

Disposing of the Sewage Effluents

Before we discuss, in our next chapter, the various treatments that may be given to raw sewage before disposing it of, it shall be worthwhile to first discuss the various methods and sources of disposal of sewage. The study of the sources of disposal is important, because the amount of treatment required to be given to sewage depends very much upon the source of disposal, its quality and capacity to tolerate the impurities present in the sewage effluents, without itself getting potentially polluted or becoming less useful.

There are two general methods of disposing of the sewage effluents :

- Dilution i.e. disposal in water ; and*
- Effluent Irrigation or Broad Irrigation or Sewage Farming, i.e. disposal on land.*

Disposal by dilution is more common of these two methods, which are described below :

DISPOSAL BY DILUTION

Disposal by dilution is the process whereby 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*. The degree and amount of treatment given to raw sewage before disposing it of into the river-stream in question, will definitely depend not only upon the quality of raw sewage *but also upon the self purification capacity of the river stream and the intended use of its water.*

8.1. Conditions Favouring Disposal By Dilution

The dilution method for disposing of the sewage can favourably be adopted under the following conditions :

(i) When sewage is comparatively fresh (4 to 5 hr old), and free from floating and settleable solids, (or are easily removed by primary treatment).

(ii) When the diluting water (*i.e.* the source of disposal) has a high dissolved oxygen (D.O.) content.

(iii) Where diluting waters are not used for the purpose of navigation or water supply for *at least some reasonable distance* on the downstream from the point of sewage disposal.

(iv) Where the flow currents of the diluting waters are favourable, causing no deposition, nuisance or destruction of aquatic life. It means that swift forward currents are helpful, as they easily carry away the sewage to the points of unlimited dilution. On the other hand, slow back currents tend to cause sedimentation, resulting in large sludge deposits.

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

8.2. Standards of Dilution for Discharge of Wastewaters into Rivers

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

Table 8.1. Standards of Dilution Based on Royal Commission Report

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

The above standards have been operative in England since 1912, and had also been followed in India without much variance. However, with the increasing pollution of surface streams due to indiscriminate discharge of domestic and industrial wastewaters, without bothering to look into the available dilution ratios, it has become imperative to limit the concentrations of various pollutants being discharged in to the surface water sources along with the sewage and industrial effluents. The tolerance limits for such constituent pollutants have therefore been prescribed by various countries, including India. These limits are based upon the desirability of giving full fledged treatment to sewage and industrial liquid wastes, up to minimum level of 'secondary treatment'.

The Bureau of Indian Standards (BIS), previously known as Indian Standard Institution (ISI), has therefore laid down its *guiding standards* for sewage effluents, vide IS 4764-1973, and for industrial effluents vide IS : 2490-1974, as shown in table 8.2. These tolerance limits are supposed to be the *national guidelines* for guiding the various *State Pollution Control Boards** for prescribing their legally enforceable standards, depending upon the water quality and dilution available in their respective surface water sources, and the type of effluents produced by the different industries. These standards have also been notified by GOI under Environment (Protection) Rules, 1986, and are shown in Table 8.3. When the industrial wastewaters are *disposed of in to public sewers*, then also, their quality has to be checked, by following the standards prescribed by IS 3306-1974 (Refer col. (5) of table 8.2) or the standards notified by GOI under Environment (Protection) Rules, 1986, as shown in Table 8.3.

*Indian States like Karnataka, Kerala, Maharashtra, U.P. and West Bengal have already published their legally enforceable standards for various industries, and other States are in the process of doing so. The standards adopted by these States are almost the same as suggested by BIS(ISI), except for some locally needed changes. GOI has also notified these standards under the Environment (Protection) Rules, 1986, as shown in Table 8.3.

Table 8.2. BIS (ISI) Standards for Discharge of Sewage and Industrial Effluents in Surface Water Sources* and Public Sewers

| S. No. | Characteristic of the Effluent | Tolerance limit for Sewage Effluent discharged into Surface Waters, as per IS 4764-1973 | Inland surface waters, as per IS 2490-1974 | Public sewers as per IS 3306-1974 | Tolerance Limit for Industrial effluents discharged into | | | | |
|--------|--|---|--|-----------------------------------|--|-----------|-----------|-----------|-----|
| | | | | | (1) | (2) | (3) | (4) | (5) |
| 1. | BOD ₅ | 20 mg/l | — | — | 500** mg/l | 30 mg/l | 30 mg/l | 30 mg/l | — |
| 2. | COD | — | — | — | 5.5 to 9.0 | 250 mg/l | 250 mg/l | 250 mg/l | — |
| 3. | pH value | 30 mg/l | — | — | — | 100 mg/l | 100 mg/l | 100 mg/l | — |
| 4. | Total Suspended Solids (TSS) | — | — | — | 45°C | 10 mg/l | 10 mg/l | 10 mg/l | — |
| 5. | Temperature | — | — | — | 5 mg/l | 1 mg/l | 1 mg/l | 1 mg/l | — |
| 6. | Oil and grease | — | — | — | 2 mg/l | 0.2 mg/l | 0.2 mg/l | 0.2 mg/l | — |
| 7. | Phenolic compounds (as Phenol) | — | — | — | — | 2 mg/l | 2 mg/l | 2 mg/l | — |
| 8. | Cyanides (as CN) | — | — | — | — | 2 mg/l | 2 mg/l | 2 mg/l | — |
| 9. | Sulphides (as S) | — | — | — | — | 1 mg/l | 1 mg/l | 1 mg/l | — |
| 10. | Fluorides (as F) | — | — | — | — | 0.2 mg/l | 0.2 mg/l | 0.2 mg/l | — |
| 11. | Total residual chlorine | — | — | — | — | 2 mg/l | 2 mg/l | 2 mg/l | — |
| 12. | Insecticides | — | — | — | — | 2 mg/l | 2 mg/l | 2 mg/l | — |
| 13. | Arsenic (as As) | — | — | — | — | 0.1 mg/l | 0.1 mg/l | 0.1 mg/l | — |
| 14. | Cadmium (as Cd) | — | — | — | — | — | — | — | — |
| 15. | Chromium, hexavalent (as Cr) | — | — | — | — | 3 mg/l | 3 mg/l | 3 mg/l | — |
| 16. | Copper | — | — | — | — | 0.1 mg/l | 0.01 mg/l | 0.01 mg/l | — |
| 17. | Lead | — | — | — | — | 3 mg/l | 3 mg/l | 3 mg/l | — |
| 18. | Mercury | — | — | — | — | 0.05 mg/l | 0.05 mg/l | 0.05 mg/l | — |
| 19. | Nickel | — | — | — | — | 5 mg/l | 5 mg/l | 5 mg/l | — |
| 20. | Selenium | — | — | — | — | — | — | — | — |
| 21. | Zinc | — | — | — | — | — | — | — | — |
| 22. | Chlorides (as Cl) | — | — | — | — | — | — | — | — |
| 23. | % Sodium | — | — | — | — | — | — | — | — |
| 24. | Ammoniacal nitrogen (as N) | — | — | — | — | — | — | — | — |
| 25. | Radioactive materials (i) α-emitters (ii) β-emitters | — | — | — | — | — | — | — | — |

*Includes Rivers, Streams, Estuaries, Lakes and Reservoirs
**subject to relaxation or tightening by the local authorities.

| (1) | (2) | (3) | (4) | (5) |
|-----|--------------------------|--|--|--|
| 29. | Bio-assay test | 90% survival of fish after 96 hrs in 100% effluent | 90% survival of fish after 96 hrs in 100% effluent | 90% survival of fish after 96 hrs in 100% effluent |
| 30. | Manganese (as Mn) | 2 mg/l | 2 mg/l | 2 mg/l |
| 31. | Iron (as Fe) | 3 mg/l | 3 mg/l | 3 mg/l |
| 32. | Vanadium (as V) | 0.2 mg/l | 0.2 mg/l | 0.2 mg/l |
| 33. | Nitrate Nitrogen | 10 mg/l | — | 20 mg/l |
| 34. | Pesticides | | | |
| | (i) Benzene hexachloride | 10 µg/l | — | 10 mg/l |
| | (ii) Carboxyl | 10 µg/l | — | 10 µg/l |
| | (iii) DDT | 10 µg/l | — | 10 µg/l |
| | (iv) Endosulfan | 10 µg/l | — | 10 µg/l |
| | (v) Diamethoate | 450 µg/l | — | 450 µg/l |
| | (vi) Penitrothion | 10 µg/l | — | 10 µg/l |
| | (vii) Malathion | 10 µg/l | — | 10 µg/l |
| | (viii) Phorate | 10 µg/l | — | 10 µg/l |
| | (ix) Methyl Parathion | 10 µg/l | — | 10 µg/l |
| | (x) Phenthoate | 10 µg/l | — | 10 µg/l |
| | (xi) Pyrethrums | 10 µg/l | — | 10 µg/l |
| | (xii) Copper oxychloride | 9600 µg/l | — | 9600 µg/l |
| | (xiii) Copper sulphate | 50 µg/l | — | 50 µg/l |
| | (xiv) Ziram | 1000 µg/l | — | 1000 µg/l |
| | (xv) Sulphur | 30 µg/l | — | 30 µg/l |
| | (xvi) Paraquat | 2300 µg/l | — | 2300 µg/l |
| | (xvii) Proponil | 7300 µg/l | — | 7300 µg/l |
| | (xviii) Nitrogen | 780 µg/l | — | 780 µg/l |

8.3. 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 for ever, 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*. However, if the self-purification is not

achieved successfully either due to too much of pollution discharged into it or due to other causes, the river water itself will get polluted, which, in turn, may also pollute the sea where the river outfalls.

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

1. Physical forces are :

(i) *Dilution and dispersion*,

(ii) *Sedimentation*, and

(iii) *Sunlight (acting through bio-chemical reactions)*.

2. Chemical forces aided by biological forces (called bio chemical forces) are :

(iv) *Oxidation (Bio)*,

(v) *Reduction*.

These forces are described below :

(i) **Dilution and Dispersion.** When the putrescible organic matter is discharged into a large volume of water contained in the river-stream, it gets rapidly dispersed and diluted. The action, thus, results in diminishing the concentration of organic matter, and thus reduces the potential nuisance of sewage.

When sewage of concentration C_S flows at a rate Q_S in to a river stream with concentration C_R flowing at a rate Q_R , the concentration C of the resulting mixture is given by

$$C_S Q_S + C_R Q_R = C(Q_S + Q_R)$$

$$\text{or } C = \frac{C_S Q_S + C_R Q_R}{Q_S + Q_R} \quad \dots(8.1)$$

This equation is applicable separately to concentrations of different impurities, such as, oxygen content, BOD, suspended sediments, and other characteristic contents of sewage.

(ii) **Sedimentation.** The settleable solids, if present in sewage effluents, will settle down into the bed of the river, near the outfall of sewage, thus, helping in the self purification process.

(iii) **Sun-light.** The sun light has a bleaching and stabilising effect of bacteria. It also helps certain micro-organisms to derive energy from it, and convert themselves into food for other forms of life, thus absorbing carbon dioxide and releasing oxygen by a process known as **photo synthesis**. The evolution of oxygen in river water due to sunlight will help in achieving self-purification through oxidation, as given below :

The larger the amount of dissolved oxygen present in water, the better and earlier the self-purification will occur.

The amount and the type of organic matter and biological growth present in water will also affect the rate of self-purification. Algae which absorbs carbon dioxide and gives out oxygen, is thus, very helpful in the self-purification process.

The rate of re-aeration i.e. the rate at which the D.O. deficiency is replenished, will considerably govern the self-purification process. The greater is this rate, the quicker will be the self-purification, and there will be no chances of development of anaerobic conditions.

8.3.1. Zones of Pollution in a River-Stream. A polluted stream undergoing self-purification can be divided into the following four zones :

- (i) Zone of degradation ;
- (ii) Zone of active decomposition ;
- (iii) Zone of recovery ; and
- (iv) Zone of cleaner water.

These zones are discussed below :

(i) **Zone of degradation or Zone of pollution.** This zone is found for a certain length just below the point where sewage is discharged into the river-stream. This zone is characterised by water becoming dark and turbid with formation of sludge deposits at the bottom. D.O. is reduced to about 40% of the saturation value*. There is an increase in carbon dioxide content ; re-oxygenation (i.e. re-aeration) occurs but is slower than de-oxygenation.

These conditions are unfavourable to the development of aquatic life ; and as such, algae dies out, but fish life may be present feeding on fresh organic matter. Moreover, certain typical bottom worms such as *Limnodrilus* and *Tubifex* appear with sewage fungi, such as *sphaerotilusnatans*.

(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 methane, carbon dioxide, hydrogen sulphide, etc., bubbling to the surface, with masses of sludge forming an ugly scum layer at the surface. As the organic decomposition slackens due to stabilisation of organic matter, the re-aeration sets in and D.O. again rises to the original level (i.e. about 40%).

