(Na^+) move through the cation permeable membrane (C) while anions (Cl^-) move through the anion permeable membrane (A) from each compartment of 'CA'. The net result is the depletion of salt content in the 'CA' compartments and an increase in salt concentration in compartments 'AC'. The fresh water produced in ion depleted compartments (CA) is collected and pumped off. The concentrated brine produced in ion concentration compartments, is discharged through the outlet.

10.7. SEWAGE AND ITS TREATMENT

Sewage is the liquid waste which includes human and house hold waste water, industrial wastes, ground wastes, street washings and storm water. Sewage contains organic and inorganic matters in dissolved, suspended and colloidal states in water. Sewage may be broadly classified into:

(i) Domestic sewage and
(ii) Industrial sewage.

(i) Domestic Sewage

Domestic sewage is the liquid wastes from residences, institutions and business buildings, containing largely organic wastes from kitchens, baths and lavatories. It mainly consists of organic load such as human excreta, urine, food wastes from kitchen, detergents from wash places and bath rooms, in suspended, dissolved or dispersed form. They are also rich in microorganisms like bacteria.

(ii) Industrial Sewage

Industrial sewage is from industrial establishments such as chemical plants, fertilizer factories, tanneries, distilleries, refineries, textiles, etc. They contain wide variety of substances, such as acids, oil, toxic chemicals, metals, animal and plant matters, non biodegradable compounds, etc.

In addition to these two types, rain water from houses, roads, etc., also constitute the sewage.

CHARACTERISTICS OF DOMESTIC SEWAGE

(a) Physical Characteristics

(i) Color and Odour: Fresh domestic sewage is, usually grey-green to grey yellow in color, but darkens with time due to decomposition. Fresh domestic sewage is without any bad smell, but when becomes stale, it develops an offensive smell due to evolution of gases like hydrogen sulfide, ammonium sulfide, phosphine, etc.

(ii) Turbidity: Sewage is normally turbid due to the presence of suspended matter.

(iii) Temperature: The temperature of sewage is slightly higher than ordinary water.

(b) Chemical Characteristics

Sewage contains more than 99% of water and remaining portion is solids in the suspended or dissolved form. It contains complex organic matter from faeces, urine, etc. These compounds can be classified as nitrogen containing and those without nitrogen. Urea, proteins, etc, are nitrogenous compound, while fats, soaps, carbohydrates are non nitrogenous compounds. Sewage also contains inorganic salts and alkalis from bathrooms, kitchens, etc. Normally fresh sewage is alkaline in nature, but becomes acidic as it becomes stale.

(c) Biological Characteristics

Sewage contains living organisms such as bacteria, algae, fungi and protozoa. Bacteria in sewage carry out the process of breaking the complex compounds into simple and stable compounds. Bacterias can be pathogenic, which are disease causing, or non-pathogenic which are harmless.

Aerobic and anaerobic oxidation: Larger number of bacterias present in sewage, are of two types, depending upon the manner in which they satisfy their oxygen demands.

(i) ***Aerobic bacterias:*** which live on free oxygen or on oxygen dissolved in water.

(ii) ***Anaerobic bacterias:*** which live and develop in the absence of free oxygen. They extract oxygen from oxygen containing radicals of organic compounds and minerals such as nitrates, nitrites and sulfates.

In the presence of oxygen, organic compounds are oxidized by aerobic bacterias and the oxidation products are nitrites, nitrates, sulfates, phosphates, etc., which do not produce any offensive smell. This kind of oxidation is known as **aerobic oxidation**.

When the oxygen content is below a certain value, the sewage is said to be stale and the organic compounds are decomposed by anaerobic bacterias, producing methane, hydrogen sulfide, phosphine, etc., which give offensive odour. This type of oxidation is called anaerobic oxidation. When the anaerobic decomposition is continuing the sewage is known as **septic sewage**.

Biological oxygen demand (BOD): When aerobic conditions prevail in the sewage, the organic impurities are decomposed by aerobic bacterias by using dissolved oxygen present in the sewage water. As a result, the dissolved oxygen content decreases. As the amount of biologically oxidisable impurities increase in water, the dissolved oxygen content decreases. Therefore, the amount of biologically oxidisable organic impurities can be expressed in terms of oxygen demand for the decomposition of these impurities.

Definition: Biological oxygen demand (BOD) of a sewage is defined as the amount of oxygen required for the biological oxidation of the organic matter under aerobic conditions at 20°C and for period of 5 days.

