Chapter 3

Waste Water Engineering-I

CHAPTER HIGHLIGHTS

- *Introduction*
- *Dry weather flow and wet weather flow*
- *Design of sewers*
- *Characteristics of sewage*
- *Treatment of sewage*
- *Activated sludge process*
- *Trickling filters*
- *Sludge digestion*
- *Septic tank*
- *Oxidation ponds*

Introduction

Waste water engineering is a branch in public health engineering which deals with preservation and maintenance of health of individual and the community by preventing communicable diseases.

Dry Weather Flow and Wet Weather Flow

Fundamental Definitions of Waste Water Engineering

Refuse

It is the general term used to indicate what is rejected or left out worthless. It can be divided into six categories:

1. **Garbage:** It includes the waste paper, decayed fruits, vegetables, grass and leaves and sweepings from streets, markets and other public places. It indicates dry refuse. It is organic in nature.
2. **Rubbish:** Rubbish indicates sundry solid wastes from offices, residences, and other buildings. Generally rubbish is dry and combustible in nature.
3. **Sullage:** It is the waste water from bathrooms, kitchens, washing places and wash basins, etc. It does not create bad smell as the there is no organic matter in it.
4. **Sewage:** It indicates the liquid waste from the community. A liquid waste of domestic or industrial origin. It consists of 99.9% water. It is foul in nature.
5. **Storm water:** The run-off from roads, buildings and other catchment areas. It is generally called storm drainage or drainage.
6. **Dry weather flow (DWF):** The dry weather flow is normal flow available in any season. It is due to sanitary sewage. DWF is generally $\frac{1}{20}$ to $\frac{1}{25}$ of maximum flow during monsoon.

Sewerage

The process of collection and conveyance of sewage is known as sewerage.

Systems of Sewerage

Water carriage system can be divided into the following types:

1. **Separate system:** Two separate sewers are provided, one for foul sewage and other for rain water including surface washing of street and roads. It is suitable generally in areas of an uneven rainfall in a year and in hilly areas with steep slopes.
2. **Combined system:** This system provides only one sewer to carry sewage as well as the rain water. The combined system is advocated because street surface

washing water is also impure. It is suitable where rainfall is evenly distributed throughout the year and in plain areas where excavation is easy and less costly.

3. **Partially separate system:** In this system only one set of underground sewers is laid and excess amount of water during rain is carried by open drains to natural streams.

Types of Sewers

- **House sewer:** Pipe carrying sewage from building to point of immediate disposal.
- **Lateral sewer:** A sewer which receives discharge from number of independent houses. Also known as branch sewer or sub-mains.
- **Main sewer:** These are main sewers to which lateral sewers are connected.
- **Outfall sewer:** The sewer which transports sewage to disposal point.

Estimation of Dry Weather Flow (Sewage Discharge)

- Quantity of sewage = Quantity of water supplied.
- Net sewage quantity = 75–80% of water supplied.

$$\boxed{\text{DWF} = \text{Population} \times \text{Per capita water supply} \times \text{Factor.}}$$

SOLVED EXAMPLES

Example 1

The dry weather flow produced by the community with a population of 10,000, supplied water at a rate of 400 lpcd and 80% of which become as sewage is ______.

Solution

$$\text{DWF} = \text{Population} \times \text{Per capita water supply} \times \text{Factor}$$

$$= 10^4 \times 400 \times \frac{80}{100}\left(\frac{\text{Lts}}{\text{day}}\right)$$

$$= \frac{10^4 \times 400 \times 80}{24 \times 60 \times 60 \times 100} \times 10^{-3}$$

$$= 0.037 \text{ m}^3/\text{s}.$$

Variations in Sewage Flow

- For moderate areas, such involved for branch sewers, the following maximum flow may be assumed.

$$\text{Maximum daily flow} = 2 \times \text{Average daily flow.}$$

$$\text{Maximum hourly flow} = 1.5 \times \text{Maximum daily flow}$$
$$= 3 \times \text{Average daily flow}$$

- Sewers are designed for carrying the **maximum hourly flow** running $\frac{3}{4}$ **full**.

$$\boxed{\begin{aligned}&\text{Minimum daily flow}\\&= \frac{2}{3} \times \text{Average daily flow}\\&\text{Minimum hourly flow}\\&= \frac{1}{2} \times \text{Minimum daily flow}\\&= \frac{1}{3} \times \text{Average daily flow}\end{aligned}}$$

- Sewers must be checked for minimum velocities at their minimum hourly flow.

Estimation of Wet Weather Flow

Following formula are employed:

Rational Formula

$$\boxed{Q_{PD} = \frac{\text{AIR}}{360}}$$

Where

Q_{PD} = Peak rate of run-off in cumec.
I = Coefficient of run-off or impermeable coefficient.
A = Catchment area contributing to run-off in hectares.
R = Critical rainfall intensity in mm/hour corresponding to time of concentration.

Time of concentration (t_c): The period after which the entire area starts contributing to the run-off is called time of concentration. The maximum run-off will be obtained from the rain having a duration equal to the time of concentration and this is called 'critical rainfall duration'.

- Coefficient of run-off (I) = $\frac{\text{Run-off}}{\text{Precipitation}}$

  For paved areas, $I = 0.9–1$
  For lawns and gardens, $I = 0.15$

1. $\boxed{t_c = t_e + t_f}$

   Where;
   t_c = Time of concentration
   t_e = Time of entry (or) inlet time
   t_f = Time of flow

$$\boxed{R = \frac{25.4a}{t_c + b}}$$

$a = 30$; $b = 10$ for $t_c = 5–20$ min
$a = 40$; $b = 20$ if $t_c > 20$ min.

Empirical Formula

2. **Dicken's formula:** For North Indian catchments.

$$\boxed{Q_P = c_d\,(A)^{3/4}}$$

Where

A = Catchment area in sq km

Q_p = Peak discharge in cumec

C_d = Constant depending on different factors

Ryve's formula: For South Indian catchments

$$\boxed{Q_p = C_r\,(A)^{2/3}}$$

Design of Sewers

The sewers are designed for self-cleansing velocity without clogging as the sewage particles are heavy.

The sewage pipes carry sewage generally under gravity.

Formula for Determining Flow Velocities in Sewers and Drains

1. **Chezy's formula:**

$$\boxed{V = C\sqrt{rS}}$$

V = Velocity of flow in channel in m/s

r = Hydraulic mean radius of channel

$$= \frac{a}{p}\left(r = \frac{D}{4}\text{ for circular channel}\right)$$

Where

a = Area of channel

p = Wetted perimeter of channel

S = Hydraulic gradient

C = Chezy's constant

2. **Kutter's formula:**

$$C = \frac{\left(23 + \frac{0.00155}{S}\right) + \frac{1}{n}}{1 + \left(23 + \frac{0.00155}{S}\right)\frac{n}{\sqrt{r}}}$$

Where

n = Rugosity coefficient

S = Bed slope

3. **Bazin's formula:**

$$C = \frac{157.6}{1.81 + \frac{k}{\sqrt{r}}}$$

Where, k = Bazin's constant

4. **Manning's formula:**

$$\boxed{V = \frac{1}{n}x\,(R)^{2/3} \times (S)^{1/2}}$$

Where

V = Mean velocity of flow

n = Manning's coefficient or rugosity coefficient

S = Bed slope

R = Hydraulic mean radius

Minimum Velocity

The velocity which causes both floating and transportation of heavy solids easily is known as minimum velocity or self-cleansing velocity. The generation of such minimum velocity in a sewer atleast once in a day is important.

Self-cleansing velocity,

$$\boxed{V_s = \sqrt{\frac{8k}{f}(S-1)gd}}$$

Where

S = Specific gravity of sediment

k = A sediment characteristic constant to be determined by experiments

d = Diameter of grain

f = Friction factor

- The minimum velocity to be generated in sewers to avoid silting is equal to self-cleaning velocity.
- It is taken as 0.75 m/s generally.
- The minimum velocity also helps in:
  (a) Keeping the sewers size under control.
  (b) Preventing the sewer from setting state and decomposed by moving it faster, thereby preventing evolution of foul gases.

Shapes of Sewer

Circular Sewers

The circular sewer is suited for separate sewerage system because discharge does not vary much and chances of sewer running at low depths are less. The properties of circular sewer are

When the Sewer is Running Full	When the Sewer is Running Partially Full
Area of cross-section, $A = \frac{\pi}{4}D^2$	Area (proportionate), $A_p = \frac{\alpha}{A} = \left[\frac{\alpha}{360^\circ} - \frac{\sin\alpha}{2\pi}\right]$
Wetted perimeter, $P = \pi D$	Wetted perimeter (proportionate), $P_p = \frac{\pi}{P} = \frac{\alpha}{360^\circ}$
Hydraulic mean depth, $R = \frac{A}{P} = \frac{D}{4}$	Hydraulic mean depth (proportionate), $R_p = \left[1 - \frac{360\sin\alpha}{2\pi d}\right]$

Egg Shaped Sewer

It is preferred for combined sewage because low discharge is 1/20 to 1/25 times the maximum discharge. The diameter of egg shaped sewer = 0.48 times the diameter of circular sewer. The disadvantage of egg shaped sewers is that they are:

1. Difficult to construct
2. Less stable
3. They are costly.

Types of Sewers Based on Sewer Materials

Asbestos Cement Sewer

These are made up of mixture of asbestos fibre, silica and cement, converted under pressure. They are generally joined by simplex joints. The advantage of this type of sewers is that it is light weight and has excellent hydraulic efficiency.

RCC Pipes

They are mainly used for branch and main sewers. They are generally connected by bell and spigot joint. RCC pipes are generally provided with nominal longitudinal reinforcement equal to 0.25% of the cross-sectional area of concrete.

1. They are quite resistant to erosion and abrasion.
2. All these concrete pipe are strong in tension.

Vitrified Clay or Stoneware Sewers

These sewers are widely used for carrying sewage and drainage as house connections as well as lateral sewers. They are widely used in carrying sewage to lateral sewers. They are manufactured from clays and shale's of specified quality.

Advantages

1. Highly resistant to sulphide corrosion.
2. Their interiors are very smooth and they are hydraulically every efficient.
3. It is quite cheap, durable, easily available and can be easily laid and joined.

Disadvantages

1. They are bulky and brittle and therefore difficult to transport.
2. They cannot be utilized as main or branch sewers.

Cast Iron Sewers

They are strong and hence used for the outfall sewers. They are joined together by bell and spigot joint in which the annular space may be filled either by cement mortar or by lead.

