and also inhibits biological growth on trickling filter.
- In skimming tank, compressed air is blown from below. The rising air coagulates the grease and causes it to rise to the surface, from where it can be skimmed off.
- Chlorine gas may also be blown with compressed air or chlorine may be added to the water to destroy the colloidal effects of proteins which hold grease in emulsified form.
- Skimming tanks are not suitable in India as oils ane greases do not coagulate at higher temperature. Hence attempts are made to remove it before they enter the municipal sewer system by using oil and grease trap.
- Vacuators may also be used to remove grease.



Skimming tank



Grease and oil trap

SEDIMENTATION

In primary sedimentation, organic suspended solids are settled. They have specific gravity normally 1.2.

Types of Settling

Basically four types of settling occurs depending on the tendency of particles to interact and the concentration of solids. They are:

Type 1. Discrete settling → Grit chamber

Type 2. Flocculent settling → PST and Coagulation with sedimentation

Type 3. Hindered or zone settling → SST

Type 4. Compression settling → Thickener and Bottom layers of SST

1. **Discrete Settling** occcurs when particles do not change this size, shape or mass during settling. Grit, in waste water behave like discrete particle. Settling velocity of discrete particle is determinable using Stokes or Transition law. Organic solids in raw water and bioflocs in biologically treated waters cannot be considered as discrete particles and hence Stoke's law is not applicable to these particles.

2. **Flocculent Settling:** Flocculent particles coalese during settling increasing the mass of particles which settle faster. Flocculent settling refers to settling of flocculent particles of low concentration usually less than 1000 mg/l. The degree of flocculation depends on the contact opportunities which in turn is affected by the surface overflow rate, the depth of basin, the concentration of particles, the range particle size and the velocity gradient of the system. No adequate mathematical equation exist to decribe flocculent settling and therefore overflow rates to achieve a given removal efficiency are determined using data obtained from settling column analysis.

   Removal of raw sewage organic suspended solids in PST, settling of chemical flocs in settling tank and bioflocs in the upper portion of SST are examples of flocculent settling.

3. **Hindered or Zone Settling:** When concentration of flocculated particles is in intermediate range, they are close enough together so that their velocity fields overlap causing hindered settling. The settling of particles results in significant upward displacement of water. Particles maintain their relative positions with respect to each other and the whole mass of particles settles as a unit or zone.

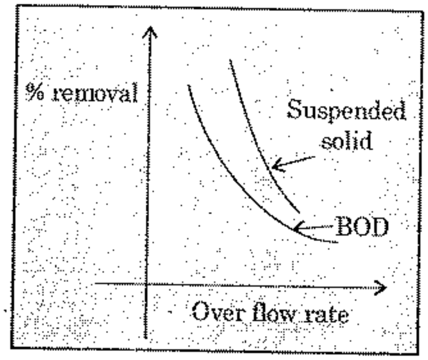
   This type of settling is applicable to concentrated suspension as are found in SST following ASP. In hindered settling zone, the concentration of particles increases from top to bottom leading to thickning of sludge. Such secondary clarifier where zone settling occurs are designed on the basis of **solid loading** and checked for **surface over flow rate**. Both of which can be determined by conducting settling column analysis.

4. **Compression:** In compression zone, concentration of particles becomes so high that particles are in physical contact with each other, the lower layers supporting the weight of upper layers. Consequently any further settling results due to compression of the whole structure of particles and is accompanied by squezzing out of water from the pores between solid particles. This settling phenomenon occurs at the bottom of deep sludge mass such as in the bottom of SST following TF, ASP and in tanks used for thickening of sludge.

In PST over-flow rate and detention time are important.

	PST	Over flowrate ($m^3/m^2/day$) Avg.	peak	Depth	Detention time
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 ASP	25-35	50-60	3.5-4.5	2-2.5 hr

- horizontal flow velocity = 0.3 m/min
- width = 6 m
- length = 4 – 5 times width.



Over flow rate can aslo be found out from % removal efficiency. From the above table, surface area is calculated both for average flow and peak flow and larger is adopted.

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

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

Sedimentation with Coagulation

- It is not used generally in sewage treatment because:
  (a) Chemicals added in this process destroys certain bacteria which are useful for sludge digestion.
  (b) It is costly.
  (c) Large sludge volume produced in this process is difficult to be dispose off.
- It may however be provided in hilly areas because space requirement for coagulation and sedimentation is lesser.
- Coagulation process removes **phosphate** from sewage which may help in controlling eutrophication of lakes.

SECONDARY TREATMENT (BIOLOGICAL TREATMENT)

Secondary treatment is generally carried out aerobically. It leads to stable end product. No foul gases are evolved in the process and rate of reaction is faster (almost 3 times faster than anaerobic process for domestic sewage)

Units based on aerobic treatment are:
- Trickling filter
- Activated sludge process
- Oxidation pond etc.

Units based on anaerobic treatments are:
- Septic tank
- Imhoff tank
- UASB Reactor (Upflow Anaerobic Sludge Blanket) (used for industrial sewage)

Attached Growth System & Suspended Growth System

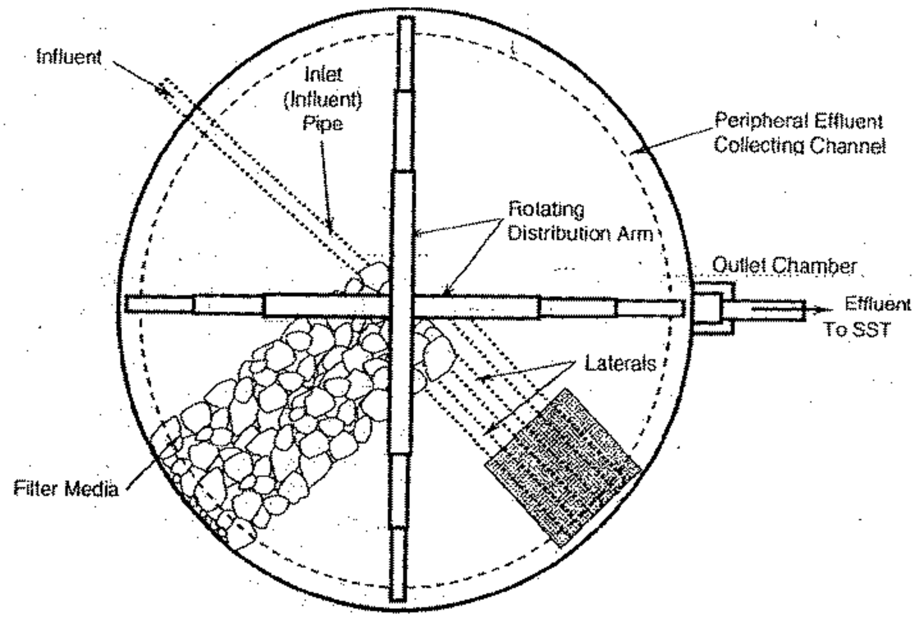
- In attached growth system, biomass is attached to a medium and sewage containing organic matter is passed through the medium.

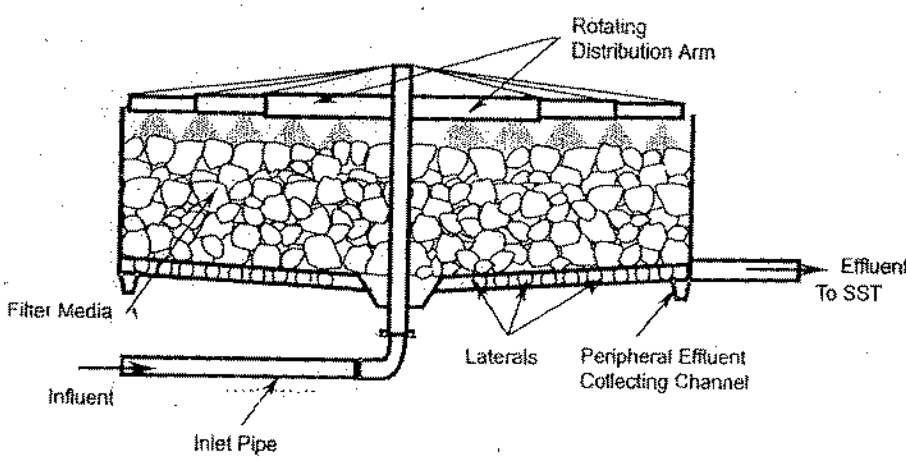
  In suspended growth system, biomass is in suspension in the liquid containing organic matter.

TRICKLING FILTERS (ATTACHED GROWTH SYSTEM)

- Standard rate trickling filter (conventional system)
- High rate trickling filter.

STANDARD RATE TRICKLING FILTER



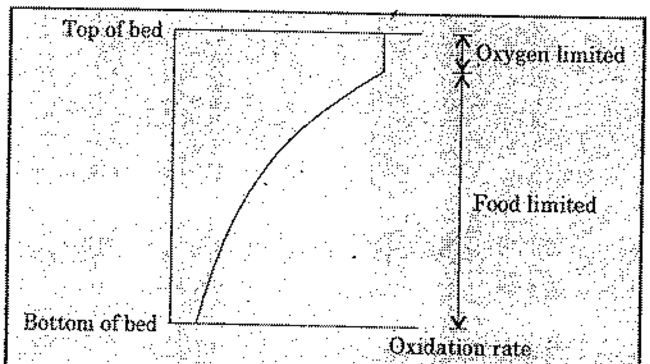


Trickling filters is the most common biological process for small and medium works in temperate climates.

- Filters are constructed as beds of stone or gravel onto the surface of which settled sewage is sprinkled.
- Air for the oxidation process enters the bed through vents at the base.
- The filter usually consists of a 2 m deep circular bed of random packed angular stone about 50 mm in size and supported on a tile floor which allows the treated liquid to escape freely and ventilation air to enter the bed.
- Circular beds permit the use of reaction jet distributors in which the discharge under a head of 0.5-0.8 m is sufficient to cause the arms to rotate.

for domestic sewage ~~aerobic~~ anaerobic process ~~from~~ form 80-200 gm from 1 kg. and 0.5 kg from 1 Kg in aerobic process.

- This provides an effective and inexpensive means of distributing the feed over a large area.
- On small installations, low flows at night may be insufficient to rotate the distributor arms.
- Hence a small tank is provided which allows the water to be applied continuously throughout the day.
- Sewage trickles through the interstices and the natural bacteria and other microorganisms like protozoa and fungi become attached to the surfaces of the media.
- The attached film is able to obtain food from the liquid and also obtain oxygen which flows up through the bed.
- The attached biomass is called biological film or slime layer.
- In a 2 m deep bed the residence time of the liquid is less than a minute but this is sufficient for the absorption of organic matter into the biological film where it is broken down more slowly.
- The rate of oxidation in a conventional bed is at a peak at the surface and just below the surface, where oxygen may possibly be limiting, and declines down through the bed as the food concentration decreases.



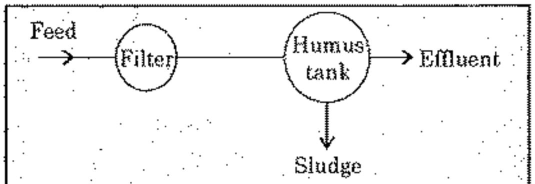
Oxidation rate in a biological filter

- In a conventional filter bed the microorganisms tend to be stratified with large numbers of bacteria and fungi carrying out carbonaceous oxidation in the upper layers. Their numbers decline with depth into the bed as the carbon content of the feed decreases and nitrifying bacteria become established in the lower layers.
- As the film thickness increases, food and O_2 cannot penetrate deep inside the film layer and endogeneous metabolism starts at film-medium interface. Thus the bond weakens and sloughing (breaking off of film from medium) starts.

Note: Actually the biological film will have both aerobic and anaerobic layers. Aerobic layer will be at surface whereas anaerobic layer will be deeper inside the film where O_2 cannot penetrate.

- The effluent from the bed will have a BOD of less than 20 mg/l and in warm climates the ammonia content will probably be less than 10 mg/l.
- Because of the continual loss of microbial cells and pieces of biological film from the bed, the effuent SS is likely to be 40-50 mg/l but on occasions when 'sloughing occurs, considerable amount of film may be released. It is thus essential to provide a final settlement stage of biological filter effluents in 2°-clarifier.
- The amount of sludge produced in biological filters is a likely to be close to the value of 0.5 kg. VSS/ kg BOD removed.

volatile suspended solid



Conventional filtration

The rate of food removal in attached system depends on

(a) Hydraulic loading rate (i.e. flow rate)

(b) Organic loading rate

(c) Rate of diffusibility of food and O_2 into biofilm

(d) Temperature.

- Higher organic loading leads to rapid growth of biomass and this excessive growth may result in plugging of pores and subsequent flooding of the tank.
- Higher hydraulic loading increases sloughing and hence helps to keep the bed. open.

Note:

(i) In standard rate trickling filter, screening and primary sedimentation is must before sewage is applied to the trickling filter.

(ii) In place of rotary distributor used for sewage application, spray nozzles can also be used for sewage application. In case of rotary distributor, tank is circular but for spray nozzle application tank is rectangular.

(iii) Foul gases are released in case of spray nozzle application. In rotary distribution no such foul gases are released.

(iv) Facultative bacteria are predominant organism in trickling filter.

Operational Trouble in Standard Rate Filter

The Common operational problems are:

(a) **Filter media ponding and clogging** which is caused by excessive organic loading, inappropriate hydraulic loading and inadequate choice and packing of the filter media.

- Remedies consist of raking or forking the filter surface.
- Washing the filter by applying high pressure stream of water at the surface.
- Chlorinating the sewage or adding $CuSO_4$ may prevent excessive growth of algae which otherwise would have clogged the filter.

(b) **Excessive fly breeding** which can be reduced by flooding the filter for 24 hours, by chlorinating the influent, applying insecticides to the filter side walls and surface.

(c) **Odour** which can be partly controlled by providing recirculation and maintaining a well ventilated filter. Odour is basically due to H_2S which is evolved during sprary nozzle application. Cl_2 may be added to the waste water to prevent H_2S formation and to neutralise that already formed.

Note: Cl_2 being oxidising agent oxidises H_2S.

These troubles are normally evident only in standard rate filter. In high rate filters as the sewage is fresh all the time and hydraulic loading is more, these troubles donot occur.

Design Data for Trickling Filters

	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 recirulation)	0.6 – 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

Standard rate trickling filter removes BOD upto 80-90%. Efficiency of standard rate trickling filter is given by National Research Council (NRC) formula.

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

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

$$\eta = \frac{100}{1+0.44\sqrt{u}}$$

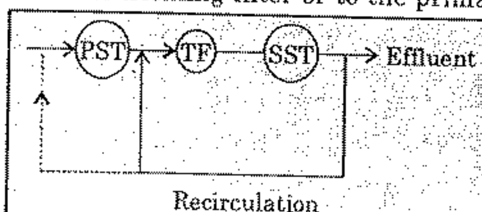
where u = organic loading in $kg/m^3/day$

η is in percentage.

- Design of TF is done for average flow, however, distributary arm under drainage pipe line etc is to be desgined for peak flow and checked for average flow.

HIGH RATE TRICKLING FILTER

All other things are same as standard rate filters except that recirculation is done by pumping the effluent of trickling filter to influent of trickling filter or to the primary sedimentation tank.



Single stage high rate trickling filter

- Recirculation has the advantage of bringing the organic matter in the waste in contact with biological film more than once. Thus without compromising on the quality of effluent, hydraulic loading can be increased.
- High hydraulic loading reduces filter clogging.
- Recirculation helps in dampening the BOD fluctuations applied on filter.
- Recirculation permits higher organic loading.
- There is no fly or odour nuisance in high rate filters as the sewage remains more fresh.
- BOD removal is great but nitrogeneous matter may not get sufficient time for nitrification, as the rate of flow is fast. Biological film may get sloughed before nitrification has had the time to take place.

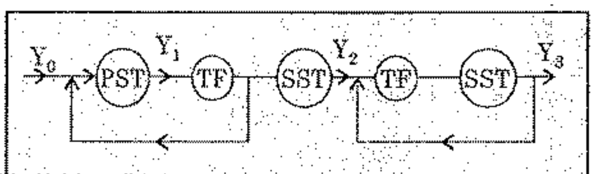
To avoid it, two stage filtration may be adopted with carbonaceous matter removal in 1st stage and nitrification in 2nd stage.

Note: BOD removal and nitrification is lesser in single stage high rate trickling filter as compared to standard rate trickling filter.

Two stage filtration is done when

(a) influent BOD is large

(b) effluent BOD desired is less than 30 mg/l

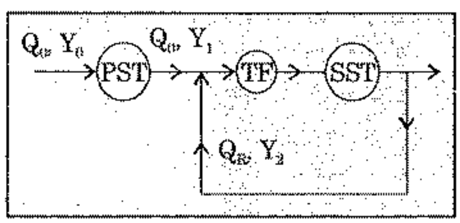


Two stage high rate trickling filter

Note: Heterotropic bacteria are more competitive than nitrifying bacteria (autotrophs) for space on fixed film packing. Thus significant nitrification occurs only after BOD concentration is appreciably reduced. The effluent BOD has to be less than 30 mg/l to initiate nitrification and less than 15 mg/l to complete nitrification.

Note: There can be various variation of the two stage filters. But there should be two TF and recirculation should be done in both of it.

Design of High Rate TF



$$\text{Surface area of trickling filter} = \frac{(Q_0 + Q_R)}{\text{Hydraulic loading (including recirculation)}}$$

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

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

Dia of trickling filter shoud not be greater than 60 m (in case rotary distribution is used). For design data, refer to the design table.

Efficiency of High Rate Trickling Filter

Efficiency of single stage high rate TF

$$\eta_1 = \frac{100}{1 + 0.44\sqrt{\frac{W_1}{V_1 F_1}}} \quad \text{(in percentage)}$$

W_1 = BOD_5 applied to trickling filter in kg/day

W_1 = $Q_0 Y_1$ (excluding recirculation)

V_1 = Volume of trickling filter in m^3

F_1 = Recirculation factor

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

f = Treatatibility factor

f = 0.9 for sewage

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

F_1 represents the no. of effective passage of sewage through TF. In case of two stage filter, 'η_1' is the efficiency of 1st-stage.

Efficiency of 2nd stage (η_2) is

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

W_2 = BOD_5 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 η_1 and η_2

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

$$= \left[1-\left\{1-\frac{\eta_1}{100}-\frac{\eta_2}{100}+\frac{\eta_1\eta_2}{100 \times 100}\right\}\right] \times 100$$

eckenfelder formula: (Without recirculation) $\frac{S_e}{S_0} = e^{-KD/(Q_L)^n}$

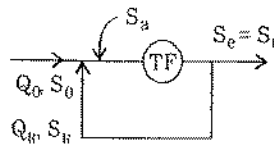
Se = BOD of effluent

→ TF → SST → Q_0 Se
Q_0 S_0 Q_0 Se

eckenfelder formula: (with recirculation) $\frac{S_e}{S_a} = \frac{e^{-KD/(Q_L)^n}}{(1+R) - R\,e^{-KD/Q_L^n}}$

K = rate Constant / minute
D = depth of filter (m)
Q_L = hydraulic loading rate

$$\frac{S_e}{S_a} = \frac{e^{-KD/(Q_L)^n}}{(1+R) - R\,e^{-KD/Q_L^n}}$$



S_a = BOD of the mixture of Raw and recycled sewage applied to the medium

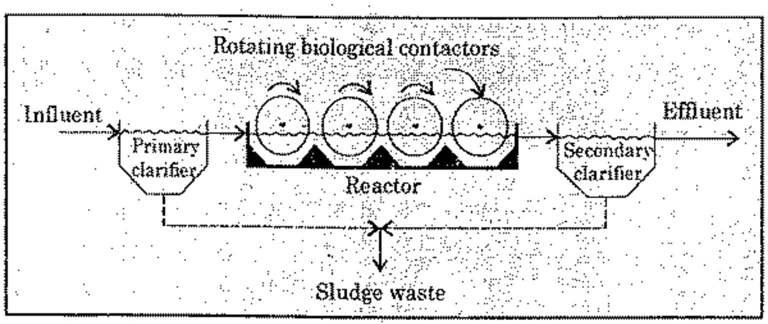
$$S_a = \frac{Q_0S_0 + Q_RS_R}{Q_0 + Q_R} = \frac{S_0 + \frac{Q_R}{Q_0} \times S_e}{1 + \frac{Q_R}{Q_0}} = \frac{S_0 + RS_e}{1+R}$$

Note: $\eta_1 = \frac{y_1 - y_2}{y_1} \times 100,\ y_2 = y_1(1-\eta_1)$

$$\eta_{overall} = \frac{y_1 - y_3}{y_1} \times 100$$

ROTATING BIOLOGICAL CONTRACTOR (RBC)

- It is based on attached growth system.



- In this case, it is the film that is moving (3-6 rpm) and not the water as in the case of TF.
- RBC discs are kept immersed only upto 40% of the diameter. The surface area of the discs is alternatively immersed and exposed to atmosphere above the liquid.
- The biofilm attached to the surface gets a chance to interact with dissolved organics when immersed. It takes oxygen from the atmosphere when exposed to atmosphere. As the growth of film becomes excessive the Biofilm is sheared off.
- Sheared off mass is kept in suspension by the turbulence created due to movement of discs. This sheared off mass remains in suspension for sometime and then taken to secondary sedimentation tank.
- As the sheared mass remains in suspension it can be thought of as suspended growth system also. (Although for a very small time).
- This method provides high degree of treatment including biological conversion upto nitrate levels.
- For a given efficiency of BOD removal and / or nitrification, the rotating disc systems have required less power than needed for any other comparable process. Recycling of the flow is not essential.

Example 5

Population of town = 30000

Domestic sewage produced = 120 lpcd having BOD = 200 mg/l

Industrial sewage produced = 3×10^5 lpd having BOD = 800 mg/l

Design a high rate single stage Trickling filter with the following data.

PST removes 35% BOD

Organic loading = 10,000 kg/ha-m/day (excluding recirculation)

Hydraulic loading = 170 ML/ha/day (including recirculation)

Recirculation Ratio = 1.0

Find the efficiency of the trickling filter and the BOD of the effluent.

Sol.

$$\eta = \frac{100}{1 + 0.44\sqrt{\frac{W_1}{V_1 F_1}}}$$

$$F_1 = \frac{1 + \frac{Q_R}{Q_0}}{\left[1 + (1 - F)\frac{Q_R}{Q_0}\right]^2} = \frac{1+1}{\left[1 + (1 - 0.9) \times 1\right]^2} = 1.6529$$

BOD of domestic sewage = 720 kg/day

BOD of industrial sewage = 240 kg/day

Total = 960 kg per day

BOD_5 applied to Trickling filter,

$$W_1 = 960 - 960 \times 0.35$$

$$= 624 \text{ kg per day}$$

$$V_1 = \frac{Q_0 S_0}{\text{organic loading excluding recircular}} = \frac{624 \text{ kg/day}}{10{,}000 \text{ kg/hac-m/day}}$$

$$= \mathbf{624\ m^3}$$

$\Rightarrow$ $\eta = 74.5\%$

BOD of effluent = $624 \times (1 - 0.745)$

= 159.10 kg/day

$$\text{BOD of effluent} = \frac{159.10 \times 10^6}{39 \times 10^5} = \mathbf{40.79} \text{ mg/l}$$

Example 6

Calculate the diameter required for a single stage trickling filter which is to yield an effluent BOD_5 of 20 mg/L when treating settled domestic sewage with a BOD_5 of 120 mg/l. The waste water flow is 2200 m^3/day and the recirculation is constant at 4000 m^3/day. The filter depth is 1.5 m.

Sol. Efficiency of treatment

$$(\eta) = \frac{120-20}{120} \times 100$$

$$= 83.33\%$$

$$\eta = \frac{100}{1+0.44\sqrt{\frac{W_1}{V_1F_1}}}$$

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

$$R = \frac{Q_R}{Q_0} = \frac{4000}{2200} = 1.818$$

$\Rightarrow$ $$F_1 = 2.018$$

$$W_1 = 120 \text{ mg/l} \times 2200 \times 10^3 \text{ l/day}$$

$$W_1 = 264 \text{ kg/day}$$

$\Rightarrow$ $$83.33 = \frac{100}{1+0.44\sqrt{\frac{264}{V_1 \times 2.018}}}$$

$\Rightarrow$ $$V_1 = 632.88 \text{ m}^3$$

$$\text{Depth of filter} = 1.5 \text{ m}$$

$\Rightarrow$ $$\text{Surface area} = \frac{632.88}{1.5} = 421.92 \text{ m}^2$$

$\Rightarrow$ $$\frac{\pi D^2}{4} = 421.92$$

$\Rightarrow$ $$D = 23.18 \text{ m}$$

Example 7

Determine the dimension of a high rate trickling filter for the following data:

(i) Sewage flow = 3.0 MLD

(ii) Recirculation ratio = 1.5

(iii) BOD of raw sewage = 250 mg/L

(iv) BOD removed in primary tank = 25%

(v) Final effluent BOD desired = 30 mg/L

By what % the diameter of the filter will have to be modified if it is to be designed as a standard rate trickling filter for the above requirement?

Sol. Total BOD in raw sewage per day

$$= 3 \times 250 = 750 \text{ kg}$$

BOD removed in primary tank = 25%

BOD entering per day in filter

$$= 0.75 \times 750 = 562.5 \text{ kg}$$

Permissible BOD concentration in the effluent = 30 mg/l

BOD load per day allowed to go in the effluent

$$= 3 \times 30 = 90 \text{ kg}$$

BOD load to be removed by filter per day = 562.5 – 90 = 472.5 kg

$$\eta \text{ of filter} = \frac{\text{BOD removed}}{\text{Total BOD entering}} \times 100$$

$$= \frac{472.5}{562.5} \times 100 = 84\%$$

$$F = \frac{1+R}{(1+0.1R)^2} = \frac{1+1.5}{(1+0.15)^2} = 1.89$$

$$\frac{100}{1+0.44\sqrt{\frac{562.5}{1.89 \times V}}} = 84$$

$$\Rightarrow \quad V = 1588.125 \text{ m}^3$$

Assumming depth = 2.0 m

$$\text{Area} = \frac{1588.125}{2} = 794.06 \text{ m}^2$$

$$\Rightarrow \quad \text{Dia} = 31.8 \text{ m}$$

For an equivalent standard rate filter, F = 1

$$\Rightarrow \quad 84 = \frac{100}{1+0.44\sqrt{\frac{562.5}{V \times 1}}}$$

$$\Rightarrow \quad V = 3001.556 \text{ m}^3$$

Assumming depth = 2 m

$$\frac{\pi D^2}{4} = \frac{3001.556}{2}$$

$$\Rightarrow \quad D = 43.724 \text{ m}$$

$$\% \text{ increase in dia} = \frac{43.724-31.8}{31.8} \times 100 = 37.5\%$$

Example 8

A low rate trickling filter has a diameter of 40 m and a depth of 1.5m. Assuming the waste removal rate constant as 1.90 d^{-1} and filter media constant n = 0.67, and using the Eckenfelder equation, determine treatment efficiency of the trickling filter for a wastewater flow of 2 MLD having 200 mg/L BOD_5.

Sol. We have wastewater flow, Q = 2 MLD = 2000 m^3/d.

(a) Compute the surface area of filter

$$A_s = \frac{\pi \times (40)^2}{4} = 1256.63 \text{ m}^2$$

(b) Compute hydraulic loading rate

$$Q_L = \frac{\text{wastewater Flow}}{\text{surface Area}} = \frac{2000}{1256.63}$$

$$= 1.59 \text{ m}^3/\text{d-m}^2$$

$$= \frac{1.59}{24 \times 60} = 1.014 \times 10^{-3} \text{ m}^3/\text{m}^2/\text{min}$$

(c) Compute effluent BOD_5 concentration

Using the Eckenfelder equation, we can compute effluent BOD_5 concentration:

$$\frac{S_e}{S_0} = \exp\left[-\frac{kD}{Q_L^n}\right]$$

Here,

S_0 = influent BOD_5 to filter in *mg/l*

S_e = effluent BOD_5 from filter, *mg/l*

k = waste removal rate constant min^{-1}

D = depth of filter in m

Q_L = hydraulic loading rate in $\text{m}^3/\text{m}^2/\text{min}$

n = constant for filter media = 0.67

Therefore,

$Q_L = 1.014 \times 10^{-3} \text{ m}^3/\text{m}^2/\text{min}$

$$k = \frac{1.9}{24 \times 60} = 1.319 \times 10^{-3} / \text{min}$$

$$S_e = S_o = S_o \exp\left[\frac{1.319 \times 10^{-3} \times 1.5}{(1.014 \times 10^{-3})^{0.67}}\right]$$

$= 40.11 \text{ mg}/l$

Therefore, the treatment efficiency is

$$\frac{200 - 40.11}{200} \times 100 = 79.945\%$$

Example 9

A trickling filter plant treats 1500 m^3/day of sewage with a BOD_5 of 220 mg/l and a SS of 250 mg/l. Estimate the total solid production assuming that primary clarification removes 30% of BOD and 60% of influent solids. Take the solid production in the trickling filter at 0.5 kg per kg of the applied BOD.

Sol. Total solid production = solid produced in PST + solid produced in TF

Solid produced in PST = $(1500 \times 10^3 \text{ l/day} \times 250 \text{ mg/l}) \times 0.6$

= 225 kg/day

Solid produced in TF = 0.5 kg/kg of BOD applied on TF

= $0.5 \times (1500 \times 10^3 \times 220 \text{ mg/l}) \times 0.7$

= 115.5 kg/day

Total solid produced = 225 + 115.5 = 240.5 kg/day.

Example 10

Design a high rate trickling filter plant to treat settled domestic sewage with a BOD_5 of 200 mg/l for an average flow of 50 MLD. Assume a peak factor of 2.25. The desired BOD_5 of effluent is 10 mg/l. Adopt recirculation ratio of 1st and 2nd stage filter as 2 & 1 respectively.

Sol. Since the BOD_5 of effluent is less than 30 mg/*l*, a two stage filtration system has to be used. The design of filters is done on the basis of average flow. However, the hydraulic design of the distribution arms, under drainage system, pipelines etc., is done for peak flow and checked for average flow.

(i) **Design using NRC equation**

Assuming a BOD loading of 0.8 kg BOD_5 applied/m³/d excluding recirculation, the volume of first stage filter,

$$\text{Volume} = \frac{BOD_5 \text{ load}}{BOD_5 \text{ loading}} = \frac{50 \times 200}{0.8}$$

$$= 12{,}500 \text{ m}^3$$

The efficiency of first stage filter using NRC equation,

$$E_1 = \frac{100}{1 + 0.44\sqrt{\dfrac{W_1}{V_1 F_1}}}$$

Adopting a recirculation ratio of 2.

$$F_1 = \frac{1 + R_1}{(1 + 0.1R_1)^2} = \frac{1 + 2}{(1 + 0.1 \times 2)^2} = 2.0833$$

$W_1 = 50 \times 200 = 10000$ Kg BOD_5/d

$$E_1 = \frac{100}{1 + 0.44\sqrt{\dfrac{10{,}000}{12{,}500 \times 2.0083}}} = 78.6\%$$

The efficiency of second stage filter , E_2

$$E_2 = \frac{200(1 - 0.786) - 10}{200(1 - 0.786)} = 76.635$$

The volume of second stage filter can be computed using the equation

$$E_2 = \frac{100}{1 + \dfrac{0.44}{(1 - E_1)}\sqrt{\dfrac{W_1(1 - E_1)}{V_2 F_2}}}$$

Adopting a recirculation ratio of one, the value of F_2 is

$$F_2 = \frac{1+R_2}{(1+0.1R_2)^2}$$

$$= \frac{1+1}{(1+0.1\times1)^2} = 1.653$$

$$76.635 = \frac{100}{1+\dfrac{0.44}{(1-0.786)}\sqrt{\dfrac{10,000(1-0.786)}{V_2\times1.653}}}$$

$$V_2 = 58876.4 \text{ m}^3$$

Example 11

Design a two stage trickling filter with each stage having equal efficiency and depth of 1.5m to treat a domestic waste water flow of 10 MLD having influent BOD_5 equal to 250 mg/*l*. The desired effluent BOD_5 is 25 mg/*l* or less.

Sol. We have

Average flow of wastewater, Q = 10 MLD = 10000 m³/d

Influent BOD_5, S_0 = 250 mg/L

Desired effluent BOD_5, S_e = 25 mg/L

Therefore, efficiency of treatment

$$\eta = \frac{S_0 - S_e}{S_0}\times100 = \frac{250-25}{250}\times100 = 90\%$$

Determine the efficiencies of two filters

Therefore, from equation, i.e. $E_1 + E_2(1 - E_1) = E$, we have

$E_1 = E_2 = 0.7$ or 70%

Compute the BOD loading to the first filter tank

BOD_5 applied per day to the filter will be

BOD_5 applied/d = $Q_0 \times S_0$

= 10000 (m³/d) × 250 (g/m³) × 10^{-3} (kg/g)

= 2500 kg/d

Compute the volume of first filter tank, V_1

V_1 can be calculated from equation

$$E_1 = \frac{100}{1+0.44\sqrt{\dfrac{W_1}{V_1F_1}}} \qquad \text{............(i)}$$

where

W_1 = BOD applied per day to the first tank (in kg/day)

V_1 = volume of the first tank (in m^3)

Adopting a recirculation ratio $R_1 = 2$, and assuming F = 0.9 (for sewage), can be calculated from equation, i.e.

$$F_1 = \frac{1+R_1}{\left[1+(1-f)R_1\right]^2} = \frac{1+2}{\left[1+(1-0.9)\times 2\right]^2} = 2.083$$

Substituting the values in equation (i), we get

$$70 = \frac{100}{1+0.44\sqrt{\dfrac{2500}{V_1\times 2.083}}}$$

or $$70+70\times 0.44\sqrt{\frac{2500}{V_1\times 2.083}} = 100$$

or $$V_1 = 1265\ m^3$$

$$\approx 1265\ m^3$$

Compute the diameter of the first filter tank, d_1

Adopting a depth of 1.5 m of filter media for the circular filter, the filter surface area,

$$A_s = \frac{1265}{1.5} = 843.33$$

$$= 843.33\ m^2$$

Therefore, the diameter of the tank,

$$d_1 = \sqrt{\frac{4\times 843.33}{\pi}}$$

= 32.77 m ; Adopt 33m

Compute the volume of the second filter tank

We can compute it from equation

$$E_2 = \frac{100}{1+\dfrac{0.44}{(1-E_1)}\times\sqrt{\dfrac{W_2}{V_2F_2}}} \qquad \text{............ (ii)}$$

where

$W_2 = BOD_5$ applied per day to the second tank

= 2500 × 0.3 kg/d = 750 kg/day

V_2 = volume of the second tank

Adopting the same recirculation ratio $R_2 = 2$, we have $F_2 = 2.083$ (same as F_1).

Substituting the values in equation (ii)

$$70.0 = \frac{100}{1 + \frac{0.44}{1-0.7} \times \sqrt{\frac{750}{V_2 \times 2.083}}}$$

or $$\frac{100}{1 + 1.476 \times \sqrt{\frac{750}{V_2 \times 2.083}}} = 70$$

or $$70.0 \times 1 + 70.0 \times 1.476 \sqrt{\frac{750}{V_2 \times 2.083}} = 100$$

or $$103.32 \sqrt{\frac{750}{\sqrt{2} \times 2.083}} = 100 - 70 = 30$$

or $V_2 = 4270.69\ m^3$

Compute the diameter of second filter tank, d_2

Adopting a depth of 1.5 m of filter media for the circular filter tank, the filter surface area,

$$A_s = \frac{4270.69}{1.5} = 2847\ m^2$$

Therefore, the diameter of the tank, $d_2 = \sqrt{\frac{4 \times 2847}{\pi}} = 60.22$ m ; Adopt 60.5 m

Example 12

A bio-tower composed of a modular plastic medium is to be used as the secondary-treatment component in a municipal wasterwater treatment plant. Flow from the primary clarifier is 20,000 m^3/d with a BOD of 150 mg/L. Pilot-plant analysis has established a treatability constant of 0.055 min^{-1} for the system at 20°C,and the η factor can be taken as 0.5 for plastic medium. Two towers are to be used, each with a square surface and separated by a common wall. The medium is to have a depth of 6.5 m, and the recirculation ratio is to be 2. Determine the dimensions of the units required to produce an effuent with a soluble BOD_5 of 10 mg/L. Minimum temperature is expected to be 25°C. Take $k_T = k_{20}(1.037)^{T-20}$.

Sol. (i) The influent concentration of BOD_5 is determined from the equation.

$$S_a = \frac{S_o + RS_e}{1+R}$$

$$S_a = \frac{150 + 2 \times 10}{1+2} = 56.7 \text{ mg/L}$$

(ii) The treatability constant must be adjusted for temperature equation 5.26

$k_{25} = k_{20}(1.035)^{25-20}$

$= 0.055(1.035)^5$

$= 0.065\ min^{-1}$

(iii) The loading rate is found by solving equation for Q.

$$\frac{S_e}{S_a} = \frac{e^{-kD/Q^n}}{(1+R) - \text{Re}^{-kD/Q^n}}$$

where D = Depth of medium, m

Q = Hydraulic loading rate, m^3/m^2.min

k = treatability constant, min^{-1}

n = coefficient related to medium characteristics

$$\frac{10}{56.7} = \frac{e^{-0.065\times6.5/Q^{0.5}}}{(1+R) - \text{Re}^{0.065\times6.5/Q^{0.5}}}$$

$$\frac{10}{56.7}(1+2) = e^{-0.42/Q^{0.5}} + \frac{10}{56.7}(2)e^{-0.42/Q^{0.5}}$$

$$0.53 = 1.35e^{-0.42/Q^{0.5}}$$

$$0.39 = e^{-0.42/Q^{0.5}}$$

$$0.94 = 0.42/Q^{0.5}$$

$$Q^{0.5} = 0.45$$

$$Q = 0.20 \text{ m}^3/\text{m}^2 \text{ min}$$

(iv) The surface area of each unit:

$$\text{Discharge} = 20{,}000 \times \frac{1}{1440} = 13.9\text{m}^3/\text{min}$$

$$\text{Surface area} = \frac{13.9}{2\times0.2} = 34.8\text{ m}^2$$

Each unit is square, so dimensions are

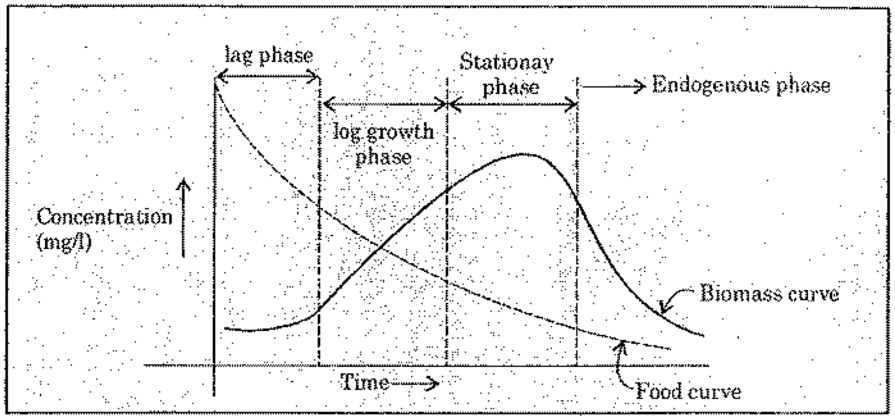
$$L = W = (34.8)^{1/2} = 5.89\text{m} \approx 6\text{m}$$

Each unit is 6.0m × 6.0m × 6.5m deep.