In this zone, bacteria flora will flourish. At the upper end, anaerobic bacteria will replace aerobic bacteria ; while at its lower end *Saturation value at 30°C = 7.6 mg/l. (Pl. see standard tables given at the end of the book).

(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. The process of oxidation will continue till the organic matter has been completely oxidised. This is the most important action responsible for affecting self purification of rivers.

(v) **Reduction.** Reduction occurs due to hydrolysis of organic matter settled at the bottom either chemically or biologically. Anaerobic bacteria will help in splitting the complex organic constituents of sewage into liquids and gases, and thus paving the way for their ultimate stabilization by oxidation.

The various factors on which these natural forces of purification depend are : (a) temperature ; (b) turbulence ; (c) hydrography such as the velocity and surface expanse of the river-stream ; (d) available dissolved oxygen, and the amount and type of organic matter present, (e) rate of re-aeration, etc.

Besides affecting the dilution and chemical activities, the temperature also affects the rate of biological and subsequent nuisance to avoid the anaerobic decomposition and influenced by temperature. At higher temperatures, 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. This is likely to lead to anaerobic conditions, when the pollution due to putrescible organic matter is heavy.

The turbulence in the body of water helps in breaking the surface of the stream or lake, and helps in rapid re-aeration from the atmosphere. Thus, it helps in maintaining aerobic conditions in the river stream, and in keeping it clean. Too much of turbulence, however, is not desirable, because it scours the bottom sediment, increases the turbidity, and retards algae growth, which is useful in re-aeration process. Wind and undercurrents in lakes and oceans cause turbulences which affect their self-purification.

The Hydrography affects the velocity and surface expanse of the river stream. High velocities cause turbulence and rapid re-aeration, while large surface expanse (for the same cubic contents) will also have the same effects.

end, the position will be reversed. Protozoa and fungi will first disappear and then reappear. Fish life will be absent. Algae and Tubifex will also mostly be absent. Larvae of *maggots* and *psychoda* (sewage fly) will, however, be present in all but the most septic sewage.

(iii) **Zone of recovery.** In this zone, the river stream tries to recover from its degraded condition to its former appearance. The water becomes clearer, and so the algae reappears while fungi decreases. B.O.D. falls down and D.O. content rises above 40% of the saturation value; *protozoa*, *rotifers*, *crustaceans* and *large plants like sponges, bryozons*, etc. also reappear. Bottom organisms will include: *tubifex*, *mussels*, *snails*, etc. The organic material will be

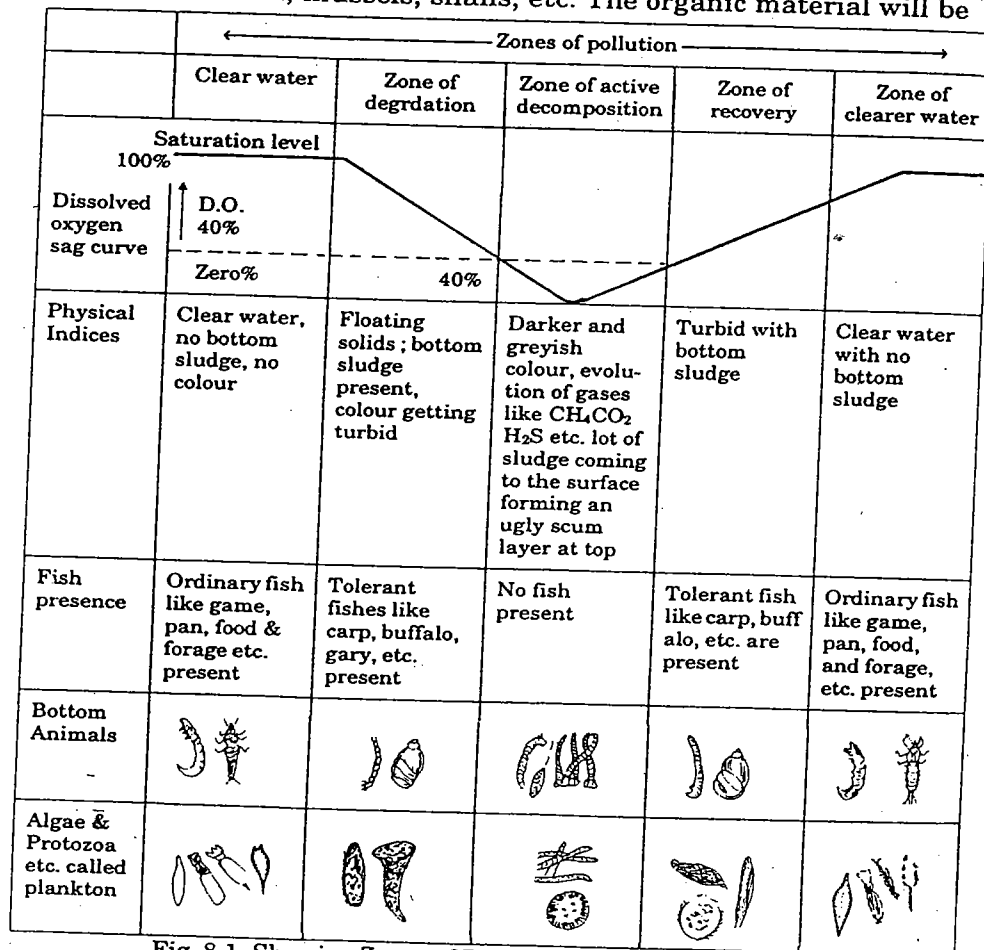


Fig. 8.1. Showing Zones of Pollution along a River stream.

mineralised to form nitrates, sulphates, phosphates, carbonates, etc.

(iv) **Zone of clearer water.** In this zone, the river attains its original conditions with D.O. rising up to the saturation value. Water becomes attractive in appearance, and Game fish (which requires atleast 4 to 5 mg/l of D.O.) and usual aquatic life prevails. Same pathogenic organisms may still, however, survive and remain present, which confirms the fact that "when once a river water has been polluted, it will not be safe to drink it, unless it is properly treated."

8.3.2. Indices of Self-Purification. The stage of self-purification process can be determined by the physical, chemical and biological analysis of the water. Colour and turbidity are the physical indices, while D.O., B.O.D. and suspended solids are the chemical indices which can mark the stages of purification. Moreover, the biological growth present in water can also indicate the stage of purification process, as different types of micro and macro organisms will exist in polluted water under different conditions, as discussed in the previous sub article.

The different zones of pollution (i.e. various stages in the self-purification process) and the physical, chemical and biological indices, characteristics of each zone, are shown in Fig. 8.1.

8.3.3. The Oxygen Deficit of a Polluted River-Stream. The oxygen deficit D at any time in a polluted river-stream is the difference between the actual D.O. content of water at that time and the saturation D.O. content* at the water temperature; i.e.

$$\text{Oxygen deficit } (D) = \text{Saturation D.O.} - \text{Actual D.O.} \quad \dots(8.2)$$

In order to maintain clean conditions in a river-stream, the oxygen deficit must be nil, and this can be found out by knowing the rates of de-oxygenation and re-oxygenation.

De-oxygenation Curve. In a polluted stream, the D.O. content goes on reducing due to decomposition of volatile organic matter. The rate of de-oxygenation depends upon the amount of the organic matter remaining to be oxidised at the given time (i.e. L_t) as well as on the temperature of reaction (i.e. t). Hence, at a given temperature, the curve showing depletion of D.O. with time, i.e. deoxygenation curve (Refer curve 1 of Fig. 8.2) is similar to the first stage B.O.D. curve (Refer Fig. 7.3). It can also be expressed mathematically as per Eq. (7.12).

*It means the amount of D.O. which will be present in water if it is fully saturated with oxygen. The normal saturation D.O. value for fresh water varies between 14.6 mg/l to 7.6 mg/l for temperature varying between 0°C to 30°C.

It can also be seen that when the de-oxygenation rate exceeds the re-oxygenation rate, the oxygen sag curve shows increasing deficit of oxygen; but when both the rates become equal, the critical point is reached, and then finally when the rate of de-oxygenation falls below that of re-oxygenation, the oxygen deficit goes on decreasing till becoming zero.

The entire analysis of super-imposing the rates of deoxygenation and re-oxygenation have been carried out mathematically, and the obtained results expressed in the form of famous Streeter-Phelps equation; i.e.,

$$D_t = \frac{K_R \cdot L}{K_R - K_D} \left[(10) - K_D \cdot t - (10) - K_R \cdot t \right] + \left[D_0 \times (10) - K_R \cdot t \right] \quad \dots(8.3)$$

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

L = Ultimate first stage B.O.D. of the mix at the point of waste discharge in mg/l.

D_0 = Initial oxygen deficit of the mix at the mixing point in mg/l.

K_D = De-oxygenation coefficient for the wastewater, which can be considered as equal to the BOD rate constant* determined in the laboratory, through BOD tests performed at different times on BOD bottles, as discussed in article 7.4.1.9. Also, K_D varies with temp. as per Eq. (7.18), as :

$$K_{D(7)} = K_{D(20)} \left[1.047 \right]^{-T-20}$$

The typical values of $K_{D(20)}$ vary between 0.1 to 0.2, generally taken as 0.1.

K_R = Re-oxygenation coefficient for the stream. It can be determined by the same, as determined in the laboratory.

*Deoxygenation coefficient for a river is, in fact, a little more than the BOD rate constant, since BOD is exerted more rapidly in a river than that in a BOD bottle due to turbulent mixing in a river. However, for practical purposes, this value is taken to be the same, as determined in the laboratory.

**Certain authors use K_2 as the symbol for this constant.

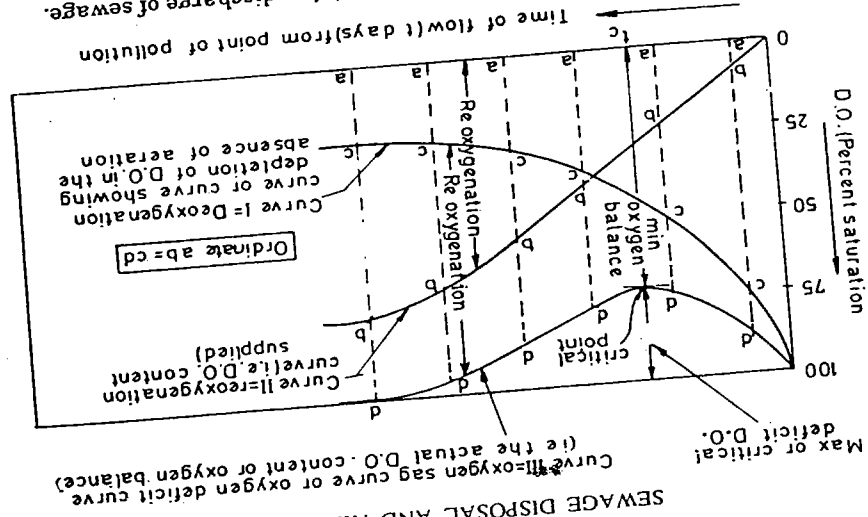


Fig. 8.2. Oxygen sag curve in a river receiving discharge of sewage.

Re-oxygenation Curve. In order to counter-balance the consumption of D.O. due to de-oxygenation, atmosphere supplies oxygen to the water, and the process is called re-oxygenation. The rate at which the oxygen is supplied by the atmosphere to the polluted water depends upon :

- the depth of the body of water (rate is more in a shallow stream than in a quiescent pond) ;
- the condition of the body of water (rate is more in a running stream than in a quiescent pond) ;
- the saturation deficit or the oxygen deficit (i.e. the deficit of D.O. below the saturation value) ; and
- the temperature of water.

Depending upon these factors, the rate of re-oxygenation can also be expressed mathematically and plotted in the form of a curve called re-oxygenation curve (Refer curve II—Fig. 8.2).

Oxygen Deficit Curve. In a running polluted stream exposed to the atmosphere, the de-oxygenation is more rapid than the re-oxygenation, an oxygen deficit becomes zero, aerobic conditions will go hand in hand. If de-oxygenation is more rapid than the re-oxygenation, the de-oxygenation will set in.]

The amount of resultant oxygen deficit can be obtained by algebraically adding the de-oxygenation and re-oxygenation curves (see curve III—Fig. 8.2). The resultant curve so obtained is called the oxygen sag curve or the oxygen deficit curve. From this curve, the oxygen deficit and oxygen balance (i.e., $100 - D$) per cent in a stream after a certain lapse of time, can be found out.

mined by the field tests by using eqn. :

$$K_D(20^\circ) = \frac{3.9 \sqrt{v}}{y^{1.5}} \quad \dots(8.4)$$

where v = Av. stream velocity in m/s

y = Av. stream depth in m.

