MODULE 3 : STREAM SANITATION

The self purification of natural water systems is a complex process that often involves physical, chemical, and biological processes working simultaneously. The amount of Dissolved Oxygen (DO) in water is one of the most commonly used indicators of a river health. As DO drops below 4 or 5 mg/L the forms of life that can survive begin to be reduced. A minimum of about 2.0 mg/L of dissolved oxygen is required to maintain higher life forms. A number of factors affect the amount of DO available in a river. Oxygen demanding wastes remove DO; plants add DO during day but remove it at night; respiration of organisms removes oxygen. In summer, rising temperature reduces solubility of oxygen, while lower flows reduce the rate at which oxygen enters the water from atmosphere.

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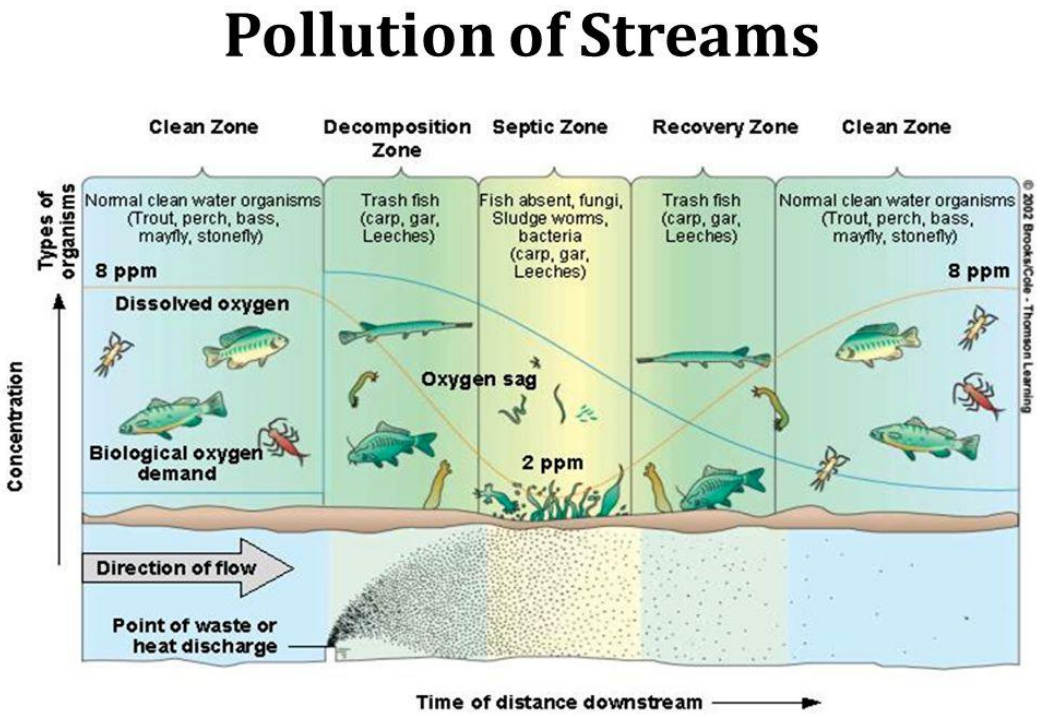
ZONES OF POLLUTION: A polluted stream undergoing self-purification presents the following four distinct zones of pollution

(1) ZONES OF DEGRADATION: This usually occurs below the output sewer when discharge its contents into the stream. The zone is characterized by water becoming dark and turbid with the formation of sludge deposits on the bottom. Dissolved oxygen gets reduced to 40%. There is an increase in the carbon dioxide content, reaeration occurs but is slower than deoxygenation. Conditions are unfavorable to the development of aquatic life; fungi at higher, points and bacteria at lower points breed small worms, which “work over” and stabilize the sewage sludge.

(2) ZONES OF ACTIVE DECOMPOSITION: this is marked by heavy pollution. It is characterized by the absence of dissolved oxygen; water is grayish and darker with active anaerobic organic decomposition accompanying and with the evolution of methane (CH_4), Hydrogen sulphide (H_2S), Carbon dioxide (CO_2) and Nitrogen (N_2), bubbling to the surface with masses of sludge forming black scum. Fish life is practically absent, fungi and bacteria disappear. As the organic decomposition slackens, reaction sets in and D.O. again rises to its original level (i.e. 40%).

