CHAPTER 01

Waste Water Characteristics

INTRODUCTION

- When untreated sewage is discharged into river stream, floating solids present in the discharged sewage get decompose and create foul smells and bad odours.
- The organic matter present in the discharged sewage consume the dissolved oxygen of river stream in getting oxidised and decrease the dissolved oxygen causing fish kills and other undesirable effects.
- Waste water are usually classified as industrial waste water or municipal waste water
- Industrial waste water with characteristic compatible with municipal waste water is often discharged into the municipal sewers.
- Many industrial waste water require pretreatment to remove non-compatible substances prior to discharge into the municipal system.
- Water collected in municipal waste water system contains wide variety of contaminants.
- Commonly found contaminants with their source and environmental significance are given below.

Table: 1.1 Important waste water contaminants

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

- Hence for its safe disposal, it is very necessary to study the characteristics and behavior of sewage

NOTE: Even though municipal sewage is 99.9 percent water, it requires treatment, if nuisance is to be avoided.

1.1 Characteristics of Sewage

The quality of sewage can be checked and analysed by studying and testing its physical, chemical and bacteriological (biological) characteristics.

1.1.1 Physical Characteristics of Sewage and their Testing

The most important physical characteristics of waste water are

(i) Turbidity (ii) Colour (iii) Odour (iv) Temperature

(i) Turbidity

- Sewage is normally turbid, resembling dirty dish water or waste water from baths having other floating matter like faecal matter, pieces of paper, cigarette-ends, match-sticks, greases, vegetable debris, fruit skins, soaps, etc. The turbidity increases as sewage becomes stronger.
- Turbidity is measured photometrically by determining the percentage of light of a given intensity that is either absorbed or scattered.
- It is expressed as the amount of suspended solids in mg/L or ppm (parts per million).
- The degree of turbidity can be measured and tested by
  (i) Turbidity rods (ii) Turbidimeters

NOTE

(i) Turbidity rod consists of an aluminium rod which is graduated, as to give the turbidity in silica units.

(ii) Turbidimeter works on the principle of measuring the interference caused by water sample to the passage of light rays.

(ii) Colour

- The colour of sewage can normally be detected by the naked eye and it indicates the freshness of sewage.
- If colour is yellow, grey or light brown, it indicates fresh sewage and if the colour is black or dark brown it indicates stale or septic sewage.
- Some industrial waste water may also add colours to the domestic waste water.
- The common method of colour removal is by coagulation followed by sedimentation.

NOTE: When all the oxygen has disappeared from sewage, it becomes septic

(iii) Odour

- Fresh sewage is practically odourless.
- Odour in waste water usually is caused by gases produced by the decomposition of organic matter.
- The most characteristic odour of stale or septic waste water is that of hydrogen sulphide which is produced by anaerobic microorganisms that reduces sulphate to sulphides.
- The extent of odour present in a particular sample of waste water is measured by a term called odour intensity, which is related with the Threshold Odour Number (TON).

NOTE: Threshold odour number, represents the number of dilutions required to reduce an odour.

(iv) Temperature

- The temperature of waste water is commonly higher than that of water supply because of addition of warm waste from households and industrial activities.
- The average temperature of sewage in India is 20°C, which is near about the ideal temperature for the biological activities.
- The temperature of water is very important parameter because of its effect on the aquatic life, the chemical reactions and reaction rates and suitability of the water for beneficial uses.

1.1.2 Chemical Characteristic

Chemical characteristics are result of the solvent properties of water and they are often important in specifying water quantity. Important chemical characteristics of waste water are listed below:

(a) Total solids, suspended solids and settleable solids
(b) pH value
(c) Chloride content
(d) Nitrogen content
(e) Presence of fats, greases and oils
(f) Sulphides, sulphates and H_2S gas
(g) Dissolved oxygen
(h) Chemical oxygen demand (COD)
(i) Theoretical oxygen demand (ThOD)
(j) Total organic carbon
(k) Bio-chemical oxygen demand (BOD)

(a) Total Solids, Suspended Solids and Settleable Solids

- Solids present in sewage may be in any of the four forms, suspended solids, dissolved solids, colloidal solids and settleable solids.
- Suspended solids are those solids which remain floating in sewage.
- Colloidal solids are finely divided solids remaining either in solution or in suspension.
- Settleable solids are that portion of solid matter which settles out, if the waste water is allowed to remain undisturbed for a period of 2 hours.

NOTE: It has been estimated that about 1000 kg of sewage contains about 0.45 kg of total solids, out of which 0.225 kg is in solution, 0.112 kg is in suspension and 0.112 kg is settleable.

- The solids in sewage comprise of both: the organic and inorganic solids, which is about 45 and 55 percent of total solids respectively.
- Inorganic matter consist of sand, gravel, debris, chlorides, sulphates etc.
- Organic matter consist of
  - Carbohydrates such as cellulose, cotton, fibre, sugar etc.
  - Fats and oils from kitchen, garages, shops etc.
  - Nitrogenous compounds like proteins, urea, fatty acids etc.
- The amounts of various kinds of solids present in waste water can be determined as follows:
  (a) Total amount of solids can be determined by evaporating a known volume of waste water sample and weighing the dry residue left. The mass of residue left divided by the volume of sample is total solids in mg/*l*.
  (b) The suspended solids also called non-filtuable solids, as they are retained by a filter of 1 μm pores. Their quantity can be determined by passing a known volume of sewage sample through glass-fibre filter apparatus and weighing the dry residue left and dividing by volume of sample filtered will give suspended solids in mg/*l*.

(c) The difference between the total solids (S_1) and the suspended solids (S_2) represent dissolved solids plus colloidals or filterable solids (S_3)

i.e. $S_3 = S_1 - S_2$.

(d) Now the total suspended solids (S_2) may either be volatile or fixed. Let the volatile suspended solids concentration be S_4(mg/l).

∴ $S_2 - S_4 = S_5$ will represent the fixed solids

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

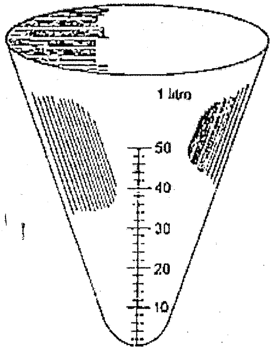


Fig. 1.1 Imhoff cone (Conical Glass Vessel)

(b) pH Value

- The pH value of sewage indicates the negative log of hydrogen ions concentration present in sewage.
  i.e. $pH = -\log H^+$ or $H^+ = (10)^{-pH}$
- The determination of pH value is very important, as it gives an idea about certain treatments which depends upon pH value.
- The pH value can be measured by the help of potentiometer which measure the electrical potential exerted by the hydrogen ions, and thus indicating their concentration.