Characteristics of BOD parameter

- The unit of BOD is mg.dm^{-3} or ppm.
- It is empirical and semi quantitative.
- It represents only biodegradable organic load in sewage. Strictly aerobic conditions are needed.
- Determination is slow and time consuming method.

BOD indicates the amount of decomposable organic matter in the sewage. It is an expression of how much oxygen is needed for microbes to oxidize the organic matter in the sewage. It gives information about the following:

- Polluting power of sewage or its nuisance value.
- The load of organic matter on the sewage treatment plants.
- The amount of clean diluting water required for disposal of sewage.

It is important to know the BOD of sewage before disposing into rivers or lakes because, dissolved oxygen content in the water will be decreased by the sewage if its BOD is high resulting in the death of fishes and other aquatic animals.

Determination of BOD: The parameter is commonly measured by the quantity of oxygen utilized by aerobic bacteria during 5 days period.

$$\underset{\text{Biodegradable load}}{(CHONS) + O_2} \xrightarrow{\text{Aerobic bacteria}} CO_2 + H_2O + NO_3^- + SO_4^{2-}$$

Winkler's method for BOD measurement: In this method BOD is determined by measuring the dissolved oxygen (DO) content before and after 5 days incubation period by indirect iodometric method.

Principle: In this method, the given sample of water is treated with manganous sulfate and alkaline potassium iodide solution. In alkaline medium, dissolved oxygen oxidizes Mn^{2+} to Mn^{4+}, which gets precipitated as $MnO_2.H_2O$ (H_2MnO_3). On acidification, Mn^{4+} oxidizes iodide to free iodine, and the liberated iodine is then titrated with standard sodium thiosulfate solution using starch as indicator.

Fixation of dissolved oxygen,

$$Mn^{2+} + 2OH^- + \tfrac{1}{2}O_2 \rightarrow MnO_2.H_2O$$

Liberation of iodine,

$$H_2MnO_3 + 4H^+ + 2I^- \rightarrow Mn^{2+} + 3H_2O + I_2$$

$$I_2 + 2Na_2S_2O_3 \rightarrow Na_2S_4O_6 + 2NaI$$

Procedure: A definite volume of sewage sample is diluted to a known volume with dilution water which contains nutrients for bacterial growth and sufficient free oxygen. Equal volumes of diluted sample are filled into two BOD bottles.

Blank Titration: DO content in one of the bottles is determined immediately.

2ml of $MnSO_4$ solution, 3ml of alkaline KI solution are added into the bottle, stoppered, mixed well by shaking for 10–15 minutes, and allowed to stand for 2 minutes. 1ml of conc. H_2SO_4 is then added, stoppered and mixed well to dissolve the MnO_2 precipitate. A known volume of this solution is titrated with standard $Na_2S_2O_3$ solution using starch as indicator till the discharge of violet color. Repeated for agreeing values.

Sample Titration: The second bottle is incubated for 5 days at 20°C. After 5 days unconsumed DO is measured as described above.

$$\text{BOD} = \frac{D_1 - D_2}{A} \times B \text{ mg.dm}^{-3}$$

where D_1 is the DO in mg.dm^{-3} in the solution at the start. D_2 is the DO in mg.dm^{-3} in solution after 5 days. A is the volume of sample in ml before dilution and B is the volume of sample in ml after dilution.

Example 10.3: 20 ml of sewage sample was diluted to 600 ml and equal volumes were filled in two BOD bottles. DO in one bottle was determined immediately and 200 ml. of the solution required 4.2ml of N/40 $Na_2S_2O_3$ solution. The second sample was incubated for 5 days and in DO determination, 200 ml solution required 2.2 ml of N/40 $Na_2S_2O_3$ solution. Calculate BOD of the sample.

Solution:

Given,

Volume of the sample before dilution, A	= 20 ml
Volume of the sample after dilution, B	= 600 ml
Volume of the sample used for titration	= 200 ml
Volume of $Na_2S_2O_3$ solution required for blank	= 4.2 ml
Volume of $Na_2S_2O_3$ solution required for sample after 5 days	= 2.2 ml
Normality of $Na_2S_2O_3$ solution	= N/40

(a) DO of the blank solution.