K_R varies with temperature as per the eqn. :

$$K_R(T) = K_R(20) \left[1.016 \right]^{T-20^\circ} \quad \dots(8.5)$$

where $K_R(T)$ is the K_R value at $T^\circ\text{C}$ and $K_R(20)$ is the K_R value at 20°C .

Typical values of $K_R(20)$ are given in Table 8.4.

Table 8.4. Values of Re-oxygenation Coefficient (K_R) at 20°C

| S. No. | Type of water body | Value of $K_R(20)$ per day |
|--------|---|----------------------------|
| 1. | Small ponds and back waters | 0.05—0.10 |
| 2. | Sluggish streams, large lakes and impounding reservoirs | 0.10—0.15 |
| 3. | Large streams of low velocity | 0.15—0.20 |
| 4. | Large streams of normal velocity | 0.20—0.30 |
| 5. | Swift streams | 0.30—0.50 |
| 6. | Rapids and waterfalls | Over 0.5 |

The oxygen deficit curve can be plotted easily with the help of Eq. (8.3), by using different values of t in days :

The critical time (t_c) after which the minimum dissolved oxygen occurs can be found by differentiating Eq. (8.3) and equating it to zero ; which on solving gives

$$t_c = \left[\frac{1}{K_R - K_D} \right] \log \left[\left\{ \frac{K_D \cdot L - K_R D_0 + K_D D_0}{K_D \cdot L} \right\} \frac{K_R}{K_D} \right] \quad \dots(8.6)$$

and the critical or max. oxygen deficit is given by

$$D_c = \frac{K_D L}{K_R} \left[10 \right]^{-K_D \cdot t_c} \quad \dots(8.7)$$

The constant $\frac{K_R}{K_D}$ is sometimes represented by f , called **self-purification constant**, the values of which are given in Table 8.5.

Table 8.5. Values of Self-Purification Constant $\left(f = \frac{K_R}{K_D} \right)$

| S. No. | Type of water body | Value of f |
|--------|---|--------------|
| 1. | Small ponds and Back waters | 0.5—1.0 |
| 2. | Sluggish streams, Large lakes and Impounding reservoirs | 1.0—1.5 |
| 3. | Large streams of low velocity | 1.5—2.0 |
| 4. | Large streams of normal velocity | 2.0—3.0 |
| 5. | Swift streams | 3.0—5.0 |
| 6. | Rapids and Waterfalls | Over 5.0 |

Using $\frac{K_R}{K_D}$ as f , the Eq. (8.6) becomes as

$$t_c = \frac{1}{K_D(f-1)} \log \left[\left\{ 1 - (f-1) \frac{D_0}{L} \right\} f \right] \quad \dots(8.8)$$

and equation (8.7) becomes

$$D_c = \frac{L}{f} \left[10 \right]^{-K_D \cdot t_c} \quad \dots(8.9)$$

Taking log, we get

$$\log D_c = \log \frac{L}{f} - K_D \cdot t_c \quad \dots(8.10)$$

Substituting the value of t_c from Eq. (8.8) in Eq. (8.10), we get

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

$$\text{or} \quad \log D_c = \log \frac{L}{f} - \frac{1}{(f-1)} \log \left[f \left\{ 1 - (f-1) \frac{D_0}{L} \right\} \right]$$

$$\text{or} \quad (f-1) \left[\log \frac{L}{f} - \log D_c \right] = \log \left[f \left\{ 1 - (f-1) \frac{D_0}{L} \right\} \right]$$

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

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

$$= 2.625 \text{ days.}$$

$$(vi) \text{ Now, Distance = Velocity} \times \text{Travel Time}$$

$$= 0.2 \text{ m/s} \times (2.625 \times 24 \times 60 \times 60 \text{ sec})$$

$$= 45.36 \text{ km. Ans.}$$

(vii) D_c is now given by eqn. (8.11) as

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

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

$$\frac{21.45}{1.888 D_c} = \left(1.692 \right)^{\frac{1}{0.888}}$$

$$= (1.692)^{1.126} = 1.808$$

$$D_c = \frac{21.45}{1.888 \times 1.808}$$

$$= 6.28 \text{ mg/l.}$$

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

Example 8.10. A treated waste water is discharged at the rate of $1.5 \text{ m}^3/\text{sec}$ into a river of minimum flow $5 \text{ m}^3/\text{sec}$. The temperature of river flow and waste water may be assumed as 25°C . The BOD removal rate constant K_1 is $0.12/d$ (base 10). The BOD_5 at 25°C of the waste water is 200 mg/l , and that of the river water upstream of the wastewater outfall is 1 mg/l . The efficiency of waste water treatment is 80% . Evaluate the following:

- BOD_5 at 25°C , if river water receives untreated waste water
- BOD_5 at 25°C if river water receives treated waste water
- ultimate BOD of the river water after it receives treated waste water.

(Civil Services, 1993)

Solution.

$$\begin{aligned} \text{Discharge of waste water} &= Q_w = 1.5 \text{ m}^3/\text{s} \\ &= Q_R = 5 \text{ m}^3/\text{s} \\ \text{Discharge of river} &= T = 25^\circ\text{C} \\ \text{Temperature} & \end{aligned}$$

$$K_D(25^\circ) = K_1 = 0.12/d.$$

$$C_w = \text{Conc. of BOD}_5 \text{ for untreated waste water} = 200 \text{ mg/l}$$

$$C_R = \text{Conc. of BOD}_5 \text{ for river water} = 1 \text{ mg/l}$$

Using eqn (8.1),
(i) Conc. of BOD_5 of the mixture if untreated waste water is discharged into the river

$$C = \frac{C_w \cdot Q_w + C_R \cdot Q_R}{Q_w + Q_R} = \frac{200 \times 1.5 + 1 \times 5}{1.5 + 5}$$

$$= 46.92 \text{ mg/l. Ans.}$$

(ii) BOD_5 of the treated wastewater is given by

$$C_{TW} = 20\% \text{ of the BOD}_5 \text{ of untreated wastewater}$$

$$\therefore \text{efficiency of wastewater treatment is } 80\%$$

$$= 20\% \times C_w = 20\% \times 200 \text{ mg/l}$$

$$= 40 \text{ mg/l.}$$

BOD_5 of mixture if treated wastewater is discharged into the river

$$C' = \frac{C_{TW} \cdot Q_w + C_R \cdot Q_R}{Q_w + Q_R}$$

$$= \frac{40 \times 1.5 + 1 \times 5}{1.5 + 5} = 10 \text{ mg/l. Ans.}$$

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

Ultimate BOD of this mixture = $Y_\infty = L = ?$

Using eqn. (7.16), we have

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

$$Y_5 = L \left[1 - (10)^{-0.12 \times 5} \right]$$

$$10 = L \left[1 - (10)^{-0.6} \right]$$

$$L = 13.35 \text{ mg/l. Ans.}$$

8.4. Disposal of Wastewaters in Lakes and Management of Lake Waters

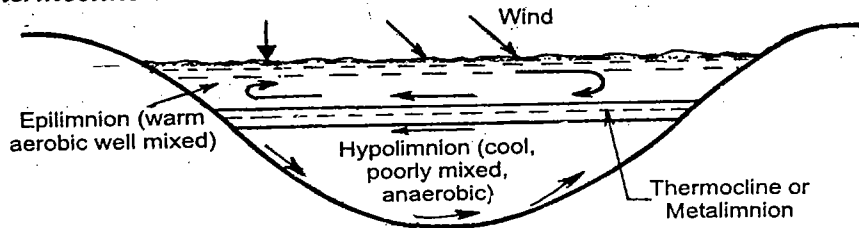
8.4.1. Lake Pollutants. Disposal of wastewaters in confined lakes or reservoirs, is much more harmful than its disposal in flowing streams and rivers. Water quality management in lakes is entirely different from that in rivers. It is in fact the phosphorous (a nutrient largely contained in industrial as well as domestic waste waters), which seriously affects the water quality of lakes; and is hence considered as the prime lake pollutant. Oxygen demanding

wastes may be the other important lake pollutants. The toxic chemicals from industrial waste waters may also sometimes very adversely effect some special classes of the lakes. However, phosphorous (a nutrient) constitute the most important lake pollutant, and needs special study in water quality management of lakes.

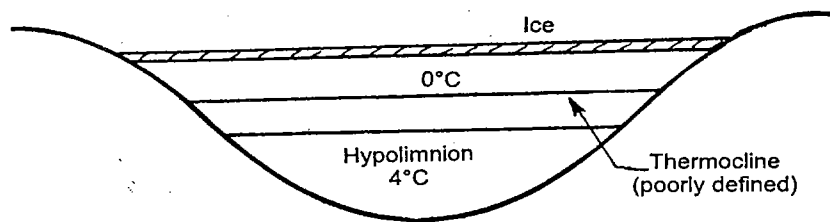
A study of the lake systems is essential to understand the role of phosphorus in lake pollution. The study of lakes is called **limnology**.

8.4.2. Stratification in Lakes. The water of a lake gets stratified during summers and winters, as discussed below :

During summer season, the surface water of a lake gets heated up by sunlight and warm air. This warm water being lighter, remains in upper layers near the surface, until mixed downward by turbulence from winds, waves, boats and other forces. Since such turbulence extends only to a limited depth from below the water surface, the top layers of water in the lake become well mixed and aerobic. This warmer, well mixed and aerobic depth of water is called **epilimnion zone**. The lower depth, which remains cooler, poorly mixed and anaerobic, is called the **hypolimnion zone**. There may also exist an intermediate zone or a dividing line, called **thermocline** or **metalimnion**, as shown in Fig. 8.3 (a).



(a) Stratification of a lake during summer.



(b) Stratification of a lake during winter.

Fig. 8.3. Stratification of lakes.

The change from epilimnion to hypolimnion can be experienced while swimming in a lake. When you swim in top layers horizontally, you will feel the water warmer ; and if you dive deeper, you will find

the water cooler. The change line will represent *monocline*. The depth of epilimnion zone depends upon the size of the lake for the same temperature changes. It may be as little as 1m in small lakes and may be as large as 20 m or more in large lakes. This depth also depends upon the storm activity in the spring when stratification is developing. A major storm at the right time will mix the warmer water to a substantial depth and thus create a deeper epilimnion zone than its normal depth. *Once formed, lake stratification is very stable, and can only be broken by exceedingly violent storms.* As a matter of fact, as summer progresses, this stability increases, the epilimnion continues to warm, while the hypolimnion remains at a fairly constant temperature.

With the onset of winter season, the epilimnion cools, until it is more dense than the hypolimnion. The surface water then sinks, causing 'overturning'. The water of the hypolimnion rises to the surface, where it cools and again sinks. *The lake, thus becomes completely mixed*, making it quite aerobic. In regions of freezing temperatures, when the temperature drops below 4°C, the above process of overturning (or *turn over*) stops, because water is most dense at this temperature. Further cooling or freezing of the water surface results in winter stratification, as shown in Fig. 8.3 (b).

With the passing of winters and commencement of spring season, the surface water again warms up and overturns, and lake becomes completely mixed. The lakes in regions of temperate climate will, therefore, have at least one, if not two, cycles of stratification and *turn-over* every year.

8.4.3. Biological Zones in Lakes. Lakes have been found to exhibit distinct zones of biological activity, largely determined by the availability of light and oxygen. The most important biological zones are :

- (i) *euphotic zone* ;
- (ii) *littoral zone* ; and
- (iii) *benthic zone*.

These zones are shown in Fig. 8.4, and briefly discussed below :

8.4.3.1. Euphotic zone. The upper layer of lake water through which sunlight can penetrate, is called the euphotic zone. All plant growth occurs in this zone. In deep water, algae grow as the most important plants, while rooted plants grow in shallow water near the shore.

The depth of the euphotic zone is reduced by the turbidity, which blocks sunlight penetration. In most lakes, the turbidity is due to algal growth ; although colour and suspended clays may substantially reduce sunlight penetration in some lakes. It is important to

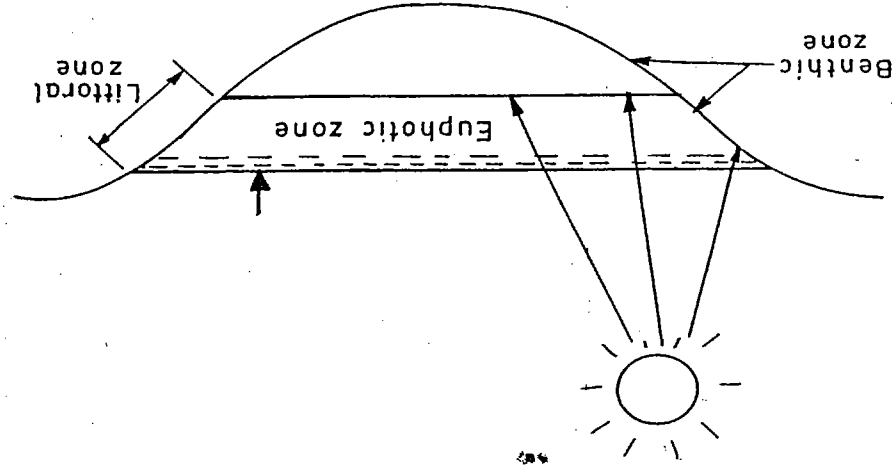


Fig. 8.4. Biological zones in a lake.

note that the bottom of euphotic zone only rarely coincides with the thermocline.