ACTIVATED SLUDGE PROCESS (SUSPENDED GROWTH SYSTEM)

It is an aerobic supended growth type biological process that uses the active microorganisms kept in supension in the reactor to decompose and stabilize the soluble and particulate (colloidal and suspended) organic matter present in wastewater.

REACTION KINETICS



- If 'S' represents the quantity of soluble food applied and 'X' represents total biomass that is maintained in the reactor to oxidise the incoming organic matter and stabilize them or MLSS (mixed liquor suspended solids). MLSS represents both living and dead bacteria.

Note: MLVSS (mixed liquor volatile suspended solid) represent living bacteria only; MLVSS = 80% MLSS.

- Then, rate of biomass gowth $= \frac{dX}{dt}$

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

- The microorganisms first become acclimated to their environment and to the food provided. During this bacterial growth will not be much. The acclimatization period is represented by the lag phase.
- If the organisms are accustomed to a similar environment and similar food, lag phase would be very small.
- In log growth phase bacterial cell reproduce by cell division and the rate is very high.
- The stationary phase represents the time during which production of new cellular mass is roughly offset by death due to endogenous respiration. In this zone food supply becomes limited.
- The endogenous respiration predominates in the last stage in which biomass slowly decreases and approaches zero asymptotically.

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

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

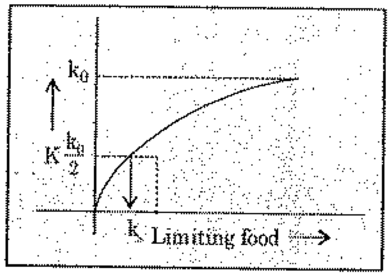
  k represents here the overall growth rate constant of different types of bacteria

  (it depends on the type of food, concentration and temperature),

  k_0 = maximum growth rate constant

  s = concentration of limiting food (in mg/l)

  k_s = Half saturation constant



k_s represents the concentration of limiting food when rate constant is $\frac{k_0}{2}$.

If $S >> k_s$ i.e. concentration of limiting food is in excess, then

$$\boxed{k = k_0}$$

when $S << k_s$ then $\frac{dX}{dt}$ = constant (zero order equation)

If food is in excess growth would be logarithimic and if food is in deficiency growth would be constant.

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

- If all the food is converted to biomass rate of food utilization will be equal to rate of biomass growth or.

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

But catabolism converts part of the food into waste product, and energy. Hence.

$$\frac{dX}{dt} < \frac{-dS}{dt}$$

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

where y is the fraction of food mass converted to biomass

Note:

	For aerobic reaction,	y = 0.4 - 0.8 kg biomass/kg of BOD_5
	For anaerobic reaction,	y = 0.08 - 0.2 kg biomass/kg of BOD_5
Normally,	For municipal sewage,	y = 0.5 kg biomass/kg of BOD_5

- In the endogenous phase, the growth is also taken as 1st order growth i.e.

$$\frac{dX}{dt}(\text{at end}) = -k_D X$$

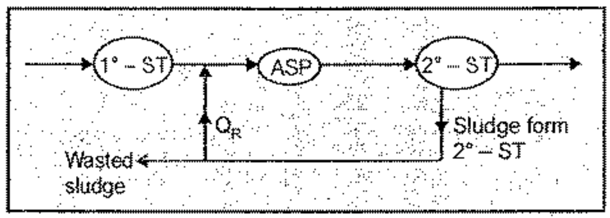
- For whole system, the equation for overall biological growth is

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

where k_d = endogenous decay rate constant. For municipal sewage

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

ACTIVATED SLUDGE



- The settled sludge in secondary clarifier containing living microorganisms is returned to the reactor to increase the available biomass and speed up the reaction.
- The returned sludge from secondary sedimentation tank is active hence it is called activated sludge.
- ASP is a suspended culture process with sludge return. The process can be :
  (i) completely mix process
  (ii) plug flow process
- These process are aerobic and for this oxygen is supplied from outside.

(i) Completely Mix Process

- It is adopted for plant less than 25 MLD.
- It utilizes completely mix flow regime.
- In completely mix process, circular or square tank is used and complete mixing is achieved by mechanical aerator installed at the centre of the tank.
- Complete mixing has a capacity to hold high MLSS level in the aeration tank and hence the volume is reduced.
- It has increased operation stability at shock loading and also increased capacity to treat toxic biodegradable waste like phenol.
- Food/mass ratio (F/M) and oxygen demand is uniform in completely mix process.

(ii) Plug Flow Process

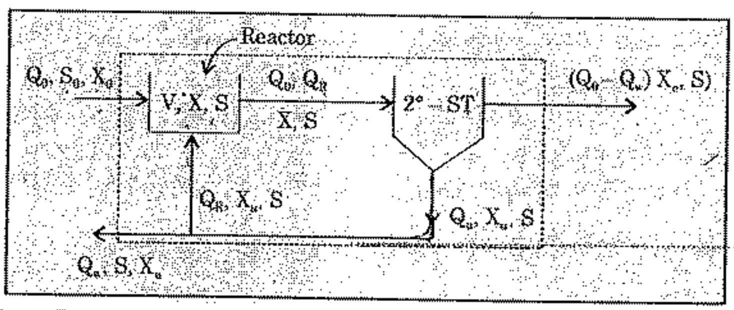
- It is a conventional system and this process has been adopted even for large plant upto 300 MLD.
- Plug flow implies that sewage moves progressively down along the aeration tank essentially unmixed with rest of the tank contents.
- In this case, long narrow channel is used.
- Length is normally taken as $\geq 5 \times$ width.
- The sewage and MLSS (mixed liquor) are let in at the head of tank and withdrawn at the opposite end. In plug flow regime $\frac{F}{M}$ ratio and oxygen demand is high at the inlet end of aeration tank and will then decrease progressively.
- Plug flow regime lacks operational stability at times of excessive variation in rate of flow and in influent strength.
- The conventional system is always preceded by primary settling
- BOD removal efficieny is 85–92%.

Extended Aeration Process

(Adopted for Less than 4 MLD Plant)

- The flow scheme of extended aeration process is completely mix process.
- In this case, **PST** is avoided.
- The process employs low organic loading, long aeration time, high MLSS concentration and low food to mass ratio.
- The BOD removal efficiency is high in this case (because F/M is less).
- System works in endogeneous phase.
- Because of long detention in aeration tank, the mixed liquor solids undergo considerable endogenous respiration and get well stabilized.
- The excess sludge does not require separate digestion and can be directly dried on sand beds. Oxygen requirement is high in this case.

Completely Mix Process



Biomass in + Biomass growth = Biomass out

$$\Rightarrow \quad Q_0X_0 + V\left[\left(\frac{k_0S}{k_s+S}\right)X - k_dX\right] = Q_w X_u + (Q_0 - Q_w) X_e \quad \text{... (i)}$$

Also, Food in – Food consumed = Food out

$$Q_0S_0 - V\left[\left(\frac{k_0S}{k_s+S}\right)\times\frac{X}{Y}\right] = (Q_0 - Q_w) S + Q_wS \quad \text{... (ii)}$$

Assumptions

(a) Influent and effluent biomass concentration are negligible compared to biomass at other points (i.e. X_0 and X_e are negligible).

(b) All reactions occur in the reactor (Aeration Tank)

From (i) We get

$$XV\left[\frac{k_0S}{k_s+S} - k_d\right] = Q_wX_u$$

$$\Rightarrow \quad \frac{k_0S}{k_s+S} = \frac{Q_wX_u}{VX} + k_d$$

From (ii), we get

$$Q_0S_0 - Q_0S = \frac{VX}{Y} \times \frac{k_0S}{k_S + S}$$

$$\Rightarrow \quad \frac{k_0S}{k_s + S} = \frac{Q_0Y(S_0 - S)}{VX}$$

$$\therefore \quad \frac{Q_wX_u}{VX} + k_d = \frac{Q_0Y(S_0 - S)}{VX}$$

$$\Rightarrow \quad \boxed{\frac{Q_wX_u}{VX} = \frac{Q_0Y(S_0 - S)}{VX} - k_d} \quad \text{... (iii)}$$

DESIGN PARAMETERS

1. **Hydraulic retention time (θ) or Aeration time or detention time**

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

$$\Rightarrow \quad \boxed{\theta = \frac{V}{Q_0}} = t_d$$

2. **Volumetric BOD loading (or organic loading rate)**

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

$$= \frac{Q_0S_0}{V}$$

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

$U = \dfrac{Q_0(S_0 - S)}{VX}$ = mass of BOD removed per unit mass of biomass in the aeration tank

If the value of S is small compared to S_0, which is often the case, U can be also expressed as food applied to biomass ratio (F/M ratio) i.e.

$$\text{F/M ratio} = \frac{Q_0S_0}{VX}$$

Lower the food to mass ratio, greater will be the removal of BOD

4. **Sludge age (θ_c)**

It is defined as the average time for which a biomass remain in the system. It thus indicates the residence time of biological solids in the system.

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

$$\boxed{\theta_c = \frac{VX}{(Q_0 - Q_w)X_e + Q_wX_u}}$$

If X_e is neglected, then

$$\theta_c = \frac{VX}{Q_w X_u}$$

From (iii), we get

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

Also

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

5. Sludge Volume Index (SVI)

- MLSS concentration in the aeration tank is controlled by sludge recirculation ratio and sludge settleability.
- Sludge recirculation and settleability are determined by SVI.
- SVI indicates the physical state of sludge in the biological aeration system.
- SVI represents the degree of concentration of sludge in the system and hence decides the rate of recycle of sludge required to maintain desired MLSS and F/M ratio in the aeration tank to achieve the required degree of purification.
- SVI is defined as volume occupied in ml by 1 gm of solid in the mixed liquor after settling for 30 minutes. It unit is ml/gm.
- Writing balance eq. about aeration tank

$$Q_0X_0 + Q_RX_u = (Q_0 + Q_R)X$$
$$Q_R(X_u - X) = Q_0X - Q_0X_0$$

Neglecting X_0, $\frac{Q_R}{Q_0} = \frac{X}{X_u - X}$

If α = SVI

$$\frac{1}{\alpha}\text{ g/mL} = \frac{10^3\text{mg}}{\alpha \times 10^{-3}l} = \frac{10^6}{\alpha}\frac{\text{mg}}{l}$$

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

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

Note: If α = SVI

$$\Rightarrow \quad \frac{1}{\alpha}\text{ m/mL} = \frac{10^3\text{mg}}{\alpha\, 10^{-3}l} = \frac{10^6}{\alpha}\frac{\text{mg}}{l} = \frac{10^6}{SVI}$$

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

Note: *Unless otherwise given, we should design the plug flow system which is a conventional system.*

- Value of SVI should be between 80 – 150 (in ml/g). This will ensure that there is sufficient settleability of sludge.

Experiment

The standard test, which is performed in the laboratory to compute SVI of an aeration system involves collection of one litre sample of mixed liquor from the aeration tank from near its discharge end in a graduated cylinder. This 1 litre sample of mixed liquor is allowed to settle for 30 minutes and the settled sludge volume (V_{ob}) in *ml* is recorded as to represent sludge volume. This volume V_{ob} in *ml* per litre of mixed liquor will represent the quantity of sludge in the liquor in *ml*/l.

The above sample of mixed liquor, after remixing the settled solids, is further tested in the laboratory for MLSS by the standard procedure adopted for measuring the suspended solids in sewage. Let this concentration of suspended solids in the mixed liquor in mg/l be X_{ob}. Then SVI is given by the equation

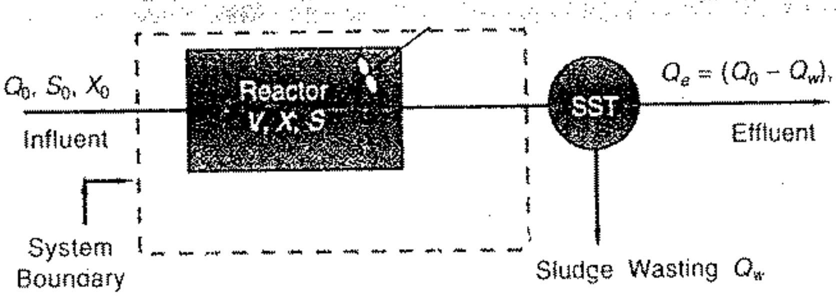
$$\text{SVI} = \frac{V_{ob}(ml/mg)}{X_{ob}(l/mg)} = \frac{V_{ob}}{X_{ob}} ml/mg$$

or

$$\boxed{\text{SVI} = \frac{V_{ob}}{X_{ob}} \times 1000\ ml/g}$$

Example 13

For the activated sludge process system, shown in Figure, compute the mean cell residence time and recirculation ratio R, for the given data:



(a) Without recirculation of sludge

Daily average flow of wastewater, $Q_{avg} = Q_0 = 10$ MLD

Effluent flow rate of wastewater, $Q_e = 9.92$ MLD

Sludge wasting rate, Q_w = 0.08 MLD

Hydraulic Retention Time (HRT), θ = 6 hours

Active biomass concentration in reactor, X = 3000 mg/L (MLVSS)

Biomass concentration in effluent, X_e = 20 mg/L

Biomass concentration in X_u = 9000 mg/L

Sol (a) Computation of MCRT

MCRT can be computed from the relation:

$$\theta_c = \frac{\text{biomass in the reactor}}{\text{biomass leaving the reactor or system}}$$

$$= \frac{(V)(X)}{(Q_w)(X_w)+(Q_e)(X_e)}$$

Now, V = volume of the reactor = Q × t

= 10 × (6/24) = 2.5 ML

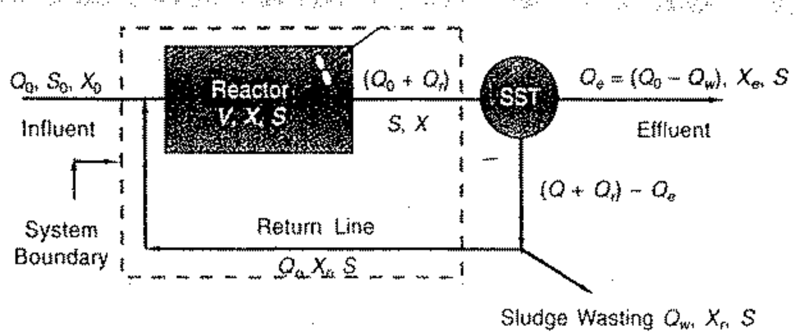
$$\text{So, } \theta_c = \frac{2.5\times3000}{0.08\times9000+9.92\times20}$$

$$= \frac{2.5\times3000}{0.08\times9000+9.92\times20}$$

$$= \frac{7500}{720+198.4} = 8.166 \text{ days}$$

(b) Computation of recirculation ratio, R

Consiering the mass balance of suspended solids of the reactor in the boundary line shown in Fig., we have



(b) With recirculation of sludge from SST

$$Q_0X_0+Q_rX_r = (Q_0+Q_r)X$$

$$\text{or } (Q_0+Q_r)X = Q_rX_r$$

(Assuming X_0 = 0, i.e., neglecting the influent biomass concentration)

$(10 + Q_r)3000 = Q_r\ 9000$

$Q_r = 5.0$ MLD

Now, $R = Q_r/Q_0$, where R is the recirculation ratio.

$R = 5.0/10.0 = 0.5$

Example 14

A mixed liquor with 2,000 mg/L of suspended solids has the settled volume of 200 mL from a litre of this mixed liquor. Calculate its sludge volume index. Is it safe?

Sol. Settle sludge volume V_{0b} = 200 ml concentration of suspended solids in mixed liquor X_{0b} = 2000 mg/l

Sludge volume index is given by

$$SVI = \frac{V_{0b}}{X_{0b}} \times 1000 \text{ ml/g}$$

$$= \frac{200}{2000} \times 1000 = 100 \text{ ml/g}$$

The range SVI is between 80 – 150 ml/g thus it is safe.

Operation

- The most important aspect in the operation of activated sludge plant is to maintain proper food to mass ratio which is achieved by increasing or decrasing MLSS levels in the aeration tank to suit the influent BOD load.
- The MLSS in the aeration tank is regulated by controlling the **rate** of **sludge return** based on SVI determine experimentally.
- The excess sludge is wasted i.e., taken out of the system. The excess sludge is taken to the sludge digestion tank and then to the sand drying bed.
- In case of extended aeration process the wasted sludge is directly taken to the sludge drying bed.
- The excess sludge is wasted to maintain desired MLSS in aeration tank and also to reduce sludge age (θ_c).

DESIGN OF AERATION TANK

Process type	Flow regime	MLSS mg/l	MLVSS/MLSS	F/M	HRT (hr.)	θ_c days	Q_R/Q	η	kg O_2 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
Complely mix	Comple-ly mix	3000-4000	0.8	0.3 – 0.5	4 – 5	5 – 8	0.25 – 0.8	85 – 92%	0.8 – 1.0
Extended Aeration	Comple-ly mix	3000 – 5000	0.8	0.1 – 0.18	12 – 24	10 – 15	0.5 – 1.0	95 – 98%	1.0 – 1.2

- Volume of aeration tank can be calculated from equation

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

by assuming the value of θ_c and X from the table.

- If can also be calculated from

$$F/M = \frac{Q_0 S_0}{VX}$$

by assuming F/M and X from the table.

- Completely mix tank is designed as square or circular whereas plug flow system is designed as long narrow channel.
- Depth controls the aeration efficiency. Depth for plug flow system is adopted between 3 – 4.5 m. For plant capacity greater than 50 MLD, 4.5 m depth is economical.
- Width controls mixing efficiency (excessive width will lead to settlement of solid in tank). Width adopted is between 5 – 10 m for plug flow system.
- Width by depth ratio is 1.2 to 2.2, length should be greater than 30 m and should not be more than 100 m.
- Horizontal velocity of flow = 1.5 m/min.
- Oxygen required $= \dfrac{Q_0(S_0 - S)}{f} - 1.42\, Q_w \times X_u$

  = Biological COD – COD of wasted sludge

  where $f = \dfrac{BOD_5}{BOD_u} \approx 0.68$

  1.42 is oxygen demand of biomass in gm per gm of sludge wasting.

  This formula does not allow for nitrification. It allows only for carbonaceous BOD removal. Extra theoretical oxygen required for nitrification is 4.56 kg oxygen per kg of ammonia converted to nitrate.

Excess Sludge Wasting

- It is done to maintain steady level of MLSS in the tank and to maintain sludge age.
- Excess sludge **quantity will increase** with increasing food to mass ratio and decreases with increasing temperature.
- For domestic sewage excess sludge is 0.35 – 0.5 kg per kg of BOD_5 removal for conventional plant. It is 0.25 – 0.35 kg per kg of BOD_5 removed in extended aeration process having no primary clarifier.

Nitrification

- ASP plant is normally designed for removal of carbonaceous BOD only. However, there may be some nitrification taking place which will consume oxygen supplied and hence reduces dissolved oxygen in aeration tank.

- This problem can be overcome by increasing the sludge wasting rate. (So as to reduce θ_c and hence nitrification will reduce)
- Nitrification can lead to subsequent denitrification ($N_2 \uparrow$) in secondary tank causing sludge rising problem called **blanket rising**.
- Nitrification is aided by low F/M ratio and long aeration time. It may be pronounced in extended aeration plant especially in hot weather.
- Nitrification is generally not desired but may be required when nitrification and subsequent denitrification is proposed for elimination of nitrogeneous matter from the effluent to control Eutrophication of lakes.
- In such cases plug flow system has been designed for efficient removal of both carbon and nitrogen.
- Alternatively, a two stage system may be designed with carbonaceous BOD removal in Ist stage and nitrification in 2nd stage.

Sludge Bulking

- Sludge with poor settling characteristics is termed as bulking sludge.
- Sludge bulking results in poor effluent due to presence of excessive suspended solids and also in rapid loss of MLSS from the aeration tank.
- Sludge bulking is due to inadequate air supply resulting in lower pH and septicity. This facilitates the growth of filamentuous organism.
- Filamentous bacteria also form due to low nutrient concentration and its growth is supported by **high sludge age, low F/M ratio** and higher waste temperature.

This can be reduced by :

(a) reducing the sludge age.

(b) chlorination of returned activated sludge.

(c) addition of nutrient if it is less ($BOD_5 : N_2 : P$ ratio recommended = 100 : 5 : 1).

CONVENTIONAL SYSTEMS AND ITS MODIFICATION

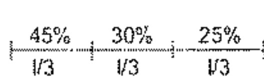
The conventional system represents early development of ASP. Over the several years modifications to the conventional system has been developed to meet the specific treatment objectives.

Step aeration

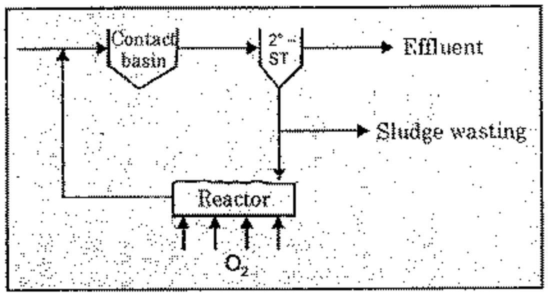
In step aeration method, settled sewage is introduced at several points along the tank length which will produce uniform oxygen demand throughout.

Tapered aeration

In tapered aeration, air is supplied to match the oxygen demand along the length of the tank. For example, in successive $\frac{1}{3}$rd lengths, O_2 supplied are 45%, 30% and 25% respectively.



Contact Stabilization (Biosorption Process)



- The sewage is first introduced in contact basin. Where the biomass absorbs organics and settles out in 2°-clarifier.
- The thickened sludge in SST is aerated in reactor before being returned to the contact basin.
- By this process poor settling or rising sludge problem is avoided.

Completely mix Process

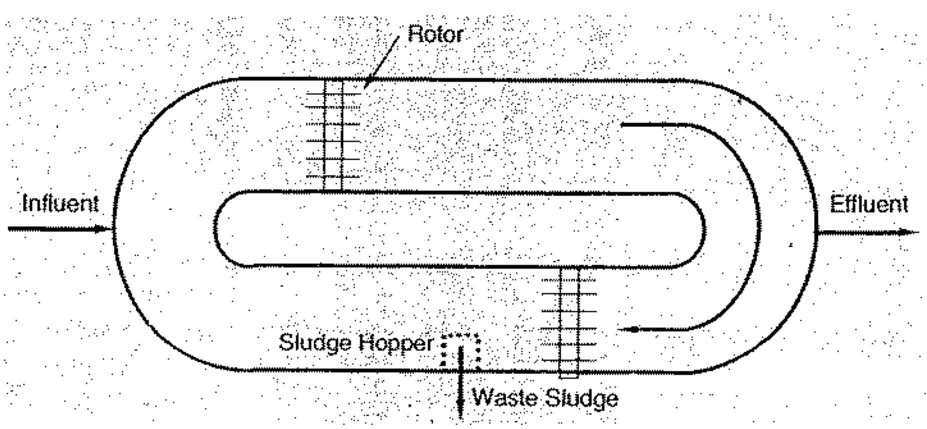
- In this sewage is maintained in log-growth phase by keeping high F/M ratio.
- Detention time is smaller.

Extended Aeration

- F/M ratio is kept lower and detention time is kept more, so as to maintain the reaction in endogenous phase.
- This process produces lesser quantity of stabilized sludge.
- Primary sedimentation tank is avoided and the sludge is directly taken to sludge drying bed.

OXIDATION DITCH

- An oxidation ditch is basically an extended aeration system of a modified activated sludge process.
- It is designed and operated on the same basic principles of the activated sludge process.
- Oxidation ditch employed in the field consists of an oval or ring-shaped long shallow channel (known as ditch) of about 1.0 m depth. A rotor (i.e., an aerator) is provided across the ditch to supply the required oxygen and to circulate the wastewater and mix the content of the ditch at flow thorugh velocity of about 0.3 to 0.6 m/s.
- Extended aeration produces a very clear effluent (low BOD) as biological solids produced are destroyed completely by endgenous respiration and separate sludge handling is not required.



Schematic diagram of a typical oxidation ditch

Note : Normally, raw wastewater is applied to the reactor only after screening and grit removal. The system does not requires a PST.

Based on operational methods, oxidation ditches are Continuous flow type and Intermittent flow type.

Continuous Flow Type : In such system, after screening and grit removal, the wastewater is fed to the ditch along with recycled flow. The mixed liquor content is aerated and kept in circulation by rotors for a longer hydraulic detention time. The effluent of the ditch is then taken to the settling tank (SST) or clarifier to separate the sludge, part of which is returned to the ditch and remaining extra sludge is taken to drying beds.

Intermittent Flow Type : In specific cases, an oxidation ditch can be designed to operate intermittently where the ditch itself works as a settling tank when aerators are shut off periodically at predetermined time. No separate clarifier or settling tank is required as excess sludge is removed through "sludge trap" provided in the tank.

Example 15

A completely mix process is designed with the following data:

Q_0 = 10000 m³/d, BOD after PST = 150 mg/l, effluent BOD = 5 mg/l

Y = 0.5 kg/kg, k_d = 0.05 per day, MLSS = 3000 mg/l

Underflow concentration (X_u) = 10000 mg/l for 2° sedimentation tank.

Determine (a) reactor volume, (b) mass and volume of the sludge wasted per day (c) recycled ratio.

Sol. (a) $VX = \dfrac{\theta_c (S_0 - S)\, \theta_0 Y}{1 + 0.05\,\theta_c}$

$$\text{Assuming} \quad \theta_c = 8 \text{ days}$$

$$V \times 3000 = \frac{10000 \times (150 - 5) \times 8 \times 0.5}{1 + 0.05 \times 8}$$

$$V = \frac{2761.90}{2} \text{ m}^3 = 1380.95 \text{ m}^3$$

(b) Sludge wasted per day = $Q_w X_u$

$$\theta_c = \frac{VX}{Q_w X_u + (Q_0 - Q_w) X_e}$$

Neglecting X_e

$$\theta_c = \frac{VX}{Q_w X_u}$$

$$\theta_c = \frac{1380.95 \times 3000 \times 10^3}{Q_w X_u}$$

$\Rightarrow$

$$Q_w X_u = \mathbf{517.857} \quad \text{kg/day}$$

$$Q_w = \frac{Q_w X_u}{X_u} = \frac{517.88}{10^4 \times 10^{-6}} \times 10^{-3}$$

$$Q_w = 51.786 \text{ m}^3/\text{day}$$

(c) $X, S, (Q_0 + Q_R) \longrightarrow$ [$2° - ST$] $\longrightarrow (Q_0 - Q_w), X_e, S$

$\downarrow Q_w + Q_R, SX_u$

$$(Q_0 + Q_R) + X = (Q_0 - Q_w)X_e + (Q_w + Q_R)X_u$$

$$\Rightarrow (Q_0 + Q_R) \times X = Q_w X_u + Q_R X_u \text{ (neglecting } X_e)$$

$$\Rightarrow Q_0 X + Q_R X = Q_w X_u + Q_R X_u$$

$$\Rightarrow Q_R = \frac{Q_w X_u - Q_0 X}{X - X_u} = 4.27 \times 10^6 \ l/\text{day}$$

$$\frac{Q_R}{Q_0} = \frac{4.27 \times 10^3}{10^4} = 0.427$$

Example 16

Flow = 50,000 m³/day, Raw waste water BOD_5 = 250 mg/l, SS = 400 mg/l, efficiency of PST = 35% and 75% w.r.t. BOD and SS respectively, k_d = 0.06/day. Primary and Secondary excess sludge SS concentration = 40 and 10 kg/m³. Aeration equipment transfer efficiency = 1.8 kg oxygen per kWhr. The sludge age can be adopted at 6.5 days. Determine aeration tank volume, excess sludge wasted both in weight and volume, sludge recirculation ratio, oxygen required, total sludge generated, and sludge recirculation pump capacity.

Sol. (i) $VX = \dfrac{Q_0(S_0 - S)\, Y\theta_c}{1 + k_d\theta_c}$

$$\text{Assume, } Y = 0.5 \text{ kg/kg}$$

$$\text{Assume efficiency} = 90\%$$

$$VX = \frac{50000 \times 250 \times (1 - 0.35) \times 0.9 \times 6.5 \times 0.5}{1 + 0.06 \times 6.5}$$

Assume conventional plant

$$X = 2000 \text{ mg/l}$$

$$V = 8548.78 \text{ m}^3$$

$$\text{Hydraulic retention time} = \frac{V}{Q_0}$$

$$= \frac{8549}{50000} \times 24$$

$$= 4.1 \text{ hr within the range of 4–6 hr} \quad \textbf{OK}$$

(ii) $$Q_w X_u = \frac{VX}{\theta_c} = \frac{8549 \times 2000}{6.5} = 2630.46 \text{ kg per day}$$

$$\text{Volume of excess sludge} = \frac{2630.46}{10} = 263.05 \text{ m}^3/\text{day}$$

(iii) $\frac{Q_R}{Q_0} = \frac{X}{X_u - X} = \frac{2000}{10000 - 2000} = 0.25$ [X_u = density of 2°–sludge = 10 kg/m³]

$$\text{Sludge recirculation pump capacity} = Q_0 \times \text{Recirculation Ratio}$$
$$= 50000 \times 0.25 = 12500 \text{ m}^3/\text{day}$$

$$\text{Oxygen required} = \left\{\frac{Q_0(S_0 - S)}{f} - 1.42 Q_w X_u\right\}$$

$$\text{Carbonaceous } O_2 \text{ demand} = \frac{50000 \times 10^3 \times (250 \times 0.65) \times (0.9) \times 10^{-3}}{0.68} - 1.42 \times 2630 \times 10^3$$
$$= 7019.07 \text{ kg/day}$$

$$\text{Oxygen required per kg } BOD_5 \text{ removed} = \frac{7019.07 \times 10^3}{0.90 \times 65 \times 250 \times 50000}$$
$$= 0.96 \text{ (in range)}$$

$$\text{Sludge generated in 1° ST} = 50000 \times 400 \times 0.75$$
$$= 15000 \text{ kg/day}$$

$$\text{Volume of sludge in PST} = \frac{15000}{40} = 375 \text{ m}^3/\text{day}$$

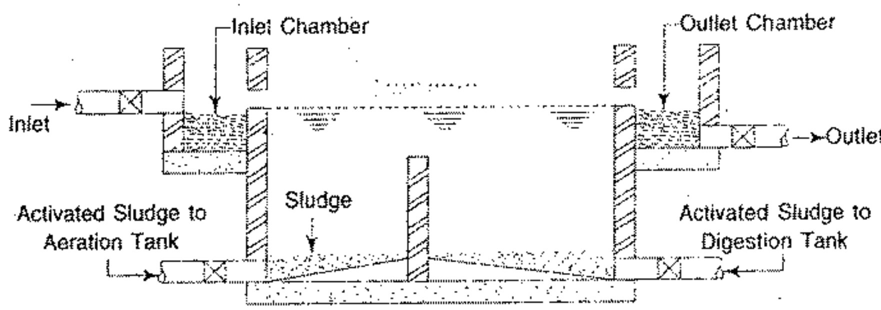
$$\text{Sludge generated in 2° ST} = Q_w X_u$$
$$= 2630.46 \text{ kg/day}$$

$$\text{Volume of sludge in SST} = \frac{2630.46}{10} = 263.046 \text{ m}^3\text{day}$$

$$\text{Volume of total sludge} = 375 + 263.046 = 638.046 \text{ m}^3/\text{day}$$

SECONDARY SEDIMENTATION TANK

- The secondary sedimentation tank is also known as secondary clarifier or secondary settling tank.



Secondary sedimentation tank

- Secondary clarifer for ASP must accomplish two objectives :
  (i) They must produce an effluent sufficently clarified.
  (ii) They must concentrate the biological solids to minimize the quantity of sludge that must be handled.

- Secondary sedimentation tank removes **bioflocculated solids.**
- It is designed on the basis of :
  - (a) Solid loading rate
  - (b) Over flow rate (Hydraulic loading rate)
- In SST hindered settling or zone settling occurs because bioflocculated solids are close enough so that their velocity fields overlap causing hindered settling.
- The settling of particles results in significant upward displacement of water.
- The particles maintain their relative positions w.r.t. each other and the whole mass of particles settles as a unit or zone.
- In the hindered settling zone concentration of particles increase from top to bottom leading to thickening of sludge. Such secondary clarifier where zone settling occurs are designed on the basis of solid loading rate and checked for surface overflow rate.

	Overflow rate ($m^3/m^2/day$)		**Solid loading rate ($kg/m^2/day$)**		**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

Note: Detention time in SST is small as otherwise denitrification will occur and N_2- will evolve.

- Surface area adopted should be maximum of the surface area from solid loading rate and overflow rate.

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

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

in Trickling filter $(Q_0 + Q_R)X$ should be replaced by amount of bioflocs added to the SST from TF.

- The value of surface area so obtained is checked for peak conditions also because under peak conditions efficiency may reduce (peaking factor = $\frac{Q_{max}}{Q_{av.}}$).
- The suspended solid in 2° – ST are light in weight and are thus markedly influenced by currents.
- Thus, in SST considerable length of overflow weir is desirable to reduce the velocity, hence check for weir overflow rate should also be done.
- Weir overflow rate should be 185 $m^3/m/day$ for SST with ASP i.e. discharge per unit perimetre length should be 185 $m^3/m/day$ for SST with ASP.
- Weir overflow rate for SST with trickling filter should be 125 $m^3/m/day$.

Example 17

Design SST to treat effluent from ASP with the following data :

Average sewage inflow = 20 MLD

MLSS in influent = 3000 mg/l

peak flow factor = 2.25

Sol. Assume Avg. overflow rate as 20 $m^3/m^2/day$ ASP

$$\text{Surface area of tank} = \frac{20\times10^6\times10^{-3}}{20}$$

$$= 1000\ m^2$$

Check for peak over flow rate

$$= \frac{2.25\times20\times10^3}{1000}$$

$$= 45\ m^3/m^2/day$$

For solid loading rate, Assume loading rate = 80 $kg/m^2/day$

$$\text{Solid Applied} = 20\times10^3\frac{m^3}{d}\times3000\,mg/l\times10^{-6}$$

$$= 60{,}000\ \text{kg per day}$$

$$\text{Area} = \frac{60{,}000}{80} = 750\ m^2$$

Hence adopting the maximum value of 1000 m^2

$$\frac{\pi D^2}{4} = 1000$$

$$D = 35.69\ m = \text{Adopt } 36\ m$$

$$\text{Weir overflow rate} = \frac{20\times10^3 m^3/day}{\pi\times36} = 176.84\ m^3/m/day$$

$$< 185\ m^3/m/day,\ \text{hence OK}$$

Adopt depth as 4 m.

Note: As data is not given sufficiently to calculate Q_R hence solid applied to SST has been calculated as Q_0X. It should actually have been calculated as $(Q_0 + Q_R)X$.

SLUDGE THICKENER short note:

- To reduce the volume to be handled in sludge digestor, sludge thickner is provided.
- There are three types of thickening that are commonly practiced
  1. Gravity thickening
  2. Air floating
  3. Centrifugation
- **Gravity thickening** is done for primary sludge or primary sludge combined with ASP sludge. It is never adopted for ASP sludge independently. It is also not effective if in combined sludge the

Design for solid over loading rate as well as over flow rate.

activated sludge portion exceeds 40% of the total sludge weight. It is designed for surface loading rate of 20 – 25 m^3/m^2/day. The solid loading is 25 – 30 kg/m^2/day.

Solid loading for

(a) ASP = 25-30 kg/m^2/day

(b) 1°-sludge = 90-140 kg/m^3/day

(c) TF sludge = 40-45 kg/m^2/day

(d) 1° sludge + ASP = 30-50 kg/m^2/day

(e) 1° sludge + TF sludge = 50-60 kg/m^2/day

- Depth is normally 3 to 4 m.
- Detention period is 4 hrs.

Air Flotation

- This unit employs floatation of sludge by air under pressure or vacuum and is normally used for activated sludge.
- The supernatant (liquid) (water) is pressurized at 3 – 5 kg/cm^2 and saturated with air in pressure tank.
- The effluent from the pressure tank is mixed with influent sludge immediately before it is released in the flotation tank.
- The excess dissolved air then rises up in the form of bubbles attaching themselves to particles. Thus a sludge blanket is formed on the surface. This blanket is sufficiently thickened. The blanket is then skimmed off.

Centrifugation

- When there is a space restriction, this method is adopted.

SLUDGE DIGESTION

- Waste water sludge is a considerable hazard to environment and must be rendered inert prior to disposal.

  The sludge from PST is called raw sludge or primary sludge.

  Raw sludge is more objectionable. It contains about 95% moisture content. Sludge of SST contains 96 – 98% moisture.

  Sludge form PST has excess organic matter and sludge from SST have excess biomass.
- 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.
- This goal can be achieved aerobically or anaerobically.

Aerobic Digestion

- It is adopted only for biological sludge (2°-sludge) that does not contain primary sludge.
- It is just an extension of **extended aeration process**.
- In aerobic digestion as there is scarcity of food, endogenous respiration will start.
- The digested sludge consists of cell walls, and other cell fragments. This process is energy consumptive.
- The sludge dewaters poorly.