$$N_1V_1 = N_2V_2$$

$$N_1 \times 200 = \frac{N}{40} \times 4.2$$

$$\text{Normality of DO} = \frac{1}{200} \times \frac{1}{40} \times 4.2$$

$$\text{DO in the blank } D_1 = \frac{1}{200} \times \frac{1}{40} \times 4.2 \times \text{ eq. wt of oxygen}$$

$$= \frac{1}{200} \times \frac{1}{40} \times 4.2 \times 8$$

$$= 4.2 \times 10^{-3} \text{ g dm}^{-3}$$

$$= \mathbf{4.2 \text{ mg. dm}^{-3}}$$

(b) DO of the sample after 5 days:

$$N_1 \times 200 = \frac{1}{40} \times 2.2$$

$$\text{Normality of DO after 5 days} = \frac{1}{200} \times \frac{1}{40} \times 2.2$$

$$\text{DO in the sample, } D_2 = \frac{1}{200} \times \frac{1}{40} \times 2.2 \times 8$$

$$= 2.2 \times 10^{-3} \text{ g.dm}^{-3}$$

$$= \mathbf{2.2 \text{ mg. dm}^{-3}}$$

Threrefore,
$$\text{BOD} = \frac{D_1 - D_2}{A} \times B$$

$$= \frac{4.2 - 2.2}{20} \times 600$$

$$= \mathbf{60 \text{ mg. dm}^{-3}}$$

Chemical oxygen demand (COD): BOD value takes into account only biologically oxidisable impurities and does not account for biologically non oxidisable and very slowly oxidisable impurities.

Therefore, chemical oxygen demand (COD) parameter is introduced to measure the total oxidisable impurities present in the sewage. This includes both biologically oxidisable and biologically inert but chemically oxidisable organic matter present in the sewage.

Definition: COD is defined as the amount of oxygen used while oxidizing the total organic load of the sample with a strong chemical oxidant, $K_2Cr_2O_7$ in acid medium. It is represented in $mg.dm^{-3}$ or ppm.

Characteristics of COD parameter

- It is a satisfactory, quantitative method for measuring total organic load..
- It is preferable to BOD as the results are reliable.
- Rapidly measurable parameter and needs about 3 hours for completion.
- In general COD > BOD since both biodegradable and non biodegradable organic load are completely oxidised.
- When used along with BOD test, it gives biologically resistant organic matter.

Determination of COD

Principle: A suitable aliquot of the sample is refluxed with a known excess of $K_2Cr_2O_7$ solution in H_2SO_4 medium and in the presence of Ag_2SO_4 and $HgSO_4$. $K_2Cr_2O_7$ oxidizes all oxidisable impurities. Ag_2SO_4 catalyses oxidation of straight chain organic compounds, aromatics and pyridine. $HgSO_4$ avoids the interference of Cl^- ions by forming soluble complex with them.

The amount of unconsumed $K_2Cr_2O_7$ is determined by titration with standard ferrous ammonium sulfate solution. The amount of $K_2Cr_2O_7$ solution consumed corresponds to the COD of the sewage sample.

Procedure: To an aliquot of sample taken in a 250 ml conical flask with ground glass joint, 1g of $HgSO_4$ and 1g of Ag_2SO_4 are added, followed by a known volume of $K_2Cr_2O_7$ solution and acidified with dilute H_2SO_4. The conical flask is fixed with a water condenser and the solution is refluxed for 2 hours. The contents are cooled and titrated with standard ferrous ammonium sulfate solution, using ferroin as indicator, till the color changes from blue green to reddish brown.

Blank Titration: The above procedure is repeated by taking the same volume of distilled water in place of the sample.

Calculations:

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Volume of sample taken	= V ml
Volume of std FAS used in sample titration	= A ml
Volume of std FAS in Blank titration	= B ml

Normality of FAS solution = N

Amount of $K_2Cr_2O_7$ consumed in satisfying the COD in term of FAS solution = (B – A) ml

$$N_1 \times V = N \times (B - A)$$

Normality of COD of the sample, $N_1 = \dfrac{N \times (B - A)}{V}$

COD of the sample $= \dfrac{N \times (B - A)}{V} \times 8 \text{ g.dm}^{-3}$

$$= \frac{N \times (B - A)}{V} \times 8 \times 1000 \text{ mg.dm}^{-3}$$

Example 10.4: 20 ml of sewage sample for COD is reacted with 25 ml of $K_2Cr_2O_7$ solution and the unreacted $K_2Cr_2O_7$ requires 9.0 ml of N/4 FAS solution. Under similar conditions, in blank titration 15.0 ml of FAS is used up. Calculate the COD of the sample.

