CHAPTER 03

Disposing of the Sewage Effluents

INTRODUCTION

The study of the sources of disposal is important, because the amount of treatment required to be given to sewage depends very much upon the source of disposal, its quality and capacity to tolerate the impurities present in the sewage effluents, without itself getting potentially polluted or becoming less useful.

There are two ways of disposing of the sewage effluents

(a) Dilution i.e. disposal in water

(b) Effluent Irrigation or Broad Irrigation or Sewage Farming i.e. disposal on land.

Disposal by dilution is more common of these two methods.

3.1 Disposal by Dilution

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

3.1.1 Condition Favouring Disposal by Dilution

The sewage can favourably be adopted under the following conditions:

(i) When sewage is comparatively fresh (4 to 5 hour old)

(ii) When the diluting water has a high dissolved oxygen (D.O) content.

(iii) Where diluting waters are not used for the purpose of navigation.

(iv) Where the flow currents of the diluting waters are favourable, causing no deposition, nuisance or destruction of aquatic life.

(v) When the outfall sewer of the city or the treatment plant is situated near some natural waters having large volumes.

3.1.2 Standards of Dilution for Discharge of Wastewaters into Rivers

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

Table: 3.1 Standards of Dilution Based on Royal Commission Report	
Dilution factor	**Standards of purification required**
Above 500	No treatment is required. Raw sewage can be directly discharged into the volume of dilution water.
Between 300 to 500	Primary treatment such as plain sedimentation should be given to sewage, and the effluents should not contain suspended solids more than 150 ppm.
Between 150 to 300	Treatments such as sedimentation, screening and essentially chemical precipitation are required. The sewage effluent should not contain suspended solids more than 60 ppm.
Less than 150	Complete thorough treatment should be given to sewage. The sewage effluent should not contain suspended solids more than 30 ppm, and its 5 days B.O.D. at 18.3°C should not exceed 20 ppm.

The Bureau of Indian Standard (BIS) has laid down its guiding standards of sewage effluents, vide IS 4764 : 1973 and for industrial effluents vide IS 2490 : 1974 as shown in table

Table: 3.2 BIS (ISI) Standards for Discharge of Sewage and Industrial Effluents in Surface Water Sources and Public Sewers

S. No	Characteristic of the Effluent	Tolerance limit for Sewage Effluent discharged into Surface Water Sources, as per IS4764-1973	Tolerance Limit for Industrial effluents discharged into	
			Inland surface waters, as per IS 2490-1974	Public sewers as per IS 3306 - 1974
(1)	(2)	(3)	(4)	(5)
1.	BOD_5	20 mg/l	30 mg/l	500 mg/l
2.	COD	—	250 mg/l	—
3.	pH value	—	5.5 to 9.0	5.5 to 9.0
4.	Total Suspended Solids (TSS)	30 mg/l	100 mg/l	600 mg/l
5.	Temperature	—	40°C	45°C
6.	Oil and grease	—	10 mg/l	100 mg/l
7.	Sulphides (as S)	—	2 mg/l	—
8.	Fluorides (as F)	—	2 mg/l	—
9.	Total residual chlorine	—	1 mg/l	—

3.2 Dilution in Rivers and Self Purification of Natural Streams

When sewage is discharged into a natural body of water, the receiving water gets polluted due to waste products, present in sewage effluents. But the conditions do not remain so forever, because the natural forces of purification, such as dilution, sedimentation, oxidation reduction in sun light, 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 the self purification phenomena.

The various natural forces of purification which help in effecting self-purification process are as below:

1. Physical forces are
   (i) Dilution and dispersion (ii) Sedimentation (iii) Sunlight
2. Chemical forces aided by biological forces are
   (i) Oxidation (Bio) (ii) Reduction

3.2.1 Dilution and Dispersion

- This result in diminishing the concentration of organic matter, and thus reduces the potential nuisance of sewage.
- When sewage of concentration C_S flow at a rate Q_S into a river stream with concentration C_R flowing at a rate Q_R, the concentration C of the resulting mixture is given by,

$$C_SQ_S + C_RQ_R = C(Q_S + Q_R)$$

or

$$C = \frac{C_SQ_S + C_RQ_R}{Q_S + Q_R}$$

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

Example 3.1 In a certain situation, waste water discharged into a river mixes with the river water instantaneously and completely. Following is the data available:

Waste water DO = 2.00 mg/L
Discharge rate = 1.10 m³/s
River water DO = 8.3 mg/L
Flow rate = 8.70 m³/s
Temperature = 20°C

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

Ans. (c)

$$DO_{mix} = \frac{Q_V DO_V + Q_R DO_R}{Q_V + Q_R} = \frac{(1.10 \times 2.00) + (8.70 \times 8.3)}{1.10 + 8.70} = 7.6 \text{ mg/L}$$

Example 3.2 The treated domestic sewage of a town is to be the discharged in a natural stream. Calculate the percentage purification required in the treatment plant with the following data.

(i) Population = 50,000
(ii) BOD contribution per capita = 0.07 kg/day
(iii) BOD of stream on U/S side = 3 mg/l
(iv) Permissible maximum BOD of stream on downstream side = 5 mg/l
(v) Dry weather flow of sewage = 140 litres per capita per day
(vi) Minimum flow of stream = 0.13 m³/s

Solution:

$$\text{Population} = 50000$$

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

$$\text{Total BOD per day} = 0.07 \times 50000 = 3500 \text{ kg/day}$$

$$\text{Sewage discharge} = \frac{140 \times 50000}{86400} \, l/\text{sec} = 0.081 \text{ m}^3/\text{s}$$

$$\text{BOD of the mix} = 5 \text{ mg}/l$$

$$\text{BOD of the river} = 3 \text{ mg}/l$$

Let BOD of treated sewage be C_S

we know that

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

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

$$C_S = 8.21 \text{ mg}/l$$

$$\text{BOD of untreated sewage} = \frac{3500 \times 10^6 \text{ mg/d}}{50000 \times 140 \, l/\text{d}} = 500 \text{ mg}/l$$

$$\text{Percentage treatment required} = \frac{500 - 8.21}{500} = 98.358\%$$

Example 3.3 **A waste water effluent of 560 l/s with a BOD = 50 mg/l, DO = 3.0 mg/l and temperature of 23°C enters a river where the flow is 28 m^3/sec, and BOD = 4.0 mg/l, DO = 8.2 mg/l, and temperature of 17°C. k_1 of the waste is 0.10 per day at 20°C. The velocity of water in the river downstream is 0.18 m/s and depth of 1.2 m. Determine the following after mixing of waste water with the river water.**

(i) Combined discharge **(ii) BOD**

(iii) DO and **(iv) Temperature**

Solution:

Particulars of Sewage thrown

$$Q_s = 560 \, l/\text{s} = 0.56 \text{ m}^3/\text{sec}$$

Concentrations (C_S)

$$\text{BOD} = 50 \text{ mg}/l$$

$$\text{DO} = 3.0 \text{ mg}/l$$

$$\text{Temperature} = 23^\circ\text{C}$$

Particulars of River

$$Q_R = 28 \text{ m}^3/\text{sec}$$

Concentrations (C_R)

$$\text{BOD} = 4.0 \text{ mg}/l$$

$$\text{DO} = 8.2 \text{ mg}/l$$

$$\text{Temperature} = 17^\circ\text{C}$$

$$k_1 \text{ at } 20^\circ = 0.1 \text{ per day}$$

(i) Combined discharge $= Q_S + Q_R = 0.56 + 28 = 28.56$ m^3/sec

Now, using equation for concentration of mix as

$$C = \frac{C_S \cdot Q_S + C_R \cdot Q_R}{Q_S + Q_R}, \text{ we have}$$

(ii) $$\text{BOD of mix} = \frac{50 \times 0.56 + 4.0 \times 28}{0.56 + 28} = \frac{140}{28.56} = 4.9 \text{ mg}/l$$

(iii) DO of mix $$= \frac{3.0 \times 0.56 + 8.2 \times 28}{0.56 + 28} = 8.098 \text{ mg}/l$$

(iv) Temp. of mix $$= \frac{23 \times 0.56 + 17 \times 28}{0.56 + 28} = 17.12^\circ\text{C}$$

3.2.2 Sedimentation

- The settleable solids, if present in sewage effluents, will settle down into the bed of the river, near the outfall of sewage, thus helping in the self purification process.
- Primarily the settled organic solid at bottom will be stabilized by anaerobic bacteria.