The depth of the euphotic zone

can be approximated and measured by a simple device, called the Secchi disk, shown in Fig. 8.5. This disk is lowered into the lake water until the observer can no longer distinguish between the boundaries between its white and black quadrants. This depth, called the *Secchi disk depth*, does not correspond exactly to the depth of euphotic zone, but provides a good approximation of its extent. This Secchi disk

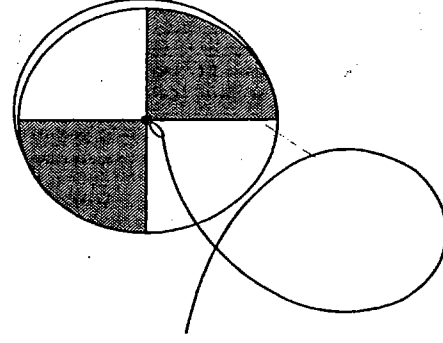


Fig. 8.5. Secchi disk.

depth also provides a measure of the aesthetic quality of water. The greater is the *Secchi disk depth*, the clearer is the water.

8.4.3.2. Littoral zone. The shallow water near the shore, in which rooted plants grow, is called the littoral zone. The extent of the littoral zone depends on the slope of the lake bottom, and the depth of the euphotic zone. The littoral zone cannot extend deeper than the euphotic zone, as shown in Fig. 8.4.

8.4.3.3. Benthic zone. The bottom sediments in a lake comprises what is called the benthic zone. As the organisms living in the overlying water die, they settle down to the bottom, where they are

decomposed by the organisms living in the benthic zone. Bacteria are always present in this zone. The presence of higher life forms, such as worms, insects and crustaceans however, depends upon the availability of oxygen at the lake bottom.

8.4.4. Productivity of a Lake. The productivity of a lake is defined as a measure of its ability to support a food chain. Since the algae forms the base of this food chain, which is required by the other forms of living organisms to thrive, its presence measures the lake productivity. Although, more productive lakes will have a higher fish population, yet since such a lake will have to support heavier algal growth, its water quality will be reduced, because of the undesirable changes that occur as algal growth increases. Moreover, due to reduced water quality, the most desirable fish which flourish in better quality waters, will be lost.

A lake's productivity level may, therefore, be determined by measuring the amount of algal growth that can be supported by the available nutrients. This productivity level of a lake is thus, reflective of the water quality of the lake. As the productivity of a lake increases, its water quality reduces. Because of the important role productivity plays in determining water quality, it forms a basis for classifying lakes.

Depending upon the increasing level of its productivity, the lakes may be classified as :

- (i) *Oligotrophic lakes* ;
- (ii) *Mesotrophic lakes* ;
- (iii) *Eutrophic lakes* ; and
- (iv) *Senescent lakes*.

There four types are discussed below :

8.4.4.1. Oligotrophic lakes. Oligotrophic lakes have a low level of productivity due to a severely limited supply of nutrients to support algal growth. The water of such a lake is, therefore, clear enough as to make its bottom visible upto considerable depth. In such a case, the euphotic zone often extends into the hypolimnion, which is aerobic. Oligotrophic lakes, therefore, support cold water game fish. An important example of such a lake is offered by the *Tahoe lake* on California-Nevada border in USA.

8.4.4.2. Mesotrophic lakes. The lakes having medium productivity levels, with medium growth of algae and turbidity, are usually classified as mesotrophic lakes. In such a lake, although substantial depletion of oxygen may occur in the hypolimnion, yet it remains aerobic.

8.4.4.3. Eutrophic lakes. Eutrophic lakes do have a high level of productivity, because of an abundant supply of algal nutrients. The

flourishing growth of algae make the lake water to be highly turbid, so that the euphotic zone may extend only partially into the epilimnion. As the algae die, they settle to the lake bottom, where they are decomposed by benthic organisms. In a eutrophic lake, this decomposition is sufficient to deplete the hypolimnion of oxygen during summer stratification.

Because the hypolimnion is anaerobic during summer, such a lake will only support warm water fish. As a matter of fact, all types of cold water fish are driven out of the lake, before the hypolimnion becomes anaerobic, because they generally require dissolved oxygen levels of at least 5 mg/L. Highly eutrophic lakes may also have large mats of floating algae that typically impart unpleasant tastes and odours to the water.

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

8.4.5. Eutrophication of Lakes. Eutrophication is a natural process under which lakes get infested with algae and silt up gradually to become shallower and more productive through the entry and cycling of nutrients like carbon, nitrogen and phosphorus. The initially clear water of oligotrophic lakes, therefore, gradually turns into mesotrophic, eutrophic, and senescent stages, due to continuous entry of silt and nutrients.

This natural process of eutrophication in fact can always get its carbon and nitrogen requirements from the atmospheric gases like CO_2 and NO_2 ; while the requirement of phosphorus is met by its presence in natural run off due to disintegration of rocks, which produce phosphorus. The increased phosphorus in lake water, entering either through the agricultural use of its drainage area or through the entry of domestic and industrial waste waters, will cause accelerated eutrophication of lakes, and is called the **cultural eutrophication**. The natural process of eutrophication thus, gets intensified by the entry of wastewater discharge into the lakes, causing permanent damage to its water quality and leading to its siltation. *Eutrophic lakes are, however, not necessarily polluted, but pollution contributes to eutrophication.*

The water quality management for a lake, therefore, aims at reducing its eutrophication to at least at its natural level, by controlling and reducing the input of phosphorus in the lake water. Once the input of phosphorus, (which directly controls the production of *chlorophyll* and hence the algal development) is reduced, the phos-

phorus concentration will gradually fall down, as the existing phosphorous will get buried into the sediment or is flushed out of the lake along with the excess river flow feeding the lake.

Strategies suggested for reducing eutrophication by removal of phosphorus by its precipitation by addition of lime to the lake water; or by dredging out the phosphorus rich sediment from the lake bottom, will not succeed until the entry of phosphorus is not curtailed. It, therefore, becomes imperative to stop the entry of sewage and industrial wastewaters, which largely contain phosphorus, into the lakes. Even the treated sewage will not be low in phosphorus, since phosphorus can be removed only by costly advanced methods of waste treatment. *The lake waters should, therefore, not be used even for discharge of treated sewage.* The phosphorus content of the domestic sewage can, however, be reduced by banning the use of phosphorus rich polyphosphates in detergents, which presently contribute heavy input of phosphorus in domestic sewage, as large as twice that contributed by human excreta. Several advanced countries have, therefore, banned the use of phosphates in detergents and soaps. India has yet to follow suit.

The continuous entry of seeping septic tank effluents from cottages and houses built adjoining the lakes, through the sub-soil towards the lake, will also cause phosphorus pollution in the lake, after the soil gets too saturated to absorb any further phosphorus, finally passing it on to the lake. The time it takes for phosphorus to break through to the lake depends on the type of soil, the distance to the lake, the amount of wastewater generated, and the concentration of phosphorus in the seeping wastewater. Entry of phosphorus through such sources should also be controlled to reduce cultural eutrophication of lakes, by collecting the effluents of septic tanks in sewers, to be carried up to the treatment plants, before disposing them off, safely.

The use of fertilizers in fields in the drainage area should also be controlled to reduce the entry of phosphorus through the surface run off flowing over such fields and finally entering the lakes. Treatment of such catchments to reduce soil erosion will also help in reducing phosphorous entry into the surface runoff.

8.5. Disposal of Wastewaters in Sea Water

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

Table 8.6. BIS (ISI) Standards for Wastewater Effluents to be Discharged into Marine Coasts

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

Note. In addition to these major constituents, limits are prescribed for many trace metals and non-metals.

The standards prescribed for discharge of polluted waste waters into the marine coasts by Gol under Environmental (Protection) Rules, 1986 are shown in Table 8.3 (col. 5).

An Indian example of discharge of city's sewage into the sea can be seen in Mumbai city, where the Love Grove Waste Water Treatment Facility Terminal at Worli Mumbai, is disposing of the partially treated sewage at 3.5 km distance inside the sea, via an underground marine outfall tunnel, at 65 m below the ground level, after removing the floating material and inorganic solids through the screens and aerated grit chambers. This STP (Sewage Treatment Plant) facility is designed for treating a peak flow of 1820 MLD. The sewage discharge from the area comprising of church gate on south to Dadar on north, Mumbai harbour, Ray road, Sewer on the east and Arabian sea on the west, flows upto this STP site, and is lifted, at the Influent Pumping Station (IPS) containing seven duty pumps (with one additional standby unit), each having a designed capacity of 260 MLD for a designed head of 12.5 m. Before being lifted, the sewage is made to pass through 2 No. trash racks (size of openings = 150 mm) and 4 No. coarse screens (size of openings = 100 mm) through 8 No. fine screens (size of openings = 20 mm), which discharge the sewage to 4 No. aerated grit chambers of size 3.4.5 m × 7 m × 5.1 m. The grit chambers are designed as spiral flow aeration tanks, provided with air diffusion tubes placed on one side of the tank. The compressed air is discharged at a pressure of 70 kN/m² @ 1500 m³/hr. The compressed air and the geometry of the tank induces a "spiral roll" that provides centrifugal force to assist in the

The discharge of wastewaters into the sea should, however be controlled in respect of the quality of the effluents, by adhering to the prescribed standards. The standards prescribed by BIS under IS : 1968—1976 are shown in Table 8.6.

and wave action, floating debris, etc.

(iv) The outfall sewer should be placed on a firm rocky foundation, and encased in thick stone masonry, so as to properly protect it from shore by the winds, and not brought back near the shore.

(iii) Before deciding the position of outfall point, the sea currents, wind direction, velocity, etc. should be thoroughly studied. The point of disposal should be such that the sewage is taken away from the baths and recreation centres on the shores.

from accumulating on the shore, and thus preventing nuisance to 1 ½ km) from the shore line. This measure will prevent the sewage below the water level, and by taking it sufficiently inside (about

(ii) In order to mix the sewage properly with sea water, the sewage should be released at a minimum depth of 3 to 5 metres

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

ing sewage into the sea to avoid marine pollution :

In all, the following points should be kept in mind while discharging the sewage during high tides.

hold the sewage during high tides.

with a non-return valve at the outfall end, is also an alternative to the sewage during high tides. Provision of a large sized sewer, grated

Large sized tanks may, therefore, sometimes, be constructed to hold shore, the sewage should preferably be disposed off during low tides.

To prevent the backing up and spreading of sewage on the sea sewage at the top surface of sea in a thin film or 'sleek'.

thrown into the sea water. This will result in spreading of the the lighter and the warmer sewage will rise up to the surface when

sewage, and temperature of sea water is lower than that of sewage, Since the specific gravity of sea water is greater than that of

from the coast line.

As pointed out earlier, the oxygen content of sea water is less than that of fresh water, and also, its re-aeration is slower. However, since the sea contains too larger volumes of water, most of these deficiencies are removed, provided the sewage is taken deep into the sea and away

hydrogen sulphide gas by reacting with the sulphate rich water of banks are undesirable, as they are likely to produce offensive appearance to the sea water and forming sludge banks. These sludge resulting in precipitating some of the sewage solids, giving a milky water, chemically react with the dissolved matter of sea water,

removal of inorganic materials of size 0.2 mm in diameter or larger, with a sp. gravity of 2.65, thereby keeping organic matter of lower sp. gravity in suspension. The roll also "sweeps" the settled grit into a bottom hopper or collection trough, from where it is periodically removed.

The outflowing screened and degritted sewage from the grit chambers flows to the sea through *marine outfall conduit*, normally by by-passing the *Effluent Pumping Station (EPS)*. At higher discharges from the IPS, sewage from the grit chambers spills over to the EPS, containing 5 centrifugal pumps of 520 MLD capacity each at 5.8 m head. As the water level rises in the EPS wet well, the pumps at the EPS are turned on. Once the EPS is discharging into the channel leading to *marine outfall*, the flow in the by-pass channel will backup, closing the by-pass flap gates. All flow will then be pumped through the EPS.

The sewage coming out of the EPS channel or the by-pass channel now enters into a *drop shaft* on shore, from which it flows into a 3 km long underground R.C.C. circular tunnel of 3.5 m diameter, constructed at an upward slope under the sea bed at a depth of about 65 m below the ground level. This underground tunnel is named as the *marine outfall*.