Example 2

A 20 cm diameter sewer is laid at a slope of 0.004 and is designed to carry a discharge at depth of 10 cm with Manning $n = 0.014$, the design discharge is

[GATE, 1991]

(A) 9.6 lit/s (B) 19.2 lit/s
(C) 0.009 lit/s (D) None of these

Solution

$$Q = AV = A \times \frac{1}{n} \times (R)^{2/3} \times (S)^{2/3}$$

$$A = \frac{\pi}{8} D^2 \text{ when running half full}$$

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

$$Q = \frac{\pi}{8} \times D^2 \times \frac{1}{n} \left(\frac{D}{4}\right)^{2/3} \times S^{2/3}$$

$$= \frac{\pi}{8} \times (0.2)^2 \times \frac{1}{0.014} \left(\frac{0.2}{4}\right)^{2/3} \times (0.004)^{1/2}$$

$$= 9.6 \times 10^{-3} \text{m}^3\text{/s}$$

$$= 9.6 \text{ lit/s.}$$

Hence, the correct answer is option (A).

Characteristics of Sewage

Physical Characteristics

Turbidity

Turbidity of waste water depends on the quantity of solid matters present in suspension state. Turbidity is the measure of light emitting properties of waste water and turbidity test is used to indicate the quality of waste discharges with respect to colloidal water.

Colour

Fresh domestic sewage is grey, somewhat resembling a weak solution soap, with the passage of time, as putrefaction starts, it begins to get black.

Odour

Normal sewage has musty odour which is normally not offensive, but as it starts to get stale, it begins to give offensive odour. Oxygen present in sewage get exhausted and offensive odour of H_2S and CO_2, CH_4 starts coming out.

Temperature

The average temperature of waste water in India is around 20°C, which is quite close to the ideal temperature for biological activities. The solubility of gases decreases with increase in temperature. When temperature is more, dissolved oxygen (DO) get reduced.

Total Solids

The mass of the residue divided by the volume of the sample evaporated, represents total solids in mg/lit.

- **Suspended solids:** The solids retained by a filter of 1μ pores.
- **Dissolved and colloidal solids:** Difference between the total solids and suspended solids.
- **Volatile and fixed solids:** Total suspended solids = Volatile + Fixed.

1. **Volatile solids:** Loss of weight due to ignition represents volatile solids.
2. **Settleable solids:** Sewage is allowed to stand in an Imhoff cone for a period of 2 hours. The quantity of solids settled in the bottom of the cone can be directly read as settleable solids.

Chemical Characteristics

pH Value

Fresh sewage is generally alkaline (pH = 7.3–7.5), with the passage of time pH falls due to production of acids and sewage tend to become acidic.

Chloride Content

Presence of high chloride content of a given sewage indicates the presence of industrial waste or infiltration of sea water, there by indicating strength of sewage.

Nitrogen Content

Nitrogen is found in three stages in sewage

1. Free ammonia—First stage
2. Albuminoid nitrogen—Just before decomposition of organic matter is started.
3. Nitrite formation—Indicates presence of partly decomposed final stage
4. Nitrate formation—Final stage

Fats, Oils and Greases

Oils and greases are soluble in ether and when the ether is evaporated it leaves behind ether soluble matter like fats and oils.

Sulphide, Sulphates and H_2S Gas

Sulphur compound are oxidized and the end product is SO_4^{2-} which are unobjectionable. It is called aerobic decomposition. Reduce the sulphur and its compounds to sulphides, with evolution of H_2S, $CH_4\uparrow$ and $CO_2\uparrow$, thus causing very obnoxious smells and odour.

Dissolved Oxygen

It is determined by Winkler's method. The solubility of oxygen is 95% in sewage to that of in distilled water. If temperature of sewage is more, the DO content is less. At least 4 ppm of DO should be ensured while discharging sewage into river stream.

Chemical Oxygen Demand (COD)

It is chemical oxidation with potassium permanganate or potassium dichromate in an acid solution. The test for determining extent of readily oxidizable organic matter present in sewage. [$K_2Cr_2O_7$ or $KMnO_4$ are used in the presence of H_2SO_4 for oxidizing organic matter].

Bio-chemical Oxygen Demand (BOD)

It is measure of oxygen required for biological decomposition of organic matter in the sewage under aerobic condition at standard temperature. COD present both biologically active and inactive organic matter, where BOD gives biologically active organic matter only.

$$\therefore \text{COD} > \text{BOD}$$

- BOD = [Initial DO in the beginning for sample diluted with water – Final DO of sample incubated for 5 days at 20°C] × Dilution factor

Example 3

In a BOD test initial DO of the 2% diluted sample is 5 mg/lit and its DO after 5 day incubation at 20°C is 3 mg/lit. The 5 day BOD of sewage sample is ______.

Solution

$Y_5^{20°} = \{DO_{initial} - DO_{final}\} \times$ Dilution factor $= [5-3] \times \dfrac{100}{2} = 100$ mg/lit.

Mathematical Expression for BOD

$$\frac{dL}{dt} \propto -L_t$$

Where

L_t = Amount of organic matter present at time t.
K = Rate constant
K_T = Deoxygenation constant

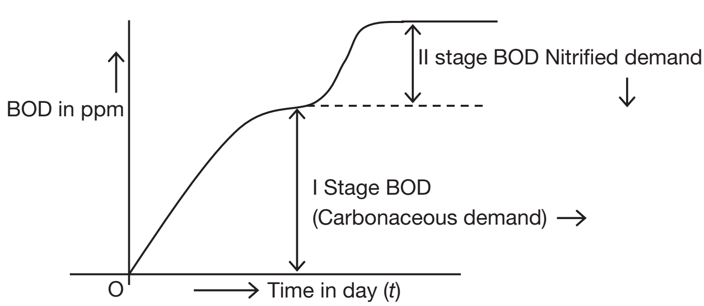
$$L_t = L_0 e^{-kt} = L_0 \cdot 10^{-K_D t}$$

$$\text{BOD}_t = L_0(1-e^{kt}) = L_0\,(1-10^{-K_D t})$$

$$\text{BOD}_u = \text{Ultimate BOD} = L_0$$

$$K_T = K_{20}\,[1.047]_{(T-20)}$$

$$K_{20}(\text{Base } 10) = 0.1/\text{day}.$$



Example 4

If 5 day BOD at 20°C is 100 mg/lit, then find 3 day BOD at 15°C and 8 day BOD at 30°C. Take $K_{20} = 0.23d^{-1}$.

Solution

$$K_T = K_{20}(1.047)^{T-20}$$
$$K_{15} = 0.23(1.047)^{15-20}$$
$$= 0.182d^{-1}$$
$$K_{30} = 0.23(1.047)^{30-20}$$
$$= 0.364d^{-1}$$
$$y_5 = L_0(1-e^{-k_{20}t}) \Rightarrow 100$$
$$= L_0(1 - e^{-0.23\times 5})$$
$$L_0 = 146.33 \text{ mg/lit}$$

3 day BOD at 15°C is

$$y_3 = 146.33[1-e^{-k_{15}}]$$
$$= 146.33\,[1 - e^{-0.182\times 3}]$$
$$= 61.56 \text{ mg/lit}$$

8 day BOD at 30°C is

$$y_8^{30°} = 146.33[1-e^{-k_{30}t}]$$
$$= 146.33[1 - e^{-0.364\times 8}]$$
$$= 138.37 \text{ mg/lit.}$$

Relative Stability

It is the ratio of amount of oxygen available in the effluent to the total oxygen required to satisfy the first stage BOD demand. The available oxygen will include dissolved oxygen as well as oxygen present as nitrite or nitrate.

Population Equivalent

Industrial waste waters are generally compared with per capita normal domestic waste water so as to charge industries properly.

- Population equivalent

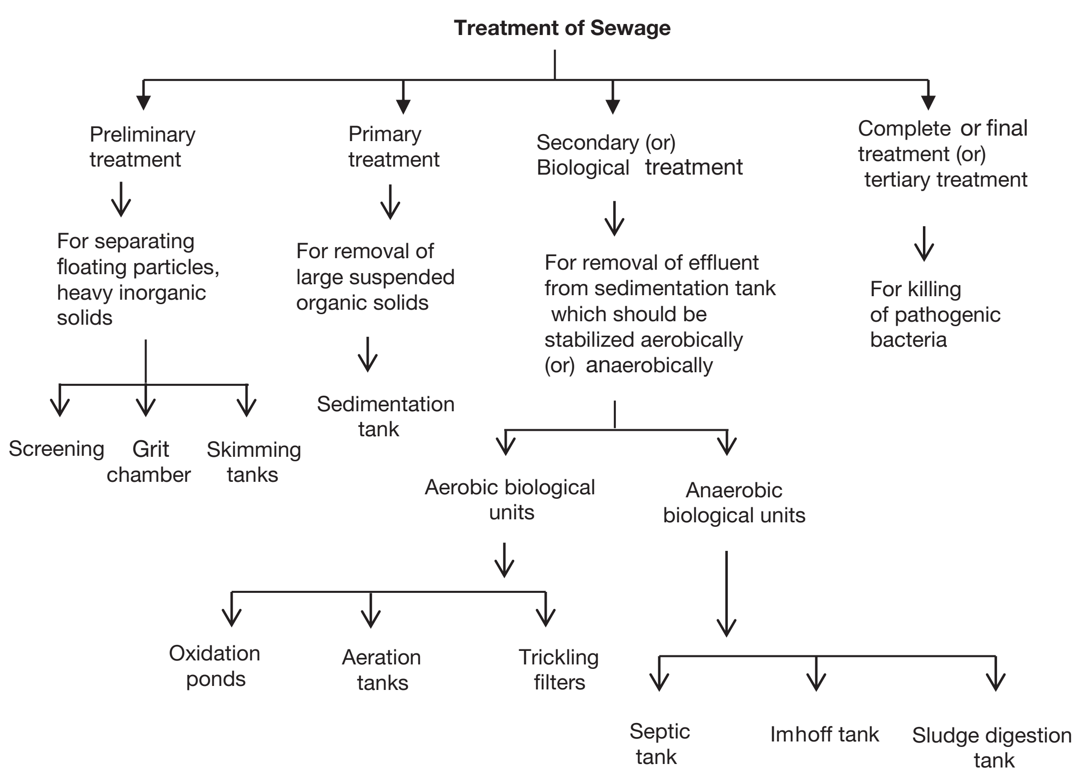
$$= \frac{\text{Total Standard BOD}_5 \text{ of industrial sewage per day}}{\text{Standard BOD}_5 \text{ of domestic sewage per person per day}}$$

Treatment of Sewage

Preliminary Treatment

Screens

It is a device generally of uniform size ranging from 3 mm to 50 mm to retain the floating coarse solids.