3.2.3 Sunlight

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

3.2.4 Oxidation

- The oxidation of the organic matter will start due to dissolved oxygen in river water.
- The deficiency of oxygen created will be filled up by atmospheric oxygen.
- This is the most important action responsible for affecting self purification of rivers.

3.2.5 Reduction

- Reduction occurs due to hydrolysis of organic matter settled at the bottom either chemically or biologically.
- Anaerobic bacteria helps in splitting the complex organic matters of sewage into simple compounds and gases.
- These simple compounds can come in contact with oxygen during thorough mixing of river water, hence they will be stabilized eventually.

3.3 Various Factors on which Natural Forces of Purification Depends

3.3.1 Temperature

- The temperature affects the rate of biological and chemical activities, which are enhanced at higher temperature and depressed at lower temperature.
- Increase in temperature leads to decrease in D.O. and increase in rate of reaction. This is likely to lead to anaerobic condition.

3.3.2 Turbulence

- Turbulence will lead to increase in the oxygen mixed in water
- Wind and undercurrents in lakes and oceans causes turbulence which affect their self purification.

NOTE: Too much of turbulence is not desirable, because it scours the bottom sediment, increase the turbidity, and retards algae growth, which is useful in reaeration process.

3.3.3 Hydrography

- It affects the velocity and surface expanse of the river stream.
- Higher velocity and larger surface area leads to greater turbulence and greater dilution of sewage added. This helps in self purification.

3.3.4 Amount and type of organic matter

- Some compounds can be easily oxidised and some will take time thereby purification will be slow or fast depending on the type of organic matter.
- Algae which absorbs carbon dioxide and gives out oxygen is thus, very helpful in the self-purification process.

3.3.5 Rate of reaeration

- More is the rate of reaeration faster will be the self purification.

3.4 Zone of Pollution in River Stream

The polluted stream undergoing self purification can be divided into the following four zones.

(i) Zone of degradation (ii) Zone of active decomposition

(iii) Zone of recovery (iv) Zone of cleaner water

(i) Zone of degradation

- This zone is found for a certain length just below the point where sewage is discharged into river stream.
- This zone is characterised by water becoming dark and turbid.
- D.O. is reduced to about 40% of the saturation value.
- In this zone algae dies out but the fish survives.

(ii) Zone of active decomposition

- This zone is marked by heavy pollution.
- Water becomes greyish and darker. D.O. concentration falls down to zero.
- In this zone, bacteria flora will flourish. Anaerobic condition sets in and thus gases like CH_4, H_2S, CO_2 will be evolved and ugly scum forms on the surface.
- At the end of this zone D.O. concentration will reach upto to 40% of the saturation D.O.
- Protozoa and fungi will first disappear and then reappear. Fish life will be absent.

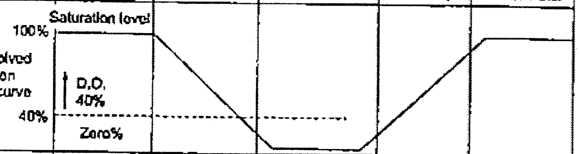
(iii) Zone of recovery

- In this zone, the river stream tries to recover from its degraded condition to its former appearance.
- B.O.D. falls down and D.O. content rises above 40% of the saturation value.
- Organic matter will produce nitrate, sulphate, phosphate, carbonate etc.

(iv) Zone of Cleaner Water

- In this zone, the river attains its original conditions with D.O.
- Water becomes attractive in appearance and usual aquatic life prevails.
- Some pathogenic organisms may still survive and remain present, which confirms the fact that "When once a river water has been polluted, it will not be safe to drink it, unless it is properly treated".

Table: 3.3 Showing zone of pollution along a river stream

	← Zones of pollution →				
	Clear water	Zone of degradation	Zone of active decomposition	Zone of recovery	Zone of clearer water
Dissolved oxygen sag curve					
Physical Indices	Clear, water, no bottom sludge, no colour	Floating solids; bottom sludge present, colour getting turbid	Darker and greyish colour, evolution of gases like CH_4, CO_2, H_2S etc. lot of sludge coming to the surface forming on ugly scum layer at top	Turbid with bottom sludge	Clear water with no bottom sludge
Fish presence	Ordinary fish like game, pan, food & forage etc. present.	Tolerant fishes like carp, buffalo, gary, etc. present	No fish present	Tolerant fish like carp, buffalo, etc. are present	Ordinary fish like game, pan, food, and forage, etc. present
Bottom Animals					
Algae & Protozoa etc. called plankton					

3.5 Indices of Self Purification

- The stage of self-purification process can be determined by the physical, chemical and biological analysis of water.
- Colour and turbidity are the physical indices.
- D.O. and B.O.D. and suspended solids are the chemical indices.
- Different types of micro and macro organisms exist in polluted water are biological indices.

3.6 Oxygen Deficit of a Polluted River Stream

- Dissolved Oxygen is one of the most important constituents of natural water system. Dissolved oxygen required for tolerant fish and aquatic animal are 4 mg/*l*.
- When biodegradable oraganics are discharged into a stream containing dissolved oxygen, micro organisms begin the metabolic processes that convert the organics, along with the dissolved oxygen, into new cells and oxidized the waste products.
- The rate at which the dissolved oxygen is used depends on the quantity of the organics, the ease with which they are biodegraded, and the dilution capacity of the stream.
- The dissolved oxygen that is used from the stream must be replaced or anaerobic conditions will develop.
- Two mechanisms are known to contribute oxygen to surface waters
  (i) Dissolution of oxygen from the atmosphere, often called reaeration and
  (ii) Production of oxygen by algal photosynthesis.

3.6.1 Reaeration

- When the concentration of dissolved oxygen drop below the equilibrium value, the net movement of oxygen will be from the atmosphere into the water.
- The difference between the equilibrium concentration and the actual concentration is called oxygen deficit and is represented by

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

where, D = D.O. deficit
C_S = equilibrium concentration
C = actual oxygen concentration

The unit of all the terms are milligrams per litre of oxygen.

- For constant equilibrium condition i.e. C_S does not change, the rate of change in the deficit is

$$\boxed{\frac{dD}{dt} = -\frac{dC}{dt}}$$

The deficit thus increases at the same rate that the oxygen is used up.

- The dissolved oxygen deficit is the driving force for reaeration. The greater the deficit, the greater the rate of reaeration from above equation the rate of reaeration increases as the concentration of dissolved oxygen decreases.