(3) ZONE OF RECOVERY: In this zone the stream tries to recover its former appearance. Most of the organic matter has been settled as sludge, B.O.D. falls and the D.O. content rises above 40% microscopic aquatic life reappears. Water becomes clearer, fungi decrease and algae reappear. Mineralization is active and products such as nitrates, sulphates, and carbonates are formed.

(4) CLEAR WATER ZONE: In this the natural stream condition is restored, the D.O. is higher than the BOD oxygen balance (D.O. minus total B.O.D. in the first stage) is attained and recovery is said to be complete. Water becomes attractive in appearance. Some pathogenic organisms may, however be present.



Factors Affecting Self Purification :

1.Dilution: When sufficient dilution water is available in the receiving water body, where the wastewater is discharged, the DO level in the receiving stream may not reach to zero or critical DO due to availability of sufficient DO initially in the river water before receiving discharge of wastewater.

2.Current: When strong water current is available, the discharged wastewater will be thoroughly mixed with stream water preventing deposition of solids. In small current, the solid matter from the wastewater will get deposited at the bed following decomposition and reduction in DO.

3.Temperature: The quantity of DO available in stream water is more in cold temperature than in hot temperature. Also, as the activity of microorganisms is more at the higher temperature, hence, the self-purification will take less time at hot temperature than in winter.

4.Sunlight: Algae produces oxygen in presence of sunlight due to photosynthesis. Therefore, sunlight helps in purification of stream by adding oxygen through photosynthesis.

5. Rate of Oxidation: Due to oxidation of organic matter discharged in the river DO depletion occurs. This rate is faster at higher temperature and low at lower temperature. The rate of oxidation of organic matter depends on the chemical composition of organic matter.

<u>EFFECT ON INDUSTRIAL WASTES ON SELF PURIFICATION OF STREAMS AND FISH LIFE</u>

- The effect of wastewater on the water environment may be physical, chemical and iological.
- Physical effect includes increase in turbidity and suspended solids, addition of color, taste and odor producing substances, and formation of sludge banks on the beds and sides of the water bodies.
- Industrial wastes such as coolingwaters from power stations, dyeing and printing wastes from textile industry, spent wash from alcohol istilleries etc raise the temperature of water in the receiving body and reduce the DO content in it.
- These conditions impart an aesthetically unacceptable appearance to the water, create an environment unsuitable for aquatic creatures such as fish, render it difficult to treat, and initiate the chain of chemical and biological effects.
- Chemical effects include a drastic change in the pH value of the receiving water due to a discharge of acidic wastes such as mine drainages or alkaline wastes such as textile wastes.
- High chlorides renders the water unacceptable as a source of drinking water, high sulphates, under favorable circumstances tend to form hydrogen sulphide and produce malodorous condition, nitrates and phosphates encourage algal and other aquatic growths, toxic and inhibitory substances either wipe out the aquatic life or severely limit its growth and reduce the available DO in the water.
- The DO may even become zero in the presence of a slag of oxygen-demanding wastewater.
- Biological industrial wastes alone are not very serious because many of them do not contain pathogenic organisms that are present in domestic sewage.

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- When industrial wastes are discharged in combination with domestic sewage, biological effects become significant although a large number of micro-organisms in the sewage are killed by unfavourable environmental conditions in the industrial waste.
- The physical and chemical effects have an adverse effect on the aquatic life, turbidity and suspended solids, along with color, cut-off penetration of sunlight into the water and reduce photosynthetic activity.
- Suspended solids can choke the gills of fish and kill them. Organic suspended solids settle to the bottom of the receiving body of water and in the presence of micro-organisms, decompose anaerobically.
- The products of anaerobic decomposition gradually diffuse to the upper layers of water and add to the total oxygen demand.
- Anions such as chlorides, sulphates add to the total dissolved solids content of the water and interfere with the metabolic process of micro-organisms. Nitrates and phosphates encourage enormous algal growth in the water.
- Organic waste and ammonia which come from domestic sewage and industrial waste of plants and animal origin, contribute to the reduction of oxygen in the receiving stream.
- The wastes are ususally degraded or decomposed by bacteria. The bacteria need or utilize oxygen during this process.
- As the oxygen is depleted , fish and other aquatic life that depend on the oxygen to live, start to die.
- Low- dissolved oxygen levels due to oxygen demand also may significantly delay the process of self purification of stream.
- Typically, industrial wastes that have high oxygen demand are sulfite wastes liquors from pulp mills. Effluents from canning plants, metal packing wastes, textile scouring ad dying effluent, wastes from milk production and fermentation wastes.