There are 3 types of screening, they are:

1. Racks or bars
2. Mesh screen
3. Grating

Grit Chamber

The inorganic content of sewage is termed as grit. The size varies from 0.2 mm diameter and above. It is a settling tank with lesser detention time of 1 minute and flow velocity of 0.2 to 0.3 m/s. The flow velocity should neither be far low as to cause settling of either organic matter nor should it be so high as not to cause the settlement of entire silt and grit present.

There are two types of grit chambers:

1. Manually cleaned grit chambers
2. Mechanically cleaned grit chambers
   - **Design of grit chambers:** Grit chambers are designed based on
   - Volume of grit chamber $V = Q \times DT$
   - Surface area of grit chamber $= \dfrac{Q}{V_0}$
   - Cross-sectional area of grit chamber $= \dfrac{Q}{V_H}$.

Example 5

The dimension of grit chamber to handle a waste water flow of 30 MLD with $V_H = 0.3$ m/s and depth = 0.8 m; DT : 1 minute is ________.

Solution

Volume of grit chamber $= Q \times DT$

$$= \frac{30 \times 10^6}{10^3 \times 24 \times 60} \times 1$$
$$= 20.83 \text{ m}^3$$

Cross-sectional area of grit chamber

$$= \frac{Q}{V_H} = \frac{30 \times 10^6 \times 10^{-3}}{0.3 \times 24 \times 60 \times 60} = 1.157 \text{ m}^2$$

$$B \times H = 1.157 \text{ m}^2$$

$$\Rightarrow B = \frac{1.157}{0.8} = 1.446 \text{ m.}$$

- **Detritus tank:** The detention time should be kept between 3 to 4 min.
- **Skimming tank:** It is used to remove greases and oils. These interfere with water and inhibits the bacterial growth in trickling filters. The detention time should be 3–5 minutes.
- **Primary treatment:** Detention time is 2 hours with a velocity of flow of 0.3 m/min.

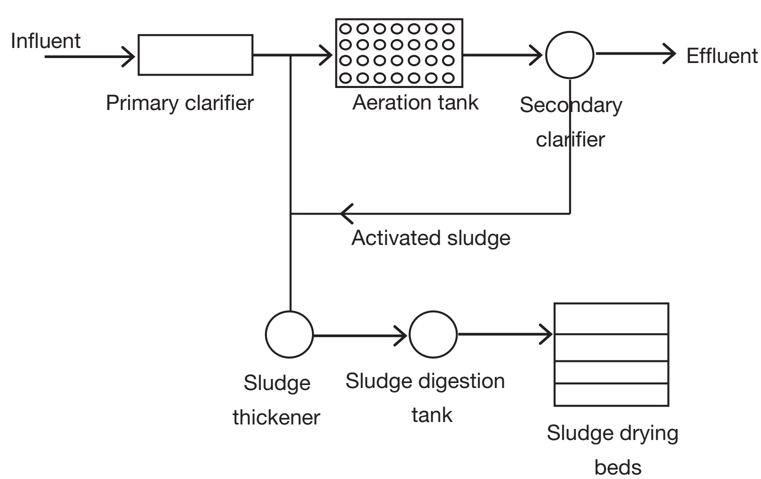
Activated Sludge Process

The activated sludge is the sludge which is obtained by settling sewage in presence of abundant oxygen so as to be supercharged with favourable aerobic micro-organisms.

Generalized biological process reaction in the activated sludge process is

$$\text{Organic material} + O_2 + \text{Nutrient} \xrightarrow[\text{organisms}]{\text{micro}} CO_2 + H_2O + \text{Energy} + \text{Micro organisms}$$

Flow Diagram



Q = Rate of flow of sewage
Q_r = Rate of returned sludge
Q_E = Rate of sewage effluent
Q_W = Rate of wasted sludge
X_t = Mixed liquor suspended solids (MLSS) in mg/lit in a aeration tank
X_R = Concentration of solids in the returned sludge
X_E = Concentration of solids in effluent

X_W = Concentration of solids in wasted effluent
Y_i = BOD_5 of influent sewage
Y_e = BOD_5 of effluent sewage
V = Aeration tank volume

Components of Activated Sludge Process

1. **Primary settling tank:** It has very less detention time of 1.5–2 hours.
2. **Aeration tank:** It is the tank in which oxygenation and mixing takes place. The aeration has three main functions. They are:
   - Oxygenation of the mixed liquor.
   - Flocculation of colloids in sewage influent.
   - Suspension of activated sludge floc.
3. **Secondary sedimentation tank:** The detention time of the secondary sedimentation tank ranges from 1.5 to 2 hours.
4. **Sludge thickener:** The moisture content of the sludge is reduced from 98% to 93% in sludge thickener. It helps in reducing the capacity of digestion tank. The detention time is generally 12–24 hours.

Design Parameters

1. **Hydraulic retention time:**

$$\text{HRT} = \frac{\text{Volume of the tank}}{\text{Rate of sewage flow in to the tank}}$$

(sewage in flow rate excluding sludge returned)

2. **Volumetric BOD loading or organic loading:** It is the BOD load applied per unit volume of aeration tank.

$$\boxed{V_L = \frac{Q \cdot Y_i}{V}}$$

3. **Food (F) to micro-organism (M) ratio:** It is also called organic loading

$$\frac{F}{M} = \frac{\text{kg of BOD applied per day}}{\text{Kg of MLSS in aeration tank}} = \frac{Q \cdot Y_i}{V \cdot x_t}$$

   - Lower the F/M ratio, higher the BOD removal in plant.

4. **Mean cell residence time:** It is the average time for which particles of suspended solids remain under aeration.
5. **Sludge volume index (SVI):** It is the volume occupied in ml by one gram of solids in a mixed liquor after settling for 30 minutes.

$$\boxed{\text{SVI} = \frac{\text{Volume of Sludge settle in ml}}{\text{MLSS in gm}}}$$

Example 6

A completely mixed active sludge process is used to treat a waste water flow of 2 million litres per day 2 MLD having a BOD_5 of 300 mg/lit. The biomass concentration in the aeration tank in 1500 mg/lit and the concentration of net biomass leaving system is 100 mg/lit. The aeration tank has volume of 200 m^3. The hydraulic retention time of the waste water in aeration tank is

(A) 0.2 hour (B) 4.8 hours
(C) 10 hours (D) 2.4 hours

Solution

Hydraulic retention time

$$= \frac{\text{Volume of aeration tan}\,k}{Q}$$

$$Q = 2\text{ MLD} = 2 \times 41.66\text{ m}^3\text{/hr} = 83.32$$

$$\Rightarrow \frac{200}{83.32} = 2.4\text{ hours.}$$

Trickling Filters

Trickling filters are commonly used secondary treatment of sewage and treatment of industrial wastes also. They are also known as **sprinkling** or **percolating** filters. **Trickling** filters are of two types namely:

1. Conventional or low rate trickling filters
2. High rate trickling filters

Low rate trickling filters	High rate trickling filters
Purification of sewage is brought about by aerobic bacteria which form a bacterial film around the particles.	Purification of sewage is brought by aerobic bacteria same as low rate trickling filters.
The size of filter media is 25–75 mm stone aggregate and depth of filter is 2–3 m.	Size and depth of filter media are same as low rate trickling filters
BOD removal efficiency is 7580%	BOD removal efficiency is 80–95%
Nuisance of psychoda fly is found in this type of filters	Nuisance of psychoda fly is very less due to recirculation
Filtration gets clogged due to growth of algae and fungi which is known as ponding. It can be prevented by adding chlorine or copper sulphate	Recirculation of sewage helps in reducing the ponding
Efficiency, $\eta = \frac{\text{BOD removed}}{\text{BOD applied}} \times 100$ $= \frac{100}{1 + 0.0044\sqrt{u}}$, u = organic loading in kg/ha m/day	Efficiency $\eta = R/I$ It is the ratio of volume of sewage (R) to volume of raw sewage

Example 7

Find the influent BOD of standard trickling filter if the diameter is 39.5 m, desired effluent BOD is 20 mg/lit, to handle 2 MLD of waste water. Assume depth = 3 m and organic loading = 0.245 ha/m.

Solution

$$\eta = \frac{y_i - y_e}{y_i} \times 100 = \frac{100}{1+0.0044\sqrt{\frac{Qy_i}{VF}}}$$

$$\eta = \frac{x-20}{x} \times 100 = \frac{100}{1+0.0044\sqrt{\frac{2\times x}{VF}}}$$

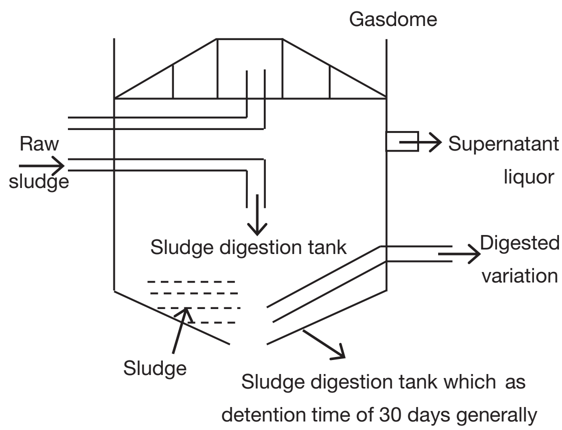
$$1 + 0.0044\sqrt{\frac{2\times x}{0.245}} = \frac{x}{x-20}$$

On solving we get

Initial BOD $y_i = 150$ mg/lit.

Sludge Digestion

Sludge drawn from sedimentation tank is decomposed in sludge digestion process. In this process 40–60% of organic solids are converted into CO_2, CH_4 (anaerobically). It generally takes $4\frac{1}{2}$ months for better sludge decomposition.



