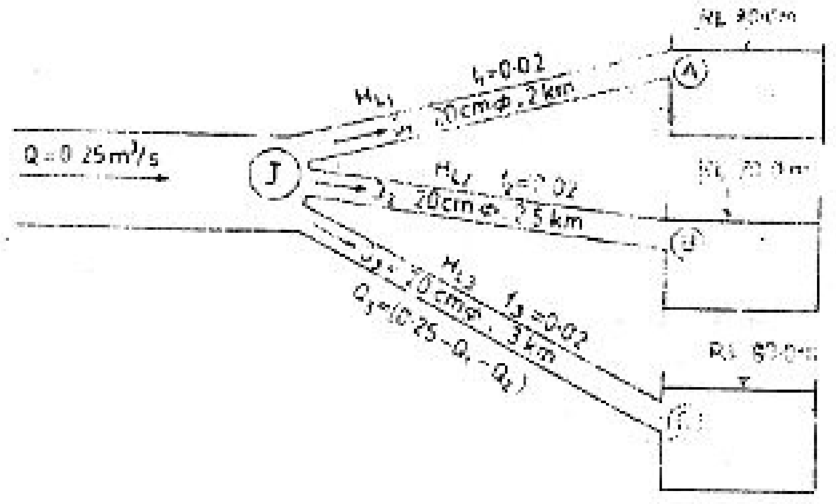
Solution. Analysing the given data using Bernoulli's equation.



Pressure at $J = 80 + \frac{p_a}{w} + H_{L_1}$

$$= 70 + \frac{p_a}{w} + H_{L_2}$$

$$= 60 + \frac{p_a}{w} + H_{L_3}$$

$\therefore \quad H_{L_1} + 10 = H_{L_2};$

and $\quad H_{L_2} + 10 = H_{L_3}$

where, $\quad H_{L_1} = \dfrac{fLQ^2}{2gd.\left(\frac{\pi}{4}\right)^2.d^4}$

$$= \frac{0.2 \times 2000 \times Q_1^2}{2 \times 9.81 \times \left(\frac{\pi}{4}\right)^2 (0.2)^5}$$

$$= 1,03,388\ Q_1^2$$

Similarly, $H_{L_2} = \dfrac{0.2 \times 2500 \times Q_2^2}{2 \times 9.81 \times \left(\frac{\pi}{4}\right)^2 (0.2)^5}$

$$= 1,29,234\ Q_2^2$$

$\therefore\ 1,03,388\ Q_1^2 + 10 = 1,29,234\ Q_2^2$

or $\quad Q_1 = \sqrt{\dfrac{1,29,234\ Q_2^2 - 10}{1,03,388}}$

$$H_{L_3} = \frac{0.2 \times 3000 \times (0.25 - Q_1 - Q_2)^2}{2 \times 9.81 \times \left(\frac{\pi}{4}\right)^2 (0.2)^5}$$

$$= 1,55,081\,[0.25 - Q_1 - Q_2]^2$$

But $H_{L_2} + 10 = H_{L_3}$

$\therefore\ 1,29,234\,Q_2^2 + 10$

$$= 1,55,081\left[0.25 - \sqrt{\frac{1,29,234\ Q_2^2 - 10}{1,03,388}} - Q_2\right]^2$$

Solving by trial,

we get $\quad Q_2 = 0.0296\ m^3/s$

$\therefore \quad Q_1 = 0.1921\ m^3/s$

and $\quad Q_3 = 0.25 - 0.1921 - 0.0296$

$= \mathbf{0.0283}$

SYSTEM OF SANITATION

(i) Old conservancy system

(ii) Modern water

Types of sanitary sewage:

(i) Domestic sewage

(ii) Industrial sewage

(iii) Storm sewage

Types of Sewerage system :

(i) Combined system

(ii) Separate system

(iii) Partially separate system

ESTIMATING THE MAXIMUM SEWAGE DISCHARGE

Components of sewerage system

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

- The pipes should be designed to flow under gravity with 1/2 to 3/4 th full.
- Quantity of sewage produced = Quantity of water supplied from the water work

  + unaccounted private water supplies

  + Infiltration – water loses

  – water not entering the sewerage system.
- Net quantity of sewage produced = 70 to 80% of water supplied
- **For branch sewers:**

  Maximum daily flow = 2 times the average daily flow.

  Maximum hourly flow = 3 times the average daily flow.

Hourly variations in sewage flow:

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

- Sizes of the sewers can be easily designed for carrying computed maximum hourly flows, with sewers running 3/4th full.

Peak sewage flow: $Q_{max} = \frac{18+\sqrt{P}}{4+\sqrt{P}} Q_{av}$.

where P = Population in thousand.