NOTE: The fresh sewage is generally alkaline in nature (with pH more the 7) but as time passes its pH tends to fall due to production of acids by bacterial action in anaerobic or nitrification processes.

(c) Chloride Content

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

(d) Nitrogen Content

The presence of nitrogen in sewage indicates the presence of organic matter and may occur in one or more of the following forms.

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

NOTE: Lack of nitrates causes the body to turn bluish, it may lead the child to turn blue. Hence, this disease, popularly called blue baby disease or mathemoglobinemia.

(e) Presence of Fats, Oils and Greases

- Greases, fats and oils are derived in sewage from the discharge of animals and vegetable matter or from industries like garages, kitchen of hotels and restaurants etc.
- Such matter form scum on the top of the sedimentation tanks and clog the voids of the filtering media. Therefore, they interfere with the normal treatment methods, and hence need proper detection and removal.
- Fats and oils are compounds of alcohol or glycerol with fatty acids.
- The amount of fats and greases in sewage sample can be determined by evaporating it and then mixing the residual solids left, with ether (hexane). The solution is then poured off and evaporated, leaving behind the fats and greases as residue, which can be easily weighed.

(f) Sulphides, Sulphates and Hydrogen Sulphide Gas

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

(g) Dissolved Oxygen (D.O)

- Dissolved oxygen present in sewage is very important for respiration of aerobic micro-organism as well as for all other aerobic life forms.
- The dissolved oxygen in fresh sewage depends upon temperature. If the temperature of sewage is more, the D.O. content will be less. Maximum quantity of D.O. that can remain mixed in water at a particular temperature is called Saturation Dissolved Oxygen.
- The D.O. content of sewage is generally determined by the Winkler's Method.

NOTE: The solubility of oxygen in sewage is 95% of that in distilled water.

Do You Know

1. It is necessary to ensure at least 4 ppm of dissolved oxygen in discharged treated sewage, otherwise fish are likely to be killed
2. Dissolved oxygen is desirable in drinking water but it is usually removed from boiler feed waters because of the manner in which it accelerates corrosion of metals.

(h) Chemical Oxygen Demand (COD)

- The COD test is used to measure the content of organic matter of waste water, both biodegradable and non biodegradable
- The oxygen equivalent of organic matter that can be oxidised is measured by using a strong chemical oxidising agent in an acidic medium. [Potassium dichromate has been found to be excellent for this purpose ($K_2Cr_2O_7$)]
- This test is also called dichromate-oxygen demand test

(i) Theoretical Oxygen Demand (ThOD)

The oxygen required to oxidise the organic matter present in a given waste water can be theoretically computed, if the organics present in waste water are known. Thus, if the chemical formulas and the concentration of the chemical compounds present in water are known, we can easily calculate the ThOD of each of these compounds by writing the balanced reaction for the compound with oxygen to produce CO_2, H_2O and oxidised inorganic components.

Remember: For most practical cases COD = ThOD (taken) [However, generally COD > ThOD > BOD > TOC]

(j) Total Organic Carbon

It is another important method of expressing organic matter in terms of its carbon content.

(k) Bio-Chemical Oxygen Demand

The organic matter is of two types :

(a) Biologically active or biologically degradable (b) Biologically inactive

- Biochemical oxygen demand is used as a measure of the quantity of oxygen required for oxidation of biodegradable organic matter present in water sample by aerobic biological action.
- Oxygen demand of waste water is exerted by three classes of materials
  (a) Carbonaceous organic materials.
  (b) Oxidisable nitrogen derived from nitrite, ammonia and other organic nitrogen compounds which serves as food for specific bacteria (Nitrosomonas and nitrobacter).
  (c) Chemical reducing compounds e.g. Fe^{2+}, SO_3^{2-} (sulfites), S^{2-} (sulfide) which are oxidised by dissolved oxygen.
- For domestic sewage, nearly all oxygen demand is due to carbonaceous organic material and is determined by BOD test.

NOTE

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

- BOD test constitutes the most important test for waste waters and is discussed below:
  (i) If sufficient oxygen is available in waste water, the useful aerobic bacteria will flourish and cause the aerobic biological decomposition of waste water, which will continue until oxidation is completed. The amount of oxygen consumed in this process is the BOD.
  (ii) Hence the BOD of water during 5 Days at 20°C is generally taken as the standard and is about 68% of the total demand. A 10 days BOD is about 90% of the total.
  (iii) This standard 5 day BOD, is written as BOD_5 or simply as BOD and is determined in the laboratory by mixing or diluting a known volume of a sample of waste water with known volume of aerated pure water and then calculating the D.O. of this diluted sample. The diluted sample is then incubated for 5 days at 20°C. The D.O. of diluted sample after this period of incubation, is again calculated. The difference between the initial D.O. value and the final D.O. value will indicate the oxygen consumed by the sewage sample in 5 days. The BOD in ppm is then calculated by using the equation.

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

The factor in the bracket is called dilution factor

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

- The first demand occurs due to the oxidation of organic matter and is called carbonaceous demand or first stage demand or initial demand and the later demand occurs due to biological oxidation of ammonia, and is called Nitrogeneous demand or second stage demand. The term BOD is usually used to mean the first state BOD i.e. the demand due to the presence of Carbonaceous matter alone.
- Nitrogenous demand starts only after 5-8 days because the reproduction rate of nitrofication bacteria is slow.

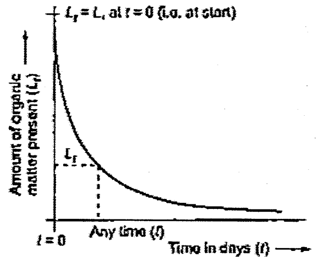


Fig. 1.2 Ist Stage BOD curve

NOTE

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

Reaction Kinetics

At a certain temperature, the rate of deoxygenation is assumed to be directly proportional to the amount of organic matter present in sewage at that time. i.e.

$$\frac{dL_t}{dt} = -kL_t \qquad ...(i)$$

where L_t = oxygen equivalent of carbonaceous oxidisable organic matter present in sewage after t days from the start of oxidation in mg/l.

t = time in days

k = rate constant signifying the rate of oxidation of organic matter and it depends upon the nature of organic matter and temperature. Its unit is per day.