Anaerobic Digestion

- It is carried out primarily for primary sludge because this sludge contains large amount of readily available organics that can induce rapid growth of biomass if treated aerobically.
- The anaerobic process produces lesser biomass and also the primary function of anaerobic digestor is to convert as much of sludge as possible to liquids and gases while producing little biomass.
- The waste water contains wide variety of organics and hence requires wide variety of organisms also.
- In anaerobic process the organisms are broadly classified as : (a) acid formers and (b) methane formers.
- **Acid formers**: They consist of facultative and anaerobic bacteria and organisms which solublize the organic acids through hydrolysis. The soluble end products are then fermented to acids and alcohols of lower molecular weight.
- **Methane former**: They are strictly anaerobic and convert acids and alcohol along with hydrogan and carbon dioxide to methane. Methane formers act in the pH range of 6.5 – 7.5 and they are very delicate. A shock loading can be disastrous to such anaerobic bacteria. Acid former respond quickly to food supply and hence acid increases quickly. The methane formers do not respond so quickly and hence pH may reduce. As pH level falls down below **"pH tolerance level"** of the methane former, methane formation ceases and the pH may fall to even toxic level. To control this lime is added.

pH < 3, or pH > 11 are toxic.

Merits and Demerits of Anaerobic Digestion

Merits

1. Recovery of energy in the form of methane.
2. Anaerobically digested sludge contains nutrients and organic matter that can improve the fertility of soil.
3. Pathogens in the sludge die off during relatively long detention period.

Demerits

1. Close process control is required to prevent upsets.
2. Supernatant liquid from an anaerobic digestor have high O_2-demand.

Note: Supernatant has BOD apox. 1500 mg/l and high concentration of nitrogen in suspended solid.

$$V(100 - p) = V_1(100 - p_1)$$

where V = Volume of sludges at moisture content p

V_1 = Volume of sludge at moisture content p_1

SLUDGE DIGESTION PROCESS

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

(a) digested sludge

(b) supernatant liquor

(c) gases of decomposition

- Of the total solid originally present 70% are volatile and remains 30% are fixed (inorganic solids)
- Volatile solids are measured by an equipment called muffle furnace. organic solid get converted to gases at 600°C
- Of the total volatile solids approx. 65% are reduced to gases in digestion tank.
- The gases produced

  = 0.9 m^3/kg of volatile solids reduced

  = 0.6 m^3/kg of volatile solid present.
- Of the total gases produced 65% are methane and 30% are CO_2 and remaining are other gases like H_2S, N_2 etc.
- Heat content of methan is 8600 kcal/m^3.
- Supernatant liquid has a high BOD of 1500-3000 mg/l. Hence it should be retreated along with the raw sewage.

Note: Volatile solids are measured by an equipment called muffle furnace.

STAGES IN SLUDGE DIGESTION PROCESS

(a) Hydrolysis

(b) Fermentation (Acidogenesis)

(c) Methane formation (Methanogenesis)

Hydrolysis

It is the 1st step for most of the fermentation process in which particulate material is converted to soluble compounds that can be hydrolysed further to simple monomers which are used by bacteria to perform fermentation.

In this stage, complex organic matter like proteins, cellulose and lipids are converted by extra cellular enzymes into simple soluble organic matters.

Fermentation (Acidogenesis)

In this stage, soluble organic matter is converted by acid formers like acetogenic bacteria into acetic acid, hydrogen and CO_2 and other lower molecular wt organic acids.

Methane Formation (Methanogenesis)

In this stage two group of methane forming bacteria (strictly anerobic) are active

(a) Aceticlastic methanogens – split acetic acid into CH_4 and CO_2.

(b) Hydrogen–utilising bacteria – converts hydrogen and CO_2 into CH_4

FACTORS AFFECTING SLUDGE DIGESTION AND THEIR CONTROL

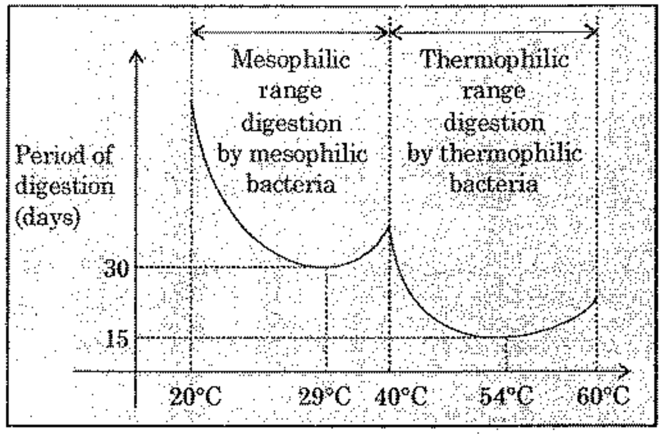
(a) Temperature

(b) pH value

(c) Seeding with digested sludge

(d) Mixing and Streering of raw sludge with digested sludge

(e) Nuisance organism



(a) Temperature

- In mesophilic range (20 – 40°C), measophilic bacteria acts on the sewage and the most efficient temperature of this range is 29°C.
- In thermophilic range (40 – 60°C), thermophilic bacteria acts on the sewage and the most optimum temperature of this zone is 54°C.
- Digestion is generally not done in thermophilic range because of huge offensive odour and operational difficulties. Hence the most efficient temperature during sewage digestion is 29° and duration is 30 days respectively.

(b) pH

- Lower pH value suppresses methane formation.
- pH decreases due to overdosing of raw sewage, over withdrawal of digested sludge and by sudden admission of industrial waste.
- Remedy is to add hydrated lime.

(c) Seeding with Digested Sludge

It helps in achieving quick balance condition. Bacteria put from outside (seeding)

(d) Mixing and Steering of Raw Sludge

- Excess steering is not desired as it will kill bacteria but steering helps in even distribution of incoming sludge.
- It breaks and reduces scum.
- It helps in increasing the production of gases.

Note: When steering is not done, mixing takes place due to rising gas bubbles.

(e) Nuisance Organisms

Nuisance organism in anaerobic operations are sulphate-reducing bacteria. When sufficient amount of sulphate is present, these organisms reduce sulphate to sulphide which is toxic to methane forming bacteria.

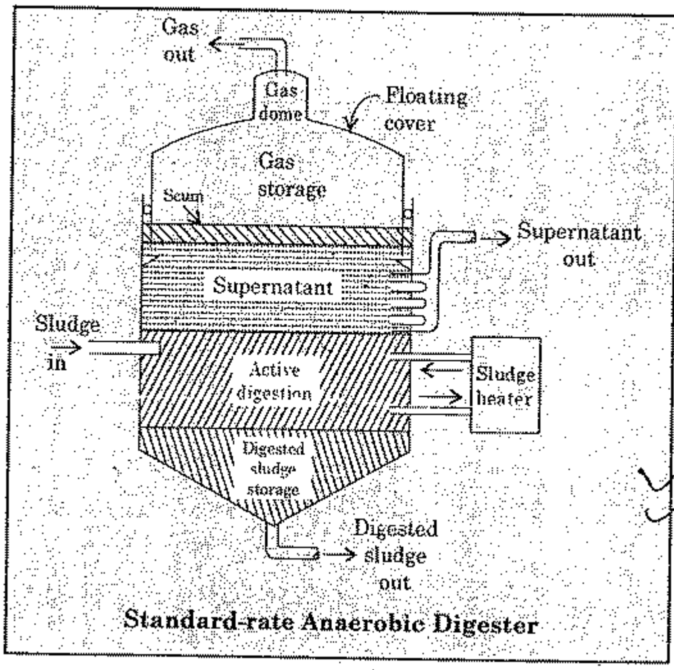
Remedy is to add iron to precipitate iron sulphide.

REACTOR FOR ANAEROBIC DIGESTION

(a) Standard rate

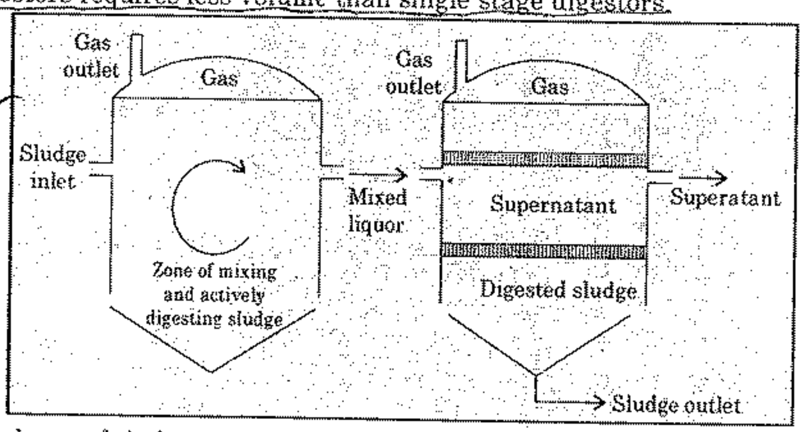
(b) High rate

- The reactors consists of close tank with air tight covers.



Standard-rate Anaerobic Digester

- For plant of capacity approx upto 4 MLD, standard rate digestor is used.
- The conical bottom facilitates sludge withdrawal and floating cover accomodates volume changes due to sludge addition and withdraw and also gas storage.
- The sludge is fed into digestor intermittently and supernatant liquor is withdrawn and returned to primary treatment because it has huge suspended solid.
- The digested sludge is taken to sludge drying bed.
- Bubbles of sewage gas provides some degree of mixing.
- If the capacity of treatment plant is more than 4 MLD, high rate digestors are used.
- High rate digestors requires less volume than single stage digestors.



- In 1st stage, volume of sludge remains the same as no dewatering occurs but the solid content is changed.
- In 2nd stage, completely mixed sludge from 1st stage is taken and dewatering occurs in this stage. Influent in this stage is super saturated with gases which is released in this stage.
- Complete mixing in 1st stage creates homogeneous environment throughout the digester and raw sludge is quickly brought in contact with microorganisms. Hence the rate of digestion increases.

- If any toxic substance comes with the sludge it is evenly distributed throughout the 1st stage tank and hence its effect is reduced.
- The raw sludge if pre thickened, will lead to reduction in the volume of sludge and hence energy required for mixing will be reduced.
- But thickening should not lead to **solid concentration greater than** 6% in raw sludge as otherwise the viscosity increases and mixing becomes difficult. This may lead to increase in the toxicity of sludge.
- The combined volume of 1st and 2nd stage tank will be less than the standard rate tank.

DESIGN (STANDARD RATE DIGESTOR)

- Diameter of tank is normally 6 – 38 m
- Depth of tank is approximately 6 – 12 m
- Lower slope is 1 : 1 to 1 : 3.
- Dia/depth = 1.5 – 4.

- Volume of digestor is calculated as follows:

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

V = Volume of digestor

V_1 = Volume of raw sludge added per day

V_2 = Volume of digested sludge withdrawn per day. It may be taken equal to volume of digested sludge produced per day

t = digestion period.

- Digestion period = 30 days (Most optimum duration for mesophilic range).
- If during flooding, it is not possible to withdraw digested sludge because the sludge drying bed will be flooded, storage is provided to keep the digested sludge during the flooding monsoon period. Hence volume of tank will be

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

T = Monsoon period.

The above formula for volume of tank is calculated with the assumption that volume changes in digestion tank takes place parabolically.

If volume changes are assumed to take place linearly.

$$V = \left(\frac{V_1 + V_2}{2}\right)t$$

and if monsoon storage is also taken into account then

$$V = \left(\frac{V_1 + V_2}{2}\right)t + V_2 T$$

Note: All units of treatment are kept above HFL of river except sludge drying bed. Hence during flooding only sludge drying bed will be flooded, and other units will be operational.

Example 18

A sewage containing 200 mg/L of suspended solids is passed through primary settling tank. The solids from the primary settling tank are digested to recover the gas. Find the likely volumes of methane and carbon dioxide produced in the digestion of the sludge from 10,000 m^3 of sewage. Calculate the fuel value of the gas produced. State clearly the assumptions made.

Sol. Given:

Suspended solid = 200 mg/l

Volume of sewage = 1000 m^3

Total suspended solid = 200 × 10000 × 1000

= 2000 kg

Assumption 1: 60% suspended solid removed in PST

∴ Solid removed in PST = 0.6 × 2000 = 1200 kg

Assumption 2: 70% of total solid is volatile solid is digestor

Volatile solid = 0.7 × 1200 = 840 kg

Assumption 3: Total gas produced = 0.6 m^3/kg of voltile solid present

∴ Total gas produce = 0.6 × 840 = 504 m^3

Assumption 4: Of the total gas 65% is methane

⇒ Methane volume = 0.65 × 504 = 327.6 m^3

Assumption 5: Calorific value of CH_4 is 8600 k cal/m^3

∴ Total calorific value = 8600 × 327.6

= 2817360 k cal.

Example 19

Determine the size of an aerobic digestor to treat the activated sludge generated from the treatment of 10 MLD of domestic waste water flow.

Quantity of sludge solid produced = 2000 kg/d

Specific gravity of sludge = 1.03

Solid concentration in sludge = 3.5%

Hydraulic retention time = 15 days

Volatile solids (% of total solids) = 80%

Side water depth = 6m

Also calculate the O_2 required if 2 kg of O_2 is required per kg of volatile solid destroyed. The volatile solid destroyed in the digestor is 40% of the volatile solid present to provide the O_2 required to be supplied, calculate the amount of air supplied if its density is 1.201 kg/m^3 and oxygen content in air = 21%.

Sol. (a) Compute the volume of sludge to be digested per day

The volume of sludge produced,

$$V_{sl} = \frac{W_s}{\rho_w \times S_{sl} \times P_s}$$

$$= \frac{2000}{1000 \times 1.03 \times 0.035} \approx 55.50 \text{ m}^3/\text{d}$$

(b) Compute the volume of the digester, V_D

The volume of the digester = 55.50 × 15

or $V_D = 832.5 \text{ m}^3$

(c) Determine the size of the tank

Assuming side water depth 6m, the surface area of tank,

$$A_s = \frac{832.5}{6.0} = 138.75 \text{ m}^2$$

Therefore, the diameter of the tank is

$$\sqrt{\frac{4 \times A_s}{\pi}} = 13.3 \text{ m}$$

However provide a tank of 13.5 m diameter.

(d) Compute the amount of O_2 required

Assuming amount of oxygen required at 2.0 kg/kg-d of cell (VS) oxidized and 40% of cell is destroyed completely, determine the O_2 required using the following relationship:

O_2 needed = (Rate of O_2 required per kg of VS destroyed) × Total VS destroyed per day

= 2.0 × [0.80 × 2000 × 0.40] = 1280 kg/d

(e) Compute the volume of air required per day

Assuming density of air at STP (0°C and 1 atmospheric pressure) as 1.201 kg/m³ and oxygen content in air as 21%,

$$\text{air required} = \frac{1280}{1.201 \times 0.21}$$

= 5075.14 m³/d

= 5075.0 m³/d

Assuming 10% O_2 transfer efficiency of aeration equipment.

$$\text{Air needed per minute} = \frac{5075}{0.10 \times 1440} = 35.24 \text{ m}^3/\text{min} \approx 35.5 \text{ m}^3/\text{min}$$

Example 20

A waste water plant produces 1000 kg of dry solids per day at a moisture content of 95%. The solids are 70% volatile with a specific gravity of 1.05 and the remaining are non-volatile with a specific gravity of 2.5. Find the sludge volume after digestion, which reduces volatile solids content by 50% and decreases the moisture content to 90%.

Sol. Total solid produced = 1000 kg

$$\text{Volatile solid} = 70\%$$
$$= 0.70 \times 1000 = 700 \text{ kg}$$
$$\text{Non volatile solid} = 30\%$$
$$= 300 \text{ kg}$$
$$\text{Volatile solid removed in digestion} = 50\%$$
$$= 0.50 \times 700 = 350 \text{ kg}$$

Volatile solid remaining in digestion tank

$$= 350 \text{ kg}$$
$$\text{Total solid in digestion tank} = 300 + 350 = 650 \text{ kg}$$
$$\text{Moisture content of digested sludge} = 90\%$$

wt of water in digested sludge

$$= \frac{0.90}{0.10} \times 650 = 5850 \text{ kg}$$

Density of volatile solids

$$= 1000 \times 1.05 = 1050 \text{ kg/m}^3$$

Vol. of volatile solids in digested sludge

$$= \frac{350}{1050} = 0.333 \text{ m}^3$$

Volume of non volatile solid in digested sludge

$$= \frac{300}{2500} = 0.12 \text{ m}^3$$

Vol. of water in digested sludge

$$= \frac{5850}{1000} = 5.85 \text{ m}^3$$

Total volume of digested sludge

$$= 0.333 + 0.12 + 5.85 = 6.303 \text{ m}^3 \quad \textbf{Ans.}$$

Example 21

Find out the volume of an anaerobic digestion tank for 5 MLD of domestic waste water treatment plant having 60% suspended solid removal efficiency of primary clarifier and 250 mg/L suspended solids in waste water. Moisture content of influent sludge is 96%, initial volatile solids content in sludge is 70%, volatile solids destroyed is 65%, digested sludge solid concentration is 8.0%, specific gravity of primary sludge is 1.03, specific gravity of digested sludge is 1.04, density of water is 1000 kg/m^3, mean cell residence time is 15 days.

Sol. Average sewage flow = 5 MLD

Total suspended solid in waste water

$$= 250 \times 5 \times 10^6 = 1250 \text{ kg per day}$$

Suspended solid removed in primary clarifier

$$= 0.60 \times 1250$$
$$= 750 \text{ kg/day}$$

Now moisture content of influent sludge = 96% (given)

i.e., 4 kg of dry solids will make 100 kg of wet sludge

∴ 750 kg of solid will make 18750 kg of wet sludge

Specific gravity of raw sludge = 1.03

Density of raw sludge

$= 1.03 \times 1000 = 1030 \text{ kg/m}^3$

Volume of primary sludge produces

$$V_1 = \frac{18750}{1030} = 18.2 \text{ m}^3\text{/day}$$

Initial volatile solids content in sludge = 70% (given)

Mass of volatile solid = 0.70×750

= 525 kg/day

Mass of non volatile solid = 0.3×750

= 225 kg/day

Volatile solid destroyed = 65%

Mass of digested solid = 0.65×525

= 341.25 kg/day

Mass of undigested volatile solid

$= 0.35 \times 525$

= 183.75 kg/day

Mass of solids in anaerobically digested sludge

$= 225 + 183.75 = 408.75$ kg

Digested sludge solid concentration = 8%

⇒8 kg of dry sludge makes 100 kg of wet sludge

∴ 408.75 kg dry sludge $= \dfrac{100 \times 408.75}{8}$

= 5109.375 kg wet sludge/day

Specific gravity of digested sludge

= 1.04

Density of digested sludge

$= 1.04 \times 1000 = 1040 \text{ kg/m}^3$

Volume of digested sludge produced is given by

$$V_2 = \frac{5109.375}{1040} = 4.91 \text{ m}^3\text{/day}$$

Mean cell residence time is 15 day

∴ Capacity of digestor tank

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

$$= \left[18.2 - \tfrac{2}{3}(18.2 - 4.91)\right] \times 15$$

$$= 9.34 \times 15$$

$$= 140.10 \text{ m}^3$$ **Ans.**

Example 22

Assuming the following criteria and the quantity of dry solids in the generated sludge as 0.20 kg/m^3, determine the capacity of an anaerobic sludge digester to treat the sludge generated from a 10 MLD domestic wastewater treatment plant.

Moisture content of influent sludge = 96.0%

Initial volatile solids content = 75%

Volatile solids destroyed = 65%

Digested sludge solid concentration = 8.0%

Specific gravity of primary sludge = 1.02

Specific gravity of digested sludge = 1.04

Density of water, ρ_w = 1000 kg/m^3

Detention time, t = 15 days

Sol. The volume of the digester is determined by the following empirical relationship:

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

where

V_D = volume of the digester, m^3

V_1 = volume of raw sludge fed to the digester per day, m^3/d

V_2 = volume of digested sludge removed per day, m^3/d

t = detention time (digestion time), d

(a) Compute the volume of raw sludge, V_1

(i) Determine the quantity of dry solids: Quantity of dry solids generated/d,

W_s = rate of dry solids generation × wastewater flow

= 0.20 (kg/m^3) × 10000 (m^3/d)

= 2000 kg/d

(ii) Determine the volume of raw sludge, V_1: For 96% moisture content of raw sludge, the solid content of sludge, P_s is 4%. Therefore, P_s = 0.04 (in decimal). The volume of raw sludge,

$$V_1 = \frac{W_s}{\rho_w \times P_s \times S_1} \qquad (S_1 = \text{Specific gravity of sludge})$$

$$V_1 = \frac{2000}{1000 \times 1.02 \times 0.04} = 49.0 \text{ m}^3/\text{d}$$

(b) Compute the volume of digested sludge, V_2

Determine the quantity of fixed solids in fresh sludge

Fixed solids, kg/d = 25% of total solids (as VS content = 75%)

= 0.25 × 2000 kg

= 500 kg

Determine the quantity of volatile solids in fresh sludge

Volatile solids, kg/d = 75% of total solids

= 0.75 × 2000 kg

= 1500 kg

Determine the quantity of volatile solids destroyed

volatile solids destroyed, kg/d = 65% of volatile solids

= 0.65% × 1500 kg

= 975 kg

Determine the quantity of sludge solids in the digester

Sludge solids in digester = fixed solids + volatile solids after destruction

= 500 + (1500 – 975) kg

= 1025 kg

volume of digested sludge, $V_2 = \frac{W_s}{\rho_w \times S_2 \times P_s}$ (S_2 = specific gravity of digested sludge)

$$V_2 = \frac{1025}{1000 \times 1.04 \times 0.08}$$

$$\therefore \; V_2 = 12.32 \text{ m}^3/\text{d}$$

(c) Compute the volume of the digester, V_D

Substituting the values in the following equation,

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

we have, V_D = [49.0 (m^3/d) – 0.66 (49.0 – 12.32) (m^3/d)] × 15 (d)

= **372.0 m^3**

Therefore, the net volume of the digester is **372.0 m^3**

Example 23

For the characteristics of raw and digested sludge given in Table below determine the volume of sludge before and after sludge digestion and find the percent reduction in sludge volume for 500 kg of solids in raw sludge. If digested sludge is further dewatered to obtain 20% solids, determine the volume of dewatered sludge.

Characteristics of raw and digested sludge		
Particulars	**Raw Sludge**	**Digested Sludge**
Total solids, TS, %	4.0	10
Volatile solids, VS, % of TS	60.0	70% of VS destroyed
Specific gravity of sludge, S	1.02	1.04
Specific gravity of Fixed Solid	2.5	2.5

Sol. Compute the volume of raw sludge, V_1 having 4% solids content

We can compute it using the following equation:

$$V_1 = \frac{W_s}{\rho_w \times S_{sl} \times P_s} \qquad \text{.................(i)}$$

Assuming the density of water, $\rho_w = 1000$ kg/m^3

$$V_1 = \frac{500}{1000 \times 1.02 \times 0.04} = 12.25 m^3 = \text{volume of sludge before digesters}$$

Compute the total solids in digested sludge

Fixed solids FS in raw sludge = 40% of TS (as VS in raw sludge is 60%)

= 0.4 × 500 kg

= 200 kg

Also, as 70% of VS is destroyed in digested sludge, 30% VS will remain in the sludge after digestion.

Therefore,

VS remaining in digested sludge = 0.30 × (0.60 × 500) = 90 kg

So the total mass of solids in digested sludge is

FS of raw sludge + VS remaining after disgestion

= 200 kg + 90 kg

= 290 kg

Compute the volume of digested sludge having 10% solids content

$$\text{Volume of digested sludge, } V_2 = \frac{290}{1000 \times 1.04 \times 0.10}$$

$$= 2.788 \text{m}^3 \approx 2.8 \text{m}^3$$

So, the volume of sludge after digestion is **2.8 m^3**

Compute the reduction in sludge volume

$$\% \text{ reduction in sludge volume} = \frac{(\text{volume of raw sludge}) - (\text{volume of digested sludge})}{(\text{volume of raw sludge})} \times 1000$$

$$= \frac{(12.25 - 2.8)}{12.25} \times 100$$

= 77.14%

So, the reduction in sludge volume is 77.14%

Now, the sludge volume has to be computed when digested sludge is further dewatered to have 20% solids.

Compute the specific gravity of soilds in digested sludge

We can compute it, using the equation given below derived

$$S_{s(d)} = \frac{P_s \times S}{1 - S(1 - P_s)} \quad \text{..........(ii)}$$

where

$S_{s(d)}$ = Specific gravity of solids in digested sludge

P_s = Percentage of solids in digested sludge

$1 - P_s$ = Percentage of water in digested sludge

S = Specific gravity of digested sludge

Now, substituting the values in equation (ii), we have

$$S_{s(d)} = \frac{0.1 \times 1.04}{1 - 1.04(1 - 0.1)} = 1.625$$

Compute the specific gravity of dewatered sludge, S_d

We can compute it, using the following equation

$$\frac{W_d}{S_d} = \frac{P_s \times W_d}{S} + \frac{(1 - P_s)W_d}{1}$$

where, W_d = weight of dewatered sludge

S_d = specific gravity of dewatered sludge

S = specific gravity of solid

Substituting the values, we get

$$\frac{1}{S_d} = \frac{0.2}{1.625} + \frac{(1 - 0.2)}{1} \quad \text{(specific gravity of water is 1.)}$$

$= 0.923$

Therefore, $S_d = 1.08$

(g) Compute the volume of dewatered sludge (V_d)

$$V_d = \frac{W_s}{\rho_w \times S_d \times P_s} \quad \text{........}$$

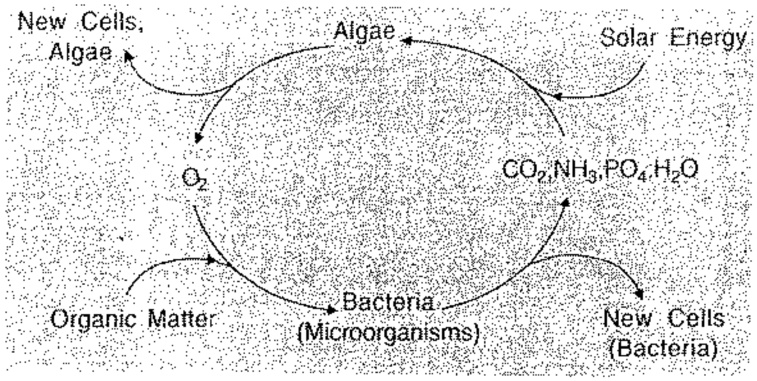
$$= \frac{290}{1000 \times 1.08 \times 0.2} = 1.34 \text{ m}^3$$

So, the volume of dewatered sludge after digestion = **1.34 m³**

OXIDATION POND AND STABILIZATION POND

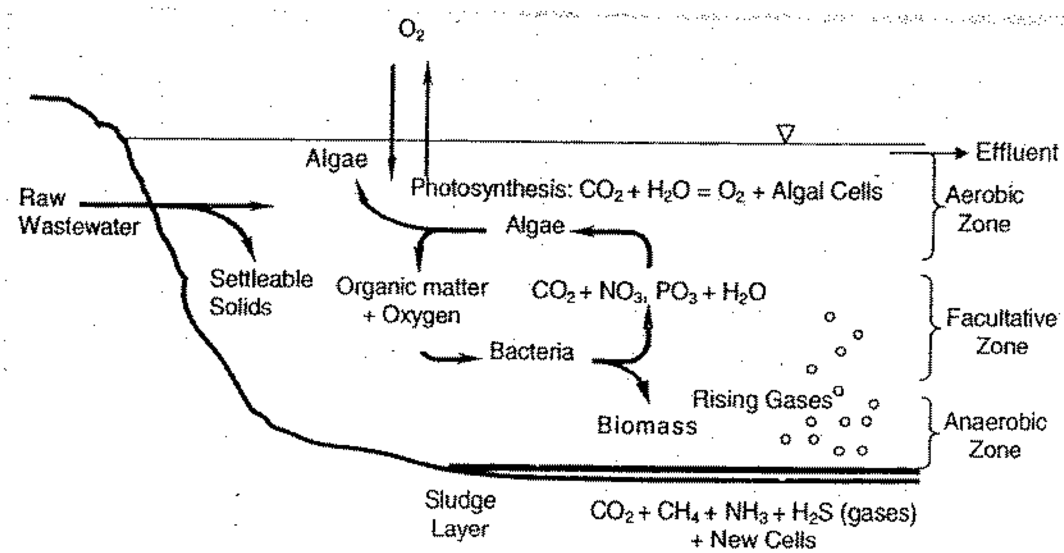
- They are open flow through earthern basin. Such ponds provide comparatively long detention period during which the waste get stabilized by the action of natural forces.
- In a totally aerobic pond stabilization is brought about by aerobic bacteria. The oxygen demand is met by combined action of algae and other microorganism. The process is called **algal photosynthesis** or **algal symbiosis.**
- In this symbiosis, the algae while growing in the presence of sunlight produces oxygen by photosynthesis and this oxygen is utilized by the bacteria for oxidising the waste organic matter.

The end product of the processes are CO_2, NH_3, PO_4, H_2O which are required by algae to grow and continue producing oxygen. This mutually beneficial arrangement is called symbiotic relationship.



Symbiotic relation between bacteria and algae.

- In a totally aerobic pond depth should be 0.5 m at the max so that sunlight can penetrate the whole depth. For totally aerobic pond PST is necessary so that turbidity reduces and sunlight can penetrate the whole depth. Removal of soluble BOD_5 is as high as 95%, effluent have large concentrations of algae, which may ultimately exert a higher BOD_5 into receving stream.
- For industrial sewage anaerobic pond may be used. Its depth is 2.5-5 m.
- The actual oxidation pond used for domestic sewage is actually facultative in nature in which three zones exist throughout the pond depth, viz, aerobic zone at the surface, anaerobic zone at the bottom and faculative zone at the mid depth of the pond.
- The applied sewage organics are stabilized by both aerobic and anaerobic reaction in different zones of the ponds. In the top aerobic layer, where oxygen is supplied through algal photosynthesis and dissolved organic matter in the incoming sewage is oxidised to CO_2 and H_2O. The settled sludge mass originating from raw waste and microbial synthesis in the aerobic layer and dissolved and suspended organics in the bottom layers undergo stabilization through conversion to CH_4 which escapes the pond in the form of bubble. Each kg of BOD ultimate stabilized to 0.25 kg or 0.35 m^3 of CH_4. at STP
- Aerobic layer at the top prevents foul gases to comeout.



Solids removal mechanism in a faculative stabilization pond

- The anaerobic bacteria at the bottom produces gases which rises up to serve as food for aerobic bacteria. The biological solids produced in aerobic zone settles down and forms food for anaerobic bacteria.

  Algae can be expressed by empirical formula $C_{106}H_{180}O_{45}N_{16}P_{1}$

Design Parameters for Oxidation Pond (Oxidation Pond in Reality is a Facultative Pond)

- Depth is 1 – 1.5 m.
- Detention time is 15 – 30 days.
- Organic loading rate depends on the latitude of the place.

In India Latitude (N)		Organic loading rate (kg BOD_5/hac/day)
36	—	150
32	—	175
28	—	200
24	—	225
20	—	250
16	—	275
12	—	300
8	—	325

Latitude 36°–Northern state

Latitude 8°–Southern state

- L/B ratio is normally 3 but $L \ngtr 750$ m.
- Each unit should be 0.5 – 1 hac
- Pathogenic bacteria removal = 99.9%.
- BOD removed approximately = 80 – 90%.
- Oxidation pond effluent is not discharged into river as it contains algae.
- The effluent is better used for irrigation.
- Sludge accumulation is 2 – 5 cm/year.
- Minimum depth of water to be kept in pond is 0.3 m.
- Due to overloading, odour problem may exist. To avoid it $NaNO_3$ is added to facilitate algal growth. $NaNO_3$ is both a plant food and also an oxidising agent.
- Oxidation pond is generally used for small communities.
- It is very cheap, the capital cost being 10 – 30% of that of the conventional plant (using trickling filters or activated slude process)

Note : Roughly detention time is calculated as :

$$t_d = \frac{1}{k_D}\log_{10}\left(\frac{L}{L-Y}\right) \text{ days}$$

L = BOD of influent in the pond

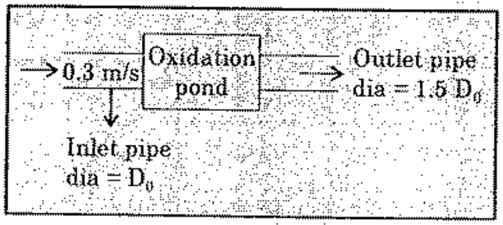
Y = BOD removed

k_D = rate constant = 0.1 per day at 20°C

$$k_{D_T} = k_{D_{20}}[1.047]^{T-20}$$

Ponds Inlets and Outlets

The pipeline conveying raw sewage to the pond may be designed to maintain an average velocity of 0.3 m/sec. The outlet should be so located (or designed) with reference to the inlets as to avoid shrot circuiting.



Example 24

Calculate the dimensions of an oxidation pond and determine the detention time for treating sewage from a residential colony in the southern state with a population of 8000 persons. Assume that the sewage to be treated is at the rate of 125 lpcd, the 5 day BOD of sewage is 325 ppm.

Sol: Given:

Population = 8000

Av. sewage treated = 125 lpcd

BOD_5 = 325 ppm

Total av. sewage flow = 8000 × 125 = 1 million litre/day

BOD_5 per day = 325 × 1

= 325 kg/day

Now assuming the organic loading in the pond as = 300 kg/hectare/day.

The surface area required

$$= \frac{325}{300} = 1.0833 \times 10^4\ m^2$$

Let length : width = 3 : 1 then $3B^2 = 1.0833 \times 10^4\ m^2$

$B = 60.09\,m \approx 61\,m$

$L = 3 \times B = 180.27$ m $(L \ngtr 750)$

= 181.0 m (assumed)

Let us assume depth = 1.5 m

Dimension = 181 × 61 × 1.5 m

$$\text{Detention time} = \frac{181 \times 61 \times 1.5 \times 10^3\, l}{1 \times 10^6\, l/d}$$

= 16.56 day (OK)

≈ 17 days

Total Depth = 1.5 + 0.3 (assumed free Board)

$= 1.8$ m

Hence Diemension $= 181 \times 61 \times 1.8$ m

Example 25

Population of a town is 20000 with an assured water supply of 150 litre per head per day. BOD of the waste water is 150 mg/L. Design the most suitable waste water treatment system (without power supply) for the town.

Sol. Given:

Population = 20000

Seawage flow = 150 litre per head per day

BOD = 150 mg/l

Total sewage flow = 20000 × 150

= 3 MLD

Total BOD supply = 3 × 150

= 450 kg

Now assume organic loading in the pond 300 kg/hectare/day

$$\therefore \quad \text{Surface area} = \frac{450}{300} = 1.5 \text{ hac.}$$

Let us adopt two ponds area of one pond, req. is 0.75 hac.

$$\text{Let} \quad \frac{\text{length}}{\text{width}} = 3$$

$$\Rightarrow \quad 3B^2 = 0.75 \times 10^4 \text{ m}^2$$

$$\Rightarrow \quad B = 50 \text{ m}$$

$$L = 50 \times 3 = 150 \text{ m} \quad (\not> 750)$$

Adopt depth = 1.5 m

$$\text{Detention time} = \frac{150 \times 50 \times 1.5 \times 10^3 l}{\frac{3 \times 10^6}{2} l/\text{day}}$$

$$t_d = 7.5 \text{ days} \quad (< 15 \text{ days})$$

Hence by increasing the dimension adopt B = 100

L = 300

d = 1.5

$$t_d = \frac{300 \times 100 \times 1.5 \times 10^3}{1.5 \times 10^6} = 30 \text{days(OK)}$$

Example 26

Design an oxidation pond with inlet and outlet pipes for treating sewage from a residential colony with 500 persons contributing sewage at 120 lpcd. The 5-day BOD of sewage is 300 ppm. Assume velocity of sewage flow as 0.9 m/s, and daily flow for 8 hrs and organic loading in the pond at 300 kg/ha/day.

Sol. Given: Population = 500

Avg. sewage flow = 120 litre/capital/days

BOD_5 of sewage = 300 ppm

Total sewage per day = 500 × 120

= 0.06×10^6 litre

Total BOD = $0.06 \times 10^6 \times 300$ = 18 kg/day

Organic loading of pond = 300 kg/ha/day (given)

$\therefore$ Surface area = $\frac{18}{300} = 0.06$ ha

= 600 m^2

Now let us assume length is thrice of width

$3B^2 = 600$

$\therefore$ B = 14.14 m or 15 m (say)

$\therefore$ Length = 3 × 15 = 45 m

Using depth of tank = 1.2 m

$\therefore$ Capacity of tank = 45 × 15 × 1.2 m^3

$$\text{Detention time in day} = \frac{45\times15\times1.2\times10^3}{500\times120} = 13.5 \text{ days}$$

So, adopt L = 60 m, B = 20 m, depth = 1.2 m

$$\Rightarrow \quad t_d = \frac{60\times20\times1.2\times10^3}{0.06\times10^6} = 24 \text{ days} \quad \textbf{(OK)}$$

Adopt free board as 0.3 m

$\Rightarrow$ Dimension of tank = 60 × 20 × 1.5 m

Example 27

Determine the amount of methane produced in m^3 from 1 kg of BOD_L stabilized at STP. A ssume that the BOD_L contribution is due to glucose ($C_6H_{12}O_6$) and anaerobic decomposition of glucose produces Co_2 and CH_4.

Sol. Determine the quantity of methane generated

The balanced equation for anaerobic decomposition of glucose is given below:

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$$

Molecular weight 180 132 48

Thus 48g of methane is produced from 180 gram of glucose. 1kg of glucose produces $\frac{48}{180}$ kg of methane.

also, $C_6H_{12}o_6 + 6O_2 \rightarrow 6O_2 + 6H_2o$

180 192

$\Rightarrow$ 192 g of O_2 required for oxidation of 180 g of glucose.