The outfalling 240 m end length of this tunnel is provided with 10 No riser pipes, each of 1 m diameter, capped just above the sea bottom with circular caps containing horizontal outlet ports, the elevation of which is about 1 m above the sea bottom above the layer of sediments suspended by waves. There are 10 outlet ports of size varying from 220 mm diameter to 280 mm diameter on each riser. As such, there are 100 outlets on 10 risers. They are at a depth of about 9 m from the mean sea level to maximise dilution in initial discharges, as they rise to the surface. At this selected discharge point in the sea, the direction of currents is such that the plume of sewage is taken away from the shore side to towards the deep sea side, and spreading the sewage on a wide area.

DISPOSAL ON LAND

8.6. Disposal of Sewage Effluents on Land for Irrigation

In this method, the sewage effluent (treated or diluted) is generally disposed of by applying it on land. The percolating water may either join the water-table, or is collected below by a system of under-drains. This method can then be used for irrigating crops.

This method, in addition to disposing of the sewage, may help in increasing crop yields (by 33% or so) as the sewage generally

contains a lot of fertilising minerals and other elements*. However, the sewage effluent, before being used as irrigation water, must be made safe. In order to lay down the limiting standards for sewage effluents, and the degree of treatment required, it is necessary to study as to what happens when sewage is applied on to the land as irrigation water.

When raw or partly treated sewage is applied on to the land, a part of it evaporates, and the remaining portion percolates through the ground soil. While percolating through the soil, the suspended particles present in the sewage are caught in the soil voids. If proper aeration of these voids is maintained, the organic sewage solids caught in these voids get oxidised by aerobic process. Such aeration and aerobic conditions will more likely prevail, if the soil is sufficiently porous and permeable (such as sands and porous loams). However, if the land is made up of heavy, sticky and fine grained materials (such as clay, rock, etc.), the void spaces will soon get choked up, and thus resulting in non-aeration of these voids. This will lead to the developing of non-aerobic decomposition of organic matter, and evolution of foul gases. Moreover, excessive clogging may also result in ugly ponding of sewage over the farm land, where mosquitoes may breed in large number, causing further nuisance.

Application of too strong or too heavy load of sewage will also similarly result in the quick formation of anaerobic conditions. The greater is the sewage load, more likely it will be for the soil to get clogged. Hence, if the sewage load is reduced either by diluting it or by pre-treating it, it may be possible to avoid the clogging of the soil pores. The degree of treatment required will, however, considerably depend upon the type of the soil of the land. *If this soil, to be irrigated, is sandy and porous, the sewage effluents may contain more solids and other wastes, and thus requiring lesser treatment, as compared to the case where the soil is less porous and sticky.*

The pretreatment process may be adopted by larger cities which can afford to conduct treatment of sewage; whereas the dilution technique may be adopted by smaller cities. When sewage is diluted with water for disposal for irrigation, too large volumes of dilution water are generally not needed, so as not to require too large areas for disposal. The extent of land area required for disposing a certain volume of sewage effluent can be worked out from the values given in Table 8.7.

*Fertilising elements like nitrogen, phosphate, potash, etc. do help in increasing the yields of cash crops like cotton, sugarcane, plantain, etc. However, crops to be eaten raw or which do not have any skin to be removed before eating, should not be grown on sewage farms, although this is seldom practised by the farmers.

(2) *Sub-surface Irrigation*. In this method, sewage is supplied directly to the root zone of crops, through a system of properly laid open-jointed pipes. Sewage, as it flows through these pipes, percolates through the open joints, and is distributed in the surrounding area by the action of capillarity.

(3) *Sprinkler or Spray Irrigation*. In this method, sewage is spread over the soil through nozzles, which are fitted at the tips of pipes carrying sewage under pressure. The process, being costly, is not preferred in India, although it gives very good results, like those of a natural rainfall.

All these methods of irrigation have been thoroughly discussed in "Irrigation Engineering and Hydraulic Structures" (Chapter 1) by the same author; and can be referred to in special needs.

8.10. 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 conditions 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 hydrogen sulphide, carbon dioxide and methane. This phenomenon, of soil getting clogged, is known as *sewage sickness of land* in question.

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

(i) *Primary Treatment of Sewage*. The sewage should be disposed of, only after primary treatment, such as screening, grit removal, and sedimentation. This will help in removing settleable solids and reducing the B.O.D. load by 30% or so; and as such, soil pores will not get clogged, quickly.

(ii) *Choice of Land*. The piece of land used for sewage disposal should normally be sandy or loamy. Clayey lands should be avoided.

(iii) *Under-drainage of Soil*. The land on which the sewage is being disposed of, can be better drained, if a system of under-drains (i.e. open joined pipes) is laid below, to collect the effluent; and this will also minimise the possibilities of sewage sickness.

(iv) *Giving Rest to the Land*. The land being used for disposal should be given rest, periodically, by keeping some extra land as *As discussed earlier, porous sandy soils will clog less as compared to heavy clayey soils.

8.8. 'Effluent Irrigation' and 'Sewage Farming'—Difference Thereof

This method is, therefore preferred when sewage can be diverted to some river streams (flowing high during rainy season). This method is preferred in areas of low water-table, where rate of percolation may be quite high.

Although, outwardly, both these terms are used as synonyms to each other, yet there is one basic difference between them. This difference is that: 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.

Hence, in broad irrigation, the raw or settled sewage is discharged on a vacant land, which is provided underneath, with a system of properly laid under-drains. These under-drains, usually, consist of 15 to 20 cm dia porous tile pipes, laid open joined at a spacing of 12 to 30 m. The effluent collected in these drains after getting filtered through the soil pores is generally small (as a large quantity gets evaporated) and well stabilised, and can be easily disposed into some natural water courses, without any further treatment.

In case of *sewage farming*, however, the stress is laid upon the use of sewage effluents for irrigating crops and increasing the fertility of the soil. The pre-treatment of sewage, in removing the ingredients which may prove harmful and toxic to the plants is, therefore, necessary in this case.

However, in general, for all practical purposes, both these terms are used as synonyms, and both means: use of sewage effluents for irrigating crops.

8.9. Methods of Applying Sewage Effluents to Farms

The sewage effluents can be used for irrigating farms exactly in the same manner as irrigation water is used for farming. The various techniques that are employed for irrigating crops are:

(1) *Surface Irrigation called Broad Irrigation*. In this method, sewage is applied in different ways, on to the surface of the land. Depending upon the mode of application, it can be of different types, such as:

- (i) *Free flooding*;
- (ii) *Check flooding*;
- (iv) *Basin flooding*; and
- (ii) *Border flooding*;
- (v) *Furrow irrigation method*.

reserve and stand-by for diverting the sewage during the period the first land is at rest. Moreover, during the rest period, the land should be thoroughly ploughed, so that it gets broken up and aerated.

(v) *Rotation of Crops*. Sewage sickness can be reduced by planting different crops in rotation instead of growing single type of a crop. This will help in utilising the fertilising elements of sewage and help in aeration of soil.

(vi) *Applying shallow Depths*. The sewage should not be filled over the area in larger depths, but it should be applied in thin layers. Greater depth of sewage on a land does not allow the soil to receive the sewage satisfactorily, and ultimately results in its clogging.

A sewage-sick land can be improved and made useful by thoroughly ploughing and breaking the soil, and exposing it to the atmosphere.

8.11. Crops Grown in Sewage Farms and Their Hygienic Aspect

In fact, the city sewage is screened and sedimented before discharging it for irrigation. Neither biological treatment is given to it, nor it is disinfected. Due to this fact, the sewage effluents used for irrigation, normally remain contaminated. And since in all the broad irrigation methods (except furrow irrigation method), sewage applied for irrigation will come in direct contact with the plants, it may endanger the life and health of the people, if at all the crops grown are eaten raw, as the sewage is a potential carrier of germs and pathogenic bacteria, likely to cause diseases like typhoid, cholera, dysentery, etc. From public health point of view, therefore, *no crops which are to be eaten raw or without any skin removal, and which come in direct contact with the sewage, should be grown on sewage farms.*

Green vegetables, potatoes, etc. should, therefore, never be grown in such farms. However, crops like cotton, groundnut, grains, tobacco, sugarcane, etc. may be raised successfully on a sewage farm. Grass and fodder may also be raised, provided however, care is taken to see that the cattle do not graze on sewage wet fodder.

In any case, the crops grown on sewage farms should be properly labelled and marked*, so that the public knows about their source, and is cautious in their use.

It is suggested that, if at all vegetables are grown and sold in the market without any control, as is happening in Delhi (the capital city of India), the public should take preventive measures by keeping the raw vegetables submerged for at least 10 minutes in 1 in 400

*Practically, no farmer does so, as it will reduce the cash value of his crop.

water solution of bleaching powder, and then thoroughly wash them with water, before use. The use of potassium permanganate for disinfecting vegetables is not recommended, as by its use, the vegetables tend to lose freshness and crispness.

The health of the farmers working in the fields, is also an important factor. They should also take adequate precautions by wearing gum boots and gloves, as otherwise, the larvae present in sewage effluent may get into their body, through direct contact, causing diseases, most commonly the intestinal worms.

8.12. Dilution Method Vs. Land Disposal Method for Disposal of Sewage

(i) For disposal by dilution, large volumes of natural clean waters (with nil or very low B.O.D.) are required; whereas, for land disposal, large areas of land, preferably with sandy soils, are required.

(ii) The cost of land, in land disposal method, is generally very high, specially in cities and urban areas, which are generally situated near rivers or oceans, and thus suggesting the choice of dilution method. Whereas, in the rural areas, where the amount of sewage produced is less, land being available at lesser cost, no easy water source being available, the land disposal method is a better choice.

(iii) When the cost of land is high in land disposal method, some return may be available due to sewage farming; but then good management is also required. Dilution method of disposal, however, when possible, is a simple method, and does not require too much of management.

(iv) Land disposal method requires either no pre-treatment of sewage or only preliminary treatment; whereas, dilution method of disposal, generally requires either full or at least partial treatment.

(v) Dilution method of sewage disposal requires nil or small head pumping, because rivers flow through the lowest contours, while land disposal requires high head pumping, thus making the land disposal method costlier.

(vi) Land disposal method is generally found to be a better choice in hot climatic areas. This is because of the fact that in hot areas, D.O. contents of natural waters are reduced, while fish and aquatic life need higher D.O. concentrations, thus rendering rivers (particularly those with small dry weather flows) susceptible to too much pollution and unfit for throwing untreated or less treated sewage. A lot of pretreatment, if required, will make the dilution method costlier.

(vii) Land disposal saves the inland rivers from getting polluted by sewage, and returns to the land the fertilising elements, which were once drawn from it. Dilution in river water will naturally cause downstream river water to become polluted, and an unavoidable

health hazard. The towns and the cities situated downstream of the disposal point (particularly those near the zone of degradation and zone of active decomposition) cannot utilise river water without thorough and costlier treatment. Sometimes, the river water may get so much polluted that it may become almost impossible to purify it within the normal economics. Due to the pollution of the river, fish life may be lost, resulting in a good loss to the economy. Moreover, the recreational uses of the river will be gone, if it becomes polluted.

For most of the Indian towns and cities, the land disposal method is a better choice, because of the following reasons :

- (i) Due to hot climate, D.O. contents of river waters are low, while the fish and aquatic life requires higher D.O. concentrations for their survival, thus rendering the dilution method more difficult and prohibitive.
- (ii) There are only a few coastal towns in India, which have strong tidal currents moving in the forward directions, and the necessary depth of water at the point of disposal, thus, prohibiting the disposal of sewage in the sea on large scale.
- (iii) Most of the inland rivers, flowing in the vicinity of our cities and towns, do have very small amounts of dry weather flows in them. Most of them run dry during summer season. Even the perennial rivers like Yamuna, have very low dry weather flows in them. Further, these very rivers are the only sources of water supply to these cities and towns. All these factors make it almost imperative upon us, as not to throw away our sewage in rivers, but to throw it away on land. Even if it is decided to be thrown into the rivers, a lot of pre-treatment will be required, which will make it very costly.
- (iv) Except for a few major cities, the water supplies in India are very low (90 to 120 litres per capita per day), thus resulting in the production of highly concentrated sewage, which or travelling in out hot climate, becomes stale and septic by the time it reaches the disposal point, thus prohibiting the use of dilution method for its disposal.

PROBLEMS

1. Enumerate the two general methods adopted for sewage disposal, and discuss their merits, and demerits explaining the conditions favourable for their adoption.
2. What are the factors affecting self-purification of polluted streams? What measures would you recommend to control stream pollution in India.
3. What is meant by "Environmental Pollution"? Describe what happens when untreated sewage from a town is discharged into a nearby stream.