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

3.6.2 Rate of Oxygen Removed

If y = BOD of stream added with sewage i.e. diluted BOD. The rate at which dissolved oxygen disappears from the stream coincides with the rate of BOD exertion.

therefore,

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

but,
$$D = C_S - C$$

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

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

This indicates that an increase in rate of BOD exertion result in an increase in the rate of change of oxygen deficit.

Now, $y = L_0 - L_t$

where, L_0 = ultimate BOD of mix
L_t = oxygen equivalent of organic matter present at any time t

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

but,
$$\frac{dL_t}{dt} = -k_1 L_t$$

k_1 = Deoxygenation constant at base 'e'

$$\Rightarrow \quad -\frac{dL_t}{dt} = k_1 L_t = \frac{dy}{dt} = \frac{dD}{dt}$$

$\Rightarrow$ r_o = Rate of de-oxygenation

$$\boxed{K_D = k_1 L_t}$$

3.6.3 The Oxygen Sag Curve

- The oxygen deficit in a stream is a function of both oxygen utilization and reaeration.
- The rate of change in the deficit is the sum of the two reaction.

$$\Rightarrow \quad \boxed{\frac{dD}{dt} = k_1 L_t - k_2 D} \qquad \text{...(iii)}$$

$\Rightarrow$ Net rate of oxygen deficit = rate of reaeration + rate of deoxygenation

Remember: Deficit is maximum, when rate of reaeration = rate of deoxygenation

Integrating equation (iii) gives D.O. deficit at any time t i.e. D_t

From D_t, D.O can be calculated in river stream at any time 't'.

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

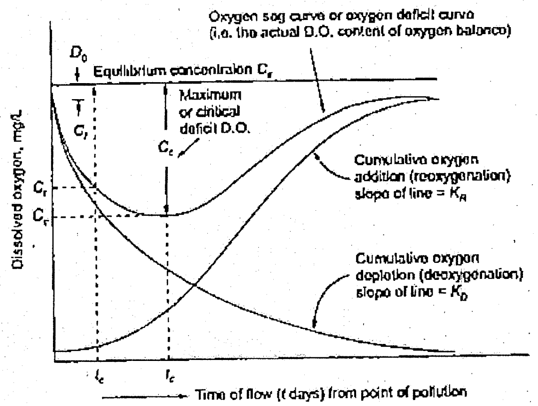


Fig. 3.1 Oxygen sag curve in a river receiving discharge of sewage

From equation (iii),

$$\frac{dD}{dt} + k_2 D = k_1 L_t = k_1 L_0 e^{-k_1 t}$$

$$e^{k_2 t}\frac{dD}{dt} + k_2 D \cdot e^{k_2 t} = k_1 L_0 e^{(k_2 - k_1)t}$$

$$\frac{d}{dt}\left(D \times e^{k_2 t}\right) = k_1 L_0 e^{(k_2 - k_1)t}$$

$$\int d\left(D e^{k_2 t}\right) = \int k_1 L_0 e^{(k_2 - k_1)t} dt$$

$$\Rightarrow \quad D e^{k_2 t} = \frac{k_1 L_0}{k_2 - k_1} e^{(k_2 - k_1)t} + C'$$

The constant of integration C' can be determined from known boundary condition.

at $t = 0$, $D = D_0$

Therefore, $D_0 = \frac{k_1 L_0}{k_2 - k_1} \cdot 1 + C'$ and $C' = D_0 - \frac{k_1 L_0}{k_2 - k_1}$

The final solution becomes

$$D e^{k_2 t} = \frac{k_1 L_0}{k_2 - k_1} e^{(k_2 - k_1)t} + D_0 - \frac{k_1 L_0}{k_2 - k_1}$$

or,
$$D = \frac{k_1 L_0}{k_2 - k_1}\left(\frac{e^{(k_2 - k_1)t}}{e^{k_2 t}}\right) - \frac{k_1 L_0}{(k_2 - k_1) e^{k_2 t}} + \frac{D_0}{e^{k_2 t}}$$

or,
$$\boxed{D = \frac{k_1 L_0}{k_2 - k_1}\left[e^{-k_1 t} - e^{-k_2 t}\right] + D_0 e^{-k_2 t}}$$

or,
$$\boxed{D_t = \frac{k_1 L_0}{k_2 - k_1}\left[10^{-k_1 t} - 10^{-k_2 t}\right] + D_0 10^{-k_2 t}} \quad \text{...(iv)}$$

where k_1 and k_2 are on base 10. This equation is called Streeter-Phelps equation

$k_1 \rightarrow k_D$, $k_2 \rightarrow k_R$

NOTE Saturation D.O at

$0°C = 14.6$ mg/*l* $\quad 20°C = 9.2$ mg/*l* $\quad 30° = 7.6$ mg/*l*

k_1 at $T°C = k_1$ at $20° (1.047)^{T-20}$ $\quad$ k_2 at $T°C = k_2$ at $20° (1.016)^{T-20}$

Critical time at which D.O is minimum is given by

or,
$$\boxed{t_c = \frac{1}{k_2 - k_1}\log_{10}\left[\left\{\frac{k_1 L_0 - (k_2 - k_1) D_0}{k_1 L_0}\right\}\frac{k_2}{k_1}\right]} \quad \text{...(v)}$$

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

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

$$\boxed{D_c = \frac{k_1 L_0}{k_2} 10^{-k_1 t_c}}$$

or,
$$\boxed{\left(\frac{L_0}{D_c f}\right)^{(f-1)} = f\left[1 - (f-1)\frac{D_0}{L_0}\right]} \quad \text{...(vi)}$$

where $f = \frac{k_2}{k_1}$ = self purification constant

Example 3.4 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

Ans. (a)

Rate of depletion of dissolved oxygen, coincides with the rate of BOD exertion.

$$\therefore \quad \frac{dy}{dt} = -\frac{dC}{dt}$$

where C is the concentration of D.O.

$$y_t = L_0 - L_t$$

$$\frac{dC}{dt} = -\frac{dL_t}{dt} = -kL_0 e^{-kt}$$

y_t is BOD at any time t
L_0 is ultimate BOD
L_t is oxygen equivalent of the organics at time t

Example 3.5 In dissolved oxygen sag curve, the sag curve results because

(a) it is a function of rate of addition of oxygen to the stream
(b) it is a function of rate of addition of oxygen from the stream
(c) it is a function of both addition and depletion of oxygen from the stream
(d) the rate of addition of oxygen is linear but the rate of depletion is non-linear

Ans. (c)

The rate of change of deficit

$$-\frac{dL_t}{dt} = -kL_0e^{-kt}$$

k_1, k_2 are reaction rate constants for oxygen removal and addition respectively.

L_t is BOD at time t

D is oxygen deficit

Example 3.6 A large stream has a reoxygenation constant of 0.4 per day. At a velocity of 0.85 m/s; and at the point at which an organic pollutant is discharged, it is saturated with oxygen at 10 mg/L (D_0 = 0). Below the outfall, the ultimate demand for oxygen is found to be 20 mg/L and the deoxygenation constant is 0.2 per day. What is the D.O. 48.3 km downstream?

