Module 13 : Characteristics Of Sewage And Overview of Treatment Methods

Lecture 16 : Characteristics Of Sewage And Overview of Treatment Methods

13.1 Sewage Characteristics

Characterization of wastes is essential for an effective and economical waste management programme. It helps in the choice of treatment methods deciding the extent of treatment, assessing the beneficial uses of wastes and utilizing the waste purification capacity of natural bodies of water in a planned and controlled manner. While analysis of wastewater in each particular case is advisable, data from the other cities may be utilized during initial stage of planning.

Domestic sewage comprises spent water from kitchen, bathroom, lavatory, *etc.* The factors which contribute to variations in characteristics of the domestic sewage are daily per capita use of water, quality of water supply and the type, condition and extent of sewerage system, and habits of the people. Municipal sewage, which contains both domestic and industrial wastewater, may differ from place to place depending upon the type of industries and industrial establishment. The important characteristics of sewage are discussed here.

13.1.1 Temperature

The observations of temperature of sewage are useful in indicating solubility of oxygen, which affects transfer capacity of aeration equipment in aerobic systems, and rate of biological activity. Extremely low temperature affects adversely on the efficiency of biological treatment systems and on efficiency of sedimentation. In general, under Indian conditions the temperature of the raw sewage is observed to be between 15 and 35 ^{0}C at various places in different seasons.

13.1.2 The pH

The hydrogen ion concentration expressed as pH, is a valuable parameter in the operation of biological units. The pH of the fresh sewage is slightly more than the water supplied to the community. However, decomposition of organic matter may lower the pH, while the presence of industrial wastewater may produce extreme fluctuations. Generally the pH of raw sewage is in the range 5.5 to 8.0.

13.1.3 Colour and Odour

Fresh domestic sewage has a slightly soapy and cloudy appearance depending upon its concentration. As time passes the sewage becomes stale, darkening in colour with a pronounced smell due to microbial activity.

13.1.4 Solids

Though sewage generally contains less than 0.5 percent solids, the rest being water, still the nuisance caused by the solids cannot be overlooked, as these solids are highly degradable and therefore need proper disposal. The sewage solids may be classified into dissolved solids, suspended solids and volatile suspended solids. Knowledge of the volatile or organic fraction of solid, which decomposes, becomes necessary, as this constitutes the load on biological treatment units or oxygen resources of a stream when sewage is disposed off by dilution. The estimation of suspended solids, both organic and inorganic, gives a general picture of the load on sedimentation and grit removal system during sewage treatment. Dissolved inorganic fraction is to be considered when sewage is used for land irrigation or any other reuse is planned.

13.1.5 Nitrogen and Phosphorus

The principal nitrogen compounds in domestic sewage are proteins, amines, amino acids, and urea. Ammonia nitrogen in sewage results from the bacterial decomposition of these organic constituents. Nitrogen being an essential component of biological protoplasm, its concentration is important for proper functioning of biological treatment systems and disposal on land. Generally, the domestic sewage contains sufficient nitrogen, to take care of the needs of the biological treatment. For industrial wastewater if sufficient nitrogen is not present it is required to be added externally. Generally nitrogen content in the untreated sewage is observed to be in the range of 20 to 50 mg/L measured as TKN.

Phosphorus is contributing to domestic sewage from food residues containing phosphorus and their breakdown products. The use of increased quantities of synthetic detergents adds substantially to the phosphorus content of sewage. Phosphorus is also an essential nutrient for the biological processes. The concentration of phosphorus in domestic sewage is generally adequate to support aerobic biological wastewater treatment. However, it will be matter of concerned when the treated effluent is to be reused. The concentration of PO_4 in raw sewage is generally observed in the range of 5 to 10 mg/L.

13.1.6 Chlorides

Concentration of chlorides in sewage is greater than the normal chloride content of water supply. The chloride concentration in excess than the water supplied can be used as an index of the strength of the sewage. The daily contribution of chloride averages to about 8 gm per person. Based on an average sewage flow of 150 LPCD, this would result in the chloride content of sewage being 50 mg/L higher than that of the water supplied. Any abnormal increase should indicate discharge of chloride bearing wastes or saline groundwater infiltration, the latter adding to the sulphates as well, which may lead to excessive generation of hydrogen sulphide.

