SOLID WASTE AND WASTEWATER TREATMENT

QUALITY OF SEWAGE

Characteristics and Quality of sewage must be determined before its disposal because of following :

(*i*) Floating solids of untreated sewage decompose and create unpleasant smells and odour in the river water.

(*ii*) Large amount of organic matter present in untreated sewage starts consuming dissolved oxygen of the river water. Due to less amount of dissolved oxygen in river water, fish start dying.

(*iii*) Untreated sewage is also responsible for contaminating source water with harmful micro-organisms called *pathogenic bacterias.* Pathogens are responsible for causing serious water borne diseases such as cholera, typhoid, dysentry, etc.

Though municipal sewage normally contains 99.9% of water content, it is always desirable to treat the sewage before discharging the same in the river water to safe guard against the above defects.

Factors deciding Extent and Type of treatment required for the Sewage so as not to pollute Source of disposal :

1. Character and quality of sewage
2. Source of disposal

Treatment of Sewage

Out of millions bacterias generally found per litre of untreated sewage, only a small number are harmful to man. These harmful bacterias are called *pathogens.* The remaining large number of bacterias called *non-pathogens* are not only harmless but useful for the process of decomposition of the sewage. The main basis of treatment of sewage is to provide a suitable environment for the action of aerobic and anaerobic bacterias for stabilising organic matter present in sewage either through aerobic or anaerobic decomposition.

Decomposition of Sewage

(*i*) Aerobic decomposition. During treatment, in aeration tanks, contact beds, intermittent sand filters, trickling filters and oxidation ponds, it is primarily done by oxidation.

(*ii*) Anaerobic decomposition. During treatment, in septic tanks, Imhoff tanks and sludge digestion tanks, it is mainly done by putrefaction alone.

CHARACTERISTICS OF SEWAGE

I. Physical Characteristics

1. Turbidity. Degree of turbidity of sewage may be measured either by a turbidity rod or turbid meter. The degree of turbidity increases with the increase of sewage strength.

2. Colour. Colour of sewage indicates degree of its freshness. Black or dark brown colours indicate stale and septic sewage.

3. Odour. Fresh sewage remains practically odourless. As soon as dissolved oxygen gets exhausted, the sewage first becomes septic and thereafter offensive odours are evolved due to decomposition of sewage. Hydrogen sulfide gas is generally liberated from stale decomposed sewage.

4. Temperature. *Temperature of untreated sewage affects following*

(*i*) Biological activities of the bacterias present in the sewage.

(*ii*) Solubility of gases in the sewage.

(*iii*) Viscosity of sewage which ultimately affects the sedimentation process.

Average temperature of sewage in India is about 20°C which is favourable for the biological activities. At higher temperature, dissolved oxygen gets reduced considerably.

5. Solids. It contain 99.9% water and 0.1% solids.

II. Chemical Characteristics

1. Total Solids

Solids may exist in the sewage in any of the following forms :

(*i*) **Suspended solids :** These solids remain floating in sewage.

(*ii*) **Dissolved solids :** These solids remain dissolved in sewage.

(*iii*) **Colloidal solids :** These are finely divided solids which remain either in solution or in suspension.

(*iv*) **Settleable solids :** These are solid matter which settles at the bottom of the container in case sewage-is kept undisturbed for a period of two hours.

Proportion of different types of Solids per 1000 kg of sewage

Total solids	......	0.45 kg.
Suspended solids	......	0.112 kg.
Dissolved solids	......	0.225kg.
Settleable solids	......	0.112 kg

Proportion of Organic and Inorganic solids in total solids

Organic matter (carbohydrates), fats and nitrogenous compounds	.....	45%
Inorganic matter (generally harmless)	.....	55%

2. pH value

Logarithm of reciprocal of hydrogen ion concentration present in sewage, is called *pH value*. If pH value is less than 7, the sewage is acidic, and if more than 7, the sewage is alkaline. pH value may be determined with the help of a potentiometer.

3. Chloride Contents

Chloride upto 120 mg/ litre is obtained from domestic sewage. Large quantity of chlorides is added from industrial waste. High content of chloride in the sewage indicates presence of industrial waste.

Chloride content in the given sample of sewage may be measured by titrating with standard silver nitrate solution, using potassium chromate as indicator.

Two tests are conducted for chlorine

(*i*) **Chlorine Demand Test:** This test is done to determine amount of chlorine required for proper disinfection. Unstable organic matter present in sewage has a demand for chlorine and the amount of chlorine required for this purpose is called *chlorine demand*. It thus indicates the amount of organic matter present in the sewage.

(*ii*) **Chlorine Residual Test :** After treatment of sewage, it is necessary to chlorinate it to kill any bacteria present. If residual chlorine is present after its application, it indicates that chlorination is sufficient. Residual chlorine test is conducted in the same manner as that for water.

4. Nitrogen contents

Presence of nitrogen in sewage indicates presence of organic matter.

It may occur in one or more of the following forms

(*i*) ***Free ammonia :*** During first stage of decomposition of organic matter, free ammonia is liberated. The amount of free ammonia present in sewage is measured by simply boiling sewage, and measuring the gas thus liberated.

(*ii*) ***Albuminoid nitrogen :*** Quality of nitrogen present in sewage before commencement of decomposition of organic matter indicates the albuminoid nitrogen. The amount of albuminoid nitrogen may be measured by adding strong alkaline solution pottasium permaganate ($KMNO_4$) to the already boiled sewage sample and again boiling the same. Ammonia gas thus liberated is required quantity of albuminoid nitrogen in the given sample.

(*iii*) ***Nitrites :*** Presence of nitrites indicates that organic matter in the sewage in only partly decomposed. Quantity of nitrites present in the sewage sample may be measured by colour matching method by adding sulphonorilic acid and naphthamine. The colour developed in the water is compared with standard colour of solution of known concentration.

(*iv*) ***Nitrates :*** Presence of nitrates in the sewage indicates that organic matter is fully oxidised. Amount of nitrates present in the sewage sample may be measured by colour matching method by adding phenol-di-sulphuric acid and potassium hydroxide. Colour developed in the waste water is compared with standard colour of known concentration.

(*v*) ***Presence of Fats and Grease :*** Sources of grease, fats, and oils in the sewage is from the discharges of animal and vegetable matter. These matters forms scum on the top of the sedimentation tanks, and clog voids of the filtering media. To determine amount of fats and grease, sewage sample is first evaporated and the residual solids so left are mixed with either ether or hexane. Thus solution obtained is allowed to evaporate. The residue is of fats and grease.

(*vi*) ***Hydrogen Sulphide gas :*** Presence of hydrogen sulphide gas in sewage indicates anaerobic decomposition. Excess amount of hydrogen sulphide gas may cause corrosion of concrete sewers and may produce bad odours at the treatment plant. To safegaurd against these bad effects, hydrogen sulphide gas (H_2S) is kept below 1 ppm in fresh sewage.

(*vii*) ***Dissolved oxygen (DO) :*** Because of rapid absorption of oxygen from the atmosphere, dissolved oxygen is always present in variable quantities in sewage water. Its content in sewage is dependant upon amount and character of unstable organic matter in it.

The test of dissolved oxygen is carried out before discharging treated sewage into source water to ensure that at least 4 ppm of DO is available in the sewage for the existence of fish life.

DO content of sewage is generally determined by Wrinkler's method which depends on the fact that, in alkaline solution, the dissolved oxygen oxidises magnaneous ion to maganic ion which in turn oxidises iodide to liberate iodine in quantities equivalent to the amount of dissolved oxygen present. The dissolved oxygen is reported as mg/*l* or as percentage saturation with dissolved oxygen.

If G_s is dissolved oxygen saturation in mg/*l*, *n* is salinity of chloride content in mg/*l*, T is temperature of sewage in centigrade, P is barometric pressure in mm of Hg and P_w is saturated vapour pressure of water in mm of Hg, then

- for temperature between 0°C to 30°C, $C_s = 0.678\,(P - P_w)\,(1 - n \times 10^{-5})/(T + 35)$
- and for temperature between 30°C to 50°C, $C_s = 0.827\,(P - P_w)\,(1 - n \times 10^{-5})/(T + 49)$

5. Presence of fats, greases, and oils

6. Sulphides, sulphates and H_2S gas

Gases, which are generally evolved during aerobic decomposition of sewage are :

$$CO_2 + NH_3 + H_2S$$

Gases, which are generally evolved during anaerobic decomposition of sewage are :

$$CO_2 + NH_3 + H_2S + CH_4.$$

7. Strength of Sewage

It gives an indication of the nuisance value of sewage. *It is generally indicated by following characteristics:*

(*i*) Total volatile solids, both suspended and dissolved

(*ii*) Odour

(*iii*) Chlorine demand

(*iv*) **Theoretical Oxygen Demand (T.O.D).** Amount of oxygen required for complete oxidation of organic matter into CO_2 is called TOD.

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

(180) (192)

(From Organic matter)

Hence 1 gm of glucose is requiring $\frac{192}{180}$ gms of oxygen. This demand is called *theoretical oxygen demand* (TH.O.D.). It is of academic use only because determination of exact composition of organic matter is difficult.

(*v*) **Chemical Oxygen Demand (COD).** Amount of oxygen required for chemical oxidation is called COD. It is defined as amount of oxygen absorbed by waste water from a strong oxidising agent like $K_2Cr_2O_7$, $KmnO_4$.

Importance of Chemical Oxygen Demand is due to following reasons :

(*a*) Rapid chemical oxidation.

(*b*) Chemical oxidation does not depend on many variables.

(*c*) Chemical oxidation requires less equipment, hence economical.

(*d*) In highly toxic sewage, chemical procedure is the only method lo determine the organic load.

Method of determination of COD : It is *Refluxing*. COD results although less than T.O.D and depends on composition. Time required for COD test is 3 to 4 hrs.

Advantages of COD test

(*i*) Computation of various parameters are not required

(*ii*) Time required for conducting COD test is less than T.O.D. test

Disadvantages of COD test : This does not defferentiate between biodegradable organic matter and non-biodegradable organic matter.

Total Organic Carbon (TOC)

This test involves oxidation of the sample to convert inorganic carbon to CO_2, which is then stripped. Both COD and TOC measures biodegradable fraction of the organics, but unlike COD it is independent of the oxidation state of the organic matter. CO_2 released in the test can be measured by a infrared analyzer. This test is rapid, accurate and correlates moderately well with BOD.

(*vi*) Biochemical Oxygen Demand (BOD)

BOD is most commonly used parameter to define strength of municipal or organic industrial waste water. It is defined as the amount of oxygen required by micro-organisms for the decomposition of bio-degradable matters under aerobic condition.

Standard BOD test : It determines the amount of oxygen required by micro-organism for decomposition of bio-degradable matter under aerobic condition in 5 days at 20°C.

Why 5 days 20°C is atdopted as standard BOD

(*i*) All countries have adopted the same, hence to make standards with others, this standard is adopted.

(*ii*) Night defined bacterias are developed at 5th day.

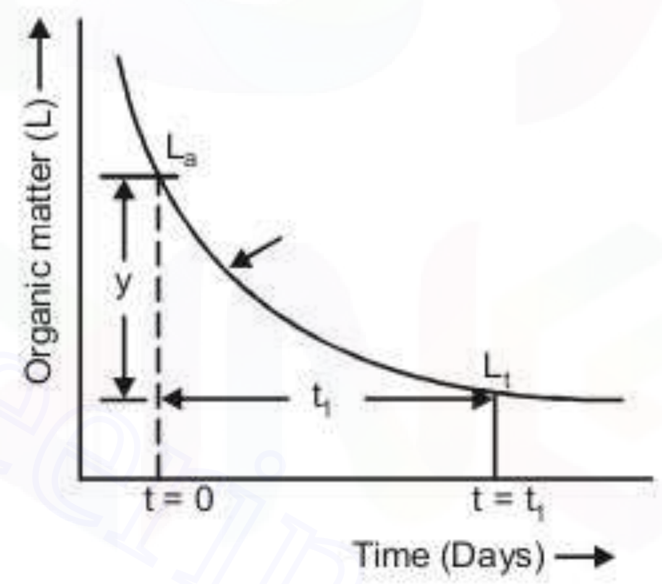
(*iii*) In 5 days about 2/3rd organic matters are oxidised, hence ultimate BOD, $BOD_u = \frac{3}{2} BOD_5$

Note : 10 days BOD is about 90% of the total.

BOD by Dilution Technique :

BOD tests consists of diluting the sewage with water containing a known amount of dissolved oxygen and noting the loss of oxygen after a period of storage or incubation. The usual incubating period is 5 days at a temperature of 20°C. The diluting water is aerated, contains a small amount of sodium bicarbonate and has a pH of 7.0 to 7.6.

The rate of biochemical oxidation of organic matter is proportional to remaining concentration of the unoxidized substance that is measured in terms of *oxidizibility*. The relationship is shown graphically.



From the figure, L is the oxygen demand at t = 0 day. It may also be called *first stage demand* though the same relationship applies at the beginning of oxidation period. Then L_t is remaining oxygen demand at the end of any time '*t*' days. K is a constant associated with days and temperature and determinable experimentally.

BOD of to Days

Then oxygen absorbed or used in milligrams per liters in t days,

$$X_t = L(1 - 10^{-K_1 t})$$

where, L = first stage demand

K = *de-oxygenation constant* or *BOD rate constant*

Ultimate First Stage BOD

First demand during first 20 days or so, occurs due to oxidation of organic matter, and is called Carbonaceous demand or first stage demand or initial demand. The latter demand occurs due to biological oxidation of ammonia, and is called Nitrogeneous demand or second stage demand.

Ultimate first stage BOD, X_t can be obtained by substituting $t = \infty$ days in the above equation.

Therefore, $$X_u = L\left[1 - 10^{-K_1 \infty}\right] = \left[1 - \frac{1}{10^{\infty}}\right] = L[1 - 0] = L$$

Hence ultimate BOD is a fixed quantity equal to initial equivalent of the organic matter present in the sewage and does not depend upon temperature of oxidation.

Constant K_1 varies with temperature as, $K_{D(t^\circ)} = K_{D(20^\circ)}[1.047]^{T-20^\circ}$

where, $K_D(T)$ = deoxygenation constant at T°C.

Initial BOD or L varies with temperature as, $LT = L_{20}(0.02\,T + 0.6)$

where L_T is value of L at T°C, and L_{20} is its value at 20°C

The 5 day BOD determination at 20°C is generally used as providing a sufficient time to eliminate accidental factors which might affect results and temperature is close to the averages temperature of sewage and plant effluents.

Test for BOD in Sewage

Complete oxidation of the organic matter (both carbonaceous and nitrogenous) takes more than 2 months; however within about 10 days nearly 90 per cent of the biological oxygen demand is satisfied. After that period the rate is very slow. Usually 5 day BOD is tested and within this period nearly 70% of the BOD is satisfied. To carry out this test, sewage of the effluent is diluted with aerated pure water in the ratio of 1 : 100. Then D.O. of the diluted sample is calculated. The diluted sample is incubated for 5 days at 20°C and loss of oxygen in this period is calculated.

$$\text{B.O.D. in p.p.m (of 5 days)} = \text{Loss of oxygen in ppm} \times \frac{100}{\%\ \text{diluted sample}}$$

First stage demand : It occurs due to oxidation of organic matter and is called *carbonaceous demand* or *initial demand.* The term BOD is usually means the first stage demand.

Second stage demand : It occurs due to biological oxidation of ammonias and is called *Nitrogenous demand.*

5 days, 20°C BOD of municipal waste water: It generally vary between 100 to 500 mg/l.

$$COD > BOD_U$$

$COD - BOD_U$ = Non-biodegradable organics

$$\frac{BOD_U}{COD} = 0.92 \text{ to } 1 \text{ for fully biodegradable.}$$

$$\frac{BOD_5}{0.68} = 0.92 \text{ to } 1 \qquad \text{....(since } BOD_5 = 68\ \%\text{ of } BOD_U)$$

$$\frac{BOD_5}{COD} = 0.68 \times 0.92 \text{ to } 1 \times 0.68 = 0.63 \text{ to } 0.68 \text{ for fully biodegradable.}$$

Hence, any waste water having its $\frac{BOD}{COD}$ ratio more than 0.63, can be considered to be quite amenable to biological treatment; since it does not contain non-biodegradable organisms.

Rate of Deoxygenation

The rate at which BOD is satisfied at any time (i.e. rate of deoxygenation) depends upon temperature and amount and nature of organic matter present in the sewage at that time.

BOD/COD Ratio

Since difference of ultimate BOD (i.e. BOD_u) and COD represents the quantum of Non- Biodegradable organics (NBO's)present in the given waste water, therefore COD will always more than BOD_u. Hence $\frac{BOD_u}{COD}$ ratio will always less than 1.0 but will approach towards 1.0 with the decreasing amount of NBO's.

If this ratio is found between 0.92 and 1.0, the waste water can be considered to be fully biodegradable.

Usually $\frac{BOD_5}{COD}$ is referred as $\frac{BOD}{COD}$ ratio. Since BOD_5 is about 68% of BOD_U, therefore $\frac{BOD_5}{COD}$ ratio should vary between $0.92 \times 0.68 = 0.63$ to $1.0 \times 0.682 = 0.68$

Descending Order of Various Oxygen Demands

$$\text{Th.O.D} > \text{C.O.D} > \text{B.O.D}_U > \text{B.O.D}_5 > \text{T.O.C}$$

Application of BOD

Information about BOD of waste is considered in designing treatment facilities. It is used to determine size of certain units like trickling filters and activated sludge units, in the operation of treatment plants and efficiency of various units.

Claracteristics of Domestic Waste water

1. Based on Strength domestic waste water is classified as follows :

Classification	BOD_5(mg/*l*)	COD (mg/*l*)
Weak	< 200	< 400
Medium	350	700
Strong	500	1000
Very strong	> 750	> 1500

Strength given in this table depends on water consumed per person

2. $\frac{BOD}{COD} = 0.5$ (approx.), and $\frac{BOD_u}{COD} = 1.5$

3. In tropical condition, sewage is strong because less quantity of water is consumed.

4. In developed countries, sewage is weak because more water is consumed

Population Equivalent

Population equivalent of a sewage is the number of the persons who could be responsible for the sewage which would have the same characteristics of B.O.D. as the standard sewage.

Industrial wastes are compared with per capita domestic waste for charging industries properly.

$$\therefore \quad \begin{Bmatrix} \text{Standard 5 day BOD} \\ \text{of industrial sewage} \end{Bmatrix} = \begin{Bmatrix} \text{Standard 5 day BOD of domestic} \\ \text{sewage per person per day} \end{Bmatrix} \times \text{Population Equivalent}$$

Average standard BOD of 5 days of domestic sewage is worked out as 0.08 kg/day/person.

Hence if 5 day BOD of sewage coming from an industrial area is 300 kg./day, then

$$\text{Population Equivalent} = \frac{300}{0.08} = 3750$$

III. BIOLOGICAL CHARACTERISTICS

Sewage contains living organisms, such as bacteria, algae, fungi and protozoa.

Following two types of bacteria in sewage carry out the process of breaking the complex organic compounds into simple and stable compounds :

1. **Aerobic bacteria :** It live in the presence of oxygen dissolved in water or free oxygen.
2. **Anerobic bacteria :** It live and carry on their activities in the absence of free oxygen.

Decomposition of sewage. It takes place in following two stages:

(*i*) Aerobic Decomposition

Sewage contains organic matter, waster products, water, etc. Aerobic bacteria convert this matter, in the presence of the dissolved oxygen in the sewage water, initially to nitrogeneous, carbonaceous and sulphurous compounds, which are more stable. With the supply of more oxygen, these compounds are further decomposed into more stable nitrites and then to nitrates. Aerobic decomposition is also called *oxidation*, because during this process, organic matter is broken up and oxidised to more stable products.

Aerobic bacteria produce gases which are not offensive in odour. When oxygen supply in the water is exhausted, the aerobic bacteria die.

Following treatment plants work on the oxidation principle : Aeration tanks, Contact beds, Intermittent sand filters, Trickling filters and Oxidation ponds.

(*ii*) Anerobic Decomposition

When aerobic bacteria die, anerobic bacteria start their activity with the oxygen available in the organic matter. These bacteria break up organic compounds to nitrites, nitrates, proteins, etc. The gases produced in the process are very offensive in odour. Anerobic decomposition is also called *putrefaction* and the end products include black residue called *humus*, ammonia, methane, hydrogen sulphides, etc.

Following treatment units work on the principle of putrefaction : Septic tanks, Imhoff tanks, Sludge digestion tanks, etc.

Plants use products of decomposition such as carbon dioxide or nitrates to produce chlorophyll. When plants die they are decomposed by aerobic and anerobic bacteria and so the cycle goes on.

Fresh sewage does not have offensive odour. But after a few hours it becomes stale, septic and foul. Hence in sewage treatment, aerobic decomposition is encouraged by supplying oxygen for its activity by the following ways:

(*a*) Allowing sewage to pass through porous medium, and circulating through the pores as in the case of trickling filters.

(*b*) Adding activated sludge to fresh sewage and blowing air.

In a sewage treatment plant, activity of anerobic bacteria is controlled so that odour is not noticeable.

Biological Tests

Biological tests on sewage are carried out to determine types of bacteria and biological life in them. Sewage is added to culture media and allowed to develop in an incubator at a specified temperature and for a specified time. Bacteria form colonies which can be counted with a microscope and depending on the type and quantity of bacteria present in the sewage, treatment is given.

Micro - Organisms Composition of Sewage : [C HOPKINS, CaFe. Mgr]

C = carbon, H= Hydrogen, O = oxygen, P = Phosphorus, K = Potassium, I = Iodine, N = Nitrogen, S = Sulfer, Ca = Calcium, Fe = Ferrous, Mg = Magenesium.

Example. Average sewage flow from a city is 80×10^6 l/day. If average 5 BOD is 285 mg/lit, compute total daily 5 day oxygen demand in kg and population equivalent of storage. Assume, per capita BOD of sewage/day ax 75 gms.

Solution : Total daily 5 day oxygen demand $= \dfrac{285 \times 80 \times 10^6}{10^6} = 22{,}800$ kg.

$$\text{Population equivalent} = \frac{22800}{0.075} = \mathbf{3{,}04{,}000}$$

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

Solution :

Again, 5 day B.O.D. per capita at 20°C of a standard sewage, is assumed between 73 to 82 gm/day.

Given : Total 5-day B.O.D. per day $= 95 \times 10^6 \times 300$ mg $= \dfrac{95 \times 10^6 \times 300}{10^6} = 95 \times 300$ kg

Assuming 5-day B.O.D. per capita at 20°C as 0.075 kg/day, Population equivalent $= \dfrac{95 \times 300}{0.075} = \mathbf{3{,}80{,}000}$

Example. A average standard BOD_5 of domestic sewage is worked out to be about 0.08 kg/day/person. If BOD_5 of industrial waste is 300 kg/day, calculate population equivalent of the waste.

Solution : Population Equivalent $= \dfrac{\text{Standard BOD}_5\text{of industrial waste}}{\text{Standard BOD}_5\text{of domestic sewage/capita}} = \dfrac{300}{0.08} = \mathbf{3750}$

Example. An industry discharging waste at a rate of 2000 m³/day with BOD of 100 mg/lit. Calculate population equivalent of the waste.

Solution : Assuming 45 *mg/lit* person is the BOD of the city,

$$\text{Population Equivalent} = \frac{1000 \times 2000 \times 10^3}{45 \times 1000} = \textbf{44445 persons}$$

Thermal Pollution

Discharge of heated waste water into the water body is called *thermal pollution.* It increases metabolic decay of fish and saturation D.O.

Relative Stability of Sewage Effluent

It is the ratio of oxygen available in the effluent (as D.O. nitrite or nitrate) to the total oxygen required to satisfy first state BOD.

Relative Stability

$$\text{Relative stability } (S) = \frac{\text{Quantity of D.O. present in waste water}}{\text{Quantity of D.O. required to satisfy its first stage BOD}}$$

$$= \frac{L_0\left(1-10^{-k_D t}\right)}{L_0} \times 100 = [1-10^{-k_D t}] \times 100$$

$\therefore$ $$S = 100\,[1-(0.794)^{t20}]$$

$\Rightarrow$ $$S = 100\,[1-(0.630)^{t37}]$$

where, t_{20} and t_{37} represent the time in days for a sewage sample to decolourise a standard volume of methylene blue solution, when incubated at 20°C or 37°C respectively.

In India, BOD test are generally conducted at 37°C, because here it becomes very costly to maintain the equipments at 20°C.

$$= 100\,[1-(0.794)^{t_{20}}] \quad \text{or} \quad 100\,[1-(0.63)^{t_{37}}]$$

where t_{20} and t_{37} represents time in days for a sewage sample to decolourise a standard volume of methylene blue solution when incubated at 20°C or 37°C respectively.

Example. If period of incubation is 10 days at 20°C in the relative conductivity test on sewage, calculate percentage of relative stability.

Solution : $S = 100\,[1-(0.794)^{t}{}_{20}] = 100\,[1-(0.794)^{10}] = \mathbf{90.04\%}$

Example. In a test conducted for determining relative conductivity at 20°C, the period of incubation was found to be 12 days. Calculate percent of relative stability.

Solution : Relative stability at 20°C is given by, $S = 100\,[1-(0.794)^{t_{20}}]$

where, $t_{(2o)}$ = number of days at 20°C test temperature = 12 days (given)

$$\therefore \quad S = 100\,[1-(0.794)^{12}] = \mathbf{93.7\%}$$

Example. If 2.5 ml of raw sewage has been diluted to 250 mg/lit. and D.O. concentration of diluted sample at the beginning BOD test was 10 mg/lit. and 5 mg/lit. after 5-day incubation at 20°C, find BOD of raw sewage.

Solution : $\text{Dilution ratio} = \dfrac{250}{2.5} = 100$

Loss of D.O. during test = D.O. before testing – D.O. after testing = (10 – 5) = 5 mg/l

B.O.D. of sewage = Loss of oxygen × dilution factor = 5 mg/l × 300 = 500 mg/l

Example. If two day B.O.D. of a sample of sewage is 200 mg/l at 25°C, what will be its 5-day B.O.D. at 30°. Assume K = 0.1 at 20°C?

Solution : $(\text{B.O.D.})_{25^\circ C}, X_{25} = 200 \text{ m}/l$

Now, $K_{(25^\circ C)} = K_{(20^\circ C)}[1.047]^{25-20} = 0.1 \times 1.047^5 = 0.1258$

$K_{(30^\circ C)} = {}^{K}(20^\circ C)\,[1.047]^{30-20} = 0.1 \times 1.047^{10} = 0.1582$

From $X_t = L[1-(10)^{Kt}]$

At 25°C and for two days, $X_{(25^\circ C)} = L_{(25^\circ C)} \quad [1-10^{-K_{25}\times 2}]$

$\therefore \quad 200 = L_{(25^\circ C)}[1-10^{0.1258\times 2}]$,

$\Rightarrow \quad L_{(25^\circ C)} = 358.97 \text{ mg}/l$

Now, $L_{25} = L_{20}\,[0.02 \times 25 + 0.5]$,

$\therefore \quad 256.97 = L_{20}[1.1]$

$\Rightarrow \quad L_{20} = 324.52 \text{ mg}/l$

and $L_{30^\circ C} = L_{20^\circ C}\,[0.02 \times 30 + 0.6] = 324.52\,[1.2] = 389.42 \text{ mg}/l$

$X_{30^\circ C} = L_{30^\circ C}\,[1-10^{-0.7910}]$

$= 389.42\,[1-0.1618] = \mathbf{326.41 \text{ mg/l}}$

Example. If BOD of sewage incubated for 1 day at 30°C has been found to be 110 mg/l, then what will be the 5 day 20°C BOD?

Solution : From the relation, $K_1(T) = K_{1(20)}\,[1.047^{(T-20)}]$

$K_{1(30)} = 0.1[1.047^{(30-20)}] = 0.158$

Again from the relation, $Xt = L\,[1-10^{kt}]$

$110 = L_{30}(1-10^{-0.158\times 1})$

$\Rightarrow \quad L_{30} = 360 \text{ mg}/l$

and $L_{20} = 360\,[0.02(30) + 0.6] = 300 \text{ mg}/l$

$X_{20} = 300\,(1-10^{-0.1\times 5}) = 205 \text{ mg}/l$. at 5 days

Example. 125 cumecs of sewage of a city is discharged in a perennial river which is fully saturated with oxygen and flaw at a minimum rate of 1600 cumecs with a minimum velocity of 0.12 m/sec. If 5-day BOD of the sewage is 300 mg/l, find out where critical DO will occur in the river.

Assume : coefficient of purification of the river as 4, coefficient DO is 0.11, and ultimate BOD is 126% of the 5 - day BOD of the mixture of sewage and river water.

Solution: Initial DO deficiency of the river, $D_0 = 0$

Given : $C_S = 300$; $Q_S = 125$ m³/sec; $C_R = 0$; $Q_R = 1600$ m³/sec

5 -day B.O.D. of the mixture of sewage and river,

$$C = \frac{C_s\,Q_S + C_R\,Q_R}{Q_S + Q_R} = \frac{304 \times 125 + 0 \times 1600}{125 + 1600} = 21.739 \text{ mg}/l$$

$\therefore$ Ultimate B.O.D., $L = \frac{21.739 \times 125}{100} = 27.17 \text{ mg}/l$

From $\frac{L}{D_c} = f^{\left(\frac{f}{f-1}\right)}$; where $f = 4$

$$\frac{27.17}{D_c} = (4)^{4/(4-1)} = 6.34$$

$\therefore$ Critical or max. oxygen deficit, $D_c = \frac{27.17}{6.34} = 4.285 \text{ mg}/l$

Again, $t_c = \frac{1}{K_D(f-1)} \log f = \frac{1}{0.11(4-1)} \log_{10} 4 = 1.818$ days

Distance = Velocity of river × time

= 0.12 × (1.818 × 24 × 60 × 60) = 18,849 m ≈ **8.85 km.**

Example. Following observations were made on 4% dilution of waste water :

D.O. of aerated water used for dilution = 4 mgll

D.O. of diluted sample after 5 days incubation = 0.6 mg/l

D.O. of original sample = 0.5 mg/l

Calculate B.O.D. of 5 days and ultimate B.O.D. of sample assuming deoxygenation coefficient at test temperature as 0.1.