Integrating equation (i)

$$\int \frac{dL_t}{L_t} = \int -k\,dt$$

or
$$\log_e L_t = -kt + C \qquad ...(ii)$$

when t = zero i.e. at start $L_t = L$. Substituting in equation

$$\log_e L = k(0) + C$$

or
$$C = \log_e L$$

∴ From equation (ii)

$$\log_e L_t = -kt + \log_e L$$

or
$$\log_e L_t - \log_e L = -kt$$

or
$$\log_e \frac{L_t}{L} = -kt$$

or
$$2.3 \log_{10} \frac{L_t}{L} = -kt$$

or
$$\log_{10} \frac{L_t}{L} = \frac{-k \cdot t}{2.3} = -0.434\,kt$$

using $0.434\,k = K_D$, where K_D is the Deoxygenation rate constant or more strictly, the BOD rate constant (on base 10) at the given temperature

∴
$$\log_{10} \frac{L_t}{L} = -K_D t$$

or
$$\boxed{L_t = L(10)^{-K_D t}} \quad ...(iii)$$

Now, L is the organic matter present at the start of BOD reaction and L_t is the organic matter left after t days (Fig. 1.3)

∴
$$BOD = L - L_t = L - L(10)^{-K_D t}$$

$$\boxed{(BOD)_t = L\left[1 - 10^{-K_D t}\right]} \quad ...(iv)$$

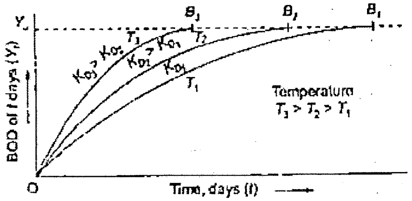


Fig. 1.3 BOD exertion as a function of K_D

The value of K_D determines the speed of the BOD reaction, without influencing the ultimate BOD. It is found to vary with temperature of sewage and this relationship is approximately given by the equation.

$$K_{D(T^\circ)} = K_{D(20^\circ)}[1.047]^{T-20^\circ} \quad ..(v)$$

Table: 1.2 Typical Values of K_D at 20°C for Various Types of Waters and Waste water	
Water Type	**K_D value per day**
Tap waters	< 0.05
Surface waters	0.05 – 0.1
Municipal wastewaters	0.1 – 0.15
Treated sewage effluents	0.05 – 0.1

$K_{D(20°C)}$ = Deoxygenation constant at 25°C. It numerical value varies between 0.05 to 0.2 per day, depending upon the nature of the organic matter present in sewage. Simple compounds such as sugars and starches are easily utilised by the micro-organism and have a high K_D rate, while complex molecules such as phenols are difficult to assimilate and hence have low K_D values. Some typical K_D values are given in Table 1.2.

$K_{D(T)}$ = Deoxygenation constant at temperature T°C.

- Equation (v) shows that K_D will be higher at higher temperature, which means that the speed at which BOD is consumed in the oxidation of the organic matters is higher at higher temperature. This mean that the entire carbonaceous organic matter will get oxidised quickly and in lesser time at higher temperature.
- Equation (iv) is called the first stage equation of BOD reaction and is presented by the curve OAB in figure 1.4 below:

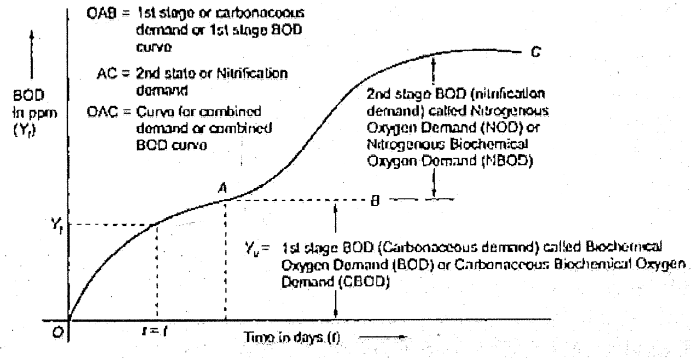


Fig. 1.4 *Different BOD stages with time*

- The portion AC of the curve represent the nitrification stage which follows the carbonaceous stage, so that the BOD curve for the complete oxidation is represented by OAC.

NOTE

(i) The equations given is only for the first stage BOD and have nothing to do with the second stage BOD.

(ii) Values of 5-days 20°C BOD of municipal waste water generally vary between 100 to 500 mg/l.

Estimation of K_D

$$\boxed{K_D = 2.61\frac{A}{B}}$$

where, A = Slope of line

B = Intercept of the line on y-axis

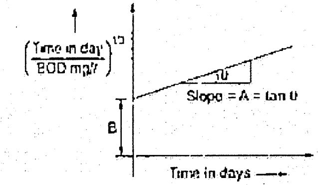


Fig. 1.5 Relation between K_D and Time (in days)

Example 1.1 For a waste, the 5-day BOD at 20°C is found to be 200 mg/L. For the same waste, 5-day BOD at 30°C will be

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

Ans. (b)

The effect of temperature on BOD can be approximately given by the Van't Hoff-Arrhenius models:

$$K_T = K_{20}(1.047)^{T-20}$$

At
$$T = 30°C,\ K_T > K_{20}$$

$$BOD_{t,30°C} = L_0\left(1 - e^{-K_T t}\right)$$

∴
$$BOD_{5,30°C} > BOD_{5,20°C}$$

Example 1.2 The ultimate BOD value of a waste

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

Ans. (c)

Ultimate BOD represents the biodegradable organic matter, so it will remain unchanged

Example 1.3 For a waste water the BOD_5 at 20° is found to be 200 mg/l. For same waste BOD_3 at 30°C will be? The reaction constant 'K' (to the base e) is 0.2 per day.

Solution:

$$BOD_5 \text{ at } 20°C = L_0[1-e^{-K\times5}]$$
$$BOD_3 \text{ at } 30°C = L_0[1-e^{-K'\times3}]$$
$$L_0 = BOD_u \quad \text{(Remain constant)}$$
$$200 = L_0[1-e^{-5K}] \quad ...(i)$$
$$BOD_3 = L_0[1-e^{-3K'}] \quad ...(ii)$$

From (i) and (ii)

$$\frac{200}{1-e^{-5K}} = \frac{BOD_3}{1-e^{-3K'}} \Rightarrow \frac{1-e^{-3K'}}{1-e^{-5K}} = \frac{BOD_3}{200}$$

But,
$$K' = K(1.047)^{30-20} = 0.2[1.047]^{10} = 0.316$$

$$\Rightarrow \quad BOD_3 = 200\left[\frac{1-2.72^{-3\times0.316}}{1-2.72^{-5\times0.2}}\right] = \frac{0.6127}{0.632}\times 200 = 193.89 \text{ mg/l}$$