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OXYGEN SAG ANALYSIS

The oxygen sag or oxygen deficit in the stream at any point of time during self purification process is the difference between the saturation DO content and actual DO content at that time.

Oxygen deficit, D = Saturation DO – Actual DO

The saturation DO value for fresh water depends upon the temperature and total dissolved salts present in it; and its value varies from 14.62 mg/L at 0^oC to 7.63 mg/L at 30^oC, and lower DO at higher temperatures. The DO in the stream may not be at saturation level and there may be initial oxygen deficit 'Do'. At this stage, when the effluent with initial BOD load L_o, is discharged in to stream, the DO content of the stream starts depleting and the oxygen deficit (D) increases. The variation of oxygen deficit (D) with the distance along the stream, and hence with the time of flow from the point of pollution is depicted by the 'Oxygen Sag Curve. The major point in sag analysis is point of minimum DO, i.e., maximum deficit. The maximum or critical deficit (Dc) occurs at the inflexion points of the oxygen sag curve.

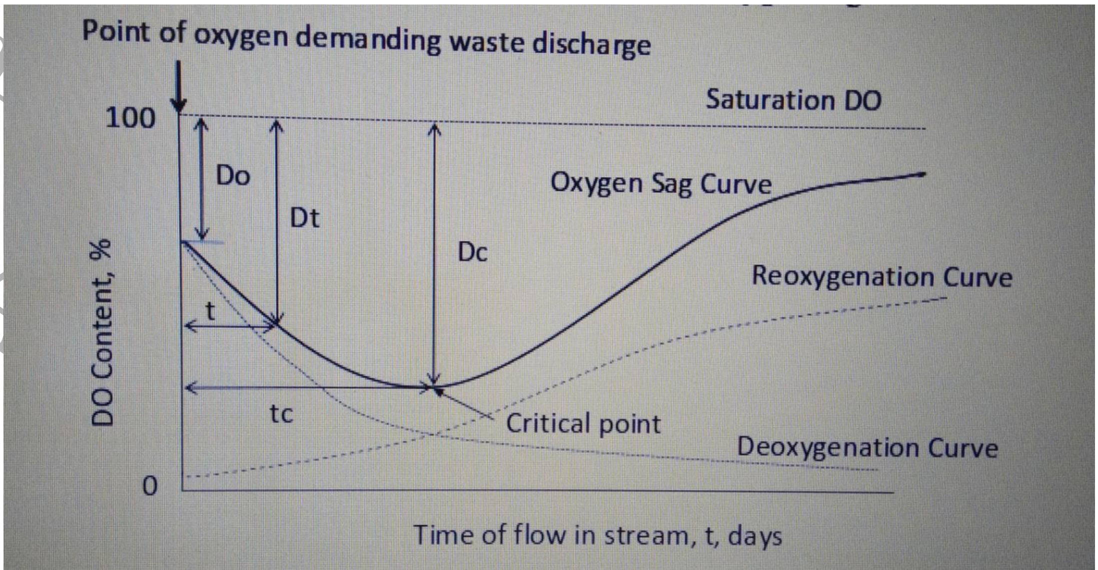

Figure 12.1 Deoxygenation, reoxygenation and oxygen sag curve

Deoxygenation and Reoxygenation Curves

When wastewater is discharged into the stream, the DO level in the stream goes on depleting. This depletion of DO content is known as deoxygenation. The rate of deoxygenation depends upon the amount of organic matter remaining (Lt) to be oxidized at any time t, as well as temperature (T) at which reaction occurs. The variation of depletion of DO content of the stream with time is depicted by the deoxygenation curve in the absence of aeration. The ordinates below the deoxygenation curve indicate the oxygen remaining in the natural stream after satisfying the bio-chemical oxygen demand of oxidizable matter.

When the DO content of the stream is gradually consumed due to BOD load, atmosphere supplies oxygen continuously to the water, through the process of re-aeration or reoxygenation, i.e., along with deoxygenation, re-aeration is continuous process.

The rate of reoxygenation depends upon:

i)Depth of water in the stream: more for shallow depth.

ii)Velocity of flow in the stream: less for stagnant water.

iii)Oxygen deficit below saturation DO: since solubility rate depends on difference between saturation concentration and existing concentration of DO.

iv)Temperature of water: solubility of oxygen is lower at higher temperature and also saturation concentration is less at higher temperature.