Solution : 100% of contents of diluted samples contain 4% waste water and 96% of aerated water used for dilution.

$\therefore$ Its D.O. = D.O. waste water × its content + D.O. dilution water × its content

= 0.5 × 0.04 + 4 × 0.96 = 3.86 mg/l

D.O. of incubated sample after 5 days = 0.6 mg/l

D.O. spent in oxidising organic matter = 3.86 – 0.6 = 3.26 mg/l

B.O.D. of 5 days = D.O. consumed × dilution factor = $3.26 \times \frac{100}{4} = 81.5 \text{ mg}/l$

$$X_5 = L\,[1 - 10^{-kt}]$$

Now $81.5 = L\,[1 - 10^{0.15 \times 5}] = 0.6838L$

$\therefore$ Ultimate B.O.D., L = **119.19 mg/*l***

Sewage Disposal Into Streams

By superimposing rates of deoxygenation and reoxygenation mathematically, following equation called *Streeter - Phelps equation* is obtained.

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

where, D_t = D.O. deficit in mg/l after t days

L = ultimate first stage B.O.D. at the point of water discharge in mg/l

D_0 = initial oxygen deficit in mg/l of the water (if any)

K_n = deoxygenation coefficient which can be determined either by laboratory or field tests.

K_D varies with temperature as, $K_{D(T)} = K_{D(20°C)} = [1.047]^{T-20}$

Typical values of $K_{D(20°C)}$ vary between 0.1 and 0.2. generally taken as 0.10.

K_R = Reoxygenation coefficient that can be found out by field tests. K_R varies with temperature as per the equation,

$$K_{R(T)} = K_{R(20°C)}.(1.016)^{T-20}$$

where $K_{R(T)}$ is K_R value at T°C and $K_{R(20°C)}$ is K_R value at 20°C.

Critical time (t_c) at which minimum D.O., occurs can be found from Streeter- Phelps equation as

$$t_c = \left(\frac{1}{K_R - K_D}\right).\log\left(\left\{\frac{K_D.L - K_R.D_0 + K_D.D_0}{K_D.L}\right\}.\frac{K_R}{K_D}\right)$$

and critical or maximum deficit is given by, $\quad D_c = \frac{K_D.L}{K_R}(10)^{-K_D.t_c}$

$\frac{K_D}{K_R}$ is sometimes represented by 'f' and is called *self- purification constant.*

$$t_c = \frac{1}{K_D(f-1)}\log\left[\left\{1-(f-1)\frac{D_o}{L}\right\}f\right]$$

and equation for D_c can be reduced to, $\quad \left(\frac{L}{D_c f}\right)^{f-1} = f\left[1-(f-1)\frac{D_o}{L}\right]$

This is an important first stage equation in which L is B.O.D. of the mixture of sewage and stream.

When initial deficit, D_o is zero, then $\quad \frac{L}{D_c} = [f]^{f/(f-1)}$

Example. A stream having a flow of 0.80 m^3/s and BOD 4 mg/litre is saturated with DO. It receives an effluent discharge of 0.20 m^3/s, B.O.D. 18 mg/l and DO 4 mg/l. If average velocity of flow is 0.15 m/s, calculate DO deficit at points 25 km and 50 km downstream. Assume that temperature is 20°C throughout and B.O.D. is measured at 5 days. Take constants for effluent and stream as 0.12 and 0.30 per day respectively.

Solution : Let X_0 = B.O.D. of mix, i.e. B.O.D. of stream at effluent discharge.

Q_r = Stream flow = 0.80 m^3/s

X_r = B.O.D. of stream = 4 mg/l

Q_e = Effluent discharge = 0.20 m^3/s

X_o = B.O.D. of effluent = 18 mg/l

Then, $\quad X_5 = \frac{(X_r \times Q_r)+(X_c \times Q_e)}{(Q_r + Q_e)} = \frac{(4\times 0.80)+(18\times 02.0)}{(0.80+0.20)} = 6.80 \text{ mg}/l$

Now, $\quad X_4 = L\,(1 - 10^{-Rt})$

$\therefore \quad 6.80 = L(1 - 10^{-0.12\times 5})$

$\Rightarrow \quad L = 9.07$, say 9.10 mg/$l$

The stream is saturated with DO at 12°C

Also, $(DO)_r$ = 9/10 mg/l, and $(DO)_e$ = DO of effluent discharge = 4 mg/l

$\therefore \quad$ DO of mixture, $(DO)_m = \frac{(D.O.)_r \times Q_r + (D.O.)_e \times Q_e}{(Q_r + Q_e)} = \frac{(9.10\times 0.80)+(4\times 0.20)}{(0.80+0.20)} = 8.08$ mg/l

$\therefore \quad$ Initial D.O. deficit = 9.10 – 8.08 = 1.02 mg/l

D.O. deficit at a point 25 km downstream :

$$\text{Time} = \frac{\text{distance}}{\text{velocity}} = \frac{d}{v} = \frac{25000}{0.15\times 36000\times 24} = 1.93 = 2 \text{ days}$$

Now, from Streater – Phelps equation.

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

$$= \frac{0.12\times 9.10}{(0.30-0.12)}\left[(10)^{-0.12\times 2} - (10)^{-30\times 2}\right] + 1.02\times(10)^{-0.30\times 2} = \mathbf{2.26\ mg/lit}$$

D.O. deficit at a point 50 km downstream:

$$\text{time, } t = \frac{50000}{0.15\times 3600\times 24} = 3.86, \text{ say 4 days}$$

Now, using Streater-Phelps equation,

$$D_t = \frac{0.12\times 9.10}{0.60\times 0.12}\left(10^{-0.12\times 4} - 10^{-0.30\times 4}\right) + 1.02\times 10^{-0.30\times 4} = \mathbf{1.68\ mg/}\boldsymbol{l}$$

Example. A reactive chemical plant disposes by dilution in a river at the uniform rate of dissipation of 0.12 mg/l per hour. The waste discharged per day is 30×10^6 litres having chemical concentration of 25 mg/l. The flow of river above the sewer outfall is 5 m^3/s. If river has zero chemical concentration, calculate distance on downstream side upto which the chemical residue persists. Assume mean velocity of river flow as 20 cm per second.

Solution: Flow of waste water, $Q_w = \dfrac{30 \times 10^6}{24 \times 60 \times 60 \times 1000} = 0.348\ m^3/s$

Diluted chemical concentration of mixture = $\dfrac{(5 \times 0) + (0.348 \times 25)}{(5 + 0.348)} = 1.63$ m/l

Uniform rate of chemical dissipation = 0.12 mg/l per hour

$\therefore$ 1.63 mg/l chemical will dissipate in $\dfrac{1.63}{0.12}$ hour = 48900 seconds.

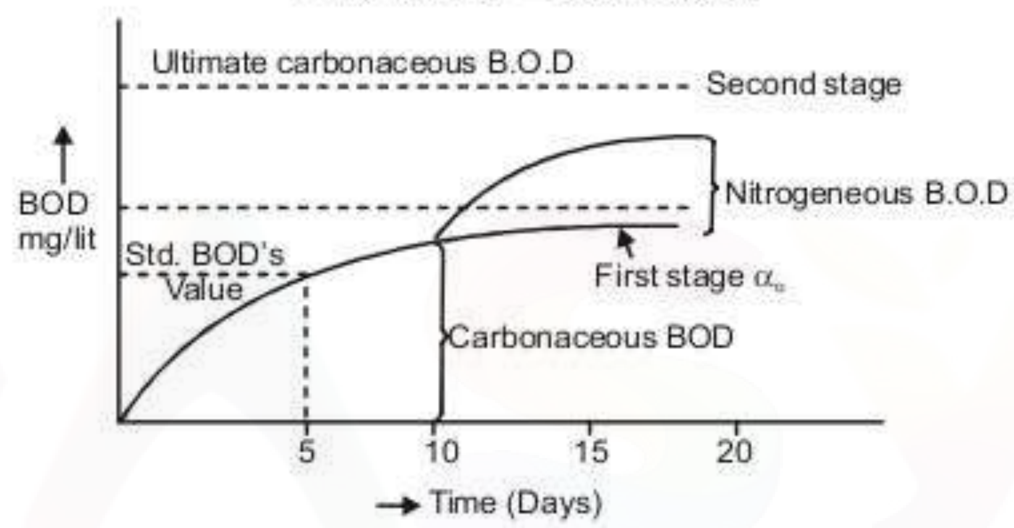
Now, mean velocity of flow= 20 cm/sec = 0.20 m/sec

$\therefore$ Distance on downstream side upto which the chemical residual persists = 0.20×48900

= 9780 m. = **9.78 km.**

Carbonaceous and Nitrification Oxygen Demand

This hypothetical curve shows BOD exerted, D.O. depleted as the biological reactions progresses with time.



Carbonaceous oxygen demand : It progresses at a decreasing rate with time, since rate of biological activity decreases as the available food supply diminishes. Shape of the hypothetical curve is best expressed mathematically by first order kinetics, *i.e.*

BOD at any time, t = ultimate BOD $(1 - 10^{-Kt})$

Nitrification oxygen demand : Nitrifying Bacteria can exert on oxygen demand in the BOD test, fortunately growth of nitrifying bacteria lags behind that of the micro-organisms performing carbonaceous reaction. Nitrification generally does not occur untill several days after the standard 5 day incubation period for BOD test.

Also, Carbonaceous demand – first stage demand

Nitrification demand – second stage demand

BOD and Oxygen Equivalent Relationship

The rate at which organics are utilized by micro organisms is assumed to be a first order action, i.e. the rate at which organics utilized is proportional to amount available.

Therefore, if y_t is BOD exerted in time t, and L is BOD of sewage at starting, i.e. oxygen equivalent of organic matter present in sewage at start, then

BOD remaining to be exerted at any time t, $L_t = (L - y_t)$

$$\frac{dL_t}{dt} \propto L_t$$

$$\Rightarrow \quad \frac{dL_t}{dt} = -K.L_t$$

$$\Rightarrow \quad \frac{dL_t}{L_t} = -K.dt$$

$$\Rightarrow \quad \text{Log } L_t = -K.t + c$$

At $t = 0$, $\quad L_t = L$

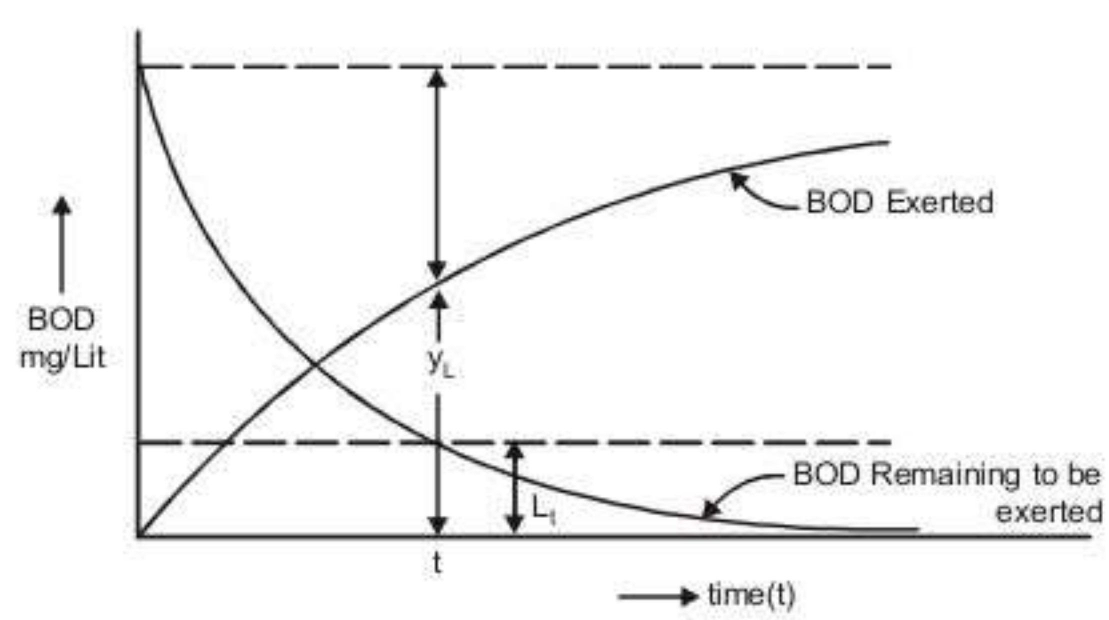
$$\Rightarrow \quad c = \log L$$

$$\Rightarrow \quad \log L_t = -K.t + \log L$$

$$\Rightarrow \quad \log L_t - \log L = -K.t$$

$$\Rightarrow \quad \log \frac{L_t}{L} = -K.t$$

$$\Rightarrow \quad \frac{L_t}{L} = e^{-Kt}$$



$\Rightarrow \quad L_t = L.e^{-K.t}$

as $\quad L_t = L - y_t$

$\Rightarrow \quad L - y_t = L.e^{-K.t}$

$\Rightarrow \quad y_t = L - L.e^{-K.t}$

$= L\,(1 - e^{-K.t})$

$\Rightarrow \quad \boxed{y_t = L\,(1 - e^{-K.t})}$ or $\boxed{y_t = L.\,(1 - 10^{-K_D.t})}$

where $K_D = 0.434$ K

Temperature Dependance of Rate Constant

Ultimate BOD is independent of temperature but the rate constant (K or K_D) are dependent on temperature. Higher the temperature, higher will be the value of rate constant and vice-versa.

Relation of temperature dependence is given by, $K_T = K_{20}\,(\theta)^{T-20}$

In most cases, $\theta = 1.047$, therefore $\quad K_T = K_{20}\,(1.047)^{T-20}$

From laboratory determination, K_{20} has been found to be 0.1/day (base '10') or 0.23 (base '*e*').

Unit of rate constant is $(\text{Day})^{-1}$.

Example. BOD_5 of a waste water is determined to be 150 mg/lit at 20°C. If K-value is known to be 0.23/day, what would be the BOD_8 if the test were ran at 15°C ?

Solution : From $\quad y_t = L(1 - e^{-Kt}),\ y_5 = L(1 - e^{K \times 5})$

$150 = L\,(1 - e^{-0.23 \times 5})$

$\Rightarrow \quad L = 219.5$ mg/lit

K value for 15°C : $K_{15} = K_{20}(1.047)^{15-20} = 0.23\,(1.047)^{-5} = 0.183$

Determination of BOD_8 : $y_8 = 219.5(1 - e^{-0.183 \times 8}) = \mathbf{16.865}$ **mg/lit**

Example. The two day BOD at 18°C is reported to be 250 mg/l. Find BOD_5 ultimate BOD at 25°C. Assume rate constant at 20°C is 0.1 /day (base 10).

Solution : $\quad K_{18} = K_{20}(1.047)^{T-20} = 0.1\,(1.47)^{-2} = 0.091$

Now $\quad 250 = L\,(1 - 10^{-0.091 \times 2})$

$\Rightarrow \quad L = 728.8$ mg/*l*

BOD_5 at 20°C : $\quad y_5 = 728.8\,[1 - 10^{-0.1 \times 5}] = \mathbf{498.33}$ **mg/lit**

Example. If 5 day BOD of waste is 400 mg/lit and its ultimate BOD is 600 mg/lit, then at what rate the waste being oxidised ?

Solution : *Given* : L = 600 mg/lit, $y_1 = 400$ mg/lit, $t = 5$ days

$\therefore \quad L_t = L - y_t = 600 - 400 = 200$ mg/lit

From $\quad \dfrac{L_t}{L} = 10^{-Kt}\,;\ \dfrac{200}{600} = 10^{-K \times 5}\,; \quad \Rightarrow \quad$ **K = 0.22 day**

Example. Prove that 5 day 20°C BOD is equal to 2.5 day 35°C BOD.

Solution: We have, $\quad L_t = L\,(1 - 10^{-Kt}),$

$\therefore \quad y_5 = L\,(1 - 10^{-K \times 5})\ \ldots.(i)$

Let $K_{20} = K$ /day. Therefore from, $\quad K_T = K_{20}(1.047)^{T-20}$

and $\quad K_{35} = K(1.047)^{15} = 1.992\,K \approx 2K$

Now 2.5 day 35°C BOD, $\quad y_{2.5} = L(1 - 10^{-2k \times 2.5})$

$= L\,(1 - 10^{-5k})\quad \ldots.(ii)$

From equation (*i*) and (*ii*), $\quad$ 5 day, **20°C BOD = 2.5 day 35°C BOD**

Example. Sewage is applied to trickling filter at a rate of 3000 m^3/day. Average BOD_5 of the influent is 140 mg/lit and it contains no DO. The effluent has BOD_5, 30 mg/lit and contain 2.5 mg/lit of D.O. If K (base 'e') = 0.251 day, how many kg of oxygen dose the filter transfer per day ?

Solution : *Given* : Influent BOD, $L_i = 140$ mg/lit; Effluent BOD, $L_e = 30$ mg/lit

Ultimate BOD of influent : $\quad 140 = L_i(1 - e^{-0.35 \times 5}),$

$\Rightarrow \quad L_i = 196.22$ mg/lit

Ultimate BOD of effluent : $\quad 30 = L_e\,(1 - e^{-0.25 \times 5}),$

$$\Rightarrow \qquad L_e = 42.05 \text{ mg/lit}$$

Hence oxygen transferred by filter to the sewage

$$= \frac{[(L_i - L_e) + 2.5] \times Q \times 1000}{10^6} = \frac{[(196.22 - 42.05) + 2.5] \times 3000}{1000} = \mathbf{470.01\ kg/day}$$

Example. BOD_5 of a waste has been measured as 500 mg/lit. If $K_1 = 0.1$/day (base 10), what is the BOD_4 of the waste, and what proportion of BOD_4 would remain unoxidised after 20 days?

Solution : *Given* : $BOD_5 = 500$ mg/lit; $K_1 = 0.1$/day (base 10)

From $\qquad y_t = L(1 - 10^{-k_1 t})$

$$500 = L(1 - 10^{-10 \times 5}) \; ; \; \Rightarrow \; L = 131.24 \text{ mg/lit}$$

Now $\qquad y_{20} = L(1 - 10^{-0.1 \times 20}) = (BOD)_4\,(1 - 0.1) = 0.99\,(BOD_4)$

It means that 99% BOD_4 is utilized in 20 days and hence only 1% of the ultimate BOD would be left unoxidised after 20 days.

SEWAGE AND SEWERAGE TREATMENT

Sewage

Types of Sanitary Sewage

1. Domestic sewage
2. Industrial sewage
3. Storm sewage

System of Sanitation

1. Old conservancy system
2. Modern water carriage system

Sewerage System

Types of Sewerage System

1. Combined system
2. Separate system
3. Partially separate system

Components of Sewage System

1. House sewers
2. Lateral sewers
3. Branch sewers
4. Main sewers (Trunk sewers)
5. Outfall sewers
6. Manholes

Quantity of Discharge in Sewers

In the design of sewers, it will be necessary to determine quantity of sewage which will be conveyed through them.

Quantity of sewage consists of following :

1. Infiltration.

It is the water that enters sewers through poor joints, cracks, manhole covers, etc. During dry weather, there will be no infiltration and hence only domestic sewage and industrial waste will be conveyed. During rains, infiltration will be due to rise in ground water table and from roofs.

Infiltration depends on the following factors :

(*i*) Height of ground water level
(*ii*) Type of soil in which sewers are laid
(*iii*) Workmanship of laying pipes

2. Dry Weather Flow

Minimum sewage discharge through combined seweage system during non-monsoon period is called *dry weather flow* (D.W.F).

Drainage discharge, which is produced during monsoon season is generally very high, say 20 to 25 times that of the sewage discharge called dry weather flow (D.W.F).

Quantity of dry weather flow depends on following factors

(*i*) **Population :** As in a water-supply project, probable life of the sewage system has to be fixed according to the life of different components, say 40 or 50 years. The population to be served at the end of the period will have to be determined to fix size of sewers and other components of the system.

(*ii*) **Rate of Water Supplied :** Quantity of domestic sewage entering the sewer depend on the water-supply. However, all the water supplied may not reach the sewer as part of it may have been used for a purpose such as watering gardens, which may not return to the sewer. It may also happen that industries may have their own supply of water which may be led into sewers. Thus it is usually assumed that average rate of sewage flow equals average rate of consumption of water.

Thus following two factors should be closely checked before deciding proportion of water-supply appearing as sewage:

(*a*) Purpose for which water is being used has to be carefully studied.

(*b*) Intensity of pressure in the pipelines has to be checked. More the pressure, more the wastage of water and leakage and so quantity reaching consumers will be less than that supplied.

(*iii*) **Nature of Industries :** Quantity of industrial waste depends on the type of industry. Hence, each industry has to be carefully studied before estimating quantity of industrial sewage.

Variation in Rate of Sewage

In the design of sewers, it is necessary to determine maximum rate of sewage discharge that will be flowing in them. They should be large enough to allow flow at the maximum rate. Otherwise there may be backing up of sewage into plumbing fixtures of buildings. Peak discharge occurs much after the peak water consumption as sewers take time to fill to high-point flow before it starts travelling.

3. Storm Water

Storm water is that water which runs-off after a rainfall.

Quantity of storm water : *It is estimated by following two methods:*

(*i*) **Rational Formula**

$$Q_p = \left(\frac{1}{36}\right).k.p_c.A$$

Q_p = peak rate of run-off in m^3/s

K = Coefficient of run-off

A = Area of catchment in hectare

P_c = Critical rainfall intensity in cm/hour

Factors affecting Quantity of Storm Water

(*a*) **Catchment area :** It is that area of land which drains into a sewer or is served by a sewer. This area is measured from the map of the locality.

(*b*) **Run-off Coefficient :** Impermeability factor of the surface of the catchment called *run-off coefficient.*

Rain water falling over an area is disposed of mainly in the following three ways:

- Percolates into ground
- Evaporates into air
- *Runs off over the surface of ground, called run-off*

Factors affecting Run-off

Impermeability of the soil

Slope of ground

Duration of rainfall

Shape of catchment.

Type of Surface	Run-off coefficient
Watertight roofs	0.70 – 0.95
Asphaltic cement streets	0.85 – 0.90
Portland cement streets	0.80 – 0.95
Paved driveways and walks	0.75 – 0.85
Gravel driveways and walks	0.15 – 0.30

Run-off coefficient for an area can be determined by calculating percentage area covered by each category viz., roofs, paving, lawns, etc., and then multiplying each by appropriate coefficient and then adding the products.

(c) Intensity of Rainfall : Rainfall may be heavy during some years while it may be normal or below normal during some others. Heavy rain may occur say once in 5 to 10 years, Extraordinary rain storms may occur once in 10 to 15 years and an extremely heavy rain storm may happen once in 40 to 50 years. A sewer cannot be designed for the peak storm water as size of the sewers will be extraordinarily large. At the same time, sewers should not be very small as it will lead to accumulation of water and cause damage to life and property. Generally, storm water occurring once in five years is assumed.

Intensity of rainfall is greater when shorter periods are considered while it is lower when large periods are considered.

$$\text{Intensity of rainfall, R} = \frac{25.4a}{t+b}\ \text{mm/hour}$$

where, t = duration of storm in minutes

a and b = constants depending on frequency (number of years) considered, and nature of area

Following constants are considered adequate:

When t is 5 to 20 minutes, a = 30 and b = 10

When t is 20 to 100 minutes, a = 40 and b = 20

Time of Concentration : When there is rainfall, water will run off from roofs, pavements, etc., and flow into the gutter and then reach inlet of the sewer after some time. Thus, storm water takes some time to travel to the inlet. Areas immediately adjacent to the sewer will flow quickly while area which is far away will take more time. Time required for developing maximum rate of runoff is called *time of concentration*.

It consists of following :

(a) Time of entry : asumed a 5 or 10 minutes.

(b) Time of flow through the sewers to the point at which the rate of flow is required to be known. Time of flow is determined from gradient and hydraulic mean depth of sewer.

Example : If catchment served by a sewerage system is 30 hectares, and duration of the storm is 15 minutes, what is the run-off from catchment determined by rational method? Take impermeability coefficient as 0.5.

Solution : As t = 15 mintues, here a = 30, b = 10 (for storms of duration 5 – 20 minutes)

$$\text{Intensity of rainfall, R} = \frac{25.4a}{t+b} = \frac{25.4\times 30}{15+10} = 30.48\ \text{mm/hour}$$

By rational method, $$Q = \frac{\text{C A R}}{360}$$

Here, C = impermeability factor = 0.5

A = area of catchment = $30 \times 10\,000\ \text{m}^2$

$$R = 30.48\ \text{mm/hour} = \frac{30.48}{1000\times 60}\ \text{m/min}$$

$$\therefore \quad Q = \frac{0.5\times 30\times 10000\times 30.48}{1000\times 60} = 76.2\ \text{m}^3/\text{min.}$$

Note : Rational method for determining quantity of storm water is used for small areas, say less than 400 hectares, and without any ponds or swamps. It is generally used for urban areas and should be used with great care and judgement according to the conditions available. For larger areas empirical formulae are used.

(*ii*) Empirical Formulae

When area is large, following empirical formulae are used to determine storm water run-off, which are based on experience and experimental studies.

Empirical formulae are based on the following factors :

(*a*) Area of catchment
(*b*) Intensity of rainfall
(*c*) Impervious nature of soil
(*d*) Slope of ground

Examples of Empirical Formulae

(*i*) Burkli – Zieglar formula
(*ii*) Dicken's formula
(*iii*) Ryve's formula
(*iv*) Inglis formula
(*v*) Nawab Jung Bahadur formula
(*vi*) Dredge or Bunge's formula

Self-Cleaning Velocity

Sewage contains organic and inorganic matter. So, if velocity of flow in sewers is low, this solid matter is likely to settle down and get deposited thus blocking the flow. If velocity is high, particles in the solids cause wear and tear of the sewer. Hence velocity of flow in sewers should be within certain limits. Minimum velocity required to prevent silting in sewers is called *self-cleaning velocity*. This velocity should be attained once a day or preferably twice a day to keep the sewers free from trouble.

Diameter of sewer	Self-cleaning velocity
1. 150 – 250mm	1.00 m/s
2. 300 – 60 mm	0.75 m/s
3. Above 600 mm	0.60 m/s

Shapes for Cross-section of Sewers

Following section are commonly use for sewers

1. Rectangular

This is constructed with RCC and may be precast or cast in situ.

2. Circular pipe

This is the most commonly used sewer. Circular shape is very economical as least quantity of materials is required. Also for least perimeter, it has maximum hydraulic depth when running full or half-filled. This section is suitable for the separate system of sewerage as the discharge is almost uniform, but not suitable for combined system as it is difficult to develop the self-cleaning velocity.

3. Semi-elliptical

It is suitable for sewers of large size, *i.e.* more than 1.8 m diameter.

4. Horse-shoe

It has a semi-circular shape at top with sides inclined or vertical. Invert (bottom) may be flat, circular or paraboloid in section. It is suitable for heavy discharges.

5. Egg-shaped Sewers

It has small section at bottom and larger section at top. It is efficient even during dry weather, as self-cleaning velocity is available. It is suitable for separate system but more suitable for combined system.

For designing egg shaped sewer of an equivalent section, diameter of circular section (D) is multiplied by a constant factor so as to get top horizontal diameter (D′) of the egg shaped section.

$$D' = 0.84\ D$$

Disadvantge

It is difficult to construct and is less stable.

Design of Sewers

Sewers are designed as open channels. Design consists in determining diameter of sewer to carry estimated quantity of sewage at a velocity that is equal to self-cleaning velocity. Thus if Q is discharge, V velocity of flow, area of cross-section A of a sewer, then

$$Q = A \times V$$

Knowing discharge and velocity, the area is calculated.

1. Quantity of Sewage

It depends on the following

(*i*) **Area to be served :** Area of the drainage system is divided into zones, which are marked on the contour plan.

(*ii*) **Arrangement of sewerage :** Location of main sewers is decided according to different patterns such as intercepter pattern, radial pattern, which are marked on the plan. It is economical to isolate low lying areas and pumping stations installed for these areas .

(*iii*) **Type of system adopted (Separate, Combined or Partially separate) :** Maximum discharge in sewer likely to flow is estimated from quantity of water supplied multiplied by a factor. If combined system is adopted, storm water and time of concentration have to be taken into account.

Sewers should be designed for peak flow.

Population	Peak factor for Design of Sewers
1. Up to 20,000	3.5
2. 20,000 to 50,000	2.5
3. 50,000 to 7,50,000	2.25
4. Above 7,50,000	2.0

Estimating Maximum Sewage Discharge

- Pipes should be designed to flow under gravity with $\frac{1}{2}$ to $\frac{3}{4}$th full.
- Quantity of sewage produced

  = Quantity of water supplied from the water work + unaccounted private water supplies

  + Infiltration – water loses – water not entering the sewerage system.
- Net quantity of sewage produced = 70 to 80% of water supplied

For Branch Sewers

Maximum daily flow = 2 times the average daily flow.

Maximum hourly flow = 3 times the average daily flow.

Variations in Sewage Flow:

S.No.	Types of sewer	Ratio of maximum flow to average
1.	Trunk mains above 1.25m in diameter	1.5
2.	Mains upto 1m in diameter	2.0
3.	Branch upto 0.5m in diameter	3.0
4.	Lateral and small sewers upto 0.25m in diameter	4.0

Peak Sewage Flow

$$Q_{max.} = \frac{18+\sqrt{P}}{4+\sqrt{P}}\, Q_{av.}$$

where P = population in thousand.

Minimum flow passing through laterals, may be even lesser than 25% of the average, while in the mains, they can be 50% to 70% of the average.

For branch sewer : Minimum daily flow = $\frac{2}{3}$ × Average daily.

Minimum hourly flow = $\frac{1}{3}$ × Average daily. = $\frac{1}{2}$ minimum daily flow

Thus sewers must be checked for minimum velocities at there minimum hourly flows (*i.e.* $\frac{1}{3}$rd Average daily).

Computation of Peak Drainage Discharge

Time of Concentration

The period after which the entire area will start. countributing to the runoff is called ***time of concentration.***

Time of concentration of a drainage basin may be defined as the time required by the water to reach the outlet from the most remote point of the drainage area.