There are 3 stages of sluge decomposition:

Acid fermentation

↓

Acid regression

↓

Alkaline fermentation

1. **Acid fermentation:** It is acidic in nature.
2. **Acid regression:** In this stage scum forms at the top due to trapping of gases.
3. **Alkaline fermentation:** In this stage the BOD falls rapidly and large volume of methane gas along with small amount of other gases are evolved.

Factors Affecting Sludge Digestion

- **Temperature:** Temperature is directly proportional to the sludge digestion. The more the temperature, the more is sludge digestion. The optimum temperature is 29°C.
- **pH value:** As the pH value increases the alkaline conditions prevail and the sludge digestion increases. The optimum pH value is 7.2–7.4.
- **Seeding with digested sludge:** Proper seeding will always help in the digestion of sludge.
- **Mixing and stirring of raw sludge with digested sludge:** The more thorough mixing of the digested sludge with raw sludge, the better is the decomposition.

$$\boxed{V_1(100 - P_1) = V_2(100 - P_2)}$$

Where

V_1 = Volume of sludge at moisture content of P_1%

V_2 = Volume of sludge at moisture content of P_2%

Sludge from sedimention tank has 95% moisture content. Secondary sludge from trickling filter has 96–98% moisture content.

Example 8

The moisture content of sludge is reduced from 97%–93% in a sludge digestion tank. The percentage decrease in volume of sludge is ______.

Solution

$$V_2 = \frac{(100-P_1)}{(100-P_2)} V_1$$

$$= \left(\frac{100-97}{100-93}\right) \times V_1$$

$$= 0.25\text{V}_1$$

∴ Percentage decrease in volume

$$= \frac{V_1 - V_2}{V_1} \times 100$$

$$\frac{V_1 - 0.25V_1}{V_1} \times 100 = 75\%.$$

$$\boxed{\text{Volume of sludge digester} = \left(\frac{V_f + V_d}{2}\right)}$$

Where

V_f = Volume of fresh sludge added per day

V_d = Volume of digested sludge added per day

t = Digesting period

$$V_f = \left(\frac{100}{100-P_1}\right) \times \frac{M}{\rho_f}$$

$$V_d = \left(\frac{100}{100 - P_2}\right) \times \frac{M}{\rho_d}$$

$\rho_f = s_f \times \rho_w$

= Specific gravity of fresh sludge × Density of water

$\rho_d = s_d \times \rho_w$

= Specific gravity of digested sludge × Density of water

M = Mass of solids in sludge in kg/day

Example 9

The quantity Q = 20 MLD, SS in waste water flow = 200 mg/lit

Percentage of SS removed from clarifier = 80

Moisture content of fresh sludge P_1 = 98%

Moisture content of digested sludge 3 = 90%

Specific gravity of fresh sludge = 1.06

Specific gravity of digested sludge = 1.02

Digestion period = 50 days

Find the capacity of the digester.

Solution

$$M = 20 \times 200 \times \frac{80}{100}$$

$$= 32 \text{ kg/day}$$

$$\rho_f = 1.06 \times 1000 = 1060 \text{ kg/m}^3$$

$$\rho_w = 1.02 \times 1000 = 1020 \text{ kg/m}^3$$

$$V_f = \frac{100}{100 - P_1} \times \frac{M}{\rho_f}$$

$$= \frac{100}{100 - 98} \times \frac{320}{1060} = 15.094 \text{ m}^3\text{/day}$$

$$V_d = \frac{100}{100 - P_2} \times \frac{M}{\rho_d}$$

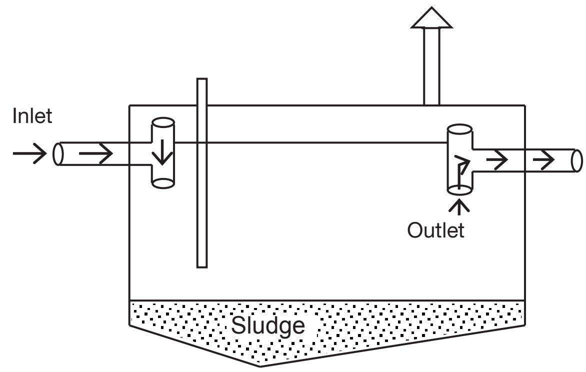
$$= \frac{100}{100 - 90} \times \frac{320}{1020} = 3.132 \text{ m}^3\text{/day}$$

$$\text{Capacity of digester} = \left[\frac{V_f + V_d}{2}\right] \times t$$

$$= \left[\frac{15.094 + 3.13^2}{2}\right] \times 50 = 455.65 \text{ m}^3.$$

Septic Tank

Septic tank is the primary sedimentation tank which is generally provided in areas where sewers have not been laid and for isolated communities, schools, hospitals, other public institution etc. The detention period of septic tank is 12–36 hours generally. It works on the principle of anaerobic decomposition. Septic tank removes 60–70% of the dissolved matter. The effluents from the septic tank are disposed-off into the sub-surface irrigation or in cess pools or soak pits.



Design Details

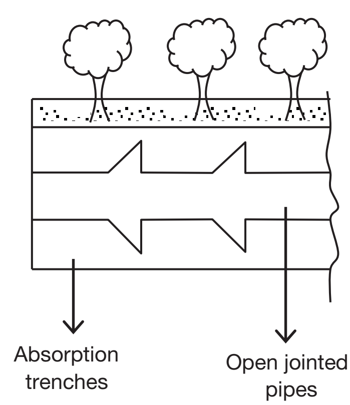
Capacity of tank = Sewage stored in detention time + Volume of sludge stored during period of cleaning.

If only water closets are connected to the septic tank, the sewage flow will be about 40 to 70 lit/capita/day. The period of cleaning 6 months to 3 years. The detention time is 12–36 hours.

The effluent of septic tank has BOD of 100 to 200 mg/lit. The free board is 0.3 m and length to width ratio L/B is 2 to 3 m.

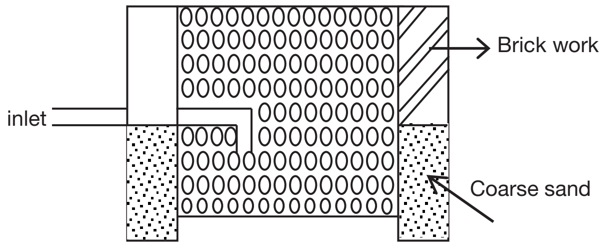
Methods of Septic Tank Effluent Disposal

1. **Sub-surface irrigation methods using absorption trenches:**

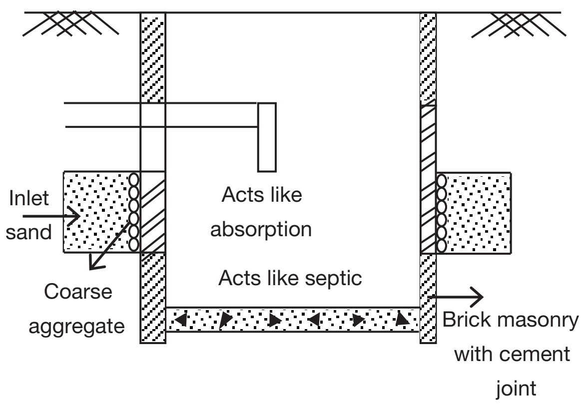


Suspended organic matter present in effluent will be absorbed in absorption trench filled with gravel.

2. **Soak pit:** The effluent is allowed to be soaked or absorbed into the surrounding soil. It is filled with gravel brick, etc.



3. **Cess pool:** The top portion acts as a absorption trench and bottom portion acts as a septic tank. It is used when sub-soil is porous and when there is no well nearby.



Example 10

The width of the septic tank for the following data is

Number of people = 200

Sewage/capita/day = 110 lit

De-sludging period = 1 year

L : B = 4 : 1, Detention time = 36 hours

Sludge accumulation rate = 30 lit/person/year

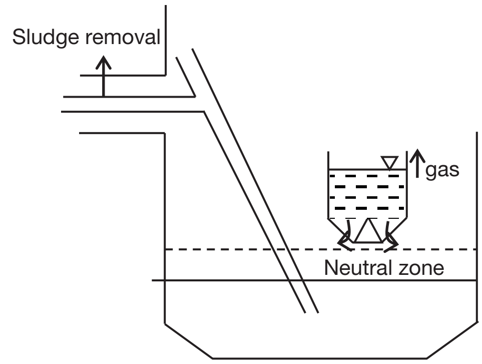
Depth of the tank = 1.5 m

Percolating capacity = 1250 lit/m^3/day

Solution

$$\text{Sewage flow rate} = 110 \times 200$$
$$= 22000 \text{ lit/day} = 0.91 \text{ m}^3\text{/h}$$
$$\text{Sludge accumulation rate} = 200 \times 30$$
$$= 6000 \text{ lit/year} = 6 \text{ m}^3\text{/year}$$
$$\text{Volume} = Q \times D_t + q_{SL} \times t_c$$
$$= (0.91 \times 36) + (6 \times 1)$$
$$= 38.76 \text{ m}^3$$
$$V = L \times B \times D$$
$$38.76 = 4B \times B \times 1.5$$
$$B = 2.54 \text{ m} \Rightarrow L = 10.166 \text{ m.}$$

4. **Imhoff tank:** It is an improvement to septic tank, in which sewage is not allowed to get mixed with sludge produced, depth of the tank is more and it is costlier to construct. It is an anaerobic unit. The upper chamber is used for sedimentation of solids and the lower chamber is meant for digestion and storage.



Imhoff tank

Oxidation Ponds

Oxidation pond is the modified form of extended aeration of activated sludge process. This is an open flow through earthen basin specifically designed for treating sewage with the combined action of algae and aerobic bacteria.

Advantages

1. These ponds require low initial cost and low operation cost.
2. They are able to withstand both organic and hydraulic shock loads.
3. They can be easily redesigned and reconstructed for any alteration in the degree of treatment.

Disadvantages

1. It requires more land.
2. Maintaining effluent standard of 30 mg/lit suspend solids is difficult.
3. Expansion of city may encroach the pond.

Principle of Oxidation Ponds

Stabilization of organic matter is carried out by combined action of algae and other micro-organisms by symbolic relationship.

Symbolic relationship exists between algae and micro-organisms in the sense, algae produce oxygen while growing in the presence of sunlight and that oxygen is utilized by micro organisms.