1.2 Population Equivalent

- Average standard BOD of domestic sewage is 80 gms per person per day.
- The number of person which produce the amount of BOD at the rate of 80 gms per person per day equal to that produced by industrial sewage is called population equivalent of industrial sewage.
- Industrial wastewater are generally compared with per capita normal domestic wastewater, so as to rationally charge the industries for the population caused by them. The strength of the industrial sewage is, thus worked out as below.

$$\begin{bmatrix}\text{Standard BOD (5 days)}\\ \text{of industrial sewage}\end{bmatrix} = \begin{bmatrix}\text{Standard BOD (5 days) of domestic}\\ \text{sewage per person per day}\end{bmatrix} \times \begin{bmatrix}\text{Population}\\ \text{equivalant}\end{bmatrix}$$

- The average standard BOD_5 of domestic sewage is worked out to be about 0.08 kg/day/person. Assume. BOD_5 of sewage coming from on industries is worked out as 300 kg/day, then

$$\Rightarrow \quad \text{The population equivalent} = \frac{\text{Total } BOD_5 \text{ of the industry in kg/day}}{0.08 \text{ kg/day/person}} = \frac{300}{0.08} = 3750$$

Example 1.4 Data from an unseeded domestic waste water BOD test are : 5 ml of waste in 300 ml bottle, initial D.O. of 7.8 mg/l, and 5 days DO equal to 4.3 mg/l. Compute

(a) the BOD; and
(b) the ultimate BOD, assuming a k-rate of 0.10 per day

Solution:

(a)
$$\text{Initial D.O.} = 7.8 \text{ mg/l}$$
$$\text{D.O. after 5 days of incubation} = 4.3 \text{ mg/l}$$
$$\therefore \quad \text{D.O. consumed in 5 days} = 7.8 - 4.3 = 3.5 \text{ mg/l}$$

$$BOD_5 \text{ of wastewater} = \text{D.O consumed by diluted sample} \times \left[\frac{\text{vol. of diluted sample}}{\text{vol. of undiluted sewage used}}\right]$$
$$= 3.5 \text{ mg/l} \times \left[\frac{300 \text{ ml}}{5 \text{ ml}}\right] = 210 \text{ mg/l}$$

(b) Now, using equation $Y_t = L\left(1-(10)^{-K_D t}\right)$, we have

$$Y_5 = L\left(1-(10)^{-K_D 5}\right) \quad \text{where, } K_D = 0.1 \text{ per day and } Y_5 = 210 \text{ mg/l}$$

$$\therefore \quad 210 = L\left[1-(10)^{-0.1\times5}\right] = L\left[1-\frac{1}{(10)^{0.5}}\right] = L[1-0.316] = 0.684\,L$$

or
$$L = \frac{210}{0.684} \text{ mg/l} = 307.1 \text{ mg/l}$$

Example 1.5 A certain waste has a BOD of 162 mg/L and its flow is 1000 cubic metres per day. If the domestic sewage has a BOD of 80 gram per capita per day, then the population equivalent of the waste would be

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

Ans: (c)

$$\text{Daily BOD contributed by waste} = 162 \times \frac{1000\times1000}{10^3} = 162{,}000 \text{ g/day}$$

$$\text{Population equivalent} = \frac{162000}{80} = 2025 \text{ persons}$$

NOTE: The population equivalent, thus, indicates the strength of the industrial wastewater for estimating the treatment required at the municipal treatment plant

Example 1.6 A dairy processing about 1,33,000 kg of milk daily produces an average of 246 cubic metre per day of waste water with a BOD of 1400 mg/l. The principal operations are bottling of milk, and making ice cream, with limited production of cheese. Compute the waste water flow and BOD per 1000 kg of milk received, and the equivalent population of the daily waste discharge.

Solution:

$$\text{Daily milk processed} = 1{,}33{,}000 \text{ kg}$$
$$\text{Daily wastewater produced} = 246 \text{ m}^3$$
$$\text{BOD of wastewater} = 1400 \text{ mg/l}$$

Evidently,

$$\text{Wastewater produced per 1000 kg of milk} = \frac{246}{133000}\times 1000 \text{ m}^3 = 1.85 \text{ m}^3$$

BOD of the wastewater = 1400 mg/l = 1400 × 10^3 mg/cum

$$= \frac{1400 \times 10^3}{1000} \text{ gm/cum} = \frac{1400 \times 10^3}{10^3 \times 10^3} \text{ kg/cum}$$

Hence, BOD produced per 1000 kg of milk processed

= 1.4 × 1.85 kg = 2.59 kg

Daily BOD produced by 246 m^3 of wastewater

= 1.4 kg/m^3 × 246 m^3 = 344.4 kg/day

From equation, we have

$$\text{Population equivalent} = \frac{\text{BOD of industry in kg/day}}{0.08} = \frac{344.4}{0.08} = 4305 \text{ persons}$$

NOTE: The dairy is producing as much pollution as is likely to be produced by 4305 persons.

1.3 Relative Stability

The term *relative stability* of a sewage effluent may be defined as the ratio of oxygen available in the effluent (as D.O., nitrite or nitrate) to the total oxygen required to satisfy its first stage BOD demand.

It is expressed as percentage of the total oxygen required, and can be expressed by the equation.

$$\text{Relative stability} = S = 100\left[1-(0.794)^{t_{20}}\right]$$

or,

$$S = 100\left[1-(0.630)^{t_{37}}\right]$$

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

The decolourisation caused by the enzymes produced by anaerobic bacteria, infact, is an indication of the available oxygen in oxidising the unstable organic matter.

Remember: The above test for determining relative stability is suitable only in case of polluted stream water or sewage effluents and not suitable for raw sewage.

Example 1.7 If the period of incubation is 10 days at 20°C in the relative conductivity test on sewage, calculate the percentage of relative stability.

Solution: Using equation, we have

$$\text{Relative stability} = S = 100\left[1-(0.794)^{t_{(20)}}\right]$$

where $t_{(20)}$ = Time in days to decolourise a standard vol. of methylene blue at 20°C = 10 days (given)

$$\therefore \quad S = 100\left[1-(0.794)^{10}\right]$$

$$= 100[1-0.0995875] = 90.04\%$$

1.4 Ratios

1.4.1 $\frac{BOD}{COD}$ Ratio

Ultimate BOD (BOD_u), as we know, is the oxygen required for oxidising the Biodegradable Organics of a given waste water.

- COD, on the other hand, is the oxygen required to oxidise the Biodegradable Organics (BO'_s) as well as the Non-Biodegradable Organics (NBO'_s) both.
- COD of a waste water will, therefore, always be more than its BOD_u, since their difference will represent the quantum of NBO'_s present in given wastewater.
- The $\frac{BOD_u}{COD}$ ratio will, therefore, always be less than 1.0, but this value shall approach towards 1.0 with the decreasing amount of NBO'_s.
- If this ratio is found to be between 0.92 to 1.0 the wastewater can be considered to be virtually fully biodegradable.