Critical Rainfall Intensity

Maximum runoff will be obtained from the rain having a duration equal to time of concentration and this duration of rainfall is called *critical rainfall duration* and rainfall intensity during initial critical duration is called ***critical rainfall intensity.***

$$Q_p = \left(\frac{1}{36}\right) kP_c A$$

It is applicable when A < 50 hectare.

where, Q_p = peak rate of runoff in cumecs.

k = coefficient of runoff or impervious factor = $\frac{\text{precipitation}}{\text{run off}}$.

A = catchment area contributing to runoff at the considered point, in hectares.

P_c = critical rainfall intensity of the design frequency, *i.e.* rainfall intensity during the critical rainfall duration equal to the time of concentration, cm/*h*

Time of Concentration for a Given Storm Water Drain

It generally consists of two parts :

(*i*) **Inlet time or Overland flow time or Time of equilibrium :** It is the time taken by the water to flow overland from the critical point upto where it enters the drain mouth.

$$T_i = \left(0.885\frac{L^3}{H}\right)^{0.385} \text{ in hours}$$

where, L = length of overload flow in km from critical point to the mouth of the drain.

H = total fall of level from critical point to the mouth of the drain in metres.

(*ii*) **Channel flow time or gutter flow time (T_f) :** It is the time taken by water to flow in the drawn channel.

$$T_f = \frac{\text{Length of the drain}}{\text{Velocity in the drain}}$$

Total Time of Concentration at a Given Point in the Drain to Obtain Discharge at Point

$$T_c = T_i + T_f$$

Intensity of rainfall during this much of time can be easily obtained from standard intensity duration curves or DAD curves.

In the absence of standard intensity-duration curves, value of P_c can also be determined in the following two ways:

(*i*) $$P_c = P_0\left(\frac{2}{1+T_c}\right)$$

where P_0 = one hour rainfall × a real distribution factor.

T_c = time of concentration in hours

(*ii*) $$P_c = \frac{a}{T_c + b}$$

where, T = time in minutes

P = rainfall intensity in cm/hr

For T_c varies between 5 to 20 minutes, $P_c = \frac{75}{t_c + 10}$

For T_c varies between 20 to 100 minutes, $P_e = \frac{100}{T_c + 20}$

Suggested Empirical equations :

(*i*) For rains having frequency of 5 years, $P_c = \frac{343}{T_c + 18}$

(*ii*) For rains having frequency of 10 years, $P_c = \frac{38}{\sqrt{T_c}}$

(*iii*) For rains having frequency of 1 year, $P_c = \dfrac{15}{t^{0.620}}$

(*iv*) Kuichling's formula's

For storm having frequency of 10 years, $P_c = \dfrac{267}{T_c + 20}$

For storm having frequency of 15 years, $P_c = \dfrac{305}{T_c + 20}$

Empirical formulae

(*i*) Dicken's formula: $Q_p = CM^{3/4}$ (Used in North India)

where, C = a constant with values ranging from 250 to 1600

M = catchment area in km^2

Q_p is in cumecs

(*ii*) Ryve's formula: $Q_p = C_1 M^{2/3}$

where, M = area in sq. km.

Q_p = peak dischargs in cumec

C_1 = constant = 6.8

(*iii*) Inglis formula : $Q_p = 123\sqrt{M}$

$$Q_p = 19.6\,\frac{M}{L^{2/3}}$$

where, L = length of the drainage basin in kilometres.

Total Area of District

It can be considered to be made up of smaller areas $A_1, A_2, A_3, \ldots A_n$, having runoff ratio (*i.e.* coefficient of runoff) k for the entire area may be computed by using

$$k = \frac{\Sigma kA}{\Sigma A} = \frac{k_1A_1 + k_2A_2 ----+ k_n A_n}{A_1 + A_2 + ---+ A_n}$$

2. Velocity of Flow

Following formulae are commonly used for finding velocity of flow :

(*i*) *Chezy's formula :* Velocity of flow (m/sec), $V = C\sqrt{RS}$

where, S = hydraulic gradient

R = hydraulic mean depth

C = Chezy's constant. It depends upon factors like size and shape of the channel, roughness of the channel surface, hydraulic characteristics of the channel, etc.

(*ii*) *Manning's formula :* $V = \dfrac{1}{n} R^{2/3} S^{1/2}$

where, n = Manning's constant = 0.012

(*iii*) *Crimp and Burge's formula :* $V = 83.5\, R^{2/3} S^{1/2}$

(*iv*) *William-Hazen's formula :* $V = 0.85\, C_H R^{0.63} S^{0.54}$

(*v*) *Bazin's Formula :* $C = \dfrac{157.6}{181 + \dfrac{K}{\sqrt{R}}}$

where, K = Bazin's constant

S. No.	Nature of inside surface of sewer	Value of K
1.	Very smooth surface	0.109
2	Smooth brick and concrete surfaces	0.290
3.	Smooth rubble masonry surface	0:833
4.	Good earthen channels	1.540
5.	Rough brick and concrete surfaces	0.500
6.	Rough earthen channels	3.170

Required Maximum and Minimum Velocities in Sewers

How velowcities in the sewer should be such that wether the suspended materials in sewage get silted upnor the sewage pipe materials gets seoure out.

Minimum velocity : Generation of a minimum self-cleaning velocity in the sewer, atleast once a day, is important.

$$\text{Self cleaning velocity,} \quad V_s = C\sqrt{kd'(G_s - 1)}$$

where, k = 0.04 for inorganic matter

= 0.60 for organic matter

d' = diameter of the grain

G_s = specific gravity of sewage particle.

or $$V_s = \sqrt{\frac{8k}{f'}(G_s - 1)\,gd'} \qquad \text{......(here, } f' = 0.03)$$

and $$V_s = \frac{1}{n}\,r^{1/6}\sqrt{kd'(G_s - 1)}$$

For removing impurities mostly present in sewage, it is necessary that minimum velocity of about 0.45 m/s and an average velocity of about 0.9 m/s is developed in sewers, design flow velocity = 0.8 m/s.

Minimum velocity would be generated at minimum discharge (*i.e.* about 1/3rd of average discharge) depends only upon the hydroulic mean depth of sewer and the slope on which the sewer has been laid.

Maximum velocity : Non-scouring velocity mainly depend upon material of the sewer.

For cast iron sewers – 3.5 to 4.5 m/s.

For cement concrete sewers – 2.5 to 3 m/s.

Sewers have to be designed such that self-cleaning velocity is developed with minimum discharge. Generally the self-cleaning velocity is kept between 0.45 and 0.9 m/s.

3. Gradient of Sewers

Velocity of flow depends directly on the slope or grade, hydraulic mean depth and roughness of the sewer.

The velocity in a sewer cannot be increased to any limit as it will cause wear and tear of the sewer. Maximum permissible velocities or limiting velocities depend on the material of the sewer.

Material of the sewer	Maximum Permissible Velocities in Sewers
1. Cast-iron sewer pipe	3.5 – 4.5 m/s
2. Earthen channel	0.6 – 1.2 m/s
3. Brick sewer pipe	1.5 – 2.5 m/s
4. Stoneware sewer pipe	3.0 – 4.5 m/s
5. Concrete sewer pipe	2.4 – 3.0 m/s

4. Size of Sewers

Area of cross-section for the sewer is found from Q/V. Minimum size of sewer is 100 mm for a maximum length of 6 m. When length is more, 150 mm is minimum diameter. Sewer size should be so designed that commercially available diameter could be arrived at. When diameter exceeds 3 m, it is desirable to provide two pipes.

Design of Circular Sewer Section

Circular section is most widely adopted for sewer pipes when running full or partially full.

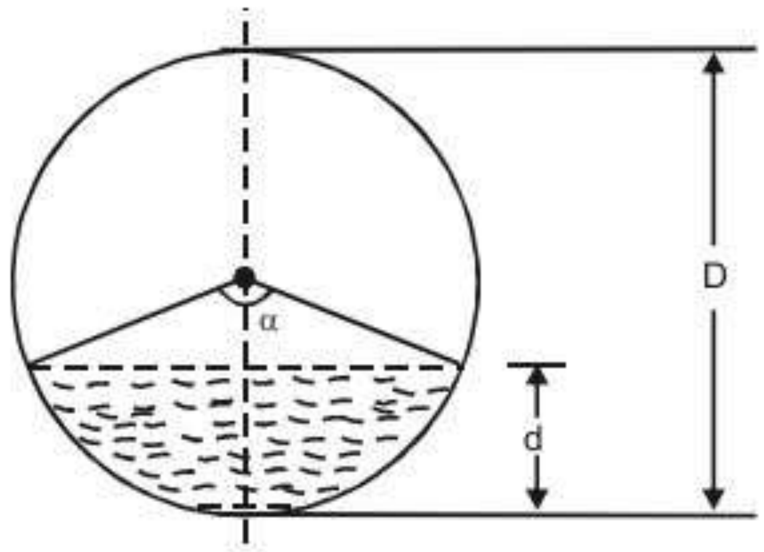
Hydraulic characteristics :

$$\text{Area of cross-section, } A = \frac{\pi}{4}D^2$$

$$\text{Wetted perimeter, } P = \pi D$$

$$\text{Hydraulic mean depth, } R = \frac{A}{P} = \frac{D}{4}$$

When sewers run partially full at depth d, then



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

Proportionate area $= \frac{a}{A} = \left[\frac{\alpha}{360^\circ} - \frac{\sin\alpha}{2\pi}\right]$

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

Proportionate hydraulic mean radius $= \frac{r}{R} = \left[1-\frac{360^\circ\sin\alpha}{2\pi\,\alpha}\right]$

Proportionate velocity $= \frac{v}{V} = \frac{N}{n}\,\frac{r^{2/3}}{R^{2/3}}$

Assuming $n = N$, $\quad \frac{v}{V} = \frac{r^{2/3}}{R^{2/3}} = \left[1-\frac{360^\circ\sin\alpha}{2\pi\,\alpha}\right]^{2/3}$

$$\text{Proportionate discharge} = \frac{q}{Q} = \frac{av}{AV} = \frac{a}{A}\cdot\frac{v}{V} = \left[\frac{\alpha}{360} - \frac{\sin\alpha}{2\pi}\right]\left[1-\frac{360^\circ\sin\alpha}{2\pi\alpha}\right]^{2/3}$$

Here, except α all are constant.

Let s = bed slope when running partially full, and

S = bed slope when running full

$$\therefore \quad \gamma_w r.s = \gamma_w RS$$

$$\Rightarrow \quad s = \left(\frac{R}{r}\right)S$$

$$\frac{V_v}{V} = \frac{N}{n}\left(\frac{r}{R}\right)^{2/3}\sqrt{\frac{s}{S}} = \frac{N}{n}\left(\frac{r}{R}\right)^{1/6} \quad \text{........[since } \frac{s}{S} = \frac{R}{r}\text{]}$$

$$\therefore \quad \frac{q}{Q} = \frac{N}{n}\left(\frac{a}{A}\right)\left(\frac{r}{R}\right)^{1/6}$$

Note: Capital letters are related to running full condition while small letters are related to running partially full conditions.

Limitations of Depth of Flow (Due to Ventilation Considerations)

- Sewers upto 400mm diameter may be designed to run at $\frac{1}{2}$ depth.
- Sewers between 400 to 900 mm diameter may be designed for $\frac{2}{3}$ depth.
- Larger sewers may be designed for $\frac{3}{4}$ depth at ultimate peak design flow.

Shape of Sewer

Two sewers of different shapes are said to be hydraulically equivalent when they discharge at the same rate, while running full, on the same grade.

Example : Calculate velocity of flow and discharge in a sewer of dia. 1 m laid at a gradient of 1 in 400. Assume the sewer to run half-filled. Use Manning's formula. in Manning's formula N = 0.012.

Solution : From Manning's formula, velocity of flow, $V = \frac{1}{n} R^{2/3} S^{1/2}$

where, n = coefficient of rugosity = 0.012 (given)

S = slope = 1/400 (given)

R = hydraulic mean depth $= \frac{A}{P}$

where, A = area of cross-section of sewer

$$P = \text{wetted perimeter} = \frac{\pi d^2}{4 \times \pi d} = \frac{d}{4} = 0.25\,d$$

$$\therefore \quad V = \frac{1}{0.012} \times (0.25)^{2/3} \times \left(\frac{1}{400}\right)^{1/2} = 1.653 \text{m/s}$$

Quantity of discharge for a sewer running half-filled, $Q = \frac{1}{2}AV = \frac{1 \times \pi \times 1^2 \times 1.653}{2 \times 4} = 0.6494 \text{ m}^3/\text{s}$.

SEWER MATERIALS

1. **Asbestos Cement sewers.**

   It is best suited to be used as verticals for bringing down either the rain water from the roofs, or comparatively foul sullage from kitchens and bathrooms situated at the upper floors of the buildings.

   Precast pipe : cast in factories.

   Cast in situ pipes : cast at site.

2. **Plain cement concrete and Reinforced cement concrete Sewers.**

   Usual concrete mix used is 1 : 1½ :3. Size of aggregate is limited to 6mm.

   Reinforced cement concrete (R.C.C) sewers are those concrete sewers which are provided with circumferential reinforcement to carry internal or external stresses, and a nominal longitudinal reinforecement equal to 0.25 % of the cross-section area of concrete.

3. **Vitrified clay or Stoneware or Salt-glazed Sewers.**

   It is widely used for carrying sewage and drainage, as house connections as well as lateral sewers.

4. **Brick Sewers.**

   Preformed for constructing large sized cambined sewers or particularly for stone water drains.

5. **Cast iron Sewers.**

   These are manufactured by following two methods :

   (*i*) Sand moulding method

   (*ii*) Centrifugal process.

LAYING OF SEWERS

It consists of following operations:

1. **Setting out Alignment**

   Centre line is marked starting from the outfall (lowest point) and proceeds upwards. Generally, sewer is laid along the middle of the street and existing underground structures like water-mains should be avoided. Setting out is done by a theodolite and chain.

   Centre line is marked by an offset line parallel to the proposed alignment which will not be disturbed during construction. Temporary B. Ms are established at 200-400 m intervals. Reduced levels of these bench marks are fixed with reference to a GTS benchmark. Pegs or spikes are also driven at 10 m intervals. Position of appurtenances are marked as per plan. This method is suitable when inconvenience to traffic should be caused only for a short duration of time.

   Another method of marking centre line is by driving two vertical posts into the ground on either side of the centre of the trench. A horizontal rail called *sight rail* is fixed between these two posts at a convenient height from the ground level. A suitable vertical height is added to the levels of the invert (bottom) of pipe given on the plan and top of sight rail is adjusted to the modified level and the levels are marked on nails driven into sight rails. A string is stretched between the rails. Thus an imaginary line parallel to the sewer line on the ground is obtained at the level of the string.

2. **Excavation of Trenches**

   First the pavement is removed. Width of trench to be excavated is 150 mm more than the external diameter of the sewer. A minimum trench width of 600 -1000 mm has to be provided to enable the pipes to be laid and jointed. Sometimes even for small diameter pipes, width is made 150 mm more than the diameter but at the ends where joints are situated, the trench is made larger.

3. **Bracing and Dewatering**

   In rocky and hard soils, sides of the trenches will remain in the cut position. However, in loose soil as well as made-up soil, the sides will collapse and hence shoring and strutting is necessary. This is also necessary to prevent caving to reduce danger to workmen. When sides of trenches are of depth more than 1.5m, they are held securely by shoring and bracing or sloped to the angle of repose of the soil.

If trench has to be excavated below the ground water table, then water flows into it and causes difficulty in laying pipes. The common method adopted is to allow the water to flow into a sump from where it is pumped out. As the water will contain gritty materials, only centrifugal pumps are suitable.

However, if soil encountered is sandy material, then moving water separates grains of sand and undermines side walls, in such a condition, that the problem is overcome by using well points. These are pipes 50 - 75 mm in diameter, pointed at the lower ends, with perforations just above the point. These pipes are driven into the ground on one or both sides of the trench about 2 m from centre line, 1 m apart, and driven well below the watertable. 150-203 mm header pipes parallel to the trench are fixed to the well pipes and connected to a pump. Water is pumped out and keeps the trench dry.

For large sewers, an underground tiled drain with open joints with gravel around is provided below the sewer. The drain discharges into a sump from where it is pumped. The advantage is that water will not enter the trench and damage bottom and sides. Drain can be left after the work is completed but should be closed to prevent continuous drainage of the soil.

4. Laying of Pipe

Pipe should be inspected to ensure that it has no cracks or defects. Pipe lengths are placed in line and grade after the trench has been completely dewatered.

Small-sized pipes can be laid by the pipe-layers manually, but heavier pipes are lowered into the trenches by means of ropes. Pipes are laid with their socket end on the upgrade for easy jointing. Pipes are lowered and spigot-end of one pipe is placed in the socket of the one before it.

Levels of the invert of the sewers are checked by means of a boning rod or traveller. Boning rod has a shoe at the bottom. Length of the boning rod is adjusted so that its level at the top coincides with the line of sight. Verticality of the boning rod is checked by a plumb bob. Boning rod is placed with its shoe touching invert of the sewer. Level of the invert is then adjusted.

Sewers are generally laid on a concrete bedding so that weight of the pipe is distributed uniformly.

5. Jointing

In ordinary bell-and-spigot pipes, cement mortar (1 : 1) or bitumen joints are adopted. A gasket is inserted with a caulking tool and the joint is filled with mortar or bitumen. The cement-mortar joint is finished by applying cement mortar at an angle of 45 on the outer face

Cement-mortar joints have the disadvantage that they are rigid and any settlement of pipe will produce cracks, which will cause infiltration. When ground water table is above the sewer, special precautions are necessary. In such situations it is preferable to adopt bituminous materials. Bitumen is poured at 200°C and a jute gasket is caulked in place to prevent the bitumen from entering the pipe.

6. Testing of Sewers

Testing is carried out in sections of sewer lines between manholes. Lower end of the pipe is provided with a plug. Pipe is filled with water and allowed to stand for a week before commencing application of pressure.

7. Backfilling of Trenches

After testing and removing defects in the pipeline, trenches are refilled with the excavated soil. Soil is laid in layers of 150 mm thickness and is watered and rammed well. When height of backfilled earth reaches 600 mm above the crown of the pipe, then backfilling is stopped for a weak. Then trench is filled 150 mm above the ground level.

SURFACE DRAINS

These are used to carry storm water and sullage. These are open drains and are constructed along both sides of the streets next to the boundary walls of buildings. These require cleaning at short intervals.

Surface drain should satisfy following requirements:

(*i*) It should develop self-cleaning velocity with minimum discharge.

(*ii*) It should have sufficient free board even during maximum discharge.

(*iii*) It should be capable of being easily cleaned.

(*iv*) It should be structurally stable and safe.

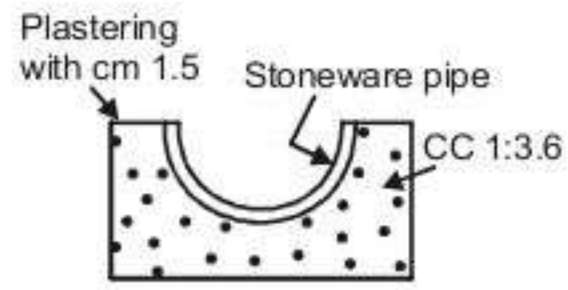
(*v*) It should be free from corrosion.

Shapes of Surface Drains

1. Semi-circular Section

In this type, semi-cylindrical glazed-stoneware pipe is used, and is laid on a bed of concrete.

Disadvantages :

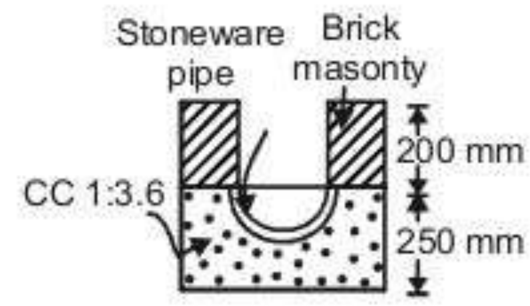


(*i*) If discharge decreases, self-cleaning velocity will not be developed. This cause suspended particles to settle down in the bottom and hence drain will not function properly.

(*ii*) Suitable only for small discharges.

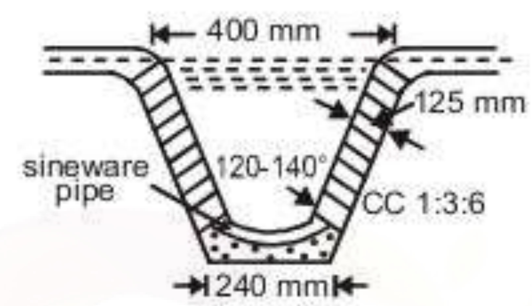
(*iii*) For large discharges, diameter required is large and more space is, therefore, occupied.

2. U-Section



In this sides are raised to get a 'U' shape. Semi-cylindrical stoneware pipes used for bottom part (called *invert*) of the drain and sides are lilt with brick masonry and hence they can be constructed very easily.

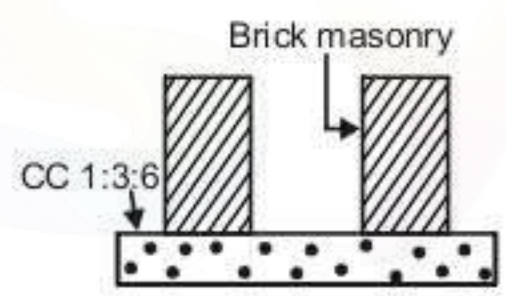
3. V-Section



In this section, bottom is laid with 1/3 or 1/4 stoneware pipe and sides are constructed with brick or stone slabs and plastered. Angle subtended by the sides make 120°, 100° or 60° at the centre of pipe.

V-section gives self-cleaning velocity even for very small discharges be cause of the greater depth available for the same area of cross-section.

4. Rectangular Section



It is constructed by laying plane concrete bed, over which sides are constructed with stone or brick masonry and finally plastered inside.

This type is suitable for large discharges. For small discharges, self-cleaning velocity will not be developed and causes suspended particles settle down.

SEWER APPURTENANCES

For efficient operation and maintenance of the sewer system, some additional structures called *appurtenances are provided. Sewer appurtenances include following :*

1. Manholes

These are masonry or R.C.C chambers, constructed at suitable intervals and at every change in gradient along the sewer lines for providing access into the sewers, help in joining sewer lengths, and also help in their inspection, leaning & maintenance.

The spacing of manholes is more on large sized sewers, because they can be entered more easily by men for inspection.

Components : *Manhole has following components :*

(*i*) Working chamber (*ii*) Access shaft (*iii*) Cover and rungs (*iv*) Channels

2. Drop Manholes

When a sewer connects with another sewer which is at a materially different level, drop manhole is adopted. A vertical drop pipe from the higher to the lower sewer is provided.

If drop pipe is outside the shaft, the sewer should be continued through the shaft wall to enable inspection and rodding.

3. Street Inlet (or Gullies)

An opening through which storm water from a street is allowed to enter a storm sewer or a combined sewer is called *street inlet*. Inlets are placed on street gutters generally at street intersections where level is low.

4. Catch Basins or Pits

These are small chambers constructed to prevent entry of grit, sand debris, etc. into the sewer lines. When storm water enters the pit, the grit, sand, etc. settle down at the bottom.

Catchpits are used in the following situations :

(*i*) When sewers are laid at a flat gradient and self-cleaning velocity is not developed, then solids present in the sewage accumulate in the sewer which requires frequent cleaning. However, if a catchpit is provided, the solids accumulate in the pit, and can be periodically removed.

(*ii*) When sewer passes through areas where lot of debris is likely to get into the sewer, such as market places, it is likely to be blocked. In such places, catchpits are provided under street inlets.

5. Flushing Tank

Where it is not practicable to obtain a gradient in the sewers to give a self cleaning velocity of 0.75 m/s, it should be flushed occasionally to prevent deposition and clogging.

Methods used for flushing

(*i*) Construction of special flushing tanks at suitable points in the sewer line.

(*ii*) Admission of a limited amount of surface water into sewer line at required point.

(*iii*) Provision of gates at the outlet side of an ordinary manhole. Closing the gate will permit sewage to accumulate and opening it will allow a rush of sewage to pass down the pipe.

6. Inverted Syphon

It is a portion of a sewer constructed lower than the adjacent stretch, to pass beneath a valley, water course, or other obstruction. It runs full at greater than atmospheric pressure because its crown is depressed below hydraulic grade line. Generally, velocity should not be less than 1.2 m/s.

7. Stormregulators

Combined system of sewer is designed to convey dry weather flow and a certain quantity of storm water. When rainfall is unusually heavy, the storm water is also high and this excess water is disposed of from the sewers by means of storm relief works or regulators. Extra quantity of sewage from the main sewer flows over a weir and enters another overflow sewer which conveys the water directly to a stream. Top of the weir is fixed in such a way that extra quantity over and above a predetermined amount of sewage is disposed off. Overflow weir may overflow on one side and is called *single-acting*.

8. Pumping Stations

IS: 4111—1968 gives guidance for design and construction of pumping stations and pumping mains.

Following considerations should be taken into account while locating pumping stations :

(*i*) The site should be above the highest recorded flood level. When construction on ground liable to flood is unavoidable, it should be designed so that motors are well above the highest recorded flood level.

(*ii*) In the event of power failure any overflow which occurs should be able to find its way into a water course without causing flooding or serious damage to property.

(*iii*) Pumping station should be located as far as possible from the residential areas to avoid bad smell.

SEWAGE TREATMENT

Sewage, before being disposed off either in river streams or an land, has generally to be treated, so as to make it safe.

Sewage has to be treated for the following reasons:

(1) To prevent pollution of water into which the sewage is let off, as water may be used downstream for drinking water supply. This causes a health hazard as sewage contains pathogenic bacteria.

(2) To prevent offensive odour in the water if water is used for swimming, boating, etc., and to the people living near the water or land where sewage is disposed off as it causes health hazard.

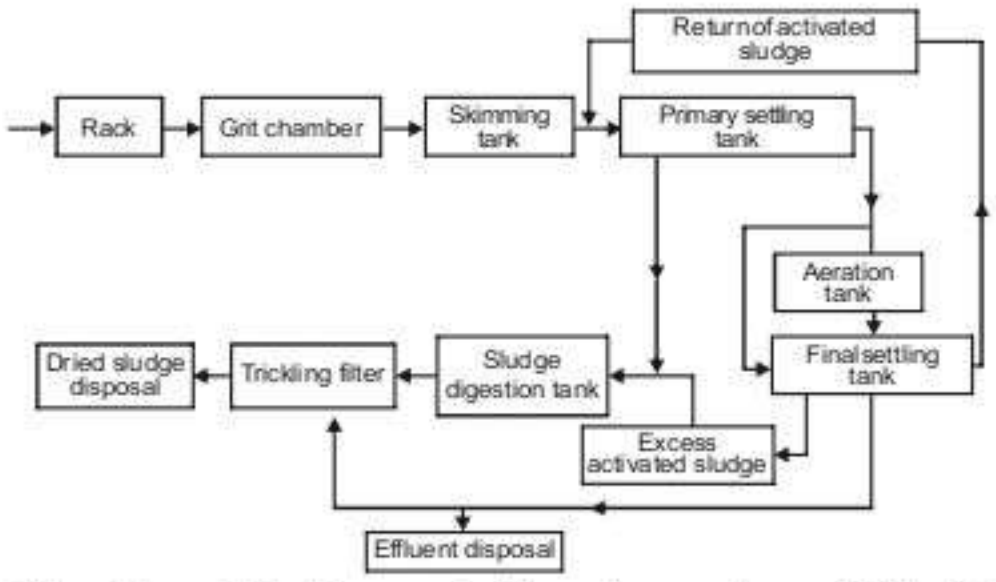
(3) To prevent destruction of fish and other aquatic life.

(4) If sewage has to be disposed of on land, soil will become sewage sick after some time and cannot take any more sewage. This creates a very messy scene at the site and produces offensive odour polluting the entire atmosphere and affecting the neighbourhood.

SEWAGE TREATMENT PROCESS.

It can be classified into the following four categories :

I. Preliminary treatment
II. Primary treatment
III. Secondary or Biological treatment
IV. Final or tertiary treatement (Disinfection)



Types of Treatment Units Employed in Sewage Treatment, and Their Functions

Type of Treatment	Purification effected	Process or unit employed	BOD removal as% of original	Removal bacteria as% of original	Disposal of residuals
1. Preliminary treatment	(*i*) Removal of floating materials like dead animals, tree branches etc.	Coarse and fine screens of different designs.	5-10	10-20	Screenings can be disposed off, easily, either by burials or burnings
	(*ii*) Removal of heavy settleable inorganic solids	Grit chamber or detritus tanks	10-20	10-20	Grit can be easily disposed off eitehr by burials or burning
	(*iii*) Removal of fats and greases Removals of suspended settleable organic solids.	Skimming tanks or Vacuators	20-30	10-20	Skimmings was unstable volatile materials, and to disposed off by stablising them in tanks by anaerobic decomposition.
2. Primary treatment	Removal of fine suspended nonsettleable solids and colloidals, including dissolved organic matter	(*i*) Sedimentation tank	30-35	25-75	Sludge containing organic materials has to be stabilised
		(*ii*) Septic tank	20-30	25-75	Stabilised first, in disgestion tank and the digested materials is then used as a
		(*iii*) Imhoff tanks	30-40	25-75	manure or soil builder Effluents are disposed off for sewage farming on lands. These units sludge digestional along with sedimentation tanks.
3. Secondary or Biological treatment	Removal of pathogens and the remaining very fine dissolved organic matter	(*i*) Chemical flocculations and sedimentation	50-85	40-80	Sludge containing organic materials has to be stabilised in digestion tanks and residue is used as manure or soil builder.
		or			
		(*ii*) Intermittent sand filters, followed and proceeded by sedimentation	90-95	95-98	same as above
		or			
		(*iii*) Conventional low rate tricking filters followed and proceeded by sedimentation	90-95	95-95	same as above
		(*iv*) Modern high rate trickling fitter followed and proceded by sedimentation	75-95	90-98	Effluents are generally disposed off by using them for irrigation
		(*v*) Activated sludge treatment in aeration tank and secondary settling tank			
		or			
		(*vi*) Oxidation ponds	85-90	90-98	
4. Final or tertiary treatment		Chlorinotion	100%	100%	

I. Preliminary Treatment

It consists solely in separating floating materials and heavy settleable inorganic solids. This treatment reduces BOD of the waste water by about 15 to 30%.