Design Criteria

1. Organic loading for hot countries: 150–300 kg/ha/day.
2. Organic loading for cold countries: 60–90 kg/has/day.
3. Each unit has an area of 0.5–1 ha
4. Depth may be kept between 1–1.5 m
5. Detention time: 20–30 days
6. Removal of BOD is up to 90%

Example 11

The detention time of an oxidation pond for residential colony with 2500 persons contributing sewage at 120 lit/capita/day. The 5 day BOD of sewage is 300 ppm. The organic loading is 300 kg/ha/day.

Assume, $L : B = 1 : 2$, if depth of pond is 1 m.

Solution

$$Q = \text{Population} \times \text{Per capita sewage flow}$$

$$= 2500 \times 120$$

$$= 3 \times 10^5 \text{ lts/day} = 0.3 \text{ MLD}$$

$$\text{Surface area of pond} = \frac{\text{QV}}{\text{OLD}}$$

$$= \frac{0.3 \times 300}{300}$$

$$= 0.3 \text{ Ha}$$

$$L \times B = 0.3 \times 10^4 \text{ m}^3$$

$$L = 2B \therefore B = \sqrt{\frac{0.3 \times 10^4}{2}}$$

$$L = 38.72 \text{ m}$$

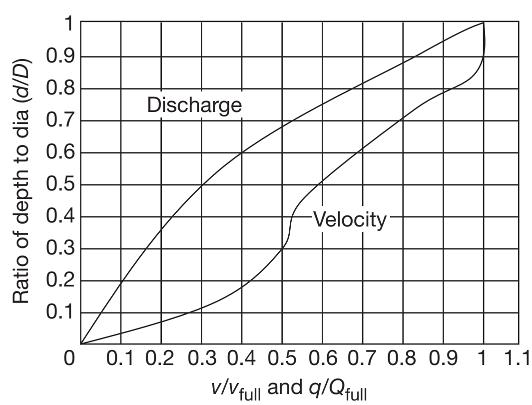
$$\text{Detention time} = \frac{\text{Volume}}{Q}$$

$$= \frac{0.3 \times 10^4 \times 1}{\frac{0.3 \times 10^6}{10^3}}$$

$$= 10 \text{ days.}$$

Exercises

1. At the same mean velocity, the ratio of head loss per unit length for a sewer pipe flowing full to that for the same pipe flowing half-full would be
   (A) 2.0 (B) 1.63
   (C) 1.00 (D) 0.61
2. An inverted siphon is a
   (A) device for distributing septic tank effluent to a soil absorption system.
   (B) device for preventing overflow from elevated water storage tank.
   (C) device for preventing crown corrosion of sewer.
   (D) section of sewer which is dropped below the hydraulic grade line in order to avoid an obstable.
3. A circular sewer 2 m diameter has to carry a discharge of 2 m^3/s when flowing nearly full. What is the minimum required slope to initiate the flow? (Assume Manning's $n = 0.015$)
   (A) 0.00023 (B) 0.000036
   (C) 0.000091 (D) 0.000014
4. An existing 300 mm diameter circular sewer is laid at a slope of 1 : 280 and carries a peak discharge of 1728 m^3/d. Use the partial flow diagram shown in the figure and assume Manning's n = 0.015. At the peak discharge, the depth of flow and the velocity are, respectively.



Partial flow diagram for a circular sewer

   (A) 45 mm and 0.28 m/s
   (B) 120 mm and 0.50 m/s
   (C) 150 mm and 0.57 m/s
   (D) 300 mm and 0.71 m/s
5. Determine the correctness or otherwise of the following Assertion (A) and Reason (R).
   Assertion (A): The crown of the outgoing larger diameter sewer is always matched with the crown of incoming smaller diameter sewer.
   Reason (R): 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 correct reason for (A).
(C) Both (A) and (R) are false.
(D) (A) is true but (R) is false.

6. The BOD_5 of a surface water sample is 200 mg/lit at 20°C. The value of the reaction constant is $K = 0.2$/day with base 'e'. The ultimate BOD of the sample is
(A) 126 mg/lit (B) 544 mg/lit
(C) 146 mg/lit (D) 316 mg/lit

7. Standard 5 day BOD of a waste water sample is nearly x% of the ultimate BOD, where x is
(A) 48 (B) 58
(C) 68 (D) 78

8. The BOD removal efficiency, in percentage, during primary treatment under normal conditions is about
(A) 65% (B) 85%
(C) 30% (D) zero

9. If the BOD_5 of waste is 150 mg/lit and the reaction rate constant (to the base 'e') at 20°C is 0.35/day, the ultimate BOD in mg/lit is
(A) 97.5 (B) 181.5
(C) 212.9 (D) 230.5

10. In a domestic waste water sample, COD and BOD were measured. Generally which of following statement is true for their relative magnitude?
(A) COD = BOD
(B) COD > BOD
(C) COD < BOD
(D) Nothing can be said

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

Waste Water Volume, ml	Initial DO mg/lit	DO After 5 Day, mg/lit
5	9.2	6.9
10	9.1	4.4
50	8.4	0.0

Based on the data, the average BOD_5 of the waste water is equal to
(A) 139.5 mg/lit (B) 126.5 mg/lit
(C) 109.8 mg/lit (D) 72.2 mg/lit

12. In a BOD test using 5% dilution of the sample (15 ml of sample and 285 ml of dilution water), dissolved oxygen values for the sample and dilution water blank bottles after five days incubation at 20°C were 3.80 and 8.80 mg/lit, respectively. Dissolved oxygen originally present in the undiluted sample was 0.80 mg/lit. The 5 day 20°C BOD of the sample is
(A) 116 mg/lit (B) 108 mg/lit
(C) 100 mg/lit (D) 92 mg/lit

13. In a BOD test, 5 ml of waste is added to 295 ml of aerated pure water. Initial dissolved oxygen (DO) content of the diluted sample is 7.8 mg/lit, after 5 days of incubation at 20°C, the DO content of the sample is reduced to 4.4 mg/lit. The BOD of the waste water is
(A) 196 mg/lit (B) 200 mg/lit
(C) 204 mg/lit (D) 208 mg/lit

14. Consider a glucose solution ($C_6H_{12}O_6$) of molarity 1.75×10^{-3} that is completely oxidized to CO_2 and H_2O. Find the amount of oxygen required for this reaction. The chemical mass balance equation for the above reaction is given as:
$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$
(Atomic weight are: C = 12; H = 1; O = 16)

15. The dissolved oxygen (DO) in an unseeded sample of diluted waste having an initial DO of 9.5 mg/lit is measured to be 3.5 mg/lit after 5 days. The dilution factor is 0.03 and the reaction rate constant, $K = 0.22$/day (to the base 'e' in the decay curve at 30°C). Estimate:
(a) The 5 day BOD of the waste at 20°C
(b) Ultimate carbonaceous BOD

16. The theoretical oxygen demand of a 0.001 mol/lit glucose solution is
(A) 180 mg/lit (B) 192 mg/lit
(C) 90 mg/lit (D) 96 mg/lit

17. A waste water sample has an initial BOD of 222 mg/lit. The first order BOD decay coefficient is 0.4/day. The BOD consumed (in mg/lit) in 5 days is
(A) 150 (B) 192
(C) 30 (D) 50

18. Water samples (X and Y) from two different sources were brought to the laboratory for the measurement of dissolved oxygen (DO) using modified Winkler method. Samples were transferred to 300 ml BOD bottles. 2 ml of $MnSO_4$ solution and 2 ml of alkaliodide-azide reagent were added to the bottles and mixed. Sample X developed a brown precipitate, where as sample Y developed a white precipitate. In reference to these observations, the correct statement is:
(A) Both the samples were devoid of DO.
(B) Sample X was devoid of DO while sample Y contained DO.
(C) Sample X contained DO while sample Y was devoid DO.
(D) Both the samples contained DO.

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

(A) 4.9°C (B) 24.9°C
(C) 31.7°C (D) 35.0°C

20. The 5 day BOD of a waste water sample is obtained as 190 mg/lit (with $K = 0.01$/hour). The ultimate oxygen demand (mg/lit) of the sample will be
(A) 3800 (B) 475
(C) 271 (D) 190

21. In the design of storm sewers, 'time of concentration' is relevant to determine the
(A) rainfall intensity.
(B) velocity in the sewer.
(C) time of travel.
(D) area served by the sewer.

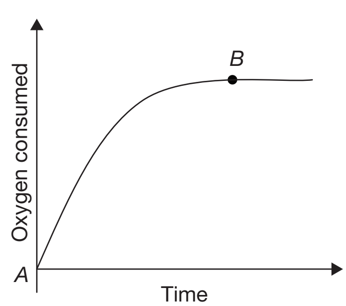
22. **Assertion (A):** Laterals of minimum specified diameter in sewerage system have to be laid at slopes designed for self-cleaning velocity.

Reason (R): For the specified minimum lateral diameter at specified slopes, a minimum flow rate is not essential to maintain self-cleansing velocity.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not a correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

23. The self-cleansing velocity in a sewer depends on:
I. BOD (soluble)
II. Slope of the sewer
III. Ratio of depth of flow sewage to sewer diameter ratio
(A) I, II and III (B) I and II only
(C) II and III only (D) I and III only

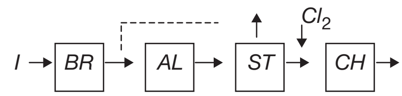
24. The correct statement of comparison of ultimate BOD, COD, Theoretical Oxygen Demand (ThOD) and 5-day BOD (BOD_5) is
(A) $BOD_u > COD > ThOD > BOD_5$
(B) $COD > ThOD > BOD_u > BOD_5$
(C) $ThOD > COD > BOD_u > BOD_5$
(D) $COD > BOD_u > BOD_5 > ThOD$

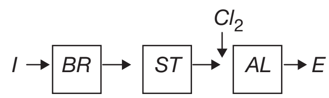
25. The following figure shows, BOD curve when the experiment was conducted at 20°C. If the experiment is conducted at 30°C, then the portion AB of the curve

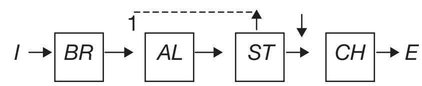


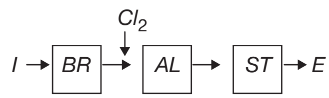
(A) shifts to the left (B) shifts to the right
(C) remains unchanged (D) shrinks

26. A typical biological process in treating waste water using aerated lagoon can be described by one of the following schematic diagrams

(A) 

(B) 

(C) 

(D) 

27. The unit in which both sedimentation and digestion processes of sludge take place simultaneously is
(A) skimming tank (B) imhoff tank
(C) detritus tank (D) digestion tank

28. In aerobic environment, nitrosomonas convert
(A) NH_3 to NO_2 (B) NO_2^- to NO_3
(C) NH_3 to N_2O (D) NO_2^- to HNO_3

29. A municipal waste treatment plants to work with average and peak loading rates of 4,000 and 8,000 m^3/day respectively. Design a primary clarifier to remove 65% suspended matter at average flow. An average overflow rate of 35 m^3/m^2 day is expected to correspond to 65% suspended matter removal efficiency. Obtain the diameter, side wall depth, detention time and calculate the overflow rate at peak condition.