4. Sewage disposal systems are to be provided for :
 - (i) an isolated residential building with ten users ;
 - (ii) a small town of 2000 persons located on the bank of a river ;
 - (iii) a town with 10,000 persons located on the bank of a small river.
 Describe the possible methods of sewage disposal for each case and bring out the advantages and disadvantages of the various methods listed.
5. Write a detailed note on land treatment of sewage dealing with the chemical as well as the engineering aspects of the process.
6. What do you understand by self-purification property of a stream? Explain the factors affecting this property.
7. (a) A district town with a population of 60,000 has to discharge its sewage into a small stream. Explain various considerations involved in determining the degree of treatment required.
- (b) In what process of treatment, do you observe the following phenomenon, and why :
 - (i) sewage sickness ;
 - (ii) sludge bulking.
 Mention the remedial measures that are normally taken to correct the situation.
8. (a) What is sewage farming? What are its advantages over the method of disposal of sewage by dilution? What crops should be grown on such farms? What precautions should be taken in its operations to prevent health hazards either to the farm workers or to the consumers using the produce?
- (b) Calculate the area of sewage farm and type of crop to be grown if waste flow is 5 Mpd, (nitrogen required may be taken as 40 kg/ha/crop and nitrogen available in waste as 20 ppm).
- (a) Write a brief note on the use of sewage effluent for irrigation. Mention the places (Indian cities)*, where such uses of sewage are being made on a large scale.
- (b) A town with a population of 25,000 is to be provided with a sewage treatment plant to handle both its industrial as well as domestic wastes. A sanitary survey has revealed the following facts :

Dairy wastes of 2.7×10^8 litre/day with B.O.D. of 800 mg/l and sugar mill waste of 2.2×10^6 litre/day with B.O.D. of 800 mg/l are produced. In addition, domestic sewage produced at the rate of 200 litres/capita/day, the per capita BOD of sewage being 76 gm/day. An expansion factor of 10% is to be provided. The effluent from the treatment plant is to be discharged into a stream with a minimum flow of 7000 litres/sec and a dissolved oxygen content of 8 mg/l. It is necessary to maintain a D.O. content of 4.0 mg/l. Find the degree of treatment required for the plant.
10. (a) Explain self-purification of streams and indicate how sun-light helps in such purification.

*Bangalore, Delhi, Ahmedabad and Pune, all using partly treated i.e. sedimented sewage for irrigating crops.

Various other sophisticated methods for the recovery of hydrochloric acid from the hydrochloric acid-pickle waste, and ferrous sulphate and sulphuric acid from the sulphuric acid-pickle waste are also available.

The process of electrolysis of spent liquor is gaining importance in the matter of regeneration of acid and recovering of iron. This iron in the form of sheet or as powder has good demand in the growing industry of power-metallurgy.

QUESTIONS

1. What are the major operations in an integrated Steel Plant?
2. How are the wastes from the following units in a steel plant treated? (a) coke ovens, (b) oxygen plant, (c) rolling mills, (d) power plant, (e) pickling bath.

18 | Oil Refineries Waste

18.0 INTRODUCTION

The number of oil refineries in India has increased substantially after the independence. But, while most of the earlier refineries are located near the sea-shore, many of the new installations are located far away from the sea, and discharge their waste to the inland water courses. As such, the pollution potential of the refinery wastes has gone up considerably and demands a careful attention. However, most of the government owned refineries have undertaken antipollution measures, and are designed to discharge a waste of acceptable quality.

The large refineries practice a number of enormously complicated basic and auxiliary operations, description of which is beyond the scope of this book. In this chapter, the basic operations and the most important auxiliary processes will be described in brief to give some idea of the refinery practices. This will be followed by a description of the sources of the waste water, composition of wastes and the available treatment methods.

Other processes in large refineries in relation to the production of different petrochemicals will be described in the next chapter.

18.1 BASIC AND AUXILIARY REFINERY OPERATIONS

Crude oils are complex mixtures of hydrocarbons of varying molecular weight and structure. These hydrocarbons range from simple highly volatile substances to complex waxes and asphaltic compounds. The final petroleum products are obtained from the crude oil through a series of operations, viz., topping, thermal cracking, catalytic cracking, catalytic reforming etc. These basic

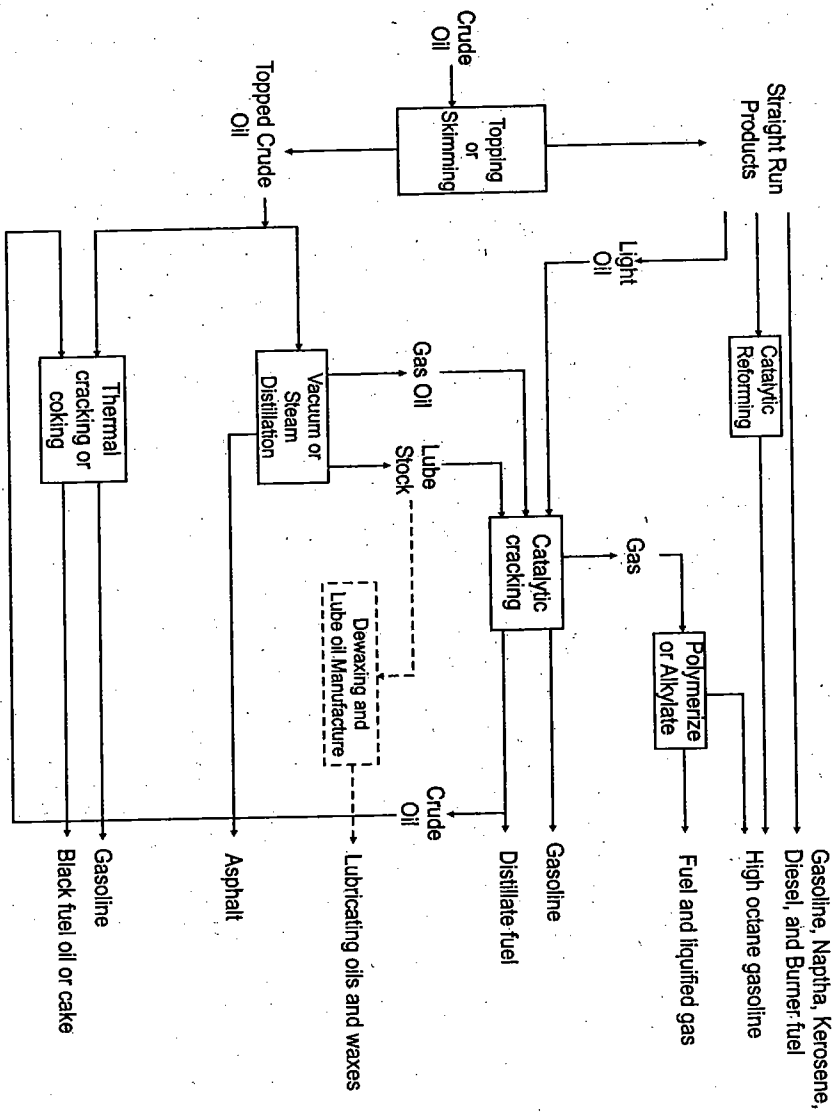


Figure 18.1: Basic Refinery Operations.

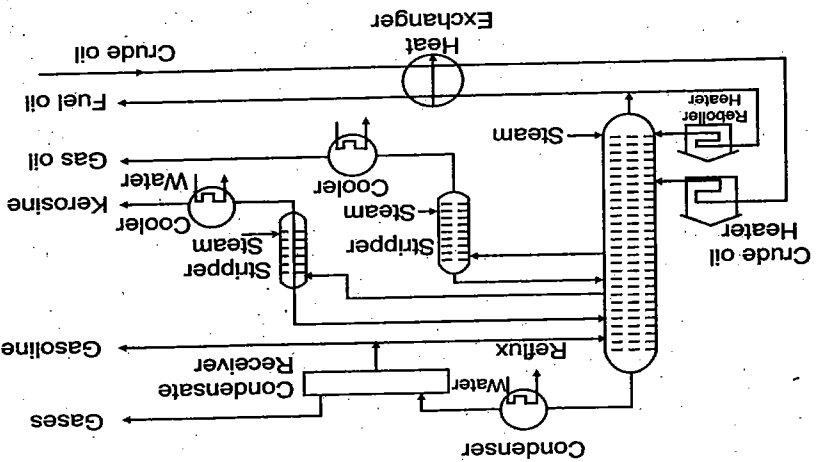


Figure 18.2: Simplified Flow Diagram for the Distillation Process.

Now these intermediate refinery products are again treated to yield various finished market products as per the requirements. The operations practiced include "catalytic cracking" or "thermal cracking", and further purification processes like "acid treatment", "sweetening treatment", "hydrodesulphurization" etc. The decomposition of heavy or high boiling petroleum distillates like gas oil and fuel oil to lighter products like gasoline is called cracking. These reactions take place practically at the atmospheric pressure and at a high temperature. In catalytic cracking, however, an acid type solid catalyst (such as synthetic silica alumina) is introduced into the reactor. A residue of heavy black material, known as coke, is obtained

operations however vary from plant to plant depending upon the properties of the crude oil and the desired grade of the final product. The basic refinery operations as mentioned above are shown diagrammatically in Fig. 18.1. In general, the crude oil is first subjected to fractional distillation in the process known as "topping". The products obtained are called raw products and include raw gasoline, raw naphtha, raw kerosene, gas oil, fuel oil etc. A simplified flow-diagram for the process is shown in Fig. 18.2.

out of the process of cracking. In the catalytic cracking process, however, the asphaltic or tar-like products get adsorbed on to the surface of the catalysts in the form of coke.

When "high octane" fuels are in demand, much of the naptha is "catalytically reformed" into high octane gasoline; the process involved is another form of cracking.

Again when market is available the most degraded carbonaceous high boiling parts of the crude oil distillates are subjected to the "coking process". This "Coking process" is nothing but a cracking process with a prolonged time of cracking, the end product of which is called "coke".

The wax distillates of the crude oil may be used as raw-material for the manufacture of light lubricating oils. The process of their manufacture consists of chilling the distillates and filtering the wax from the oil.

The products thus obtained either as final product or as feedstock for further processing may contain certain undesirable constituents which must be either removed or converted into less harmful compounds by further refining processes. Such refining processes include (i) removal of hydrogen sulfide gas and mercaptans by washing with strong caustic soda solution, or (ii) absorption of hydrogen sulphide gas in an alkaline absorber liquid (which is immiscible with the product) followed by the recovery of the hydrogen sulphide gas, in the process known as regenerative process, (iii) conversion of mercaptans to less harmful desulphide, employing solutions like lead oxide in caustic soda together with sulphur, or sodium hypochlorite or copper chloride, in a process known as "sweatening", and (iv) conversion of alkylsulphides and thiophenes and practically all other sulphur compounds into hydrogen sulphide in a catalytic reaction in the process known as "hydrodesulphurization"—hydrogen sulphide thus formed is recovered by the regenerative process.

The crude oil is sometimes pretreated with caustic soda along with water to remove salts from the crude.

Water may be removed by passing the product through a bed of calcium chloride or similar drying agent.

The brine, which comes out of the desalting operation, and the spent drying agent, used for the removal of the water goes to the

sewer. But wherever possible, the removed impurities are recovered and sold or are used for manufacture of other products; the process chemicals are reused after the recovery of the impurities. As such, these impurities do not join the waste water stream directly, but may be introduced to the flow through the condensate and wash waters which come into contact with products at some stage of the processing.

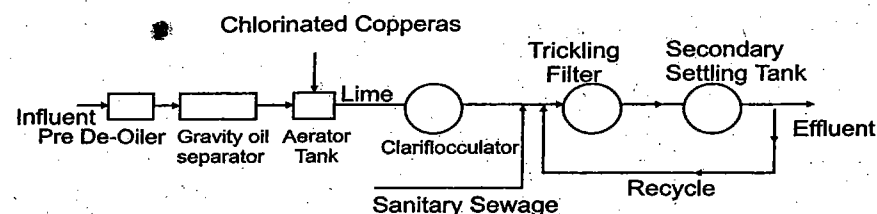


Figure 18.3. Flow Diagram for the Treatment of a Typical Petroleum Refineries Waste.

18.2 SOURCES OF WASTE WATER

A large amount of water is used in the refinery processes, and a big fraction of it comes out as waste after getting polluted by oil and other toxic substances.

Major amount of water used in a refinery, is for cooling. Like any other industry, the extent of recirculation and reuse of this water will determine the volume of the effluent discharge.

Second to cooling, the major use of water is for boiler feed. The steam obtained is utilised for different operations like desalting of crude oil, distillation and steam-stripping in topping process, and in catalytic cracking. Steam is also used for the stripping of spent catalyst before the later is sent for regeneration.