Example 1.8 What will be the maximum upper limit of BOD of a glucose solution of concentration 300 mg/l.

Solution: Since the $\frac{BOD_u}{COD}$ ratio is always less than 1 or at the most equal to 1, the maximum ultimate BOD value can be taken as equal to the value of COD. Moreover, the value of COD, can either be determined by the dichromate test for complex wastewaters; or may be determined theoretically if the organic compounds and their concentrations present in the wastewater are known. Such a theoretical oxygen demand of an organic compound can be calculated by writing the balanced reaction for the compound with oxygen to produce CO_2, H_2O and oxidixed organic components.

In the present case, the water contains only glucose, which is oxidised under the following equation.

$$\underset{\substack{180 \\ \text{Glucose}}}{C_6H_{12}O_6} + \underset{192}{6O_2} \longrightarrow \underset{264}{6CO_2} + \underset{108}{6H_2O}$$

From this balanced equation of oxidation of glucose, it can be stated that the theoretical oxygen demand for glucose is $\frac{192}{180}$ = 1.07 mg of O_2/mg of glucose.

∴ Total theoretical oxygen demand of the 300 mg/l glucose solution

= 1.07 × 300 mg/l = 321 mg/l

This demand can be taken to be equal to the maximum upper limit of BOD.

Hence, the maximum upper limit of BOD = 321 mg/l

1.4.2 $\frac{COD}{TOC}$ Ratio

The total carbonaceous organics present in given wastewater can be ascertained by computing TOC of the wastewater, by converting the carbonaceous organics to CO_2, which is measured by infrared analysis, and converted instrumentally to the original organic carbon content.

- $\frac{COD}{TOC}$ ratio is considered to be an important factor in monitoring wastewater treatments.
- TOC is related to COD through a carbon-oxygen balanced, such as in the oxidation of Glucose.

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

we will have, $$\frac{COD}{TOC} = \frac{6 \text{ mol of } O_2}{6 \text{ mol of C}} = \frac{6 \times 32}{6 \times 12} = 2.66$$

NOTE: The TOC test is rapid and accurate, but has not become popular in our country, because it needs a costly instrument and sufficient skill in using the same.

Example 1.9 Consider the following statements associated with water pollution parameters:

1. One of the primary indicators of the degree of water pollution is the concentration of organic matter.
2. Total organic carbon (TOC), chemical oxygen demand (COD) and biochemical oxygen demand (BOD) are important parameters of water pollution.
3. Generally TOC > COD > BOD.

Which of these statements are correct?

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

Ans. (b)

Generally, COD > BOD > TOC.

Illustrative Examples

Example 1.10 The BOD_5 of a water has been measured as 600 mg/*l*. If k_1 = 0.23 day (base e), what is the ultimate BOD_u of the waste. What proportion of the BOD_u would remain unoxidised after 20 days.

Solution: Use equation as

$$Y_t = L\left[1-(10)^{-K_D \cdot t}\right]$$

Here, $K = k_1 = 0.23$/day (given)

$\therefore$ $K_D = 0.434\, K = 0.434 \times 0.23 = 0.1$

Using t = 5 days, we have

$$Y_5 = \text{BOD of 5 days} = 600 \text{ mg}/l = L[1-(10)^{-0.1\times 5}]$$

$$= L\left[1-(10)^{-0.5}\right] = L\left[1-\frac{1}{(10)^{0.5}}\right] = L\left[1-\frac{1}{3.16}\right] = L[1-0.316] = 0.684\,L$$

$\therefore$ $0.684\,L = 600$ mg/*l*

$\therefore$ $L = \frac{600}{0.684}$ mg/*l* = 877.5 mg/*l*

Now $$Y_{20} = L\left[1-(10)^{-0.1\times 20}\right] = Y_u\left[1-\frac{1}{(10)^2}\right] = Y_u[1-0.01] = Y_u[0.99]$$

$\therefore$ $Y_{20} = 0.99\, Y_u$

It means that 99% of BOD_u is utilised in 20 days, and hence only 1% of ultimate BOD would be left unoxidised after 20 days.

Example 1.11 The following observations were made on a 3% dilution of waste water.

Dissolved oxygen (*D.O.*) of aerated water used for dilution = 3.0 mg/*l*

Dissolved oxygen (*D.O.*) of diluted sample after 5 days incubation = 0.8 mg/*l*

Dissolved oxygen (*D.O.*) of original sample = 0.6 mg/*l*

Calculate the B.O.D. of 5 days and ultimate BOD of the sample assuming that the deoxygenation coefficient at test temp. is 0.1.

Solution:

The 100% contents of the diluted sample consists of 3% wastewater and 97% of aerated water used for dilution

Hence its D.O = D.O. of waste water × its content + D.O. of dilution water × its content

= 0.6 × 0.03 + 3.0 × 0.97 = 0.018 + 2.91 = 2.928 mg/*l*

D.O. of the incubated sample after 5 days = 0.8 mg/*l*

Thus, *D.O.* consumed in oxidising organic matter = 2.928 − 0.8 = 2.128 mg/*l*

$\therefore$ B.O.D. of 5 days = D.O. consumed × Dilution factor

$$= 2.128 \times \frac{100}{3} = 70.93 \text{ mg}/l$$

Ultimate B.O.D. is given by L

Using equation, we have, $$Y_t = L\left[1-(10)^{-K_D \cdot t}\right]$$

or $$Y_t = L\left[1-(10)^{-K_D \cdot 5}\right] \quad ...(i)$$

The value of K_D at test temp. is given as 0.1. Substituting the known values in equation (i) above, we have

$$70.93 = L\left[1-(10)^{-0.1\times 5}\right] = L\left[1-(10)^{-0.5}\right]$$

$$= L\left[1-\frac{1}{(10)^{0.5}}\right] = L\left[1-\frac{1}{3.16}\right] = L[1-0.316] = L \times 0.684$$

or $$L = \frac{70.93}{0.684} = 103.7 \text{ mg}/l$$

Example 1.12 If the per capita contribution of suspended solids and B.O.D. is 90 gm and 55 gm, find the population equivalents of

(i) A combined system serving 1000 persons and having 75 gm per capita daily of B.O.D. and

(ii) 40,000 litres daily of industrial waste water containing 1800 mg/*l* of suspended solids.