Assume depth of flow = 3 m.

30. The following data are given for a channel type grit chamber of length 7.5 m.
I. Flow through velocity = 0.3 m/s
II. The depth of waste water at peak flow in the channel = 0.9 m
III. Specific gravity of inorganic particles = 2.5
IV. $g = 9.80$ m/s^2, $m = 1.002 \times 10^{-3}$

N–s/m^2 at 20°C r_w 1000 kg/m^3

Assuming that the Stokes law is valid, the largest diameter particle that would be removed with 100 per cent efficiency is
(A) 0.04 mm (B) 0.21 mm
(C) 1.92 mm (D) 6.64 mm

31. A circular primary clarifier processes an average flow 5005 m^3/d of municipal waste water. The overflow rate is 35 m^3/d. The diameter of clarifier shall be
(A) 10.5 m (B) 11.5 m
(C) 12.5 m (D) 13.5 m

32. Design a septic tank for a colony of 200 people. The colony is supplied water at a rate of 135 litres/person/day. Assume a detention period of 24 hours and 75% of the water becomes waste water. The tank is cleaned once in a year. The rate of deposition of sludge is 40 litres/person/years. Depth of tank is to be kept as 2.0 m. Provide a free board of 0.3 m. Length to breadth ratio may be kept as 3 : 1.

Direction for questions 33 and 34:

A conventional activated sludge plant treating 1000 m^3/d of municipal waste water disposes of its anaerobically digested sludge on relatively impervious farmland. Use the following data

I. Raw sewage.
SS = 225 mg/lit (70% volatile)
BOD = 190 mg/lit
(Excess activated sludge returned to primary)

II. Primary settling.
SS = 50% removal
BOD = 30% removal

III. Excess activated sludge.
0.4 g VSS produced per g BOD applied
(80% volatile of total)

IV. Anaerobic digester.
VSS reduced 50%
Digested sludge
Concentration = 60%
Sludge = Specific
Gravity = 1

V. Application farmland.
2m^3/ha.d

33. Total volatile suspended solid to be anaerobically digested (kg/d VSS) shall be
(A) 133 (B) 168
(C) 233 (D) 245

34. Area requirements (ha) for disposal of the sludge on farmland shall be
(A) 2.95 (B) 1.95
(C) 0.95 (D) 0.55

35. Match the following:

	List I		List II
P.	Thickening sludge	**1.**	Decrease in volume of sludge by chemical oxidation
Q.	Stabilization of sludge	**2.**	Separation of water by heat or chemical treatment
R.	Conditioning of sludge	**3.**	Digestion of sludge
S.	Reduction of sludge	**4.**	Separation of water by floatation or gravity

Codes:

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

36. A trickling filter is designed to remove
(A) settleable solids.
(B) colloidal solids.
(C) dissolved organic matter.
(D) None of these

37. Which of the following sewage treatment methods has inherent problems of odour, ponding, and fly nuisance?
(A) UASB system
(B) Activated sludge process
(C) Trickling filters
(D) Stabilization ponds

38. Chlorine is sometimes used in sewage treatment
(A) to avoid flocculation.
(B) to increase biological activity of bacteria.
(C) to avoid bulking of activated sludge.
(D) to help in grease separation.

39. Critical factors for the activated sludge treatment process are
(A) maximum hourly flow rate.
(B) maximum and minimum flow rate.
(C) maximum hourly flow rate and maximum daily organic load.
(D) minimum hourly flow rate and minimum daily organic load.

40. Bulking sludge refers to having
(A) $F/M < 0.3/d$ (B) $0.3/d < F/M < 0.6/d$
(C) F/M = zero (D) $F/M > 0.6/d$

41. An activated sludge aeration tank (length 30.0 m; width 14.0 m; effective liquid depth 4.3 m) has the following parameter:

Flow 0.0796 m^3, soluble BOD_5 after primary settling 130 mg/lit; mixed liquor suspended solids (MLSS) 2100 mg/lit; mixed liquor volatile suspended solids (MLVSS) 1500 mg/lit; 30 minute settled sludge volume 230 ml/gm; and return sludge concentration 9100 mg/lit. Determine the aeration period, food to micro organisms (F/M) ratio, sludge volume index (SVI) and return sludge rate.

42. Settling test on a sample drawn from aeration tank liquor of ASP (MLSS = 2800 mg/lit) was carried out with 1 litre sample. The test yielded a settled volume of 200 ml. The value of sludge volume index shall be
(A) 14.0 (B) 34.2
(C) 71.4 (D) 271

43. An analysis for determination of solids in the return sludge of activated sludge process was done as follows:
I. A crucible was dried to a constant mass of 62.485 g.
II. 75 ml of a well-mixed sample was taken in the crucible.

III. The crucible with the sample was dried to a constant mass of 65.020 g in a drying oven at 104°C.
IV. The crucible with the dried sample was placed in a muffle furnace at 600°C for an hour. After cooling, the mass of the crucible with residues was 63.145 g.

The concentration of organic fraction of solids present in the return sludge sample is
(A) 8800 mg/lit (B) 25000 mg/lit
(C) 33800 mg/lit (D) 42600 mg/lit

44. The data of an activated sludge process are as follows:
MLSS = 5000 mg/lit
Flow = 0.15 m^3/s
SS of inflow = 400 mg/lit
Solids settled after 30 min = 25%
Volume of aeration tank = 3000 m^3
Sludge wastage rate = 120 m^3/day with VSS of 15000 mg/lit.
Calculate sludge volume index (SVI), return sludge ratio (Q_1/Q) and mean cell residence time (θ_c).

45. Sewage treatment in an oxidation pond is accomplished primarily by
(A) algal bacterial symbiosis.
(B) algal photosynthesis only.
(C) bacterial oxidation only.
(D) chemical oxidation only.

46. From amongst the following sewage treatment options, largest land requirements for a given discharge will be needed for
(A) trickling filter. (B) anaerobic pond.
(C) oxidation ditch. (D) oxidation pond.

47. Maximum run-off will be obtained from the rain having a duration equal to time of concentration, and this is called the
(A) point rainfall intensity.
(B) time of equilibrium.
(C) one hour rainfall.
(D) critical rainfall duration.

48. A well oxidized sewage will contain
(A) nitrites and sulphur.
(B) more ammonia and H_2S but less nitrates and sulphates.
(C) less ammonia and H_2S but more nitrates and sulphates.
(D) H_2S, CO_2 and water.

49. Particles whose size is greater than 1 μm are
(A) colloidal solids. (B) suspended solids.
(C) settleable solids. (D) dissolved solids.

50. In determination of chemical oxygen demand, sewage is titrated with ferrous ammonium sulphate using potassium dichromate as oxidant in the presence of silver sulphate and mercuric sulphate as catalyst and inhibitor respectively. In this the excess amount of _______ left in sample after digestion is found.
(A) potassium dichromate
(B) ferrous ammonium sulphate
(C) mercuric sulphate
(D) oxygen

51. The degree and amount of treatment given to raw sewage before disposing off into river stream will depend upon:
I. Quantity of raw sewage only
II. Self purification capacity of river stream
III. Intended use of its water
(A) I, III (B) II only
(C) I, II, III (D) I only

52. Preliminary treatment reduce the BOD of the waste water by
(A) 5–10% (B) 10–20%
(C) 15–30% (D) 25–40%

53. The girt chambers of a sewage treatment plant normally need cleaning
(A) every hour. (B) everyday.
(C) every fortnight. (D) every year.

54. Activated sludge treatment plants are normally preferred for
(A) large sized cities.
(B) towns and smaller cities.
(C) medium sized cities.
(D) All of these

55. Prechlorination of sewage before it enters the sedimentation tank may help in
I. Controlling odour
II. Prevent flies in trickling filter
III. Assist in removal of grease
IV. Reduce bacterial count
(A) I and IV (B) I, II, III only
(C) II, III, IV only (D) All of these

56. In the final stage of sludge digestion, more resistant materials like proteins and organic acids are attacked and broken up by anaerobic bacteria called
(A) acid formers. (B) suspended culture.
(C) mesophilic organisms. (D) methane formers.

57. A river with a flow of 0.25 m^3/s receives waste water at a rate of 0.1 m^3/s. River has 8 mg/lit of DO with no BOD. The waste water with BOD 30 mg/lit having no DO disposed into it. If deoxygenating and reoxygenation constant are 0.36/day and 0.7/day respectively. Find the critical deficit (D_C) and distance at which it occurs on D/S of disposal of waste water?

Assume $(DO)_{saturation}$ = 9 mg/lit and velocity of flow in river = 0.4 m/s.
(A) D_C = 3.825 mg/lit at 30.96 km
(B) D_C = 3.4 mg/lit at 5 km
(C) D_C = 3.29 mg/lit at 30 km
(D) D_C = 2.8 mg/lit at 15 km

58. In a community of 1500 people water is supplied at 200 lit/head/day. If BOD produced is 40 g/head/day and BOD loading rate for oxidation pond is 20 kg/ha/day. (Assume depth of pond, $d = 2$ m and efficiency of pond as 80%).

Find the BOD of the effluent and whether it can be used for irrigation.

(A) 100 mg/lit and suitable for irrigation.
(B) 150 mg/lit and not suitable for irrigation.
(C) 75 mg/lit and not suitable for irrigation.
(D) 50 mg/lit and suitable for irrigation.

59. Following data pertaining to activated sludge process is given below:

Flow rate $Q = 12{,}000$ m^3/day
BOD of influent, $y_i = 280$ mg/lit
BOD of effluent, $y_e = 30$ mg/lit
X: MLSS concentration = 3000 mg/lit
X_u: MLSS in underflow = 10,000 mg/lit
X_e: MLSS in effluent = 0

If $\frac{F}{M} = 0.3$/day and $\theta_C = 12$ days. Find mass of solids wasted in kg/day.