Solution:

Given, $K_R = 0.4$/day, $K_D = 0.2$/day

Velocity of river, V = 0.85 m/s

Saturation, DO = 10 mg/l

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

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

$$= \frac{48.3\times10^3}{0.85} = 56823.53 \text{ sec} = \frac{56823.53}{86400} = 0.6577 \text{ day}$$

The D.O. deficit after time t

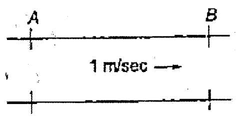
$$D_t = \frac{K_D L}{K_R - K_D}\left[10^{-K_D t} - 10^{-K_R t}\right] + \left(D_0 \times 10^{-K_R t}\right)$$

$$D_t = \frac{0.2\times20}{0.4-0.2}\left[10^{-2\times0.6577} - 10^{-0.4\times0.6577}\right] + \left(0\times10^{-0.4\times0.6577}\right)$$

$$= 20 \times 0.1927 + 0 = 3.85 \text{ mg/l}$$

DO at 48.3 km down stream = 10 − 3.85 = 6.15 mg/l

Example 3.7 The BOD rate constant (K) for a river's BOD assimilation was determined to be 2/day (base e). The BOD of the river after leaving a heavily populated town was determined to be 50 mg/l. Determine the distance after which the rivers BOD would become 4 mg/l when the average velocity of river was 1 m/s. What would have been this 'K' value if the distance would have been 300 km and state what K manifests.



Solution:

∴ $y_t = y_0(1 - 10^{-kt})$

or $y_t = y_0(1 - e^{-kt})$

Given: y_0 = 50 mg/l

y_t = 4 mg/l, k = 2/day (base e)

⇒ $4 = 50(1 - e^{-2t})$

⇒ $e^{-2t} = 0.92$

$\ln 0.92 = -2t$

⇒ $t = \frac{\ln 0.92}{-2} = 0.04169$ day or 3602.08 s

So length of river = $Vt = 1 \times 3602.08 \times 10^{-3} = 3.6$ km (∵ V = 1 m/s given)

Now, ∵ l = 300 km

So it will take t time to reach 300 km

$$t = \frac{300\times10^3}{1} \text{ s or } 3.47 \text{ day}$$

Now, because k value is BOD rate constant which depends on the type of waste water and temperature. So (i.e., municipal, industrial etc.) due to change in time, it will not change.

Example 3.8 A city discharges 100 cumecs of sewage into a river, which is fully saturated with oxygen and flowing at the rate of 1500 cumecs during its lean days with a velocity of 0.1 m/sec. The 5-days BOD of sewage at the given temperature is 280 mg/l. Find when and where the critical D.O. deficit will occur in the downstream portion of the river, and what is its amount. Assume coefficient of purification of the stream (f) as 4.0, and coefficient of deoxygenation (K_D) as 0.1.

Solution:

The initial D.O. of river = Saturation D.O. at the given temp = 9.2 mg/l (say)

D.O. of mix at t = 0 i.e., at start

$$= \frac{9.2\times1500 + 0\times100}{1500+100} = 8.62 \text{ mg/l (assuming that D.O. of sewage is nil)}$$

Initial D.O. deficit of the stream, $D_0 = 9.2 - 8.62 = 0.58$ mg/l

Also, 5-day BOD of the mixture of sewage and stream is given by

$$C = \frac{C_S Q_S + C_R Q_R}{Q_S + Q_R} = \frac{280\times100 + 0\times1500}{100+1500} = 17.5 \text{ mg/l}$$

∴ 5 day BOD of mix at the given temp = Y_5 = 17.5 mg/l

$$Y_5 = L\left(1-(10)^{-K_D\times5}\right) \text{ and } K_D = 0.1 \text{ (at 20°C)}$$

∴ The ultimate BOD of the mix (i.e. L) = $\frac{17.5}{0.684}$ = 25.58 mg/l

Now, using equation, we have

$$\left[\frac{L}{D_c \cdot f}\right]^{f-1} = f\left[1-(f-1)\frac{D_0}{L}\right] \quad \text{or} \quad \left[\frac{25.58}{D_c\times4}\right]^3 = 4\left[1-\frac{3\times0.58}{25.58}\right]$$

or D_c = 4.12 mg/l

Now, from equation, we have

$$t_c = \frac{1}{K_D(f-1)}\log_{10}\left[f\left\{1-(f-1)\frac{D_0}{L}\right\}\right]$$

or

$$t_c = \frac{1}{0.1(4-1)}\log_{10}\left[4\times\left(1-\frac{3\times0.58}{25.58}\right)\right] = \frac{1}{0.3}\times0.571 = 1.905 \text{ days}$$

Now, distance = Velocity of river × Travel time

= 0.1 m/sec × (1.905 × 24 × 60 × 60 sec) = 16460 m = **16.46 km**

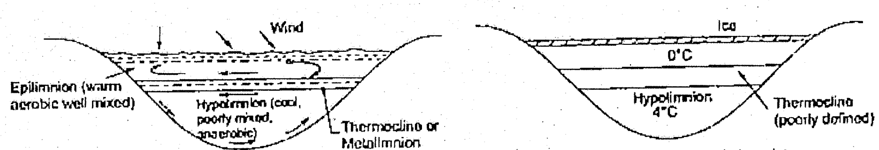
3.7 Disposal of Waste Waters in Lakes and Management of Lake Water

- Disposal of wastewaters in confined lakes or reservoirs, is much more harmful than its disposal in flouring streams and river.
- Phosphorous present in industrial and domestic waste, seriously affects the water quality of lakes and is considered as a prime lake pollutant.
- Oxygen demanding wastes may be the other important lake pollutant

3.8 Stratification of Lakes

- The water of a lake gets stratified during summers and winter.
- During summer season, the surface water of a lake gets heated up by sunlight and warm air. This warm water being lighter, remains in upper layer near the surface, until mixed downward by turbulence from winds, waves, boats and other forces. Since such turbulence extends only to a limited depth from below the water surface, the top layers of water in the lake become well mixed and aerobic. This warm, well mixed and aerobic depth of water is called 'epilimnion zone'.
- The lower depth, which remains cooler, poorly mixed and anaerobic is called the 'hypolimnion zone'.
- There may also exist an intermediate zone or a dividing line called 'thermocline or metalimnion.
- In winter seasons, the epilimnion cools, until it is more dense than the hypolimnion. The surface water then sinks causing 'overturning'.
- The water of the hypolimnion rises to the surface then where it cools and again sinks. The lake, thus becomes completely mixed, making it quite aerobic.
- The lakes in regions of temperature climate will, therefore, have at least one, if not two, cycles of stratification and turn over every year.

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



(a) Stratification of a lake during summer.
(b) Stratification of a lake during winter

Fig. 3.2 Stratification of lakes

3.9 Biological Zones in Lakes

Lakes have been found to exhibit distinct zone of biological activity, largely determined by the availability of light and oxygen the most important biological zones are:

(i) Euphotic zone (ii) Littoral zone (iii) Benthic zone

(i) Euphotic zone

- The upper layer of lake water through which sunlight can penetrate, is called the euphotic zone.
- All plant growth occurs in this zone.
- The depth of the euphotic zone is reduced by the turbidity which block sunlight penetration.
- The depth of the euphotic zone can be measured by a device called the Secchi disk.

NOTE: The bottom of euphotic zone only rarely coincides with the thermocline.

(ii) Littoral Zone

- The shallow water near the shore, in which rooted plants grow, is called the littoral zone.
- The extent of the littoral zone depends on the slope of the lake bottom and the depth of the euphotic zone.
- The littoral zone cannot extend deeper than the euphotic zone.

(iii) Benthic zone

- The bottom sediments in a lake comprises the benthic zone.
- Living organism when die settles down to the bottom which are decomposed by bacteria present in benthic zone.