13.1.7 Organic Material

Organic compounds present in sewage are of particular interest for environmental engineering. A large variety of microorganisms (that may be present in the sewage or in the receiving water body) interact with the organic material by using it as an energy or material source. The utilization of the organic material by microorganisms is called metabolism. The conversion of organic material by microorganism to obtain energy is called catabolism and the incorporation of organic material in the cellular material is called anabolism.

To describe the metabolism of microorganisms and oxidation of organic material, it is necessary to characterize quantitatively concentration of organic matter in different forms. In view of the enormous variety of organic compounds in sewage it is totally unpractical to determine these individually. Thus a parameter must be used that characterizes a property that all these have in common. In practice two properties of almost all organic compounds can be used: (1) organic compound can be oxidized; and (2) organic compounds contain organic carbon.

In environmental engineering there are two standard tests based on the oxidation of organic material: 1) the Biochemical Oxygen Demand (BOD) and 2) the Chemical Oxygen Demand (COD) tests. In both tests, the organic material concentration is measured during the test. The essential differences between the COD and the BOD tests are in the oxidant utilized and the operational conditions imposed during the test such as biochemical oxidation and chemical oxidation. The other method for measuring organic material is the development of the Total Organic Carbon (TOC) test as an alternative to quantify the concentration of the organic material.

Biochemical Oxygen Demand (BOD): The BOD of the sewage is the amount of oxygen required for the biochemical decomposition of biodegradable organic matter under aerobic conditions. The oxygen consumed in the process is related to the amount of decomposable organic matter. The general range of BOD observed for raw sewage is 100 to 400 mg/L. Values in the lower range are being common under average Indian cities.

Chemical Oxygen Demand (COD): The COD gives the measure of the oxygen required for chemical oxidation. It does not differentiate between biological oxidisable and nonoxidisable material. However, the ratio of the COD to BOD does not change significantly for particular waste and hence this test could be used conveniently for interpreting performance efficiencies of the treatment units. In general, the COD of raw sewage at various places is reported to be in the range 200 to 700 mg/L.

In COD test, the oxidation of organic matter is essentially complete within two hours, whereas, biochemical oxidation of organic matter takes several weeks. In case of wastewaters with a large range of organic compounds, an extra difficulty in using BOD as a quantitative parameter is that the rate of oxidation of organic compounds depends on the nature and size of its molecules. Smaller molecules are readily available for use by bacteria, but large molecules and colloidal and suspended matters can only be metabolized after preparatory steps of hydrolysis. It is therefore not possible to establish a general relationship between the experimental five-day BOD and the ultimate BOD of a sample, *i.e.*, the oxygen consumption after several weeks. For sewage (with k=0.23 d^{-1} at 20^oC) the BOD_5 is 0.68 times of ultimate BOD, and ultimate BOD is 87% of the COD. Hence, the COD /BOD ratio for the sewage is around 1.7.

13.1.8 Toxic Metals and Compounds

Some heavy metals and compounds such as chromium, copper, cyanide, which are toxic may find their way into municipal sewage through industrial discharges. The concentration of these compounds is important if the sewage is to treat by biological treatment methods or disposed off in stream or on land. In general these compounds are within toxic limits in sanitary sewage; however, with receipt of industrial discharges they may cross the limits in municipal wastewaters.

13.2 Effect of Industrial Wastes

Wastewaters from industries can form important component of sewage in both volume and composition. It is therefore necessary that details about nature of industries, the quantity and characteristics of the wastewater and their variations, which may affect the sewerage system and sewage treatment process, should be collected.