Main operations. It consist of following main operations:

1. Screening

Sewage admitted to sewage treatment plant and pumping stations should be effectively screened to protect the machinery in the plant and to avoid difficulties in subsequent stages of treatment. Screens are also necessary when raw sewage is discharged into a water-course without treatment to prevent unsightly and repulsive floating matter being discharged.

Screening device consists of flats placed vertically, inclined or curved (at 45° to 60° to the horizontal) and spaced at close and equal intervals across a channel through which sewage flows. It is used for removal of certain materials such as pieces of wood, floating debris, rags etc. found in sewage.

Depending on the clear spacing between flats, screens are classified as follows :

Coarse screens	.. Above 50 mm
Medium screens	.. 20 to 50 mm
Fine screens	.. Less than 20 mm

Types of Screens : *These are mechanically or manually operated.*

(*i*) **Manually cleaned Screens :** In these a perforated platform is provided from which an operator may rake the screenings from the screen. A hand-rake is provided. Screen is placed inclined between 45° and 60° to the horizontal.

While designing the screens, clear openings should have sufficient total area, so that velocity through them is not more than 0.8 to 1m/s

$$\text{Head loss through the screen} = 0.0729\,(V^2 - v^2)$$

where, V = velocity through screen = 0.8 to 1m/s.

v = velocity above screen = 0.8 or 5/6 m/s

(*ii*) **Mechanically cleaned Screens :** In these a mechanical raking device is provided. Inclination of the screen should be between 60 and 90° with the horizontal. Raking mechanism cleans the screens and lifts up screenings and empties into a trough.

2. Grit Removal

Sewage contains inorganic matter such as sand, broken crockery etc., which can create problem in sludge digestion as it combines with other organic matter in the sludge. It also causes wear and tear on pumps.

(*i*) **Grit Chamber :** It removes grit. It is a tank in which velocity of flow of sewage is reduced. Sand being heavier than organic matter, settles down on the bottom. Chamber may be horizontal or vertical type. Grit chamber is provided after screening operation.

In grit chambers, flow velocity should neither be too low so as to cause setting of lighter organic matter, nor should be too high so as to cause setting of entire silt in the sewage.

For grit chamber, critical scour velocity, $V_H = 0.3$ to 0.45 m/s

In practice, a flow velocity of about 0.25 to 0.3 m/s is adopted for design of grit basins.

Detention time of about 40 to 60 seconds is generally sufficient for a water depth of about 1 to 1.8 m.

$$\text{Detention time (D.T)} = \frac{\text{Depth of the tank}}{\text{Settling velocity}} \text{ or D.T.} = \frac{\text{Length of the tank}}{\text{Horizontal velocity}}$$

$$V_s = d\,(3T + 70)$$

Grit chambers of sewage treatment plant is normally cleaned periodically at about 3 week interwale.

(*ii*) **Detritus tank :** It remove finer particles but is meant to remove finer particles including some organic matter. For this, velocity is reduced more than that in the grit chamber and detention period is longer. This causes part of the organic matter also to settle down. Detritus is was hed mechanically and the organic matter is returned to sewage. Sometimes compressed air is blown through the chamber to lift up organic matter which is lighter, and to make it flow forward.

3. Removal of Oil, Grease, etc.

Grease and oil creates following difficulties :

(*i*) Produce foul odour when sewage has to be directly discharged into water. Aeration is also retarded that causes anaerobic conditions.

(*ii*) Clogging of trickling filters.

(*iii*) Interfere with the working of bacteria.

(*iv*) Not easily digested in sludge digestion tanks.

Skimming Tanks

Tanks for removing oils and grease is called *skimming tanks.* These are narrow rectangular tanks. Air diffusers are provided at the bottom and compressed air is blown through them. Oil and greasy substances are changed to a soapy mixture by the air and are lifted to the surface. Floating substance is removed manually or mechanically. Chlorine is sometimes added which helps to remove effectively the oils and grease. Grease and oils may be removed by addition of chemicals including sulphuric acid.

Floating substance is disposed off by filling up the low lying areas or burnt along with sludge.

Detention periods of about 3 to 5 minutes is usually sufficient, and amount of compressed air required is about 300 to 6000 m^3 per millions litres of sewage.

$$\text{Surface area required for the tank, } A = 0.00622\ \frac{q}{V_r}$$

where, q = rate of flow of sewage in m^3/day.

V_r = minimum rising velocity of grease material to be removed = 0.25 m/minutes (mostly)

II. Primary Treatment

It removes large suspended organic solids. This is accomplished by sedimentation in settling besins. The effluent contains a large amount of suspended organic material and has a high BOD / about 6% of original.

Finaly divided suspended solids in the sewage are made to settle down by the sedimentation process.

Sedimentation in sewage works are corried out for following :

(*i*) To remove 80 – 90% of settleable solids

(*ii*) To reduce strength of sewage by 30—35%

1. Sedimentation Tanks

Classification of sedimentation tanks

(*i*) According to Use

(*a*) Primary sedimentation tank : When a sedimentation tank is used for settling suspended solids before biological treatment *i.e.,* soon after the grit chamber, it is called *primary sedimentation tank*.

(*b*) Secondary sedimentation tank : When a sedimentation tank is used for settling suspended solids after biological treatment, it is called *secondary sedimentation tank.*

(*ii*) According to Flow type

(*a*) Vertical flow type : These have rectangular, circular or hopper bottom shapes.

(*b*) Horizontal flow type : *These are further classified as follows :*

(*a*) Radial flow type

(*b*) Circumferential flow type

Note : The liquid sewage coming out of tanks after sedimentation process is called *effluent*. The thick viscous liquid settled at the bottom of the tank is called *sludge*.

Design of Primary Sedimentation Tank

Sedimentation tanks are desinged to remove a part of the organic matter from the sewage effluent coming out from the grit chambers.

In a complete sewage treatment, the sedimentation is carried twice

(*i*) Before the biological treatment (*i.e.* primary sedimentation)

(*ii*) After the biological treatment (*i.e.* secondary sedimentation).

Settling velocity

For $d < 0.1$ mm, $V_s = \frac{1}{18} . g . d^2 \left[\frac{G_s - 1}{\upsilon}\right]$

For $d > 0.1$ mm, $V_s = 418 (G_S - 1) d^2 \left(\frac{3T + 70}{100}\right)$

For $d > 1$ mm, $V_s = 1.8 \sqrt{gd(G_S - 1)}$

For d between 0.1 to 1 mm, $V_s = 418 (G_S - 1) d \left(\frac{3T + 70}{100}\right)$

where, d = diameter of particle (in mm)

T = temperature (in°C)

G_s = specific gravity of particle

V_s = settling velocity (in cm/sec)

Hazen equation for transition zone : $V_s = 60.6\, d\, (G_S - 1) \left(\frac{3T + 70}{100}\right)$

For inorganic solids $V_s = d\,(3T + 70)$

For organic solid $V_s = 0.12 d\,(3T + 70)$

Flow velocity $V = \frac{Q}{BH}$

From geometric consideration $\frac{V}{V_s} = \frac{L}{H}$

But, $V = \frac{Q}{BH}$, hence $V_s = \frac{Q}{BL}$

Discharge per unit plan area $\frac{Q}{BL}$, is an important term for the design of flow type of settling tanks.

It shows that all those particles with a settling velocity equal to or greater than $\frac{Q}{BL}$ will settle down and be removed.

Overflow rate : Selting velocity in tanks is also called **overflow rate** or **surface loading** or **overflow velocity**

Normal value of overflow rates ranges between:

40 to 50 cum/m^2/ day 1650 to 2100 l/h m^2 - for plain primary sedimentation tanks

50 to 60 /m^2/day - for sedimentation tanks using coagulants. as aid

about 25 to 35 cm/m^2/day - for secondary sedimentation tanks.

Note : Smaller particles will also settle down, if overflow rate is reduced.

Effective depth : Usual value of effective depth (*i.e.* depth excluding bottom sludge zones) range between 2.4 to 3.6 m.

Detention time

For rectangular tank, detention time = $\frac{BLH}{Q}$

For circular tank, detention time = $\frac{(0.011/d + 0.785\,H) d^2}{Q}$

Dimensions of tank

- Width of tank is usually kept about 6 m, and not allowed to exceed 7.5m or so.
- Length of the tank is generally not allowed to exceed 4 to 5 times the width.

Flow velocity : Generally taken as 0.3 m/minute.

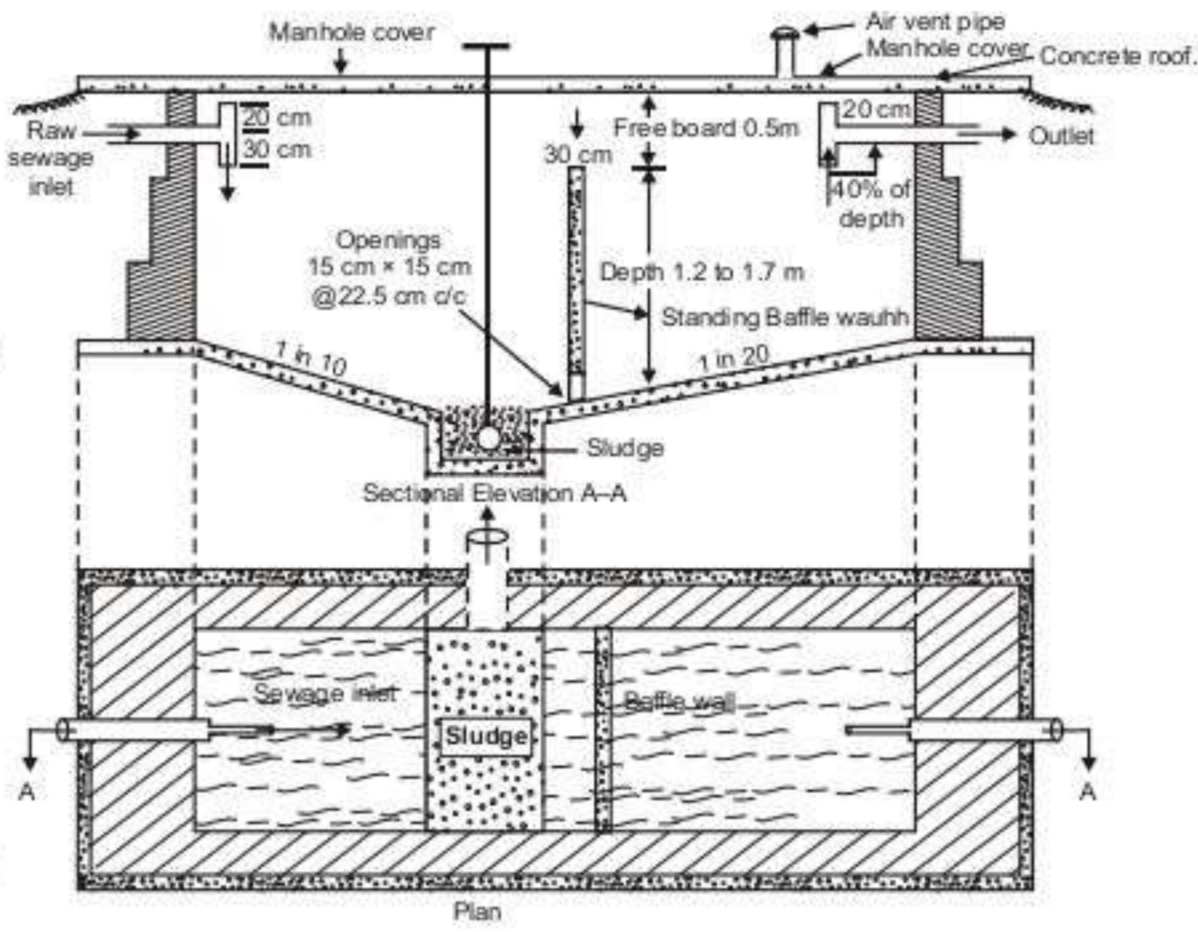
$$\textit{Displacement efficiency} = \frac{\text{flowing through period}}{\text{detention period.}}$$

Sludge zone : For tanks without mechanical sludge removal equipment, an additional minimum depth of about 0.8 to 1.2 m should be provided for storage of settled materials, and is called *sludge zone.*

2. Septic Tanks

It may be defined as a primary sedimentation tank, with a longer detention period (12 to 36 hr.) and with extra provisions for digestion of the settled sludge.

Septic tank unit is generally classified under the units which work on the principle of anaerobic decomposition. It is completely covered and provided with a high vent shaft for escape of gases.



It is a horizontal continuous flow type of a sedimentation tank, directly admitted raw sewage, and removing about 60 to 70% of the dissolved matter from it. Effluent from such a tank will be sufficiently foul in nature, and will have to be disposed off either for sub-surface irrigation or in cess-pools or soakpits or to be treated in trickling filter before disposed it off in water courses.

These are generally provided in areas where sewers have not been laid.

Design criteria

(*i*) Capacity of septic tanks = Quantity of sewage produced during detention periocs

+ Volume of sludge for 6 months to 3 years, depending upon periodicity of cleaning.

Rate of accumulation of sludge has been recommended as 30 lit./person/years.

A free board of about 0.3 m. may be provided above the top sewage line in the tank.

(*ii*) *Inlet and outlet baffles :* Inlet should penetrate by about 30 cm below the top sewage line, and the out let should penetrate to about 40% of the depth of sewage.

(*iii*) *Detention period :* It for septic tank generally varies between 12 to 36 hr. but is commonly adopted as 24 hours.

(*iv*) *Length to width ratio :* L/B = 2 to 3. Width should not be less than 90 cm. Depth of the tank generally ranges between 1.2 to 1.8m.

Methods of disposal of Effluent from Septic tanks

(*i*) Sub-surface irrigation method using dispersion trenches

(*ii*) Disposal in soak-pits

(*iii*) Disposal in a leaching cess–pool.

Design of soak-well

Soak-well or soak-pit can be designed by assuming percolating capacity of the filtering media, say as 1250 lit/m^3 /day.

3. Imhoff Tanks or Two-storey Digestion Tanks

It is a two storeyed tank in which upper portion is called *sedimentation tank* and lower portion is called *digestion chamber.*

Design criteria

(*i*) *Sedimentation tank :* *It is rectangular in shape with the following specifications :*

(*a*) Detention period = 2 to 4 hours (usually 2 hours).

(*b*) Flowing through velocity should not be more than 0.3 m./minute.

(*c*) Surface loading should not exceed 30, 000 litres/m^2 of plan area/day.

(*d*) $L \leq 30$ m, $\frac{L}{B} = 3$ to 5.

(*e*) Total depth = 9 to 11 m, Depth of sedimentation chamber is about 3 to 3.5 or so.

Free-board = 45 cm.

(*ii*) ***Digestion chamber:*** This chamber is generally designed for a minimum capacity of 57 litres per capita.

Note: Working conditions in imhoff tanks are **anaerobic in lower** compartment and **aerobic** in upper compartment.

Clarigesters : These are small patented circular imhoff type double storey tanks, without bottom hoppers, and fitted with mechanical sludge and scum breaking equipment.

III. Secondary or Biological Treatment

It involves further treatment of the effluent, coming from the primary sedimentation tank. This is generally accomplished through biological decomposition of organic matter which can be carried out either under aerobic or anaerobic conditions. In these biological units, bacteria will decompose the fine organic matter to produce clear effluent.

Secondary Treatment Processes

These processes helps in changing the unstable organic matter into stable forms. All the secondary treatment process are designed to work on aerobic bacterial decompositions.

1. Chemical Precipitation and Coagulation

When chemicals are used to hasten settling of suspended solids, the process is called *chemical precipitation*. When certain chemicals are added to the sewage, a gelatinous precipitate called *floc* is formed which enmeshes smaller particles and grows in size to form larger particles. These particles then settle down.

Process of Coagulation or Chemical preciptation is carried out in following two stages:

(*i*) Chemical is added to the sewage and agitated briskly so that chemical is mixed well.

(*ii*) When slow agitation of the mixture for a longer period is done, chemical mixes intimately with the sewage. The particles grow in size and settle down. This process is called *flocculation*.

Advantages of Coagulatin over Plain sedimentation

(*i*) Sedimentation by coagulation is more effective

(*ii*) BOD, colour and turbidity are reduced

(*iii*) Less capacity of sedimentation tanks

(*iv*) Process is simple

Disadvantages of Coagulation over Plain sedimentation

(*i*) Chemicals destory the bacteria that digest the sludge

(*ii*) Chemicals increase the cost of sedimentation

(*iii*) Skilled supervision is required

(*iv*) Large quantity of sludge is produced

Note : Coagulation is not necessary when biological treatment is resorted to and hence the process is not used nowadays.

2. Filtration

In filtration process, aerobic bacteria present in sewage form a thin film around the filter media (sand or gravel) particles and oxidise the organic matter.

Types of Filters used

(*i*) **Contact beds :** (obselete these days)

It is a water tight rectangular tank, filled with a filtering media, consisting of gravel, ballast, or broken bricks or stones. Size of the media particles may vary between 20 to 40 mm. Depth of the filtering media varies between 1 to 1.8 m.

(*ii*) **Intermittent sand filters :** (used at small plants)

These are more or less like contact beds, with the difference that contact media is finer than that in the contact beds; and also, these is no concrete lining around the filter media.

When sewage is passed over the sand, Zoogleal film is formed around the particles. Aerobic bacteria oxidise organic matter trapped in the voids and absorb the colloidal matter.

(*iii*) Trickling filters (commonly used)

Conventional trickling filters and their improved forms, called *high rate trickling filters* are now almost universally adopted for giving secondary treatment to sewage. These filters, also called *percolating filters* or *sprinkling filters*, consists of tanks of coarser filtering media, over which the sewage is allowed to sprinkle or trickle down, by means of spray nozzles or rotary distributors.

Trickling filter is an artificial bed of stones over which waste water is distributed and applied in drops, films or spray through which it trickles to the under drains. A zoogleal film is formed on the surface media.

(*iv*) Miscellaneous type of filters (used under special circumstances)

Sewage influent entering the filter must be given pre-treatment including screening and primary sedimentation.

Design of Trickling Filters

It primarily involves following

(*i*) Design of the filter size : *It is based on the values of filter loadings, which on a filter can be expressed in two ways :*

(*a*) By quantity of sewage applied per unit of surface area of filter per day (Hydraulic loading rate)

Value of hydraulic loading for conventional filters may vary between 22 to 44 (normally 28) ML/ha./day (as against of 1.1 ML/ha./day for intermittent sand filters).

Hydraulic loading can still be increased to about 110 to 330 (normally 220) ML/ha./day in the high rate trickling filters.

(*b*) By means of BOD per unit volume of filtering media per day (Organic loading rate) :

It is expressed in kg of BOD per hectare meter of the filter media per day. Value of organic loading for conventional filters may vary between 900 to 2200 kg. of BOD per ha-m. This organic loading value can be further increased to about 6000–1800 kg. of BOD per ha–m in high rate trickling filters.

$$\text{Volume of the filter} = \frac{\text{Total BOD of the sewage entering the sewage}}{\text{Organic loading rate.}}$$

$$\text{Area of the filter bed} = \frac{\text{Total volume of sewage entering the bed}}{\text{hydraulic loading rate}}$$

(*ii*) Design of Filter diameter and Depth of filter Tank :

It is designed for average value of sewage flow.

(*iii*) Design of Rotary distributors, under-drainage system and other connected pipe lines

These are designed for peak flow, and checked for the average flow.

Types of Trickling Filters

(*i*) Conventional trickling filter or Ordinary trickling filters or Standard rate or Low rate trickling filters

In these waste water is applied intemittently by means of dosing tanks.These tank automatically supply the waste water by syphonic action for 2 to 2.5 minutes and then stop.

Effluent obtained from a conventional trickling filter plant is highly nitrified and stabilised. BOD is reduced to about 80 to 90% of the original value.

As per National Reseasch Council of U.S.A, $\eta = \dfrac{100}{1 + 0.0044\sqrt{u}}$

where, η = efficiency of the filter in terms of % of applied BOD removed

u = organic loading in kg/ha-m/day applied to the filter.

(*ii*) High Rate Trickling filters

These also function on the same lines, and have same constructional details as Standards rate trickling filters, but with the difference that provision is made in them for recirculation of sewage through the filter.

Recirculation of Treated Sewage

It is an essential and important feature of high rate filters. Filters consists in returning part of the treated or partly treated sewage to the treatment proccess.

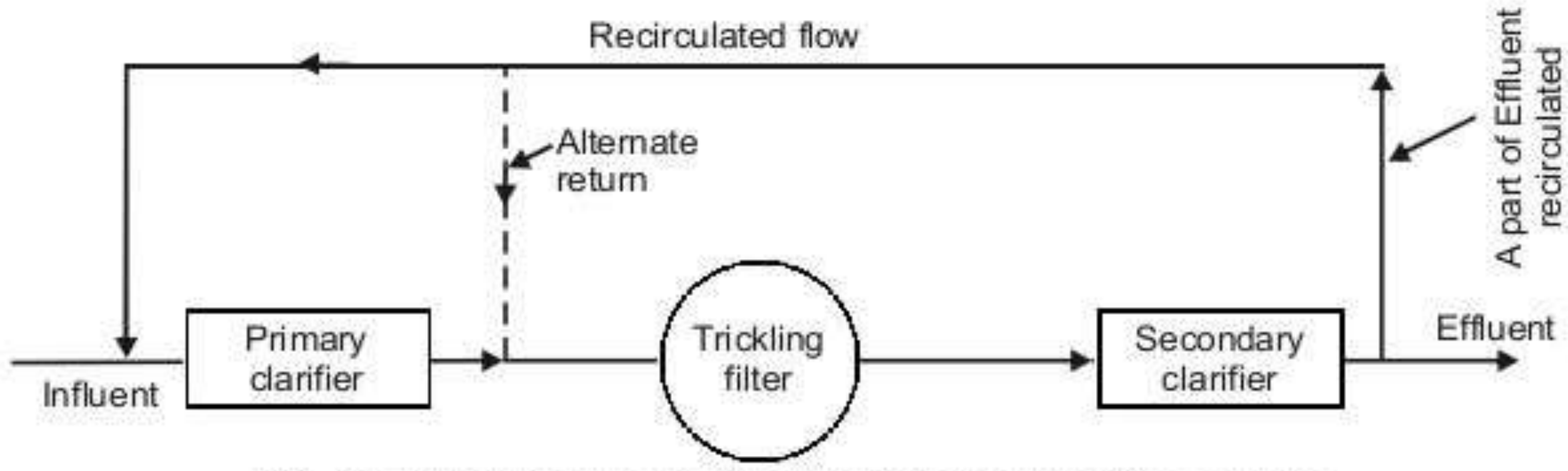


Fig. Single stage commonly adopted recirculation process

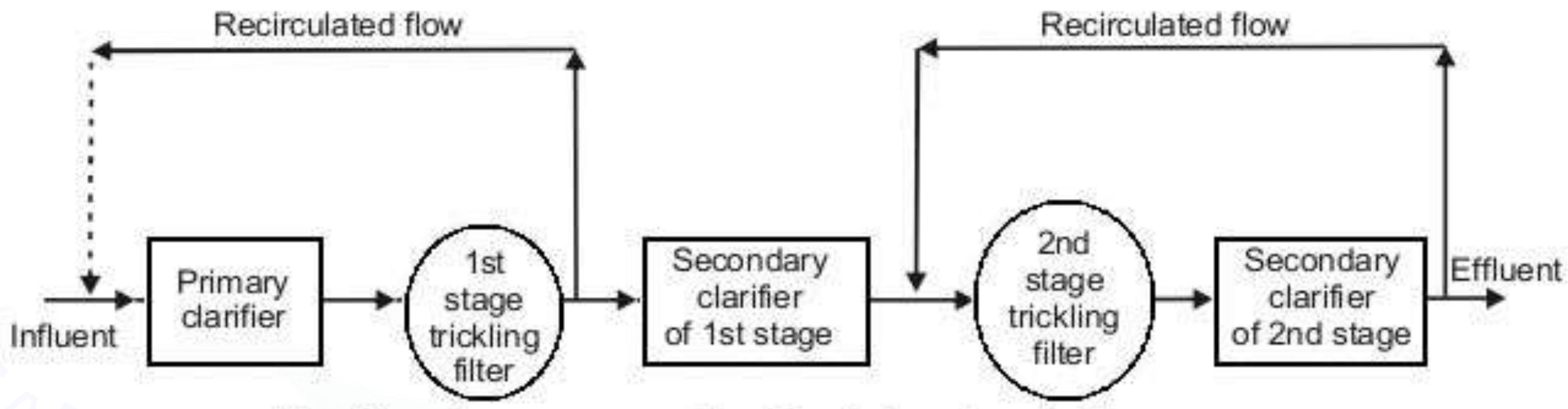


Fig. Two stage commonly adopted recirculation process

In recirculated flow, a large volume of sewage through the filter tends to wash off the filter before nitrification has had time to take place, resulting in loss of nitrates in the effluent, therefore slightly lowering quality of the effluent. For this reason, a high rate filter plant with single stage recirculation may not show as good results as those obtained from a conventional trickling filter plant.

Recirculation ratio: It is the ratio of volume of sewage recirculated (R) to the volume of raw sewage (I)

Recirculation factor (F): It represents number of effective passage through the filter.

$$\text{Recirculation factor} = \frac{1 + \frac{R}{I}}{\left[1 + 0.1\frac{R}{I}\right]^2}$$

Effeciencies

Efficiency of Single stage high rate trickling filter,

$$\eta\,\% = \frac{100}{1 + 0.0044\sqrt{\frac{Y}{VF}}}$$

where, Y = total organic loading in kg/day applied to the filter

V = filter volume in hectare-metre

F = recirculation factor

Efficiency of Two stage high rate trickling filter,

$$\eta' = \frac{100}{1 + \frac{0.0044}{1-\eta}.\sqrt{\frac{Y'}{V'.F'}}}$$

where, Y′ = total BOD in effluent from first stage in kg/day

V′ = volume of second stage filter in ha-m

F′ = recirculation factor for the seconds stage filter

η′ = final efficiency obtained after two stage filtration

Effect of Recirculation on Sizes of treatment units

Recirculation through primary sedimentation tanks requires extra capacity in these tanks, because flow passing through them is increased, and under same conditions, size of the secondary sedimentation tanks many also have to be increased.

Types of High rate trickling filters

(*a*) Biofilters

(*b*) Accelo filters : These filter are normally 1.8 to 2.4m deep, and utilises the direct recirculation of unsettled filter effluent to the distribution feed.

(*c*) Aero filters

Comparison of Conventional and High Rate Trickling Filters

S.N.	Characteristics	Conventional or Standard rate filters	High rate filters
1.	Depth of filter media	Varies between 1.6 to 2.4 m.	Varies between 1.2 to 1.8 m
2.	Size of the filter media	25 to 75 mm	25 to 60 mm.
3.	Land required	More land area is required as ilter loading is less.	Less land area is required as filter loading is more.
4.	Cost of operation	More for treating equal quantity of sewage.	Less for treating equal quantity of sewage.
5.	Method of operation	Continuous application, less flexible requiring, less skilled supervision.	Continuous application, more flexible, and more skilled operation is required.
6.	Type of effluent produced.	Effluent is highly nitrified and stabilised with BOD in effluent 20 ppm or so.	Effluent is nitrified up to nitrite stage only and is thus less stable and hence it is of slightly inferior quality BOD in effluents
7.	Dosing interval	Generally varies between 3 to 10 minutes.	$20 \geq 20$ ppm or so.
8.	Filter loading values		
	(i) Hydraulic loading	Varies between 20 to 44 M.L. per ha./day	Varies between 110 to 330 ML per hectare per day.
	(ii) Organic loading	Varies between 900 to 2200 kg of BOD per ha.m.of filter media per day.	Varies between 6000 to 18,000 of BOD per ha. m. of filter media per day.
9.	Recirculation system.	Not provided generally.	Always provided for increasing hydraulic loading.
10.	Quality of secondary sludge produced.	Black, highly oxidised with slight fine particles	brown, not fully oxidised with fine particles.

Eckenfelder Trickling filter equation

It is used for measuring performance of trickling filters, on the basis of rate of waste removal. Eckenfelder trickling filter equation is,

$$\frac{Y_t}{Y_0} = (e)^{\frac{-KD}{(Q_L)^n}}$$

where, $Y_0 = BOD_5$ of the influent entering the filter ; mg/l

$Y_t = BOD_5$ of the effluent getting out of the filter ; mg/l

K = rate constant ; per day

D = depth of filter in ; *m*

Q_L = hydraulic loading rate per unit area of filter in $m^3/day/m^2 = Q/A$

3. Activated Sludge Process

Sewage effluent from primary sedimentation tank, is mixed with 20 to 30% of volume of activated, sludge, which contains a large concentration of highly active aerobic micro-organism, and sewage are intimately mixed together, with a large quantity of air for about 4 to 8 hours. Under these conditions, moving organisms will oxidise the organic matter and suspended and colloidal matter tend to coagulate and forms precipitate, which settled in secondary settling tank.

Effluent obtained from a properly operated activated sludge plant is of high quality. BOD removed is upto 80-95%, and bacterica removal is upto 90–95%.

Activated Sludge Plant

These are normally preffered for large size cities.