Solution:

Given,

Volume of sample taken = 20 ml

Volume of N/4 FAS required to react with unconsumed $K_2Cr_2O_7$ = 9.0 ml

Volume of FAS consumed in blank = 15.0 ml

Amount of $K_2Cr_2O_7$ consumed to satisfy COD in terms of FAS solution = 15.0 – 9.0

= 6 ml

$$N_1V_1 = N_2V_2$$

$$N_1 \times 20 = 0.25 \times 6.0$$

Therefore, normality of COD sample, $N_1 = \dfrac{0.25 \times 6}{20}$

...ple sample

$$= N_1 \times \text{eq. wt. of oxygen}$$

$$= \frac{0.25 \times 6}{20} \times 8$$

$$= 0.6 \text{ g. dm}^{-3}$$

$$\mathbf{= 600 \text{ mg. dm}^{-3}}$$

...treatment: The domestic sewage contains heavy load of BOD, pathogenic bacteria, color ...ing smell. If such raw waste water is discharged into natural water bodies like rivers, lakes ...they get contaminated causing following possible effects:

- Depletion of dissolved oxygen – destruction of fish and other aquatic life.
- Color and smell affecting the quality of water.
- Pathogenic bacteria causing water borne diseases.

...domestic sewage, therefore, needs proper treatment before it is either discharged into natural ...dies or recycled. The treatment aims at the removal of oxygen demanding organic compounds, ...id and floating matter, and other matters such as ammonium salts, phosphates, pathogenic ...etc. The sewage treatment is carried out in three stages.

- Primary treatment
- Secondary treatment
- Tertiary treatment

...ary treatment: Primary treatment involves:

- Screening
- Silt and grit removal
- Oil and gas removal
- Sedimentation

...ning: It is a physical process which removes large suspended or floating matter in the ... This is accomplished by using bar screens and mesh screens which retain the floating and ...d coarse particles when sewage water is passed through it.

...nd grit removal: Grit, i.e., sand, broken glass, etc., are removed by passing sewage through ...bers, in which the velocity of flow of sewage is reduced. Being heavier, silt and grit particles ...wn at the bottom.

...al of oil, grease, etc.: Oil, grease, etc., are removed in skimming tanks. They are converted ...py mixture by blowing compressed air through sewage water in skimming tanks, and lifted ...face in the form of a foam. The floating substance is skimmed off.

(d) Sedimentation process: It removes finer suspended impurities. This is brought about by plain sedimentation in a continuous flow type sedimentation tank or by sedimentation with coagulation. The coagulants used are alum, ferrous sulfate, etc., which help in the easy settlement of the finely suspended particles.

(ii) Secondary treatment (Biological treatment): This process involves an aerobic biochemical oxidation or aeration. The sewage water, after sedimentation, is subjected to aerobic oxidation, during which the organic matter is converted into CO_2, the nitrogen into ammonia, and finally into nitrites and nitrates. Bases present in the sewage water form salts like ammonium nitrite, ammonium nitrate, calcium nitrate, etc.

Secondary treatment or biological treatment is generally accomplished by either trickling filter method or activated sludge process.

Trickling filter method: Trickling filter consists of a rectangular or circular vessel, with a filter bed made up of broken rock, broken bricks or large anthracite coal (Fig. 10.5). Sewage is sprayed over this bed by means of a rotating distributor. As the sewage trickles or percolates downwards through the filter bed, micro organisms grow on the surface of aggregates; using organic materials of the sewage as food. Aerobic conditions are maintained and the purified sewage is removed from the bottom. The process removes 90% of biologically oxidisable impurities.

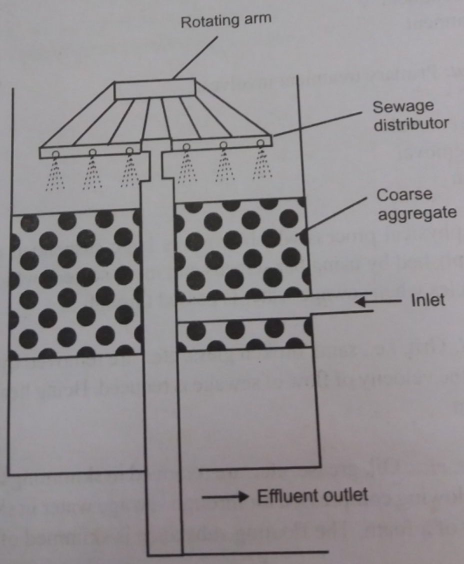

Fig. 10.5. Trickling filter

Activated sludge process: Activated sludge process involves extensive aeration of the sewage water and the process of aerobic oxidation being enhanced by the addition of a part of sludge from previous oxidation process, into sewage water. The added sludge from the previous oxidation batch is known as activated sludge, since it contains large number of aerobic bacteria and other micro organisms.