$\Rightarrow$ 1 kg of glucose produces $\frac{192}{180}$ kg of BOD = 1.06 kg BOD

$\Rightarrow$ Methane generated from 1 kg BOD = $\frac{\frac{48}{180}}{1.06}$ kg = 0.25kg

Determine the volume of methane generated

It is known that at STP, 16 gm of CH_4 is equivalent to 22.4 litres of CH_4

$\therefore$ Volume of 0.25 kg of $CH_4 = \frac{0.25 \times 22.4 \times 10^{-3}}{16 \times 10^{-3}} = 0.35\ m^3$

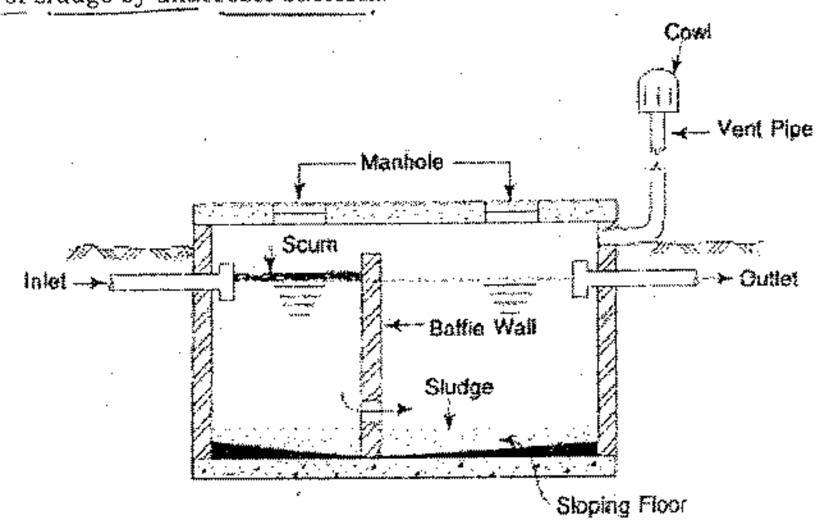
So, 1 kg of BOD_L of glucose will generate 0.35 m^3 (or 350 L) of CH_4.

USE OF LAGOONS FOR DISPOSAL OF RAW SLUDGE

This method, is sometimes, used at smaller places for disposing of raw sludge without digestion. In this method, the raw sludge is kept at rest in a large shallow open pond, called a *lagoon*. The detention period is 1 to 2 months and may extend up to 6 months. During its detention in the lagoon, the sludge undergoes anaerobic digestion thereby getting stablised. Due to this anaerobic decomposition of sludge, foul gases will be evolved from a lagoon ; and hence the lagoons, should be located away from the town. After the sludge has been stabilised, and the moisture has been drained away or evaporated during its detention in the lagoon, the contents are dug out to about half of their original vol., and used as manure.

SEPTIC TANK

- It is designed as ordinary settling tank except that detention time is 12-36 hrs, with extra provision for digestion of sludge by anaerobic bacteria.



Septic Tank

- Directly raw sewage is entered in the septic tank. The sludge settles at the bottom of tank and oil and greases rises to the top surface as scum.
- The settled sewage is allowed to remain in the tank for 6 –12 months during which they are digested anaerobically.

- The scum remaining in the tank helps in holding back odour and acts as a sort of heat insulation which aids the bacterial action.

Design Parameters of Septic Tank

- Flow of sewage is taken as 40 – 70 lpcd.
- If sullage is also allowed in septic tank, flow is taken as 90 – 150 lpcd.
- Rate of accumulation of sludge = 30 lpc per year.
- Detention time is 12 – 36 hrs.
- Length/width ratio = 2 to 3.
- Width should not be less than 0.75 m.

  Min. liquid capacity = 1000 litre
- Depth is 1.2 – 1.8 m.

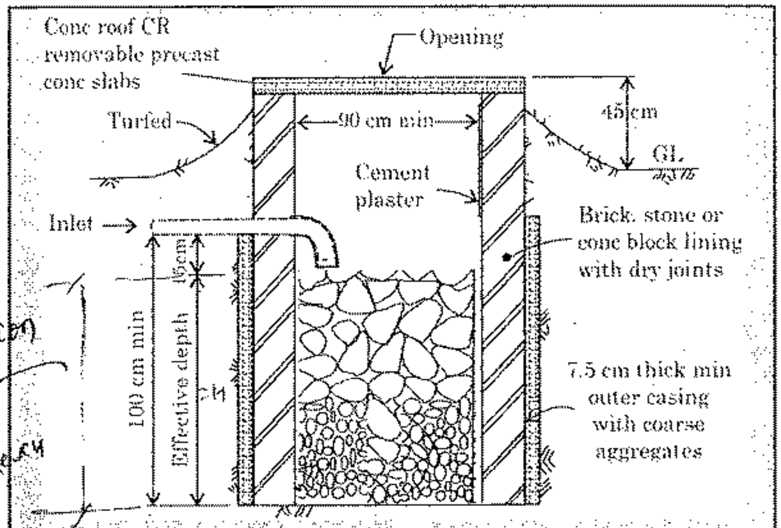
  Cleaning period 6 month-1 yr

  Free board = 0.3 m
- Volume of septic tank = (Sewage flow × Detention time) + (Sludge accumulation rate × cleaning period).
- The tank effluent coming out from a septic tank is no better than the effluent of an ordinary sedimentation tank. It contains large amount of putrescible organic matter (200 to 250 mg/l), and its BOD is quite high (100 to 200 mg/l).
- So, the effluent from the septic tank is disposed of in soakpit or in dispersion trenches.
- Soak pit and dispersion trenches should be sufficiently permeable to allow easy percolation of the effluent in the ground.
- Percolation rate is defined as the time in minute required for seepage of water through ground by 2.5 cm.
- Soak pit is adopted when percolation rate is not greater than 30 minutes and dispersion trench is adopted when percolation rate is not greater than 60 minute.
- The maximum rate of effluent application is $Q = \frac{204}{\sqrt{t}}$ l/m²/day, where 't' is percolation rate in min.

  percolation area
- Percolation area required = $\frac{Q_0}{Q}$; Q_0 = inflow, Q = max rate of effluent application.

Soak pit: It may be of any suitable shape with the least cross-sectional dimension of 0.9 m and not less than 1.0 m in depth below the invert level of inlet pipe. Inlet pipe may be taken 0.9 m from the top as antimosqueto measure.

$\frac{Q \text{ l/day}}{204 \text{ l/m}^2\text{/day}}$ = Percolation area required.



Empty pit with lining

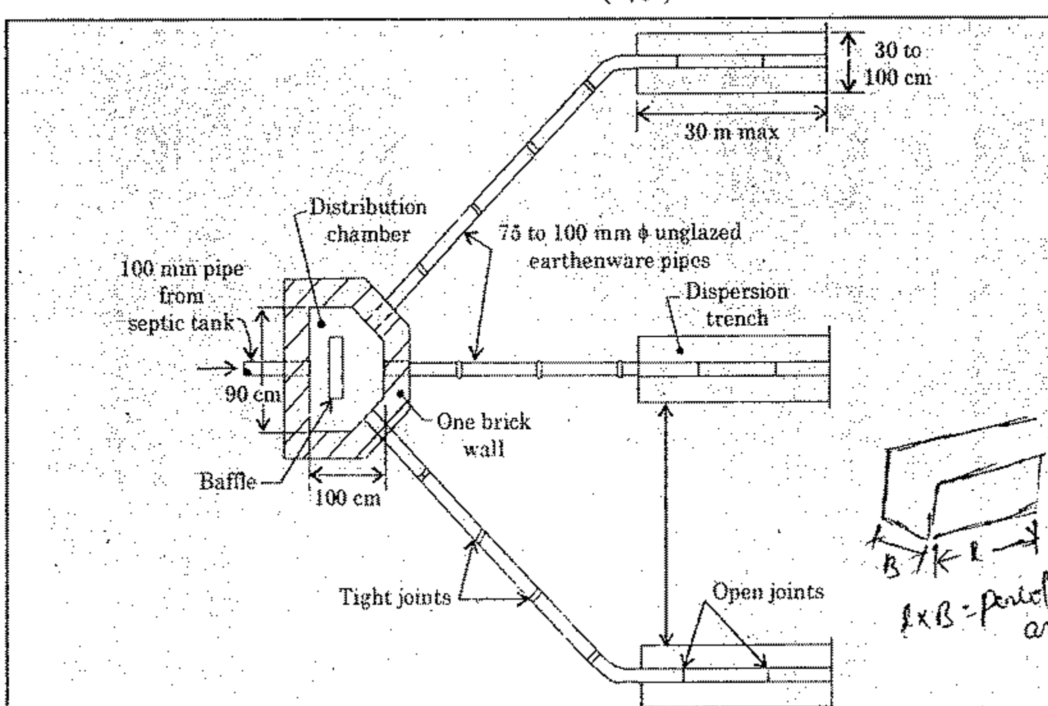
Absorption area for soak pit is the effective side wall area, effective depth being 15 cm below invert level of inlet pipe to the bottom of pit.

Dispersion Trench

Dispersion trench shall be 0.5-1.0 m deep and 0.3-1.0 m wide. Each dispersion trench should not be longer than 30 m and trenches should not be placed closer than 2.0 m.

Absorption area for trench should be the trench bottom area.

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



Typical soil absorption system with dispersion trenches

IMHOFF TANKS

An Imhoff tank is an improvement over septic tank, in which the incoming sewage is not allowed to get mixed up with the sludge produced, and the ougoing effluent is not allowed to carry with it large amount of organic load, as in the case of septic tank. They are sometimes also known as *Two-storey Digestion Tanks*. It removes 60 to 65% solids and 30 to 40% BOD.

Design Considerations

(A) Sedimentation Chamber. It is rectangular in shape with the following specifications :

(i) Detention period = 2 to 4 hours (usually 2 hours)

(ii) Flowing through velocity < 0.3 m/minute.

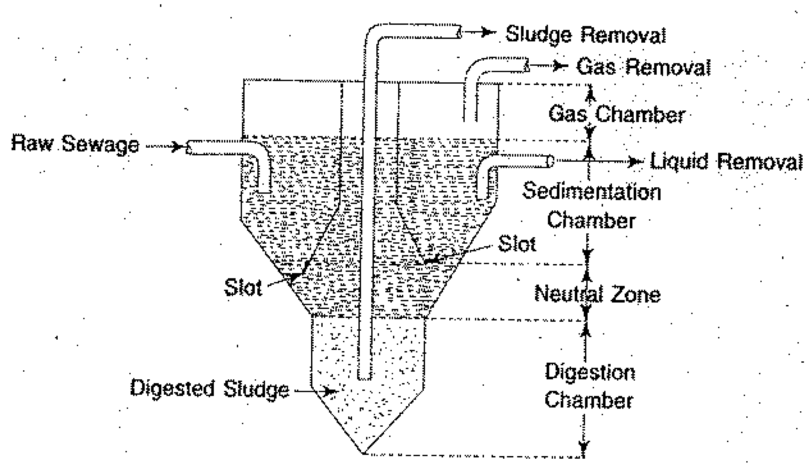
< 30,000 litres/m^2 of plan area/day.

It may, however, be increased to about 45,000 liters/m^2/day for effluent coming from activated sludge plant, or where recirculation is adopted.

(B) $\frac{L}{B} = 3 \text{ to } 5 \quad (L \ngtr 30\text{m})$

(C) Total depth = 9 to 11 m.

- Imhoff tanks use in case of small treatment plants requiring only primary treatment. They are quite economical, and do not require skilled attention during operations.



Example 28

Design a septic tank for 200 persons with a water supply of 125 litre per capita per day. Assume any other data and mention it. If percolation rate is 15 minutes, find the effective percolation area required.

Sol.

$$\text{Quantity of water supplied} = \text{population} \times \text{rate of water supply}$$
$$= 200 \times 125$$
$$= 25000 \text{ litre/day}$$
$$= 25 \text{ m}^3\text{/day}$$

Now assume the detention time 24 hr

Assume rate of accumulation of sludge = 30 litre per capita per year

Also assuming the period of cleaning = 1 year.

Assuming that 80% of water supply goes as sewage, sewage flow = 0.8×25 m^3/day

$= 20$ m^3/day

$$\text{Volume of tank} = \left(20 \times 1 + \frac{30 \times 200}{1000}\right) m^3$$

$= 26$ m^3

Assume depth of tank = 1.5 m

$$\therefore \quad \text{Surface area of tank} = \frac{26}{1.5} = 17.33 \text{ m}^2$$

$= 17.33$ m^2

Let us assume ratio of length to width = 2 : 1

$\therefore$ $2B^2 = 17.33$

$\therefore \Rightarrow$ $B = 2.94 \approx 3$ m

$\therefore$ L = 6 m

Take free board = 0.3 m

$\therefore$ Over all depth = 1.5 + 0.3 = 1.8

$\therefore$ Dimension of septic tank = $3 \times 6 \times 1.8$ m^3 **Ans.**

As per percolation rate is less than 30 min, we shall 30 min, We shall provide soak pit for disposal of septic tank effluent.

$$\text{Maximum rate of effluent application} = \frac{204}{\sqrt{t}} \; l/\text{m}^2/\text{D}$$

$$= \frac{204}{\sqrt{15}} = 52.67 \; l/\text{m}^2/\text{D}$$

$$\text{So percolation area required} = \frac{Q_0}{Q_{max} m} = \frac{20{,}000}{52.07} = 379.8 \text{ m}^2$$

In soak pit if effective depth is 1.5 m.

$\Rightarrow$ $\pi D \times 1.5 = 379.8$

D = 80.57 m (Not good)

So, adopt H = 6 m and adopt 5 such units

$$\Rightarrow \quad \pi D \times 6 = \frac{379.8}{5}$$

D = 4.03 m **Ans.**

Example 29

On the basis of a detention period of 24 hours, determine the size (assuming length to width ratio of around 2 and depth of waste water about 1m) of a septic tank required for a large house dwelling of 100 persons. The flow into the tank may be assumed at the rate of 70 lpcd. What will be the surface loading?

Sol. Quantity of sewage supplied

$$= \text{population} \times \text{rate of sewage supply per capita}$$
$$= 100 \times 70 = 7000 \text{ litres/day}$$
$$\text{Detention period} = 24 \text{ hours}$$
$$\text{Total sewage produce per day} = 7000 \text{ litres} = 7 \text{ m}^3$$
$$\text{Depth of waste water} = 1 \text{ m}$$
$$\therefore \text{Surface area of tank} = \frac{\text{Volume of waste water}}{\text{Depth of waste water}}$$
$$= \frac{7}{1} = 7 \text{ m}^2$$

Given that length to width ratio equal to 2

$$L \times B = 7 \text{ m}^2$$
$$\therefore 2B^2 = 7$$
$$\Rightarrow B = 1.87 \text{ m}$$
$$L = 3.75 \text{ m}$$
$$\Rightarrow \text{Dimension of tank} = 3.75 \text{ m} \times 1.87 \text{ m}$$
$$\therefore \text{Surface loading rate} = \frac{7}{3.75 \times 1.87} \text{ m}^3/\text{m}^2/\text{day}$$
$$= 0.998 \text{ m}^3/\text{m}^2/\text{day}$$

HIGH RATE ANAEROBIC SYSTEMS

High rates of conversion of organics into methane and carbon dioxide, by anaerobic tratement process, can be obtained by maintaining a high concentration of microbes in a reactor, and preventing them from escaping with the effluent.

The various rate anaerobic systems are as follows :

(a) *Anaerobic Contact (AC) process*
(b) *Anaerobic filters (AF)*
(c) *Anaerobic fixed films (AFF) reactors*
(d) *Upflow Anaerobic Sludge Blanket (UASB) reactor*

These reactors usually provide a little bit of incomplete treatment, bringing down the BOD and S.S. by 50 to 70% only. Their effluents may therefore need post treatment either by *aerobic filters, aerated langoons, etc.*

(a) Anaerobic Contact (AC) Process : The system involves a closed stirred tank reactor, in which the biomass leaving with the reactor effluent, is settled in a sedimentation tank and is recycled to the stirred tank. This process has been generally used for treatment of industrial wastewaters.

(b) Anaerobic Filter (AC) In an anaerobic filter, a stationary filter media, are packed in a closed tank, and the wastewater is entered from the bottom to move up the packing media.

(c) Anaerobic Fixed Films (AFF) Reactors : Like an anaerobic filter (AF), this process is also characterised by the presence of stationary packing material. In order to prevent accumulation of solids in the reactor, the AFF reactor is worked with downflow mode.

(d) Fluidized and Expanded Bed Reactors : A fluidized bed reactor as well as an expanded bed reactor are both characterised by the presence of mobile packing material, such as sand, in which clay, coal etc. The wastewater is entered from the bottom of the tank with an upflow velocity to move (Fluidize) the media particles, which act as mobile biomass carriers, causing digestion of the organics present in the wastewater.

(e) The UASB Reactor : Maintains a high concentration of biomass thorugh the formation of highly settleable microbial sludge aggregates. The wastewater flows upwards thorugh a layer of very active sluge to cause anaerobic digestion of organics of the wastwater. The process is suitable for both soluble wastewater as well as wastewater containing particulate matter.

Example 30

Calculate the no. of drying beds and depth of sludge application on each bed required to dewater a digested sludge produced from waste water treatment plant based on activated sludge process designed for 50000 population. Assume the following data:

1. Dry solid concentration in digested sludge = 70 g/capita/dat
2. Dry solid loading rate 100 kg/m^2/year
3. Size of one bed = 30m × 8m
4. No. of time a bed can be used in a year = 10
5. Solid content of digested sludge = 7%
6. Specific gravity of digested sludge = 1.02

Sol. Compute the amount of dry solids produced each day

Dry solids concentration in sludge 70 g/capita/d,

Dry solids produced = 50000 × 70

= 3500000 g/d

= 3500 kg/d

Compute the area of drying heds needed

Dry solids loading rate100 kg/m^2/year,

$$\text{Area of bed needed} = \frac{\text{dry solids applied/year}}{\text{dry solid loading rate}}$$

$$= \frac{3500 \times 365}{100}$$

=12775 m^2/year

Compute the number of heds

Providing 30 m long × 8 m wide beds,

$$\text{The number of beds needed} = \frac{\text{total area of the beds}}{\text{area of one bed}}$$

$$= \frac{12775}{30 \times 8} = 53.22 \approx 54$$

Compute the depth of sludge applied on each hed

Specific gravity of mixed digested sludge is 1.02, and solid content = 7%

$\Rightarrow$ Volume of digested sludge $= \dfrac{W_s}{\rho_w \times S_{sl} \times P_s}$

$= \dfrac{3500}{1000 \times 1.02 \times 0.07}$

$= 49.0 \text{ m}^3/\text{d}$

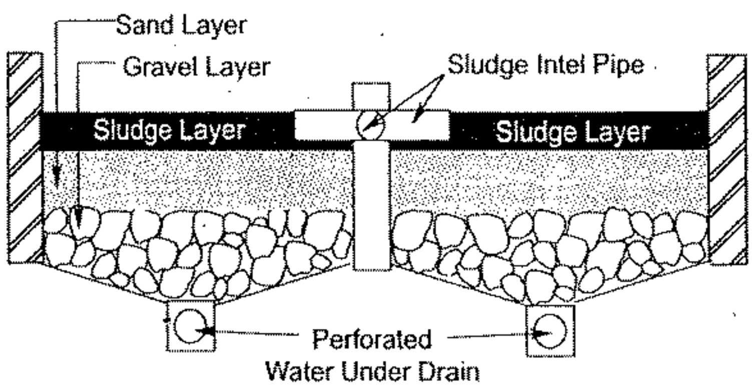
Therefore,

the sludge depth $= \dfrac{\text{total volume of sludge applied/year}}{\text{number of beds} \times \text{area of each bed} \times \text{number of cycles of each bed}}$

$= \dfrac{49.0 \times 365}{54 \times 240 \times 10} = 0.138$

$\approx 0.15 \text{ m} = 15.0 \text{ cm}$

Therefore, provide 56 beds (54 working + 2 standby), each of 30 m × 8m, with the standard sand and gravel media and under drainage system as shown in figure below.



OBJECTIVE QUESTIONS

1. Match **List-I** (Process) with **List-II** (Biological agent) and select the correct answer using the codes given below the lists:

List-I	**List-II**
A. Oxidation ditch	**1.** Facultative bacteria
B. Waste stabilization pond	**2.** Anaerobic bacteria
C. Imhoff tank	**3.** Aerobic bacteria (suspended culture)
D. Rotating Biological Contractor (RBC)	**4.** Aerobic bacteria (attached culture)

Codes:

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

2. One litre of sewage, when allowed to settle for 30 minutes gives a sludge volume of 27 cm^3. If the dry weight of this sludge is 3.0 grams, then its sludge volume index will be
(a) 9 (b) 24
(c) 30 (d) 81

3. **Assertion (A):** In waste water treatment, waste stabilisation ponds are more successful in sunny tropical regions.
Reason (R): The bacterial action of purification is achieved through photo-synthetic bacteria.

4. The waste stabilization ponds can be
(a) aerobic (b) anaerobic
(c) facultative (d) any of the above

5. The following are the sewage treatment processes:
1. Primary sedimentation
2. Screening
3. Grit removal
4. Secondary sedimentation

When only preliminary treatment is to be given for sewage, select the required treatment processes including their correct sequence from the codes below:
(a) 2, 3 (b) 2, 3, 1
(c) 1, 2, 3, 4 (d) 3, 1, 2, 4

6. A grit chamber of dimensions 12.0 m × 1.50 m × 0.80 m liquid depth has a flow of 720 m^3/hr. Its surfae loading rate and detention time are, respectively
(a) 4000 $m^3/hr/m^2$ and 1.2 minutes
(b) 40000 Lph/m^2 and 40 minutes
(c) 40 $m^3/hr/m^2$ and 12 minutes
(d) 40000 Lph/m^2 and 1.2 minutes

7. Match **List-I** (Impurities to be removed from sewage) with **List-II** (Treatment unit used) and select the correct answer using the codes given below the lists:

List-I	**List-II**
A. Large floating matter	**1.** Trickling filter
B. Suspended inorganic matter	**2.** Primary clarifier
C. Suspended organic matter	**3.** Grit chamber
D. Dissolved organic matter	**4.** Screens

Codes:

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

8. Which of the following are claimed advantageous in respect of aerobic sludge digestion as compared to anaerobic sludge digestion?

1. Lower BOD concentration in supernatant liquor.
2. Production of a sludge with excellent dewatering propensity.
3. Greater production of methane.
4. Lesser operating cost.
5. Lesser capital cost.

Select the correct answer using the codes given below:

(a) 1, 2 and 4 (b) 2, 3, 4 and 5
(c) 3, 4 and 5 (d) 1, 2 and 5

9. Match **List-I** with **List-II** and select the correct answer using the codes given below the lists:

List-I	**List-II**
A. Sludge disposal	**1.** Seeding
B. Sludge digestion	**2.** Biofilters
C. Aerobic action	**3.** Lagooning
D. Recirculation	**4.** Contact bed

Codes:

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

10. Which of the following waste disposal tasks are achieved by a septic tank with its dispersion trench?

1. Aerobic sludge digestion
2. Settling and anaerobic sludge digestion
3. Anaerobic sewage stabilization
4. Bio-oxidation of effluent

Select the correct answer using the codes given below:

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

11. Which of the following pairs is/are correctly matched?

1. Eutrophication... Nutrient accumulation leading to ecosystem change occurring in impounded water
2. Autotrophism... Utilization, rearrangement and decomposition of complex materials predominate
3. Heterotrophism... Predominance of fixation of light energy, use of simple inorganic substances and built-up of complex substances

Select the correct answer using the codes given below:
(a) 1, 2 and 3 (b) 1 alone
(c) 2 and 3 (d) 1 and 3

12. **Assertion (A):** Horizontal velocity of flow through grit chambers is maintained between 24 to 30 cm/sec.

Reason (R): Removal of organic and inorganic particles larger than 0.1 mm diameter is very essential.

13. The following three stages are known to occur in the biological action involved in the process of sludge digestion:

1. Acid fermentation
2. Alkaline fermentation
3. Acid regression

The correct sequence of these stages is
(a) 1, 2, 3 (b) 2, 3, 1
(c) 3, 1, 2 (d) 1, 3, 2

14. Fresh sludge has moisture content of 99% and, after thickening, its moisture content is reduced to 96%. The reduction in volume of sludge is

(a) 3% (b) 5%
(c) 75% (d) 97%

15. Match **List-I** (Nature of the solids) with **List-II** (Unit operation or process connected with its removal) and select the correct answer using the codes given below the lists:

List-I	**List-II**
A. Dissolved solids	**1.** Sedimentation
B. Colloidal solids	**2.** Reverse osmosis
C. Volatile solids	**3.** Coagulation
D. Settleable solids	**4.** Digestion

Codes:

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

16. In the oxidation ditch, the excess sludge is taken to

(a) anaerobic digestor (b) aerobic digester
(c) drying beds (d) incinerator

17. The flow sheet of the liquid stream of a sewage treatment scheme consists of

1. Trickling filter
2. Primary settling tank
3. Grit chamber
4. Screen chamber
5. Secondary settling tank

The correct sequence of these units in the sewage treatment scheme of a liquid stream is

(a) 3, 4, 1, 2, 5 (b) 3, 4, 2, 1, 5
(c) 4, 3, 1, 2,5 (d) 4, 3, 2, 1, 5

18. Which one of the following pairs is NOT correctly matched?

(a) Activated sludge ... aeration
(b) Trickling filters...attached growth system
(c) Oxidation ditch...algae
(d) Channel grit chamber...proportional weir

19. The two main gases liberated from an anaerobic sludge digestion tank would include

(a) ammonia and carbon dioxide
(b) carbon dioxide and methane
(c) methane and hydrogen sulphide
(d) ammonia and methane

20. Which one of the following sewage treatment units has a Parshall flume?

(a) Trickling filter (b) Oxidation ditch
(c) Grit chamber (d) Aerated lagoon

21. Which one of the following principal types of reactors is related to trickling filter?

(a) Plug flow (b) Complete-mix
(c) Packed-bed (d) Fluidized-bed

22. Which one of the following is LEAST important in the activated sludge process?

(a) Proper porportion of the return sludge from the secondary settling tank
(b) Adequate aeration in the biological reactor, so as to maintain certain minimum dissolved oxygen
(c) Proper food to micro-organisms (F : M) ratio
(d) The sludge volume index of the return sludge to be less than 200

23. Sludge bulking can be controlled by

(a) chlorination (b) coagulation
(c) aeration (d) denitrification

24. For a colony of 10,000 persons having sewage flow rate of 200 L/capita/day, BOD of applied sewage of 300 mg/L and organic loading of 300 kg/day/hectare, the area of an oxidation pond required for treating the sewage of the colony is

(a) 0.2 hectares (b) 1 hectare
(c) 2 hectares (d) 6 hectares

25. The purpose of proportional weir at the effluent end of a channel type grit removal unit is to

(a) provide easy passage of solid particles
(b) measure the rate of flow in the channel
(c) keep the depth of flow in the channel above a certain vlaue
(d) maintain constant mean velocity in the channel

26. The correct sequence of the sludge digestion steps is

(a) acid formation, hydrolysis, methane formation
(b) methane formation, acid formation, hydrolysis
(c) hydrolysis, methane formation, acid formation
(d) hydrolysis, acid formation, methane formation

27. Consider the following statements about waste stabilization ponds:

1. The pond has a symbiotic behaviour of waste stabilization through algae on one hand and bacteria on the other.
2. The oxygen in ponds is provided by algae through photosynthesis.
3. The detention period for waste stabilization pond is of the order of two to three days.
4. The bacteria, which develop in the pond, are aerobic bacteria.

Which of these statements are correct?

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

28. In which one of the following tests is the organic matter in the wate water used as food by micro-organisms?

(a) BOD (b) Most probable number
(c) COD (d) Chlorine demand

29. The function of algae in an oxidation pond is to

(a) provide a mat over the surface of the oxidation pond so as to prevent evaporation of water
(b) provide oxygen for bacteria to degrade organic matter
(c) provide a greenish appearance to the pond
(d) prevent the odour nuisance

30. Consider the following advantages:

1. Lower BOD concentration in supernatant liquor.
2. Production of a sludge with excellent dewatering capacity.
3. Recovery of methane gas.
4. Lower operation cost.

Which of these are the advantages of anaerobic digestion over aerobic digestion?

(a) 1 and 4 (b) 1 and 2

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

31. The MLSS concentration in the aeration tank of extended aeration activated sludge process is 4000 mg/L. If one litre of sample settled in 30 minutes and the measuring cylinder showed a sludge volume of 200 mL, then the sludge volume index would be nearly

(a) 200 (b) 150

(c) 100 (d) 50

32. Match **List-I** (Treatment units) with **List-II** (Type of processes) and select the correct answer using the codes given below the lists:

List-I	**List-II**
A. Trickling filter	**1.** Symbiotic
B. Activated sludge process	**2.** Extended aeration
C. Oxidation ditch	**3.** Suspended growth
D. Oxidation pond	**4.** Attached growth

Codes:

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

33. In a high rate-trickling filter, the problem of ponding can be solved by

(a) flooding and raking (b) chlorination and supply of air

(c) raking and chlorination (d) flooding and supply of air

34. Consider the following statements:
The process of activated sludge can be explained as

1. a physical action whereby the finer suspended particles of sewage form a sublayer for a bacterial film at the surface
2. a chemical action whereby the finer suspended particles and colloidal solids are combined into masses of large bulk
3. a biochemical action whereby the sludge flocs so formed act as vehicles for aerobic bacteria oxidizing the organic matter

Which of these statements are correct?

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

(c) 2 and 3 (d) 1 and 3

35. **Assertion (A):** Settled sewage is subjected to biological treatment.
Reason (R): Any biological treatment is preceded by a settling tank.

36. At a sewage treatment plant for a flow of 3 m^3/s, the cross-sectional area of grit chamber will be about

(a) 3 m^2 (b) 10 m^2
(c) 25 m^2 (d) 30 m^2

37. Consider the following data in the design of grit chamber:
 1. Specific gravity of grit = 2.7
 2. Size of grit particle = 0.21 mm
 3. Viscosity of water = 1.0×10^{-2} cm^2/s

 The settling velocity (cm/s) of the grit particle will be
 (a) 1 to 2.5 (b) 2.6 to 5.0
 (c) 5.1 to 7.8 (d) > 7.8

38. Amongst the various sewage treatment methods, for the same discharge, the largest area is needed for
 (a) trickling filter (b) anaerobic pond
 (c) oxidation ditch (d) oxidation pond

39. In an activated sludge process, the sludge volume index can be controlled by
 (a) aeration (b) adding chlorine
 (c) reducing recycling ratio (d) increasing the depth of aeration tank

40. The total volume of a primary settling tank is 2500 m^3 and the waste water flow is 25×10^6 liters per day. The detention time in settling tank is
 (a) $\frac{10}{24}$ h (b) $\frac{24}{10}$ h
 (c) 24 h (d) $\frac{1}{24}$ h

41. In conventional activated sludge process, the mean cell residence time in aeration tank is
 (a) less than 1.5 h (b) in the range of 5 to 8 days
 (c) in the range of 12 to 24 h (d) in the range of 4 to 15 days

42. Match **List-I** (Treatment system) with **List-II** (Item) and select the correct anser using the codes given below the lists:

	List-I		**List-II**
A.	Activated sludge process	**1.**	Fixed film reactor
B.	Trickling filtration	**2.**	Algae
C.	Oxidation ponds	**3.**	F/M ratio
D.	Anaerobic sludge digestion	**4.**	Proportional flow weir
		5.	Methane recovery

Codes:

	A	B	C	D
(a)	3	4	2	1
(b)	3	4	5	2
(c)	4	3	5	2
(d)	4	3	2	1

43. **Assertion (A):** The effluent of a septic tank needs further treatment before it is discharged into any receiving body, say public sewer.

Reason (R): The organic strength of the effluent is high.

44. **Assertion (A):** A sewage is said to be biologically treatable when the BOD/COD is more than 0.5.

Reason (R): In biological treatment, biodegradable organic matter is being only removed.

45. Allowable disposable rate of application of sludge on land is determined by

(a) carbon content of sludge
(b) nitrogen content of sludge
(c) phosphorus content of sludge
(d) potassium content of sludge

46. **Assertion (A):** The unit process involved in the sequential batch reactor and conventional activated sludge process is identical.

Reason (R): Aeration and sedimentation/clarification are carried out in both systems.

47. For a grit channel, if the recommended flow velocity is 0.25 m/s and the detention period is 1 minute, then length of the tank is

(a) 15 m (b) 25 m
(c) 32.5 m (d) 40 m

48. Match **List-I** (Techniques of aeration) with **List-II** (Description) and select the correct anser using the codes given below the lists:

List-I

A. Step aeration process
B. Completely mixed process
C. Extended aeration
D. Short term aeration

List-II

1. Dispenses the incoming waste and return sludge uniformly throughout the basins
2. Pre-treatment process similar to a roughening filter
3. Distributes the waste flow to a number of points along the basin
4. Mixed process operated along hydraulic detention time

Codes:

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

49. Acceptable lower limit of bacteria removal through activated sludge process is

(a) 60% (b) 70%
(c) 80% (d) 90%

50. Match **List-I** (Unit) with **List-II** (Action) and select the correct answer using the codes given below the lists:

	List-I		**List-II**
A.	Screening	**1.**	Removal of organic matter only
B.	Sedimentation tank	**2.**	Breaking up of solids
C.	Comminutor	**3.**	Removal of floating and/or suspended solids
D.	Trickling filter	**4.**	Removal of settleable solids

Codes:

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

51. The proportion of the suspended solids in the incoming waste water that should be removed in a typical primary treatment system is

(a) 1/4 (b) 1/3
(c) 1/2 (d) 2/3

52. The five days BOD of the effluents obtained from septic tanks is of the order of

(a) 0.5 mg/*l* (b) 10-20 mg/*l*
(c) 100-200 mg/*l* (d) 50-200 mg/*l*

53. Match **List-I** (Unit operation or process) with **List-II** (Sizing criterion) in respect of secondary treatment plant facilities and select the correct answer using the codes given below the lists:

	List-I		**List-II**
A.	Activated sludge	**1.**	Overflow rate
B.	Grit removal	**2.**	Hydraulic residue time
C.	Screening	**3.**	Channel approach velocity
D.	Trickling filters	**4.**	Hydraulic and organic loading rate-detention time

Codes:

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

54. Consider the following statements with reference to oxidation ponds:

1. They require high initial investments.
2. They have low operational cost.
3. They are also called stabilization ponds

Which of these statements are correct?

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

55. Match **List-I** (Treatment process) with **List-II** (Classification) and select the correct anser using the codes given below the lists:

List-I	**List-II**
A. Trickling filter	**1.** Anaerobic attached
B. Activated sludge	**2.** Aerobic process attached
C. Dispersion trench	**3.** Aerobic suspended
D. Septic tank	**4.** Anaerobic suspended

Codes:

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

56. Consider the following statements:

1. Primary sludge is to be treated with an anaerobic digester.
2. Secondary sludge is the living biomass.
3. Sludge volume gets decreased with increase in water content of sludge.
4. Sludge consists of higher solids content than the moisture content.

Which of these statements is/are correct

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

57. Match **List-I** (Unit of treatment) with **List-II** (Type of settling process) and select the correct answer using the codes given below the lists:

List-I	**List-II**
A. Grit chamber	**1.** Zone and compression settling
B. Sludge blanket clarifier	**2.** Flocculent settling
C. Clariflocculator	**3.** Discrete settling
D. Secondary settling tank (ASP)	**4.** Zone settling (principally)

Codes:

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

58. Match **List-I** with **List-II** and select the correct anser using the codes given below the lists:

List-I	**List-II**
A. Activated sludge	**1.** Is done in settling tank with detention time 1-1.5 hr
B. Primary treatment	**2.** Very active and can treat fresh sewage
C. Sludge index	**3.** Estimating of quality of return sludge
D. Return sludge	**4.** Active sludge obtained from final settling tank

Codes:

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

59. If the efficiencies of BOD removal of first-stage and second-stage trickling filters are each 65.0%, then what is the overall BOD removal efficiency of these filters?

(a) 6% (b) 77.25%
(c) 87.75% (d) 92.6%

60. Why is a proportional flow weir provided in a grit chamber?

(a) To reduce the suspended solids entering into the grit chamber
(b) To maintain the constant flow depth in the grit chamber
(c) To take care of maintaining constant flow velocity in the grit chamber over a certain depth range
(d) To allow the sewage afresh into the grit chamber

61. **Assertion (A) :** In the secondary sedimentation tank of a sewage treatment plant, the settling particles form a blanket which descends and captures more particles.

Reason (R) : The particles are flocculant and in very high concentration whenever there is an efficient working activated sludge, or trickling filter, process.

62. A septic tank of 7 m^3 in volume serves for 5 people. If the rate of accumulation of sludge is 70 litres per capita per year and sludge is removed when it occupies 50% of its volume, what is the cleaning interval of septic tank?

(a) 3 years (b) 5 years
(c) 7.5 years (d) 10 years

63. A primary sludge having volume of 14 m^3 and moisture content of 94% was dewatered to have a solid content of 16%. What is its final volume?