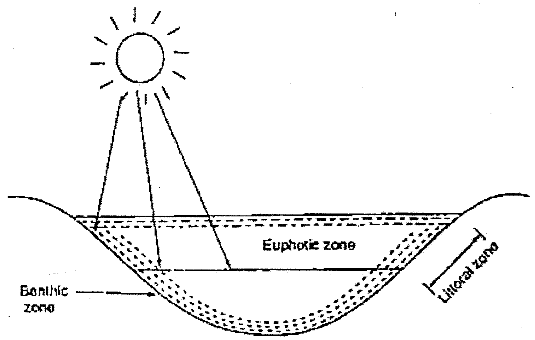


Fig. 3.3 Biological zones in a lake

3.10 Productivity of Lake

- The productivity of a lake is defined as a measure of its ability to support a food chain.
- Since the algae forms the base of this food chain. The higher algal growth leads to decreased water quality.
- Depending upon the increasing level of its productivity, the lakes may be classified as
  (i) Oligotrophic lake (ii) Mesotrophic lake
  (iii) Eutrophic lake (iv) Senescent lake

(i) Oligotrophic Lake

- Oligotrophic lakes have a low level of productivity due to a severely limited supply of nutrients to support algal growth.
- The water of such a lake is, therefore, clear enough as to make its bottom visible upto considerable depth.
- In such a case, the euphotic zone often extends into the hypolimnion, which is aerobic.
- Oligotrophic lakes, support cold water game fish.

(ii) Mesotrophic Lake

- The lakes having medium productivity levels, with medium growth of algae and turbidity, are usually classified as mesotrophic lakes.
- Hypolimnion remains aerobic although substantial depletion of oxygen occurs.

(iii) Eutrophic Lakes

- Eutrophic lakes do have a high level of productivity, because of an abundant supply of algal nutrients.
- Euphotic zone will partially extent into epilimnion.

(iv) Senescent Lake

- These are very old shallow lakes, having thick organic sediment deposits at their bottoms.
- Rooted water plants abundantly grow in such shallow ponds, which ultimately become marshes.

Eutrophication of Lakes

- It is a natural process under which lakes get infested with algae and silt up gradually to become shallower and more productive through the entry and cycling of nutrients like carbon, nitrogen and phosphorus.
- The initial clear water of oligotrophic lakes, therefore, gradually turns into mesotrophic, eutrophic and senescent stages, due to continues entry of silt and nutrients.
- Disintegration of rocks produces phosphorus, Increased phosphorus in lake water accelerate eutrophication of lake and this is called cultural eutrophication.
- Once phosphorus is mixed in lake, only solution is to add lime and to dredge out the sediment at the bottom of lake.
- To avoid eutrophication, lakes should not be used for disposal of even the treated sewage.

3.11 Disposal of Waste Water in Sea Water

- Sea water normally contains 20% less oxygen than that contained in fresh water of a river stream.
- Moreover sea water normally contains a large amount of dissolved matter. As such, the capacity of sea water to absorb sewage solids is not as high as that of fresh water of a stream.
- Sewage solids, when thrown into sea water, chemically react with the dissolved matter of the sea water and forming sludge banks.

NOTE

Following points should be kept in mind while discharging sewage into the sea to avoid marine pollution

(i) The sewage should be discharged in deep sea only.

(ii) To mix the sewage properly with sea water, the sewage should be released at a minimum depth of 3 to 5 meters below the water level.

(iii) The point of disposal should be such that the sewage is taken away from the shore by the winds and not brought back near the shore. It should be more than 15 km away from shore.

- The discharge of waste waters into the sea should, however be controlled in respect of the effluents, by achieving to the prescribe standards. The standards prescribe by BIS under IS: 1968-1976 are shown in table.

Table: 3.4 BIS (ISI) Standards for Wastewater Effluents to be Discharged into Marine Coasts

S. No	Constituent pollutant contained in the Wastewater Effluent	Tolerance Limit
(1)	(2)	(3)
1.	BOD_5	100 mg/l
2.	COD	250 mg/l
3.	pH value	5.5 to 9.0
4.	Total suspended solids	100 mg/l
5.	Oil and grease	20 mg/l
6.	Fluorides (as *F*)	15 mg/l
7.	Ammoniacal Nitrogen (as *N*)	50 mg/l

Disposal on Land

- In this method, the sewage effluent (treated or diluted) is disposed of by applying it on land.
- The percolating water may either join the water table, or is collected below by a system of under drains. This method can then be used for irrigating crops.
- This helps in increasing crop yields as the sewage contains a lot of fertilizing minerals and other elements, but the sewage effluent before being used as irrigation water. must be made safe.
- The degree of treatment required will, depends upon the type of the 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 requiring lesser treatment. as compared to the case where the soil is less porous and sticky.

Table: 3.5 BIS (ISI) Standards of Wastewater Effluents to be Discharged on Land for Irrigation

S. No	Constituent pollutant contained in the Wastewater Effluent	Tolerance Limit
(1)	(2)	(3)
1.	BOD_5 at 20°C	500 mg/l*
2.	pH value	5.5 to 9.0
3.	Total dissolved solids (TDS)	2100 mg/l
4.	Oil and grease	30 mg/l
5.	Chlorides (as *Cl*)	600 mg/l
6.	Boron	2 mg/l
7.	Sulphates	1000 mg/l
	Percentage of Sodium with respect to total content of Sodium, Calcium, Magnesium and Pottasium Radioactive Materials	60%
	(i) α-emitters	10 ' μC/ml
	(ii) β-emitters	

Illustrative Examples

Example 3.9 A city discharges 1500 litres per second of sewage into a stream whose minimum rate of flow is 6000 litres per second. The temperature of sewage as well as water is 20°C. The 5 day B.O.D. at 20°C for sewage is 200 mg/*l* and that of river water is 1 mg/*l*. The D.O. content of sewage is zero, and that of the stream is 90% of the saturation D.O. If the minimum D.O. to be maintained in the stream is 4.5 mg/*l*, find out the degree of sewage treatment required. Assume the deoxygenation coefficient as 0.1, and re-oxygenation coefficient as 0.3.

Solution: The value of saturation D.O. at 20°C is 9.17 mg/*l*. (say)

$$\text{D.O. content of the stream} = 90\% \text{ of the saturation D.O.} = \frac{90}{100} \times 9.17 = 8.25 \text{ mg}/l$$

D.O. of mix at the start point (i.e. at $t = 0$)

$$= \frac{8.25 \times 6000 + 0 \times 1500}{6000 + 1500} = 6.6 \text{ mg}/l \qquad (\because \text{D.O. of sewage is zero})$$

$\therefore$ D_0 = initial D.O. deficit

= [Saturation D.O. at mix temp − D.O. of mix] = 9.17 − 6.6

= 2.57 mg/*l* (Assume instantaneous mixing)

Minimum D.O. to be maintained in the stream = 4.5. mg/*l*

$\therefore$ Maximum permissible saturation deficit (i.e., critical D.O. deficit) = D_c = 9.17 − 4.5 = 4.67 mg/*l*

Now, using equations, the first stage B.O.D of mixture of sewage and stream (L) is given by

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

Substituting the values as

$$D_0 = 2.57 \text{ mg}/l \text{ and } D_c = 4.67 \text{ mg}/l$$

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

we get,

$$\left[\frac{L}{4.67 \times 3}\right]^{3-1} = 3\left[1-(3-1)\frac{2.57}{L}\right]$$

or

$$\left[\frac{L}{14.01}\right]^{3-1} = 3\left[1-(3-1)\frac{2.57}{L}\right] \quad \text{or} \quad \left[\frac{L}{14.01}\right]^{2} = 3\left[1-\frac{5.14}{L}\right]$$

Solving by hit and trial, we get the value

$$L = 21.1 \text{ mg}/l$$

Now, using $Y_t = L\left[1-10^{-K_D t}\right]$, we have

Maximum permissible 5 day B.O.D. of the mix (at 20°C)

$$Y_5 = 21.1\left[10 - 10^{-0.1 \times 5}\right] = 14.43 \text{ mg}/l \qquad (\text{where } K_D \text{ at } 20°\text{C} = 0.1)$$

Now, using equation, we have

$$C = \frac{C_S Q_S + C_R Q_R}{Q_S + Q_R} \qquad \text{where } C \text{ stands for concentrations of B.O.D}$$

Substituting the values, we get

$$14.43 = \frac{C_S \times 15 + 1 \times 6000}{1500 + 6000}$$

Where C_S will represent the permissible B.O.D.$_5$ (at 20°C of course) of the discharged wastewater.