Solution:

(i) Population served by the combined system = 1000

Daily per capita B.O.D of the combined system = 75 gm

Total daily B.O.D. produced by the system = 1000 × 75 gm = 75000 gm

But standard per capita B.O.D. (given) = 55 gm

$$\therefore \text{Population equivalent} = \frac{75000}{55} = 1364 \text{ persons}$$

(ii) 1 litre of industrial wastewater contains 1800 mg of suspended solids.

$\therefore$ 40,000 liters of industrial wastewater (daily) will produce

$$= \frac{1800 \times 40000}{10^3} \text{ gm of suspended solids}$$

$$= 72{,}000 \text{ gm of suspended solids}$$

But standard daily per capita solid contribution is 90 gm.

$$\therefore \quad \text{Population equivalent} = \frac{72000}{90} = 800 \text{ persons}$$

Example 1.13 : Change in concentration of organic matter, L, with time, t, is given by $\frac{dL}{dt} = -K.L$

Calculate the organic matter remaining after 3 days if the initial concentration was 200 mg/*l*, and $K = 0.4$ per day. (base e).

Solution:

$$\frac{dL}{dt} = -KL \text{ or } \frac{dL}{L} = -K \cdot dt$$

Integrating, we have

$$\log_e L = -Kt + C$$

or $$2.3 \log_{10} L = -Kt + C$$

When $t = 0$ (at start), $L = 200$ mg/*l*

$\therefore$ $$2.3 \log_{10} 200 = 0 + C$$

or $$C = 2.3 \times 2.301 = 5.28$$

Now, the value of L after 3 days in given by

$$2.3 \log_{10} L = -0.4 \times 3 + C$$

or $$2.3 \log_{10} L = -1.2 + 5.28 = 4.08$$

or $$\log_{10} L = \frac{4.08}{2.3} = 1.773$$

or $$L = 59.3 \text{ mg/}l$$

Hence the organic matter left after 3 days = 59.3 mg/*l*

Example 1.14. The 3 day 15°C BOD of a sample of sewage is 150 mg/*l*. Draw a graph of 5 day BOD as a function of temperature in the range 10°C to 30°C in steps of 5°C.

Solution:

Assume K_D at 20°C = 0.1

Then K_D at 15°C is given as

$$K_{D(T)} = K_{D(20°)}[1.047]^{T-20}$$

or $$K_{D(15)} = 0.1[1.047]^{15-20°}$$

$$= 0.1(1.047)^{-5}$$

$$= \frac{0.1}{(1.047)^5} = 0.079$$

Now, using

$$Y_{t \text{ at } T} = L\left[1-(10)^{-K_D t}\right], \text{ we have}$$

$$Y_{3 \text{ at } 15} = 150$$

$$= L\left[1-(10)^{-0.079 \times 3}\right]$$

$$= L\left[1-\frac{1}{(10)^{0.237}}\right] = 0.422\,L$$

or $$L = 355.53 \text{ mg/}l$$

$$K_{D(10°C)} = 0.1[1.047]^{10-20} = 0.063$$

$$K_{D(15°C)} = 0.1[1.047]^{25-20} = 0.1258$$

$$K_{D(20°C)} = 0.1[1.047]^{30-20} = 0.1583$$

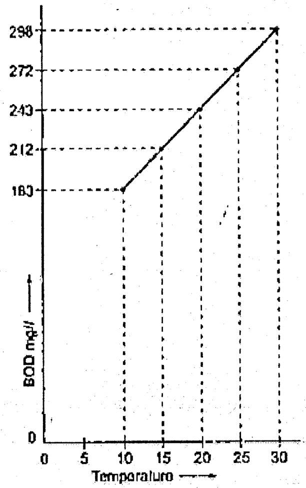
(i) $Y_{5 \text{ at } 10°C} = 355.33[1-(10)^{-0.063 \times 5}] = 183$ mg/*l*

(ii) $Y_{5 \text{ at } 15°C} = 355.33[1-(10)^{-0.079 \times 5}] = 212$ mg/*l*

(iii) $Y_{5 \text{ at } 20°C} = 355.33[1-(10)^{-0.1 \times 5}] = 243$ mg/*l*

(iv) $Y_{5 \text{ at } 25°C} = 355.33[1-(10)^{-0.1258 \times 5}] = 272$ mg/*l*

(v) $Y_{5 \text{ at } 30°C} = 355.33[1-(10)^{-0.1583 \times 5}] = 298$ mg/*l*



These calculated five number BOD values w.r.t. temperature are plotted in figure, so as to obtain the requisite graph, which is almost a straight line.

Important Expressions

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

2. $$(\text{BOD})_t = L\left[1-10^{-K_D t}\right]$$

$$\Rightarrow \quad L_t = L\left[10^{-K_D t}\right]$$

where, K_D = Deoxygenation constant

L = Organic matter present at the start of BOD reaction

L_t = Organic matter left after t days

3. $$K_{D(T°C)} = K_{D(20°C)}[1.047]^{T-20°C}$$

4. $$K_D = 2.61\frac{A}{B}$$

where, A = Slope of line of $(\text{time/BOD})^{1/3}$ Vs (time)
B = Intercept of the line on Y-axis

5. Relative stability, $S = 100\left[1-(0.794)^{t_{20}}\right]$

$$S = 100\left[1-(0.630)^{t_{37}}\right]$$

6. Population Equivalent = $\dfrac{\text{Total BOD}_5 \text{ of the industry in kg/day}}{0.08 \text{ kg/day/person}}$

Summary

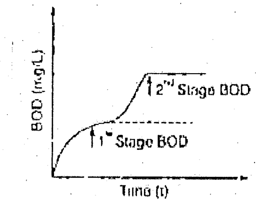
- The most obnoxious odour of waste water is that of hydrogen sulphide, which is produced by anaerobic microorganisms that reduce, sulphates to sulphites.
- The average temperature of sewage in India is 20°C, which is near about the ideal temperature for the biological activities.
- The quantity of settleable solids can be determined using Imhoff cone.
- The pH value can be measured by the help of potentiometer which measure the electrical potential exerted by the hydrogen ions, and thus indicating their concentrations.
- The chloride content can be measured by titrating the sample of waste water with standard silver nitrate solution, using potassium chromate as an indicator.
- Free ammonia indicates recent pollution, nitrates indicates partly decomposed condition and nitrates indicates old pollution.
- Dissolved oxygen less than 4 ppm is detrimental to the survival of fish.
- For most practical cases, COD = ThOD
  However, generally COD > ThOD > BOD > TOC
- Average standard BOD of domestic sewage is 80 gms per person per day.