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

For branch sewer,

$$\text{Minimum daily flow} = \frac{2}{3} \times \text{Average daily}$$

$$\text{Minimum hourly flow} = \frac{1}{3} \times \text{Average daily}$$

$$= \frac{1}{2} \times \text{minimum daily flow}$$

The sewers must therefore be checked for minimum velocities at there minimum hourly flows (*i.e.* 1/3 rd Average daily).

Estimating the peak drainage discharge

- The minimum sewage discharge through combined sewerage system during non-monsoon period is known as *dry weather flow (D. W.F).*
- The drainage discharge, which is produced during monsoon season is generally very high, say 20 to 25 times that of the sewage discharge called *dry weather flow (D. W.F).*
- The partial separate sewers may be designed for carrying the sewage discharge plus part of the storm drainage particularly that coming from the roofs and courtyards.
- The experts have recommended 2 year rain frequency for designing smaller link drains and 5 years frequency for designing all the major drains.

Estimating Peak Runoff

Factor affecting runoff are :

(*i*) Type of precipitation
(*ii*) Intensity and duration of rainfall
(*iii*) Rainfall distribution
(*iv*) Soil moisture defficiency
(*v*) Direction of the prevailing storm
(*vi*) Climatic condition
(*vii*) Shape, size and type of catchment basin, etc.

RATIONAL FORMULAE FOR COMPUNTIY PEAK DRAINAGE DISCHARGE

- The period after which the entire area will start contributing to the runoff is called the *time of concentration.*
- Time of concentration of a drainage basin may be defined as the time required by the water to reach the outlet from the most remote point of the drainage area.
- It has been established that the maximum runoff will be obtained from the rain having a duration equal to the time of concentration and this duration of rainfall is called the critical rainfall duration and the rainfall intensity during initial critical duration is called *critical rainfall intensity.*

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

It is applicable when A < 50 hectare.

where, Q_p = peak rate of run off in cumecs.

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

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

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

- The intensity of rainfall can be determined with the help of automatic rain gauges.
- The average intensity of rainfall can be determined by non-recording type rain gauge.

Time of concentration for a given storm water drain:

It generally consists of two parts:

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

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

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

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

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

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

The total time of concentration at a given point in the drain, for working out the discharge at point, can be obtained as

$$T_c = T_i + T_f$$

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

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

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

where P_0 = one hour rainfall × areal distribution factor

T_c = time of concentration in hours

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

where, T = time in minutes

i.e., $P_c = \frac{75}{t_e + 10}$ *for* T_c varies between 5 to 20 minutes.

and $P_e = \frac{100}{T_c + 20}$ for T_c varies between 20 to 100 minutes.

- Besides the above general equations, certain other empirical equation suggested are:

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

(*b*) $P_c = \frac{38}{\sqrt{T_c}}$ for rains having frequency of 10 years

(*c*) $P_c = \frac{15}{t^{0.620}}$ for rains having frequency of 1 year

(*d*) Kuichling's formula's

$P_c = \frac{267}{T_c + 20}$ for storm having frequency of 10 years

$P_c = \frac{305}{T_c + 20}$ for storm having frequency of 15 years

Peak Drainage Discharge Computation by the use of Empirical Formula

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

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

   M = catchment area in km^2

   Q_p is in cumecs

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

   where, M is area in sq. km., Q_p is peak discharge in cumec and C_1 is a constant.

   value of C_1 = 6.8

3. **English formula:** $Q_p = 123\sqrt{M}$

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

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

   The total area A of the district can be considered to be made up of smaller areas A_1, A_2, A_3, ----- A_n, having run of ratio (*i.e.* co-efficient of runoff) k for the entire area may be computed by using.

$$k = \frac{\Sigma kA}{\Sigma A} = \frac{k_1 A_1 + k_2 A_2 + ------- + k_n A_n}{A_1 + A_2 + ---- + A_n}$$

Hydraulic Design of Sewers and Storm Water Drain Sections

1. The hydraulic design of sewers and drains, which means finding out their sections and gradients.
2. In order to avoid clogging or silting of sewers, it is necessary that the sewer pipes to be of such a size and laid at such a gradient, so as to generate self-cleaning velocities at different possible discharge.
3. Generally, the sewer pipes of sizes less than 0.4 m diameter are designed as running half full at maximum discharge, and the sewer pipes greater than 0.4 m in diameter are designed as running 2/3rd or 3/4th full at maximum discharge.

Hydraulic formulas for determining flow velocities in Sewers and Drains.

1. **Chezy's formula:** $V = C\sqrt{RS}$

   where, V = velocity of flow in metre per second,

   S = hydraulic gradient

   R = hydraulic mean depth

   $W = \frac{\text{Area of channel } (a)}{\text{vetted perimeter } (p)}$

   C = Chezy's constant

   The Chezy's constant depends upon various factors such as the size and the shape of channel, roughness of the channel surface, the hydraulic characteristics of the channel, etc.