(a) 2.38 m^3 (b) 3.50 m^3
(c) 5.25 m^3 (d) 7.00 m^3

64. What is the cause of bulking of sewage?

(a) Absence of micro-organisms
(b) Low sludge volume index
(c) Poor to nil settlement of micro-organisms
(d) High organic loading

65. What is the value of generally accepted BOD/N/P weight ratio required for aerobic biological treatment?

(a) 100/17/3 (b) 100/5/1
(c) 100/23/5 (d) None of these

66. Activated sludge is the

(a) resultant sludge removable from the aeration unit
(b) sludge settled in the humus tank
(c) sludge in the secondary tank post-aeration, rich in microbial mass
(d) sludge in the secondary tank post-aeration, rich in nutrients

67. Where does sloughing occur?

(a) Grit chamber
(b) Biological treatment unit
(c) Trickling filter
(d) Septic tank

68. Which one of the following sewage treatment unts works on the principle of aerobic decomposition of organic matter?

(a) Septic tank
(b) Trickling filter
(c) Imhoff tank
(d) Sludge digestion tank

69. Sutro-weir is provided in which of the following?

(a) Water treatment clarifiers
(b) Sludge banket clarifiers
(c) Rectangular grit chambers
(d) UASB launders

70. Primary treatment of waste water is made with the application of which of the following?

(a) Physical forces only
(b) Biological cells only
(c) Gravitational pull
(d) Both physical and biological agents

71. The maximum efficiency of BOD removal is achieved in which of the following?

(a) Oxidation ditch
(b) Oxidation ponds
(c) Aerated lagoons
(d) Trickling filter

72. What does the biological layer stricking to the trickling filter consist of?

(a) Bacteria only
(b) Protozoa only
(c) Bacteria + Algae
(d) Bacteria + Protozoa + Fungi

73. What is the most generally adopted detention period (approximately) for a septic tank under the Indian conditions?

(a) 12 hours
(b) 24 hours
(c) 36 hours
(d) 48 hours

74. Which of the following sewage treatment methods has inherent problems of odour, ponding and fly nuisance?

(a) UASB system
(b) Activated sludge process
(c) Trickling filters
(d) Stabilization ponds

75. From amongst the following sewage treatment options, largest land requirements for a given discharge will be needed for

(a) trickling filter (b) anaerobic pond
(c) oxidation ditch (d) oxidation pond

76. Settling test on a sample drawn from Aeration Tank liquor of ASP (MLSS = 2800 mg/L) was carried out with 1 litre sample. The test yielded a settled volume of 200 mL. The value of Sludge Volume Index shall be

(a) 14.0 (b) 34.2
(c) 71.4 (d) 271

77. Match **List-I** with **List-II** and select the correct answer using the codes given below the lists:

List-I

A. Thickening of sludge
B. Stabilization of sludge
C. Conditioning of sludge
D. Reduction of sludge

List-II

1. Decrease in volume of sludge by chemical oxidation
2. Separation of water by heat or chemical treatment
3. Digestion of sludge
4. Separation of water by floatation or gravity

Codes:

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

78. A circular primary clarifier processes an average flow of 5005 m^3/d of municipal waste water. The overflow rate is 35 $m^3/m^2/d$. The diameter of clarifier shall be

(a) 10.5 m (b) 11.5 m
(c) 12.5 m (d) 13.5 m

Common Data for Ques 79 and 80:

A completely mixed activated sludge process is used to treat a wastewater flow of 1 million litres per day (1 MLD) having a BOD_5 of 200 mg/L. The biomass concentration in the aeration tank is 2000 mg/L and the concentration of the net biomass leaving the system is 50 mg/L. The aeration tank has a volume of 200 m^3.

79. What is the hydraulic retention time of the wastewater in aeration tank?

(a) 0.2 h (b) 4.8 h
(c) 10 h (d) 24 h

80. What is the average time for which the biomass stays in the system?

(a) 5 h (b) 8 h
(c) 2 days (d) 8 days

81. Match **List-I** (Terminology) with **List-II** (Definition/Brief Description) and select the correct answer using the codes given below the lists:

List-I

A. Primary treatment
B. Secondary treatment
C. Unit operation
D. Unit process

List-II

1. Contaminant removal by physical forces
2. Involving biological and/or chemical reaction
3. Conversion of soluble organic matter to biomass
4. Removal of solid materials from incoming wastewater

Codes:

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

82. Consider the following statements :
Activated sludge process can be said to comprise.
1. Conversion of dissolved organic matter into biological flocs
2. Removal of dissolved BOD of the waste water
3. Digestion of the sludge

Which of these statements are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

83. During sewage treatment, effluent from which one of the following treatment unit has minimum wt. vol amount of suspended solids?
(a) Detritus channel
(b) Secondary sedimentation tank
(c) Primary sedimentation tank
(d) Activated sludge process aeration tank

84. When sufficient energy through mechanical mixing is supplied to keep the entire contents, including the sewage solids, mixed and aerated, the reactor is termed :
(a) An aerobic lagoon (b) An aerobic pond
(c) An facultative lagoon (d) A facultative pond

85. Deep ponds, in which oxygen is absent except, perhaps, across a relatively thin surface layer, are called :
(a) Aerobic ponds (b) Anaerobic ponds
(c) Facultative ponds (d) Polishing ponds

ANSWERS

1. (b)	23. (a)	45. (b)	67. (c)
2. (a)	24. (c)	46. (a)	68. (b)
3. (c)	25. (d)	47. (a)	69. (c)
4. (d)	26. (d)	48. (c)	70. (a)
5. (a)	27. (d)	49. (d)	71. (a)
6. (c)	28. (a)	50. (c)	72. (d)
7. (c)	29. (b)	51. (d)	73. (b)
8. (d)	30. (c)	52. (c)	74. (c)
9. (a)	31. (d)	53. (d)	75. (d)
10. (c)	32. (d)	54. (b)	76. (c)
11. (b)	33. (c)	55. (c)	77. (c)
12. (b)	34. (a)	56. (a)	78. (d)
13. (a)	35. (a)	57. (d)	79. (b)
14. (c)	36. (b)	58. (c)	80. (d)
15. (a)	37. (a)	59. (c)	81. (a)
16. (c)	38. (d)	60. (c)	82. (b)
17. (d)	39. (c)	61. (a)	83. (b)
18. (c)	40. (b)	62. (d)	84. (a)
19. (b)	41. (b)	63. (c)	85. (c)
20. (c)	42. (a)	64. (c)	
21. (c)	43. (a)	65. (b)	
22. (d)	44. (a)	66. (c)	

CHAPTER

6

Solid Waste Management

INTRODUCTION

- Solid wastes are the total wastes arising from human and animal activities that are normally solid and hence are useless or unwanted.
- It encompasses the heterogeneous mass of throw away from houses of commerical centres as well as the nearby homogeneous accumulation of a single industrial activity.
- Refuse represents the dry wastes or solid wastes of the society.
- The term 'refuse' is often used interchangeably with term solid wastes.
- The density of Indian refuse is generally higher than that of the developed countries and hence the Indian refuse can be carried efficiently and economically by mechanical transport (carrying more wt. for the same volume).
- The calorific value of Indian refuse is much smaller, and its moisture content is high.

TYPES OF SOLID WASTES

Major categories of solid waste generation are :

(i) Municipal wastes

(ii) Industrial wastes

(iii) Hazardous wastes.

Municipal wastes

- Solid wastes generated from different zones of the city differs in characteristics. There solid waster comprise refuse, ordinary refuse (includes garbage & rubbish) and trash.
- Refuse, refers to nonhazardous solid waste from the community requiring collection and transporting to processing/disposal site.
- Garbage comprises items that are highly decomposable (putrescible) food, waste vegetables and meat scraps.
- Rubbish contains mostly dry, nondecomposable (nonputrescible) material— glass, rubber, tin cans, also, or combustible material - paper, textiles, wooden articles, etc.
- Hence, community refuse can be referred to as municipal solid waste (MSW).

Industrial wastes

- Industrial wastes are generated from the industrial activities or manufacturing processes.
- All the three types of wastes, solid, liquid and gaseous are generated
- Industial wastes can be categorised as non-hazardous and hazardous. It is well known that hazardous wastes have a potential for very deleterious impact on environment and life in general.
- Some of the common industries which generate solid waste along with other wastes on a large scale are : (i) Paper and pulp (ii) Metallurgical industries (iii) Pesticides/Insecticides (iv) Fertilizers (v) Plastics (vi) Refineries

Hazardous wastes

- Hazardous substance can be defined as anything which because of its quantity, concentration or characteristics may contribute to increased mortality, illness or hazard to human health and environment if not properly stored and transported or disposed off.
- As per the Resource Conservation and Recovery Act (RCRA), USA, the hazardous waste is one which possesses any one of the four characteristics, such as, *ignitabilty, corrosivity, reactivity* or *toxicity*.
- Hazardous differ in form as well as behaviour from ordinary solid wastes. They generally are produced in liquid form; however, they can also occur as solids, sludges, or gases. They are infectious and radioactive.
- Some of the common industries which generate hazardous waste are: (i) Ferrous, non-ferrous industries (ii) Foundries, (iii) Fertilizer industries (iv) Cement industries (v) Petroleum industries (vi) Chemical industries

CLASSIFICATION OF REFUSE

Based on the type of wastes

(a) Garbages: It includes all sort of putrescible organic wastes, obtained from kitchens, hotels, restaurants like waste food articles, vegetable peelings, fruit peelings, etc. These wastes are organic in nature, and hence, likely to decompose quickly, producing foul odours and health hazards. They may also result in breeding of flies, mosquitoes, insects, etc. Hence, garbage must be disposed of, properly and quickly. When it is scientifically processed and composted then we may obtain some valuable products like grease, fertiliser, etc. from garbage. The density of garbage usually varies between 450 to 900 kg/m^3.

(b) Ashes: Ashes are the *incombustible waste products* from hearths and furnaces, and houses or industries. The density of ashes generally vary between 700 to 850 kg/m^3

(c)Rubbish: Rubbish includes all *non-putrecible wastes except ashes*. All combustible wastes, such as rags, paper pieces, broken pieces of glass and furniture, card-boards, broken crockery comes under. Rubbish is lighter, and normally has a density varying between 50 to 400 kg/m^3.

Based on the source

Refuse may also be classified, depending on its source, as:

(i) House refuse (ii) Street refuse and (iii) Trade refuse

These terms are self explanatory .

Note: The usual density of refuse (mixture of all types of dry wastes) generally varies between 300 to 600 kg/m^3.

ON-SITE HANDLING, STORAGE, AND PROCESSING

The handling, storage, and processing of solid wastes at the source before they are collected are the functional elements in a solid-waste management system.

On-site handling refers to the activities associated with the handling of solid wastes until they are placed in the containers used for their storage before collection. Depending on the type of collection service, handling may also be required to move loaded containers to the collection point and to return the empty containers to the point where they are stored between collections.

Factors considered in the **on-site storage** of solid wastes include : (i) the type of container to be used, (ii) the container location, (iii) public health and aesthetics, and (iv) the collection methods to be used.

On-site processing methods are used to recover usable materials from solid wastes, to reduce the volume, or to alter the physical form. The most common on-site processing operations include manual sorting, compaction, and incineration.

Processing Techniques

Processing techniques are used in solid waste management systems to : (i) improve the efficiency of solid-waste disposal systems, (ii) to recover resources (usable materials), (iii) to prepare materials for the recovery of conversion products and energy.

Important processing techniques used routinely in municipal solid-waste systems include; *compaction, thermal volume reduction (incineration), and manual separation of waste components.*

(i) Mechnical volume reduction : It is the most important factor in the development and operation of solid-waste management systems. Vehicles equipped with compaction mechanisms are used for the collection of most municipal solid wastes. Wastes are compacted to increase the useful life of landfills.

(ii) Thermal volume reduction : The volume of municipal wastes can be reduced by more than 90 percent by incineration. Incineration was quite common in the past, however, with more restrictive air-pollution control requirements,only a limited number of municipal incinerators are currently in operation.

(iii) Manual component separation : The manual separation of solid waste components can be accomplished at the source where solid wastes are generated, at a transfer station, at a centralized processing station, or at the disposal site. Manual sorting at the source of generation is the most positive way to achieve the recovery and reuse of materials. The number and types of components salvaged or sorted (e.g., cardboard and high quality paper. metals, and wood) depend on the location, the opportunities for recycling, and the resale market.

METHODS OF SOLID WASTE COLLECTION

Collection, removal and carriage of refuse

- Regular collection and transport of solid waste are most important operations in any efficient solid waste management which costs about 80% of the total cost of solid waste management
- In India, refuse is generally collected in individual houses in small containers and from there it is collected by sweepers in small hand driven lorries/carts and then dumped into the community storage bins made by municipalities placed at intervals of 50-200m depending on the layout of street and density of population.
- The capacity of the bins may vary from 100 to 500 litres depending on the quantity of zone wise waste generation.
- In case of large quantity of putrescible garbage from residential area, it will be appropriate to follow on-site storage .

- The waste from the community storage bins is collected by transport vehicles daily for final disposal or treatment.Combined collection of garbage and rubbish is more economical.If materials are to be recycled, home owners can practice source separation i.e into paper, glass etc.
- Methods adopted in India are not satisfactory and needs further improvements and changes.

Points to be taken care of during solid waste collection

- Spreading or scattering of refuse while dumping in the community storage bins by the house sweepers and street scavengers should be avoided.
- Transport vehicles should be cleaned periodically, thus avoiding decomposition and evolution of health hazard causing obnoxious gases.
- Community storage bins as well as transport vechicles should have cover/lid thus reducing incidence of rodents, insect infestationand unpleasent sights at the site .
- Transport vehicles should visit the houses; twice a day, once in the morning and once in the evening to collect household refuse and street sweepings.
- Transport vehicles should be strong, durable and water tight and made of stainless steel with smooth interior having round corners and edges for facility of cleaning
- Transport vehicles should have a low loading line (about 1.5 m), so that minimum of time and effort is required in filling them.
- Mechanical devices should be installed in these vehicles for lifting the body to the sides or back or for pushing the refuse out in order to empty it quickly and easily.
- An optimum collection route, particularly for large and densely populated area should be selected in order to optimize the collection system

DISPOSAL OF SOLID WASTE

Disposal on or inside the earth is the only feasible method for the long term handing of the following

(i) solid wastes that are collected and are of no further use

(ii) residual matter remaining after solid wastes have been processed.

(iii) residual matter remaining after the recovery of conversion products and/or energy has been accomplished

Note : Landfilling is the method of disposal used most commonly for municipal wastes; landfarming and deep-well injection have been used for industrial wastes. Although incineration is often considered a disposal method, it is, in reality, a processing method.

Points to be kept in mind during disposal of solid waste

- Appropriate method of disposal of solid waste should be chosen among the methods discussed in the section ahead in order to satisfy the present as well as future requirements .
- It should no createenvironmental pollution and should result in recovery of material as well as energy.

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

(i) Open dumping,

(ii) Sanitary land fill,

(iii) Composting,

(iv) Shredding (or Pulverisation)

(v) Incineration,

(vi) Pyrolysis

DISPOSAL OF REFUSE BY OPEN DUMPING

- Oldest method of disposing SW
- Very simple method and commonly adopted in our country.
- SW collected from the city zone is dumped in low lying areas located far off from the city.
- Not an eco-friendly method and thus results in contamination of environment.
- This method is highly unacceptable as it gives unsightly nuisances, obnoxious smell and is a breeding place for flies and mosquitoes.
- The method is still in practice in semi-urban and rural areas.

DISPOSAL OF REFUSE BY SANITARY LAND FILLING

Important aspects in the implementation of sanitary landfills 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.

- In this method, refuse is carried and dumped into low lying areas under an engineered operation, designed and operated according to acceptable standards.
- It involves a controlled disposal of SW on or in the upper layers of the earth's surface.
- The refuse is dumped and compacted in layers of 0.3 to 0.6 m and after the days work when depth of filling becomes about 1.5 m, it is covered by earth layer of about 15 to 30 cm thickness .
- Filling is done by a grid pattern, (ie dividing the entire site into smaller portions)
- Before dumping the second layer, compaction is done by movement of bull dozers, trucks etc.
- A minimum clearance distance of 6m from the surrounding area should be left during filling operation of low lying areas.
- Insecticides like DDT, creosote etc. should be sprayed to prevent mosquito breeding.
- Final cover of about 0.6m of earth is laid and compacted at the top of the filled up land in order to finish the complete oeration and prevent rodents from burrowing into the refuse.
- The filled up refuse gets stabilised due to the decomposition of organic matter in due course of time; subsequently getting converted into stable compounds.

Steps involving refuse stabilisation

The entire period of refuse stabilisation can be divided into five distinct phases

(i) Aerobic bacteria and fungi, which are dominant, deplete the available oxygen to effect oxidation of organic matter. As a result of aerobic respiration, the temperature in the fill increases.

(ii) Anaerobic and facultative bacteria develop to decompose the organic matter; and H_2 and CO_2 gases are thus evolved through acidogenic activity.

(iii) Methanogenic bacteria develop to cause evolution of methane gas.

(iv) Methanogenic activity gets stabilised.

(v) Methanogenic activity subsides, representing depletion of the organic matter; and ultimately, the system returns to aerobic conditions within the land fill.

Note : The refuse, in managed landfills, generally gets stabilised, within a period of 2 to 4 months and settle down by 20-40% of its original height. Hence, filled up land can be used for developing some green land, parks, or other recreational spots.

Advantages

(i) This method is most simple and economical. No costly plant or equipment is required in this method

(ii) Separation of different kinds of refuse is also not required in this method.

(iii) No residues or by products left out/evolved in this method, and hence no further disposal is required

(iv) Low lying water-logged areas and odd quarry pits can be easily reclaimed and put to better use.

Disadvantages

(i) Low lying depressions or dumping sites may not always be available as they may become scarce or unavailable in future.

(ii) There is a continuous evolution of foul gases near the fill site, especially during the time of dumping the refuse. These gases may often be explosive in nature, and are produced by the decomposing or evaporating organic matter.

Occurence of gases and leachates in landfills

The following events occur when solid wastes are placed in a sanitary landfill:

(i) biological decay of organic materials (aerobically/anaerobically) with the evolution of gases and liquids

(ii) chemical oxidation of waste materials

(iii) escape of gases from the fill

(iv) movement of liquids caused by differential heads

(v) dissolving and leaching of organic and inorganic materials by water and leachate moving through the fill;

(vi) movement of dissolved material by concentration gradients and osmosis

(vii) uneven settlement caused by consolidation of material into voids.

Gases in landfills

- Gases found in landfills include air, ammonia, carbon dioxide, carbon monoxide, hydrogen, hydrogen sulfide, methane, nitrogen, and oxygen. Carbon dioxide and methane are the principal gases produced from the anaerobic decomposition of the organic solid-waste components.
- The movement of gas in landfills can be controlled by constructing vents and barries and by gas recovery.
- The movement of landfill gases can be controlled by the landfill sealants
- Compacted clay is most commonly used as landfill sealants

Leachate in landfills

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

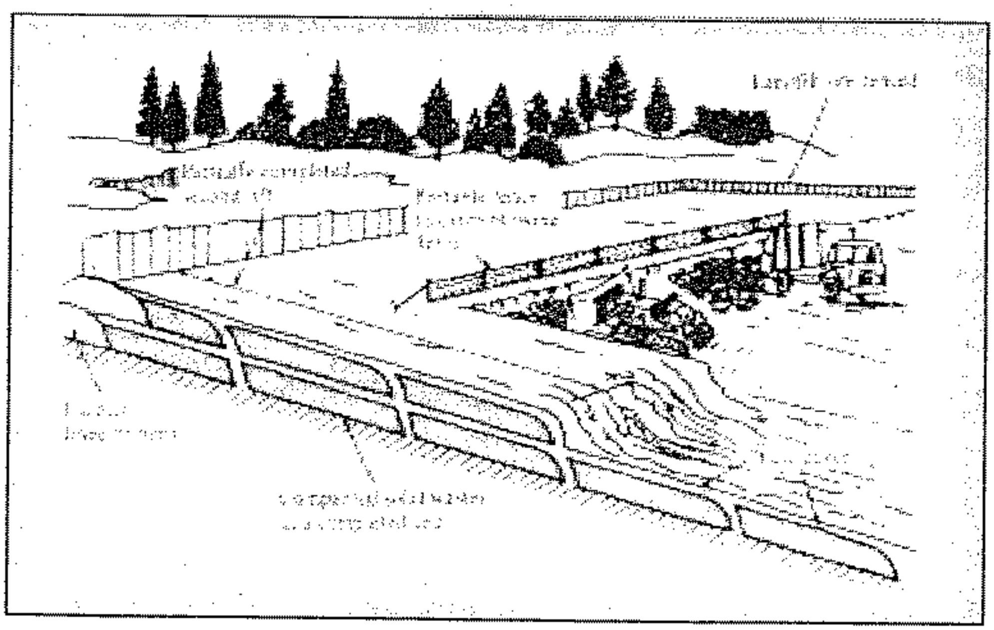
- In most landfills, the liquid portion of the leachate is composed of the liquid produced from the decomposition of the wastes and liquid that has entered the landfill from external sources, such as surface drainage, rainfall, groundwater, and water from underground springs.
- Under normal conditions, leachate is found in the bottom of landfills. From there, it moves through the underlying strata(although some lateral movement may also occur) depending on the characteristics of the surrounding material.
- The use of clay liners or synthetic liners like geotextiles has been the most method favourable method for reducing and eliminating the percolation of leachate
- An important method to control the production of leachate is to eliminate the infiltration of surface water from the landfill which is the major contributor to the total volume of the leachate . For this we use an impervious clay layer over the top of the fill at a decent slope , provided with adequate drainage and surface infiltration.

Landfilling methods at sanitary landfill sites

The principal methods used for landfillingdry areas may be classified as (i) area method (ii) trench method (iii) depression method

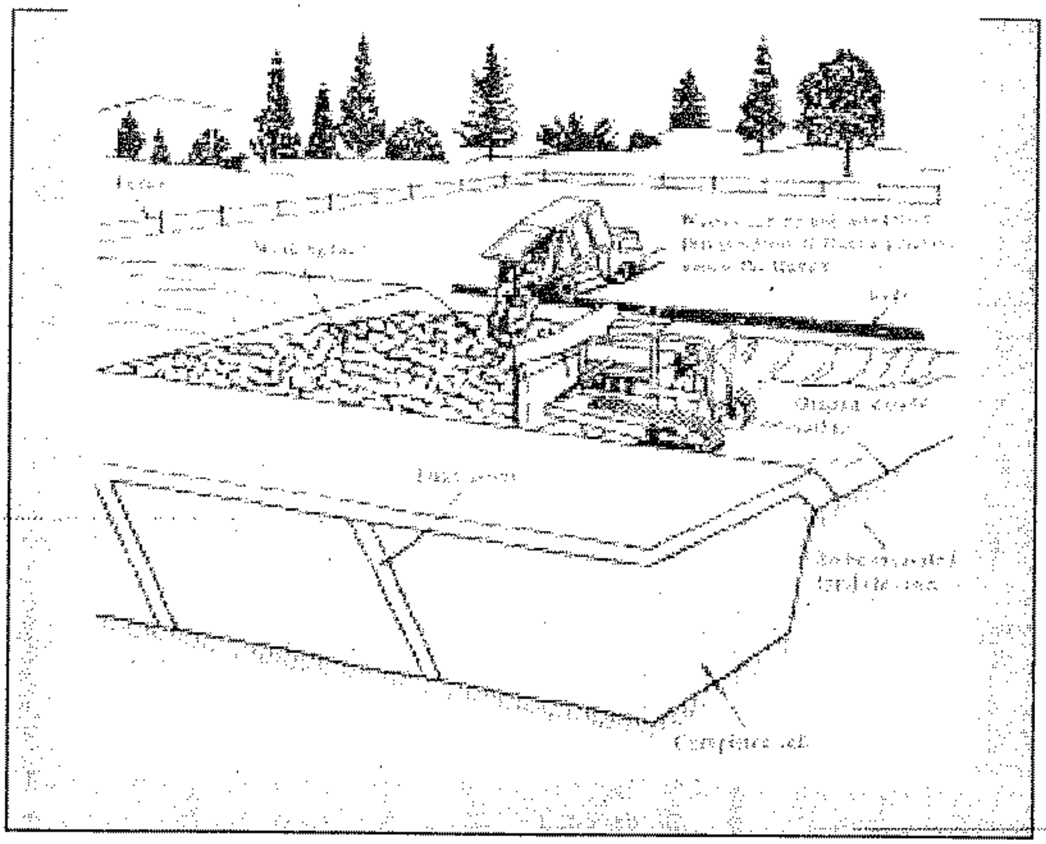
Area method is used when the terrain is unsuitable for trench excavation especially when the water table is high

- Entire land fill sites is divided into no of sub-areas by constructing enbankments and roads.
- The sub areas are called *sub-division cells* or simply *cells*. Rest method is similar to as described earlier



Trench method of landfilling is ideally suited to areas where an adequate depth of cover material is available at the site and where the water table is well below the surface.

- In this method, a trench is excavated and then filled with waste cells of daily waste, seperated by the earth cover, as described earlier.
- The earth excavated from the trench can be used to provide daily cover as well as final cover on the waste fillings.
- Other than the addition of excavation and subtraction of earth imports for cover material, the entire method is excatly the same as described earlier.



Depression method

- At locations where natural or artificial depressions exist, it is often possible to use them effectively for landfilling operations. Canyons, ravines, dry borrow pits, and quarries have all been used for this purpose.
- The techniques to place and compact SW in depression landfills vary with the geometry of the site, the characteristics of the cover material, the hydrology and geology of the site, and the access to the site.
- In a canyon site, filling starts at the head end of the canyon and ends at the mouth. This practice prevents the accumulation of water behind the landfill.
- Wastes usually are deposited on the canyon floor and from there are pushed up against the canyon face at a slipe of about 2 to 1. In this way, a high degree of compaction can be achieved.

DISPOSAL OF REFUSE BY COMPOSTING

- Composting of refuse is a biological method of decomposing SW.
- If the organic materials excluding plastics, leather and rubber are separated from the solid wastes and are subjected to decomposition, either acrobically 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*.
- Basically, composting is considered to be an aerobic process, because it involves piling up of refuse and its regular turning, either manually or by mechanical devices, so as to ensure sufficient supply of air and oxygen during its decomposition by bacteria, fungi and other microorganisms, like antinomycetes.

- Initially, the process starts with the mesophilic bacteria, which oxidise the organic matter (in the refuse) to carbon dioxide and liberate heat. The temperature rises to about 45° C, and at this point, the thermophillic bacteria take over and continue the decomposition. During this phase, the temperature further rises to about 60°. After about 3 weeks, the compost is stabilised, and this is shown by an appreciable fall in the temperature of the compost mass.
- The final compost should have an earthy smell and a dark brown colour.
- Moisture content of the compost mass should however be controlled to ensure optimum aerobic decomposition, because excessive moisture will make it difficult to maintain aerobic conditions, while deficient moisture inhibits biological life. A moisture content of about 55% should be established, so that aerobic hiological activity may proceed at an optimum rate.

Carbon-nitrogen ratio

- C/N of the input material in the compost heap is an important factor for the bacterial activity to continue, since the bacteria use nitrogen for building their cell structures (as proteins) and carbon for food (as energy).
- The anaerobic bacteria, developing in this digestion, use up carbon about 30-50 times faster than they use up nitrogen. Hence, for proper development of anaerobic digestion, C/N ratio of the digestive material should be between 30 to 50 for optimum digestion.
- When there is too much of carbon, *i.e.* 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.
- When there is too much of nitrogen, *i.e.* C/N ratio is lower than the optimum, then the carbon will soon get exhausted and fermentation stop, leaving nitrogen in the digestor which will combine with hydrogen to form ammonia (NH_3). This can kill or inhibit the growth of bacteria especially the methane producers.
- The anerobic digestion will require an optimum C/N ratio of about 30-50.

In India, the composting is practised in rural areas on the mixture of night soil and refuse. Two methods, which are generally adopted here, are : (i) Indore process (ii) Bangalore process

Indore method

- It uses manual turning of piled up mass for its decomposition under aerobic conditions.
- In this method, layers of vegetable wastes and night soil are alternatively piled in depths of about 7.5 to 10 cm each, to a total depth of about 1.5 m in a trench; or above the ground to form a mound called a *windrow*.
- The mixture is kept aerobic by turning regularly for 2 to 3 months.
- This compost mass is then left for another about 1 to 1½ months without any turning; after which, the compost becomes ready for use. The entire prosses thus takes about 4 months. This method is primarily aerobic in nature.

Bangalore method

- In this method, the refuse and night soil are piled up in layers in an underground earthen trench of about 10m × 1.5m × 1.5m.
- This mass is covered at its top by layer of earth of about 15 cm depth, and is finally left over for decomposition.
- Within 2 to 3 days of burial, intensive biological action starts taking place and organic matter begins to be destroyed.

- Considerable heat evolved in the process raises the temperature of the decomposing mass to about 75°C, thus preventing the breeding of flies by destroying the larvae.
- After about 4 to 5 months (depending upon the season), the refuse gets fully stabilised and changes into a brown coloured odourless innocuous powdery mass, called humus.
- This humus is removed from the trenches, sieved on 12.5 mm sieves to remove stones, broken glass, brickbats, etc., and then sold out in the market as manure. The empty trenches can again be used for receiving further batches of refuse.
- This method does not involve any turning or handling of the mass and is more clean than the Indore method.
- This method is widely adopted by municipal authorities throughout the country.

Mechanical composting plants

- All the operations like shredding, grinding and separation of wastes are carried out mechanically.
- The degradation of the organic wastes takes place in a rotating cylinder while it registers change in moisture and air contents.
- Optimum moisture and air contents are maintained for better results.
- Approximately 60 to 70 tonnes of compost can be generated from 100 tonnes of refuse.
- Large no. of mechanical compost plants in India are at Ahmedabad, Baroda,Calcutta and Bangalore.

DISPOSAL OF REFUSE BY PULVERIZATION

- In this method of refuse disposal, refuse is pulverized in grinding machines, so as to reduce its volume and to change its physical character. The pulverized refuse becomes practically odourless and unattractive to the insects.
- This pulverized refuse, though contains fertilising elements like potash, phosphorous, and nitrogenous material, yet cannot be suitably used as a manure. It has, therefore, to be further disposed of by filling in trenches, or digested in open windrows or closed digestors.

DISPOSAL OF REFUSE BY INCINERATION AND THERMAL PYROLYSIS

Incineration exothermic

- One of the most effective methods of reducing the volume and weight SW by burning it is a well designed furnace
- When the available land is scarce, disposal requirements are string out and destruction of toxic water is necessary, incineration is the best method for treatment of SW.
- There are mainly stages involved is the process of incineration first dring and then combusion
- Drying and combusion may be accomplished either in separate mits as successively in the same unit depending on temperature coustraints and control parameter.
- Estimation of oxygen requirement and heat balance are very vital for efficient functioning vof the incineration process.
- This method is widely used in countries like USA where the calorific value of refuse is high and hence are quite suitable for burning.
- Large scale air pollution particularly due to the emissions of ***dioxins*** remains a serious problem with the incinerators

Advantages

(i) Most sanitary method of refuse disposal and ensures complete destruction of pathogenic bacteria more than 80% volume reduction takes place by this process

(ii) No odour trouble or dust nuisances

(iii) Some cost can be recovered by selling the steam power and clinkers

Disadvantages

- The process is a bit expensive and requires a lot of technical know how
- Solid waste to be burnt should have a high calorific value
- Smoke , odour and ash nuisance may result due to the improper and incompetent behaviour of the plant

Pyrolysis

- Most organic compounds can be converted into gaseous , liquid and solid fraction through a combination of thermal cracking and condensation reactions in absence of oxygen. This process is known as pyrolysis
- This process is also known as destructive distillation
- It differs from conventional incineration in a way that it is an endothermic process- requiring continuous input of heat energy , while incineration is an exothermic process ie the process gives off heat as oxidation proceeds

Following three types of products are generated when the organic solid waste is pyrolysed

(i) *a gas stream* containing gases like H_2, CH_4, CO, CO_2 and other gases depending on the characteristics of SW

(ii) *a liquid fraction* consisting of a tar or oil stream containing chemical like acetic acid, acetone and methanol

(iii) *a solid fraction* consisting of charcoal like product plus any inert material

OBJECTIVE QUESTIONS

1. Which one of the following comprehensive classifications is used for different types of solid wastes?
   (a) Residential, commercial and treatment plant wastes
   (b) Food, demolition and construction wastes
   (c) Municipal, industrial and hazardous wastes
   (d) Rubbish, special wastes and wastes from open areas

2. The description of solid waste collected is as follows :

Night soil	35 t
Rubbish	40 t
Debris	25 t
Garbage	40 t

   The organic solids in the above composition is
   (a) 35 t (b) 60 t
   (c) 100 t (d) 75 t

3. In a sanitary landfill, decomposition and chemical changes within organic content of the solid waste goes on. Consequential changes within landfill can be ....
   1. temperature changes within landfill
   2. production of gases like H_2S, CO, Co_2 and CH_4
   3. destruction of pathogens
   4. production of other gases like SO_2 and NO_2

   Which of these statements are correct?
   (a) 1,2,3 and 4 (b) 1,2 and 3
   (c) 1 and 4 (d) 2 and 3

4. Bangalore method and Indore method of disposing solid wastes are
   (a) identical
   (b) different as Bangalore method is an anaerobic method
   (c) different as Bangalore method doesw not contain human excreta
   (d) different as Indore method is an incineration method

5. Which one of the following statements explains the term pyrolysis?
   (a) Solid waste is heated in closed containers in oxygen free atmosphere
   (b) Solid waste is incinerated in presence of oxygen
   (c) Wastewater is treated with oxygen
   (d) Dissolved solids from water are removed growth in atown normally depend?

6. The term 'Refuse' generally does not include
   (a) putrescible solid waste (b) excreta
   (c) non-putrescible solid waste (d) ashes

7. **Assertion (A)** : Composting is the most commonly used process for the decomposition of the organic components of municipal solid wastes.

   Reason (R) : Bangalore method is a common anaerobic method used for biological conversion of organic components of municipal solid wastes.

8. Consider the following statements : In solid waste management
   1. density separation of solid wastes can be accomplished by air classifiers
   2. iron recovery from solid wastes can be done by magnetic separators
   3. aluminium separation from solid wastes can be accomplished by eddy current separators

   Which of these statements are correct?

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

9. Which one of the following methods of solid waste management conserves energy most efficiently in the form of gas or oil?
   (a) Incineration with heat recovery
   (b) Combusting
   (c) Fluidized-bed incineration
   (d) Pyrolysis

10. The daily cover of MSW landfills consists of which one of the following?
    (a) Compacted soil (b) Geomemebrane
    (c) Geotextile (d) Geocomposite

11. Banglore and Indore process of composting are which of the following?
    (a) Both anaerobic processes
    (b) Both aerobic processes
    (c) Anaerobic process and aerobic process, respectively
    (d) Aerobic process and anaerobic process, respectively

12. A solid waste sample has been segregated and one of the components has been subjected to elemental analysis. The result of analysis in per cent by mass revealed C (40%), H (6.0%) O (44%), N(0.3%). What is the likely waste component?
    (a) Food waste (b) Paper and cardboard
    (c) Plastic waste (d) Leather waste

13. Which one of the following parameters is not included in the routine characterization of solid waste for its physical composition?
    (a) Moisture content (b) Density
    (c) particle size analysis (d) Energy value

14. What are the gases produced by landfills primarily comprised of?
    (a) Carbon monoxide and hydrogen sulphide
    (b) Methane and carbon dioxide
    (c) Sulphur dioxide and nitrogen dioxide
    (d) Ethane and oxygen

15. Dioxin is released during which one of the following processes?
(a) Composting
(b) Incineration
(c) Sanitary land filling
(d) Bio-fertilization

16. The leachate is an effluent from which of the following?
(a) Septic tanks
(b) Sanitary lands fills
(c) Compost plants
(d) Aerated lagoons

17. Which of the following statements related to C/N (Carbon/Nitrogen) ratio is not correct?
(a) Lower initial C/N ratio leads to loss of nitrogen and slows down the rate of decomposition
(b) Higher initial C/N ratio leads tro cell destruction to obtain nutrition
(c) Higher initial C/N ratio leads to lower conservation of nitrogen in the finished compost
(d) An initial C/N ratio of 30 to 50 is optimal for composting

18. Two biodegradable components of municipal solid waste are
(a) plastics and wood
(b) cardboard and glass
(c) leather and tin cans
(d) food wastes and garden trimmings

ANSWERS

1. (c)	6. (c) b	11. (c)	16. (b)
2. (d)	7. (b)	12. (a) b	17. (a)
3. (b)	8. (d)	13. (d)	18. (d)
4. (b)	9. (d)	14. (b)	
5. (a)	10. (a)	15. (b)	

CHAPTER

7

Air Pollution

INTRODUCTION

Air is the most essential part of the life and man can hardly survive for few minutes without air although he can survive for few days or few weeks with water or food. But sometimes even the most important life supporting element, if gets polluted, can cause harmful effects both to human beings and plants and animals.

Polluted air is also harmful to non living materials like metals, stones, woods, papers etc. These materials gets spoiled by the contact with polluted air either due to physical corrosive action of polluted air or/and due to the chemical attack of the pollutants on such material.

- The earliest pollutants noted in the atmosphere were probably of natural origin.
- Smoke, fumes, ash, and gases from volcanoes and forest fires; sand and dust from windstorms in arid regions; fog in humid, low-lying areas; were part of our environment long before human-induced or anthropogenic problems came on the scene.
- Air pollution can be defined as the presence of one or more air contaminants (i.e., dust, fumes, gas, mist, smoke, or vapor) in the outdoor atmosphere in sufficient quantities, of such characteristics and of such duration, that it becomes injurious to human, plant, or animal life or to property and also interferes with the comfortable enjoyment of life or property.

Note: Smoke is one of the earliest anthropogenic air pollutants.

SOURCE AND CLASSIFICATION OF AIR POLLUTANTS

Air pollutants can be classified as follows:

1. Natural contaminants : natural fog, pollen grains, bacteria and products of volcanic eruption.
2. Aerosols (particulates) : dust, smoke, mists, fog and fumes.
3. Gases and vapours

Air Contaminants

S.No.	Group	Examples
1.	Sulphur compounds	SO_2, SO_3, H_2S, mercaptans
2.	Nitrogen compounds	NO, NO_2, NH_3
3.	Oxygen compounds	O_3, CO, CO_2
4.	Halogen compounds	HF, HCl
5.	Organic compounds	Aldehydes, hydrocarbons
6.	Radioactive compounds	Radioactive gases

Some of these contaminants undergo chemical reactions when they enter the atmosphere. As a result, the end products formed are more harmful than the original contaminants. For example, unsaturated hydrocarbons react with nitrogen dioxide in sunlight to form smog.

NATURAL CONTAMINANTS

Among natural contaminants pollen is important because of its peculiar properties irritating to some individuals. They are discharged into the atmosphere 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.
- It can also be defined as a colloidal system in which the dispersion medium is a gas and the dispersed phase is solid or liquid.
- The term 'aerosol' is used during the time it is suspended in the air. After it has settled, the term no longer applies. Thus, particulate matter is an air pollutant only when it is an aerosol.

The following are the various aerosols

(i) ***Dust***

- Dust is made up of solid particles predominantly larger than those found in colloids and capable of temporary suspension in air or other gases.
- Dust is produced by the crushing, grinding, etc., of organic and inorganic materials.
- Most of the dust particles settle to the ground as dust fall, but particles 5 μ or smaller tend to form stable suspension.
- Dust may range insize from 1 to 1000 μ

(ii) ***Smoke***

- Smoke consists of finely divided particles produced by incomplete combustion.
- It consists predominantly of carbon particles and other combustible materials.
- Generally the size of the particles ranges from 0.5 to 1 μ.