Objective Brain Teasers

Q.1 An industrial waste water enters a stream having a BOD concentration of 10 mg/L and a flow of 20 m³/s. If the flow of wastewater is 1.5 m³/s and its BOD concentration is 250 mg/L, then the BOD concentration in the stream at a point downstream of the point of confluence of wastewater with the stream will be
(a) 2.67 mg/L (b) 12.09 mg/L
(c) 13.00 mg/L (d) 26.74 mg/L

Q.2 The following data pertain to a sewage sample:
Initial DO = 10 mg/L
Final DO = 2 mg/L
Dilution to 1%
The BOD of the given sewage sample is
(a) 8 mg/L (b) 10 mg/L
(c) 100 mg/L (d) 800 mg/L

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



(a) experimental error
(b) increased activity of bacteria
(c) nitrification demand
(d) interference by certain chemical reactions

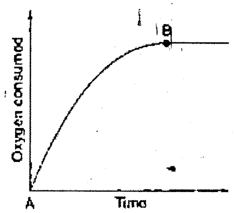
Q.4 If the BOD_3 of a wastewater sample is 75 mg/L and reaction rate constant k (base e) is 0.345 per day, the amount of BOD remaining in the given sample after 10 days is
(a) 3.12 mg/L (b) 3.45 mg/L
(c) 3.69 mg/L (d) 3.92 mg/L

Q.5 Which one of the following pairs is not correctly matched?
(a) BOD/COD = 0 : Waste-water is toxic
(b) BOD/COD ≤ 0.2 : Acclimatization of seed is necessary
(c) BOD/COD ≥ 0.6 : Waste-water is non-biodegradable
(d) BOD = COD = 0 : Waste-water is devoid of organic matter

Q.6 What is 5 days 20°C BOD equal to?
(a) 3 days 27°C BOD
(b) 4 days 30°C BOD
(c) 6 days 32°C BOD
(d) 7 days 35°C BOD

Q.7 In context of water polluted with sewage, what does BOD signify?
(a) Biological oxygen demand
(b) Bacteriological oxygen demand
(c) Biochemical oxygen demand
(d) Biology of degradation

Q.8 The figure below shows, BOD curve when the experiment was conducted at 20°C. If the experiment is conducted at 30°C, then the portion AB of the curve



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

Q.9 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

Q.10 A sample of sewage is estimated to have a 5 day 20° C BOD of 250 mg/l. If the test temperature be 30°C, in how many days will the same value of BOD be obtained?
(a) 1.5 days (b) 2.5 days
(c) 3.3 days (d) 7.5 days

Q.11 Consider the following statements:
The time of BOD assimilation in a stream can be affected by
1. Ratio of stream depth to flow width.
2. Stream BOD value.
3. BOD rate constant.
Which of these statements are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

Q.12 Statement (I) : The BOD test is conducted for 5 days at 20°C.
Statement (II) : The amount of oxygen utilized by microorganisms anaerobically is called BOD.
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

Q.13 High COD to BOD ratio of an organic pollutant represents
(a) high biodegradability of the pollutant
(b) low biodegradability of the pollutant
(c) presence of free oxygen for aerobic decomposition
(d) presence of toxic material in the pollutant

Q.14 Biochemical oxygen demand (BOD) of waste-water is a measure of
(a) total concentration of biochemicals
(b) total concentration of organic matter
(c) concentration of biodegradable organic matter
(d) concentration of chemically oxidizable matter

Q.15 Chemical Oxygen Demand (COD) of a sample is always greater than Biochemical Oxygen Demand (BOD) since it represents
(a) biodegradable organic matter only
(b) biodegradable and non-biodegradable organic matter
(c) non-biodegradable organic matter
(d) inorganic matter

Q.16 A waste water sample diluted to 100 times with aeration water had an initial dissolved oxygen (DO) of 7.0 mg/L and after 5 days of incubation at 20°C, the DO was zero. The BOD of waste water is
(a) 700 mg/L
(b) 100 mg/L
(c) Cannot be determined
(d) 7 mg/L

Q.17 A student began an experiment of 5 day 20°C BOD on Monday. Since the 5th day fell on Saturday. The final DO reading was taken on Monday. On calculation BOD (i.e. 7 day 20°C) was found to be 150 mg/L. What would be the 5 day, 20°C BOD (in mg/L). Assume value of BOD rate constant (K) at standard temperature of 20°C as 0.23/day (base e).

Q.18 A single rapid test to determine the pollution status of river water is
(a) biochemical oxygen demand
(b) chemical oxygen demand
(c) total organic solids
(d) dissolved oxygen

Q.19 The 5-day BOD of a wastewater sample is obtained as 190 mg/L (with k = 0.01 h^{-1}). The ultimate oxygen demand (mg/L) of the sample will be
(a) 3800 (b) 475
(c) 271 (d) 190

Q.20 A portion of waste water sample was subjected to standard BOD test (5 days, 20°C), yielding a value of 180 mg/L. The reaction rate constant (to the base 'e') at 20°C was taken as 0.18 per day. The reaction rate constant at other temperature may be estimated by $k_T = k_{20} (1.047)^{T-20}$. The temperature at which the other portion of the sample should be tested, to exert the same BOD in 2.5 days, is
(a) 4.9°C (b) 24.9°C
(c) 31.7°C (d) 35.0°C

Q.21 List-I contains some properties of water/waste water and List-II contains list of some tests on water/ waste water. Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I
A. Suspended solids concentration
B. Metabolism of biodegradable organics
C. Bacterial concentration
D. Coagulant dose

List-II
1. BOD
2. MPN
3. Jar test
4. Turbidity

Codes:

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

Q.22 To determine the BOD_5 of a waste water sample, 5, 10 and 50 mL aliquots of the waste water were diluted to 300 mL and incubated at 20°C in BOD bottles for 5 days. The results were as follows:

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

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

Answers

1. (d) 2. (d) 3. (c) 4. (c) 5. (c)
6. (a) 7. (c) 8. (a) 9. (a) 10. (c)
11. (c) 12. (c) 13. (b) 14. (c) 15. (b)
16. (c) 17. (128) 18. (d) 19. (c) 20. (d)
21. (b) 22. (a)

Hints and Explanations:

Ans.1 (d)

$$BOD_{stream} = \frac{Q_1y_1 + Q_2y_2}{Q_1 + Q_2}$$

$$= \frac{20 \times 10 + 15 \times 250}{20 + 15}$$

$$= 26.74 \text{ mg/L}$$

Ans.2 (d)