Water is also required to wash the products like gasoline to remove the traces of chemical reagents used in earlier operation. The process waste water includes the condensates and wash waters which come into contact with the petroleum products at some stage of the processing. So the waste water contains free or emulsified oil, spent caustic and acid solutions, impurities of petroleum products like hydrogen sulphides, ammonia, mercaptans, phenols, and spent catalysts.

Again where semicontinuous delayed coking is adopted and hydraulic method is used for decoking the chamber, water in the form of water jets is used for cutting and breaking down the cokes from the chamber walls. The next operation of dewatering and drying of coke produces a waste containing large amount of coke fines. Oil enters into the waste water from leaks, spills etc., at various stages.

It is not possible to generalise on the characteristics of waste water from the petroleum refineries. These characteristics vary widely with the size of the refinery, type of crude oil used, complexity of processing, water economy adopted, etc. The following table gives the general characteristics of the composite waste from a typical Indian oil refinery (Chakravarty and Bhaskaran):

TABLE 18.1: Characteristics of Oil Refineries Wastes.

| | |
|--------------------------|----------------|
| Free oil | 2000-3000 mg/l |
| Emulsified oil | 90-120 mg/l |
| H ₂ S and RSH | 10-220 mg/l |
| Phenolic compounds | 12-30 mg/l |
| 5 day 20°C BOD | 100-300 mg/l |
| Suspended solids | 200-400 mg/l |

18.3 EFFECT OF WASTES ON RECEIVING STREAMS/SEWERS

Even a negligible amount of petroleum in the order of 0.5 mg/l can impart a bad taste to water. Naphthalene also imparts bad odour and becomes toxic at a concentration of 5 mg/l. Mercaptans produces a very strong and unpleasant odour at a very low concentration. The odorous compounds of the waste impart a bad taste of the fish living in that stream. Again as the waste contains various organics, it exerts an oxygen demand and on the other hand, the oil film on the surface of the water prevents re-aeration of the stream. Cattle drinking such a polluted water, frequently get attacked by some lethal diseases.

18.4 TREATMENT OF REFINERY WASTE WATER

In general, the treatment of refinery wastes is carried out in three steps:

- (i) Physical separation of free oil.
- (ii) Chemical coagulation of emulsified oil.
- (iii) Biological treatment for the removal of BOD, phenol and other toxic materials.

The physical separation of oil is accomplished in "gravity separators". These are essentially rectangular tanks with the arrangements for oil skimming and sludge scraping. The design of gravity separator is based on fundamental principles of sedimentation, and it is assumed that all oil globules of 0.015 cm in diameter and above will be removed in the separator. A factor of safety of 1.2 is applied to the surface area to allow for short circuiting. Whatever may be the theoretical efficiency of this type of gravity separator, in practice, the efficiency reduces due to the fact that certain portion of the free oil forms agglomerates with the suspended solids present in the waste, and are not separated in the tank.

Dissolved air floatation with or without flocculation is also tried to remove the oil content of refinery wastes, and is found satisfactory in some special cases.

Effluent of the gravity separator is given a chemical treatment, consisting of coagulation, flocculation and sedimentation, to remove emulsified oil and certain other chemicals, and also to condition the waste for final treatment of the waste in biological reactors. Various coagulating agents like ferrous sulphate, ferric sulphate, chlorinated copperas, calcium chloride, calcium carbonate and hydrated lime have been tried to de-emulsify an oil-separator effluent. Most suitable type of coagulant, or the combination of coagulants, and their dosage are to be determined by laboratory tests. The flocs formed in the flocculator adsorb the oil, and becomes considerably buoyant. Therefore the following sedimentation tank must be designed with low surface settling rate and large surface area. It has been observed that the size of the sedimentation tanks can be considerably reduced by adding coagulant aids like Fuller's earth during flocculation, which almost

doubles the settling velocity of the flocs. The chemical treatment not only produces effluent of low oil content, but reduces the sulphides content considerably. Chakravarty and Bhaskaran have shown that much improved quality of the effluent may be obtained if the waste is also aerated along with the chemical treatment.

The "waste decoking water" containing large amounts of coke fines is subjected to segregation and is treated separately. Coke fines are not easily wetted by water; usually the wetting is accomplished by air blowing, subsequent to which these are settled in a settling tank. As an alternative device of treatment of coke containing waste, Chakravarty and Bhaskaran reported that, treatment of the waste with a coagulant aid (2 mg/l of coagulant aid CA-15 developed by NEERI) with flocculation (1 minute) and sedimentation (15 minutes) may produce an effluent of very high quality. By this method, not only suspended solids, but certain percentage of oil content can also be removed.

Biological treatment methods include waste stabilization pond, Aerated Lagoon, Trickling Filter, and Activated Sludge Process. Waste stabilisation ponds require large area, but are capable of reducing BOD by 43%–96% and phenol by 61–99% with a retention period of 60 days. In Aerated Lagoon, with mechanical surface aerator, a retention period of 6 days may be provided but the microbial mass produced in the lagoon settles so slowly that good effluent quality cannot be obtained unless a number of ponds are provided following the lagoon in series.

Many refinery engineers favour the trickling filter as a biological treatment method. Trickling filters can absorb shock loads of toxic matter and do well without any retardation even with an influent oil concentration of upto 100 mg/l. Deep bed high rate trickling filters have been found to be very efficient in the reduction of phenols (Rao et al). All the sulphides are removed in the Trickling Filters. A flow diagram for treatment of a typical refinery employing Trickling Filter is shown in Fig. 18.3.

Treatment of the refinery waste by Activated Sludge process is affected when the oil concentration exceeds about 30 mg/l. Chakravarty and Bhaskaran observed that activated sludge treatment of chemically treated refinery wastes results in very poor removal of BOD and phenol. To tackle this situation they developed

a modified method designated as "Ferro-biological" process. In this method both microbial mass and ferric hydroxide are used simultaneously in the aeration tank to flocculate BOD, phenol and oil. In view of the toxic nature of the refinery waste, these aeration tanks are to be designed as complete mix type.

As the biological flocs formed in the above process are adsorbed with some quantity of oil, the Final Settling Tank following the Aeration Tank must be designed with a low surface settling rate and large surface area.

The selection of the most suitable methods and the sequences of the treatment processes depends not only on the raw waste characteristics, but also on the desired effluent quality specified by the local authority. The raw waste characteristics also vary from one refinery to another. All these aspects are to be considered in the final design of the treatment units of a refinery waste.

QUESTIONS

1. What are the sources of pollution in an oil refinery?
2. How are the liquid wastes from an oil refinery treated?

Dimethyl Isophthalate, Methyl formate & acetate, Methanol, o-m, and p-xylene, and Potassium sulphate—mostly from DMT unit. DMT unit alone produces a very high BOD of about 35,000 mg/l which is about 98% of the total BOD load, where as its volume of waste is only 5% of total waste flow. The combined waste includes that from DMT unit, waste cooling water, waste from demineralisation unit, sanitary waste, floor washes, and a negligible quantity of waste from xylene unit. The BOD of the composite waste is about 1900 mg/l, while COD : BOD ratio is about 1.55. The pH of the waste from DMT unit being very low it is neutralized to pH 5-6 using lime. The neutralised DMT waste along with other wastes is then treated in a two stage biological treatment plant.

The first stage of the above biological treatment consists of an oxidation ditch shaped aerator unit, where a MLSS concentration of 4000 mg/l (MLVSS = 2400 mg/l) and a hydraulic retention time of 10 hrs is maintained at a process loading of 0.5 kg of BOD₅/kg of MLSS (or 0.64 kg of BOD₅/kg of MLVSS). The second stage consists of three oxidation ditches, where similar MLSS (MLVSS=60% MLSS) is maintained but with a process loading of 0.058 kg of BOD₅/kg of MLSS (or 0.097 kg of BOD₅/kg of MLVSS) and a hydraulic retention time of 26 hr. The treatment system is having a mean cell residence time of 24 days, and 70% of the flow is recirculated to the 1st stage inlet after the clarification in the settling tank. In both the units the aeration is accomplished by aerator rotors of capacity 2.8 kg of O₂/hr/meter length, and acclimatized microorganisms are employed. Necessary nutrients are added ahead of biological treatment. The wasting of the sludge is accomplished from the recycle line, and the sludge is dried over sand drying beds. The BOD effluent of this treatment plant is 20 mg/l. It may be added that upto 5 days of aeration the first order BOD removal rate constant for the waste is found to be 0.235/day for overall BOD and 0.272/day for soluble BOD; after 5 days it was reported to have fallen rapidly to 0.098/day and 0.085/day respectively for overall and so soluble BOD.

QUESTIONS

1. Draw a flow sheet for an aromatic waste treatment plant.
2. What are the characteristics of petrochemical wastes?
3. How are the petrochemical wastes treated?

20 Pharmaceutical Plants Waste

20.0 INTRODUCTION

Like many other industries the pharmaceutical industry produces a wide variety of products. This industry uses both inorganic and organic materials as raw materials, the latter being either of synthetic or of vegetable and animal origin. Some of the pharmaceutical plants do not discharge liquid waste at all, some others discharge very small but concentrated liquid waste, while some are very difficult to make any generalisation in regard to the characteristics of the pharmaceutical plant wastes.

20.1.1 Origin and Characteristics of the Antibiotic Wastes

Antibiotics and vitamins are produced by the fermentation of fairly complex nutrient solutions of organic matter and inorganic salts, by fungi or bacteria.

In the production of penicillin, molds of "Penicillium notatum-chrysogenum group" are cultured under submerged aerobic conditions on a medium consisting of corn steep liquor (nitrogen source), peanut meal, mineral salts, and lactose. After fermentation the mold mycelium is separated by filtration. The filtrate is then acidified to a suitable pH using phosphoric acid, and the penicillin is removed by extraction with amyl acetate. The solution of penicillin is further extracted with a buffered solution of sodium chloride. The isolated penicillin is finally purified by extraction with an organic solvent.

Streptomycin is produced in a similar way, using a "step-

"*Streptomyces griseus*" culture on a medium consisting of glucose, corn steep liquor etc. The fermentation broth is filtered, and the filtrate is adsorbed on charcoal or a resin. The streptomycin is eluted from the charcoal or resin with dilute acids.

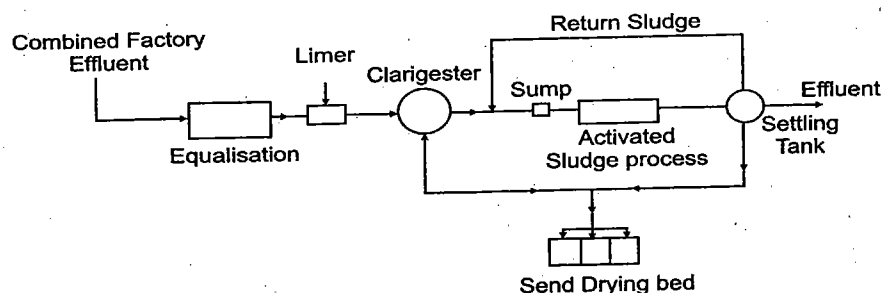


Figure 20.1. Flow Sheet for Treatment of Combined Antibiotics and Other Chemical Wastes.

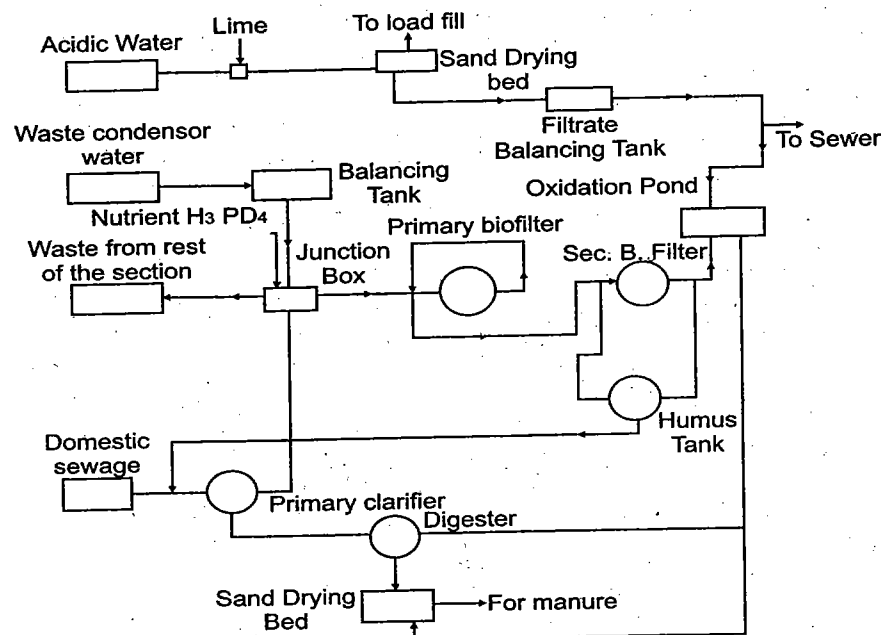


Figure 20.2 Flow Sheet for Treatment of Waste from a Large Synthetic Drug Plant.