In case, where wastewaters high in suspended solids and BOD are to be accepted, provision should be made in the design of the treatment plant to handle such wastes. In certain instances, it is more economical to tackle the industrial waste at the source itself. Where, the wastewater has high or low pH, corrective measures are necessary before admitting them to the sewers or the treatment plant. Toxic metals and chemicals having adverse effects on biological treatment processes, or upon fish life in a natural water course, or render the receiving water stream unfit as a source of water supply, should be brought down to acceptable limits at the source itself. Oil and grease in excessive amounts not only add considerably to the cost of treatment, but also pose a disposal problem. The industrial wastewaters may be discharged into public sewers if the effluents meet the tolerance limits prescribed by the authority. If the wastewaters are to be discharged into inland surface waters, tolerance limits set by the concerned authority should be satisfied.

13.3 Effluent Disposal and Utilization

The sewage after treatment may be disposed either into a water body such as lake, stream, river, estuary, and ocean or on to land. It may also be utilized for several purposes such as (a) industrial reuse or reclaimed sewage effluent cooling system, boiler feed, process water, *etc.*, (b) reuse in agriculture and horticulture, watering of lawns, golf courses and similar purpose, and (c) groundwater recharge for augmenting groundwater resources for downstream users or for preventing saline water intrusion in coastal areas.

13.4 Status of Wastewater Generation, Collection, and Treatment in Indian Metro Cities

The prime cause of critical unsanitary conditions in many cities in India is due the lack of facilities to collect wastewater and to dispose off after treatment. Data on wastewater generation and collection is less when compared to information on water supply. Hence, it is difficult to assess the total pollution potential. As per the CPCB reports the total wastewater generated by 23 metro cities is 9,275 MLD [CPCB, 1997]. Out of this, about 58.5% is generated by the first four metro cities, *viz.* Bombay, Calcutta, Delhi and Chennai. The city of Bombay generates the maximum wastewater to the tune of 2,456 MLD and Madurai generates the least with 48 MLD [CPCB, 1997]. From the available data it may be seen that the ratio of industrial to municipal wastewater varies from 0.06% to 2%. Out of the 23 metrocities, 19 cities have sewerage coverage for more than 75% of the population and the remaining 4 cities have more than 50% coverage. On the whole 78% of the total metro population is provided with sewerage facility, compared to 63% in 1988 [CPCB, 1997].

Out of 9275 MLD of total wastewater generated, only 31% (2,923 MLD) is treated before letting out and the rest *i.e.*, 6,352 MLD is disposed off untreated. Three cities have only primary treatment facilities and thirteen have primary and secondary facilities. The municipalities dispose off their treated or partly treated or untreated wastewater into natural drains joining rivers or lakes or used on land for irrigation or fodder cultivation or into the sea or combination thereof.

It is found that in 12 metrocities there is some level of organized sewage farming under the control of government or local body. The municipal corporations of Bhopal, Calcutta, Hyderabad, Indore, Jaipur, Madras, Nagpur, Patna, Pune, Surat, Vadodara and Varanasi have sewage farms organized by government / farmers and controlled by Government / Municipal Corporation / irrigation departments. The cost of sewage charge was in the range of Rs.400/ hectare / year in Jaipur to Rs.75/hectare / year in Hyderabad. The average sale price of sewage works out to be Rs.188/hectare / year for metrocities.

13.5 Economic Value of Sewage

The sewage contains nutrients, which if not optimally reused may cause eutrophication in receiving water bodies, thus causing their premature ageing. Hence, instead of directly discharging the effluents into water bodies it can be used for irrigation or fodder cultivation. The economic value of sewage can be assessed based on its nutrient value. This will guide for considering sewage as a source of income, and to make sewage treatment economically viable.

The nutrient value of sewage in terms of nitrogen 30 mg/L, phosphate 7.5 mg/L, and potassium 25 mg/L is provided by CPCB [1997]. The total value of nutrient in sewage assuming @ Rs. 4220/- per tone of nutrient (as per 1996 cost), works out to be Rs. 1018 million, *i.e.*, Rs. 890.6 million towards nutrients plus Rs. 127.4 million toward the cost of water.

A realistic rate for tariff towards sewage supplied for sewage farming should consider the cost of nutrients apart from the cost of water supplied. At present the sewage is charged at average rate of Rs. 188/hectare/ annum, which is towards the cost of irrigation water only. If nutrients in the sewage are also to be accounted for, then an additional cost of Rs. 263/MLD or Rs. 1315 per hectare/annum should be levied for application levels of 500 cm per hectare per annum. Hence, the tariff should be levied at Rs. 1503 per hectare/annum (Rs.1315 + 188) from cultivators [CPCB, 1997].