2. **Manning's formula:**

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

   where, n = Manning's constant and $\frac{1}{n}$ = 835,

   or n = 0.012

3. **Crimp and Burge's formula:**

$$V = 83.5\, R^{2/3} S^{1/2}$$

4. **William-Hazen's formula:**

$$V = 0.85\, C_H R^{0.63} S^{0.54}$$

   The channel section can be designed by using,

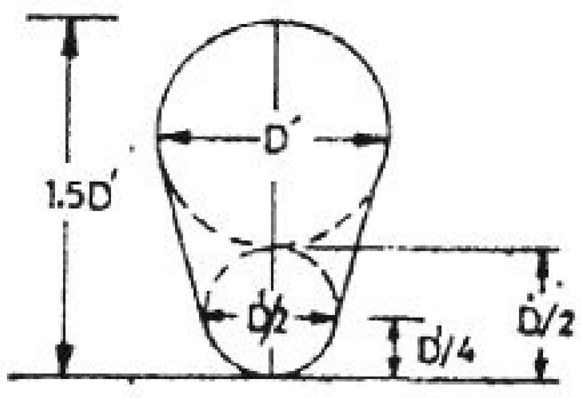
$$Q = AV$$

larger sewers may be designed for $\frac{3}{4}$ depth at ultimate peak design flow.

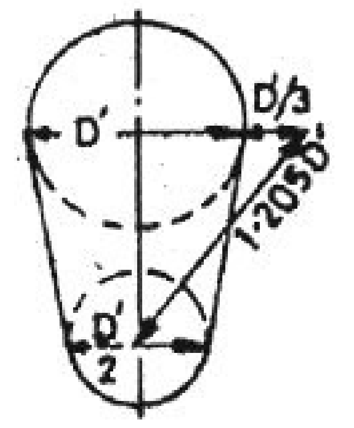
- Two sewers of different shapes are said to be hydraulically equivalent when they discharge at the same rate, while running full, on the same grade.

Egg Shaped Sewer

$$D_{egg} = 0.84\ D_{cir}$$



(a) Standard or Metropolitan egg shaped section



(b) New egg shaped section

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

SEWERS, THEIR CONSTRUCTION, MAINTENANCE, AND REQUIRED APPURTENANCE

The sewers are generally designed to flow under gravity except outfall reverse.

Forces Acting on Sewer Pipes:

Outfall sewers carries the treated and pumped sewage into the discharging source and hence flow full under pressure. Hence forces acting on sewer pipes are

1. Internal pressure of sewage
2. Pressure due to external loads
3. Temperature stresses; and
4. Flexural stresses
   - The pressure exerted by the sewage from inside the pipe when running full is called *internal pressure*.
   - When pipes are to be used as pressure pipes, they must be strong in tension.

SEWER MATERIALS

1. **Asbestos cement sewers:** It is best suited to be used as verticals for bringing down either the rain water from the roofs, or the comparatively foul sullage from kitchens and bathrooms situated at the upper floors of the buildings.
   - Precast pipe : cast in factories.
   - Cast in situ pipes: cast at site.
2. **Plain cement concrete and Reinforced Cement Concrete Sewers**
   - The usual mixt is 1 : 1½ : 3,
   - Size of aggregate is limited to 6 mm.
   - Reinforced cement concrete (R.C.C) pipes are those concrete pipes which are provided with circumferential reinforcement to carry internal or external stresses, and a nominal longitudinal reinforcement equal to 0.25 % of the cross-section area of concrete.
3. **Vitrified clay or stoneware or salt-glazed sewers:** It is widely used for carrying sewage and drainage, as house connections as well as lateral sewers.
4. **Brick sewers :** Preformed for constructing large sized combined sewers or particularly for stone water drains.
5. **Cast iron sewers:** Manufactured by two methods:
   (*i*) sand moulding method,
   (*ii*) Centrifugal process.

SEWER APPURTENANCES

1. Manholes
2. Drop manholes
3. Lampholes
4. Clean-outs
5. Street inlets called Gullies
6. Catch basins
7. Flushing tanks
8. Grease and oil traps
9. Inverted siphons; and.
10. Storm regulators

MANHOLES

- Manholes are masonry or R.C.C chambers, constructed at suitable intervals along the sewer lines for providing access into the sewers.
- The spacing of manholes is more on large sized sewers, because they can be entered more easily by men for inspection.

QUALITY AND CHARACTERISTICS OF SEWAGE

- A well oxidised sewage will contains nitrates and sulphates, but very little ammonia and hydrogen sulphide. On the other hand, lesser oxidised sewage will contain nitrates and sulphur instead of nitrates and sulphates.
- *Treatment units which work on oxidation alone (i.e. aerobic decomposition) are :*

  Aeration tanks, contact beds, intermittent sand filters, trickling filters and oxidation ponds.
- *Treatment units, which work on putrefaction alone (i.e. anaerobic decomposition) are :*

  Septic tanks, inhoff tanks, sludge digestion tanks and anaerobic lagoons.