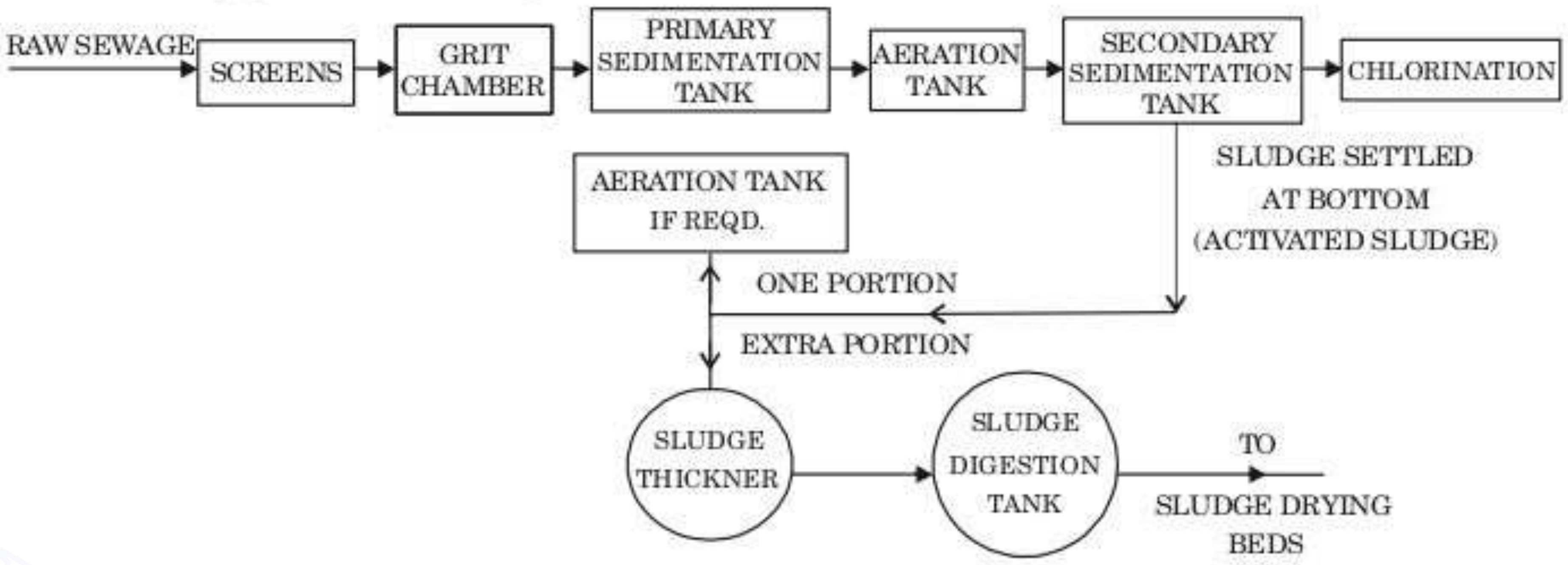


Fig. Flow diagram for a conventionel activated sludge plant.

Essential Components

(*i*) Screeing,

(*ii*) Grit removal chamber

(*iii*) Primary sedimentation tanks

Other Components

(*i*) Aeration Tanks

It is normally rectangular in shape, 3 to 4.5 m. deep and about 4 to 6 m. wide. Length ranges between 20 to 200 m.; and detenation period between 4 to 8 hours for municipal sewages. Air is continuously introduced into these tanks.

Extent of BOD removal desired in ppm	Quantity of returned sludge as % of sewage
150	25
250	30
300	35
400	40
500	48
600	53

$$\text{Capacity of aeration tank } = (V_1 + V_2)\frac{T}{24} \text{ in cu-m}$$

where, V_1 = volume of sewage flow in m^3 per day

V_2 = volume of returned sludge in m^3 per day. It generally lies between 25 to 30% of sewage flow

T = aeration period (4 to 8 hrs).

Methods of Aeration

(*a*) Diffused air Aeration : 4000 to 8000 m^3 of free air will be required per million litres of sewage being treated. With respect to BOD removal, usual rate adopted is 100 m^3 of air per kg of BOD removed. Only about 5% of the oxygen in the air is actually involved in the biochemical action.

Volume of returned activated sludge normaly depends upon extent of BOD desred to be removed. It is generally expressed as percantage of flow of sewage.

(*b*) Mechanical Aeration : In this method, atmospheric air is brought in contact with the sewage. Sewage is stirred up by means of mechanical devices like paddles etc.; so as to introduce air into it from the atmosphere by continuously changing the surface of sewage by circulation of sewage from bottom to top.

(*c*) Combined aeration.

(ii) Secondary Sedimentation Tank

Design Considerations

Weir overflow rate : Not exceeding 150 m^3/day per metre of weir based on average flow of sewage.

Solid loading rate : Based on mixed liquor flow to the settling tanks, it may be kept at about 100-150 kg./m^2 per day at average flow and should not excees 250 kg/m^2 per day at peak flows.

Surface area : It should be designed for both overflow rate and solids loading rate, and larger value is adopted.

Detention time : It may be kept between $1\frac{1}{2} - 2$ hours.

Dimensions : $\frac{\text{Length}}{\text{Depth}} = 5$ for circular tanks = 7 for rectangular ones.

Depth may be kept in the range of 3.5 to 4.5m.

Surface loading rate : 20 m^3/day/m^2.

Loading rates : *It is defined by following terms :*

(a) Aeration period (*i.e.* Hydraulic Retention Time– H.R.T).

$$\textit{Aeration period, } t = \frac{\text{Volume of the tank}}{\text{Rate of sewage flow in the tank}} = \frac{V}{Q} \text{ day (excluding recycled sludge)}$$

(b) Volumetric BOD loading or Organic loading

$$= \frac{\text{Mass of BOD applied per day to theaeration tank}}{\text{Volume of the aeration tank}} = \frac{Q.\ Y_0}{V}$$

where, $Y_0 = BOD_5$ of the influent sewage

V = aeration tank volume in m^3.

(c) Food (F) to micro-organisms (M) ratio, or F/M ratio : BOD load applied to the system in kg or gm is represented as food (F) and total microbial suspended solids in the mixed liquor of the aeration tank is represented by M.

$$\therefore \text{ Food to Micro-organism (F/M) ratio} = \frac{\text{Daily BOD load applied to the aerator system in gm.}}{\text{Total microbial mass in the system in gm.}}$$

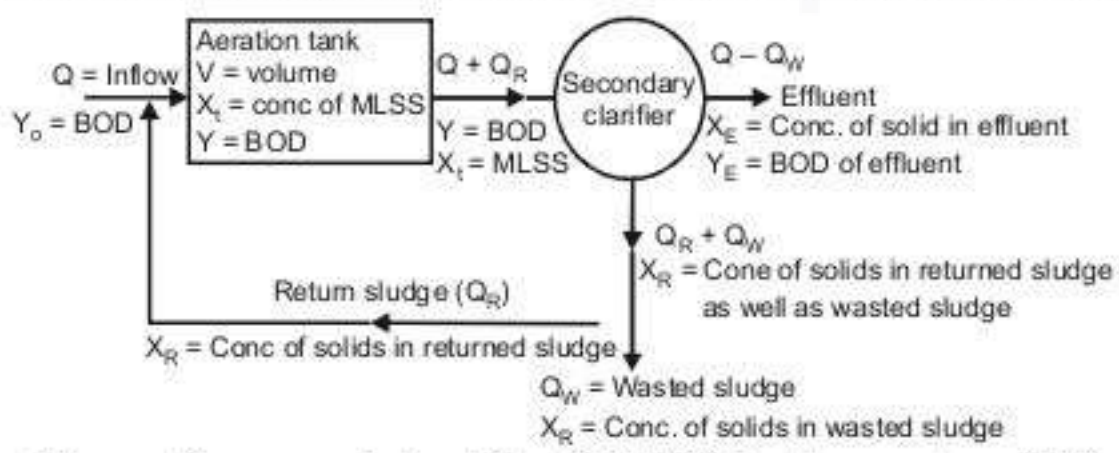
$$= \frac{Q\,Y_0}{\text{MLSS} \times \text{Volume of the aeration tank}} = \frac{Q\,Y_0}{V \cdot X_t}$$

where, X_t = mixed liguar suspended solid

= average concentration of solids in the mixed liguor of the acration tank.

F/M ratio for an activated sludge plant is the main factor controlling BOD removal. Lower the F/M ratio, higher will be the BOD removal in the plant.

(d) Sludge age (θ_c) : It may be defined as the average time for which particles of suspended solids remain under aeration. It indicates residence time of biological solids in the system.



$$\text{Sludge age } \theta_c = \frac{\text{Mass of suspended solids (MLSS) in the system (M)}}{\text{Mass of solids leaving the system per day}} = \frac{V.\ X_t}{Q_w X_R + (Q - Q_w) X_E}$$

where, V = volume of aerator

x_t = MLSS (mg/l)

X_R = cocentration of solids in the returned sludge (mg/l)

X_E = concentration of solids in the effluent (mg/l)

Q_w = volume of wasted sludge per day

Q = see wage in flow per day

Design Parameters

S.No.	Parameter	Design Values
1.	MLSS	1500–3000 mg/l.
2.	MLVSS/MLSS	0.8
3.	Food to micro-organism (F/m) ratio	0.4 to 0.2
4.	Aeration Period (HRT)	4 to 8 hrs.
5.	Volumetric loading as gm of BOD applied per m^3 of tank	300–700
6.	SRT or sludge age	5 to 15 days
7.	Volume of returned sludge/volume of influent sludge = (Q_R/Q)	0.25 to 0.5
8.	BOD removal efficiency	85 to 95%
9.	kg of O_2 required per kg. of BOD removal	0.8–1.1
10.	Air required per kg. of BOD_5	40–100 m^3

Sludge Volume Index (S.V.I).

It represents degree of concentration of the sludge in the system and hence decides rate of recycle of sludge (Q_R) required to maintain desired MLSS and food to micro-organism ratio in the aeration tank to achieve desired degree of purification.

SVI is defined as the volume occupied in ml. by one gm. of solids in the mixed liquor after settling for 30 minutes and is determined experimentally.

$$\text{SVI} = \frac{V\,(\text{ml}/\text{l})}{X\,(\text{mg}/\text{l})}$$

Excess sludge quantity increase with the increasing F/M ratio and decreases with temperature.

Rate of Return sludge (Q_R)

Emprical equation : $$Q_R = Q\left[\frac{X_t}{\dfrac{10^6}{\text{SVI}} - X_t}\right]$$

Return sludge ratio, $$\frac{Q_R}{Q} = \frac{X_t}{\left(\dfrac{10^6}{\text{SVI}} - X_t\right)}$$

where, X_t is MLSS in mg/l and $\frac{10^6}{\text{SVI}}$ is also in mg/l.

Comparison of Activated Sludge Process and Trickling Filter Process

In a trickling filter, bacterial film coating the grains of the filter media is stationary and likely to become clogged after sometimes; in the activated sludge process. The finer suspended organic particles of sewage are themselves coated with the bacterial film, which is kept moving by the constant agitation; therefore, sludge flocs are coated with bacteria and they act like free moving organisms, which are being continuously swept through the sewage, and which in their search for food and work, oxidise organic matter present in sewage in a much more efficient way than that carried out in a filter by the bacteria coated around the particles of the filter media. An activated sludge process is more efficient than a trickling filter.

Note : For towns or small cities with medium sized plants, trickling filters are better

Methods of Aeration, and Aerators

Success of the activated sludge process depends on aeration provided.

Following three methods are adopted for Aeration of sewage:

(*i*) Diffused Aeration

In this type, compressed air is blown through the sewage by air diffusers.

Types of Diffusers

(*a*) Plate diffuser : It is made of crystalline aluminimum or high silica sand of size 300 × 300 × 25 mm. The plate has holes through which air is blown.

(*b*) Tube diffusers : These are made of crystalline aluminimum about 600 mm long. It is suspended into the sewage. Generally the aeration period varies from 3-6 hours. Diffused aeration is used for large installations.

Types of Aeration tanks

(*a*) **Ridge-and-Furrow type :** Bottom of the aeration tank has rows of ridges and furrows (rises and depressions) perpendicular to the flow. Diffuser plates are fixed in the furrows. Air is blown through pipes and air bubbles rise from diffuser plates to form balls of bubbles. Aeration in this method is done thoroughly.

(*b*) **Spiral flow type :** Bottom of tank is horizontal. Plate diffusers are placed in the bottom in rows along one side. The air bubbles rise, aerate and descend during which the sewage is rotated. When combined with the horizontal flow, the motion becomes helical. Tube diffusers are commonly used for spiral flow type aeration tanks.

(*ii*) **Mechanical Aeration**

Surface of the sewage in the aeration tank is agitated. This enables oxygen from the atmosphere to be absorbed. This method is adopted for small treatment plants.

Various patented methods are available to produce the required agitation.

(*iii*) **Combination of Air Diffusers and Mechanical Diffusers**

In this type, both diffusers and mechanical devices are used for agitating the mixed liquid. Several patented devices are available.

(*iv*) **Final or Tertiary treatment (Disinfection)**

Disinfection is carried out if necessary by chlorination to kill the bacteria which remain in the effluent of sewage.

Primary and Secondary Sludge

Sludge is a semi-liquid produced from solids of the sewage, accumulated at the bottom of settling tank. Sludge has organic matter and hence capable of pollution and has to be disposed off carefully.

Type of Sludge

Sludge produced from treatment plant is classified according to the process as follows:

(*i*) Sludge produced by plain sedimentation
(*ii*) Sludge produced by chemical sedimentation
(*iii*) Sludge produced by trickling filter
(*iv*) Sludge produced by activated sluge

Sludge deposited in a primary sedimentation tank is called **raw sludge** and the sludge which deposited in a secondary clarifier is called **secondary sludge**. Raw sludge is more objectionable than secondary sludge.

Moisture content : In raw sludge : 95%.

Secondary sludge from trickling filter plant : 96 to 98%

Secondary sludge from an activated sludge treatment plant : 98% to over 99%.

Sludge containing high moisture content becomes very bulky, and difficult to handle.

If sewage sludge with volume V_1 contain certain moisture content P_1%, then

$$\text{volume of sewage at moisture content P, } V = \left[\frac{100 - P_1}{100 - P}\right] V_1$$

Sludge Digestion Process

In order to avoid pollutions at first sludge is stabilised by decomposing organic matter under controlled anaerobic condition and then disposed off suitably after drying on drying beds, etc. The process of stabilisation is called *sludge digestion;* and the tank where process is carried out is called *sludge digestion tank.*

In sludge digestion, sludge is broken into following three forms :

(*i*) **Digested Sludge :** Stable humus like solid matter, tarry black in colour.

(*ii*) **Supernatant Liquor :** Having high BOD (about 3000 ppm)

(*iii*) **Gases and Decomposition :** CH_4 (65 to 70%), CO_2 (30%) and traces other inert gases like N_2, H_2S etc.

Digested sludge is dewatered, dried up, and used as fertiliser; while gases produced are also used for fuel or for driving gas engines. Supernatant liquor contains about 1500 to 3000 ppm. of suspended solids; and thus retreated at the treatment plant along with the raw sewage.

Stages in Sludge digestion Process

(*i*) ***Acid fermentation stage*** **:** Highly putrefactive odours are evolved during this stage which continues for about 15 days or so (at about 21°C). BOD of the sludge increases to some extant, during this stage.

(*ii*) ***Acid regression stage*** : This stage continues for of period of about 3 months or so (at 21°C). BOD of the sludge remains high even during this stage.

(*iii*) ***Alkaline fermentation stage*** : During this stage, liquid separates out from the solids, and digested sludge is formed. This digested sludge is collected at the bottom of the digested tank and is also called **ripened sludge**. Digested sludge is alkaline in nature. Large volumes of methane gas along with small amount of CO_2 and nitrogen, are evolved during this stage. This stage extend for a period of about one month or so (at about 21°C). BOD of the sludge also rapidly falls down during this stage.

Note : About $4\frac{1}{2}$ months are required for complete process of digestion to take place under natural uncontrolled condition at about 21°C.

Factors affecting Sludge digestion and Their control

(*i*) **Temperature:** The rate of digestion being more at higher temperature and vice versa.

(*a*) **Zone of thermophilic digestion :** Temperature in this zone ranges between 40 to 60°C. Optimum temperature in this zone is about 54°C, and at this temperature, digestion period can be brought down to about 10–15 days only. However, thermophilic range temperature are generally not employed for digesting sewage sludge, owning to odour and other oprational difficulties.

(*b*) **Zone of mesophilic digestion:** Temperature in this zone ranges between 25 to 40°C. Optimum mesophilic temperature is about 29°C; and at this temperature, digestion period can be brought down to about 30 days.

(*ii*) **pH value:** During digestion, care must be taken to keep the acidity well under control, so that pH during the digester start-up does not fall below 6.5 or so, and thus to see that alkaline conditions may prevail ultimately, in the final stage of digestion.

(*iii*) **Seeding with digested sludge**

(*iv*) **Mixing and stirring of the raw sludge with digested sludge**

Sludge Digestion tank or Digestor

Cylindrical in shape, diameter 3 to 12 m. depth is usually taken at about 6m.

Capacity of digestion tank

It is a function of following

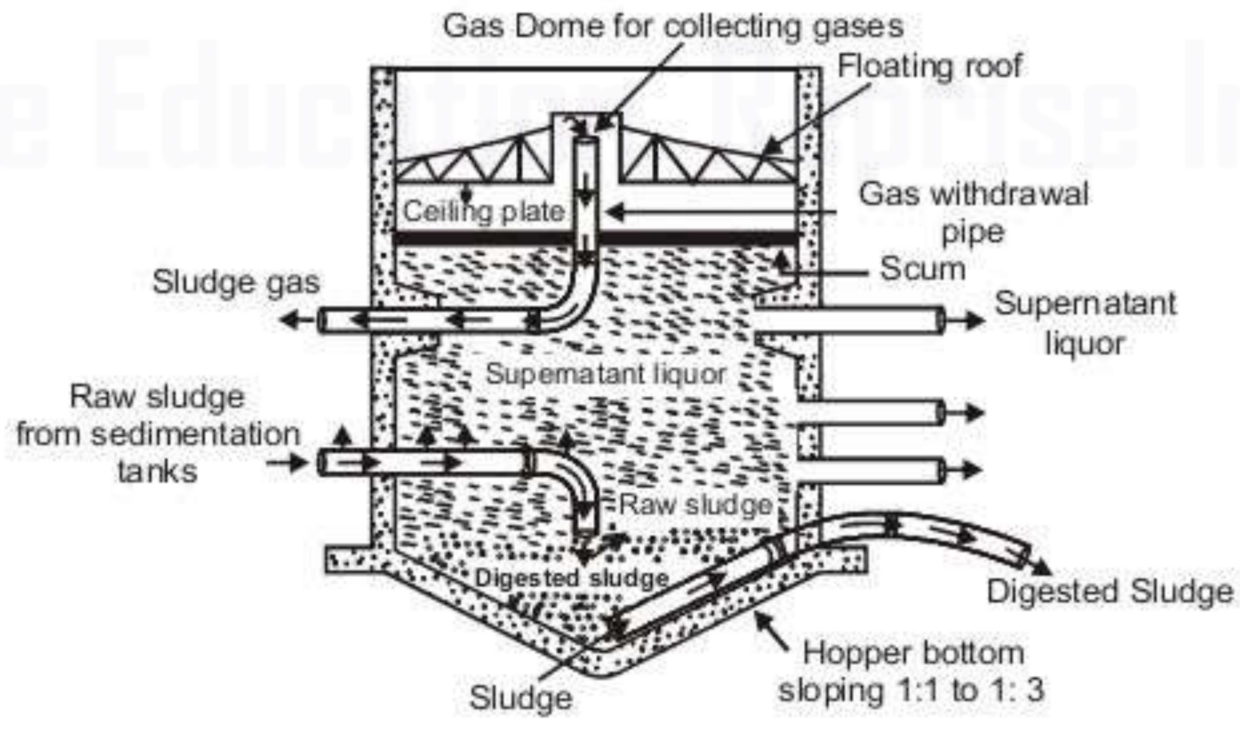
(*i*) Sludge production

(*ii*) Digestion period

(*iii*) Degree of digestion required

(*iv*) Loss of moisture

(*v*) Conversion of organic matter.



If progress of sludge digestion is assumed to be linear, then $V = \left(\frac{V_1 + V_2}{2}\right)t$

where, V = volume of the digestor, m^3

V_1 = raw sludge added per day, m^3/d

V_2 = equivalent digested sludge produced per day on completion of digestion, $m^3/day = \frac{V_1}{3}$

t = digestion period, days.

In monsoon season, total digestor volume, $V = \left(\frac{V_1 + V_2}{2}\right)t + V_2 T$

where, T = number of days for which the digested sludge is stored.

When change during digestion is assumed to be parabolic, then

without monsoon storage : $V = [V_1 - \frac{2}{3}(V_1 - V_2)]\, t$

with monsoon storage : $V = [V_1 - \frac{2}{3}(V_1 - V_2)]\, t + V_2 T$

- About 60% of the suspended solids of sewage are removed by sedimentation , 5% by chemical coagulation and settling; and 90% by complete treatment.
- About 70% of the suspened solids in the sewage are volatile, and reduction of the volatile matter in sludge, is about 65%. In digestion, the amount of gas produced is about 0.6 m^3 per kg of volatile matter present in the sewage, or is about *0.9 m^3 per kg of volatile matter reduced.*

Aerobic and Anaerobic Biological Units

Aerobic Biological Units : These are treatment reactors, in which organic matter decomposes (oxidised) by aerobic bacteria.

These consist of following :

(*i*) Filters

(*ii*) Aeration tanks

(*iii*) Oxidation ponds and Aerated lagoons.

Since all these aerobic units, generally make use of primary settled sewage, they are easily classified as *secondary units.*

Anaerobic biological Units : These are reatment reactors, in which organic matter is destroyed and stabilised by anaerobic, bacteria.

These consists of following :

(*i*) Anaerobic lagoons

(*ii*) Septic tanks

(*iii*) Imhoff tanks

Out of these units, only an aerobic lagons make use of primary settled sewage, and hence only they can be classified as *secondary units.*

Thus septic tanks and imhoff tanks using raw sewage are not classified as *secondary units.*

Note : Sewage treatment is usually confined upto *secondary treatment only*.

Anaerobic Pond

In these stabilisation of waste is mainly brought about by usual anaerobic conversion of organic water to CO_2, CH_4, and gaseous end products, with erruption of foul odours and pungent smells.

Facultative Pond

In these, upper layers work under aerobic conditions, while anaerobic conditions prevail in the bottom layers. The upper aerobic layer of the pond acts as a good check against the evolution of the foul odours from such a pond.

Aerobic Ponds

These are practically difficult to construct and use. The facultative ponds, with depth (1 to 1.5 m.) are thus most widely used for treatment of sewage.

End products of the aerobic pond are carbon dioxide, NH_3 and phosphates, which are required by the algae to grow and continue to produce oxygen.

Oxidation Pond

It was originally referred to that stabilisation pond which received *partially treated sewage* ; whereas pond that received *raw sewage* was called *sewage lagoon*. Oxidation pond has been widely used as a collective term for all types of ponds, and most particularly the facultative stabilisation ponds.

Effluents from oxidation ponds can be easily used for land irrigation, particularly at places, where they cannot be discharged into river streams.

Design criteria : Oxidation ponds works on algal-symbiosis. in which the algae while growing in the precede of sunlight, presence oxygen by the action of photosynthesis and this oxygen is utilised by the bacteria for oxidising the waste organic water. End products of the process are CO_2, NH_3 and phosphates, which are required by the algae to grow and continue to produce oxygen.

- *Organic loading :* 300 – 150 kg/hectars/day. In India to about 90 – 60 kg./ha./day.
- Each unit may have an area ranging between 0.5 to 1 hectare.
- L/B = 2, depth = 1 to 1.5 m., free board = 1 m.
- *Detention time :* 20 – 30 days.

$$\text{Detention period in days} = \frac{1}{k_D} \log_{10}\left(\frac{L}{L-Y}\right)$$

where, L = BOD of the effluent entering the pond

Y = BOD removed, say 90% of L or 95% of L etc.

k_D at 20°C = 0.1/day,

- Properly operated ponds may be as effective as trickling filters in reducing BOD of the sewage. BOD removal is upto 90%, and coliform removal is upto 99% or so.

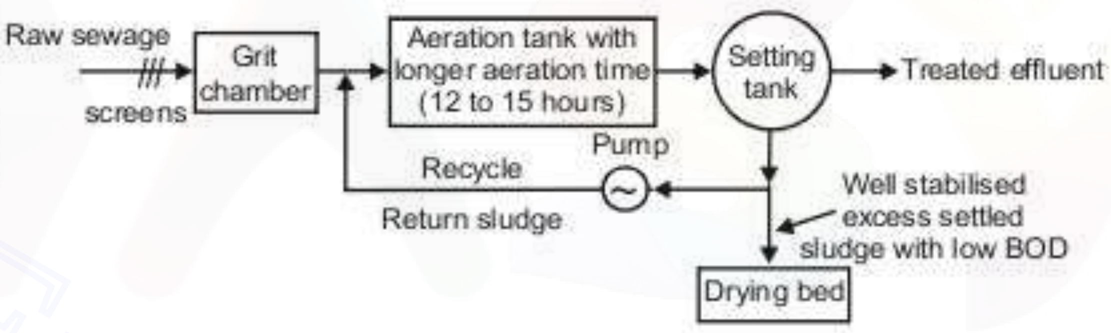
Advantage of an oxidation pond treatment : It is very cheap; capital cost being 10 to 30% of that of the conventional plant.Their maintenance cost is also very minor, and no skilled supervision is required at any stage of construction and operation.

Disadvantage of oxidation ponds : Nuisance due to mosquito breeding and bad odours.

Order may also be kept under control by avoiding the over-loading. The algae growth may be stimulated by adding sodium nitrate, which is both a plant food and an oxidising agent.

Oxidation ditches (Pasveer type) or Extended Aeration Lagoons

The normal activated sludge plant has been modified to eliminate primary sedimentation tank and sludge digestion tank, in a process, called *extended aeration*, which aims at providing an aeration tank with a longer aeration time.



Desigen Criteria

(*a*) **Detension time :** 12 to 15 hours

(*b*) **Dimensions** : Depth is about 1 to 1.5 m.

Width of the ditches is limited to the type and availability of the aeration rotors used, and may vary between 1 to 5 m. Length may vary from, say 150 m to 1000 m or so.

(*c*) **Concentration of suspended solids in mixed liquor :** Should be high say about 4000 to 5000 mg/l.

(*d*) Quality of the effluent obtained is quite good, with suspended solids removal at about 95% and BOD removal at about 98%.

Disposal of Wet Digested Sludge

1. Disposal by dumping into the sea
2. Disposal by burial into the trenches
3. Incineration.

Disposal of Waste Water

After treatment, the sewage is considerd to have following two distinct parts :

1. Effluent. It is clear sparkling liquid

2. Sludge. It is a combination of sewage solids with different proportions of water.

Disposal of effluent does not cause any problem but sludge disposal has to be carefully planned.

Selection of Disposal System

There is no single system which is best suited to the disposal of all waste waters.

1. **Stream disposal.** It is cheapest and provide water quality standards do not requiring advanced treatment of the waste.
2. **Land disposal.** It may be economical for areas where suitable land is available and stream standards are restrictive. It is generally quite expensive as compared to discharge to surface waters.
3. **Evaporation.** It is practicable only in limited areas, where water might be more profitably used to recharge ground water or irrigate crops.

Disposal of Sewage Effluents

After treatment, the sewage effluents generally is disposed off by following two methods

1. Dilution (disposal in water).
2. Effluent irrigation or Broad irrigation or sewage farming (disposal on land)

1. Disposal by Dilution

It is the process where treated sewage or effluent from the sewage treatment plant is discharged into a river stream, or a large body of water, such as a lake or sea. Discharged sewage, in due course of time, is purified by what is called *self purification process of natural waters.*

Standards of Dilution for discharging of waste water into Rivers :

Dilution factor	Standards of Purification required
Above 500	No treatment such sewage can be directly discharged into volume of dilution water.
Between 300 to 500	Primary treatment such as plain sedimentation should be given to sewage, and effluents should not contain suspended solids more than 150 ppm.
Between 150 to 300	Treatment such as sedimentation, screening and essentially chemical precipitation are required. Sewage efficient should not contain suspended solids more than 60 ppm.
Less than 150	Complete through treatment should be given to sewage. Sewage effluent should not contain suspended solids more than 30 ppm. and its BOD_5 at 18.3° should not exceed 20 ppm.

Note : Dissolved oxygen in streams is maximum at noon.

Tolerence limit for sewage effluent discharged into surface water sources as per IS: 4764–1973 is

$$BOD_5 \ - 20 mg/l \ ; TSS \ - 3. \ mg/l$$

Dilution in Rivers and Self purification of Natural Streams

When sewage is discharged into a natural body of water, the receving water gets polluted due to waste products, present in sewage effluents. But conditions do not remain so forever, because natural forces of purification, such as dilution, sedimentation, oxidation reduction in sunlight, etc; go on acting upon the pollution elements, and bring back the water into its original condition. This automatic purification of polluted water, in due course, is called *self purification phenomenon*.

Natural forces of Purification affecting Self-purification

(*i*) Physical forces

(*a*) Dilution and Dispersion : When sewage of concentration C_S flows at the rate Q_S into a river stream with concentration C_R flowing at the rate Q_R, then concentration C of the resulting mixture,

$$C = \frac{C_s Q_s + C_R \ Q_R}{Q_s + Q_R}$$

(*b*) *Sedimentation.*

(*c*) Sun light : Sun light has a bleaching and stabilising effect of bacteria. It acts through the bio-chemical reactions.

(*ii*) Chemical Forces Aided by Biological Forces

(*a*) Oxidation : Oxidation of the organic matter present in sewage effluents, will start as soon as the sewage outfalls into the river water containing dissolved oxygen. The deficiency of oxygen so created will be filled up by the atmospheric oxygen. This is the most important action responsible for effecting self purification of rivers.

(*b*) Reduction

Factors affecting Natural forces of purification

(*i*) Temperature
(*ii*) Turbulence
(*iii*) Hydrography
(*iv*) Available dissolved oxygen and the amount and type of organic matter present
(*v*) Rate of re-aeration, etc.