(A) 1000 (B) 1120
(C) 1500 (D) 800

60. Find out the theoretical oxygen demand (in mg/lit) for glucose of 300 mg/lit present in waste waters if the following chemical reaction is given:

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

(A) 320 (B) 420
(C) 120 (D) 220

61. A population of 20,000 is residing in a town having an area of 60 hectares. Water supply per capita is 120 lit/day. If the average run-off coefficient of the area is 0.5 and time of concentration of design rain is 30 minutes, Calculate the discharge for which the sewers of a proposed combined system will be designed for the town. [Use rational method for run-off. Assume 80% of water supply as wastage and maximum sewage discharge as 3 × (Average discharge)]

(A) 1.67 m^3/s (B) 2.1 m^3/s
(C) 1.74 m^3/s (D) 0.06 m^3/s

62. Match List I with List II and select the correct answer using the code given:

	List I (Process)		List II (Biological Agent)
a.	Oxidation ditch	1.	Facultative bacteria
b.	Waste water stabilization	2.	Anaerobic bacteria
c.	Imhoff tank	3.	Suspended culture (Aerobic bacteria)
d.	Rotating biological contactors (RBC)	4.	Attached culture (Aerobic bacteria)

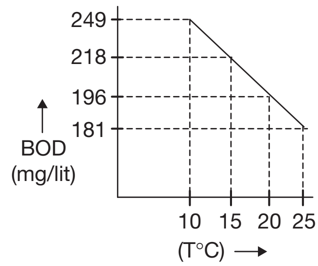
Codes:

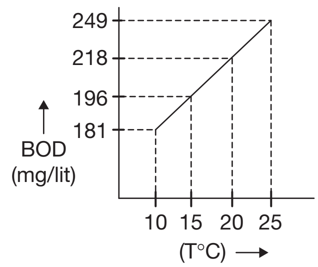
	a	b	c	d
(A)	4	1	2	3
(B)	3	1	2	4
(C)	1	2	3	4
(D)	3	4	1	2

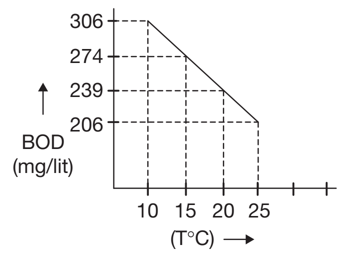
63. The sewage is flowing at 5 MLD from a primary clarifer to a standard rate trickling filter. The $y_5^{20°C} = 180$ mg/lit. The value of the adopted organic loading is to be 150 gm/m^3/day and surface loading 1500 lit/m^2/day. Calculate the efficiency of this filter unit.

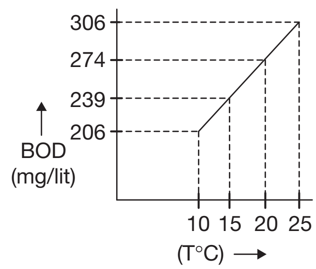
(A) 85.44% (B) 78.51%
(C) 80.03% (D) 69.91%

64. The 3 days 20°C BOD of a sample of sewage is 200 mg/lit. Draw a graph of 5 day BOD as a function of temperature in the range, 10°C to 25°C in steps of 5°C. Assume K_D at 20° $C = 0.1$

(A)


(B)


(C)


(D)


Direction for questions 65 and 66:

A completely mixed activated sludge process is used to treat a waste water flow of 2 MLD having a BOD at 5 days as 250 g/lit. The biomass concentration of aeration tank is 2100 mg/lit and the concentration of the net biomass leaving the system is 50 mg/lit. The aeration tank has a volume of 250 m^3.

65. What is the hydraulic retention time of the waste water in aeration tank? (in hours)
(A) 1 (B) 3
(C) 9 (D) 12

66. What is the average time for which the biomass stays in the system?
(A) 3.18 hours (B) 4.61 days
(C) 5.25 days (D) 8.21 hours

67. Match List I with List II

	List I		List II
P.	Grit chamber	1.	Zone settling
Q.	Secondary settling tank	2.	Stoke's law
R.	Activated sludge process	3.	Aerobic process
S.	Trickling filter	4.	Contact stabilization

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

68. **Statement I:** Nitrates are non-objectionable end products in aerobic treatment of sewage.
Statement II: Nitrates > 45 ppm cause nitrate poisoning in infants.
(A) I is true and II is false
(B) I is false and II is true
(C) Both I and II are true
(D) Both I and II are false

69. A sewer has a diameter of 250 mm and slope of 1 in 500. While running full it has a mean velocity of 0.8 m/s. If both diameter and slope are doubled, what will be the changed mean velocity when running half-full? (Use Manning's formula)
(A) 1.0 m/s (B) 1.2 m/s
(C) 1.6 m/s (D) 1.8 m/s

70. A combined sewer is serving 30,000 persons having BOD 80 gm per capita for day and 60,000 litres industrial effluent per day having BOD 500 mg/lit. If average standard BOD of domestic sewage is 0.09 kg/day/person. Find the population equivalent of sewage.
(A) 27,000 (B) 20,000
(C) 22,000 (D) 25,000

71. Match List I with List II:

	List I (Empirical Formula)		List II (Catchments)
P.	Inglis formula	1.	North India
Q.	Ryve's formula	2.	South India
R.	Nawab Jung Bahadur formula	3.	Old Bombay State
S.	Burge's formula	4.	Hyderabad Deccan
		5.	Based on Indian records

Codes:

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

72. Man hole covers are circular in shape to
(A) strengthen the cover.
(B) make entry convenient.
(C) for architectural reasons.
(D) prevent falling of cover into manhole.

73. The factors which affect the sludge digestion are:
I. Temperature
II. pH
III. Mixing and stirring of raw sludge
IV. Seeding of sludge
(A) I and II (B) II and III
(C) II, III, IV only (D) All of these

74. Primary clarifier used in waste water treatment follows ______ type of settling.
(A) type I settling (B) type II settling
(C) type III settling (D) type IV settling

75. The composition of a certain MSW sample and specific weight of its various components are given below.

Component	% by Weight	Specific Weight (kg/m^3)
Food waste	60	250
Dirt and Ash	20	400
Plastics	10	70
Wood and Yard waste	10	130

Specific weight (kg/m^3) of the MSW sample is
(A) 120 (B) 143
(C) 196 (D) 219

76. In a stream flowing at 6 m^3/s has no concentration of chemical. Industrial water is released into stream at 25 MLD with chemical concentration as 30 mg/lit. If rate of dissipation of impurities in stream is 0.13 mg/lit/h. Calculate the distance at which the chemical is removed completely from stream (velocity of stream is 0.3 m/s).
(A) 9.72 km (B) 11.47 km
(C) 8.61 km (D) 12.43 km

77. A sewage containing 300 mg/lit of suspended solids is passed through primary settling tank where 60% of suspended solids are removed. 70% of suspended solids are volatile. The solids from the primary settling tank are digested to recover the gas where volatile matter is reduced by 70%. Methane and CO_2 produced in the digestion of the sludge from 2000 m^3 of sewage are in 3 : 2 ratio. If the fuel value of methane is 36000 KJ/m^3. Find the fuel value of gas produced (Assume gas production is at the rate of 0.9 m^3/kg of volatile) in MKJ.
(A) 26.3 (B) 31.4
(C) 48.5 (D) 34.8

78. The minimum dissolved oxygen which should be present in water in order to save aquatic life is
(A) 1 ppm (B) 3 ppm
(C) 4 ppm (D) 6 ppm

79. If the moisture content of a sludge is reduced from 98% to 95%, the volume of sludge will decreased by _______.
(A) 30% (B) 40%
(C) 50% (D) 60%

80. If, bio-chemical oxygen demand (BOD) of a town is 2000 kg/day and BOD per capita per day is 0.05 kg, then population equivalent of town is _______.
(A) 20,000 (B) 40,000
(C) 50,000 (D) 60,000

81. If the efficiencies of BOD removal of first stage and second stage trickling filters are each 65%, then what is the overall BOD removal efficiency of these filters?
(A) 65% (B) 77.25%
(C) 87.75% (D) 92.60%

82. Match the following:

	List I		List II
a.	Steel pipe	**1.**	Highly resistant to corrosion but can break easily.
b.	Concrete pipe	**2.**	Virtually corrosion resistant.
c.	AC pipe	**3.**	Sulphite corrosion.
d	Vitrified clay pipe	**4.**	Electrolyte corrosion.

Codes:

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

83. A sample of waste water has 4 days 20°C BOD as 78% of the ultimate BOD. Then find the rate constant per day at 30°C.
(A) 0.4 (B) 0.5
(C) 0.6 (D) 0.7

84. 5 ml of raw sewage was diluted by 250 ml of water sample. The DO concentrations were found to be 3 mg/lit and 9 mg/lit for sewage and water samples respectively at the beginning of the test. Find the BOD (in mg/lit) of the mixed sample, if the DO of mixture is found as 6 mg/lit after 5-days incubation at 20°C.
(A) 144 mg/lit (B) 184 mg/lit
(C) 224 mg/lit (D) 239 mg/lit

85. A sewer of circular section having diameter of 1 m, laid at gradient of 1 in 500. Calculate the ratio of velocity of the flow, when sewer is running half full, and running full conditions.
(A) $\frac{1}{2}$ (B) $\frac{3}{2}$
(C) 1 (D) $\frac{2}{3}$

86. The domesitc sewage of a town is to be discharged into a stream after treatment. Determine the percentage purification required in the treatment plant, for the given particulars.
Population of town: 50,000
DWF of sewage: 150 litres per capita per day
BOD contribution per capita: 0.075 kg per day
Minimum flow of stream: 0.20 m^3/s
BOD of stream: 3 mg/lit
Maximum BOD of stream on down stream: 5 mg/lit
(A) 65%
(B) 85%
(C) 92%
(D) 98%

87. Settling test on a sample drawn from aeration tank liquor of ASP (MLSS = 2700 mg/lit) was carried out with 1 litre sample. The test yielded a settled volume of 180 ml. The value of slude volume index, SVI will be _______.
(A) 15
(B) 33.33
(C) 66.66
(D) 72.84