CHARACTERISTICS OF SEWAGE

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

1. Physical characteristics :

(*i*) Turbidity
(*ii*) Colour
(*iii*) Odour, and
(*iv*) **Temperature :** When the temperature of sewage is more, the D.O. content of sewage gets reduced. When all the oxygen has disappeared from sewage, it becomes septic.

2. Chemical characteristics of sewage :

(*i*) Total solids, suspended solids, and settleable solids
(*ii*) pH value
(*iii*) Chloride content
(*iv*) Nitrogen content
(*v*) Presence of fats, greases, and oils
(*vi*) Sulphides, sulphates and H_2S gas
(*vii*) Dissolved oxygen (D.O.)
(*viii*) Chemical oxygen demand (C.O.D.)
(*ix*) Biochemical oxygen demand (B.O.D.)

- Approximate percentage of water in sewage in 99.9 %.
- Specific gravity of sewage is slightly greater than 1.
- 1000 kg of sewage is estimated to contain, approximately, total solid equal to 0.5–1 kg.
- Imhoff cone is used to measure, settleable solids in sewage.
- pH of fresh sewage is usually more than 7.
- The normal chloride content of domestic sewage is 120 mg/l, whereas, the permissible chloride content for water supplies is 250 mg/l.
- The chloride content can be measured by the waste water with standard silver nitrate solution, using potassium chromate as indicator.
- Methaemoglobinemia disease is caused in children, by conversion of nitrates to nitrites.

Sulphides, Sulphates and Hydrogen sulphide gas:

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

$$CO_2 + NH_3 + H_2S$$

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

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

Dissolved oxygen (D.O) :

- If the temperature of sewage is more, the D.O. content will be less.
- The solubility of oxygen in sewage is 95% of that in distilled water.
- The D.O. content of sewage is generally determined by the Winker's method's which is a oxidation reduction process
- Minimum D.O. prescribed for a river stream, to avoid fish billing is 4 ppm.

Chemical Oxygen Demand (C.O.D).

The organic matter is of two types:

(*i*) Biologically active or biologically degradable
(*ii*) Biologically inactive.

- C.O.D. test gives the total of biologically active as well as biologically inactive organic matter.

Biochemical Oxygen Demand (BOD)

- The BOD of water during 5 days at 20°C is generally taken as the standard demand and is about 68% of the total demand. A 10 day BOD is about 90% of the total.
- BOD or BOD_5

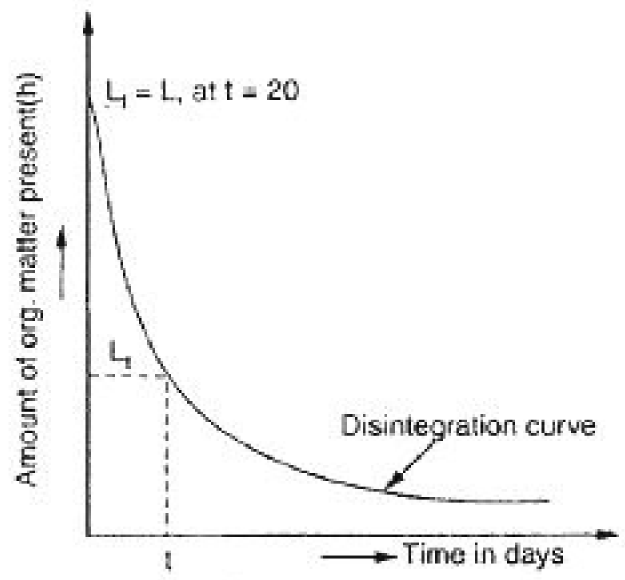
$$= \text{D.O. consumed in the test by the diluted sample} \times \left(\frac{\text{Volume of the diluted sample}}{\text{Volume of the undiluted sewage sample}}\right)$$

$$= \text{D.O. consumed} \times \text{Dilution factor.}$$

- During B.O.D. test, light must be excluded from the incubator to promote algal growth that may produce oxygen in the bottle.
- The first demand during the first 20 days or so, in fact, occurs due to the oxidation of organic matter; and is called *Carbonaceous demand* or *first stage demand or initial demand.*

  The latter demand occurs due to biological oxidation of ammonia, and is called *Nitrogeneous demand* or *second stage demand.*
- The term BOD is usually used to mean the first stage BOD, *i.e.* the demand due to the presence of carbonaceous matter alone.