Mathematical analysis of Oxygen Sag Curve: Streeter – Phelps equation

The analysis of oxygen sag curve can be easily done by superimposing the rates of deoxygenation and reoxygenation as suggested by the Streeter – Phelps analysis. The rate of change in the DO deficit is the sum of the two reactions as explained below:

dDt/ dt = f (deoxygenation and reoxygenation)

OR

$$dD_t / dt = K'L_t - R'D_t \qquad ....(1)$$

Where,

Dt = DO deficit at any time t,

Lt = amount of first stage BOD remaining at any time t

K' = BOD reaction rate constant or deoxygenation constant (to the base e)

R' = Reoxygenation constant (to the base e)

t = time (in days)

dDt/ dt = rate of change of DO deficit

Now,

$$L_t = L_o . e^{-K'.t}$$

Where, Lo = BOD remaining at time t = 0 i.e. ultimate first stage BOD

Hence,

$$dD_t/dt = K'L_o.e^{-K'.t} - R'D_t \qquad ....(2)$$

or

$$dD_t/dt + R'D_t = K'L_o.e^{-K'.t} \qquad ....(3)$$

This is first order first degree differential equation and solution of this equation is as under

$$D_t = K'L_o/(R' - K')(e^{-K'.t} - e^{-R'.t}) + D_o . e^{-R'.t} \qquad ....(4)$$

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Changing base of natural log to 10 the equation can be expressed as:

$$\mathbf{D_t = [\, K.L_o / (R-K) \,] [\, 10^{-K.t} - 10^{-R.t} \,] + D_o.10^{-R.t}} \qquad ....(5)$$

Where, K = BOD reaction rate constant, to the base 10

R = Reoxygenation constant to the base 10

Do = Initial oxygen deficit at the point of waste discharge at time t = o

t = time of travel in the stream from the point of discharge = x/u

x = distance along the stream

u = stream velocity

This is **Streeter-Phelps oxygen sag equation**. The graphical representation of this equation is given above as **Oxygen Sag Curve.**

Note: Deoxygenation and reoxygenation occurs simultaneously. After critical point, the rate of re-aeration is greater than the deoxygenation and after some distance the DO will reach to original level and stream will not have any effect due to addition of wastewater. At time t=0 at x = 0.

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Determination of Critical DO deficit (Dc) and distance Xc

The value of Dc can be obtained by putting dDt/dt = 0 in equation 3,

Hence,

$$\mathbf{D_c = (K'/R').\, L_o.\, e^{-K'.t_c}} \qquad ....(6)$$

OR

$$\mathbf{D_c = (K/R).\, L_o.\, 10^{-Kt_c}} \qquad ....(7)$$

Where, tc is time required to reach the critical point. The value of 'tc' can be obtained by differentia ting equation 4 (or 5) with respect to 't' and setting dDt/dt = 0

Therefore,

$$\mathbf{t_c = [(1/R' - K')] .\log_e (R'/K') [\, 1 - (D_o\{R'-K'\}/K'.L_o \,]} \qquad ....(8)$$

OR

$$\mathbf{t_c = [(1/R - K)] .\log_{10} (R/K) [\, 1 - (D_o\{R-K\}/K.L_o \,]} \qquad ....(9)$$

The distance Xc is given by

$X_c = t_c \cdot u$

Where, u = velocity of flow in the stream .The deoxygenation constant K, is obtained by laboratory test or field tests, and varies with temperature as given below:

$$K_T = K_{20} (\theta)^{(T-20)} \quad \text{....(10)}$$

Where, θ varies with the temperature = 1.056 in general or 1.047 for 20°C to 30° C temperature, and 1.135 for 4°C to 20°C

K = 0.1 to 0.3 for municipal sewage, base 10, (0.23 to 0.70 for base e)

The reoxygenation constant R also varies with the temperature and can be expressed as

$$R_T = R_{20} (1.024)^{(T-20)} \quad \text{....(11)}$$

Where, R'/R = 2.303

R = 0.15 to 0.20 for low velocity large stream

= 0.20 to 0.30 for normal velocity large stream

= 0.10 to 0.15 for lakes and sluggish stream

$R_T = R_{20} (1.016)^{(T-20)}$ .... (Peavy , et.al., 1985)

The ratio of R/K (or R'/K') is called the self purification constant fs and it is equal to 0.50 to 5.0.

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