- At higher temperature, capacity to maintain D.O. concentration is low; while rate of biological and chemical activities are high, causing thereby rapid depletion of D.O.
- When larger amount of D.O. present in water, then better and earlier the self-purification will occur.
- Algae which absorbs CO_2 and gives oxygen, is very helpful in the self-purification process

Zones of Pollution in a River-stream

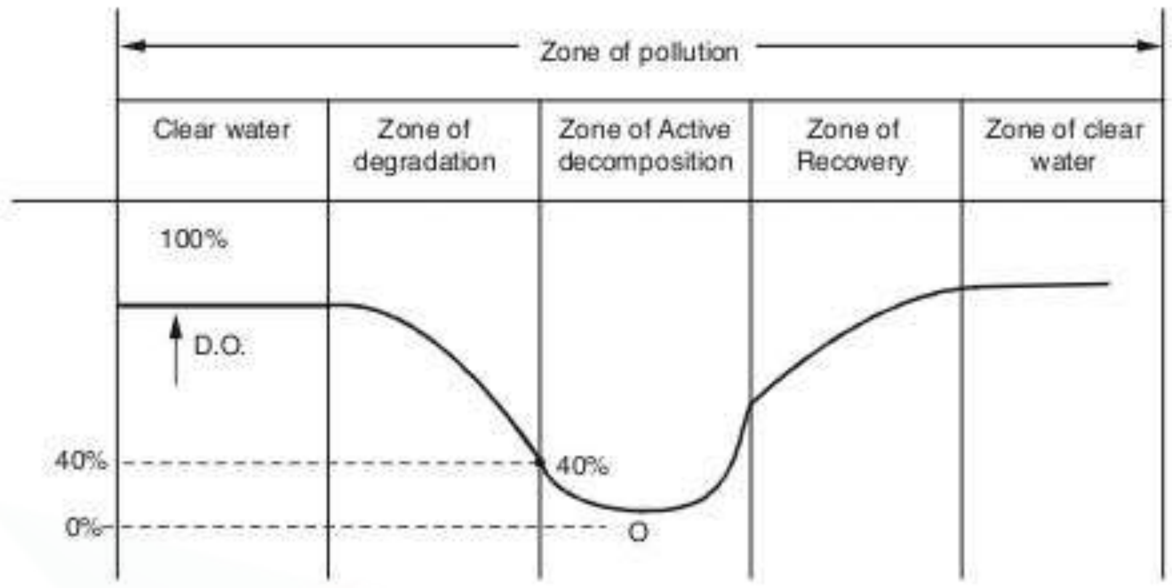


Fig. Dissolved oxygen sag curve

A polluted stream undergoing self-purification can be divided into the following four zones

(*i*) **Zone of Degradation :** D.O. is reduced to about 40% of the saturation value. Reoxygenation (*i.e.* re-areation) occurs but is slower than de-oxygentation.

(*ii*) **Zone of Active Decomposition :** This zone is marked by heavy pollution. It is characterised by water becoming greyish and darker than in the previous zone. D.O. concentration falls down to zero, and anaerobic conditions may set in with the evolution of gases like CH_4, CO_2, H_2S etc.

(*iii*) **Zone of Recovery :** In this zone, B.O.D. falls down and D.O. content rises above 40% of the saturation value. Organic material will be mineralised to form nitrates, sulphates, phosphates, carbonates etc.

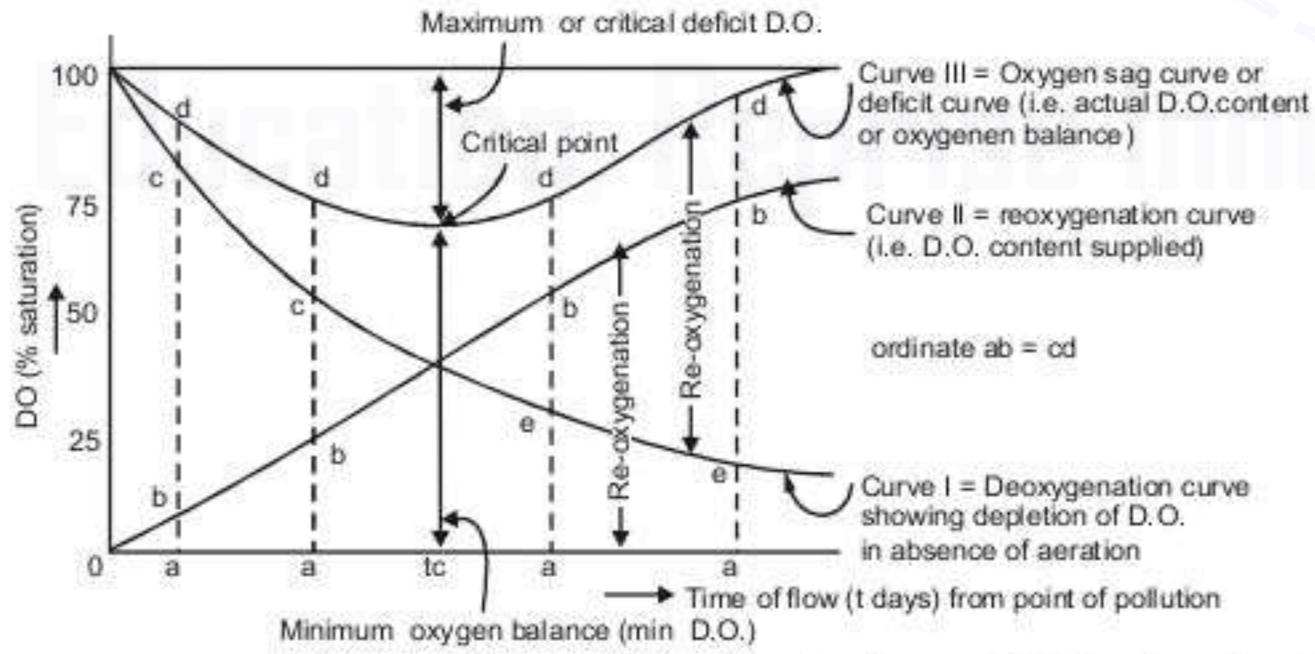
(*iv*) **Zone of Clear water :** In this zone, river attains its original conditions with D.O. rising up to the saturation value.

Oxygen Deficit of a Polluted River Stream

Oxygen deficit (D) = Saturated D.O. – Actual D.O.

Oxygen deficit can be found out by knowing the rates of *de-oxygenation* and *re-oxygenation*.

If de-oxygenation is more rapid than the re-oxygenation, an *oxygen deficit* results.



If D.O. content becomes zero, aerobic conditions will no longer be maintained and putrefaction will set in.

Amount of resultant oxygen deficit can be obtained by algebraically adding de-oxygenation and re-oxygenation curves. The resultant so obtained is called *oxygen sag curve* or the *oxygen deficit curve*. From this curve, oxygen deficit and oxygen balance (*i.e.* 100 - D) in a stream after a certain lapse of time, can be found as given below :

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

This equation is called **Streeter-Phelps** equation where, D_t = D.O. deficit in mg/l after t days.

L = ultimate first stage B.O.D. of the mixture at the point of waste discharge in mg/l.

D_o = initial oxygen deficit of the mixture at the mixing point in mg/l.

k_D = de-oxygenation co-efficient. Typical values of $k_{D\,(20)}$ vary between 0.1 to 0.2

k_R = re-oxygenation co-efficient for the stream. It can be determined by the field tests by using equation :

$$k_{D\,(20°)} = \frac{3.9\sqrt{v}}{y^{1.5}}$$

where, v = average stream velocity in m/s.

y = average stream depth in m.

k_R varies with temperature as, $k_R(T) = k_{R(20)}\,[1.016]^{T-20}$

Critical time (t_c) after which minimum dissolved oxygen occurs can be found by differentiating Streeter – Phelps and equating it to zero.

$$t_c = \left[\frac{L}{k_R - k_D}\right] \log\left[\left\{\frac{k_D L - k_R D_0 + k_D D_o}{k_D L}\right\}\frac{k_R}{k_D}\right]$$

Critical or maximum oxygen deficit is given by

$$D_C = \frac{k_D L}{k_R}\,[10]^{-k_D t_c}$$

here constant $\frac{k_R}{k_D} = f$ is called *self purification constant.*

Then $$D_C = \frac{k_D L}{k_R}\,[10]^{-k_D t_c}$$

$$\Rightarrow \quad t_c = \frac{1}{k_D(f-1)}\log_{10}\left[\left\{1-(f-1)\frac{D}{L}\right\}f\right]$$

and $$D_c = \frac{L}{f}\,[10]^{-k_D t_c}$$

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

These equations are of practical value in predicting oxygen content at any point along a stream.

Saturated D.O. at 20°C = 9.17 *mg/l* (from table.)

Disposal of Waste waters in Lakes

The intermediate zone or dividing line between Epilimnion zone and Hypolimnion zone is called Thermocline

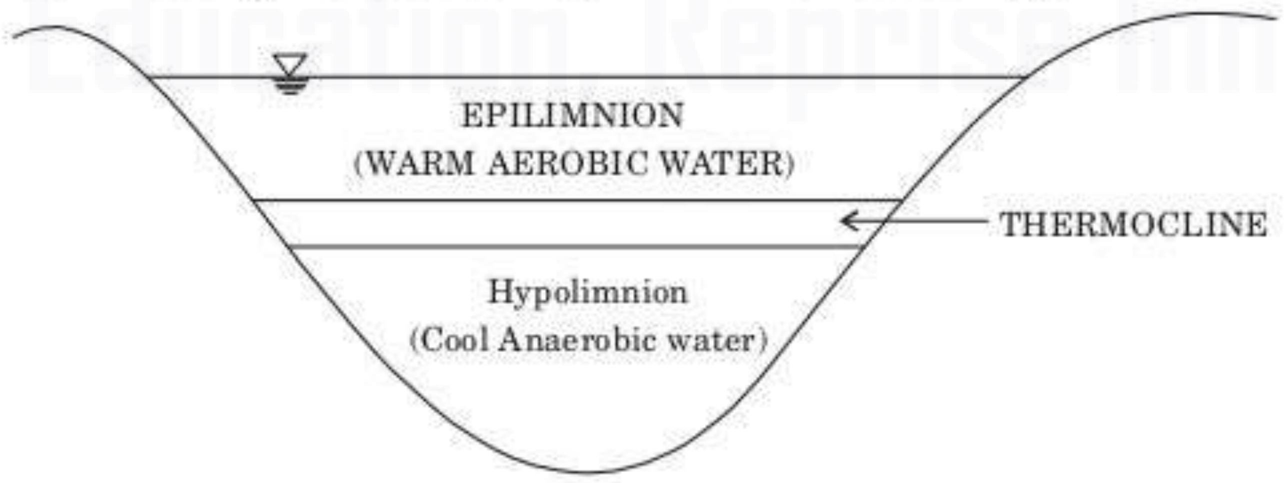


Fig. Stratification of Lake During Summer

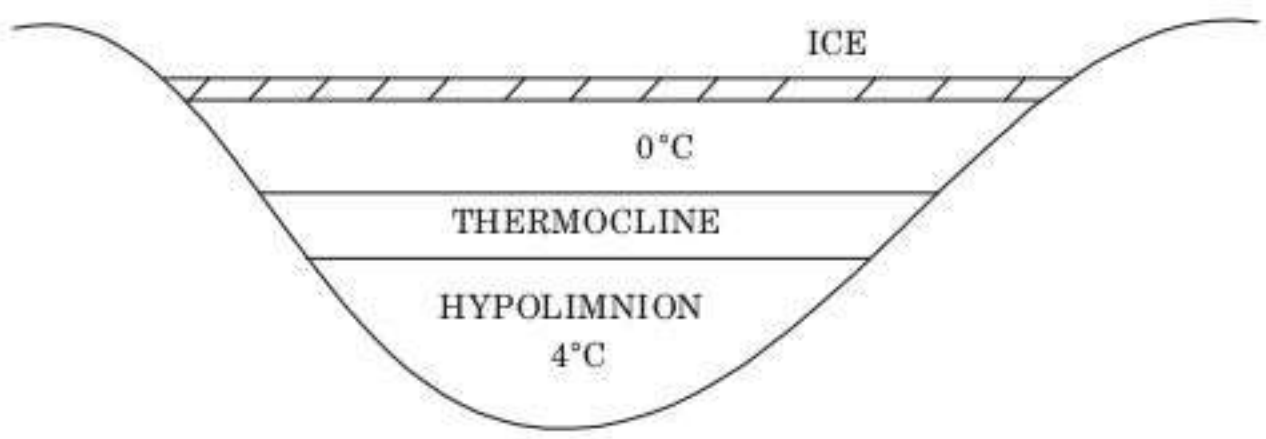


Fig. Stratification of Lake During Winter

Biological Zones in Lakes

(*i*) **Euphotic zone :** The upper layer of lake water through which sunlight can penetrate, is called euphotic zone. All plant growth occurs in this zone.

(*ii*) **Littoral zone :** The shallow water near shore, in which rooted plants grow. The littoral zone can not extend deeper than euphotic zone.

(*iii*) **Benthic zone :** The bottom sediment in a lake comprises benthic zone. Bacteria always present in this zone.

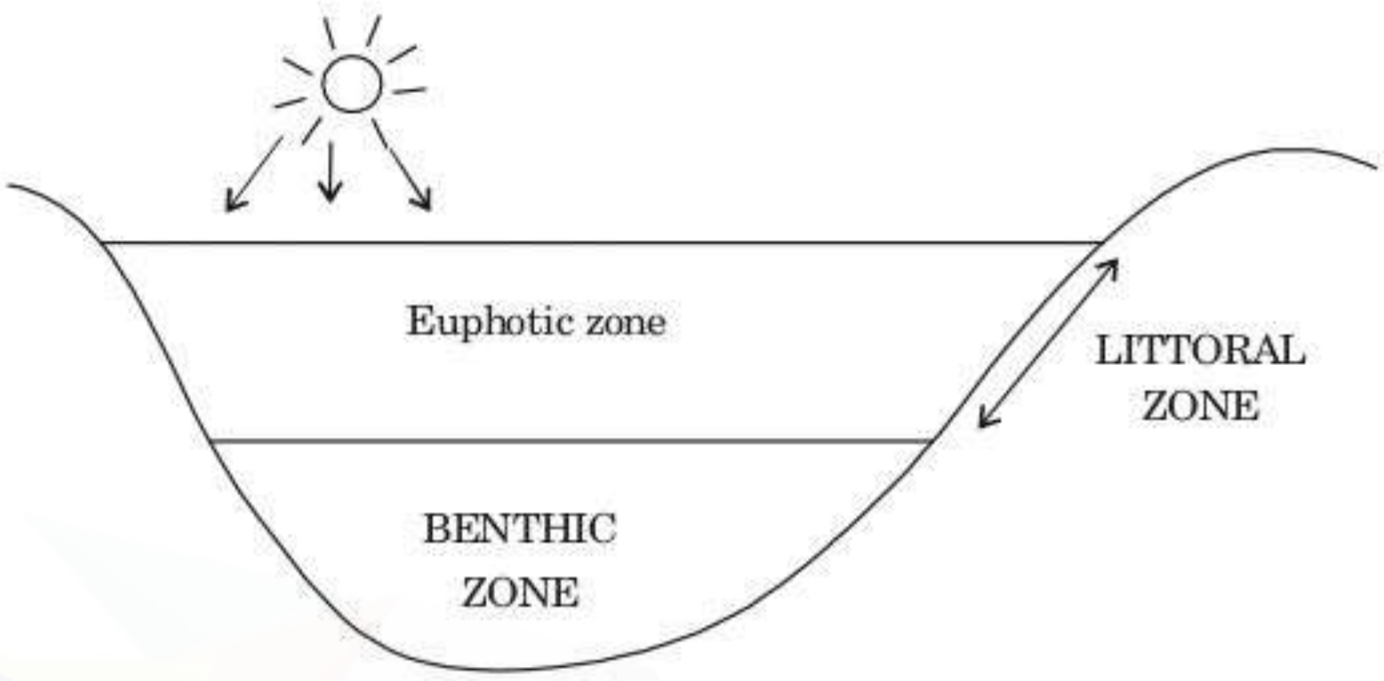


Fig. Biological zone in a lake

2. Effluent Irrigation (Disposal on Land)

In this method, sewage effluent (treated or diluted) is generally disposed off by applying it on land. Percolating water may either join the water table, or is collected below by a system of underdrawins and can be easily disposed into some natural water sources, without any further treatment.

The degree of treatment of raw sewage depend upon type of soil of the land. If this soil, to be irrigated, is sandy and porous, the sewage effluent may contain more solids and other wastes, and thus lesser treatment, as compared to the case where the soil is less porous and sticky.

Quality standards for waste water effluents to be discharged on land for irrigation

Characteristic/Constituent of effluent waste water	Tolerance limit as per IS: 3307-1965
BOD_5	500 mg/l
pH value	5.5 to 9.0
Total Dissolved Solid (TDS)	2100 mg/l
Oil and grease	30 mg/l
Chlorine (as CL)	600 mg/l
Boron	2mg/l
Sulphates	1000 mg/l

Sewage Sickness

When sewage is applied continuously on a piece of land, soil pores or voids may get filled up and clogged with sewage matter retained in them. The time taken for such a clogging depend upon type of the soil and the load present in sewage. But when once these voids are clogged, free circulation of air will be prevented, and anaerobic condition will develop within the pores. Due to this, aerobic decomposition of organic matter will stop, and anaerobic decomposition will start. Thus organic matter will be mineralised, but with the evolution of foul gases like H_2S, CO_2 and CH_4. This phenomenon of soil getting clogged is called *sewage sickness.*

Preventive measures for Sewage sickness

(*i*) Primary treatment of sewage

(*ii*) Choice of land

(*iii*) Under-drainage of soil

(*iv*) Giving rest to the land

(*v*) Rotation of crops

(*vi*) By sewage in shallow depths.

DISPOSAL OF SOLID WASTES AND REFUSE OF A SOCIETY

Refuse

All solid and semi-solid wastes of community, except human excreta and sullage is called *refuse*.

It includes garbage, ashes, rubbish, dust, etc.

Sullage

It include liquid wastes from the bath rooms, kitchen sinks, wash basins etc.

(*i*) **Garbage :** Putrescible organic wastes includes food articles, vegetable peelings, fruits peelings etc. When it is scientifically processed and composted, then it is possible to obtain valuable products, like grease, hog wood, fertilizer, etc. Garbage normally weights 450 to 900 kg/m^3.

(*ii*) **Ashes :** Incombustible waste products (700 to 850 kg/m^5).

(*iii*) **Rubbish :** It includes all non-putrescible wastes except ashes.

It includes paper, glass, rags, etc. (50 to 400 kg/m^3).

- The usual weight of refuse varies between 300 to 600 kg/m^3.
- In an average modern city, each citizen produces about 0.3 to 0.8 kg. of solid domestic waste per day.

DISPOSAL OF REFUSE

(1) By Sanitary Land Filling.

In low lying area, the refuse is filled up or dumped in layers of 1.5 m or so, and each such layer is covered by good earth of atleast 20 cm. thickness, so that refuse is not directly exposed. If the thickness of land filling is large filling shall be done in layers, and each layer shall be left out for atleast seven days, and compacted by movement of bull, motors trucks etc. for its settlement, before starting filling the second layer of refuse.

- The land filling operation is essential a biological method of waste treatment, since the waste is stabilised by aerobic as well as anaerobic process.
- The refuse get stabilised, generally within a period of 2 to 12 months, and settles down by 20–40% of its original height.
- This method is widely adopted in our country. 90% of Indian refuse is disposed off in this manner.
- Sanitary land fills may cause troubles during *peak monsoons*.
- Leachate is a coloured liquid, that comes out of sanitary land fills.
- Quantity of refuse produced in an average Indian city or a town is of the order of $\frac{1}{4}$ to $\frac{1}{5}$ heefare/day.

(2) Burning or Incineration

(3) Burrying it out into the sea (obsolete method)

(4) Pulverization

(5) By Composting

Composting of refuse is a biological method of decomposing solid wastes. This decomposition can be effected either under aerobic conditions, or under anaerobic conditions, both. The final end product is a manure, called *compost* or *humus*.

In India following two methods are adopted:

(*i*) **Indore method :** It uses manual turning of piled up mass (refuse and night soil) for its decomposition under aerobic conditions.

(*ii*) **Bangalore method :** It is primarily anaeriobic in nature; This method is widely adopted by municipal authorities throughout the country. The refuse and night soil, in this method are therefore piled up in layers in an underground earthen trench (10m × 1.5 m × 1.5 m). This mass is covered at its top by layer of earth of about 15 cm depth, and is finally left over for decomposition.

METHODS OF SLUDGE DISPOSAL

Dewatering

Digested sludge is first of all dewatered or dried up before disposal (burning or dumping).

Methods of Dewatering

(*i*) Dewatering of sludge by Sludge Drying Beds.

(*ii*) Mechanical Methods of Dewatering sludge.

Dried sludge from the drying beds is either use as a manure or is used for filling low lying areas.

Disposal of Row Sludge

1. Disposal on Land

In this method, sewage effluent is generally disposed off by throwing it away on land. The percolating water may either raise the water table or is collected below by a system of underdrains.

When sewage is applied on the ground, a part of it evopartes and remaining portion percolates through soil. Suspended particles are caught in the soil voids. If proper aeration of voids is maintained, the organic matler will get oxidised by aerobic process. But in fine grained soils like clays, pores get clogged up developing non-aerobic condition, which result in evaluation of foul gases and clogging makes the area water logged causing problem of mosquito breading. Application of the sludge sewage will also have some problem, hence primary treatment is necessary before land disposal.

Sewage Farming and Effluent Irrigation

Both these terms are synonyms and means use of sewage effluents for irrigating crops, i.e. direct application of effluent to lands. The basic difference is, in *effluent irrigation* main consideration is the successful disposal of sewage while in *sewage farming* main consideration is successful growing of crops.

Methods of Land Disposal

(*i*) Irrigation : It involves application of effluent to the land for treatment and meeting the growth needs of plants. Effluent is treated by physical, chemical and biological means as it seeps in to the soil. Where water for irrigation is valuable, crops can be irrigated as consumptive use rates of 2.5 to 7.5 cm/week depending on the crop and economic return from the crop.

(*ii*) Rapid infiltration : In this system, effluent is applied to the soil at high rates (10 to 20 cm/week) by spreading in basins or by sprinkling. Treatment occurs as the water passes through the soil matrix.

System objectives are following :

(*a*) Ground water recharge

(*b*) Natural treatment followed by pumped withdrawl or underdrain recovery.

(*c*) Natural treatment with renovated moving vertically and laterally in the soil and recharging a surface water course.

Rapid infiltration is suitable for percolation rate of 6 to 25 mm/minute. The degree of water renovation by rapid infiltration is difficult to predict.

(*iii*) Overland Flow : It is available only for slopping sites with relatively impervious soils. It is essentially a biological treatment process in which waste water is applied over upper reaches of sloped (2 to 8%) terrain and allowed to flow across the vegetated surface to runoff collection ditches. Renovation is accomplished by physical, chemical and biological means as waste water flows in a thin sheet down the relatively impervious slope.

It is suitable for percolation rate below 2mm/min. Plant or tree cover is essential to minimize errosion and assist in nutrient removal.

In this method there is difficulty in maintaining consistant quality in the runoff and site preparation. Since process is exposed to weather, biologically activity and degree of treatment are adversely affected by lack of sun-shine and cold temperature.

Fundamental Considerations in Land Treatment systems

(*i*) Knowledge of waste water characteristics and treatment mechanisms.

(*ii*) Vegetation and public health requirements.

(*iii*) Waste water characteristics and treatment mechanisms.

Treatment Mechanism

***(i)* Organic matter :** Soil in highly efficient biological treatment system. Bio-degradable compounds are oxidized in the upper few depth (mm) of soil. Higher organic loading may produce anerobic condition in the soil matrix and results in the production of odours. Between 4,50,000 – 10,00,000 kg. of organic matter per sq. km per year are required for general soil equilibrium.

***(ii)* Nitrogen :** It can be removed in the land treatment by crop uptake and dinitrification.

***(iii)* Phosphorus :** In land treatment, major phosphorus removal process are chemical presipitation and absorption (i.e. chemical precipitation with Ca, Fe, Al and absorption by clay).

***(iv)* Exchangeable Cations**

***(a)* Sodium Adsorption Ratio (SAR) :** $SAR = \dfrac{N_a}{\sqrt{\dfrac{Ca + Mg}{2}}}$

Ma, Ca, and Mg are expressed in mill equivalent per litre (mg eq./l)

High SAR value may adversely affect permeability of fine saturated soil.

***(b)* Percentage Soluble Sodium (PSS) :** Sodium hazard of irrigation water may also be expressed in terms of percentage soluble sodium.

$$PSS = \frac{100 \times Na}{\text{Total cations}}$$

Na and other cations are expressed in mg eq./lit.

Minimum possible value of PSS in irrigation water is 60. Where water with higher pH values are used, Gypsum should be added to soil occassionally for soil amandment.

***(v)* Trace Elements :** Many trace elements are essential for plant growth. Some became toxic at higher level to both plant and micro-organism.

***(vi)* Micro-organism :** Bacteria removal mechanism eliminate most element of and treatment includes Staining, Sedimentation, Enreachment and Adsorption.

***(vii)* Vegetation :** *Plants in land treatment system are used for following purposes:*

(*a*) Take up Nitrogen and Phosphorus from applied waste water

(*b*) Maintain an increased water intake rates and soil permeability

(*c*) Reduce errosion.

(*d*) Serves as a medium for micro-organisms.

***(viii)* Public Health Aspect :** *It includes following :*

(*a*) Biological agents and possible transmission of deseases to higher biological farms including humans.

(*b*) Chemicals that may reach ground water and pose risk to health if injected.

(*c*) Crops quality when crop are irrigated with waste water effluents.

Land Requirement

Total land area required includes allowance for treatment buffer zones and storage (if nccessory), sites for building, roads, ditches and land for emergencies or for future expansion. An allowance must be made for the land needed for pre application treatment of sewage (i.e. screening, sedimentation etc).

Field area : It is that portion of the site to which treatment process actually taken place.

$$\text{Field area (Hectare)} = \frac{3.65Q}{L}$$

where, Q = flow rate in m^3/day

L = annual liquid loading rate, cm/year

Crop Selection

Following are Important aspects of crop selction

(*i*) Nitrogen removal capacity

(*ii*) Water needs and tolerance

(*iii*) Sensitivity in waste water

(*iv*) Public health requirements

(*v*) Crop management considerations.

Disposal site Selection

Major consideration in disposal site selection is long term ability to move liquid through the soil and thus are limited by infiltration and percolation capacities.

Example. A sprinkler system is selected for application of the waste water for irrigation. Sprinklers are spaced in a rectangular grid pattern of 12 m × 20 m and each sprinkler nozzle discharges 2 lit/sec. What is the application rate in cm/hr? How many hours must the system be operated in a single area each week to satisfy application rate of 6 cm/week ?

Solution : $$\text{Applicate rate} = \frac{\text{discharge}}{\text{Area}} = \frac{2 \times 1000 \times 60 \times 60\,\text{cm}^3/\text{hr}}{1200 \times 2000\,\text{cm}^2} = \mathbf{3\ cm/hr.}$$

To satisfy application rate of 6 cm/week, system should operate at $\frac{6}{3}$ = **2 hour / week**

Example. A waste water effluent with BOD_5 of 30 mg/lit is applied at 50mm/week. What will be the amount of organic matter added in kg/m²/year?

Solution : Volume of sewage applied to land/m²/year $= 1 \times 1 \times 0.05 \times 52$

$$= 2.60\text{m}^3/\text{m}^2/\text{year} = 2.6 \times 10^3 \text{ lit/m}^2/\text{year}$$

$$\text{Amount of organic matter} = 2.6 \times 10^3 \times \frac{30}{1000} = 78 \text{ kg/year/m}^2.$$

Example. A rapid infiltration system is designed for an application rate of 20m/year. The system is operated throughout the year on a cycle of one day application followed by seven days of drying. If waste water has a BOD of 60 mg/lit, what is the average annual BOD loading rate in kg/hectare over the 8 days cycle? What is the average BOD loading rate in kg/hectare day. For the first day application, what is the loading rate in kg/hectare day?

Solution : Consider 1 hectare area.

$$\text{Volume of sewage applied/year} = (20\text{m} \times 1) \times 10^4 \text{ m}^3\text{/year} = 20 \times 10^7 \text{ litre/year}$$

BOD loading at 60 mg/lit $= 60 \times 10^7 \times 20 = 12 \times 10^9$mg **= 12000 kg/year/hectare**

For 8 days cycle, BOD loading rate = $1200 \times \frac{8}{365}$ **= 263 kg/8 day cycle/hectare**

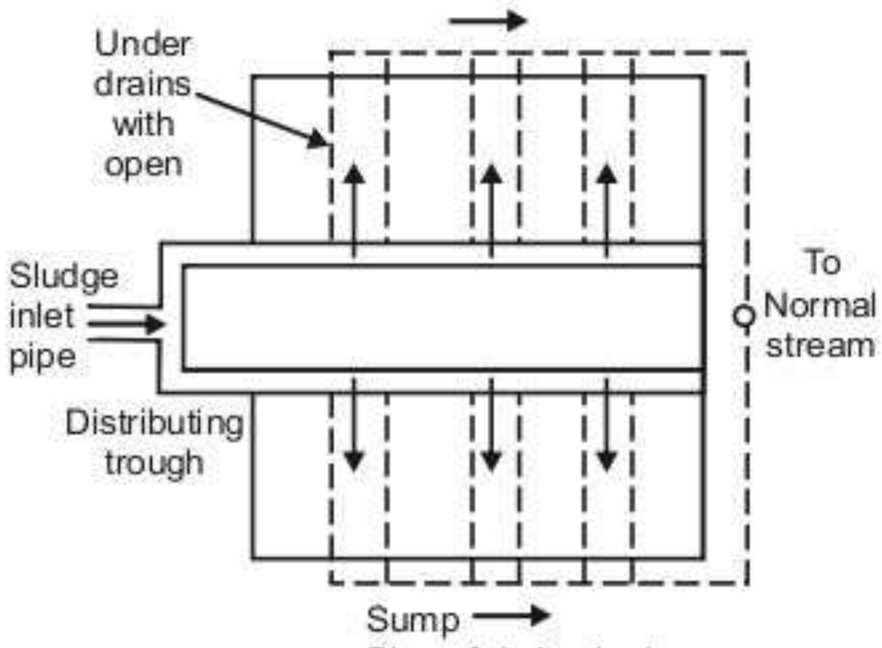
For first day of application, BOD loading = 263×8 **= 2104 kg/hectare**

Disposal of Wet Sludge

1. Drying on Drying Beds

In this method, sludge is dried by spreading over land. Drying bed is formed by excavating a trench in which underdrains with open joints are laid as shown in the figure. The portion above the drain is filled by gravel to a depth of 30 cm. A sand layer 15cm deep is laid above gravel layer.The size of sand used varies between 0.3 to 0.5 mm. Sludge is spread over the bed through distributing troughs that have openings of 15 cm × 20 cm and 3m apart. Troughs receive sludge from the inlet pipe.