- The rate at which BOD is satisfied at any time depends on temperature and also on the amount and nature of organic present in sewage at that time.



$$\frac{dL_t}{dt} = -kL_t$$

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

t = time in days.

k = rate constant its unit is per day.

Taking log, we have $\log_e \frac{L_t}{L} = -k.t$

$$\therefore \quad \log_{10} \frac{L_t}{L} = \frac{-k.t}{2.3} = -\ 0.439\ k.t.$$

$$\log_{10} \frac{L_t}{L} = -\ k_D.t$$

where, k_D = de-oxygenation constant or more strictly, the BOD rate constant

(on base 10) at given temperature of 0.434 K

i.e., k_D is a constant on base 10, as against the k which is on base e.

$$i.e. \quad \left(k_D = \frac{k}{2.3}\right) = 0.1 \text{ to } 0.15$$

$$\therefore \quad \frac{L_t}{L} = (10)^{-k_D.t}$$

where, L_t =organic matter left after t days.

Quantity of organic matter oxidised $= L - L_t$

If Y_t represents the total amount of organic matter oxidised in t days (*i.e.* the BOD after t days), then

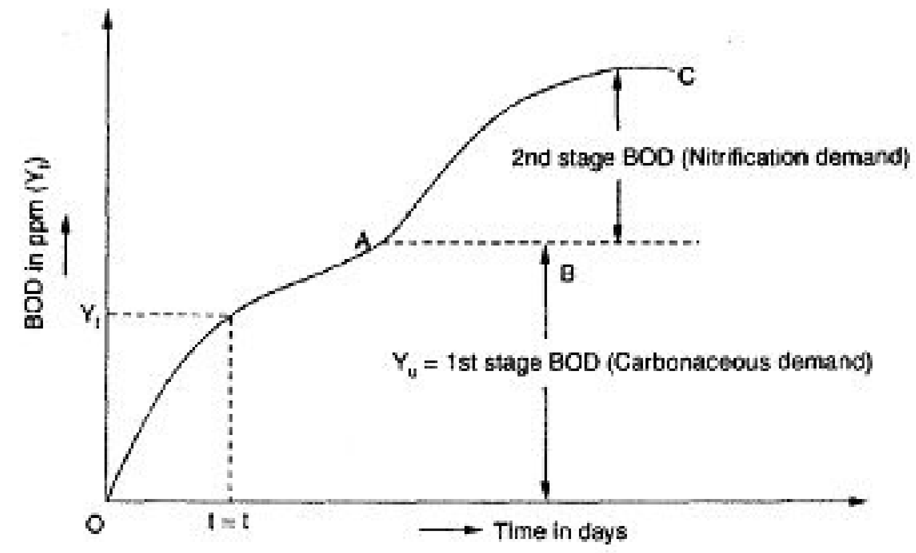
$$Y_t = L - L_t = L - L(10)^{-k_D.t}$$

$$= L\,[1 - 10^{-k_D.t}]$$

- Y_t is the oxygen absorbed in t days, *i.e.* BOD of t-days.
- The ultimate first stage BOD, $(Y_u) = L\ (t = \infty)$
- This is the fixed quantity, and does not depend upon the temperature of oxidation.

$$k_D\,(T.) = k_D\,(20.)\,[1.047]^{T-20}.$$

- k_D will be higher at higher temperature, which means that the speed at which BOD is consumed in the oxidation of the organic matter, is higher at higher temperature. This means that the entire carbonaceous organic matter will get oxidised quickly and in lesser time at higher temperature.



OA = 1st stage or carbonaceous demand

AC = 2nd stage or Nitrification demand.

OAC = Curve for combined demand or combined BOD curve.

Hence, the BOD curve for the complete Oxidation is represented by OAC.

- Values of 5 days 20°C BOD of municipal waste water generally vary between 100 to 500 mg/l.
- $COD > BOD_U$
- $COD - BOD_U$ = Non-biodegradable organics
- If this ratio is found to be between 0.92 to 1.0, the waste water can be considered to be virtually fully biodegradable.

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

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

$$\frac{BOD_5}{COD} = 0.68 \times 0.92 \text{ to } 1 \times 0.68$$

$$= 0.63 \text{ to } 0.68 \text{ for fully biodegradable.}$$

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

Total organic carbon (TOC) : Total carbonaceous organics present in a given waste water can be as certained by computing TOC of the waste water.

$\frac{COD}{TOC}$ ratios is considered to be an important factor in waste treatments, and is equal to = 2.66

POPULATION EQUIVALENT

It indicates the strength of industrial waste water for estimating the treatment required at the municipal reverse treatment plant.

- Standard BOD (5 days) of industrial sewage

  = Standard BOD (5 days) of domestic sewage per person per days × population equivalent.