Solving, we get

$$C_S = 68.16 \text{ mg}/l$$

$\therefore$ Degree of treatment required (per cent)

$$= \frac{\text{Original B.O.D. of sewage} - \text{Permissible B.O.D.}}{\text{Original B.O.D.}} \times 100$$

$$= \frac{200 - 68.16}{200} = \frac{131.84}{200} = 65.9\%$$

Example 3.10 An environmental survey for a town with population of 30000 revealed the following:

Domestic sewage produced at the rate of 240 litres per capita per day. The per capita BOD of the domestic sewage being 72 g/day.

Industrial wastes produced were estimated as 4 million litres per day with BOD of 1500 mg/L.

The sewage effluents can be discharged into a river with a minimum dry weather flow of 4500 litres/sec and a saturation dissolved oxygen content of 7 mg/L. It is necessary to maintain a dissolved oxygen content of 4 mg/L in the stream. For designing a sewage treatment plant, determine the degree of treatment required to be given to the sewage. Assume

k_D = Deoxygenation coefficient = 0.1

k_R = Reoxygenation coefficient = 0.3

An overall expansion factor of 10% to be provided.

Solution:

Per capita BOD of the domestic sewage = 72 gm/day = 72 × 10³ mg/day

Per capita sewage produced = 240 lit/day

$\therefore$ BOD per litre of the domestic sewage = $\dfrac{72 \times 10^3}{240}$ = 300 mg/L

Amount of domestic waste water produced per day = 30000 × 240 = 7.2 × 10⁶ litres

$\therefore$ Net BOD of all waste waters (domestic + industrial) = $\dfrac{7.2 \times 300 + 4 \times 1500}{7.2 + 4}$ = 728.57 mg/L

Total waste water discharge = $\dfrac{(7.2 + 4) \times 10^6}{24 \times 60 \times 60}$ = 129.63 lit/sec

Total waster water discharge with 10% expansion = 129.63 + $\dfrac{10}{100}$ × 129.63

= 142.593 lit/sec

Now, initial DO of saturated stream water = 7 mg/L

Assuming that the DO of waste water is nil, at the starting point.

$$\text{DO of the mixture} = \frac{DO \text{ of river} \times Q_r + DO \text{ of sewage} \times Q_s}{Q_r + Q_s}$$

where Q_r = 4500 lit/sec; Q_s = 142.593 lit/sec

$\therefore$ DO of mixture $= \dfrac{7 \times 4500 + 0 \times 142.593}{4500 + 142.593} = 6.785$ mg/L

$\therefore$ Initial deficit in DO $= D_o = 7 - 6.785 = 0.215$ mg/L

Given that
$$f = \frac{k_R}{k_D} = \frac{0.3}{0.1} = 3$$
$$D_c = 7 - 4 = 3 \text{ mg/L}$$
$$D_o = 0.215 \text{ mg/L}$$

We know that
$$\left[\frac{L_o}{D_c f}\right]^{f-1} = f\left[1 - (f-1)\frac{D_o}{L_o}\right]$$
$$\Rightarrow \left(\frac{L_o}{3 \times 3}\right)^{3-1} = 3\left[1 - (3-1) \times \frac{0.215}{L_o}\right]$$
$$\Rightarrow \frac{L_o^2}{81} = 3\left[1 - \frac{0.43}{L_o}\right]$$
$$\Rightarrow \frac{L_o^2}{3 \times 81} = \frac{L_o - 0.43}{L_o}$$
$$\Rightarrow L_o^3 = 243L_o - 104.49$$
$$\Rightarrow L_o^3 - 243L_o + 104.49 = 0$$
$$\Rightarrow L_o = 15.37 \text{ mg/L}$$

Maximum permissible 5 day BOD of the mix at mix temperature
$$= L_o\left[1 - 10^{-k_D t}\right] = 15.37\,[1 - 10^{-0.1 \times 5}] = 10.51 \text{ mg/L}$$

$$\text{Again BOD}_{mix} = \frac{C_s \times Q_s + C_r Q_r}{Q_s + Q_r}$$
$$\Rightarrow 10.51 = \frac{C_s \times 142.593 + 0 \times 4500}{142.593 + 4500}$$

where C_s = Maximum permissible BOD_5 of waste water
$$\Rightarrow C_s = \frac{10.51 \times (142.593 + 4500)}{142.593}$$
$$\Rightarrow C_s = 342.19 \text{ mg/L}$$

$\therefore$ Degree of treatment required
$$= \left(\frac{\text{Initial BOD of city waste water} - \text{Max. permissible BOD of waste water}}{\text{Initial BOD of city waste water}}\right) \times 100$$
$$= \frac{728.57 - 342.19}{728.57}$$
$$= 53.03\%$$

Example 3.11 A treated waste water is discharged at the rate of 1.5 m^3/sec into a river of minimum flow 5 m^3/sec. The temperature of river flow and waste water flow may be assumed as 25°C. The BOD removal rate constant K_1 is 0.12/d (base 10). The BOD_5 at 25°C of the waste water is 200 mg/*l*, and that of the river water upstream of the wastewater outfall is 1 mg/*l*. The efficiency of waste water treatment is 80%. Evaluate the following.

(i) BOD_5 at 25°C, if river water receives untreated waste water
(ii) BOD_5 at 25°C if river water receives treated waste water
(iii) Ultimate BOD of the river water after it receives treated waste water.

Solution:

Discharge of waste water $= Q_W = 1.5$ m^3/s
Discharge of river $= Q_R = 5$ m^3/s
Temperature $= T = 25$°C
$K_D(25°) = K_1 = 0.12$/d
C_W = Conc. of BOD_5 for untreated waste water = 200 mg/*l*
C_R = Conc of BOD_5 for river water = 1 mg/*l*

Using equation

(i) Conc. of BOD_5 of the mixture if untreated waste water is discharged into the river
$$= C = \frac{C_W Q_W + C_R \cdot Q_R}{Q_W + Q_R} = \frac{200 \times 1.5 + 1 \times 5}{1.5 + 5} = 46.92 \text{ mg/}l$$

(ii) BOD_5 of the treated wastewater is given by

C_{TW} = 20% of the BOD_5 of untreated wastewater
($\because$ efficiency of wastewater treatment is 80%)
$= 20\% \times C_W = 20\% \times 200$ mg/*l* $= 40$ mg/*l*

BOD_5 of mixture if treated wastewater is discharged into the river
$$= C' = \frac{C_W \cdot Q_W + C_R \cdot Q_R}{Q_W + C_R} = \frac{40 \times 1.5 + 1 \times 5}{1.5 + 5} = 10 \text{ mg/}l$$

(iii) BOD_5 of river water after it receives treated wastewater
= 10 mg/*l* (as computed above)

Ultimate BOD of the mixture $= Y_u = L$?