The elute is then neutralised and concentrated. The crude streptomycin is then precipitated by the addition of acetone, and further purified.

Yields from the above processes, in terms of weight, are small, and out of the raw materials used in the fermentation more than 90% appear as wastes. This waste mycelium may either be sold as manure or stock feed, or may be disposed off in any other way.

The liquid wastes from any antibiotic plant may be divided into the following groups:

- spent liquor of the fermentation process,
- wash waters used for cleaning of floors and equipments,
- wastes containing acids, bases, and solvents used for extraction and purification of the product,
- "Filter Aids" used in the filtration, such as, "Diatomaceous Earth",
- Condensate from barometric condensers in evaporation and drying under reduced pressure.

The composition of the combined wastes from two typical plants producing penicillin and streptomycin respectively are given below (Mudri & Phadke):

TABLE 20.1. Characteristics of Antibiotic Wastes.

| Item | Penicillin plant | Streptomycin plant |
|-----------------------------|------------------|--------------------|
| Colour | Colourless | Pale yellow |
| Odour | Fruity smell | Septic |
| BOD, mg/l (5 day, 37°C) | 650-5500 | 500-2800 |
| Free ammonia nitrogen, mg/l | 0-5.6 | 0.3-18.2 |
| Nitrate Nitrogen mg/l | 0.1-0.5 | 0-0.8 |
| Phosphate, mg/l | 18-700 | 9-700 |
| Total solid, mg/l | 480-26200 | 960-4950 |
| Suspended solid, mg/l | 70-1080 | 80-1800 |
| Total volatile solid, mg/l | 200-12180 | 480-3070 |
| pH | 3.9-7.8 | 2.9-8.7 |

The above table is based on the analysis of the grab samples taken from the plant effluents. The wide variation is observed due to the fact that the batch processes are adopted for the production in the plant.

20.1.2 Inplant Treatment of Antibiotic Wastes

Treatment of the liquid wastes formed during the production of antibiotics, starts from the plant itself. For economic reasons, most of the organic solvents used in the process, like Amyl acetate in penicillin production and Butyl alcohol in Aureomycin production, are recovered in the plant. The recovery reduces the BOD of the wastes by a great extent.

20.1.3 Effects of The Wastes on Receiving Water Sewer

If a crude waste from an antibiotic waste is discharged into a stream, it not only imparts an objectionable odour to the stream, but also adversely affects the biological population in it. This waste should not be allowed to discharge into a municipal sewer, unless the sewage treatment plant is properly designed to handle a widely varying and concentrated waste from such a plant. Penicillin waste is found to have a disturbing effect on the process occurring within the sludge digestion tank.

20.1.4 Treatment of The Antibiotic Wastes

Antibiotic wastes can neither be clarified in settling tanks, nor can be chemically coagulated to reduce BOD (Koziorowski & Kucharski). The poor response of waste to the coagulation is due to the fact that most of the substances contributing to BOD appear in solution.

Anaerobic digestion of the waste results in a good reduction of BOD. In this process the inflow of the raw waste is controlled, and never allowed to exceed 5% of the capacity of the digester; further more the contents of the digester are mixed slowly and continuously.

Aeration of the waste, seeded by microorganisms either from domestic sewage or from garden soil, may result in some reduction of BOD. But the formation of sludge is very small due to the low concentration of colloidal and finely divided particles. Aeration, followed by the biological treatment of the diluted sewage in Trickling filter produces good BOD reduction. The coloured effluent of the trickling filter may be decolorized by chlorination. A large pharmaceuticals complex in India producing antibiotics, vitamin C, symbiotics and fine chemicals, treats its liquid waste of almost similar composition as given in the last table and of very

high acidity (about 700 mg/l) in two stages as given below (Rajagopal et al).

- (i) In the first stage after equalization of the waste, the high acidity is neutralized with lime and then clarified; the clarified liquor is then anaerobically digested in the digester. This results in the BOD reduction of 28-57%.
- (ii) In the second stage the conventional biological process is employed to reduce the BOD of the waste further. In a pilot plant study, both Activated sludge process and Oxidation Ditch are found to be capable of bringing down the BOD. Same degree of BOD reduction (70-80%) is observed with the following process parameters:

| | Oxidation | Activated sludge process |
|---|-----------|--------------------------|
| (a) Organic loading kg BOD/kg MLSS/day | 0.1-0.5 | 0.3-0.7 |
| (b) MLSS concentration, mg/l | 3000-4000 | 1500-2500 |
| (c) Aeration time, hrs | 22 | 6-8 |

20.2.1. Characteristics of Synthetic Drugs Waste

The synthetic drugs plants utilize large number of both organic and inorganic chemicals, and usually produce a variety of drugs in different sections of the plant. The volume and composition of the liquid wastes not only vary from plant to plant, but also from section to section in a plant, producing different types of drugs from different raw materials and using varieties of processes. Therefore a "typical" plant cannot be considered in the synthetic drug industry.

In general, most of the wastes are toxic to biological life, and are usually characterised by high BOD, COD, and a high COD: BOD ratio. Wastes from these plants are either highly alkaline or highly acidic. These wastes have a negligible fraction of settleable solids in their total solids content. Wastes from the manufacture of sedatives contain toxic elements like potassium cyanide. Highly alkaline wastes originate from the manufacture of sulfa-drugs and vitamin B₁. Manufacture of certain organic intermediates gives rise to a highly acidic waste consisting of both organic and inorganic acids.

20.2.2. Effects of The Synthetic Drug Wastes on Receiving Streams/Sewers

Wastes containing toxic elements like cyanides and heavy metals, if discharged without any treatment are harmful to the aquatic life in the streams. These toxic elements interfere with the biological sewage treatment units very badly. Similar effects are observed with raw acidic wastes; these wastes corrode structures in the sewerage system. Due to their high BOD content, a raw waste when discharged into stream rapidly depletes the dissolved oxygen of the stream and renders the water unsuitable for further use.

20.2.3. Treatment of Synthetic Drug Waste

Due to the great pollution potential and the diversified characteristics of the wastes from different sections of a plant, the planning for the treatment of synthetic drug wastes should be preceded by a careful study of each waste. Segregation and equalization very often improve the overall treatment efficiency and reduce the cost of treatment. If the wastes have high COD: BOD ratios, bench scale laboratory biological treatment studies with acclimatized seed sludge are necessary for proper planning.

The acidic wastes, wastes containing toxic elements like cyanide, and those containing offensive-odour-producing compounds are usually segregated and are treated separately. The acidic wastes may be neutralized with lime. The odour-producing compounds are usually destroyed by chlorination; compounds which are resistant to chlorine may be destroyed by heating in a furnace.

The segregated cyanide wastes may be treated with ferrous salts, where the cyanides are converted into non-toxic complex compounds. In this particular process, lime is also added along with ferrous salts to adjust the pH to an effective range. The cyanide wastes are sometimes oxidized by a strong oxidizing agent like chlorine, in an alkaline condition. This process is commonly known as "alkaline chlorination". The cyanide-containing wastes can also be treated biologically in a two stage process—the anaerobic stage followed by an aerobic stage.

Chemical treatment for other wastes is usually found to be

ineffective in BOD and COD reduction. Biological treatment employing acclimatized microorganisms, preceded by dilution is often found to be very effective for the treatment of composite wastes, even when it contains large amounts of toxic elements.

Waste from a pharmaceutical complex, at Bangalore city, producing large number of synthetic drugs, like Dexedrine, Eskazine, Neuraphosphates, Iodex, Furasin, etc, which include many toxic compounds is found to be biodegradable when diluted with domestic sewage, and acclimatized microorganisms are used in the treatment of these wastes. The average composition of the waste after mixing with the municipal waste is tabulated in Table 20.2. The combined waste is characterised by a very high COD: BOD ratio, and with a pH in the acidic range.

TABLE 20.2. Average Composition of Combined Composite Samples of Waste from the Synthetic Drug Plant at Bangalore City and a Nearby Residential Campus.

| | |
|---------------------------------|-------------------------------|
| Total solids, mg/l | 1180–1242 |
| Volatile solids, mg/l | 798–890 |
| Fixed solids, mg/l | 382–406 |
| Settleable solids, mg/l | 1.25–1.5 |
| pH | 6.5–7.0 |
| Acidity (Phenolphthalein), mg/l | 25–55 |
| 5 day 20°C BOD, mg/l | 475–567 |
| COD, mg/l | 4680–6800 |
| COD: BOD | 8.3–13.9 |
| Chloride, mg/l | 54–102 |
| Nitrate Nitrogen, mg/l | 28–32 |
| Phosphate, mg/l | 2–5.5 |
| BOD : N : P | 100 : (5.6–6.5) : (0.42–1.04) |

A pilot plant study with the above pharmaceutical plant waste (Shivalingaiah *et al*) indicates that about 95% reduction in COD, and 88% reduction in BOD can be achieved in an extended aeration process. A process loading of 0.075 kg of BOD/kg of MLSS/day, MLSS concentration of 5000 mg/l, and a mean cell residence time of about 50 days is found to be optimum.

In another large synthetic drug plant at Hyderabad, producing a large number of synthetic drugs including Analgesics and Antipyretics, Anthelmintics, Anti-Filarials, Anti-Tuberculosis,

Diuretics, Hypnotics, Sulphas, Vitamins, and a large number of organic intermediates like Analgin, Apidin, Cernizol, Hexavit, Cebexine, Sukcee, Calmod, Compeba, Salinex, etc., different sections of the plant are found to discharge different types of waste containing about seventy chemicals including organic acids and large number of organic and inorganic toxic materials. After a careful study of the wastes from all the sections, the acidic waste is segregated and treated separately; the wastes from the remaining sections are treated biologically. The average composition of the acidic waste, and the waste from other sections are given in the Table 20.3.

TABLE 20.3. Characteristics of Wastes from a Synthetic Drug Plant at Hyderabad.

| Parameters | Acidic waste | | Composite | |
|--|------------------|----------------------|------------------|----------------------|
| | from one section | rest of the sections | from one section | rest of the sections |
| Rate of flow, m ³ /day | 307 | 202 | 9.30 | 7.73 |
| pH | 0.60 | 9.30 | 7.73 | 1.70 |
| Total solids (%) | 8.27 | 6.66 | 57.564 | NIL |
| Total volatile solids (%) | 6.66 | 57.564 | NIL | 10.754 |
| Acidity (as CaCO ₃), mg/l | NIL | 20,500 | 17,000 | 14,800 |
| Alkalinity (as CaCO ₃), mg/l | 20,500 | 37,000 | 6,202 | NIL |
| Chlorides (Cl), mg/l | 37,000 | 6,202 | 13,745 | 28,540 |
| Sulphates (SO ₄), mg/l | 6,202 | NIL | 9,400 | 15,250 |
| Total Nitrogen (N), mg/l | 13,745 | 9,400 | | |
| Phosphorus (P), mg/l | 28,540 | 15,250 | | |
| BOD, mg/l | | | | |
| COD, mg/l | | | | |

The treatment of acidic wastes consists of neutralization by lime to pH 7.0 and drying of neutralized waste over sand drying beds for 5 to 6 days, for the separation of sludge. The neutralized filtrate still contains large amount of sulfanilic acid (about 75% of that in the raw waste), but as it is found to be biodegradable it is discharged into the sewer.

The waste from other sections are diluted with domestic waste and treated in two stage biofilters with pretreatment by bar screens, grit chamber and primary clarifier. The effluent of the secondary clarifier is further treated by a number of oxidation ponds which is

then discharged into the sewers.

In a pilot plant study (Mohanrao et al) with the above waste, it was found that the waste is amenable to biological treatment only when diluted to about fourteen times (about 7%) and when acclimatized microorganisms are employed. In a laboratory biological aerobic reactor, a process loading of 0.29 kg of BOD₅/kg of MLVSS, MLVSS concentration around 3500 mg/l (MLVSS is 90% of MLSS), and a hydraulic retention time of 8 hrs. are found to be optimum for about 90% reduction in BOD. The same study indicates that the kinetic growth yield coefficient, Y , and microorganism decay coefficient, k_d , of this waste is 0.56 and 0.12/day respectively. With these values of kinetic growth coefficients and the given value of optimum process loading, U , the mean cell residence time works out to be 25 days.

As evident from Table 20.3, the waste under discussion does not need any nitrogen supplementation. But addition of phosphorus @ 0.84 kg/100 kg of BOD₅ removed was found to be necessary.

QUESTIONS

1. Trace the origin and characteristics of antibiotic wastes.
2. Draw a flow sheet for treatment of wastes from a large synthetic drug manufacturing plant.