  Average BOD_5 of domestic sewage = 0.08 kg./day/person

  Hence, Population equivalent

  $$= \frac{\text{Total BOD}_5 \text{ of the industry in kg./day}}{\text{0.08 kg./day/Person}}$$

  Relative stability. It is the ratio of oxygen available in the efficient to total oxygen required to satisfy its first stage B.O.D demand

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

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

  $$= [1 - 10^{-k_D t}] \times 100$$

$\therefore \quad S = 100\,[1 - (0.794)\,t_{20}]$

or $\quad S = 100\,[1 - (0.630)t_{37}]$

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

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

DISPOSAL OF THE SEWAGE EFFLUENTS

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

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

(*ii*) **Effluent irrigation or Broad irrigation or sewage farming,** *i.e* disposal on land.

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 what is known as self *purification process of natural waters*.

Standards of Dilution for discharging of waste water into rivers.

Standards of Dilution Based on Royal Commission Report.

Dilution factor	*Standards of Purification required*
Above 500	No treatment such as 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	Treatment such as sedimentation, screening and essentially chemical precipitation are required. The sewage efficient 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 BOD_5 at 18.3. should not exceed 20 ppm.

- Dissolved oxygen in streams is maximum at noon.
- Tolerance limit for sewage effluent discharged into surface water sources as per IS: 4764–1973 is

  BOD_5 – 20 mg/l

  TSS – 3 mg/l

Dilution in Rivers and self purification of Natural streams.

- When sewage is discharged into a natural body of water, the 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 phenomenon*.

Various natural forces of purification which affect self-purification process:

1. **Physical forces:**

   (*i*) Dilution and dispersion.

   (*ii*) Sedimentation; and

   (*iii*) Sun light (acts through bio-chemical reactions).

2. Chemical forces aided by biological forces:

(*iv*) Oxidation (Bio); and

(*v*) Reduction.

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

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

(*ii*) Sedimentation.

(*iii*) Sun-Light: The sun light has a bleaching and stabilising effect of bacteria.

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

(*v*) Reduction

- *Natural forces of purification depends on* :
  (*a*) Temperature
  (*b*) Turbulence
  (*c*) Hydrography
  (*d*) Available dissolved oxygen and the amount and type of organic matter present; and
  (*e*) Rate of reaeration, etc.
- At higher temperature, the capacity to maintain the D.O. concentration is low; while the rate of biological and chemical activities are high, causing thereby rapid depletion of D.O.
- The larger amount of D.O. present in water, the better and earlier the self-purification will occur.
- Algae which absorbs CO_2 and gives oxygen, is thus, very helpful in the self-purification process.

Zone of pollution in a River-stream:

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

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

(*ii*) Zone of active decomposition : This zone is marked by heavy pollution. It is characterised by water becoming greyish and darker than in the previous zone. D.O. concentration falls down to zero, and anaerobic conditions may set in with the evolution of gases like CH_4, CO_2, H_2S etc.

(*iii*) Zone of recovery : In this zone B.O.D. falls down and D.O. content rises above 40% of the saturation value. The organic material will be mineralised to form nitrates, sulphates, phosphates, carbonates etc.

(*iv*) Zone of clear water : In this zone, the river attains its original conditions with D.O. rising up to the saturation value.

- When once a river water has been polluted, it will not be safe to drink it, unless it is properly treated;