The sedimented sewage water is mixed with proper quantity of activated sludge and the mixture is sent to the aeration tank (Fig 10.6), in which the mixture is aerated and agitated for several hours. During this process, organic matters are oxidized. After the process is complete, the effluent is sent to a sedimentation tank, where sludge is deposited and water free from organic matter is drawn off. A part of the settled sludge is sent back for seeding fresh batch of sewage.

The effluent from secondary treatment has much lower organic load. This water, after chlorination to kill the pathogenic bacteria, is discharged into lakes, streams, rivers, and sea.

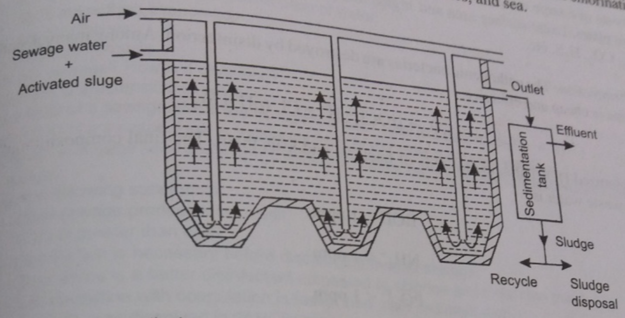

Fig. 10.6. Activated sludge method

(iii) ***Tertiary treatment:*** The aim of tertiary treatment is further purification of waste water as well as its recycling.

The tertiary treatments consists of

(a) Removal of phosphate
(b) Coagulation and sedimentation
(c) Filtration.
(d) Degasification (NH_3 Stripping)
(e) Disinfection

a. ***Removal of Phosphate:*** The phosphates are removed by adding $Ca(OH)_2$. A flocculent precipitate of calcium phosphate is formed at pH 10–11. At this pH, ammonium salts are converted into ammonia.

$$3Ca(OH)_2 + 2PO_4^{3-} \rightarrow Ca_3(PO_4)_2 + 6OH^-$$

$$Ca(OH)_2 + NH_4^+ \rightarrow Ca^{2+} + NH_3 + H_2O + OH^-$$

(b) Coagulation and Sedimentation: The suspended fine particles are removed by sedimentation in the presence of coagulants like alum, ferrous sulfate, etc. The flocculent precipitates of $Al(OH)_3$ or $Fe(OH)_2$ formed by the coagulants entrap the fine particles and help them to settle down. The highly charged ions of the coagulants also neutralize the charges on colloidal particles and make them to coagulate and settle down.

(c) Filtration: For filtration, the water is passed through a conventional sand filter beds to remove the last traces of suspended matter.

(d) Degasification: Stripping of ammonia and other gases is done in a degasifier. The degasifier consists of a large tower fitted with a number of perforated plates. The hot water trickles through these plates. Large surface area and higher temperature promote stripping of dissolved gases like NH_3, CO_2, H_2S, etc.

(e) Disinfection: The pathogenic bacterias are destroyed by disinfection. Among many disinfectants, chlorine is cheap and effective.

$$Cl_2 + H_2O \rightarrow HOCl + H^+ + Cl^- \text{ (pH 6.5)}$$

Unionized HOCl attacks the cells of bacteria and kills them. The final composition of tertiary treated waste water is.

$$BOD < 1 \text{ ppm}$$

$$NH_4^+ < 1 \text{ ppm}$$

$$PO_4^{3-} < 1 \text{ ppm}$$

The treated water has high clarity, free from odour, low BOD, and therefore, it is nearly equivalent to drinking water and can be recycled.

Sludge disposal: Sludge, which is collected from sewage treatment processes are disposed off by the following methods.

(i) Burrial at sea: At places, which are near the sea, sludge can be dumped into sea.

(ii) Land spreading: The sludge is uniformly spread over soil, followed by ploughing. It acts as a fertilizer.

(iii) Septic tank treatment and sludge digestion: The sludge is kept in a closed tank in the absence of air for prolonged period (about 30 days). The sludge undergoes anaerobic decomposition producing gases like methane, H_2S, phosphine, etc. The gas can be used as fuel for city supply or power generation.