(iii) ***Mists***

- This term refers to a low concentration dispersion of liquid particles of large size.
- It consists of water droplets suspended in the atmosphere.
- Mists are usually less than 10 μ in diameter

(iv) ***Fog***

- If mist concentration is high enough to obscure visibility, the mist is called a fog.

- Fog refers to visible aerosols in which the dispersed phase is liquid.
- It refers to dispersion of water or ice in the atmosphere near the earth's surface reducing visibility.
- In natural fog, the size of the particles ranges from 40–1.0 μ.

(v) Fumes

- These are fine solid particles generated by condensation from the gaseous state, generally after volatilisation from melted substances, and often accompanied by a chemical reaction such as oxidation.
- Fumes flocculate and then settles out.
- Ranges in size from 0.03 to 0.3 μ.

Gases

Following are the gases in air pollutants:

(i) Sulphur Dioxide

- This is one of the principal constituents of air pollutants.
- The main source of sulphur dioxide is the combustion of fuels, especially coal.
- Sulphur content of coal varies from less than 1% in anthracite to greater than 4% in bituminous coal.
- Most abundant atmospheric contaminant in cities.
- The major contibutors of SO_2 are refineries, chemical plants, municipal incineration plants etc.

(ii) Hydrogen Sulphide and Mercaptans

- Hydrogen sulphide is a foul smelling gas.
- The sources of its natural emission include anaerobic biological decay processes on land, in marshes and in the oceans.
- Volcanoes and natural water springs emit hydrogen sulphide to some extent.
- Major sources of hydrogen sulphide is the Kraft pulp industry.
- Other sulphur compound like mercaptans are important because of their strong odour. The mercaptans are emitted in mixtures of pollutants from some pulp mills, petroleum refineries, and chemical manufacturing plants.

(iii) Hydrogen Fluoride

- The major sources of fluorides are the manufacturer of phosphate fertilisers, the aluminium industry, brick plants, pottery.
- Hydrogen fluoride is an important air contaminant
- Hydrogen fluoride is more important in terms of injury to vegetation and animals than in terms of injury to humans

(iv) Oxides of Nitrogen

- Oxides of nitrogen are the second most abundant atmospheric contaminants in many cities, ranking next to sulphur dioxide.

- Highest concentration of nitrogen oxides in gaseous emissions occurs in effluents from industries where nitric acid is produced. The next highest concentration is in automobile exhausts.
- Out of seven oxides of nitrogen (N_2O, NO, NO_2, NO_3, N_2O_3, N_2O_4, N_2O_5), only nitric oxide and nitrogen dioxide are classified as pollutants.

(v) *Carbon Monoxide*

- Carbon monoxide, an odourless and colourless gas, has its major origin in the incomplete combustion of carbonaceous material.
- It is a highly poisonous gas and is generally classified as an *asphyxiant*.
- Chief source of carbon monoxide in the atmosphere is combustion, especially due to automobile exhausts.

(vi) *Aldehydes*

These are produced by the combustion of gasoline, diesel oil, fuel oil, and natural gas. They may also be formed in the air because of photochemical reactions.

PRIMARY AND SECONDARY AIR POLLUTANTS

Air pollutants can also be broadly classified into two general groups—primary air pollutants and secondary air pollutants.

- Primary air pollutants are those emitted directly from identifiable sources.

Examples of primary air pollutants

1. Finer particles (less than 100 μ in diameter)
2. Coarse particles (greater than 100 μ 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 those which are produced in the air by the interaction among two or more primary pollutants, or by reaction with normal atmospheric consitutents, with or without photoactivation.

Examples of secondary air pollutants

1. Ozone
2. Formaldehyde
3. PAN (peroxy acetyl nitrate)
4. Photochemical smog
5. Formation of acid mists (H_2SO_4) due to reaction of sulphur dioxide and dissolved oxygen, when water droplets are present in the atmosphere.

SMOG

- Smog is a synchronym of two words—smoke and fog. Smog can be of two types—photochemical or coal induced.
- Photochemical Smog is caused by the interaction of some hydrocarbons and oxidants (mainly nitrogen oxides) under the influence of sunlight giving rise to dangerous peroxy acetyl nitrate (PAN).
- Its main constitutents are nitrogen oxides, PAN, hydrocarbons, carbon monoxide and ozone.
- It reduces visibility, causes eye irritation, damage to vegetation and cracking of rubber.
- Modern smog (also called traffic smog) is a type of air pollution derived from vehicular emission from internal combustion engines and industrial fumes that react in the atmosphere with sunlight to form secondary pollutants that also combine with the primary emissions to form photochemical smog.
- Coal induced smog consist of smoke, sulpher compound and fly ash.

EFFECT OF AIR POLLUTION ON HUMAN

Sulphur dioxide (SO_2) : It is an irritant gas which effects mucous membrane when inhaled. It leads to bronchial spasms. Asthma patients are badly affected

Carbon Monoxide (CO) : Carbon monoxide has a strong affinity for combining with the haemoglobin of the blood to form carboxyhaemoglobin, COHb. This reduces the ability of the haemoglobin to carry oxygen to the body tissues. CO has about two hundred times the affinity of oxygen for attaching itself to the haemoglobin, so that low levels of CO can still result in high levels of COHb. Carbon monoxide also affects the central nervous system.

Oxides of Nitrogen : Of the several oxides of nitrogen known to exist in the ambient air, only two are thought to affect human health. These are nitric oxide (NO) and nitrogen dioxide (NO_2). It causes eye and nasal irritation and pulmonary discomfort.

Hydrogen Sulphide and Mercaptans : Hydrogen sulphide is a foul smelling gas. It is well known for its rotten egg like odour. Exposures to hydrogen sulphide for short periods can result in fatigue of the sense of smell.

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

Ozone : Ozone is a gas that has an irritant action in the respiratory tract, reaching much deeper into the lungs than the oxides of sulphur.

Fluorides : Fluorine is a cumulative poison. Hydrogen fluoride is less harmful to human beings

Lead : The main source of lead in urban atmospheres is the automobile. The effects include gastro-intestinal damage, liver and kidney damage, abnormalities in fertility and pregnancy and mental development of children gets affected.

Hydrocarbon Vapours : The effect of formaldehyde is primarily irritating. It is a major contributor to eye and respiratory irritation caused by photochemical smog.

Carcinogenic Agents : Carcinogenic agents are responsible for cancer. For example, the poly-cyclic organic compound, 3, 4-benzpyrene. The origin of these compounds is in the incomplete combustion of hydrocarbons.

Insecticides : Insecticides are not only harmful for insects but also poisonous for human DDT (Dichloro diphenyl trichloroethane). They can affect the central nervous system and may attack other vital organs.

Insecticides/pesticides can also causes premature labour and abortion, due to high concentration of pesticides in the body of expectant mothers.

Radioactive Isotopes : The important radioactive isotopes that may reach ambient air are Iodine 131, Phosphorous 32, Cobalt 60, Strontium 90, Radium 226, Carbon 14, Sulphur 35, Calcium 45 and Uranium.

The serious health effects are anaemia, leukaemia and cancer. Radioactive isotopes also cause genetic defects and sterility, as well as embryo defects and congenital malformations.

Allergic Agents : It is generally recognised by medical personnel that the air we breathe is the natural carrier of many microscopic organic materials which may act as allergens. Our body reactions to such allergens occur mainly in the skin and the respiratory tract.

EFFECT OF AIR POLLUTION ON ANIMALS

Animals are affected by air pollution because of accumulation of air-borne contaminant in the vegetation and subsequent poisoning of the animals when they eat the contaminated vegetation. They are not affected significantly by direct inhaling. The three pollutants responsible for most livestoke damage are fluorine, arsenic and lead.

Fluorine : Of all farm animals, cattle and sheep are the most susceptible to fluorine toxicosis.

Arsenic : Arsenic occurs as an impurity in many ores and in coal. It has been reported to cause poisoning of livestock near various industrial processes and smelters.

Lead : Lead contamination of the atmosphere takes place on account of various industrial sources such as smelters, coke ovens and other coal combustion processes.

EFFECTS OF AIR POLLUTION ON PLANTS

SO_2, hydrogen fluoride, ozone, Cl_2, HCl, NO_2 etc. affect plants.

- Recovery of plant from hydrogen fluoride effect is much slower than SO_2 attack.
- Chlorine is more toxic to vegetation than SO_2 by a factor of two or three.
- Hydrogen chloride is considerably less toxic to vegetation than SO_2.

AIR POLLUTION DAMAGE TO VARIOUS MATERIALS

Air Pollution Damage to Various Materials

Materials	Principal air pollutants	Effects
Metals	SO_2, acid gases	Corrosion, spoilage of surface, loss of metal, tarnishing
Building materials	SO_2, acid gases, particulates	Discolouration, leaching
Paint	SO_2, H_2S	Discolouration
Textiles and Textile dyes	SO_2, H_2S, NO_2, Ozone	Discolouration and fading
Rubber	Oxidants, ozone	Cracking, weakening
Leather	SO_2, acid gases	Disintegration, powered surface
Paper	SO_2, acid gases	Embrittlement
Ceramics	Acid gases	Change in surface appearance

PHOTOCHEMICAL AIR POLLUTION

Photochemical smog is formed due to photochemical oxidation of hydrocarbon and nitrogen oxide.

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

$$NO_2 + h\nu \longrightarrow NO_2^*$$

The highly energized molecule (NO_2^*) so formed then decomposes into nitric oxide and atomic oxygen.

$$NO_2^* \longrightarrow NO + O$$

The atomic oxygen reacts quickly with molecular O_2 to form ozone (O_3)

$$O + O_2 \longrightarrow O_3$$

Ozone may also react with NO present to form NO_2 and O_2

$$O_3 + NO \longrightarrow NO_2 + O_2$$

- In the presence of hydrocarbon other reactions take place and aldehydes, peroxides and peroxy acetyl nitrate (PAN) are formed.
- Presence of water vapour may lead to formation of nitric acid (HNO_3) also.

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. However, efficiency of this process is low.

Aldehyde Photochemical Reaction : Photochemical decomposition of aldehydes produces free-radicals and O_3

Factors Affecting Photochemical Reactions

- The nature of photochemical reactions that take place in the atmosphere depends on a number of factors. Some of these factors are:

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

- The height and intensity of atmospheric inversion is also a prime factor.

Photochemical Smog : Ozone (O_3) and PAN (Peroxy Acetyl Nitrate) are the most significant constituents of photochemical smog.

Effects of Photochemical Smog

1. Eye irritation – caused by aldehyde, PAN
2. Vegetation damage – caused by O_3, NO_2 and PAN
3. Visibility reduction
4. Cracking of rubber
5. Fading of dyes

GLOBAL IMPLICATIONS OF AIR POLLUTION

If the earth is to remain a place to live, long range effects of pollution of the atmosphere which blankets the planet should be taken care of.

Composition and Structure of the Atmosphere

- The first step towards understanding air pollution and its control is understanding the composition and structure of the atmosphere.
- The atmosphere is conceived mainly of four horizontal layers each characterized by a temperature profile, such as:

(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

- Varying amounts of most of the gases present in the atmosphere may be found in each of the four major layers of the atmosphere The total mass of each gas in the atmosphere has been shown in the table
- The air in the troposphere consists of 78 percent nitrogen (N_2), 21 percent oxygen (O_2), 1 percent argon (Ar), and 0.03 percent carbon dioxide (CO_2). Other gases are present in traces, most of which are inert.
- The layer of greatest interest in pollution control is the troposphere, since this is the layer in which most living things exist

ACID RAIN

- Phenomenon of acid rain is one of the most recent changes in the trophosphere.

- Acid rain (or acid deposition) results when gaseous emissions of sulfur oxides (SO_x) and nitrogen oxides (NO_x) interact with water vapor and sunlight and are chemically converted to strong acidic compounds (H_2SO_4 and HNO_3), along with other organic and inorganic chemicals. These compounds, along with other organic and inorganic chemicals, are deposited on the earth as aerosols and particulates or are carried to the earth by raindrops, snowflakes, fog or dew.

Generally, 'clean' rain is slightly acidic as it dissolves varying amounts of carbon dioxide. If pH of rain is less than 5.6, it is called acid rain (the lowest pH value of rain is 5.6 when it is 'clean'.)

Effects of Acid rain : The effects of acid deposition vary according to the sensitivity of ecosystems upon which the deposits fall.

(i) Acid rain affects vegetation, and soil in many ways. The growth of trees is adversely affected by acid rain. It affects forests and results in consequent vanishing of greenery.

(ii) Acidity affects soil. A plant nutrient such as potassium is gradually leached out of the soil. At the same time, a toxic element like zinc accumulates due to acid rain. Beneficial micro-organisms in the soil are reduced. The population of earthworms which are popularly called 'farmer friends', is reduced as they cannot tolerate an acidic environment.

Remedy : One of the simple solutions to the problem is to neutralise the acid with lime. It is a short-term measure, and it is required to be repeated periodically. But it is quite expensive, especially when areas is large.

GLOBAL WARMING

- The effect of increasing concentration of carbon dioxide is the much talked about topic related to global warming which is known as the *green house effect*.
- A green house is a construction of transparent walls and roof in cold countries to provide adequate heat to the soil and plants. The solar heat/energy penetrates the green house but is prevented from escaping, and thus heat remains within the green house keeping it warm. A similar process keeping the atmosphere warm is therefore, called the green house effect where mainly carbon dioxide entraps the incoming solar heat.
- 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.
- It is obvious that if the concentration of carbon dioxide keeps increasing more and more, heat will be built up in the atmosphere and on the earth's surface. Thus the atmospheric temperature will increase.

The major green house gases are

(i) Carbon dioxide (CO_2) (ii) Methane (CH_4)

(iii) Nitrous oxide (N_2O) (iv) Chloroflоro carbon (CFC)

Carbon Dioxide

- Carbon dioxide absorbs infra red rays causing increase in the heat level. Thus, the increasing concentration of carbon dioxide sets in motion a sort of heat trap.
- The contribution of carbon dioxide alone towards green house effect is estimated to be about 57 per cent.

Methane

- Its capacity to absorb heat is about twenty five times more than that of carbon dioxide but its concentration is small.
- The role of methane as an agent of green house effect is taken as about 12 per cent.

Nitrous Oxide

- Its contribution for green house effect is only 6 per cent (although the heat absorbing capacity of nitrous oxide is about 230 times more than that of carbon dioxide) because of its much lower concentration in the atmosphere.
- Excessive use of nitrogen fertilizers, increased agricultural activities and intensive vehicular traffic are responsible for increase in the concentration of nitrous oxide in the atmosphere.

Chlorofloro Carbon

- The use of chlorofloro carbon mainly takes place in the industries that manufacture refrigerators, air conditioners, paints and other sprays.
- This gas damages the ozone layer that surrounds the globe, and allows the short wave radiations to reach the surface of the earth. Thus, we can visualise that the increase of temperature due to chlorofloro carbon is not by absorbing and reflecting back the solar radiations, but by puncturing the ozone layer and consequent happenings.
- It is about 25 per cent responsible for overall green house effect.

Impact of Green House Effect

1. The temperature on earth may increase and the polar ice caps may melt vigorously and there would be rise in ocean level threatening the population near the coastal zones.
2. The flora and fauna would also be adversely affected by the increased temperature. Some of the organisms may become extinct as they may not be able to tolerate the high temperatures.
3. Sudden changes in the climate, formation of cyclones, stability of seasonal cycles, are expected to occur.

OZONE LAYER DEPLETION

- Ozone does occur in the troposphere, and plays an important role in the chemistry of air pollution, however, about 90% of the total ozone content of our atmosphere occurs in the *stratosphere* at altitude between 15 to 50 km
- The ozone layer acts as a filter for Ultra-Violet (UV) radiation from the sun. Therefore, this process serves as a protective shield to human life against the adverse effects of UV like burn and some types of skin cancer. It is obvious that any depletion of stratospheric ozone would be harmful to life on this earth. Hence, ozone layer is termed as *ozone umbrella*.
- Primary reason for ozone layer depletion is CFC (Chlorofluoro carbon) or freons.
- The freons are a group of chlorofluoro carbons used as aerosol propellants, refrigerants, solvents, and as gases for the production of foamed plastics.
- Ozone is destroyed due to the photolytic reaction of CFC as shown below:

$CF\,Cl_3 \xrightarrow{UV} Cl$ + other substances; $Cl + O_3 \longrightarrow ClO + O_2$

Methane, destroys Cl; and thus affords protection to the ozone layer. Similarly, NO_2 reacts with Cl, and helps to prevent the depletion of ozone layer.

- When there is no chlorine present in florocarbons, they are called hydroflorocarbons. These substances are a very important replacement for chloroflorocarbon because they pose no threat to the ozone layer as they do not contain chlorine.
- Vienna convention and Montreal Protocol was concerned with ozone layer depletion.

Kyoto protocol is concern with green house gases.

METEOROLOGY AND NATURAL PURIFICATION PROCESSES

Pollution problems arise due to atmospheric contaminants, adverse meteorological conditions or topographical conditions. Because of the close relationship that exists between air pollution and certain atmospheric conditions, it is necessary for the environmental engineer to have a through understanding of meteorology.

Elemental Properties of the Atmosphere

- The source of all meteorological phenomena is a basic, but variable, ordering of the elemental properties of the atmospheric heat, pressure, wind, and moisture.
- All weather, including pressure systems, wind speed and direction, humidity, temperature, and precipitation, ultimately results from variable relationships of heat, pressure, wind, and moisture.

Scales of Motion

The interaction of the four elements mentioned above may be observed on several different levels or scales. These scales of motion are related to mass movments of air which may be global, continential, regional, or local in scope.

According to their geographic range of influence, the scales of motion may be designated as macroscale, mesoscale, or microscale.

(i) **Macroscale** : Atmospheric motion on the macroscale involves the planetary patterns of circulation, the grand sweep of air currents over hemispheres. These phenomena occur on scales of thousands of kilometers and creates semipermanent high-and low pressure areas over oeans and continents.

- The direction of surface winds is usually controlled by the pressure gradient and rotation of the earth. Because of rotation of the earth along its axis the winds are deflected. The force which deflects the direction of winds is called **deflection force**.
- This force is also called **Coriolis force**. Because of Coriolis force, all the winds are deflected to the right in the northern hemisphere while they are deflected to the left in the southern hemisphere with respect to the rotating earth.
- The sun's rays heat the earth near the equator to a great extent , the heated air at the equator would rise and cool air from the poles would move in to take place.

(ii) **Mesoscale** : Secondary or measoscale, circulation patterns develop over regional geographic units, primarily because of the influence of regional or local topography. These phenomena occur on scales of hundreds of kilometers.

- Air movement on this scale is affected by the configuration of the earth's surface — the location of mountain ranges, oceanic bodies, forestation, and urban development.
- Land fronts, and urban heat islands are typical local phenomena observable on this scale.

for water 1 ppm = 1 mg/l
But in gas this is no so

(iii) Microscale : Microscale phenomena occur over areas of less than 10 km and can be exemplified by the meandering and dispersion of smoke plumes from industrial stacks.

- Phenomena on this scale occur within the friction layer, the layer of atmosphere at ground level where effects of frictional stress and thermal changes can cause winds to deviate markedly from a standard pattern.
- The frictional stress encountered as air moves over and around irregular physical surface such as buildings, trees, bushes. or rocks causes mechanical turbulence which influences the pattern of air movement.

Note: It is the movment of air on mesoscale and microscale levels that is of vital concern to those charged with the control of air pollution.

Heat

- Heat is the critical atmospheric variable, the major catalyst of climatic conditions.
- The heat energy in the atmosphere comes from the sun as short-wave radiation (about 0.5 μm) mostly in the form of visible light.
- The earth emits longer wavelengths (average of of 10 μm) than it receives, mostly in the form of nonvisible heat radiation.
- Four important ways in which heat transfer occurs in the troposphere are through the *greenhouse effect, the condensation-evaporation cycle, conduction*, and *convection*.

CONVERSION OF PPM INTO Mg/M³

Example 1

Convert 120 mg/m³ of SO_2 concentration into ppm.

Sol. We know that all gas at 0°C and atmospheric pressure occupies 22.4 litre/mole. (i.e. at STP (Standard Temp. and Pressure)

$$V_1 = 22.4 \text{ litre}$$

$$\text{Volume at } T°C = V_2$$

Now $$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$ [From gas law, (temperature is in Kelvin)]

But pressure is always atmospheric

$$\Rightarrow \quad V_2 = \frac{V_1(T_2)}{T_1} = \frac{V_1(273+T)}{273}$$

$$1 \text{ ppm } SO_2 = \frac{1 \text{ m}^3 \text{of } SO_2}{10^6 \text{m}^3 \text{ of air}}$$

Molecular wt of SO_2 = 64

$\Rightarrow$ 64 g of SO_2 occupies V_2 litre at T°C

$$1 \text{ m}^3 \text{ of } SO_4 \text{ will have } \frac{64000 \text{ mg}}{V_2} \times 1000$$

$$\Rightarrow \quad 1 \text{ ppm } SO_2 \text{ at } T^\circ C = \frac{64 \times 10^6 \text{mg}}{V_2 \times 10^6 \text{m}^3 \text{of air}}$$

$$= \frac{64}{V_2} \text{ mg/m}^3 \text{ of air}$$

$$\Rightarrow \quad \boxed{1 \text{ ppm at } T^\circ C = \left[\frac{\text{Molecular wt}}{(\text{Volume at } T^\circ C \text{ in litre/mole})}\right] \frac{\text{mg}}{\text{m}^3 \text{of air}}}$$

$$\Rightarrow \quad \boxed{\frac{1 \text{ mg}}{\text{m}^3} \text{ of } SO_2 = \left(\frac{\text{Volume } T^\circ C \text{ in litre/mole}}{\text{Molecular wt}}\right) \text{ppm}}$$

$$\Rightarrow \quad \frac{120 \text{ mg}}{\text{m}^3} \text{ of } SO_2 = \frac{120 \times 22.4 \times \frac{293}{273}}{64} \text{ ppm}$$

$$= \mathbf{45 \text{ ppm}}$$

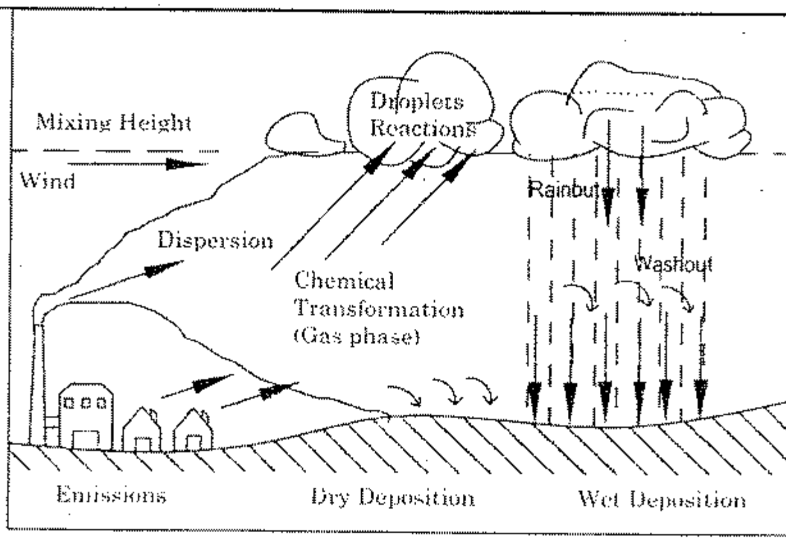
CONTROL OF AIR POLLUTION

The air pollutants in atmosphere are controlled by natural processes as well as by engineered systems wherever necessary.

Natural Processes

There are some natural processes which act as the pollution removal mechanisms in the atmosphere, such as, dispersion, settling, washout, rainout and adsorption.

- Although dispersion is not really a removal mechanism, it reduces concentration of pollutants at one place.
- Settling means gravitational settling which removes relatively larger particles of diameter greater than 20 micrometer.
- Washout or scavenging is the natural absorption process where particulates or gaseous of pollutants are collected in rain or mist and settle down with that moisture.



Process taking place between the emission of a pollutant and its ultimate deposition on the ground

- Washout occurs below cloud level.
- Rainout occurs within the clouds where the drops from around the submicron particulates.
- Adsorption takes place near the layer of atmosphere closest to the earth's surface. The pollutants, solid, liquid or gases, are attracted to the surface and retained there.

Engineered Systems

There are two approaches for air pollution control:

(a) Dilution (b) Control at Source

Dilution : Tall chimneys discharge the contaminants at a higher level from the ground where they get diluted in the atmosphere. Thus, the concentration of contaminants at ground level are greatly reduced. It is, however, obvious that the method does not remove/reduce the pollution load from the total environment.

Control at Source : Many devices are available to control the pollutants at the source itself. Depending on the type of pollutants (particulates or gaseous) various systems are:

CONTROL DEVICES FOR PARTICULATES

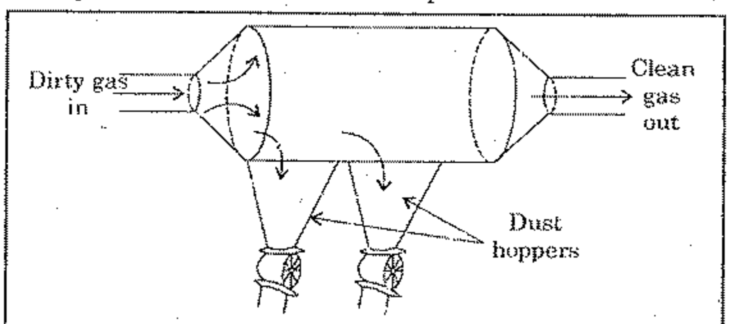
1. Gravitational Settling Chambers

- Like settling basins in water and wastewater system, settling chambers in air-pollution-control systems provide enlarged areas to minimize horizontal velocities and allow time for the vertical velocity to carry the particle to the floor.
- The usual velocity through settling chambers is between 0.5 to 2.5 m/s, although for best results the gas flow should be uniformly maintained at less than 0.3 m/s.
- The emitted smokes, when made to pass through a settling chamber, drop some of their larger sized particles in the chamber as per Stoke's Law. The largest size particle (*d*) that can be removed with 100% efficiency in such a chamber of length *L* and height *H* is given by

$$d = C.\sqrt{\frac{18\mu.v_h.H}{g.L.\rho_p}}$$

where, v_h = horizontal velocity of gas passing through the chamber, between 0.5 to 2.5 m/sec.

- Simple to design and maintain, and low pressure loss.
- Requires larger space for installation, and has low collection efficiency.
- Only larger sized particles are separated out.
- Although theoretically they should be able to remove particulates down to 5 or 10 μm, but in actual, they are not practical for the removal of particles much less than 50 μm in size.



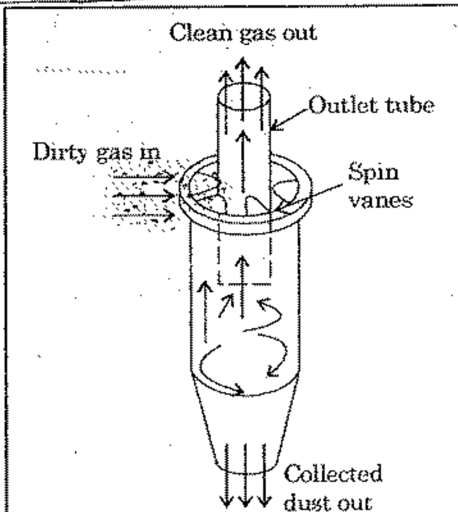
Gravitational Settling Chambers

(2) Centrifugal Gas Collectors

- Centrifugal collectors employ a centrifugal force instead of gravity to separate particles from the gas stream.
- Particles can be removed in centrifugal collectors that are much smaller than those that can be removed in gravity settling chambers.
- In general, there are two types of centrifugal collectors : cyclone collectors (or separators) dynamic precipitators.

Cyclone Collectors

- A cyclone collectors consists of a cylindrical shell, conical base, dust hopper, and an inlet where the dust-laden gas enters tangentially.
- A cyclone collector is a closed chamber, in which the inlet velocity of the gas (smoke) is transformed into a spinning vortex, which helps to throw out the particles under the generated centrifugal force. The particles then slide down the chamber walls into the hopper from where they come out.
- The operating or separating efficiency of a cyclone depends on the magnitude of the centrifugal force exerted on the particles. The greater the centrifugal force, the greater the separating efficiency.
- Large-dia. cyclone collectors have good collection efficiencies for particles 40 to 50 μm in diameter. High-efficiency cyclones with diameters of 23 cm or less have good efficiencies for particles from 15 to 20 μm.
- The cleaning efficiency for units may be as high as 90 percent for particulates in the 5- to 10-μm range.
- They are relatively inexpensive to construct and operate, and they can handle large volumes of gases at temperatures up to 980°C.
- Pressure drops across these unit are generally low and range from 2.5 to 20 cm of water.
- Cyclones have been used successfully at feed and grain mills, cement plants, fertilizer plants, petroleum refineries, asphalt mixing plants and other applications involving large quantities of gas containing relatively large particles.



A collector element of cyclone

Dynamic Precipitators

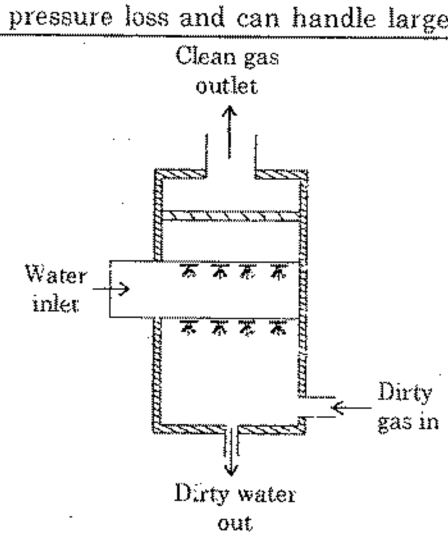
- A dynamic precipitator imparts a centrifugal force to the particulate in the incoming gas by the action of its rotating vanes.
- This process is about 7 times more effective than the cyclone type.
- This unit can function as an exhaust fan as wall as a dust collector.
- They are widely used in ceramics, food and pharmaceutical, and wood working industries.
- These machines cannot work with wet fibrous material which may tend to accumulate onto the rotating vanes.

(3) Wet Scrubbers (or Collectors)

- Wet scrubbers remove the particulates from the incoming gaseous stream by allowing the flue gases to flow up against a falling water (liquid) stream.
- The particulates mix up with the droplets (either due to interception or inertial impingement) and then fall down and gets removed.
- When aqueous chemical solutions, other than water, like lime, potasium carbonate (K_2CO_3), slurry of MnO and MgO, etc. are used, we achieve the removal of gaseous pollutants also from the flue gases.
- According to the contact-power theory developed for scrubbers, collection efficiency for well designed wet collectors of all types is a function of the energy consumed in the air-to-water contact process. The energy consumed is directly proportional to the pressure drops.
- The cleaning efficiency of wet collectors varies directly with the size of the particulates being collected in addition to the pressure drop.
- Generally, collectors operating at very low pressure loss will remove only medium- to coarse-size particles, while collectors operating at higher pressure losses (and therefore increased energy output) will be highly efficient at removing fine particles.
- Most commonly used wet collectors for control of particulate matter – the spray tower, the wet cyclone scrubber, and the venturi scrubber.

Spray Towers

- Spray towers are low-cost scrubbers that can be used to remove both gaseous and particulate contaminants.
- The units cause very little pressure loss and can handle large volumes of gases.



Spray Tower

Wet Cyclone Scrubbers

- In a simple wet cyclone scrubber, high-pressure spray nozzles located in various places within the cyclone chamber generates a fine spray that intercepts the small particles entrained in the swirling gases.
- The particulate matter thrown to the wall is then drained to the collection sump.
- Efficiency approaches 100 percent for droplets of 100 μm and 90 to 98 percent removal is achieved for droplets between 5 and 50 μm.
- Particle removal depends on contact with the liquid droplets and is a function of the liquid flow rate and liquid droplet and particle sizes.
- Efficiencies slightly higher than those obtained with the spray tower can be expected.

Venturi Scrubbers

- Venturi Scrubbers are most efficient for removing particulate matter in the size range of 0.5 to 5 μm, that makes them especially effective for the removal of submicron particulates associated with smoke and fumes.
- At velocities from 60 to 180 m/s, the contaminated gas passes through a duct that has a venturi-shaped throat section. A coarse water spray is injected into the throat, where it is atomized by the high gas velocities. The liquid droplets collide with the particles in the gas stream, and the water and particles fall down for later removal.
- Venturi scrubbers can efficiently remove gaseous as well as particulate contaminants.

(4) Electrostatic Precipitators

- In electrostatic precipitators, the emitted gas (flue gas) is passed through a highly ionised atmosphere (high-voltage field); and there in that zone particulates get electrically charged with the result that they get separated out from the gaseous stream with the help of electrostatic forces.
- They are extensively used in thermal power plants, pulp and paper industries, mining and metallurgical industries, iron and steel plants, chemical industries, etc.
- Four basic steps required in the operation of a high-voltage single-stage electrostatic precipitator

  (a) electrical charging of the particulates,

  (b) collection of charged particles on a grounded surface,

  (c) neutralization of the charge at the collector, and

  (d) removal of the particulate for disposal.

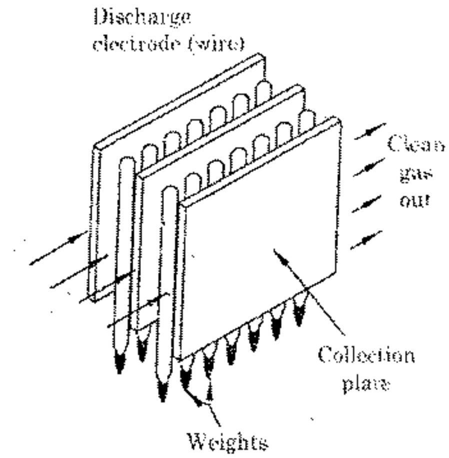
  There are many advantages associated with electrostatic precipitators:

  (i) very small particles also, wet or dry, can be easily trapped (size : about 1 μm);

  (ii) more than 99% efficiency can be achieved in their functioning (usual range of efficiency is 95 to 99%)

  (iii) they have only few moving parts, and thus the requirement of repair, etc. is minimal;

  (iv) they can be operated at high temperatures (upto 300 to 450°C).



High Voltage Electrostatic Precipitators

(5) Fabric Filters

- In fabric filters, the gas stream (laden with particles) is passed through a woven or felted fabric which filters out particulate matter, allowing the gaseous matter to flow on.
- Small, particles are initially retained on the fabric by direct interception, inertial impaction, diffusion, electrostatic attraction, and gravitational settling.
- The collection of sub-micron particles is accomplished by sieving, after a mat of dust gets found on the fabric.
- Filter bags, are capable of removing most particles as small as 0.5 μm and will remove substantial quantities of particles as small as 0.1 μm with an efficiency greater than 99%.

Applications

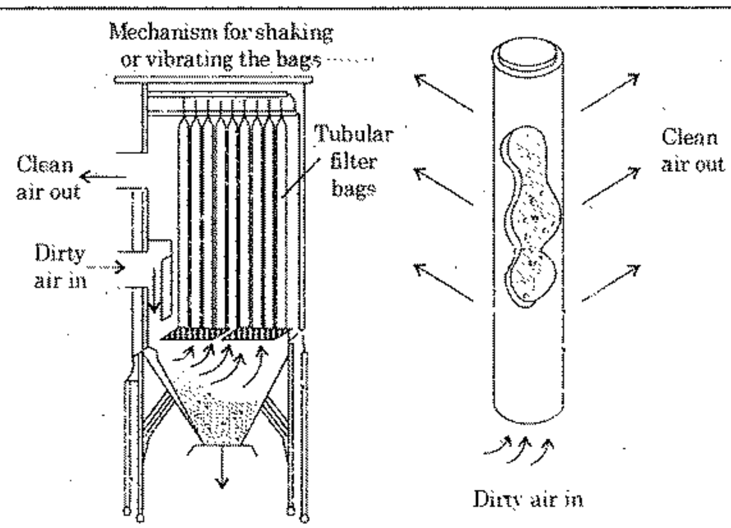
(i) Has a high collection efficiency over a broad range of particle sizes,

(ii) Extremely flexible in design,

(iii) Ability to handle large volumes of gases at relatively high speeds,

(iv) Reasonable operating pressure drops and power requirements, and the ability to handle a diversity of solid materials,

(v) They are particularly useful in many high-volume operations such as cement kilns, foundries, steel furnaces, and grain handling plants.



Bag House Fabric Filter Unit

CONTROL DEVICES FOR GASEOUS POLLUTANTS

The major air contaminants in the gaseous form are sulphur oxide (SO_x), nitrogen oxides (NO_x), carbon oxides (especially CO), hydrocarbons and organic as well as inorganic acid gases. The engineered systems available for the control of these gaseous contaminants work on various principles, such as, adsorption, absorption, condensation, and combustion.

Adsorption Unit

- The pollution laden gas is made to pass through the beds of a porous material contained in an adsorption bed (adsorbent material).
- Pollutants are effectively caught and held on the surface of the material by the process of physical or chemicals adsorption.
- The two key characteristics of solid adsorbents are — preferential affinity for specific substances and surface to volume ratio (large surface area per unit of weight is essential)
- The adsorbent commonly employed are : activated carbon, aluminium, magnesium, silica gel, and fullers earth, molecular sieve (dehydrated zeolites *i.e.* alkali or metal silicates).
- Activated carbon beds can very effectively catch hydrocarbons, H_2S and SO_2 while molecular sieve can capture NO_2.
- It may be pointed out, that almost all the adsorbents get destroyed at moderately high tempeatures : 150°C for activated carbon, 600°C for molecular sieves, 400°C for silica gel, and 500°C for activated alumina. Thus, the devices may become inefficient at such high temperatures.
- Adsorbers, the devices that contain the adsorbent solid through which the effuent gas must pass are mainly of three types — fixed bed, moving bed, or fluidized beds.

(i) Fixed bed Adsorbers

- The container for fixed bed adsorption unit can be a vertical or horizontal cylindrical shell
- In this unit, activated carbon (in general) is arranged on beds or trays in 1.3 cm thick layer in thin bed adsorbers and greater than 1.3 cm thick layers in deep bed absorbers.
- If more than one bed is used, it is called multiple fixed bed adsorbers.