13.6 Wastewater Treatment

Treatment and safe disposal of wastewater is necessary. This will facilitate protection of environment and environmental conservation, because the wastewater collected from cities and towns must ultimately be returned to receiving water or to the land. Once the minimum effluent quality has been specified, for maximum allowable concentrations of solids (both suspended and dissolved), organic matter, nutrients, and pathogens, the objective of the treatment is to attain reliably the set standards. The role of design engineer is to develop a process that will guarantee the technical feasibility of the treatment process, taking into consideration other factors such as construction and maintenance costs, the availability of construction materials and equipment, as well as specialized labour.

Primary treatment alone will not produce an effluent with an acceptable residual organic material concentration. Almost invariably biological methods are used in the treatment systems to effect secondary treatment for removal of organic material. In biological treatment systems, the organic material is metabolized by bacteria. Depending upon the requirement for the final effluent quality, tertiary treatment methods and/or pathogen removal may also be included.

Today majority of wastewater treatment plants use aerobic metabolism for the removal of organic matter. The popularly used aerobic processes are the activated sludge process, oxidation ditch, trickling filter, and aerated lagoons. Stabilization ponds use both the aerobic and anaerobic mechanisms. In the recent years due to increase in power cost and subsequent increase in operation cost of aerobic process, more attention is being paid for the use of anaerobic treatment systems for the treatment of wastewater including sewage. Recently at few places the high rate anaerobic process such as Upflow Anaerobic Sludge Blanket (UASB) reactor followed by oxidation pond is used for sewage treatment.

13.6.1 Characterization of Wastewater

The wastewater after treatment is ultimately disposed on to land or into the water body. Normally the treatment consists of removal of SS and organic matter either in suspended or soluble form, which consumes DO from the water body. The plant can be designed for 100%

removal of this pollutant, but the treatment will become uneconomical. In addition, the existing watercourses can assimilate certain portion of pollution load without seriously affecting the environment. Thus, major portion of pollutants are removed in treatment plants and the remaining treatment is left with natural purification process. Therefore, before proceeding with the design of the treatment plant, it is essential to determine

1) The characteristics of the raw wastewater, and
2) The required degree of treatment i.e., the required characteristics of the treatment plant effluent.

The characteristic of the wastewater differs from industry to industry and from city to city for domestic wastewater, depending upon the standard of living of the people and commercial and industrial activities in the city. In absence of any data for Indian cities, the per capita SS can be considered as 90 to 95 gm per day and BOD as 40 to 45 gm/day. The BOD associated with suspended solids is usually at a rate of 0.25 kg of BOD per kg of SS.

13.6.2 Characteristics of the Treatment plant effluent

The required quality of treatment plant effluent is dictated by the quality requirements of the receiving water. The quality requirements of the receiving water are established either by law or by vigorous engineering analysis giving consideration to natural purification or self-purification that occurs in the receiving water. It can either be regulated by Stream Standards looking in to assimilative capacity of the water body or discharge standards which will be implemented uniformly under jurisdiction of the authority without looking in to the rive water quality at specific location. In India the effluent standards required for domestic sewage and industrial effluent is available on the Central Pollution Control Board (CPCB) website (http://cpcb.nic.in/GeneralStandards.pdf).

13.7 Classification and Application of Wastewater Treatment Methods

The degree of treatment required can be determined by comparing the influent wastewater characteristics to the required effluent characteristics, adhering to the regulations. Number of different treatment alternatives can be developed to achieve the treated wastewater quality.

13.7.1 Classification of Treatment Methods

The individual treatment methods are usually classified as:

- Physical unit operations
- Chemical unit processes

- Biological unit processes.

Physical Unit Operations: Treatment methods in which the application of physical forces predominates are known as physical unit operations. Most of these methods are based on physical forces, e.g. screening, mixing, flocculation, sedimentation, flotation, and filtration.