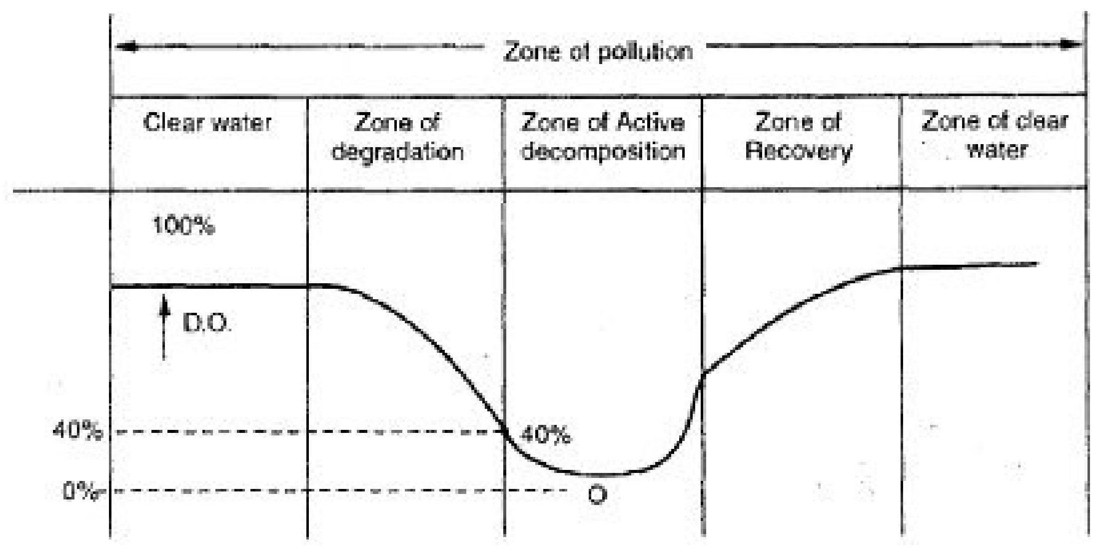
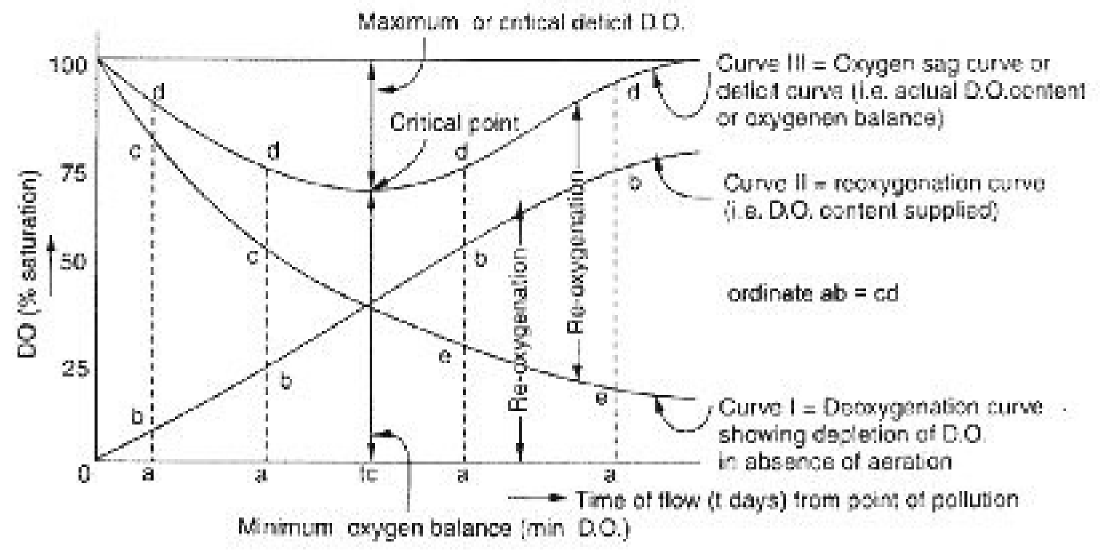


Fig. Dissolved oxygen sag curve

Oxygen Deficit of a Polluted River Stream:

- Oxygen deficit (D) = Saturated D.O. – Actual D.O.
- Oxygen deficit can be found out by knowing the rates of de-oxygenation and re-oxygenation.
- If de-oxygenation is more rapid than the re-oxygenation, an oxygen deficit results.
- If the D.O. content becomes zero, aerobic conditions will no longer be maintained and putrefaction will set in.
- The amount of resultant oxygen deficit can be obtained by algebraically adding the deoxygenation and re-oxygenation curves. The resultant so obtained is called the *oxygen sag curve* or the *oxygen deficit curve*. From this curve, the oxygen deficit and oxygen balance (*i.e.* 100 – D) in a stream after a certain lapse of time, can be found out as :

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



This equation is known as **Streeter - Phelps** equation

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

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

D_0 = initial oxygen deficit of the mixture at the mixing point in mg/l.

k_D = de-oxygenation co-efficient. Typical values of $k_{D\,(20)}$ vary between 0.1 to 0.2

k_R = re-oxygenation co-efficient for the stream. It can be determined by the field tests by using equation:

$$k_{D(20.)} = \frac{3.9\sqrt{v}}{y^{1.5}}$$

where, v = average stream velocity in m/s.

y = average stream depth in m.

k_R = varies with temperature as,

$$k_R(T) = k_{R(20)}[1.016]^{T-20}$$

- The critical time (t_c) after which the minimum dissolved oxygen occurs can be found by differentiating Streeter–Phelps and equating it to zero.

$$t_c = \left[\frac{L}{k_R - k_D}\right]\log\left[\left\{\frac{k_D L - k_R D_0 + k_D D_o}{k_D L}\right\}\frac{k_R}{k_D}\right]$$

and the critical or maximum oxygen deficit is given by

$$D_C = \frac{k_D L}{k_R}[10]^{-k_D t_c}$$

- The constant $\frac{k_R}{k_D} = f$ called *self purification constant*.

Then, above equation reduced to

$$D_C = \frac{k_D L}{k_R}[10]^{-k_D t_c}$$

or $$t_c = \frac{1}{k_D(f-1)}\log_{10}\left[\left\{1-(f-1)\frac{D}{L}\right\}f\right]$$

and $$D_c = \frac{L}{f}[10]^{-k_D t_c}$$

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

The above equations are of practical value in predicting the oxygen content at any point along a stream.