Drying beds are generally arranged in series and are not covered at the top. Sometimes, to protect from sun, rain etc., a roof is provided over the bed. Minimum number of drying beds is 4 and numbers depend upon quantity of sludge to be dried.

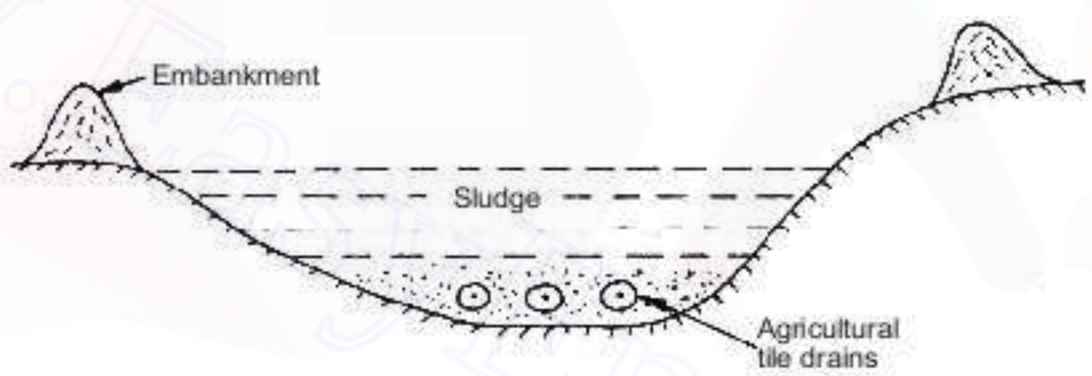


Plan of drying beds

Sludge is applied on the bed to a depth of 20 to 30 cm, depending on quantity of sludge and weather conditions. After about one week, surface of sludge cracks and is then removed in the form of sludge cakes. The cakes are dumped into a tray for further drying. If it is convenient, they may be dried on drying beds for three to four weeks.

Sludge has fertilising value. It contains nitrogen, potash and phosphoric acid and hence can be used as fertiliser. It can be dumped in low lying areas and can also be burnt.

2. Lagooning or Ponding



Lagoons are either natural depressions or artificial pits formed by excavating ground and forming embankments around the trenches with excavated material. The depth of a lagoon is 60 to 120 cm. At the bottom, a layer of ashes to a depth of 15 cm is placed. Underdrains are laid at the bottom; these consists of agricultural tile drains with open joints.

They are 100 mm in diameter and are placed at 3 centre to centre.

Sludge is admitted into the lagoon and left there to dry by natural process such as evaporation and percolation. Drying of sludge may require about 4 to 6 months. Dried sludge is then removed and used as manure. This method is cheap but it gives off an offensive odour and attracts flies.

3. Dumping into Sea

In this method, sludge is conveyed through the pipes and dumped into the sea. Sludge should be taken sufficiently deep into the sea to avoid the nuisance of it being washed back to shore.

4. Pressure Filters and Vaccum Filters

Sludge is filled in jute and cotton bags. These bags are placed between cast iron plates and then plates are pressed under pressure. This removes water from sludge and sludge cakes are formed. Each operation of filling the bags, placing, pressing and removal of sludge cake takes 45 minutes.

A vaccum filter consists of a rotating drum covered with filter cloth. Air from the drum is removed using a pump and the drum is evacuated. Due to evacuation, suction of sludge takes-place.

5. Incineration

In this method, sludge is burnt in an incinerator with the help of hot gases. Moisture in the sludge evaporates and dried sludge is collected at the bottom. Dried sludge can be used as fuel for incinerators.

6. Heat Drying

In this method, sludge is actually heated and dried. The method is costly and not commonly used.

EXERCISE – I

MCQ TYPE QUESTIONS

1. 1000 kg of sewage is estimated to contain, approximately, total solids, equal to
(*a*) 0.5 – 1kg (*b*) 2 – 5kg
(*c*) 5 – 10kg (*d*) 10 – 20kg

2. pH of fresh sewage is usually
(*a*) less than 7 (*b*) more than 7
(*c*) equal to 7 (*d*) equal to zero

3. Methaemoglovinemia disease is caused in children, by
(*a*) conversion of nitrites to nitrates
(*b*) conversion of nitrates to nitrites
(*c*) reaction between haemoglobin and carbon dioxide
(*d*) both (*a*) and (*c*)

4. Pathogenic bacteria, enter waste waters, primarily from
(*a*) industrial wastes
(*b*) both industrial as well as domestic wastes
(*c*) domestic wastes
(*d*) infiltration in sewers from the surrounding soils.

5. Chemical Oxygen Demand (COD) of sewage is the oxygen required to oxidise biologically
(*a*) active organic matter
(*b*) inactive organic matter
(*c*) both (*a*) and (*b*)
(*d*) none of these

6. While testing for COD of sewage, organic matter is oxidised by $K_2Cr_2O_7$ in the presence of
(*a*) HCl (*b*) H_2SO_4
(*c*) HNO_3 (*d*) none of these

7. Microbial utilisation of organics is a
(*a*) first order reaction (*b*) second order reaction
(*c*) third order reaction (*d*) none of these

8. Average, BOD_5 of domestic sewage is
(*a*) 80 kg/day/person (*b*) 8 kg/day/person
(*c*) 0.8 kg/day/person (*d*) 0.08 kg/day/person

9. Complete through treatment should generally be given to sewage, before its disposal in a stream, if the dilution factor available is
(*a*) less than 350 (*b*) less than 250
(*c*) less than 150 (*d*) none of these

10. For satisfactory working of a sludge digestion unit, pH range of digested sludge should be kept between
(*a*) 4.0 to 6.0 (*b*) 6.5 to 8.0
(*c*) 8.5 to 10.0 (*d*) 10.5 to 12.0

11. The detention period for oxidation ponds is generally kept as
(*a*) 4-6 hours (*b*) 24 hours
(*c*) 10-15 days (*d*) 7-42 days

12. In India, value of sludge index for normal sludge is
(*a*) 0 to 150 (*b*) 150 to 300
(*c*) 350 to 500 (*d*) 500 to 550

13. When there is no recirculation of sewage, then circulation factor is
(*a*) zero (*b*) one
(*c*) infinity (*d*) none of these

14. In high rate TRICKLING FILTER treatment, bacterias are removed by
(*a*) 20 to 40% (*b*) 40to 60%
(*c*) 60 to 80% (*d*) 80 to 95%

15. For satisfactory working of a sludge digestion unit, the pH range of digested sludge should be maintained in the range of
(*a*) 3 to 5 (*b*) 6.5 to 8
(*c*) 8.5 to 10 (*d*) all of these

16. A conventional activated sludge plant involves a mixing regime, which is essentially of
(*a*) plug flow type (*b*) completely mixed type
(*c*) both (*a*) and (*b*) (*d*) none of these

17. The least expensive and most suitable excreta disposal unit for rural areas would be the
(*a*) souk pit (*b*) pit privy
(*c*) leaching cesspool (*d*) septic tank

18. 'Air binding' may occur in
(*a*) Sewers (*b*) Artesian well
(*c*) Aerator (*d*) Filter

19. Description of solid waste collected is as follows :

Night soil	—	35 t
Rubbish	—	40 t
Debris	—	25 t
Garbage	—	40 t

Organic solids in the above composition is
(*a*) 35 t (*b*) 60 t
(*c*) 100 t (*d*) 75 t

20. Which of the following treatment processes are necessary for removing suspended solids from water ?
(*a*) Coagulation
(*b*) Flocculation
(*c*) Sedimentation
(*d*) All of these

21. Consider the following data in the design of grit chamber :

1. Sp. 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 setting 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

22. Consider the following treatment steps in a conven tional wastewater treatment plant:

1. Primary sedimentation
2. Grit removal
3. Disinfection
4. Secondary sedimentation
5. Screening
6. Secondary treatment unit

The correct sequence of these steps is

(*a*) 5, 2, 1, 6, 4, 3 (*b*) 1, 2, 4, 5, 3, 6
(*c*) 2, 3, 4, 5, 6, 1 (*d*) 6, 5, 4, 3, 2, 1

23. Which 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 by glass distillation

24. In which type of lakes, does a perfect ecological equilibrium among the producers, decomposers and consumer groups of organisms exist ?

(*a*) Senescent lakes (*b*) Mesotrophic lakes
(*c*) Oligotrophic lakes (*d*) Eutrophic lakes

25. The specific gravity of sewage is

(*a*) much greater than 1 (*b*) slightly less than 1
(*c*) equal to 1 (*d*) slightly greater than1

26. Minimum and maximum diameters of sewers shall preferably be

(*a*) 15 cm and 100 cm (*b*) 15 cm and 300 cm
(*c*) 30 cm and 450 cm (*d*) 60 cm and 300 cm

27. Velocity of flow does not depend on

(*a*) grade of sewer
(*b*) length of sewer
(*c*) hydraulic mean depth of sewer
(*d*) roughness of sewer

28. The effect of increasing diameter of sewer on the self cleaning velocity is

(*a*) to decrease it (*b*) to increase it
(*c*) fluctuating (*d*) nil

29. The type of sewer which is suitabe for both combined and separate system is

(*a*) circular sewer (*b*) egg shaped sewer
(*c*) horse-shoe type sewer (*d*) semi-elliptical sewer

30. The characteristics of fresh and septic sewage respectively are

(*a*) acidic and alkaline (*b*) alkaline and acidic
(*c*) both acidic (*d*) both alkaline

31. The correct relation between theoretical oxygen demand (TOD), Biochemical oxygen demand (BOD) and Chemical oxygen demand (COD) is given by

(*a*) TOD > BOD > COD (*b*) TOD > COD > BOD
(*c*) BOD > COD > TOD (*d*) COD > BOD > TOD

32. Sewage treatment units are designed for

(*a*) maximum flow only
(*b*) minimum flow only
(*c*) average flow only
(*d*) maximum and minimum flow

33. Which of the following unit works in anaerobic conditions ?

(*a*) Sludge digestion tank
(*b*) Sedimentation tank
(*c*) Activated sludge treatment
(*d*) Trickling filters

34. The maximum efficiency of BOD removal is achieved in

(*a*) oxidation pond (*b*) oxidation ditch
(*c*) aerated lagoons (*d*) trickling filters

35. The working conditions in imhoff tanks are

(*a*) aerobic only
(*b*) anaeroic only
(*c*) aerobic in lower compartment and anaerobic in upper compartment
(*d*) anaerobic in lower compartment and aerobic in upper compartment

36. In facultative stabilization pond, the sewage is treated by

(*a*) aerobic bacteria only
(*b*) algae only
(*c*) dual action of aerobic bacteria and anaerobic bacteria
(*d*) sedimentation

37. Composting and lagooning are the methods of

(*a*) sludge digestion
(*b*) sludge disposal
(*c*) sedimentation
(*d*) filtration

38. Sludge volume index is defined as the ratio of

(*a*) percentage of sludge by volume to percentage of suspended solids by weight

(*b*) percentage of sludge by volume to percentage of total solids by weight

(*c*) percentage of suspended solids by weight to percentage of sludge by volume

(*d*) percentage of total solids by weight to percentage of sludge by volume

39. 2.5 ml of raw sewage has been diluted to 250 ml and the D.O. concentration of the diluted sample at the beginning of the BOD test was 8 mg/l and 5 mg/l after 5 days incubation at 20°C. BOD of raw sewage will be

(*a*) 100 mg/lit (*b*) 150 mg/lit

(*c*) 250 mg/lit (*d*) 300 mg/lit

40. For the same solid content, if the quantity of sludge with moisture content of 98% is X, then the quantity of sludge with moisture content of 96% will be

(*a*) X/4 (*b*) X/2

(*c*) X (*d*) 2X

41. The gas from sludge digestion tank is mainly composed of

(*a*) nitrogen (*b*) carbon dioxide

(*c*) hydrogen sulphide (*d*) methane

42. The process of lagooning is primarily a means of

(*a*) reducing the excessive flow in sewers

(*b*) disposing of sludge

(*c*) increasing the capacity of storage reservoirs

(*d*) increasing flow of sewage through imhoff tanks

43. The biochemical treatment of sewage effluents is essentially a process of

(*a*) oxidation (*b*) dehydration

(*c*) reduction (*d*) alkalinization

44. In the design of grit chambers

(*a*) baffles are essential

(*b*) temperature is an important factor

(*c*) the detention period should be at least 30 minutes

(*d*) the maximum velocity of flow is 30 cm per second

45. BOD is preferred to COD as an index of sewage concentration because

(*a*) BOD represent both carbonaceous and nitrogenous organic matter while and nitrogenous organic matter while COD may indicate carbonaceous matter only

(*b*) BOD test is easier to perform and gives more reliable results

(*c*) BOD relates specifically to putrescible organic matter which is the most objectionable sewage constituent

(*d*) COD relates to the impurities which can only be removed by chemical treatment which is expensive

46. Sewage sickness relates to

(*a*) toxicity of sewage interfering with response to treatment

(*b*) destruction of aquatic flora and fauna due to gross pollution of receiving bodies of water by sewage

(*c*) reduction in the waste purifying capacity of the soil

(*d*) clogging of pores in soil due to excessive application of sewage to land, obstructing aeration and leading to septic conditons

47. Consider the data presented in the following table :

Temperature in °C	BOD reaction rate constant (K)
20	0.01
30	0.02
10	0.005

In the data presented above, the value of K

(*a*) should have remained constant.

(*b*) should have decreased with increase in temperature.

(*c*) should have remained the same at 20°C and 30°C.

(*d*) has followed the correct trend.

48. Various unit operations exist in a sewage treatment plant. These would include

1. screening
2. grit removal
3. secondary sedimentation
4. aeration
5. primary sedimentation

The correct sequence of these operations is

(*a*) 1, 2, 3, 4, 5 (*b*) 1, 2, 5, 4, 3

(*c*) 2, 1, 4, 5, 3 (*d*) 2, 1, 4, 3, 5

49. Following reactions take place during anaerobic digestion of organics :

1. methane production
2. alkaline fermentation
3. acid fermentation
4. acid regression.

The correct sequence of these reactions is

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

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

50. An industrial wastewater 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

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

(*a*) B.O.D. .... Strength of sewage
(*b*) Methane .... Product of anaerobic decomposition
(*c*) C.O.D. .... Biodegradability of wastewater
(*d*) Nitrate .... Methemoglobinemia

52. Following steps are involved in laying a sewer in a trench :

1. Transferring the centre line of the sewer to the bottom of the trench.
2. Setting sight rails over the trench.
3. Driving pegs to 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

53. Which of the following are clamied as advantageous in respect of aerobic sludge digestion as compared to anaerobic sludge digestion ?

(*a*) lower BOD concentration in supernatant liquor
(*b*) production of a sludge with excellent denaturing propensity
(*c*) lesser capital cost
(*d*) All of these

54. 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

55. The flow sheet of the liquid stream of a sewage treatment scheme consists of

1. trickling digester
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, 2, 1, 5 (*d*) 4, 3, 1, 2, 5

56. 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

57. 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

58. Ventilation of sewer lines is necessary to

(*a*) avoid building up of sewer gases.
(*b*) ensure atmospheric pressure in the waste water surface.
(*c*) ensure the safety of sewer maintenance people.
(*d*) all of these

59. Which of following parameters are taken into consideration for determining organic strength of a waste?

(*a*) Volatile solids
(*b*) Chemical oxygen demand
(*c*) Biochemical oxygen demand
(*d*) All of these

60. 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

61. In conventional activated sludge process, the mean cell residence time in aeration tank is

(*a*) less than 1.5h
(*b*) in the range of 4 to 8 h.
(*c*) in the range of 12 to 24 h
(*d*) in the range of 4 to 15 days

62. Ventilation in sewers is needed to avoid

(*a*) development of explosive mixtures of sewer gases

(*b*) build up of odorous gases.

(*c*) danger of asphyxiation of sewer maintenance employees

(*d*) All of these

63. The five days BOD of the effluents obtained from septic tanks is of the order of

(*a*) 0 – 5mg/l (*b*) 10 – 20mg/l

(*c*) 100 – 200mg/l (*d*) 50 – 200 mg/l

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

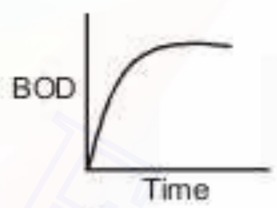
(*a*) BOD (*b*) DO

(*c*) TOC (*d*) COD

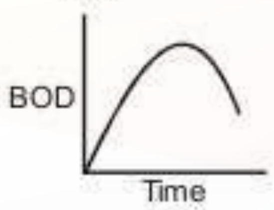
65. Choose the correct representation of BOD in mg/*l* against time in days :

(*a*)

(*b*)



(*c*)



(*d*)

66. A sewer, 1000 mm in diameter, is laid at a slope to obtain a velocity of 0.8 m/s when running full. Assuming Manning's n as constant, what is the velocity in this sewer if it is running half full ?

(*a*) 0.2 m/s (*b*) 0.4 m/s

(*c*) 0.6 m/s (*d*) 0.8 m/s

67. In which one of the following tests is the organic matter in the waste water used as food by microorganisms?

(*a*) B.O.D. (*b*) Most probable number

(*c*) C.O.D. (*d*) Chlorine demand

68. 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 organicmatter

(*c*) provide a greenish appearance to the pond

(*d*) prevent the odour nuisance

69. 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

70. For a waste, the 5-days BOD at 20°C is found to be 200 mg/l. For the same waste, 5-day BOD at 30°C 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

71. The ultimate BOD value of a waste

(*a*) increase with temperature

(*b*) decreases with temperature

(*c*) remains the same at all temperatures

(*d*) doubles with every 10°C rise in temperature

72. 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

73. 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*) respiratory activity of aquatic plants in the river

(*d*) microbial activity

74. 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

75. Process of activated sludge can be explained as

(*a*) a physical action whereby the finer suspended particles of sewage form a sublayer for a bacterial film at the surface.

(*b*) a chemical action whereby the finer suspended particles and colloidal solids are combined into masses of large bulk.

(*c*) a biochemical action whereby the sludge flocs so formed act as vehicles for aerobic bacteria oxidising the organic matter.

(*d*) all of these

76. 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

77. 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*) $COD > BOD_u > BOD_5 > ThOD$

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

(*a*) Peak hourly rate of flow

(*b*) Average hourly rate of flow

(*c*) Minimum hourly rate of flow

(*d*) Sewer running half full

79. Sewage sickness signifies

(*a*) diseases caused by sewage

(*b*) soil pores getting clogged aoej preventing free circulation of air when sewage is continuously applied on land

(*c*) raw sewage is applied and used for irrigating vegetables which^ie eaten raw

(*d*) disposal of septic sewage on land

80. A primary sedimentation tank is not required for

(*a*) Activated sludge system

(*b*) Extended aeration system

(*c*) Trickling filtration system

(*d*) Tapered activated sludge process using pure oxygen for aeration

81. Building manholes must be provided at

(*a*) every change of alignment, gradient or diameter.

(*b*) head of all sewers.

(*c*) every junction of two or more sewers

(*d*) all of these

82. Which one of the following pairs is not correctly matched ?

(*a*) BOD / COD = 0 : Waste-water is toxic

(*b*) BOD / COD £ 0.2 : Acclimatization of seed is necessary

(*c*) BOD / COD ³ 0.6 : Waste-water is non biodegradable

(*d*) BOD = COD = 0 : Waste-water is devoid of organic matter

83. In aerobic conditions, the microbial decomposition of organics results in the formation of

(*a*) stable and objectionable end products

(*b*) unstable and objectionable end products

(*c*) unstable and acceptable end products

(*d*) stable and unobjectionable end products

84. 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*

85. 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*) roughness coefficient of X sewer material should be same as that of Y sewer material

86. In dissolved oxygen sag curve, the sag results because

(*a*) it is a function of a rate of addition of oxygen to the stream

(*b*) it is a function of a rate of addition of oxygen from the stream

(*c*) it is a function of both addition and depletion of oxygen from the stream

(*d*) rate of addition of oxygen is linear, but the rate of depletion is non-linear

87. An industry manufacturing urea produces waste water, which largely contains urea and ammonia. The treatment plant consists of following units for effective control of nitrogen :

1. Nitrification followed by dentrification
2. Hydrolysis unit
3. Ammonia stripping by air
4. Lime dosing and mixing unit

Which one of the following is the correct sequence of above unit operations in the treatment plant?

(*a*) 3-2-1-4

(*b*) 2-3-1-4

(*c*) 2-4-3-1

(*d*) 4-2-3-1

88. A combined sewer is one, which transports domestic sewage and

(*a*) storm water

(*b*) industrial wastes

(*c*) overhead flow

(*d*) industrial wastes and storm water

89. Consider the following statements :

1. The velocity of flow in the rising main should not be less than 0.8 m/s at any time.
2. Maximum velocity of flow is generally limited to 1.8 m/s and never allowed to exceed 3.0 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

90. Presence of nitrogen in a waste water sample is due to the decomposition of

(*a*) Carbohydrates (*b*) Proteins
(*c*) Fats (*d*) Vitamins

91. When the recirculation ratio in a high rate trickling filter is unity, then what is the value of the recirculation factor ?

(*a*) 1 (*b*) > 1
(*c*) < 1 (*d*) Zero

92. What is 5 days 20° C BOD equal to ?

(*a*) 3 days 27° C BOD (*b*) 4 days 30° C BOD
(*c*) 6 days 32° C BOD (*d*) 7 days 35° C BOD

93. Consider the following statements in regard to aerobic and anaerobic treatment processes:

1. Biomass production in the aerobic treatment process is more as compared to the anaerobic treatment process.
2. Start-up period is more in the aerobic treatment process as compared to the anaerobic treatment process.
3. Energy consumption and production is more in the aerobic treatment process as compared to the anaerobic treatment process.

Which of the statements given above is/are correct?

(*a*) 1 and 2 (*b*) 2 and 3
(*c*) Only 2 (*d*) Only 1

94. Which one of the following statements is not correct?

(*a*) Settling and sludge digestion occurs in septic tanks in one compartment
(*b*) Settling and sludge digestion occurs in imhoff tank in different compartments
(*c*) Septic tank is a low-rate anaerobic unit whereas an imhoff tank is a high rate anaerobic unit
(*d*) The rate of sludge accumulation in septic tank is approximately 40 – 70 litres/capita/year

95. 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%

96. To determine the BOD_5 of a waste water sample, 5, 10 and 50 ml aliquots of the wastewater were dilute to 300 ml and incubated at 20°C in BOD bottles for 5 days.

The result were as follows.

Sl. No.	*Wastewater 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 wastewater is equal to

(*a*) 139.5 mg/L (*b*) 126.5 mg/L
(*c*) 109.8 mg/L (*d*) 72.2 mg/L

97. Group I contains some properties of water/waste water and Group II contains list of some tests on water/wastewater. Match the property with corresponding test.

Group I	**Group II**
A. Suspended solids concentration	1. BOD
B. Metabolism of biodegradable organics	2. MPN
C. Bacterial concentration	3. JAR TEST
D. Coagulant dose	4. S.V.I.

Codes:

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

98. If 5 day 30°C BOD of a sewage sample is 110 mg/l, then what will be its 5 days 20°C BOD? Assume deoxgenation constant at 20°C, K_{20} as 0.1.

(*a*) 78.8 mg/lit (*b*) 82.2 mg/lit
(*c*) 86.8 mg/lit (*d*) 89.8 mg/lit

99. Change in concentration of organic matter, L, with time, t, is given by

$$\frac{dL}{dt} = -k.L.$$

What will be the organic matter remaining after 3 days if the initial concentration was 200 mg/l, and k = 0.4 per day?

(*a*) 59.3 mg/lit
(*b*) 63.3 mg/lit
(*c*) 69.3 mg/lit
(*d*) 69 mg/lit

NUMERICAL TYPE QUESTIONS

1. Chlorination with Cl_2 produces hypochlorous acid (HOCl), which may further dissociate as hypochlorite ion (OCl^-) depending upon pH of the water. The reaction is represented as

$HOCl \Leftrightarrow H^+ + OCl^-$ ($k = 2.5 \times 10^{-8}$ moles/l at 20°C)

The fraction of HOCl in the water at pH 7.0 is ____

2. pH = 4, when compared to pH = 7, will be more acidic by ____ times

3. Minimum D.O. prescribed for a river stream, to avoid fish kills, is ____ *ppm*

4. The relative stability of sewage sample, whose D.O. equal the total oxygen required to satisfy its BOD, is ____ %

5. The ratio of 5 days BOD to ultimate BOD is about ____

6. In a BOD test, 1.0 ml of raw sewage was diluted to 100 ml and the dissolved oxygen concentration of diluted sample at the beginning was 6 ppm and it was 4 ppm at the end of 5 day incubation at 20°C.

The BOD of raw sewage will be ____ ppm

7. The minimum dissolved oxygen which should always be present in water in order to save the aquatic life is ____ ppm

8. A 600 mm diameter RCC sewer is laid at a slope to develop a velocity of flow of 0.6 m/s while just running full. When the sewer is running exactly half-full, the velocity of flow taking Manning's constant to be equal to 0.013, is nearly ____ m/s

9. Acceptable lower limit of bacteria removal through activated sludge process is ____ %

10. The proportion of the suspended solids in the incoming waste water that should be removed in a typical primary treatment system is ____

11. 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 ____

12. If the moisture content of a sludge is reduced from 98% to 96%, the volume of sludge will decrease by ____ %

13. 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 ____

14. At a sewage treatment plant for a flow of $3 m^3/s$, the cross-sectional area of grit chamber will be about ____ m^2

EXERCISE – II

(QUESTIONS FROM PREVIOUS GATE EXAMS)

MCQ TYPE QUESTIONS

2015

1. Solid waste generated from an industry contains only two components, X and Y as shown in the table below

Component	Composition (% weight)	Density (kg/m³)
X	c_1	ρ_1
Y	c_2	ρ_2

Assuming $(c_1 + c_2) = 100$, the composite density of the solid waste (ρ) is given by :

(*a*) $\dfrac{100}{\left(\dfrac{c_1}{\rho_1}+\dfrac{c_2}{\rho_2}\right)}$ (*b*) $100\left(\dfrac{\rho_1}{c_1}+\dfrac{\rho_2}{c_2}\right)$

(c) $100(c_1\rho_1 + c_2\rho_2)$ (*d*) $100\left(\dfrac{\rho_1\rho_2}{c_1\rho_1 + c_2\rho_2}\right)$

2. Total Kjeldahl Nitrogen (TKN) concentration (mg/L as N) in domestic sewage is the sum of the concentrations of

(*a*) organic and inorganic nitrogen in sewage

(*b*) organic nitrogen and nitrate in sewage

(*c*) organic nitrogen and ammonia in sewage

(*d*) ammonia and nitrate in sewage

3. Ultimate BOD of a river water sample is 20 mg/L. BOD rate constant (natural log) is 0.15 day^{-1}.

The respective values of BOD (in %) exerted and remaining after 7 days are:

(*a*) 45 and 55

(*b*) 55 and 45

(*c*) 65 and 35

(*d*) 75 and 25

2014

4. The potable water is prepared from turbid surface water by adopting the following treatment sequence.
   (*a*) Turbid surface water → Coagulation → Flocculation → Sedimentation → Filtration → Disinfection → Storage & Supply
   (*b*) Turbid surface water → Disinfection → Flocculation → Sedimentation → Filtration → Coagulation → Storage & Supply
   (*c*) Turbid surface water → Filtration → Sedimentation → Disinfection → Flocculation → Coagulation → Storage & Supply
   (*d*) Turbid surface water → Sedimentation → Flocculation → Coagulation → Disinfection → Filtration → Storage & Supply

5. The dominating microorganisms in an activated sludge process reactor are
   (*a*) aerobic heterotrophs
   (*b*) anaerobic heterotrophs
   (*c*) autotrophs
   (*d*) phototrophs

6. A waste water stream (flow = 2 m^3/s, ultimate BOD = 90 mg/l) is joining a small river (flow = 12 m^3/s, ultimate BOD = 5 mg/l). Both water streams get mixed up instantaneously. Cross-sectional area of the river is 50 m^2. Assuming the de-oxygenation rate constant, k = 0.25/day, the BOD (in mg/l) of the river water, 10 km downstream of the mixing point is
   (*a*) 1.68 (*b*) 12.63
   (*c*) 15.46 (*d*) 1.37

2013

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

8. Elevation and temperature data for a place are tabulated below:

Elevation, m	Temperature, °C
4	21.25
444	15.70

   Based on the above data, lapse rate can be referred as
   (*a*) Super-adiabatic
   (*b*) Neutral
   (*c*) Sub-adiabatic
   (*d*) Inversions

2012

9. A sample of domestic sewage is digested with silver sulphate, sulphuric acid, potassium dichromate and mercuric sulphate in chemical oxygen demand (COD) test. The digested sample is then titrated with standard ferrous ammonium sulphate (FAS) to determine the un-reacted amount of
   (*a*) mercuric sulphate
   (*b*) potassium dichromate
   (*c*) silver sulphate
   (*d*) sulphuric acid

10. **Assertion [A]:** At a manhole, the crown of the outgoing sewer should not be higher than the crown of the incoming sewer.
    Reason [R]: Transition from a larger diameter incoming sewer to a smaller diameter outgoing sewer at a manhole should not be made.
    The **CORRECT** option evaluating the above statements is :
    (*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

11. A town is required to treat 4.2 m^3/min of raw water for daily domestic supply. Flocculating particles are to be produced by chemical coagulation. A column analysis indicated that an overflow rate of 0.2 mm/s will produce satisfactory particle removal in a settling basin at a depth of 3.5 m. The required surface area (in m^2) for settling is
    (*a*) 210
    (*b*) 350
    (*c*) 1728
    (*d*) 21000

2011

12. Consider the following unit processes commonly used in water treatment: rapid mixing (RM), flocculation (F), primary sedimentation (PS), secondary sedimentation (SS), chlorination (C) and rapid sand filtration (RSF). The order of these unit processes (first to last) in a conventional water treatment plant is

(*a*) PS $\rightarrow$ RSF $\rightarrow$ F $\rightarrow$ RM $\rightarrow$ SS $\rightarrow$ C

(*b*) PS $\rightarrow$ F $\rightarrow$ RM $\rightarrow$ RSF $\rightarrow$ SS $\rightarrow$ C

(*c*) PS $\rightarrow$ F $\rightarrow$ SS $\rightarrow$ RSF $\rightarrow$ RM $\rightarrow$ C

(*d*) PS $\rightarrow$ RM $\rightarrow$ F $\rightarrow$ SS $\rightarrow$ RSF $\rightarrow$ C

2010

13. A coastal city produces municipal solid waste (MSW) with high moisture content, high organic materials, low calorific value and low inorganic materials. The most effective and sustainable option for MSW management in that city is

(*a*) Composting (*b*) Dumping is sea

(*c*) Incineration (*d*) Landfill

14. If BOD_3 of a wastewater sample is 75 mg/L and reaction rate constant k (base e) is 0.345 per day, then amount of BOD remaining in the given sample after 10 days is

(*a*) 3.21 mg/L (*b*) 3.45 mg/L

(*c*) 3.69 mg/L (*d*) 3.92 mg/L

2009

15. A horizontal flow primary clarifier treats wastewater in which 10%, 60% and 30% of particles have settling velocities of 0.1 mm/s, 0.2 mm/s, and 1.0 mm/s respectively. What would be the total percentage of particles removed if clarifier operates at a Surface Overflow Rate (SOR) of 43.2 m^3/m^2.d?