Using equation, we have
$$Y_{t(day)} = L\left[1 - (10)^{-K_D t}\right]$$
or
$$Y_5 = L\left[1 - (10)^{-0.12 \times 5}\right]$$
or
$$10 = L\left[1 - (10)^{-0.6}\right]$$
or
$$L = 13.35 \text{ mg/}l$$

Example 3.12 A wastewater treatment plant dispose of its effluents into a stream at a point *A*. Characteristics of the stream at a location fairly upstream of *A* and of the effluent are as below.

Temperature °C	Units	Effluent	Stream
Flow	m^3/s	0.20	0.50
Dissolved oxygen	mg/*l*	2.00	8.00
Temperature	°C	26	22
BOD_5 at 20°C	mg/*l*	40	3

Assume that the deoxygenation content K_1 at 20°C (base *e*) = 0.20 d^{-1} and the reaeration constant K_2 at 20°C (base *e*) = 0.40 d^{-1} for the mixture.

Equilibrium concentration of dissolved oxygen C_s for the fresh water is as follows:

Temperature °C	18	20	22	23	24	25	26
C_s(mg/l)	9.54	9.17	8.99	8.83	8.53	8.38	8.22

The velocity of the stream downstream of the point *A* is 0.2 m/s. Determine the critical oxygen deficit and its location. [Use temperature coefficients of 1.04 for K_1 and 1.02 for K_2]

Solution:

K_1 at 20°C (base *e*) = 0.2 d^{-1} = 0.2 d^{-1} = 0.2 per day

$\therefore$ K_D at 20°C (base 10) = $\frac{K_1}{2.3} = 0.434\,K_1 = 0.434 \times 0.2$ per day = 0.087 per day

Similarly, K_R at 20°C = $0.434 \times 0.4\ d^{-1}$ = 0.174 per day

The formulas to be used in this question for converting K_D and K_R at any other temperature (T°C) will be

$$K_{D(T)} = K_{D(20°)}\,[1.04]^{T-20°}\text{; and}$$

$$K_{R(T)} = K_{R(20°)}\,[1.02]^{T-20°} \qquad \text{(as per the given values)}$$

(i) We will now determine *DO*, *BOD* and temperature of mixture as below:

$$DO \text{ of mixture} = \frac{DO \text{ of sewage} \times Q_S + DO \text{ of river} \times Q_R}{Q_S + Q_R} = \frac{2 \times 0.20 + 8 \times 0.50}{0.20 + 0.50}$$

$$= 6.29 \text{ mg}/l$$

BOD_5 of mixture

$$\text{(i.e. 5 day BOD at 20°C)} = \frac{40 \times 0.20 + 3 \times 0.50}{0.20 + 0.50} = 13.57 \text{ mg}/l$$

$$\text{Temperature of mixture} = \frac{26 \times 0.20 + 22 \times 0.50}{0.20 + 0.50} = 23.14°\text{C}$$

(ii) Ultimate BOD of mixture (L)

$$L = \frac{Y_5\,(\textit{i.e. } 5 \text{ day BOD of mixture at } 20°\text{C})}{1-(10)^{-K_D \times 5}}$$

where K_D is at 20°C = 0.087 per day

$$= \frac{13.57}{1-(10)^{-0.087 \times 5}} = \frac{13.57}{0.633} = 21.45 \text{ mg}/l$$

(iii) Initial *D.O.* Deficit of mixture,

Saturation *D.O.* at mixture temperature of 23.14°C

$= 8.79$ (interpolated from given values)

$\therefore$ D_0 = *D.O.* deficit = 8.749 − 6.29 = 2.50 mg/l

(iv) Corrected values of K_D and K_R are

$$K_{D(23.14)} = K_{D(20)}\,[1.04]^{T-20} = 0.087[1.04]^{3.14} = 0.098$$

$$K_{R(23.14)} = K_{R(20)}\,[1.02]^{T-20} = 0.174[1.02]^{3.14} = 0.185$$

(v) The time (t_c) after which critical D.O. deficit (D_c) occurs is given by equation as

$$t_c = \frac{1}{K_D(f-1)} \log_{10}\left[\left\{1-(f-1)\frac{D_0}{L}\right\} f\right]$$

where, $K_R = 0.185$, $K_D = 0.098$

$$\therefore \quad f = \frac{K_R}{K_D} = \frac{0.185}{0.095} = 1.888$$

L = 21.45 mg/l; D_0 = 2.5 mg/l

$$\therefore \quad t_c = \frac{1}{0.098(1.888-1)} \log_{10}\left[\left(1 - \frac{0.888 \times 2.5}{21.45}\right) 1.888\right]$$

$$= \frac{1}{0.098(0.888)} \times 0.228 = 2.625 \text{ days}$$

(vi) Now, Distance = Velocity × Travel Time

= 0.2 m/s × (2.625 × 24 × 60 × 60 sec) = 45.36 km

(vii) D_c is now given by equation, as

$$\left(\frac{L}{D_c \cdot f}\right)^{f-1} = f\left(1-(f-1)\frac{D_0}{L}\right)$$

or $$\left(\frac{21.45}{D_c \times 1.888}\right)^{0.888} = 1.888\left(1 - \frac{0.888 \times 2.5}{21.4}\right)$$

or $$\frac{21.45}{1.888\,D_c} = (1.692)^{\frac{1}{0.888}} = (1.692)^{1.126} = 1.808$$

or $$D_c = \frac{21.45}{1.888 \times 1.808} = 6.28 \text{ mg}/l$$

Hence, the critical D.O. deficit equal to 6.28 mg/l occurs at 45.36 km downstream of *A*, after 2.625 days.

Important Expressions

1. $C_{mix} = \dfrac{C_S Q_S + C_R Q_R}{Q_S + Q_R}$

where, C_S = Concentration of material in sewage

C_R = Concentration of same material in river

Q_S, Q_R = Discharge of sewage and river

2. $D = \dfrac{k_D L_0}{k_R - k_D}\left[10^{-k_D t} - 10^{-k_R t}\right] + D_0 10^{-k_R t}$

3. Critical time at which DO is minimum is given by

$$t_c = \frac{1}{k_R - k_D} \log_{10}\left[\left\{\frac{k_D L_0 - (k_R - k_D) D_0}{k_D L_0}\right\} \frac{k_R}{k_D}\right]$$

4. Critical Oxygen Deficit

$$D_c = \frac{k_D L_0}{k_R} 10^{-k_D t_c}$$

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

where, $f = \dfrac{k_R}{k_D}$ = Self purification constant

where, k_R = Reoxygenation coefficient

k_D = Deoxygenation coefficient

L_0 = Ultimate BOD of mix

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

$\Rightarrow$ k_D at T°C = $k_{D_{20}}\,(1.047)^{T-20}$

$\Rightarrow$ k_R at T°C = $k_{R_{20}}\,(1.016)^{T-20}$

Summary

- Increase in temperature leads to decrease in D.O. and Increase in rate of reaction. Hence oxygen will quickly get depleted and anaerobic condition may set in.
- In zone of degradation of lakes, algae dies but the fish survives.
- Two mechanisms are known to contribute oxygen to surface water.
  (a) Dissolution of oxygen from atmosphere i.e. reaeration.
  (b) Production of oxygen by algae photosynthesis.
- Net rate of oxygen deficit = Rate of reaeration + Rate of deoxygenation
- Maximum killing of aquatic plant and animal will occur during mixing as they are not to be accustomed to such temperature change.
- The increased phosphate in lake water accelerate eutrophication of lake and this is called cultural eutrophication.
- To avoid eutrophication, lakes should not be used for disposal even the treated sewage.
- Sewage should be disposed as during low tides only.
- Due to clogging and ponding of soil due to application of waste water, reduction in soil permeability is referred to as a sewage sickness of soil.