- The saturated D.O. at 20°C = 9.17 $\frac{mg}{l}$ from table.

Disposal of waste waters in Lakes and Management of Lake waters.

- The study of lakes is called *limnology*.
- Aerobic depth of water in a lake is called epilimnion zone. The lower depth of lakes which remains cooler, poorly mixed and anaerobic called the hypolimnion zone.
- In winter season entire depth of lakes behaves aerobic.

Biological zones in lakes:

(*i*) Euphotic zone

(*ii*) Littoral zone; and

(*iii*) Benthic zone.

As compared to fresh river water, sea water contains 20% less oxygen.

DISPOSAL ON LAND

Disposal of Sewage Effluents on Land for Irrigation:

In this method, the sewage effluent (treated or diluted) is generally disposed off by applying it on land. The percolating water may either join the water table, or is collected below by a system of underdrawins and can be easily disposed into some natural water sources, without any further treatment.

- The degree of treatment of raw sewage depend upon the type of soil of the land. If this soil, to be irrigated, is sandy and porous, the sweage effluent may contain more solids and other wastes, and thus lesser treatment, as compared to the case where the soil is less porous and sticky

  If 100 hectares is capable of passing 5250 m^3 per day, then

  1 hectare is capable of passing $\frac{5250}{100}$ = 52.5 m^3 per hectare

  Hence consuming capacity of soil = 52.5 m^3 per hectare per day

Quality Standards For Waste Water Effluents to be Discharged on Land For Irrigation.

Characteristic/Constituent of effluent waste water	*Tolerance limit as per IS : 3307-1965*
BOD_5	500 mg/l
pH value	5.5 to 9.0
Total Dissolved Solid (TDS)	2100 mg/l
Oil and grease	30 mg/l
Chlorine (as CL)	600 mg/l
Boron	2mg/l
Sulphates	1000 mg/l

Effluent irrigation and sewage farming:

Although, outwardly, both these terms are used as synonyms to each other, yet there is one basic difference between them. In effluent irrigation (or broad irrigation), the chief consideration is the successful disposal of sewage, while in sewage farming, the chief consideration is the successful growing of the crops.

Sewage Sickness:

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. The time taken for such a clogging will, of course depend upon the type of soil and the load present in sewage. But when once these voids are clogged, free circulation of air will be prevented, and anaerobic condition will develop within the pores. Due to this, the aerobic decomposition of organic matter will stop, and anaerobic decomposition will start. The organic matter will thus, of course, be mineralised, but with the evolution of foul gases like H_2S, CO_2 and CH_4. This phenomenon of soil getting clogged is known as *sewage sickness*.

In order to prevent the sewage sickness of a land, the following preventive measures may be adopted.

(*i*) Primary treatment of sewage

(*ii*) Choice of land

(*iii*) Under-drainage of soil

(*iv*) Giving rest to the land

(*v*) Rotation of crops

(*vi*) By sweage in shallow depths.

TREATMENT OF SEWAGE

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

Classification of Treatment Processes :

1. **Preliminary Treatment:** It consists solely in separating the floating materials and also heavy settleable inorganic solids. This treatment reduces the BOD of the waste water by about 15 to 30%. Screening is done for removing floating papers, rags, clothes etc. Grit chambers or detrious tank removes grit and scud. Skimming tank is used for removing oils and greases.
2. **Primary treatment:** It removes large suspended organic solids. This is accomplished by sedimentation in settling besins. The effluent contains a large amount of suspended organic material and has a high BOD (about 6% of original)
3. **Secondary or Biological treatment:** Secondary treatment involves further treatment of the effluent, coming from the primary sedimentation tank. This is generally accomplished through biological decomposition of organic matter which can be carried out either under aerobic or anaerobic conditions. In these biological units, bacteria will decompose the fine organic matter to produce clear effluent.

The treatment reactors, in which the organic matter decomposes (oxidised) by aerobic bacteria are known as *aerobic biological units;* and may consist of

(*i*) Filters;

(*ii*) Aeration tanks; and

(*iii*) Oxidation ponds and Aerated lagoons.

Since all these aerobic units, generally make use of primary settled sewage, they are easily

classified as secondary units.

The treatment reactors, in which the organic matter is destroyed and stabilised by anaerobic,

bacteria are known as *anaerobic biological units* and may consists of

(*i*) Anaerobic lagoons;

(*ii*) Septic tanks;

(*iii*) Imhoff tanks, etc.

Out of these units, only an aerobic lagons, make use of primary settled sewage, and hence, only

they can be classified as secondary units.

- Septic tanks and imhoff tanks using raw sewage, are, therefore, not classified as secondary units.
- The sewage treatment is usually confined upto secondary treatment only