(*a*) 43 % (*b*) 56 %

(*c*) 86% (*d*) 100 %

16. An aerobic reactor receives wastewater at a flow rate of 500 m^3/d having a COD of 2000 mg/L. The effluent COD is 400 mg/L. Assuming that wastewater contains 80% biodegradable waste, the daily volume of methane produced by the reactor is

(*a*) 0.224 m^3 (*b*) 0.280 m^3

(*c*) 224 m^3 (*d*) 280 m^3

17. Column I

P. Grit chamber

Q. Secondary settling tank

R. Activated sludge process

S. Trickling filter

Column II

1. Zone settling

2. Stoke's law

3. Aerobic

4. Contact stabilisation

The correct match of **Column I** with **Column II** is

Codes :

	P	Q	R	S
(*a*)	1	2	3	4
(*b*)	2	1	3	4
(*c*)	1	2	4	3
(*d*)	2	1	4	3

2008

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

19. A wastewater sample contains $10^{-5.6}$ mmol/ I of OH^- ions at 25° C. The pH of this sample is

(*a*) 8.6 (*b*) 8.4

(*c*) 5.6 (*d*) 5.4

20. Group I lists estimation methods of some of the water and wastewater quality parameters. Group II lists the indicators used in the estimation methods. Match the estimation method (Group I) with the corresponding indicator (Group II).

Group I	Group II
P. Azide modified Winkler method for dissolved oxygen	**1.** Eriochrome Black T
Q. Dichromate method for chemical oxygen demand	**2.** Ferrion
R. EDTA titrimetric method for hardness	**3.** Potassium chromate
S. Mohr or Argentometric method for chlorides	**4.** Starch

Codes :

	P	Q	R	S
(*a*)	3	2	1	4
(*b*)	4	2	1	3
(*c*)	4	1	2	3
(*d*)	4	2	3	1

21. 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

22. The 5-day BOD of a wastewater sample is obtained as 190 mg/I (with k= $0.01h^{-1}$). The ultimate oxygen demand (mg/I) of the sample will be

(*a*) 3800 (*b*) 475

(*c*) 271 (*d*) 190

23. A water treatment plant is required to process 28800 m^3/d of raw water (density = 1000 kg/m^3, kinematic viscosity = 10^{-6} m^2/s). The rapid mixing tank imparts a velocity gradient of $900s^{-1}$ to blend 35 mg/I of alum with the flow for a detention time of 2 minutes. The power input (W) required for rapid mixing is

(*a*) 32.4 (*b*) 36

(*c*) 324 (*d*) 32400

24. Match **Group I** *(Terminology)* with **Group II** *(Definition / Brief Description)* for wastewater treatment systems

Group I

P. Primary treatment

Q. Secondary treatment

R. Unit operation

S. Unit process

Group 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 :

	P	Q	R	S
(*a*)	4	3	1	2
(*b*)	4	3	2	1
(*c*)	3	4	2	1
(*d*)	1	2	3	4

2006

25. To determine the BOD_5 of a wastewater sample, 5, 10 and 50 mL 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 $\frac{mg}{L}$	DO After 5 days $\frac{mg}{L}$
1.	5	9.2	6.9
2.	10	9.1	4.4
3.	50	8.4	0.0

Based on the given data, average BOD_5 of the wastewater is equal to

(*a*) 139.5 mg/L (*b*) 126.5 mg/L

(*c*) 109.8 mg/L (*d*) 72.2 mg/L

26. A synthetic sample of water is prepared by adding 100 mg Kaolinite (a clay mineral), 200 mg glucose, 168 mg NaCl, 120 mg $MgSO_4$, and 111 mg $CaCl_2$ to 1 liter of pure water. The concentrations of total solids (TS) and fixed dissolved solids (FDS)respectively in the solution in mg/L are equal to

(*a*) 699 and 599 (*b*) 599 and 399

(*c*) 699 and 199 (*d*) 699 and 399

27. The composition of a certain MSW sample and specific weights of its various components are given below.

Component	Percent by Weight	Specific Weight $\left(\frac{kg}{m^3}\right)$
Food waste	50	300
Dirt and Ash	30	500
Plastics	10	65
Wood and Yard waste	10	125

Specific weight (kg/m^3) of the MSW sample is

(*a*) 319 (*b*) 217

(*c*) 209 (*d*) 199

NUMERICAL TYPE QUESTIONS

2015

1. Consider a primary sedimentation tank (PST) in a water treatment plant with Surface Overflow Rate (SOR) of 40 $m^3/m^2/d$. The diameter of the spherical particle which will have 90 percent theoretical removal efficiency in this tank is ____ μm. Assume that settling velocity of the particles in water is described by Stokes's Law.

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

2. A groundwater sample was found to contain 500 mg/L total dissolved solids (TDS). TDS (in %) present in the sample is _______.

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

4. In a wastewater treatment plant, primary sedimentation tank (PST) designed at an overflow rate of 32.5 $m^3/day/m^2$ is 32.5 m long, 80 m wide and liquid depth of 2.25 m. If the length of the weir is 75 m, the weir loading rate (in $m^3/day/m$) is ________.

5. A landfill is to be designed to serve a population of 200000 for a period of 25 years. The solid waste (SW) generation is 2 kg/person/day. The density of the un-compacted SW is 100 kg/m^3 and a compaction ratio of 4 is suggested. The ratio of compacted fill (i.e. SW + cover) to compacted SW is 1.5. The landfill volume (in million m^3) required is ______.

2014

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

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

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

2013

9. A water treatment plant is designed to treat 1 m^3/s of raw water. It has 14 sand filters. Surface area of each filter is 50 m^2. What is the loading rate $\left(\text{in}\ \dfrac{m^3}{day.m^2}\right)$ with two filters out of service for routine backwashing _________

10. A student began experiment for determination of 5-day, 20°C BOD on Monday. Since the 5th day fell on Saturday, the final DO readings were taken on next Monday. On calculation, BOD (i.e. 7 day, 20°C) was found to be 150 mg/L. What would be the 5-day, 20°C BOD (in mg/L)? Assume value of BOD rate constant (k) at standard temperature of 20°C as 0.23/day (base e) _________

ANSWERS

EXERCISE – I

MCQ Type Questions

1. (*a*)	**2.** (*b*)	**3.** (*b*)	**4.** (*b*)	**5.** (*c*)	**6.** (*b*)	**7.** (*a*)	**8.** (*d*)	**9.** (*c*)	**10.** (*b*)
11. (*d*)	**12.** (*b*)	**13.** (*b*)	**14.** (*d*)	**15.** (*b*)	**16.** (*a*)	**17.** (*b*)	**18.** (*d*)	**19.** (*d*)	**20.** (*d*)
21. (*b*)	**22.** (*a*)	**23.** (*a*)	**24.** (*c*)	**25.** (*d*)	**26.** (*b*)	**27.** (*b*)	**28.** (*b*)	**29.** (*b*)	**30.** (*b*)
31. (*b*)	**32.** (*c*)	**33.** (*a*)	**34.** (*b*)	**35.** (*d*)	**36.** (*c*)	**37.** (*b*)	**38.** (*a*)	**39.** (*d*)	**40.** (*b*)
41. (*d*)	**42.** (*b*)	**43.** (*a*)	**44.** (*d*)	**45.** (*c*)	**46.** (*d*)	**47.** (*d*)	**48.** (*b*)	**49.** (*a*)	**50.** (*d*)
51. (*c*)	**52.** (*d*)	**53.** (*d*)	**54.** (*d*)	**55.** (*c*)	**56.** (*c*)	**57.** (*b*)	**58.** (*d*)	**59.** (*b*)	**60.** (*b*)
61. (*b*)	**62.** (*d*)	**63.** (*c*)	**64.** (*d*)	**65.** (*b*)	**66.** (*d*)	**67.** (*a*)	**68.** (*b*)	**69.** (*a*)	**70.** (*b*)
71. (*c*)	**72.** (*b*)	**73.** (*d*)	**74.** (*c*)	**75.** (*a*)	**76.** (*d*)	**77.** (*c*)	**78.** (*c*)	**79.** (*b*)	**80.** (*b*)
81. (*c*)	**82.** (*a*)	**83.** (*d*)	**84.** (*b*)	**85.** (*c*)	**86.** (*c*)	**87.** (*c*)	**88.** (*d*)	**89.** (*a*)	**90.** (*b*)
91. (*b*)	**92.** (*b*)	**93.** (*d*)	**94.** (*d*)	**95.** (*a*)	**96.** (*c*)	**97.** (*b*)	**98.** (*d*)	**99.** (*a*)	

Numerical Type Questions

1. (0.20)	**2.** (1000)	**3.** (4)	**4.** (100)	**5.** (2/3)	**6.** (200)	**7.** (4)
8. (0.6)	**9.** (90)	**10.** (1/4)	**11.** (50)	**12.** (50)	**13.** (2025)	**14.** (10)

EXERCISE – II

MCQ Type Questions

1. (*a*)	**2.** (*c*)	**3.** (*c*)	**4.** (*a*)	**5.** (*a*)	**6.** (*c*)	**7.** (*b*)	**8.** (*a*)	**9.** (*b*)	**10.** (*a*)
11. (*b*)	**12.** (*d*)	**13.** (*a*)	**14.** (*c*)	**15.** (*b*)	**16.** (*c*)	**17.** (*b*)	**18.** (*b*)	**19.** (*d*)	**20.** (*b*)
21. (*a*)	**22.** (*c*)	**23.** (*d*)	**24.** (*d*)	**25.** (*c*)	**26.** (*d*)	**27.** (*b*)			

Numerical Type Questions

1. (22.58)	**2.** 0.05	**3.** 144	**4.** 112.667	**5.** 13.6875
6. (31.0 to 32.0)	**7.** (37800 to 37800)	**8.** (49.0 to 51.0)	**9.** (143 to 145)	**10.** (127 to 132)

EXPLANATIONS

EXERCISE – I

MCQ TYPE QUESTIONS

12. For Indian conditions
S.V.I. = 150 – 350

21. Settling velocity $V_s = \frac{g}{18}\left(\frac{G-1}{v}\right).d^2$

$$= \frac{981}{18} \times \left(\frac{2.7-1}{10^{-2}}\right) \times (0.021)^2$$

$$= 4.08 \frac{cm}{s}$$

25. Sewage consists of 99.9% water and 0.1% solid and its specific gravity is 1.001 but the sewage and water are considered identical for design.

28. $V = \sqrt{KD\,(G-1)}$

30. Normally fresh sewage is alkaline and tends to become acidic as it becomes state.

34. *BOD% removal in*
Oxidation pond = 90%
Oxidation ditch = 98%
Aerated laggons = 90 – 95%
Trickling filter = 80 – 90%

39. Dilution factor = $\frac{250}{2.5} = 100$
D.O. consumed = 8 – 5 = 3 mg/l
B.O.D. of raw sewage = D.O. consumed × D.F
= 3 × 100 = **300 mg/l**

40. In 98% :
$98x \rightarrow$ water, $2x \rightarrow$ solid
In 96%, $48x$ is water
$\therefore$ Total sludge = $50x = \frac{x}{2}$

44. D.T. = 40 – 60 seconds

47. K varies with temperature T°C as
$K_T = K_{20}\,(1.047)^{T-20}$

50. $BOD = \frac{250 \times 1.5 + 10 \times 20}{1.5 + 20}$

$\Rightarrow$ BOD = 26.74 mg/l

56. Oxidation Ditch
Extended Aeration

84. BOD = Oxygen consumed x Dilution factor

$$= (8-2) \times \frac{300}{2} = 6 \times 150$$

= 900 mg/l or ppm

96. B.O.D.$_5$ of sample (1) $= (9.2 - 6.9) \times \frac{300}{5} = 138$

B.O.D.$_5$ of sample (2) $= (9.1 - 4.4) \times \frac{300}{10} = 141$

B.O.D.$_5$ of sample (3) $= 8.4 \times \frac{300}{50} = 50.4$

so average BOD$_5$ of waste water

$$= \frac{138 + 141 + 50.4}{3} = 109.8 \text{ mg/l}$$

98. Given, $k_{D(20^\circ)} = 0.1$

$\log_e \quad L = -kt + C$

We know, $k_{D(T^\circ)} = k_{D(20^\circ)}\,[1.047]^{T-20^\circ}$

$\therefore \quad k_{D(30^\circ)} = 0.1\,[1.047]^{30-20^\circ}$
$= 0.1\,[1.047]^{10} = 0.158$

Now, $\quad Y_t = L\left[1-(10)^{-k_D.t}\right]$

$\therefore \quad Y_{5 \text{ at } 30^\circ} = L\left[1-(10)^{-k_D.5}\right]$

$$= L\left[1-(10)^{-k_D(30^\circ).\times 5}\right]$$
$$= L\,[1-(10)^{-0.158\times 5}]$$
$$= L\,[1-(10)^{-0.79}]$$
$$= L\left[1-\frac{1}{(10)^{0.79}}\right] = L\,[1-0.162]$$

$\Rightarrow \quad 110 = L\,(0.838)$

$\therefore \quad L = \frac{110}{0.838} = \mathbf{131.3\ mg/l.}$

Now $\quad Y_{5 \text{ at } 20^\circ C} = L\left[1-(10)^{-k_D(20^\circ).\times 5}\right]$

$$= 131.3\,[1-(10)^{-0.1\times 5}]$$
$$= 131.3\left[1-\frac{1}{(10)^{0.5}}\right]$$
$$= 131.3 \times (1-0.316) = \mathbf{89.8\ mg/l.}$$

99. $\frac{dL}{dt} = -kL, \qquad$ or $\qquad \frac{dL}{L} = -k.dt$

Integrating, we have,

$$\log_e L = -kt + C$$

or $\quad 2.3 \log_{10} L = -kt + C.$

When $\quad t = 0$ (at start),
$L = 200$ mg/l.

$\therefore \quad 2.3 \log_{10} 200 = 0 + C$

$\Rightarrow \quad C = 2.3 \times 2.301 = 5.28.$

Now, the value of L after 3 days is given by

$$2.3 \log_{10} L = -0.4 \times 3 + C$$
$$= -1.2 + 5.28 = 4.08$$
$$\Rightarrow \log_{10} L = \frac{4.08}{2.3} = 1.773$$
$$\Rightarrow L = 59.3 \text{ mg/l.}$$

Hence the organic matter left after 3 days

$$= \mathbf{59.3\ mg/}$$

NUMERICAL TYPE QUESTIONS

5. $BOD_5 = 68\%$ of BOD_U

6.
$$BOD = \frac{DO_i - DO_f}{P\%}$$
$$= \frac{6-4}{\left(\frac{1}{100}\right)} = 200 \text{ ppm}$$

8. As velocity in sewer is given by

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

for same pipe material (means n is same) & same longitudinal slope

$$v \propto R^{2/3}$$

For full pipe flow case,

$$R = \frac{A}{P}$$
$$= \frac{rd^2/4}{\pi d} = d/4$$

For half pipe flow case,

$$R = \frac{A'}{P'}$$
$$= \frac{\frac{1}{2}(\pi d^2/4)}{\frac{1}{2} \times \pi d} = d/4$$

so velocity at half full condition will be same as in full flow condition.

11. Sludge Volume Index

$$= \frac{V}{X} \times 1000$$
$$= \frac{200 \times 1000}{4000}$$
$$= 50 \text{ ml/gm}$$

12.
$$V_2 = V_1 \frac{[100 - P_1]}{[100 - P_2]}$$
$$\Rightarrow \Delta V = 50\%$$

EXERCISE – II

MCQ TYPE QUESTIONS

2. TKN is the sum of organic nitrogen, ammonia (NH_3), and ammonimum (NH_4^+) in the chemical analysis of wastewater.

3.
$$BOD_u = 20 \text{ mg/L}$$
$$BOD_7 = BOD_u\, e^{-k \times 7}$$
$$= 20 \times e^{-0.15 \times 7}$$
$$= 6.998 \approx 7$$

$$\% \text{ of BOD remaining after 7 days} = \frac{7}{20} = 35\%$$

$$\% \text{ exerted} = 100 - 35 = 65\%$$

5. Aerobic heterotrophs :

They are organisms that cannot live without free oxygen and do not produce their own food.

6. Flow = 2 m³/sec = Q_1, ultimate BOD = Y_{v_1} = 90 mg/l

Flow = 12 m³/sec = Q_2, ultimate BOD = Y_{v_2} = 5 mg/l

$$\text{BOD of mixture } (Y_0) = \frac{Q_1 \times Y_{v_1} + Q_2 \times Y_{v_2}}{Q_1 + Q_2}$$
$$= \frac{2 \times 90 + 12 \times 5}{2 + 12} = 17.14 \text{ gm/m}^3$$

the BOD of mixture at 10 km downstream of mixing point Y_f

$$Y_f = Y_0\left[1 - \left(10^{-k_D t}\right)\right]$$
$$K_D = 0.434\, k'$$
$$= 0.434 \times 0.25 = 0.1085$$

time taken to reach 10 km

$$t = \frac{\text{length}}{\text{velocity}}$$
$$Q_2 = Q_1 + Q_2 = 2 + 12 = 14$$
$$\text{velocity} = \frac{Q}{A} = \frac{14}{50} = 0.28 \text{ m/sec}$$
$$t = \frac{10 \times 1000}{0.28} \text{ sec}$$
$$= \frac{35714.28}{60 \times 60} = 9.921 \text{ days}$$
$$\therefore \quad Y_t = Y_0\left[1 - (10)^{-k_D t}\right]$$
$$= 17.143\left[1 - (10)^{-0.1085 \times 9.921}\right]$$
$$= 15.70 \text{ mg/}l$$

So, the correct choise in (*c*)

7. A settling tank in a water treatment plant

$$\text{Surface overflow rate} = 30\frac{m^3}{\text{day}-m^2} = v_s$$

$$\text{Specific gravity } S_s = 2.65$$

$$\text{Density of water } \rho = 1000 \text{ kg/m}^3$$

Dynamic viscosity of water $\mu = 0.001$ N.S/m^2

By Soteks law

$$v_s = \frac{\gamma_w}{18}\left(\frac{S_s-1}{\mu}\right)\cdot d^2$$

Where,

γ_w is in kg/m^3

v_s is in $\frac{m^3}{\text{sec}-m^2}$

μ is in kg–s/m

then particle size get in m.

Therefore,

$$\gamma_w = 1000 \text{ kg/m}^3$$

$$v_s = \frac{30}{24\times 3600} = 3.47\times 10^{-4}\frac{s^3}{\text{sec}-m^3}$$

$$\rho = \gamma_w = 1000 \text{ kg/m}^3$$

$$\mu = \frac{0.001}{9.81} = 1.02\times 10^{-4} \text{ kg} - \text{s/m}$$

$$\because \quad v_s = \frac{\gamma_w}{18}\left(\frac{S_s-1}{\mu}\right)d^2$$

$$\Rightarrow 3.47\times 10^{-4} = \frac{1000}{18}\left(\frac{2.65-1}{1.02\times 10^{-4}}\right)d^2$$

$$d^2 = 3.85\times 10^{-10}$$

$$d = 1.96\times 10^{-5}\text{M}$$

$$d = 0.0196 \text{ mm} \approx 0.02 \text{ mm}$$

8. As per every 165 m temperature reduces by 1°C

height $= 444 - 4 = 440$ m

So, the average temp. reduction

$$= \frac{440}{165} = 2.67°\text{C}$$

The temperature after reduction

$= 21.25 - 2.67$

$= 18.58°\text{C} > 15.70$

So lapse rate is more than natural

$\because$ lapse rate referred as super adiabatic.

13. Composting is the effective and sustainable option for MSW management because waste contains good amount of organic matter.

14. *Given :* $BOD_3 = 75$ mg/l

Reaction rate constant, $k = 0.345$ per day

$$\therefore \quad k_D = 0.434\times k$$
$$= 0.434\times 0.345 = 0.15$$

Using equation, $Y_3 = L_o\left[1-10^{-k_D\times t}\right]$

$$\therefore \quad 75 = L_o\left[1-10^{-.15\times 3}\right]$$

$$\Rightarrow \quad L_o = 116.245 \text{ mg/lit}$$

Now, $Y_{10} = 116.245\times\left[1-10^{-.15\times 10}\right]$

$= 112.569$ mg/lit

$\therefore$ Remaining BOD $= 116.245 - 112.569$

$= 3.69$ mg/l or ppm

15. *Given :* $V_0 = 43.2$ m^3/m^{2}d

$$= \frac{43.2}{24\times 60\times 60} = 0.5 \text{ mm/sec}$$

For 10% particles :

$v_1(=0.1) < v_0$

$$\frac{v_1}{v_0} = \frac{0.1}{0.5} = 20\%$$

$\therefore$ Net = 20% of 10% = 0.2 × 0.1 = 2%

For 60% particles :

$v_2(=0.2) < v_0$

$$\frac{v_2}{v_0} = \frac{0.2}{0.5} = 40\%$$

$\therefore$ Net = 40% of 60% = 0.4 × 0.6 = 24%

For 30% particles :

$v_3\,(=1) > v_0 - 100\%$

$\therefore$ Net = 100% of 30% = 30%

Total = 30 + 24 + 2 = 56%

19. $[OH^-] = 10^{-5.6}$ m.mol/litre

$= 10^{-5.6}\times 10^{-3}$ mol/litre

$= 10^{-8.6}$ mol/litre

But $[H^+][OH^-] = 10^{-14}$

$\Rightarrow [H^+] = 10^{-14}\times 10^{8.6} = 10^{-5.4}$ mol/litre

$$\therefore \quad p^H = -\log_{10}[H^+]$$
$$= -\log_{10} 10^{-5.4} = 5.4 \log_{10} 10 = 5.4$$

22. $k_D = 0.434.k = 0.434\times 0.01\ h^{-1}$

$\therefore \quad k_D.t = 0.434\times 0.01\times 5\times 24 = 0.5208$

Given: $(BOD)_5 = 190$ mg/l

Now $(BOD)_5 = (BOD)_u\,\{1-10^{-kD.t}\}$

where $(BOD)_4$ = ultimate BOD

$\therefore \quad 190 \text{ mg/l} = (BOD)_u\,\{1-10^{-0.5208}\}$

$$\Rightarrow \quad (BOD)_u = \frac{190}{0.699} = 271 \text{ mg/l}$$

23. Velocity gradient, $G = \left\{\frac{P}{\mu.V}\right\}^{1/2}$

where, P = power

μ = dynamic viscosity

V = volume

$\therefore \quad P = G^2.\mu \times V$

$= (900)^2 \times (10^{-6} \times 1000) \times \frac{(28800 \times 2)}{24 \times 60}$

= 32400 watts

25.

S.No.	Waste Water Volume (mL)	Dilute factor	D.O. used = initial – final	BO D5 Dilute × DO used
1.	5	$\frac{300}{5} = 60$	9.2 – 6.9 = 2.3	60 × 2.3 = 138
2.	10	$\frac{300}{10} = 30$	4.7	141
3.	50	$\frac{300}{50} = 6$	8.4	50.4

$\therefore$ Average, $BOD_5 = \frac{138 + 141 + 50.4}{3}$

= 109.8 mg/L

27. From given data,

$\left(\frac{0.5x}{300} + \frac{0.3x}{500} + \frac{0.1x}{65} + \frac{0.x}{125}\right) = 1$

$\Rightarrow \quad 4.6 \times 10^{-3}x = 1$

$\Rightarrow \quad x = 217$

NUMERICAL TYPE QUESTIONS

1. $\%\text{removal} = \frac{V_s}{V} \times 100$

$V'_s = 0.9\,V_s$

$= \frac{0.9 \times 40}{86400}$ m/s

$\Rightarrow \quad \frac{1}{18} \times d^2 \times \frac{g}{\mu}(\rho_s - \rho_w) = \frac{0.9 \times 40}{86400}$

$\Rightarrow \quad \sqrt{\frac{0.9 \times 40 \times 18 \times V.\rho_w}{86480(G_S - 1) \times \rho_w \times g}}$

$\Rightarrow \quad d = 22.58\ \mu m$

2. Total dissolved solids (TDS) = 500 *mg/l*

$\text{TDS \%} = \frac{500}{1000 \times 1000} \times 100 = 0.05$

3. Capacity = 1 m³/s

= 3600 × 24 m³/day

Loading Rate per day

= 120 × 60 m³/day

= 7200 m³/day

No. of filters = $\frac{3600 \times 24}{7200} = 12$

Now, if 2 filters are out of service, no. of available filter = 10

So, loading rate becomes = $\frac{3600 \times 24}{10 \times (6 \times 10)} = 144$

4. Overflow rate = 32.5 m³/day/m²

Length = 32.5 m

Width = 8.0 m

Depth = 2.25 m

Capacity of tank = Overflow rate × Area of tank

= 32.5 × 32.5 × 8

Weir loading rate = $\frac{\text{Capacity}}{\text{Length of weir}}$

$= \frac{32.5 \times 32.5 \times 8}{75}$

= 112.667

5. Population = 2,00,000

Years = 25; Compaction Ratio = 4

Waste Generation = 2 kg/person/day

Density of uncompacted solid waste = 100 kg/m³

Total waste generated in 25 years

= 25 × 365 × 200000 × 2 kg

= 365 × 10⁷ kg

Volume of uncompacted,

$SW = \frac{365 \times 10^7}{100}\ m^3$

$= 365 \times 10^5\ m^3$

Compacted volume = $365 \times 10^5\ m^3/4 = 9125000\ m^3$

Also, $\frac{\text{Compacted fill (SW + Cover)}}{\text{Compacted SW}} = 1.5$

$\therefore$ Volume of cover

= (1.5 – 1) (Vol. of compacted SW)

Total volume required

= Vol. of cover + Compacted Vol. of SW

$= \frac{9125000}{2} + 9125000$

= 13687500 m³

= 13.6875 million m³

6. Settling velocity $V_S = \dfrac{Q}{\text{Surface Area of tank}}$

Surface Area of tank = B × L

∵ First we calculating settling velocity

$$V_S = \frac{(a-1)gd^2}{18\gamma}$$

$$= \frac{(2.65-1)\times 9.81\times(0.06)^2}{18\times 1.0105\times 10^{-2}}$$

$$= 0.3204 \text{ cm/sec}$$

$$= \frac{0.3204}{100} \text{ m/sec}$$

$$= 3.204 \times 10^{-3} \text{ m/sec}$$

$$V_s = \frac{Q}{\text{Surface Area of tank}}$$

$$\text{Surface Area of tank} = \frac{Q}{V_s}$$

$$= \frac{0.1}{3.204\times 10^{-3}} = 31.214 \text{ m}^2$$

7. Flow rate = 35 m^3/min

water tamperature = 15°C

alum dosage = 25 mg/*l*

∵ the alum quantity required for 30 days

$$= 35\frac{m^3}{\text{min}} \times 25\times 10^3 \frac{mg}{m^3} \times 30\times 24\times 60 \text{ min}$$

$$= 3.78\times 10^{10} mg$$

$$= \frac{3.78\times 10^{10}}{10^6}\text{Kg} = 37800 \text{ Kg}$$

9. Raw water discharge rate of plant = 1 m^3/sec

$$= 1\times 24\times 3600$$

$$= 86400 \text{ m}^3\text{/day}$$

Two filter out of service for routine backwashing.

Number of active filter = 14 – 2

= 12 Nos

Surface area of each filter = 50 m^2

$$\text{So loading rate} = \frac{86400}{12\times 50}$$

$$= 144 \text{ m}^3\text{/day.m}^2$$

10. BOD_5 = ? at 20° C

BOD_7 = 150 mg/L at 20° C

K = 0.23/day (base e) at 20° C

∴ $K_d = 0.434\text{ K} = 0.434 \times 0.23 = 0.099$

$$Y_T = L\left[1-(10)^{-KD\times T}\right]$$

t = time in days

For seven days BOD

$$Y_7 = L\left[1-(10)^{-0.099\times 7}\right]$$

$$150 = L\left[1-(10)^{-0.099\times 7}\right]$$

$$L = 188.15 \text{ mg/L}$$

So, BOD_5 at 20°C temperature

$$Y_5 = L\left[1-(10)^{-KD\times 5}\right]$$

$$Y_5 = 188.15\left[1-(10)^{-KD\times 5}\right]$$

$$Y_5 = 127.96 \text{ Mg/L} = 128 \text{ mg/L}$$

■■