(ii) Moving bed Adsorbers

In this unit, activated carbon is contained in a rotating drum. The filtered air, containing the gaseous contaminant, is moved by the fan into the rotating drum section. The vapor laden air enters ports above the carbon bed, passes through the cylindrical activated carbon bed, enters the space in the inside of this drum, then leaves by ports at the ends of the drum.

(iii) Fluidized bed Adsorbers

- The fluidized adsorber contains a shallow, floating bed of adsorbent. The expanding and fluidizing the adsorbent.
- The expanding and fluidizing of the adsorbent provides for initimate contact between the contaminated gas and the adsorbent and prevents channeling problems often associated with fixed beds.
- Once the gaseous contaminant has been adsorbed, the cleaned air stream passes through a duct collector before being discharged to the atmosphere.

Absorption Units

- The gas stream (to be purified) is brought in contact with a solvent (liquid adsorbent); and one or more contaminants, present in the gas, are removed, treated or modified depending upon the type of contaminated gas and the solvent used.
- Solvent or liquid adsorbents may utilize either chemical (reactive) or physical (non-reactive) change to remove pollutants.
- The main solvents for effective removal of SO_2 are aqueous solutions of alkalis and alkaline earths (Na, NH_3, MgO, CaO).
- Gas absorption units are designed to provide intimate contact between the gas and the liquid and to provide optimum diffusion of the gas into the solution.
- Different types of absorbers are — spray towers, plate or tray towers, packed towers, and venturi scrubbers.

(i) Spray Towers

- Spray towers can handle fairly large volumes of gas with relatively little pressure drop and reasonably high efficiency of removal - only when gaseous contaminant concentrations are fairly low.
- Effective for removal of particulate and gaseous contaminants, since they can handle gases with fairly high concentrations of particulates without plugging.
- In general, the smaller the droplet size and the greater the turbulence, the more chance for absorption of the gas.
- Spray towers are generally less effective in removal of gaseous contaminants since they have less gas-liquid interfacial area than most other types of absorbers.

(ii) Plate or Tray Towers

- Plate or tray towers contain horizontal trays or plates designed to provide large liquid gas interfacial areas.
- In the perforated plate column, the absorbent enters from the side of the column near the top and spills across the top sieve tray. The liquid flows across this trays, over a weir, and to a downpipe that directs the flow to the next tray down. Zigzag flow continues until the liquid reaches the bottom of the column.
- The polluted air, introduced at one side of the bottom of the column, rises up through the openings in each tray, and it is the rising gas that prevents the liquid from draining through the openings rather than through the downpipe.
- Through repeated contact between air and liquid, gaseous contaminants are removed, and the clean air emerges from the top of the column.

(iii) Packed Towers

- In a packed tower, packing is used to increase the contact time between vapor and liquid.
- The material chosen has a large surface-to-volume ratio and a large void ratio that offers minimum resistance to gas flow, also are light weight and virtually unbreakable.
- Typically, flow through a packed tower is countercurrent, with gas entering at the bottom of the tower and liquid entering at the top. Liquid flow over the surface of the packing in a thin film, affording continuous contact with the gases.
- Packed towers become easily clogged when gases with high particulate loads are introduced

Condensation Units

- *The principle underlying condensation technique can be stated as:* A compound will condense at a given temperature if its partial pressure in increased until it is equal to or greater than its vapor pressure.
- There are two basic types of condensation equipment — surface and contact condensers.
- In a **surface condenser**, physical adsorption plays a key role, since contaminants are adsorbed onto a surface as the gaseous compound condenses.
- In a **contact condenser**, the vapour and cooling medium are brought into direct contact. Contact condenser are less expensive and more flexible than surface condensers, and they are more efficient in removing organic compounds.
- It is generally considered as pretreatment devices for air pollution control, condensers are used in conjuction with after burners, absorbers, or adsorption units.

Combustion (or Incineration) Units

- Combustion as a process is used to purify polluted gases, only when the admixed pollutants are oxidisable to inert gases. Hydrocarbons, and carbon monoxide (CO) can be easily burnt, oxidised and removed.
- The combustion equipement used to control air pollution emissions is designed to push oxidation reactions as close as possible to completion, leaving a minimum of unburned compound.
- For efficient combustion to occur, it is necessary to have the proper combination of four basic elements — oxygen, temperature, turbulence, and time.

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** : Here waste gases are burned directly in a combustor, with or without the addition of a supplementary fuel.

(ii) **Thermal Combustion** : In cases where the concentration of combustible gaseous pollutants is too low to make direct-flame incineration feasible, a thermal incinerator or afterburner can be chosen.

(iii) **Catalytic Combustion** : It can be used when combustible materials in the waste gas are too low to make direct-flame incineration feasible. A catalyst accelerates the rate of oxidation without itself undergoing a chemical change, thus reducing the residence, or dwell, time required for incineration.

Examples of Catalysts

(i) Vanadium pentoxide (at high temperatures) — for removing SO_2

(ii) Platinum metals — for treating NO_x

(iii) Activated alumina — for hydrocarbons

(iv) Palladium II (Pd II), and Cu (II) — to oxidise CO and CO_2

CONTROLLING AIR POLLUTION CAUSED BY AUTOMOBILES

Emissions from petrol engines contain greater concentrations of HC and CO; while, the four stroke diesel engines (buses and trucks) contain greater concentrations of NO in addition to thick smoke and particulate matter.

Catalytic convertors help in oxidising CO and HC into CO_2; they also reduce NO into nitrogen. These convertors are generally made of noble metals like platinum, palladium.

Note: Maximum permissible carbon monoxide emission while idling
= 3% for cars
= 4.5% for 2- and 3-wheelers

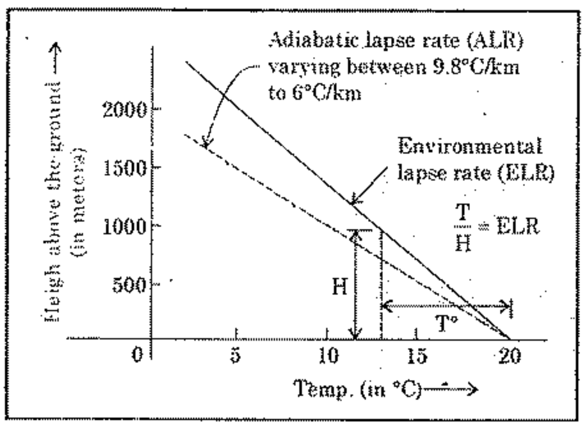
DISPERSION OF AIR POLLUTANTS INTO THE ATMOSPHERE

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 ELR can be determined by sending up a ballon equipped with a thermometer and a self recording mechanism. The lapse rate so obtained is known as the prevailing lapse rate, or the ambient lapse rate or the environmental lapse rate (ELR).



(ii) Adiabatic Lapse Rate

- When a parcel of air which is hotter and lighter than the surrounding air is released, then naturally it tends to rise up until it reaches a level at which its own temperature and density becomes equal to that of the surrounding air. This rate of decrease of temperature with height is called adiabatic lapse rate.

- A parcel of artificially heated air (e.g., stack gas or automobile exhaust) rises, expands, becomes lighter, and cools. The rate at which the temperature decreases as the parcel gains altitude (the lapse rate) may be considerably different from the ambient lapse rate of the air through which the parcel moves.

- Dry air expanding and colling adiabatically cools at rate of 9.8°C per km and it is called dry adiabatic lapse rate.

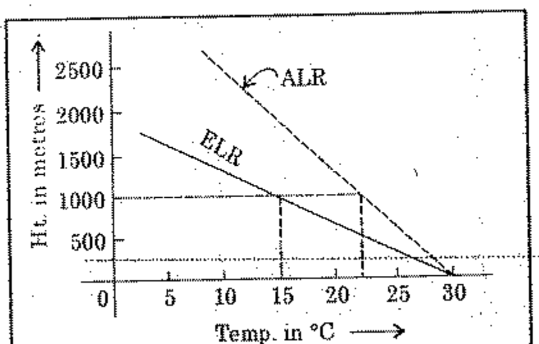
- In saturated (wet) air, this rate is calculated to be 6°C per km, and is known as wet adiabatic lapse rate(due to release of latent heat or condensation of water vapour within the saturated parcel of rising air).

- Since a rising parcel of emitted smokes will normally neither be fully dry nor full saturated, the actual (ALR) representing cooling of the emitted smokes, will be some where between the dry adiabatic rate (9.8°C/km) and wet adiabatic rate (6°C/km).

Note : Here we are talking about two major entities and interaction between them . They are parcel of air and ambient air

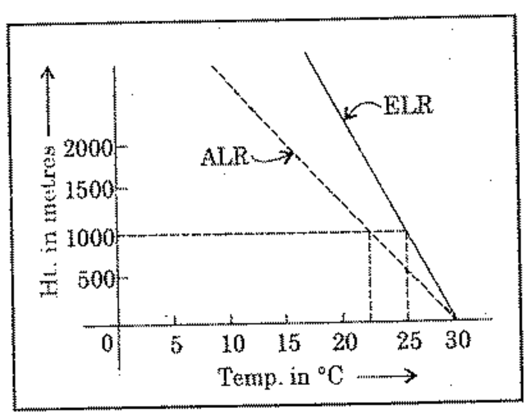
(a) *Super Adiabatic Lapse Rate*

- When the ambient lapse rate (ELR) exceeds the adiabatic lapse rate (ALR), the ambient lapse rate is said to be super adiabatic and the atmosphere is said to be highly unstable.
- In this case, parcel of air will always remain warmer and descending parcel will always remain cooler than the surrounding air. Hence, rising parcel will continue to lift up while descending particle will continue to come down.
- Dispersion of pollutants will be rapid due to rapid vertical mixing of the air making the environment unstable.



(b) *Sub-adiabatic Lapse Rate*

When the ambient lapse rate (ELR) is less than adiabatic lapse rate, the ambient lapse rate is termed sub-adiabatic lapse rate and the atmosphere is stable.

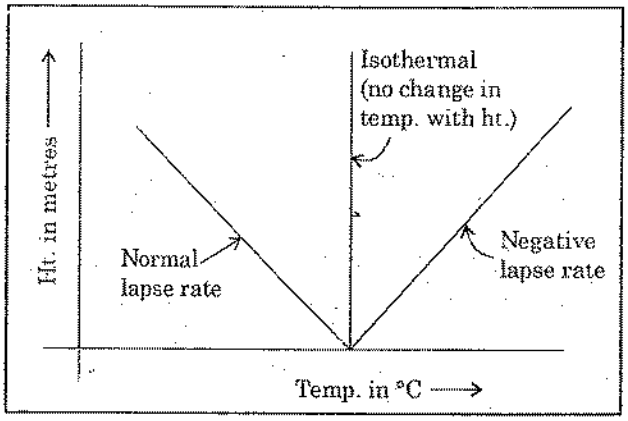


(c) *Neutral*

When the two lapse i.e. ELR and ALR are exactly equal, the atmosphere is said to be neutral.

Negative Lapse Rate and Inversion

- When the temperature of the environment increases with altitude then the lapse rate becomes inverted or negative from normal state.



- Negative lapse rate occurs under conditions usually referred to as inversion (a state in which the warmer air lies over the colder air below).
- Such situation may occur near the earth's surface or at greater height in the troposphere but the inversion of temperature near the earth's surface is of very short duration because the radiation of heat from the earth's surface during daytime warms up the cold air layer which soon disappears and temperature inversion also disappears.

  There are two types of inversion:

  (i) Radiation inversion

  (ii) Subsidence inversion

(i) *The Radiation Inversion*

- A phenomenon arising from the unequal cooling rates of the earth and the air above the earth
- In other words, the earth cools rapidly and more quickly than the air above it, naturally the temperature in the environment will be less at the earth and will increase above it causing negative lapse rate and inversion conditions.
- This type of inversion extends to a few hundred meters into the friction layer and is characteristically a nocturnal phenomenon that breaks up with the rays of the morning sun.
- Such an inversion in the environments helps in formation of fog when air is wet and simultaneously catches gases and particulate matter as it stops their upward lifting.
- It is also called ground surface inversion

(ii) *Subsidence Inversion*

- This is associated with a high pressure system and is caused by the characteristic sinking or subsiding motion of air in a high pressure area surrounded by low pressure area *i.e.* anti cyclones
- It is also called mechanical inversion
- This type of inversion may extend through the friction layer to height of over 1500 m.

Note : Sometimes both the radiation as well subsidence inversions may occur simultaneously causing what is known as double inversion.

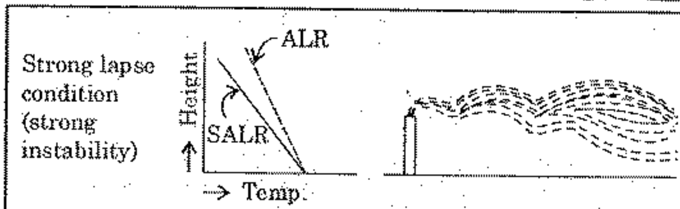
PLUME BEHAVIOUR

Plume is defined by the path taken by continuous discharge of gaseous effluents emitted from a stack or chimney. The shape of the path and the concentration distribution of gaseous plumes depends upon localized air stability.

Typical situations generally encountered in the lower atmosphere (< 300 m above ground), are (i) looping plume (ii) neutral plume (iii) coning plume (iv) fanning plume (v) lofting plume (vi) fumigating plume and (vii) trapping plume.

(i) Looping plume

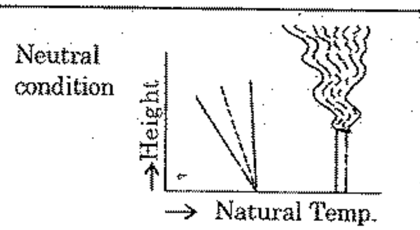
- This is common type of plume behaviour which occurs under superadiabatic lapse rate (SALR) conditions with light to moderate wind speeds on a hot summer afternoon when large scale thermal eddies are present.
- The plume has wavy behaviour since it occurs in a highly *unstable* atmosphere.
- High turbulence helps in rapid dispersion of the plume, but high concentration touch the ground.



Looping Plume

(ii) Neutral plume

- Neutral plume is the upward vertical rise of the plume from the stack, which occurs when the ELR is equal to ALR.
- The upward lifting of the plume will continue till the air density becomes similar to that of the plume itself

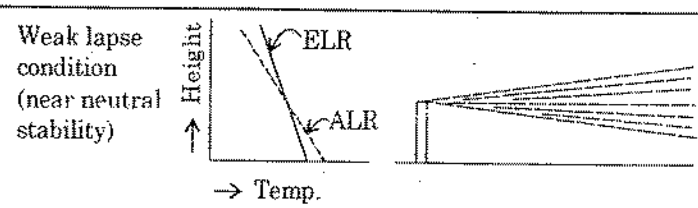


Neutral Plume

(iii) Coning plume

under Neutral Condition and W.S >32 km/hr

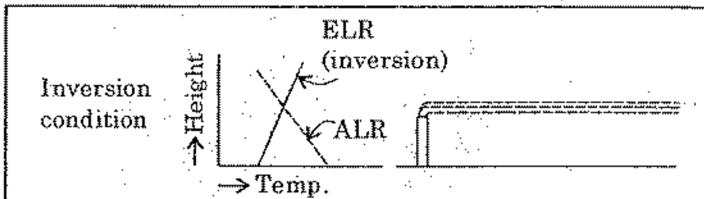
- Coning plume occurs on cloudy day or nights with strong winds velocity (> 32 km/hr) when the lapse rate is near neutral.
- The plume shape is vertically symmetrical about the plume line.
- However, the plume reaches the ground at greater distance than with looping plume.



Coning plume

(iv) Fanning plume

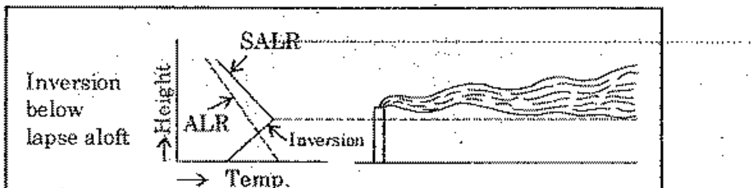
- This occurs under extreme inversion conditions, in the presence of light wind.
- Most of the vertical dispersion is suppressed by extremely stable condition, and the plume fans out in the horizontal direction.



Fanning Plume

(v) Lofting plume

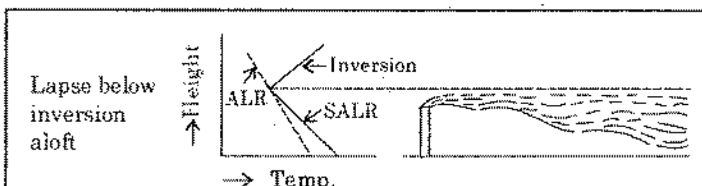
- Plume is said to be lofting when there exists a strong super adiabatic lapse rate (SALR) above inversion.
- In such a condition, downward motion and mixing is prevented by surface inversion but the upward mixing will be quite turbulent and rapid. The emission will, therefore, not reach the ground surface.
- Lofting is the most favourable plume type as far as ground level concentrations are concerned and is one of the major goals of tall-stack operation.



Lofting Plume

(vi) Fumigating plume

- The conditions for fumigation are just the inversion of lofting plume.
- Fumigation takes place when an inversion layer occurs at a short distance above the top of the stack and super adiabatic conditions prevail below it. Hence the pollutants cannot escape above the top of stack and they are brought down rapidly near ground due to turbulence in the region above the ground and below the inversion, caused by strong lapse rate.
- Fumigation represents quite a bad case of atmosphere dispersion.

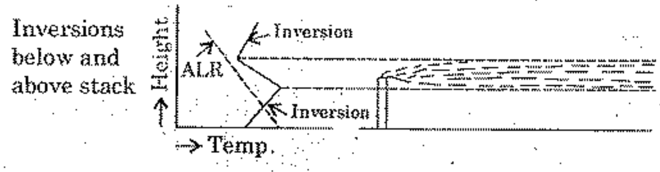


Fumigating Plume

(vii) Trapping plume

- This condition is achieved when the plume caught between two inversion layers. Hence the emitted plume can neither go up nor down and will be trapped between the two levels.

- The diffusion of the effluent will be severely restricted to the unstable layer between the two stable regions.
- A trapping plume is considered to be a bad condition for dispersion.



Trapping Plume

DESIGN OF STACK HEIGHT

Central Board for prevention and control of water pollution (New Delhi), through its publications: **Emission Regulation (July 1984) Part (I) and (II)** [a method to determine minimum chimney height] has given the following recommendations for the height of chimney:

(i) For chimney emitting particulate matter:

$h = 74\,(Q_p)^{0.27}$ (height in metre)

where h = height of chimney

Q = particulate matter emission (tonnes/hour)

(ii) For chimney emitting SO_2

$h = 14\,(Q_s)^{1/3}$ (height in metre)

where $Q_s = SO_2$ emission (kg/hour)

(iii) Minimum values

The Board has further recommended that the height of the chimney calculated on the basis of particulate matter and SO_2 emissions by the above two equations should be subject to the following minimum values:

(i) For chimney adopted for industries in general (except thermal power plants) – 30 m

(ii) For thermal power plants above 200 MW and below 500 MW capacity – – – – 220 m

(iii) For thermal power plants having greater than 500 MW capacity – – – – – – – – 275 m

Example 2

A factory uses 1.5 ML of fuel oil per month. The exhaust gases from the factory contain the following quantities of pollutants per ML per year:

(i) Particulate matter : = 4 t/year

(ii) SO_2 : 20 t/year

(iii) NO_x : 5 t/year

(iv) HC, CO and other : 3 t/year.

Determine the safe height of the chimney required for the safe dispersion of the pollutants.

Sol. The concentrations of NO_x, HC, CO and others are generally very much less than the concentration of SO_2 in various industries. Hence the Board has made only SO_2 as the criterion for design, along with the particulate matter.

(a) Height of chimney on the basis of particulate matter:

$h = 74\ (Q_p)^{0.27}$

Particulate matter emission = 4 (1.5 × 12) = 72 t/year

Assuming 300 working days in a year, and 24 hours working a day,

$$Q_p = \frac{72}{300 \times 24} = 0.01 \text{ t/hour}$$

$$\therefore \quad h = 74\ (0.01)^{0.27} = 21.34 \text{ m}$$

(b) Height of chimney on the basis of SO_2

$$h = 14(Q_s)^{1/3}$$

Now, SO_2 emission = 20(1.5 × 12) = 360 t/year

$$\therefore \quad Q_s = \frac{360}{300 \times 24} = 0.05 \text{ t/hour}$$

$$= 50 \text{ kg/hr}$$

$$\therefore \quad h = 14(50)^{1/3} = 51.58 \text{ m}$$

∴ Required height of chimney ≈ 52 m.

Example 3

A factory uses 2,00,000 litres of furnace oil (specific density .097) per month. If for one million litres of oil used per year, the particulate matter emitted is 3.0 tonnes per year, SO_2 emitted is 59.7 tonnes per year, NO_x emitted is 7.5 tonnes per year, hydrocarbons emitted are 0.37 tonnes per year, and carbon monoxide emitted is 0.52 tonnes per year, calculate the height of the chimney required to be provided for safe dispersion of the pollutants.

Sol. As per emission regulations (July 1984) part I published by the Central Board Prevention and Control of water Pollution, (New Delhi, the chimney height is to be calculated according to the formula:

$$H = 74(Q)^{0.27}$$

where, Q = particulate mater emission in tonnes per hour

H = height of chimney in metres

The particulate emission is equal to 3.0 tonnes per million litres of oil per year.

Consumption of oil is equal to 2,00,000 × 12

= 24,00,000 *l*/year

= 2.4 million *l*/year

Therefore,

Total particulate emission = 2.4 × 3.0 = 7.2 tonnes per year

$= \frac{7.2}{300 \times 24}$ tonnes per hour (assuming 300 working days and 24 hours per day).

Now,
$$H = 74\left(\frac{7.2}{300 \times 24}\right)^{0.27}$$

$= 11.47$ m

The height of the chimney for effective dispersion of SO_2 is to be calculated as per the formula

$$H = 14(Q)^{0.3}$$

where, $Q = SO_2$ emission in kg/h

H = height of chimney in metres

Q in the example $= 59.7 \times 2.4 = 144$ tonnes per year

$= 20$ kg/h

Therefore, $H = 14(20)^{0.3} = 34.4$ m

So, adopt a height of 34.4 metres.

(Since the emission of SO_2 is much more than that of NO_x, CO, and hydrocarbons, the calculation of stack height is done based on SO_2 emission data only).

OBJECTIVE QUESTIONS

1. Electrostatic precipitator is a device to control
   (a) SO_2 emission
   (b) particulate emission
   (c) both SO_2 and particulate emission
   (d) precipitation of $Al(OH)_3$ in water coagulation

2. Which of the following pollutants is responsible for depletion of ozone layer?
   (a) Unburnt hydrocarbons (b) UV rays
   (c) Chlorofluoro carbons (d) Oxides of nitrogen

3. The traffic density for a highway is 1200 vehicles/hr and the average vehicle speed is 80 km/hr. The average carbon monoxide emission per vehicle is 40 g/s. What is the source strength per unit length?
   (a) 0.4 g/ms (b) 0.6 g/ms
   (c) 1.0 g/ms (d) 1.2 g/ms

4. Match **List-I** (Pollution control equipment) with **List-II** (Pollutant removed) and select the correct answer using the codes given below the lists:

	List-I		**List-II**
A.	Cyclones	**1.**	Oily gas emission
B.	ESP	**2.**	Coarse particulate matter
C.	Wet scrubbers	**3.**	Oxides of nitrogen
D.	Adsorbers	**4.**	Fine particulate matter

Codes:

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

5. What are the phenomena of global warming and acid rain formation attributed to?
   (a) SO_2 and CO_2, respectively
   (b) CO and SO_2, respectively
   (c) CO_2 and SO_2, respectively
   (d) CO and CO_2, respectively

6. What is the plume shape during unstable super-adiabatic atmosphere conditions termed as?
   (a) Coning plume (b) Fanning plume
   (c) Looping plume (d) Lofting plume

7. The mean indoor airborne Chloroform ($CHCl_3$) concentration in a room was determined to be 0.4 $\mu g/m^3$.
Use the following data: T = 293K, P = 1 atmosphere, R = 82.05×10^{-6} atm-m^3/mol-K.
Atomic weights: C = 12, H = 1, Cl = 35.5. This concentration expressed in parts per billion (volume basis, ppbv) is equal to

(a) 1.00 ppbv (b) 0.20 ppbv
(c) 0.10 ppbv (d) 0.08 ppbv

8. Two electrostatic precipitators (ESPs) are in series. The fractional efficiencies of the upstream and downstream ESPs for size d_p are 80% and 65%, respectively. What is the overall efficiency of the system for the same d_p?

(a) 100% (b) 93%
(c) 80% (d) 65%

9. 50 g of CO_2 and 25 g of CH_4 are produced from the decomposition of municipal solid waste (MSW) with a formula weight of 120 g. What is the average per capita green house gas production in a city of 1 million people with a MSW production rate of 500 ton/day?

(a) 104 g/day (b) 120 g/day
(c) 208 g/day (d) 313 g/day

10. Two primary air pollutants are

(a) sulphur oxide and ozone (b) nitrogen oxide and peroxyacetylnitrate
(c) sulphur oxide and hydrocarbon
(d) ozone and peroxyacetylnitrate

11. Particulate matter (fly ash) carried in effluent gases from the furnaces burning fossil fuels are better removed by

(a) Cotton bag house filter (b) Electrostatic precipitator (ESP)
(c) Cyclone (d) Wet scrubber

12. Match **List-I** with **List-II** and select the correct answer by using the codes given below the lists:

List-I	**List-II**
A. Coriolis effect.........	1. Rotation of earth
B. Fumigation	2. Lapse rate and vertical temperature profile
C. Ozone layer	3. Inversion
D. Max. mixing depth (mixing height)	4. Dobson

Codes:

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

13. What are the air pollutants responsible for acid rain within and downwind areas of major industrial emissions?

(a) Hydrogen sulfide and oxides of nitrogen (b) Sulfur dioxide and oxides of nitrogen

(c) Carbon dioxide and hydrogen sulfide (d) Methane and hydrogen sulfide

14. Consider the following air pollutants:

1. NO_X 2. PAN

3. CO_2 4. CO

Which of the above air pollutant s is/are present in an auto exhaust gas?

(a) 1 only (b) 1 and 2

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

15. **Assertion (A):** Traffic 'Smog' is likely to occur in regions where vehicle mileage is consideratble and there is a low incidence of sunlight.

Reason (R): Traffic 'Smog' is caused by the raction of oxides of nitrogen and some of the hydrocarbons in presence of bright sunlight.

16. Which of the following are responsible for the formation of photochemical smog?

1. Light intensity
2. Ratio of hydrocarbons to nitric oxide
3. CO_2
4. Hydrocarbon reactivity
5. SO_2

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

(c) 2, 3 and 4 (d) 2, 3 and 5 only

17. Match **List-I** with **List-II** and select the correct answer by using the codes given below the lists:

List-I	**List-II**
A. CO	**1.** Greenhouse effect
B. CO_2	**2.** Acid rains
C. SO_2	**3.** Acute toxicity
D. NO_X	**4.** Ozone liberation at ground level

Codes:

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

18. The atmosphere extends upto a height of 10,000 m. It is divided into the following four thermal layers:

1. Mesosphere
2. Stratosphere

3. Thermosphere
4. Troposphere

The correct sequence of these starting from the surface of the earth upwards is

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

19. When was the water (Prevention and Control of Pollution) Act enacted by the Indian Parliament?

(a) 1970 (b) 1974
(c) 1980 (d) 1985

20. Ringelmann's scale is used to

(a) measure CO (b) measure SO_2
(c) grade density of smoke (d) grade automobile exhaust gas

21. Which of the following air pollutants is/are responsible for photochemical smog?

1. Oxides of nitrogen
2. Ozone
3. Unburnt hydrocarbons
4. Carbon monoxide

Select the correct answer using the codes given below:

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

22. Match **List-I** (Equipment) with **List-II** (Pollutants removed) and select the correct answer by using the codes given below the lists:

List-I	**List-II**
A. Electrostatic precipitators	**1.** Coarse particles
B. Cyclones	**2.** Fine duct
C. Wet scrubbers	**3.** Gas
D. Adsorbers	**4.** Sulphur dioxide

Codes:

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

23. Match **List-I** (Pollutants) with **List-II** (Sources) and select the correct answer by using the codes given below the lists:

List-I	**List-II**
A. Acid water	**1.** Volcanoes
B. SO_2	**2.** Automobiles
C. CO	**3.** Thermal power station
D. Fly ash	**4.** Mining

Codes:

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

24. Aerosol is

(a) carbon partricles of microscopic size

(b) dispersion of small solid or liquid particles in gaseous media

(c) Finely divided particles of ash

(d) diffused liquid particles

25. Match **List-I** (Air pollutant) with **List-II** (Environmental effectg) and select the correct answer by using the codes given below the lists:

List-I	**List-II**
A. Carbon monoxide	**1.** Respiratory distress for living beings
B. Particulate matter	**2.** Chemical reaction with haemoglobin in blood
C. Nitrogen oxides	**3.** Reduction in visibility and aeroallergens carrier
D. Sulphur dioxide	**4.** Photochemical smong in atmosphere

Codes:

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

26. If carbon monoxide is released at the rate of 0.03 m^3/min from a gasoline engine and 50 ppm is the threshold limit for an 8 hour exposure, the quantity of air which dilutes the contaminant to a safe level will be

(a) 60 m^3/min (b) 600 m^3/min

(c) 60 m^3/s (d) 600 m^3/s

27. The role of the bed material in a "packed tower" used for removing particulate matter frofm gaseous emissions is to

(a) act as a filter bed to capture the particulates within the pores

(b) provide a large surface area on which the particulate matter can be collected

(c) reduce the flow of gas

(d) uniformly distribute the spray of water

28. Which one of the following plume behaviours occurs when atmospheric inversion begins from the ground level and continues?

(a) Looping (b) Fumigation

(c) Coning (d) Fanning

29. Which one of the following pollutants or pairs of pollutants is formed due to photochemical reactions?

(a) CO alone
(b) O_3 and PAN
(c) PAN and NH_3
(d) NH_3 and CO

30. Which of the following pairs are correctly matched?

1. Ringelmann chart : To grade density of smoke
2. Pneumoconiosis : Disease caused due to coaldust
3. PAN : Secondary air pollutant

Select the correct answer using the codes given below:

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

31. **Assertion (A):** The surface of sea water is on the rise.

Reason (R): A thick layer of gases enveloping the earth does not allow heat to pass into space from the earth at a rate which is as much as the rate at which the heat coming from space penetrates it towards the earth.

32. **Assertion (A):** Wet scrubber removes particulates from a gaseus stream.

Reason (R): In the wet scrubber water dropletes come into contact with the particulates.

33. The following is a well known formula for estimating the plume rise:

$$\Delta h = \frac{V_s d}{u}\left(1.5 + 0.0096\frac{Q_h}{V_s d}\right)$$

where the letters have their usual meaning. The estimated plume rise (by the above formula) with a stack gas having heat emission rate 2000 kJ/s, the wind speed 4m/s, stack gas speed 8 m/s inside a stack diameter of 1 m at the top is

(a) 7.8 m
(b) 8.7 m
(c) 3.15 m
(d) $\frac{8000}{\pi}(1.5 + 0.0024\pi)$

34. In sampling of stack gases for measurement of concentration of Suspended Particulate Matter (SPM), the flue gases are sucked in the instrument at

(a) any rate of flow from mid diameter of chimney
(b) any point of chimney cross-section and at any rate of flow
(c) a constant rate of flow but at four equidistant points along the diameter
(d) controlled position and controlled velocities along the chimneyb diameter to get isokinetic conditions

35. Match **List-I** (Air pollutants) with **List-II** (Harmful effects) and select the correct answer by using the codes given below the lists:

List-I	List-II
A. SPM	1. Blood haemoglobin
B. NO	2. Vegetation
C. CO	3. Respiratory system
D. SO_2	4. Building materials

Codes:

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

36. Match **List-I** (Air Pollutants) with **List-II** (Emitted mainly by) and select the correct answer by using the codes given below the lists:

List-I	List-II
A. Hydrocarbons	1. Coal burning
B. Particulates and gases	2. Gasoline fuel
C. Sulphur dioxide	3. Tyres
D. Carbon monoxide	4. Carburettor

Codes:

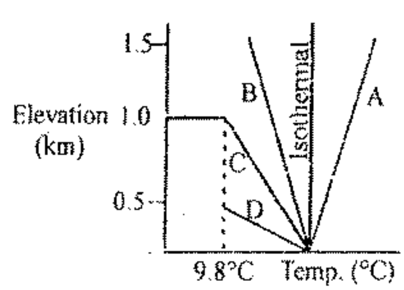
	A	B	C	D
(a)	3	4	2	1
(b)	4	3	2	1
(c)	3	4	1	2
(d)	4	3	1	2

37. In urban air pollution, the most poisonous gas is supposed to be carbon monoxide. It is hazardous because it

(a) affects our sense of smell
(b) is carcinogenic in nature
(c) combines with haemoglobine
(d) causes blindness

38. The graph shows the relationship of ambient lapse rates to the dry adiabatic lapse rate under different conditions of stability. Match stability situations A, B, C and D (as given in the graph) with the classes of stability as follows:

1. Super adiabatic 2. Dry adiabatic
3. Sub adiabatic 4. Inversion



Select the correct answer using the codes given below:

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

39. Which one of the following procedures is used for sampling of the flue gas in a chimney for SPM?

(a) Isothermal sampling (b) Isokinetic sampling
(c) Adiabatic condition (d) Variable rate of sampling

40. Which one of the following units is employed for the removel foparticulate matter above 50μm in size?

(a) Gravity settling chamber (b) Cyclone
(c) Fabric filter (d) Electrostatic precipitator

41. Which type of light energy is effectively absorbed by CO_2 in the lower boundary of the troposphere?

(a) X-rays (b) UV-rays
(c) Visible light (d) Infra-red rays

42. Which one of the following pairs is not correctly matched?

Plume Behaviour Atmospheric condition

(a) Looping : Stable
(b) Fumigation : Inversion above and lapse below the stack
(c) Fanning : Inversion
(d) Trapping : Inversion above and below the stack with lapse in between

43. Which is the major pollutant present in photochemical smog?

(a) PAN (b) SO_2
(c) HC (d) NO_2

44. Which one of the following is the range of ozonosphere in atmosphere?

(a) Troposphere to Stratosphere (b) Tropospause to Stratopause
(c) Tropopause to Mesosphere (d) Stratosphere to Mesosphere

45. Which one of the following pairs is not correctly matched?

(a) Coriolis effect : The effect of earth's rotation on wind direction and velocity
(b) PAN : Found during photochemical smog
(c) Cyclone : Employed for particulate matter removal
(d) Wind rose : Employed in forecast of dispersion in ambient air

46. Match **List-I** (Air pollutant) with **List-II** (Impact on human health) and select the correct answer by using the codes given below the lists:

List-I		List-II
A. Particulates	1.	Impairs transport of O_2 in bloodstream
B. Carbon monoxide	2.	Irriation of mucous membranes of respiratory tract
C. Sulphur oxides	3.	Causes coughing, shourtness of breath, headache, etc.
D. Photochemical oxidants	4.	Causes respiratory illness

Codes:

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

47. Which type of plume may occur during winter nights?

(a) Looping (b) Inversion

(c) Coning (d) Lofting

48. Pneumoconiosis is caused due to inhalation of which one of the following?

(a) Silica (b) NO_X

(c) Lead (d) Cadmium

49. Which one fo the following conditions of automobile gives maximum unburned hydrocarbons?

(a) Idling (b) Cruise

(c) Acceleration (d) Deceleration

50. Electrostatic precipitator is most useful for which one of the following industries?

(a) Tannery (b) Hydroelectric power generation

(c) Thermal power generation (d) Textile factory

51. Which one of the following toxic gases has physiological action as asphyxiant?

(a) SO_2 (b) NO_2

(c) Cl_2 (d) CO

52. Assuming annual travel for each vehicle to be 20000 km, what is the quantity of NO_X produced from 50000 vehicles with emission rate of 2.0 g/km/vehicle?

(a) 1800 tonnes (b) 1900 tonnes

(c) 2000 tonnes (d) 2100 tonnes

ANSWERS

1. (b)	14. (d)	27. (b)	40. (a)
2. (c)	15. (d)	28. (d)	41. (d)
3. (b)	16. (b)	29. (b)	42. (a)
4. (d)	17. (c)	30. (d)	43. (c) a
5. (c)	18. (b)	31. (a)	44. (d)
6. (c)	19. (b)	32. (a)	45. (d)
7. (d)	20. (c)	33. (a)	46. (b)
8. (b)	21. (d)	34. (d)	47. (d)
9. (d)	22. (b)	35. (c)	48. (a)
10. (c)	23. (a)	36. (d)	49. (a)
11. (b)	24. (b)	37. (c)	50. (c)
12. (d)	25. (c)	38. (b)	51. (d)
13. (b)	26. (b)	39. (b)	52. (c)

CHAPTER

8

Noise Pollution

Noise can be defined as that unwanted sound pollutant which produces undesirable physiological and psychological effects in an individual, by interfering with one's social activities like work, rest, recreation, sleep etc.

Noise of sufficient intensity and duration can induce health problems like temporary and some times permanent hearing loss, besides causing several other diseases like general annoyance, irritation, disturbance, headaches, insomnia, fatigue, mental torture, nausea, high blood pressure, high pulse rate, greater perspiration, etc.

CHARACTERISTICS OF SOUND AND ITS MEASUREMENT

Alternating compression and rarefaction of the surrounding air produces sound waves which propagate in the form of sinusoidal path.