Objective Brain Teasers

Q.1 The formation for BOD assimilation in a stream should include
(a) BOD rate constant
(b) sedimentation of organic matter
(c) BOD rate constant and sedimentation of organic matter
(d) pathogenic bacterial decay coefficient

Q.2 The following zones are formed in a polluted river
1. Zone of clear water
2. Zone of active decomposition
3. Zone of recovery
4. Zone of pollution

The correct sequence in which these zones occur progressively downstream in a polluted river is
(a) 4, 2, 1, 3 (b) 4, 2, 3, 1
(c) 2, 4, 3, 1 (d) 2, 4, 1, 3

Q.3 From ecological considerations, the minimum level of Dissolved Oxygen (DO) necessary in the rivers and streams is
(a) 1 mg/L (b) 2 mg/L
(c) 4 mg/L (d) 8 mg/L

Q.4 Which one of the following sets of processes is a part of self-purification of streams?
(a) Settling, biodegradation and desalination
(b) Settling, biodegradation and aeration
(c) Floatation, ion exchange and desalination
(d) Desalination, ion exchange and reverse osmosis

Q.5 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

Q.6 When wastewater is disposed of into a running stream, four zones are formed. In which one of the following zones will the minimum level of dissolved oxygen be found?
(a) Zone of degradation
(b) Zone of active decomposition
(c) Zone of recovery
(d) Zone of clear water

Q.7 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

Q.8 In the facultative pond systems, the aerobic zone may get extended downwards due to
(a) calm waters along with weak sunlight
(b) mixing by wind action along with weak sunlight
(c) mixing by wind action along with penetration by sunlight
(d) calm waters along with penetration by sunlight

Q.9 Deep ponds, in which oxygen is absent except, perhaps, across a relatively thin surface layer, are called
(a) aerobic ponds (b) anaerobic ponds
(c) facultative ponds (d) polishing ponds

Q.10 The reoxygeneration coefficient K of stream is 0.30 at 20°C. Its K value at 32°C is likely to be.......

Q.11 Match List-I (Parameter) with List-II [General standard for discharge into the inland surface water in mg/L (max)] and select the correct answer using the codes given below the lists:

List-I	List-II
A. BOD (5 day 20°C)	1. 250
B. COD	2. 100
C. Oil and grease	3. 20
D. Suspended solids	4. 10
	5. 30

Codes:

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

Q.12 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%

Q.13 Sewage sickness occurs when
(a) sewage contains pathogenic organisms
(b) sewage enters the water supply system
(c) sewers get clogged due to accumulation of solids
(d) voids of soil clogged due to continuous application of sewage on a piece of land

Directions: The following items consists of two statements; one labelled as 'Assertion (A)' and the other as 'Reason (R)'. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:
(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

Q.14 Assertion (A): U.K. Royal Commission on Sewage Disposal of 1898-1915 classified British rivers on the basis of 65° F, 5-day BOD.
Reason (R): British rivers do not have flow time to open sea more than 5 days.

Q.15 Assertion (A): The BOD gets removed at a very fast rate immediately after sewage is discharged into a river.
Reason (R): A part of the BOD in the sewage is due to settleable organic matter therein.

Answers

1. (a) 2. (b) 3. (c) 4. (b) 5. (d)
6. (b) 7. (c) 8. (c) 9. (b)
10. (0.36) 11. (a) 12. (c) 13. (d)
14. (a) 15. (b)

Hints and Explanations:

Ans.1 (a)

In a stream the natural purification processes are:

(i) Dilution
(ii) Sedimentation and resuspension
(iii) Filtration
(iv) Gas transfer i.e., aeration
(v) Heat transfer
(vi) Chemical conversions i.e., oxidation, reduction and precipitation
(vii) Metabolic processes

The BOD (dissolved and suspended) gets diluted when a point/line source discharges waste water into a water body. The suspended organic matter gets settled and resuspended due to eddies. The microorganism consume BOD by metabolic processes and it depends upon BOD rate.

Ans.4 (b)

Self purification of streams include physical, chemical and biological process.

A. Physical processes : Dilution; sedimentation and resuspension; filtration; gas transfer; and heat transfer.
B. Chemical Processes : Chemical conversion (oxidation and reduction)
C Biological process : Metabolic processes in micro-organisms.

Ans.5 (d)

The biodegradable matter present in sewage is consumed by microorganisms through aerobic respiration. This decreases the dissolved oxygen in river.

Ans.7 (c)

A perfect ecological system means that there are producers, consumers, and decomposers present in the system in such a manner that food and energy flows from one level to the other.

The pollutants (nitrogen and phosphorous) disturb this equilibrium by increasing productivity of a lake. As the productivity of a lake increases, its water quality reduces and equilibrium is disturbed. Oligotrophic lakes have low level of productivity so they can be considered to be perfect ecological system.

Ans.8 (c)

Aerobic conditions are maintained in the upper portions of the facultative pond by oxygen generated by algae, and, to a lesser extent by penetration of atmospheric oxygen. Stagnant conditions in the sludge along the bottom prevent oxygen transfer to that region and anaerobic conditions prevail there. The boundary between the aerobic and anaerobic zones is not stationary. Mixing by wind action and penetration by sunlight may extend the aerobic area downward. Conversely calm waters and weak lighting result in the anaerobic layer rising toward the surface.

Ans.9 (b)

Stabilisation ponds may be classified as aerobic, facultative or anaerobic, depending upon the mechanism of purification.

In a totally aerobic pond, the stabilisation of water is brought about by aerobic bacteria, which flourish in the presence of oxygen.

In an anaerobic pond, however, the stabilisation of waste is mainly brought about by the usual anaerobic conversion of organic wastes to carbon dioxide, methane, and gaseous end products, with eruption of foul odours and pungent smells.

In a facultative pond, the upper layers work under aerobic conditions, while the 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 are usually of depth of 0.5 m

Facultative ponds are usually of depth of 1 to 1.5 m

Anaerobic ponds are usually of depth of 2.5 to 4 m

Ans.10 (0.36)

$$k_{R(T^\circ C)} = k_{R(20^\circ C)}[1.016]^{T-20^\circ C}$$

$$= 0.30\,(1.016)^{32-20}$$

$$k_{R(32^\circ C)} = 0.36$$

Ans.12 (c)

The tolerance limit for BOD_5 in marine environment disposal is 100 mg/L

Minimum efficiency needed,

$$\eta_{min} = \frac{200-100}{100} \times 100 = 50\%$$

Ans.13 (d)

When sewage is applied continuously on a piece of land, the soil pores or voids may get filled up and clogged with sewage matter retained in them. Thus free circulation of air will be prevented and anaerobic conditions will develop within the pores.

Sewage sickness is the condition when soil pores get filled up and clogged with sewage matter due to continuous application of waste water effluents. This develops anaerobic conditions and foul gases like methane, carbon-dioxide and hydrogen sulphide are evolved.

In order to prevent sewage sickness:

(i) Sewage should be given primary treatment
(ii) The soil chosen for effluent irrigation/sewage farming should be sandy or loamy.
(iii) A proper under drainage system (open jointed drains) should be designed.
(iv) Land should be given rest for some time and ploughed thoroughly.
(v) Rotation of crops to be followed.
(vi) Shallow depths of water should be applied.

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