88. 50 g of CO_2 and 25 g of CH_4 are produced from the decomposition of municipal solid waste (MSW) with a formula weight of 120 g. What is the per capita CO_2 production per day in a city of 1 million people with a MSW production rate of 500 ton/day?
(A) 208 g/day (B) 313 g/day
(C) 120 g/day (D) 412 g/day

89. Fresh sludge has moisture content of 99%, after thickening its moisture content is reduced to 94%. The reduction in the volume of sludge for same gravity will be _______.
(A) 75% (B) 83%
(C) 89% (D) 92%

90. The MLSS concentration in the aeration tank of activated sludge process is 4000 mg/lit. If one litre of sample settles in 30 min, and the measuring cylinder showed a sludge volume of 250 ml, then the SVI (in ml/gm) would be ________.
(A) 42.5 (B) 62.5
(C) 82.5 (D) 132.5

91. Match List I (Treatment units) with List II (Type of process) and select the correct answer using the codes given:

	List I		List II
a.	Tricking filter	**1.**	Symbiotic
b.	Activated sludge	**2.**	Extended aeration
c.	Oxidation bitch	**3.**	Suspended growth
d.	Oxidaton pond	**4.**	Attached growth

Codes:

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

92. If the moisture content of sludge is reduced from 98% to 96%, the volume of sludge will decrease by

(A) 2% (B) 20%
(C) 25% (D) 50%

93. Match List I (Water/wastewater treatment) with List II (Operating problem) and select the correct answer using the codes given:

	List I		List II
a.	Tricking filter	1.	Negative head
b.	Activated sludge process	2.	Fly-breeding
c.	Rapid gravity filter	3.	Sludge bulking
d.	Anaerobic sludge digester	4.	pH reduction

Codes:

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

94. The different actions that take place in anaerobic decomposition process are

I. Alkaline fermentation
II. Acid fermentation
III. Acid regression
IV. Methane formation

What is the correct sequence of these actions (from earlier to later)?

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

Previous Years' Questions

Direction for questions 1 and 2:

A completely mixed activated sludge process is used to treat a waste water flow of 1 million litres per day (1 MLD) having a BOD_5 of 200 mg/lit. The biomass concentration in the aeration tank is 2000 mg/lit and the concentration of the net biomass leaving the system of 50 mg/lit the aeration tank has a volume of 200 m^3. **[GATE, 2007]**

1. What is the hydraulic retention time of the waste water in aeration tank?

(A) 0.2 hour (B) 4.8 hours
(C) 10 hours (D) 24 hours

2. What is the average time for which the biomass stays in the system?

(A) 5 hours (B) 8 hours
(C) 2 days (D) 8 days

3. A aerobic reactor receives waste water at a flow rate of 500 m^3/d having a COD of 2000 mg/lit. The effluent COD is 400 mg/lit. Assuming that waste water contains 80% biodegradable waste, the daily volume of methane produced by the reactor is **[GATE, 2009]**

(A) 0.224 m^3 (B) 0.280 m^3
(C) 224 m^3 (D) 280 m^3

4. Match the following: **[GATE, 2009]**

	List I		List II
P.	Grit chamber	1.	Zone settling
Q.	Secondary settling tank	2.	Stoke's law
R.	Activated sludge process	3.	Aerobic
S.	Trickling filter	4.	Contact stabilization

Codes:

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

5. If the BOD_3 of a waste water sample is 75 mg/lit and reaction rate constant K (base e) is 0.345 per day, the amount of BOD remaining in the given sample after 10 days is **[GATE, 2010]**

(A) 3.21 mg/lit (B) 3.45 mg/lit
(C) 3.69 mg/lit (D) 3.92 mg/lit

Direction for questions 6 and 7:

The sludge from the aeration tank of the activated sludge process (ASP) has solids content (by weight) of 2%. This sludge is put in a sludge thickener, where sludge volume is reduced to half. Assume that the amount of solids in the supernatant from the thickener is negligible, the specific gravity of sludge solids is 2.2 and the density of water is 1000 kg/m^3. **[GATE, 2011]**

6. What is the density of the sludge removed from the aeration tank?

(A) 990 kg/m^3 (B) 1000 kg/m^3
(C) 1011 kg/m^3 (D) 1022 kg/m^3

7. What is the solids content (by weight) of the thickened sludge?

(A) 3.96% (B) 4.00%
(C) 4.04% (D) 4.10%

8. **Assertion (A):** At a manhole, the crown of 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 **[GATE, 2012]**

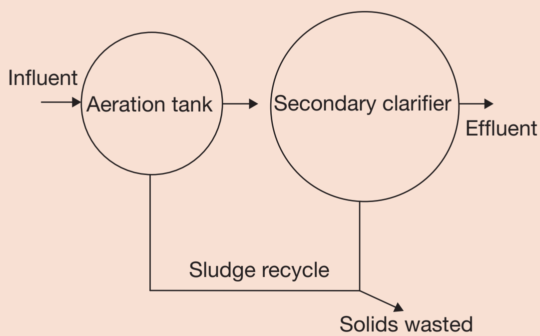
(A) Both (A) and (R) are true and (R) is the correct reason for (A).
(B) Both (A) and (R) are true bur (R) is not the correct reason for (A).
(C) Both (A) and (R) are false.
(D) (A) is true but (R) is false.

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 unreacted amount of **[GATE, 2012]**

(A) mercuric sulphate
(B) potassium dichromate
(C) silver sulphate
(D) sulphuric acid

Direction for questions 10 and 11:

An activated sludge system (sketched below) is operating at equilibrium with the following information waste water related data:



Flow rate = 500 m^3/h, influent BOD = 150 mg/lit, effluent BOD = 10 mg/lit. Aeration tank related data: hydraulic retention time = 8 hours, mean cell residence time = 240 hours, volume = 4000 m^3, mixed liquor suspended solids = 2000 mg/lit. **[GATE, 2012]**

10. The food to biomass (F/M) ratio (in kg BOD per kg biomass per day) for the aeration tank is

(A) 0.015
(B) 0.210
(C) 0.225
(D) 0.240

11. The mass (in kg/day) of solids wasted from the system is

(A) 24000 (B) 1000
(C) 800 (D) 33

12. A student began experimenting 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/lit. What would be the 5 day 20°C BOD (in mg/lit)? Assume values of BOD rate constant (K) at standard temperature of 20°C as 0.23/day (base e). **[GATE, 2013]**

13. The amount of CO_2 generated (in kg) while completely oxidizing one kg of CH_4 to the end products is ______. **[GATE, 2014]**

14. The dominating micro-organisms in an activated sludge process reactor are **[GATE, 2014]**

(A) aerobic heterotrophs
(B) anaerobic heterotrophs
(C) autotrophs
(D) phototrophs

15. 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 uncompacted SW is 1000 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 ______. **[GATE, 2015]**

16. In a waste water treatment plant, primary sedimentation tank (PST) designed at an overflow rate of 32.5 m^3/day/m^2 is 32.5 m long, 8.0 m wide and liquid depth of 2.25 m. If the length of the weir is 75 m, the weir loading (in m^3/day/m) is ______. **[GATE, 2015]**

17. Crown corrosion in a reinforced concrete sewer is caused by **[GATE, 2016]**

(A) H_2S (B) CO_2
(C) CH_4 (D) NH_3

18. Match the items in List I with those in List II and choose the right combination. **[GATE, 2016]**

List- I	List II
P. Activated sludge process	**1.** Nitrifiers and denitrifiers
Q. Rising of sludge	**2.** Autotrophic bacteria
R. Conventional nitrification	**3.** Heterotrophic bacteria
S. Biological nitrogen removal	**4.** Denitrifiers

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

19. Effluent from an industry 'A' has a pH of 4.2. The effluent from another industry 'B' has double the hydroxyl (OH^-) ion concentration than the effluent from industry 'A'. pH of effluent from the industry 'B' will be ______. **[GATE, 2016]**

20. The 2-day and 4-day *BOD* values of a sewage sample are 100 mg/lit and 155 mg/lit, respectively. The value of *BOD* rate constant (expressed in per day) is ______. **[GATE, 2016]**

21. For a waste water sample, the three-day biochemical oxygen demand at incubation temperature of 20°C (BOD 3 day, 20°C) is estimated as 200 mg/lit. Taking the value of the first order BOD reaction rate constant as 0.22 day^{-1}, the five-day BOD (expressed in mg/lit) of the waste water at incubation temperature of 20°C (BOD5day, $_{20°C}$) would be _________. **[GATE, 2016]**

Answer Keys

Exercises

1. C	**2.** D	**3.** A	**4.** C	**5.** A	**6.** D	**7.** C	**8.** C	**9.** B	**10.** B
11. A	**12.** D	**13.** C	**14.** 1.86×10^{-3}		**15.** (a) 200 mg/lit (b) 400 mg/lit			**16.** B	**17.** B
18. C	**19.** D	**20.** C	**21.** A	**22.** B	**23.** C	**24.** B	**25.** A	**26.** C	**27.** B
28. A	**29.** 70.7	**30.** B	**31.** D	**32.** B = 2.35 m; L = 7.06 m			**33.** A	**34.** B	**35.** C
36. C	**37.** C	**38.** C	**39.** C	**40.** A	**41.** 6.3 hours; 0.33 d^{-1}; 109.5 ml/gm; 0.0238 m^3/s				
42. C	**43.** B	**44.** 38.5	**45.** A	**46.** D	**47.** D	**48.** C	**49.** B	**50.** A	**51.** C
52. C	**53.** C	**54.** A	**55.** B	**56.** D	**57.** A	**58.** D	**59.** B	**60.** A	**61.** C
62. B	**63.** A	**64.** D	**65.** B	**66.** C	**67.** B	**68.** C	**69.** D	**70.** A	**71.** D
72. B	**73.** D	**74.** C	**75.** C	**76.** B	**77.** D	**78.** C	**79.** D	**80.** B	**81.** C
82. B	**83.** C	**84.** A	**85.** C	**86.** D	**87.** C	**88.** A	**89.** B	**90.** B	**91.** D
92. D	**93.** B	**94.** B							

Previous Years' Questions

1. B	**2.** D	**3.** D	**4.** D	**5.** C	**6.** C	**7.** B	**8.** B	**9.** B	**10.** C
11. C	**12.** 128.0 to 128.5		**13.** 2.75	**14.** A	**15.** 13.6875	**16.** 112.66	**17.** A	**18.** A	**19.** 4.5
20. 0.299	**21.** 276.19								