BOD = [Initial DO – Final DO] × Dilution Factor

Where Dilution Factor

$$= \frac{\text{Volume of diluted sample}}{\text{Volume of undiluted sample}}$$

$$= (10 - 2) \times \frac{100}{1} = 800 \text{ mg/L}$$

Ans.4 (c)

The BOD at any instant is given by

$$L_t = L(1 - e^{-kt})$$

$$\Rightarrow \quad 75 = L(1 - e^{-0.345 \times 3})$$

$$\Rightarrow \quad L = \frac{75}{1 - 0.355} = 116.32 \text{ mg/L}$$

BOD after 10 days,

$$L_{10} = L(1 - e^{-0.345 \times 10})$$

$$= 116.32 \times 0.968 = 112.63 \text{ mg/L}$$

Amount of BOD remaining = $L - L_{10}$

$$= 116.32 - 112.63 = 3.69 \text{ mg/L}$$

Ans.5 (c)

$BOD_5/COD \geq 0.6$ means waste water is biodegradable

Ans.6 (a)

$$BOD_t = L_0(1 - e^{-kt})$$

and $\quad k_T = k_{20}(1.047)^{T-20}$

BOD_5 at 20°C will be equal to a BOD_t for given temperature when $k_T t$ is equal to $k_{20} \times 5$.

$$k_T t = k_{20} \times 5$$

or $\quad \frac{k_T}{k_{20}} = \frac{5}{t} = (1.047)^{T-20}$

$$t = \frac{5}{(1.047)^{T-20}}$$

T	t(days)
27°C	3.63
30°C	3.16
32°C	2.88
35°C	2.51

There is no correct answer but (a) is closest.

Ans.8 (a)

The BOD of water at any time t is expressed as

$$y_t = L_0(1 - e^{-kt})$$

The value of k is temperature dependent. Because micro-organisms are more active at higher temperatures, the value of k increases with increasing temperatures. The value of y_t approaches L_0 asymptotically indicating that the total, or ultimate, BOD (y_u) is equal to the initial oxygen equivalent of the water L_0. Thus, at higher temperatures the value of y_t approaches to ultimate BOD earlier, shifting point *B* on the curve towards the left.

Ans.10 (c)

$$BOD_{5, 20°C} = L\left(1 - 10^{-K_D \times t}\right)$$

The effect of temperature on BOD can be given by

$$K_{D_{T°C}} = K_{D_{20°C}}(1.047)^{T-20}$$

$$\therefore \quad K_{D_{30°C}} = K_{D_{20°C}}(1.047)^{10}$$

$$K_{D_{30°C}} = 1.583 K_{D_{20°C}}$$

$$\therefore L\left(1 - 10^{-K_D \times 5}\right) = L\left(1 - 10^{-1.583 \times K_D \times t}\right)$$

$$\Rightarrow \quad 10^{-K_D \times 5} = 10^{-1.583 \times K_D \times t}$$

$$\therefore \quad t = \frac{5}{1.583} = 3.16 \text{ days}$$

Ans.12 (c)

If sufficient oxygen is present in water the useful aerobic bacteria will flourish and cause the biological decomposition of waste and organic matter, thereby reducing the carbonaceous material from water.

The amount of oxygen required in the process until oxidation gets completed is known as BOD. Polluted waters will continue to absorb oxygen for many months and it is not practically possible to determine this ultimate oxygen demand. Hence, the BOD of water during the first five days at 20°C is generally taken as standard demand.

Ans.15 (b)

Chemical oxygen demand (COD) is a measure of total organic matter (biodegradable as well as non-biodegradable) present in sewage.
BOD of sewage is the amount of biologically degradable organic matter present in the sewage

Ans.16 (c)

If DO of sample after 5 day is less than 2 mg/l test should be repeated.
As some amount of oxygen can't be consumed.

Ans.17 (128.0979)

$$k_D = 0.434 \times 0.23 = 0.0998$$

$$BOD_7 = L\left[1 - 10^{-k_D t}\right]$$

$$\therefore \quad 150 = L[1 - 10^{(-0.0998 \times 7)}]$$

$$\Rightarrow \quad L = 187.54 \text{ mg/L}$$

$$\therefore \quad BOD_5 = L\left[1 - 10^{-k_D t}\right]$$

$$= 187.539 \times [1 - 10^{-0.0998 \times 5}]$$

$$= 128.0979 \text{ mg/L}$$

Ans.19 (c)

The BOD of t days may be given as

$$L_t = L[1 - 10^{-kt}]$$

$$\Rightarrow \quad 190 = L[1 - 10^{0.01 \times 5 \times 2.3 \times 0.434}]$$

$$\Rightarrow \quad L = \frac{190}{0.698} = 272 \text{ mg/L}$$

Ans.20 (d)

Given data:

$$k_{D_1} = 0.434$$
$$k_c = 0.434 \times 0.18 = 0.0781\ d^{-1}$$
$$t_1 = 5 \text{ days}$$
$$Y_1 = 180 \text{ mg/L}$$
$$Y_2 = 180 \text{ mg/L}$$
$$L_{0_1} = \text{ultimate BOD} = L_{02}$$
$$t_2 = 2.5 \text{ days}$$
$$k_{D_2} = ?$$

$$\because \quad \frac{Y_1}{Y_2} = \frac{1 - 10^{-k_{D_1} t_1}}{1 - 10^{-k_{D_2} t_2}}$$

$$\Rightarrow \quad \frac{180}{180} = \frac{1 - 10^{-0.0781 \times 5}}{1 - 10^{-k_{D_2} \times 2.5}}$$

$$\Rightarrow \quad 10^{2.5 k_{D_2}} = 10^{0.3906}$$

$$\Rightarrow \quad k_{D_2} = \frac{0.3906}{2.5} = 0.15624$$

$$\text{Now} \quad k_{D_2} = k_{D_1}(1.047)^{T-20}$$

$$\Rightarrow \quad 0.15624 = 0.434 \times 0.18\,(1.047)^{T-20}$$

$$\Rightarrow \quad 2 = (1.047)^{T-20}$$

$$\Rightarrow \quad \log 2 = (T - 20) \log 1.047$$

$$\Rightarrow \quad T = 35.09°C$$

Ans.22 (a)

BOD in mg/L= [Initial *DO* – Final *DO*] × dilution factor

$$[BOD_5]_1 = (9.2 - 6.9) \times \frac{300}{5} = 138 \text{ mg/L}$$

$$[BOD_5]_2 = (9.1 - 4.4) \times \frac{300}{10} = 141 \text{ mg/L}$$

As final DO and 3[rd] sample is zero, hence the sample is discarded.

$$\text{Average}BOD_5 = \frac{138 + 141}{2}$$

$$= 139.5 \text{ mg/L}$$

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