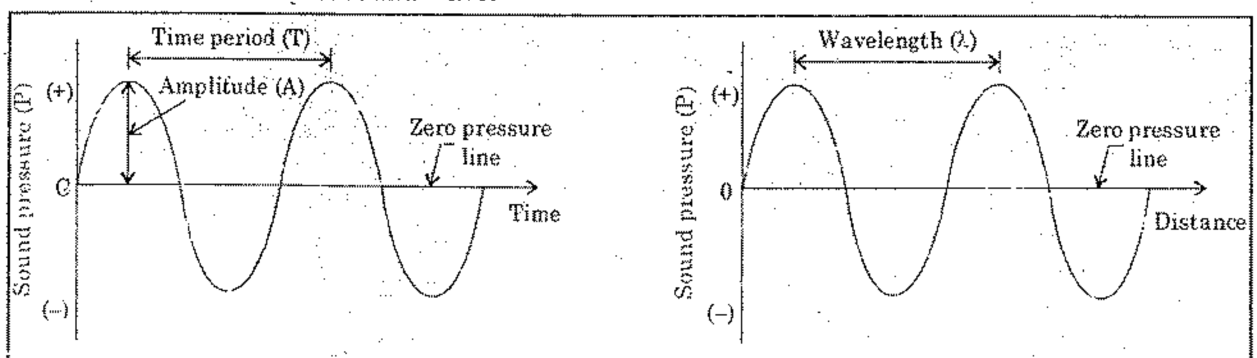
The time between the successive peaks or troughs of oscillation is called the Time period (T), and its inverse, which represents the number of times a peak arrives in one second, is called the **frequency** (f).

Hence,
$$T = \frac{1}{f}$$

The distance between successive peaks or troughs is called the **wave length** (λ), which is related to frequency (f) by the relation

$$\lambda = C \cdot \frac{1}{f}$$

where, C = The velocity of sound wave.



Typical sinusoidal sound waves produced by alternating compression and rarefaction of air molecules

- The amplitude (A) of the wave is the height of the peak sound pressure measured above or below the zero pressure line. The equivalent pressure of such a sine wave is represented by root mean square pressure (p_{rms}) as

$$p_{rms} = \sqrt{\overline{p_{(t)}^2}} = \sqrt{\frac{1}{T}\int_0^T p_{(t)}^2\, dt}$$

where, $p_{(t)}$ = Pressure at any time t.

- The **power of sound** (W) is defined as the rate of doing work by a travelling sound wave in the direction of propagation of the wave. The energy transmitted by a sound wave in the direction of its propagation is thus, defined as its power, and is represented in watts.
- The **sound intensity** (*I*) is further defined as sound power averaged over the time, per unit area normal to the direction of propagation of the sound wave. Intensity and power of a sound wave are related by the equation

$$I = \frac{W}{a}$$

where, I = Intensity of sound wave in watt/m^2

W = Power of sound wave in watts

a = A unit area ⊥ to the direction of wave motion.

Sound intensity (I) is further related to r.m.s. sound pressure by the equation

$$I = \frac{p_{rms}^2}{\rho . C}$$

where p_{rms} = r.m.s. sound pressure in pascals (Pa)

ρ = Density of air or medium in which sound wave is travelling in kg/m^3

C = Velocity of sound wave in m/s.

Levels of Noise

The sound pressure of the faintest sound that can be heard by a normal healthy individual is about 20 micro-pascal (μ-Pa). The sound level (L) is, represented as

$$L = \log_{10} \frac{Q}{Q_0} \text{ (bels)}$$

where Q = Measured quantity of sound pressure, or sound power, or sound intensity

Q_0 = Reference standard quantity of sound pressure, or sound power, or sound intensity, as the case may be

L = Sound level in bels (B).

when sound level is expressed in decibels,

$$L = 10 \cdot \log_{10} \frac{Q}{Q_0} \text{ (dB)} \quad \text{......... (i)}$$

The reference standard quantity Q_0 in the above equation is taken to be equal to 20 μPa, when sound pressure is measured.

Sound Pressure Level

$$\text{Sound pressure level} = L_p = 10 \times \log_{10}\left(\frac{p_{rms}}{20\,\mu Pa}\right)^2$$

or
$$L_p = 20 \log_{10} \left(\frac{p_{rms}}{20\ \mu Pa} \right)$$

If reference standard quantity Q_0 in the equation (i) is taken to be equal to 10^{-12} watts, when sound power is measured.

Sound Power Level

$$L_w = 10 \log_{10} \left(\frac{W}{10^{-12}} \right)$$

If reference standard quantity Q_0 is taken to be equal to 10^{-12} W/m^2, when sound intensity level is measured.

Sound Intensity Level

$$L_I = 10 \log_{10} \left(\frac{I}{10^{-12}} \right)$$

The addition of such sound levels cannot be done by simple arithmetic addition, because of the log scale involved. Hence, if you consider 50 decibel noise and want to add another 50 decibel noise, it will not make up 100 decibel noise, but will make up only 53 decibel noise, as calculated below:

$$50 \text{ decibel} = 20 \log_{10} \left(\frac{p_{rms}}{20} \right)$$

$$\therefore \quad \left(\frac{p_{rms}}{50} \right) = \text{antilog} \left(\frac{50}{20} \right) = 316.227$$

$\therefore$ 50 decibel + 50 decibel in r.m.s.

$$= \sqrt{(6324)^2 + (6324.55)^2}$$
$$= 8944.26\ \mu Pa$$

$$\text{Resultant sound pressure level} = 20 \log_{10} \left(\frac{8944.26}{20} \right) \text{dB}$$

$$= \textbf{53 decibel} \quad \textbf{Ans.}$$

Octave Band Analysis

A noise can be fully characterised by breaking it down into frequency components called spectra. Frequency is divided into various frequency ranges and noise/sound in various ranges is recorded.

The various frequency range in which the sound is to be recorded are like:

(1) 22–44 Hz—1st octave band

(2) 44–88 Hz—2nd octave band

(3) 88–175 Hz—3rd octave band

⋮ ⋮

(11)

An octave band is the frequency interval between a given frequency and twice that frequency. (Normally 8–11 nos. of octave bands are considered for any classificion).

Note:

1. Narrow band analysis $\xrightarrow{\text{done for}}$ Instrument design and testing
2. Octave band analysis $\xrightarrow{\text{done for}}$ Community noise control and identifying violators

Averaging Sound Pressure Levels

The average value of the various recorded sound pressure levels (L_p) at a particular place over a given period cannot be computed by simple averaging due to log scale involved in their values. On the other hand, the following equation is used to compute average pressure level:

Average pressure level

$$\bar{L}_p = 20 \log \frac{1}{N} \sum_{n=1}^{n=N} (10)^{L_n/20}$$

where

$\bar{L}_p$ = Average sound pressure level in dB re : 20 μPa

N = Number of measurement readings

L_n = nth sound pressure level in dB re. 20 μPa

n = 1, 2, 3, ... N

Say for example, the average of 4 measurement readings recorded as 40, 50, 62 and 72 dB re : 20 μPa is computed to be 63 dB, inplace of straight arithmetic average value of 56 dB, as follows:

$$\sum_{n=1}^{n=4} (10)^{L_n/20} = \left[(10)^{40/20} + (10)^{50/20} + (10)^{62/20} + 10^{72/20}\right]$$

$$= [100 + 316.23 + 1258.92 + 3981.07]$$

$$= 5656.22$$

and

$$\bar{L}_p = 20 \log_{10} \frac{1}{4} \times 5656.22$$

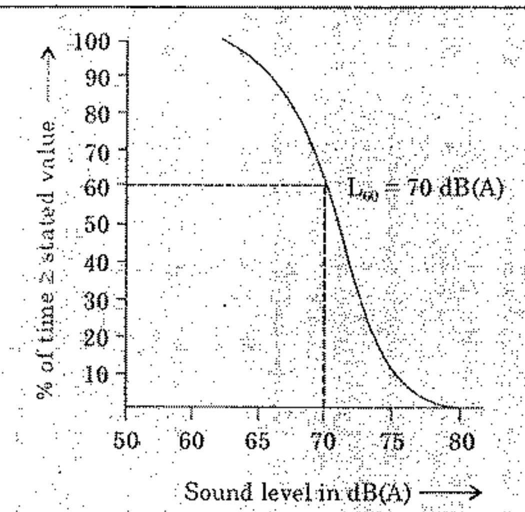
$$= 63 \text{ dB}. \quad \textbf{Ans.}$$

NOISE RATING SYSTEMS

The L_N Concept

The parameter L_N is a statistical measure indicating how frequently a particular sound level is exceeded. The value of L_N will represent the sound pressure level that will exceed for N% of the gauging time. Say for example, the given 70 dB value of L_{60} will mean that the sound level will exceed 70 dB for 60% of the measuring time.

When L_N is plotted against N (where N = 1, 2, 3. ... 100%), a cumulative distribution curve, as shown in figure is obtained.



Cumulative distribution curve.

The L_{eq} Concept

L_{eq} is defined as the constant noise level, which, over a given time, expands the same amount of energy, as is expanded by the fluctuating levels over the same time. This value is expressed

$$L_{eq} = 10 \log \sum_{i=1}^{i=n} (10)^{\frac{L_i}{10}} \times t_i$$

where n = Total number of sound samples

L_i = The noise level of any *i*th sample

t_i = Time duration of *i*th sample, expressed as fraction of total sample time.

Using the above equation, L_{eq} value for fluctuating noise level of 95 minutes indicated earlier (i.e. the one with 80 dB lasting for 10 minutes followed by scund of 60 dB for 85 min and 100 dB for 5 min can be worked out as below :

$$\sum_{1}^{3} (10)^{\frac{L_i}{10}} \times t_i = \left[(10)^{\frac{80}{10}} \times \frac{10}{95} + (10)^{\frac{60}{10}} \times \frac{80}{95} + (10)^{\frac{100}{10}} \times \frac{5}{95}\right]$$

$$= 1.053 \times 10^7 + 0.842 \times 10^6 + 0.52632 \times 10^9$$

$$= 10^6[10.53 + 0.84 + 526.32]$$

$$= 537.69 \times 10^6$$

$L_{eq} = 10 \log_{10} (537.69 \times 10^6) = 87.3$ **dB Ans.**

NOISE ABATEMENT AND CONTROL

There are certain noises which can be kept under control by legal laws and ordinances, and there are others which have to be dampened and attenuated by the use of good technology and town planning.

The noises produced by automobiles and trains, being the biggest noise nuisance in a modern city life, can be abated by construction of walls on both sides of roads and railway lines.

$$\text{Noise reduction (dB)} = 10 \log_{10}\left(\frac{20 H^2}{\lambda R}\right)$$

where H = Height of the barrier wall

λ = Wavelength of sound

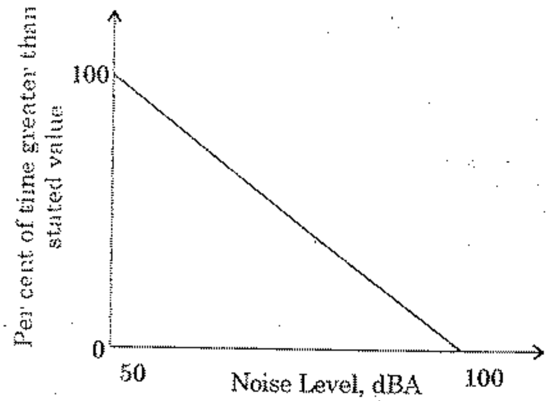
D = Distance between barrier and the receiving point.

Raising of thick and high vegetation and tree growing along sides of roads and railway lines, offer cheaper barriers to cause such noise reductions.

S. No.	Acceptable outdoor noise level in residential areas		S. No.	Acceptable indoor noise level for various type of buildings	
	Location	Noise levels dB(A)		Location	Noise levels dB(A)
1.	Rural areas	25–35	1.	Radio and TV studios	25–35
2.	Suburban areas	30–40	2.	Music rooms	30–35
3.	Urban residential areas	35–45	3.	Hospitals, class rooms, auditoria	35–40
4.	Residential and business urban areas	40–50	4.	Apartments, hotels, homes	35–40
5.	City areas	45–55		Conference rooms, small offices	
6.	Industrial areas	50–60	5.	Court rooms, private offices, libraries	40–45
			6.	Large public offices, banks, stores, etc.	45–50
			7.	Restaurants	50–50

OBJECTIVE QUESTIONS

1. The cumulative noise power distribution curve at a certain location is given below.



The value of L_{40} is equal to

(a) 90 dBA (b) 80 dBA
(c) 70 dBA (d) 60 dBA

2. The reference pressure used in the determination of sound pressure level is

(a) 20 μPa (b) 20 dB
(c) 10 μPa (d) 10 dB

3. Two sources generate noise levels of 90 dB and 94 dB respectively. The cumulative effect of these two noise levels on the human ear is

(a) 184 dB (b) 95.5 dB
(c) 94 dB (d) 92 dB

4. The sound pressure level for a jet plane on the ground with sound pressure of 2000 μ bar should be

(a) 60 decibel (b) 100 decibel
(c) 140 decibel (d) 180 decibel

5. Which of the following pairs are correctly matched?

1. Reverberation time : Time required to reduce noise by 60 dB
2. NIPTS : Responsible for permanent hearing loss
3. Sound foci : Formed when sound waves are reflected from convex surface
4. TTS : Responsible for temporary hearing loss

Select the correct answer using the codes given below :

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

6. Acoustics of an auditorium is considered to be excellent when its reverberation time is between

(a) 0.50 and 1.50 s (b) 1.50 and 2.00 s
(c) 2.00 and 3.00 s (d) 3.00 and 5.00 s

7. Which one of the following is the correct sound intensity expression with usual notations?

(a) $dB = 10 \log_{10}(I/I_0)^2$ (b) $dB = 10 \log_{10}(I/I_0)$
(c) $dB = 10 \log_{10}(I - I_0)^2$ (d) $dB = 10 \log_{10}(I - I_0)$

8. What type of noise can be abated by providing lining on walls and ceiling with sound absorbing materials?

(a) Source noise (b) Reflection noise
(c) Structural noise (d) Direct air-borne noise

9. What will be the resultant decibel level when two sources make noise of equal decibels?

(a) Decibel level will the same
(b) Decibel level will increase by 3 decibels
(c) Decibel level will decrease by 3 decibels
(d) Decibel level will be equal to the sum of decibels of the two sources

ANSWERS

1. (c)	**3. (d)**	**5. (c)**	**7. (b)**
2. (a)	**4. (c)**	**6. (a)**	**8. (b)**
			9. (b)

CHAPTER

9

Miscellaneous

VENTILATION OF BUILDINGS FOR CONTROLLING INDOOR AIR POLLUTION

Ventilation may be defined as the art of supplying air to a given space in order to provide high indoor air quality (i.e., to control temperature, replenish oxygen) and the art to remove the old vitiated air from that space (i.e., to remove unpleasant smells, smoke, dust, air borne bacteria etc)

In other words, ventilation includes both the exchange of air to the outside as well as circulation of air within the building.

Effects Produced When Oxygen on Enclosed Space is Inbabited by Humans or Animals

(i) Oxygen content of the space reduces

(ii) CO_2 content of the space increases

(iii) Humidity of the space increases

(iv) Temperature of the space increases

(v) Organic water and odours in the space increases

Purpose of Ventilation

(i) By providing necessary oxygen to remove oxygen deficit caused by respiration ;

(ii) By removing and diluting CO_2 in the air ;

(iii) By lowering down the temperature by removing hot used up air and replacing it by colder fresh air;

(iv) By reducing humidity; and

(v) By reducing body odours

SYSTEMS OF VENTILATION

A good ventilation system should generally fulfill the following requirements :

(i) It should admit sufficient quantity of fresh air, and remove the requisite used up or vitiated air.

(ii) Admitted air should be properly controlled with respect to its quantity as well as velocity of movement.

(iii) The system should be capable of changing the old air thoroughly, without leaving any stagnant pockets in the room.

(iv) Should avoid draughts, for which maximum permissible velocity of admitted air should not exceed 15 m/min i.e., 0.25 m/sec.

(vi) The system should also be capable of controlling the temperature of admitted air.

The ventilation systems can be broadly divided into two categories; viz.

(i) Natural ventilation and (ii) Mechanical ventilation.

Natural Ventilation

- It is based upon providing suitable openings in a room, at lower levels for admitting free atmospheric air, and also suitable openings at upper levels for removing the warmer and lighter used-up air.
- Doors and windows admit fresh air, and ventilators take out the vitiated air from a room.
- Windows are generally provided at about 0.75 to 0.9 m above the floor level, for admitting fresh outside air into the room.
- The size and the number of the windows provided, will depend upon the size of the room, number of occupants, the purpose and use of the room etc.
- A window area of 0.52 m^2 per person should generally be provided, so as to ensure admission of atleast 28 cum of air per hour with a velocity not greater than 9 m/min.
- About 1/10 to 1/15th of the floor area is provided in the living rooms for windows.
- Every room should preferably be provided with at least 2 windows, and at least one of them should face open space or a verandah.

Mechanical Ventilation

The artificial ventilation system can be broadly divided into :

(1) The extraction or vaccum system ;

(2) The propulsion or plenum system; and

(3) The air conditioning system.

(1) **The Vaccum System** is one in which the used-up vitiated air is thrown out to the outside atmosphere, by means of suitable exhaust fans or blowers, installed near the top ventilators. This exhaustion of the warmer air from the room, causes lower pressure inside the room, thereby permitting inward leakage of new fresh atmospheric air through the doors, windows, and walls.

- Various types of fans, usually, the rotary type are used. They are fixed in a convenient part of the ductwork, and driven usually by electric motors
- This system is simple and cheaper
- There is no control on the quality of the incoming air, hence, can be installed only where outside area is not contaminated and over crowded.
- It is also apt to cause draughts. This system is largely used for *kitchens, public halls, industrial plants, etc.*
  - In kitchens, the systems helps in exhausting smokes and odours.
  - In public halls, the system helps in exhausting out the ill effects of heavy occupancy
  - In industrial plants, the system helps in exhausting out dusts and fumes, etc.

(2) The Plenum System involves forcing or pumping in fresh air and causing the vitiated air to be exhausted out either by itself or through an exhaust fan placed at the outlet. The outlet exhaust fan is of smaller power than the inlet force fan. Due to larger rate of incoming air, a slight pressure is created which allows an outward leakage of vitiated air through the outlets.

- Example of such a plenum system of ventilation— Provision of a cooler at a window, with or without an exhaust fan at a ventilator (largely adopted these days)
- In larger buildings, such a plenum system may consists of distributing the incoming forced air at different points in the building through a system of ducts and grills.
- This arrangement is quite costly.

Advantages

(i) This system enables us to control the quality, humidity, and temperature of the incoming air. This system is largely adopted these days for cinema houses, theatres, and even for individual homes.

(ii) It prevents the risk of draughts, because of outward leakage, and by making outlets less powerful than the inlets.

Disadvantages

(i) The downward system, when adopted by providing air inlet ducts at roof level, is opposed to natural laws, and necessitates vitiated air to be rebreathed, causing discomfort.

(ii) The normal upward system when adopted, becomes costlier, as entry of air is provided at floor level under the seats, as is provided in some cinema halls, etc.

(iii) The air ducts require careful design in order to prevent draughts. This may involve using separate dampers for each room. The movement of air at the inlet as well as the outlet needs to be properly controlled.

These objections may be overcome by (i) employing the upward system ; or (ii) by air-conditioning the buildings.

THE AIR CONDITIONING SYSTEM

The atmosphere in the modern cities contains highly polluted smokes, fumes, dirts, germs, and bacteria, etc. In such environments, natural ventilation or even ordinary mechanical ventilation for bringing the outside polluted air into the building, will not serve us any useful purpose. In such conditions, it is necessary to completely control the temperature and quality of the outside air, before it is admitted into the room, and also to remove the heavy vitiated air at the optimum rates.

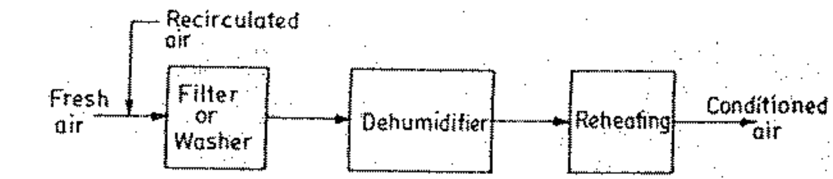
The air-conditioning may be defined as the process of controlling the temperature, humidity and distribution of air in a building, with simultaneously removing the dirt, bacteria and toxic matter from the air in order to provide a comfortable and whole-some ventilation to the buildings.

As the atmospheric conditions vary, the requirements of occupants also vary with respect to season. Accordingly, an air-conditioning system is required

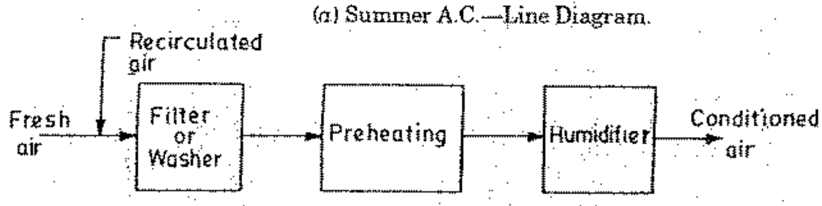
Summer Air-Conditioner

In summer season, the external, atmospheric temperature is high, and the hot air has to be cooled before it can be distributed in the building. During the process of cooling, however, the humidity of this air increases, because at lower temperatures with the same amount of moisture, the relative humidity increases. Hence, after cooling, it becomes necessary to reduce the humidity of this air, by drying it through a dehumidifer or the air is cooled and dried through the process of condensation. The clean, cooled, and dried air is then finally forced out into the space to be conditioned.

Note : *A dehumidifier is in the form of a hygroscopic substance like ammonia, calcium chloride, etc.*



(a) Summer A.C.—Line Diagram.



(b) Winter A.C.—Line Diagram.

The various steps involved in this conditioning are briefly given below:

(i) Filtration : Fresh outside air, as well as the vitiated reused air (recirculated air) is passed through a filter, so as to remove the dust and other soot particles from it. Dry filters and viscous filters are the two types of filters, used for the purpose. Dry filters, made of close grained felt or cloth or jute are more commonly used.

(ii) Cooling and Drying (Dehumidification) : This can be done by first lowering the temperature of the filtered air below the dew point, condensing out necessary amout of moisture, and then reheating the same with dry heat upto the desired temperature.

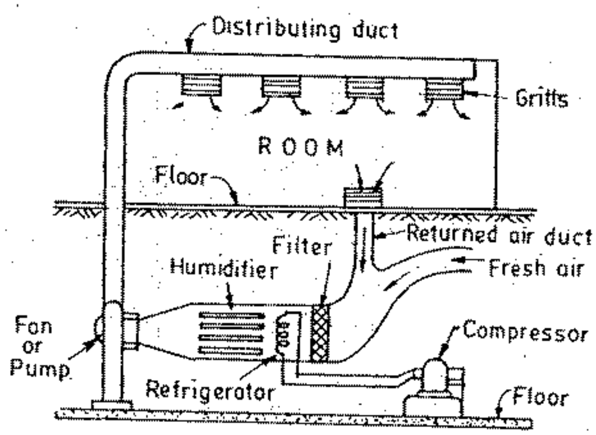
Cooling of the air may be done in several ways; two of which are :

(a) cooling by mechanical refrigeration

(b) cooling by water spray method.

(a) Mechanical Refrigeration

- It cools the air like a household refrigerator, and is more suitable to tropical countries where temperatures are to be lowered substantially.
- This method helps in cooling of air without wetting the same, with the help of a compressor and metal coils (tubes).



Central system of air conditioning.

- A liquid refrigerant such a *freon*, enters the metal coils under pressure, as soon as the machine is switched on.
- This liquid absorbs the heat from the coils and gets evaporated, thereby extracting heat from the metal coils and causing cooling of the coils.
- This gas refrigerant is then converted into liquid by the condensor coils and the compressor.
- The liquid again evaporates by adsorbing heat from the coils, causing further cooling of the coils.

- The process continues till the cooling is caused upto the desired level.

(b) Water Spray Method

- Water is first of all cooled either with the help of a refrigerant or by ice, and this cooled water is then sprayed on the hot air coming out of the filters. The air, thus; gets cooled by evaporation.
- This method increases the humidity of the air, and generally not found suitable for humid climates.

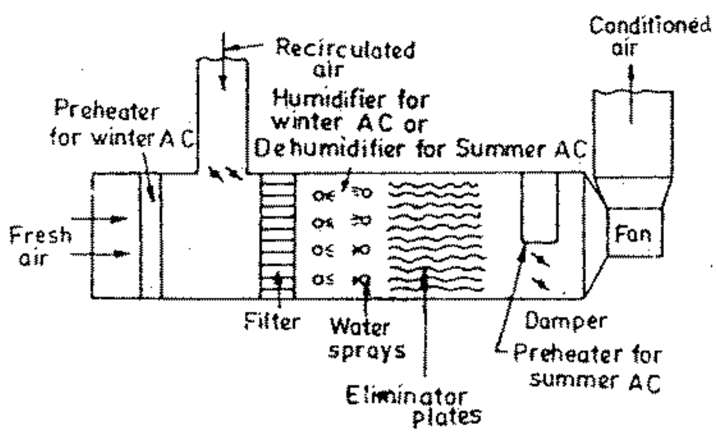
Recirculation of Air : During summer season, the temperature of room air is lower than the temperature of the outside air. And since an air conditioner has to cool down the hot air, it should be economical for it to cool the room air rather than the outside atmospheric air, if it becomes available to it.

This air, which is withdrawn by an air conditioner from the conditioned room and is recirulated through the filters and other cooling units, is known as *circulated air*, and the process is called recirculation of air.

Winter Air-Conditioner

- In winter season, the external atmospheric temperature is low, and this cold atmospheric air has to be heated up before it can be dispersed in the conditioned room.
- During this process of pre-heating the humidity of the air reduces, (at higher temperatures with the same amount of moisture, the relative humidity decreases).
- Hence, after heating it becomes necessary to increase the humidity of thie air, by carrying it through a humidifier, where air, may be mixed with the water vapour, by throwing waterover the air with the help of spray nozzles.
- This humidified air is then passed through eliminator plates, so as to remove the water droplets, if any, in the humidified air.
- The clean, hot and optimally humid air is finally forced out into the space to the conditioned.

Recirculation of air is done is the winter A.C. similar to what is done in the summer A.C. (as room air is to be heated up to lesser extent then the outside air, which causes economy).



Flow diagram of a complete two way air conditioner.

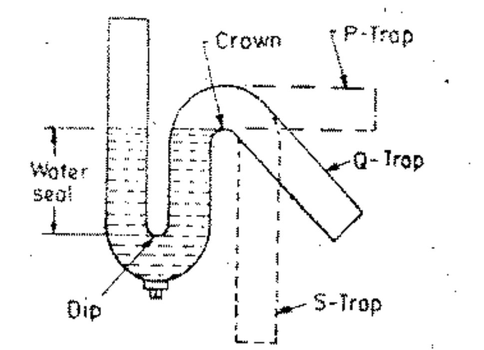
Note : *Preheating in a winter air conditioner may be done by admitting the air through a heater, or by passing it over the coils heated by hot circulating water.*

FUNCTIONS AND TYPES OF TRAPS BEING USED IN SANITARY PLUMBING SYSTEMS

- Traps may be defined as fittings, placed at the ends of the soil pipes or the sullage pipes (waste pipes) to prevent the passage of foul gases from the pipes to the outside.
- The efficiency and effectiveness of a trap will depend upon the depth of the water seal.
- This water seal generally varies from 25 mm to 75 mm; 50 mm being quiet common in most of the traps.

Depending upon their shapes, the traps may be of three types, i.e.

(i) P-trap;
(ii) Q-trap; and
(iii) S-trap



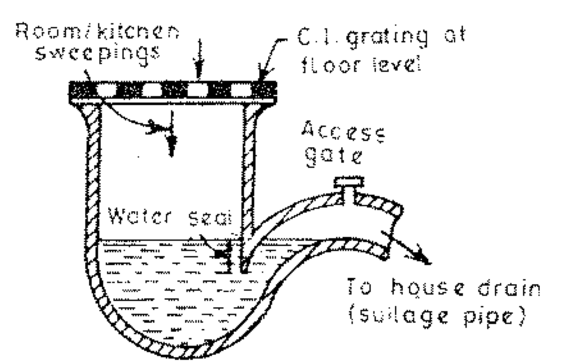
P, Q and S Traps

Depending upon their use, the traps may be of three types i.e.

1. Floor trap;
2. Gully trap; and
3. Intercepting trap

1. Floor Traps

- These traps are generally used to admit waste water (sullage) from the floors of rooms, kitchens, baths, etc. into the said room drain (sullage pipe).
- A commonly used patented name of such a trap is **Nahni trap**.



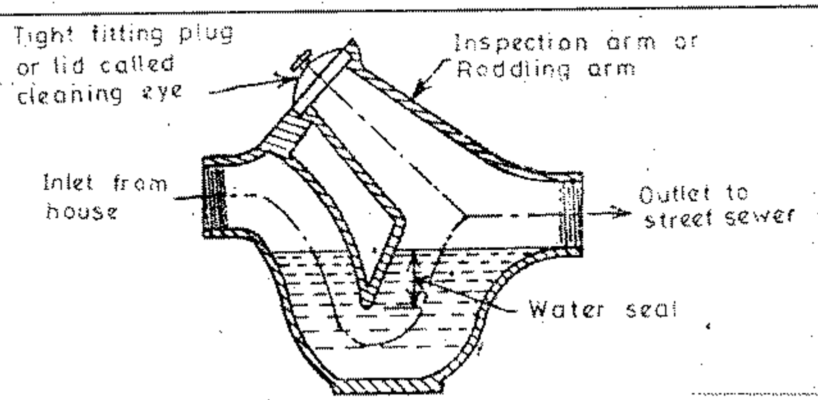
Floor Trap

2. Gully Traps

- A gully trap or a gully is often provided at the junction of a room or a roof drain and the other drain coming from bath, kitchen, etc.
- The rain water pipes or sullage pipes discharging into drains, are often connected to them through such traps. Gully traps may either have a S-trap or P-trap.
- The water seal is usually 50 mm to 75 mm deep.

3. Intercepting Traps

- An intercepting trap is often provided at the junction of a house sewer and a municipal sewer, so as to prevent the entry of the foul gases of the municipal sewer, into the house drainage system.



An Intercepting Trap

- It has a high depth of water seal, about 100 mm.

Note: *Soil pipes* are the pipes which carry the night soil, and *sullage pipes* are the pipes which carry the sullage from bathrooms and kitchens.

SYSTEMS OF PLUMBING

Following are the four principle systems adopted in plumbing of drainage work in a building :

1. Two pipe system;
2. One pipe system;
3. Single stack system; and
4. Partially ventilated single stack system

1. Two Pipe System

This is the best and the most improved type of system of plumbing. In this system, two sets of vertical pipes are laid, *i.e.*, one for draining night soil, and the other for draining sullage.

Soil pipe (night soil carrier) as well as the waste pipe (sullage pipes), are separately ventilated by providing separate vent pipes or antisiphonage pipes.

This system, thus involves a large number of pipes, and is thus quite costly.

2. One Pipe System

In this system only one main vertical pipe is provided, which collects the night soil as well as the sullage water from their respective fixtures through branch pipes. This main pipe is ventilated in itself by providing cowl at its top, and in addition to this, a separate vent pipe, however, is also provided.

3. Single Stack System

This system is a single pipe system without providing any separate ventilation pipe.

4. Partially Ventilated Single Stack or Single Pipe System

This is an improved form of single stack system. In this system, the traps of the water closets are separately ventilated by a separate vent pipe called *relief vent pipe*.

The commonly adopted sizes for house drains, for average condition, are as follows :

Soil pipe	= 100 mm ϕ
Sullage pipe (vertical)	= 75 mm ϕ
Sullage pipe (horizontal)	= 32 mm to 50 mm ϕ
Vent pipe	= 50 mm ϕ

SANITARY FITTINGS AND OTHER ACCESSORIES

The *sanitary fittings* are the appliances used in a house plumbing system, to receive the human excreta and sullage waste of the house. Such fittings include :

(A) Soil Fittings

(1) Water Closets (W.C.); and (2) Urinals;

(B) Ablution Fittings

(1) Flushing cisterns of water closets; (2) Wash basins; (3) Baths; and (4) Kitchen sinks

Water Closets (W.C.)

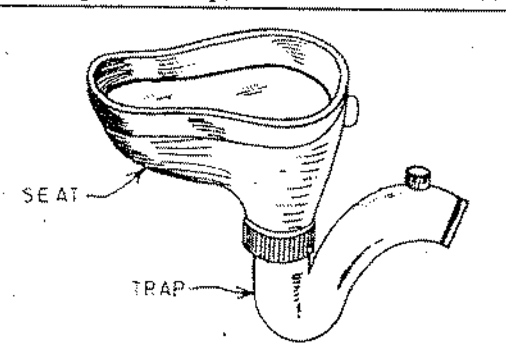
A water-closet is a water-flushed plumbing fixture, designed to receive the human excreta directly, and is connected to the soil pipe by means of a trap.

Two types of water-closets are :

(i) The squatting or the Indian type; and (ii) The pedestal or the European type

(i) The Squatting or the Indian Type W.C.

The Indian type W.C. has a squatting pan 45 cm to 63 cm in overall length, and 45 to 50 cm in height. The pan is fitted either with a *P*-trap, or *S* trap, which is then connected to the soil pipe.



Indian Type W.C. Pan and Trap.

It is made of vitreous china or porcelain.

(ii) The Pedestal or the European Type W.C.

The European type, sometimes called **wash-down type** of W.C. It is provided with a wide flushing rim and a 50 mm trap.

The W.C. may be provided with a *P-trap* or a *S*-trap, as desired, depending upon the outlet existing in the *wall* or the floor, respectively.

Flushing Cisterns

A flushing cistern is a device which releases a fixed quantity of water, under pressure, so as to flush and clean the pan and trap of a water-closet or a urinal.

High level cisterns, are those which operate with a minimum height of 1.25 m; and the **low level cisterns** are those which operate with a maximum height of 30 cm.

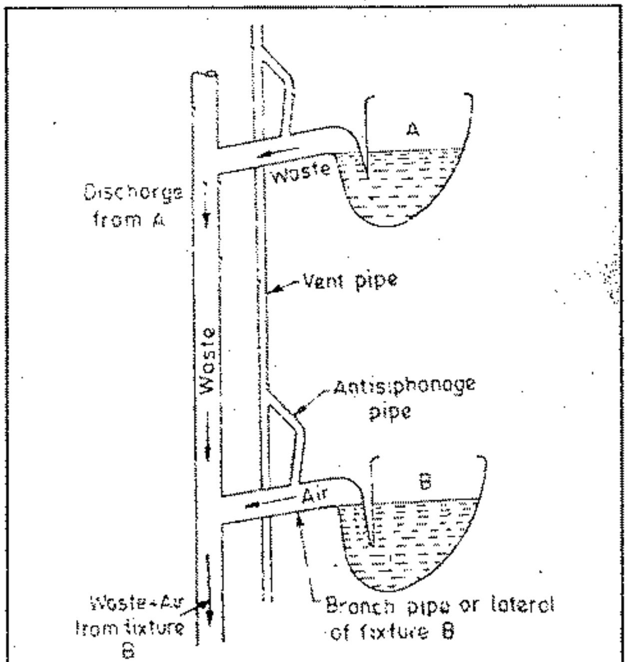
VENTILATION OF HOUSE DRAINS

The entire sewerage system of a house is ventilated by providing *vent* pipes, and *antisiphonic* pipes, and sometimes by *fresh air inlet*. Such a ventilation system is required to serve the following purposes:

(i) to relieve the pressure of foul gases developed in house drains which may otherwise break the water seals of the shallow seat traps;
(ii) to prevent breakage of trap's seals by siphonic action
(iii) to dilute the foul gases in the drains

Antisiphonage Pipes

When waste water is suddenly discharged from a sanitary fixture on the upper floor, it moves down rapidly through the soil pipe; and in its movement, it may such some air from the lateral pipe connecting the soil pipe with the fixture at the lower floor. This sucked air causes siphonic action resulting in the flow of water from the trap of the fixture to the soil pipe and thus, breaking its water seal.



Siphonage and anti-siphonic pipe.

To overcome this difficulty, a separate pipe of smaller diameter is attached to the traps, which connects the trap with the vent pipe. This pipe is known as **anti siphonage pipe** which supplies air to the short branch pipe of the lower fixture, at the time of suction; otherwise also, it acts as a vent pipe connection of the lower fixture. This pipe, will normally serve as a *vent pipe*, and as an antisiphonage pipe in case suction takes place.

OBJECTIVE QUESTIONS

1. Soil pipe in plumbing services means a pipe
   (a) made of clay
   (b) carrying soiled materials
   (c) carrying waste from water closets
   (d) carrying industrial waste water

2. The industrial process that generates industrial waste water containing chromium is
   (a) food processing (b) tannery
   (c) potteries (d) soap manufacturing

3. Match **List-I** with **List-II** and select the correct answer using the codes given below the lists:

List-I	**List-II**
A. Anti-siphonage	**1.** Protects trap seal from backflow
B. Benching	**2.** Has sloped floor in inspection chamber
C. Invert	**3.** Preserves the water seal in traps
D. Vent pipe	**4.** The lowest point

Codes:

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

4. The odour of drying paint or varnish is derived from which of the following chemical compounds?
   (a) Organic gases (b) Volatile organic compounds
   (c) Ethylene (d) Acetylene

5. Match **List-I** (Type of trap) with **List-II** (location) and select the correct answer using the codes given below the lists:

List-I	**List-II**
A. Intercepting trap	**1.** Water closet
B. Gully trap	**2.** Junction of sullage and storm water drains
C. Nahni trap	**3.** At the head of each house drain
D. P-trap	**4.** Junction of house drain and street sewer

Codes:

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

6. The ventilation of public halls, by means of air coolers and exhaust fans, is known as

(a) the plenum system (b) the vacuum system
(c) the A.C. system (d) None of these

7. The most wholesome ventilation of buildings is provided by :

(a) natural ventilation (b) plenum system of ventilation
(c) A.C. system of ventilation (d) vacuum system of ventilation

8. A cooling room air-conditioner, modifies the moisture content of the air, before letting it out, by :

(a) reducing humidity
(b) increasing humidity
(c) optimally reducing as well as increasing humidity
(d) none of these, as it does not modify humidity

9. Point out the incorrect statement :

(a) a summer A.C. uses a de-humidifier
(b) a winter A.C. uses a humidifier
(c) recirculation of room air takes place in a summer A.C. as well as in a winter A.C.
(d) all the above are correct

10. In single stack drainage system in houses, we provide :

(a) one soil pipe only (b) one soil pipe and one vent pipe
(c) one sullage pipe only (d) one soil pipe and one sullage pipe

ANSWERS

1. (c)	**3. (a)**	**5. (b)**	**8. (a)**
2. (b)	**4. (b)**	**6. (a)**	**9. (d)**
		7. (c)	**10. (a)**