Chemical Unit Processes: Treatment methods in which removal or conversion of contaminant is brought by addition of chemicals or by other chemical reaction are known as chemical unit processes, for example, precipitation, gas transfer, adsorption, and disinfection.

Biological Unit Processes: Treatment methods in which the removal of contaminants is brought about by biological activity are known as biological unit processes.

- This is primarily used to remove biodegradable organic substances from the wastewater, either in colloidal or dissolved form.
- In the biological unit process, organic matter is converted into gases that can escape to the atmosphere and into bacterial cells, which can be removed by settling.
- Biological treatment is also used for nitrogen removal and for phosphorous and sulphate removal from the wastewater.

The different treatment methods used in wastewater treatment plant are classified in three different categories as:

- *Primary Treatment* : Refers to physical unit operations.
- *Secondary Treatment*: Refers to chemical and biological unit processes.
- *Tertiary Treatment*: Referes to any one or combination of two or all three i.e., physical unit operations and chemical or biological unit processes, used after secondary treatment.

13.7.2 Elements of plant Analysis and Design

The important terms used in analysis and design of treatment plants are (CPHEEO, 1993):

Flow Sheet: It is the graphical representation of a particular combination of unit operations and processes used in treatment.

Process Loading Criteria (or designed criteria): The criteria used as the basis for sizing the individual unit operation or process is known as process loading criteria.

Solid Balance: It is determined by identifying the quantities of solids entering and leaving each unit operation or process.

Hydraulic profile: This is used to identify the elevation of free surface of wastewater as it flows through various treatment units.

Plant Layout: It is spatial arrangement of the physical facilities of the treatment plant identified in the flow sheet.

13.7.3 Order of Reaction

The reactions occurring during wastewater treatment are slow and hence, kinetic considerations are important for design. The general equation used for relating the rate of change of concentration with respect to time can be expressed as

$$dS/dt = K.\ S^n$$

Where, S is the concentration of the reacting substance, K is the reaction rate constant per unit time, and n denotes the order of the reaction (n = 1 for first order reaction, n = 2 for second order reaction, and so on).

The value of K depends on the environmental conditions in the reactor, such as (a) temperature, (b) presence of toxicity, (c) presence of catalyst, (d) availability of nutrients and growth factors.

Zero order reactions (n = 0) are independent of the substance concentration and hence their rate (dS/dt) is constant. Certain catalytic reactions occur in this way and some times even biological reaction may follow zero order reaction.

In first order reactions, the rate of change of concentration of substance is proportional to the concentration of that substance. This concentration of the substance and rate will diminish with respect to time. Decomposition of single substrate exhibits the true first order reaction.

Biological stabilization of organic matter in batch reactor is a typical example of a pseudo-first-order reaction. The rate of reaction is proportional to the concentration of a single item, organic matter in this case, provided the other parameters controlling reactions are favourable. If the substrate concentration (organic matter) is maintained constant within the narrow range (as in the case of continuous flowing, completely mixed reactors), then the rate of reaction is practically constant and then it is like pseudo-zero-order type of reaction. Some biological treatment systems behave in this manner.

There are various complex processes whose overall rate is approximately first order in nature. With a complex substrates (sewage or industrial wastewaters) over all reaction rate may appear like a first order reaction, although the individual substrate among the several may exhibit the zero order reaction. This is because, the rate of reaction may be higher initially due to higher utilization of easily biodegradable substrate, but rate will slower down with respect to time due to more difficult substrate left in the reactor.

13.7.4 Types of Reactors Used

a) ***Batch Reactor***: These reactors are operated as fill and draw type. In this the wastewater flow is not continuous in the reactor. The reactors are operated in batch mode with fill time, reaction time, and withdrawal time. For example, BOD test, Sequencing Batch Reactor (SBR). The reactor content may be completely mixed to ensure that no temperature or concentration gradient exists. All the elements in the reactor, under batch mode of operation, are exposed to treatment for the same length of time for which the substrate is held in the reactor. Hence, they are like ideal plug flow reactors.

b) ***Plug-Flow (tubular flow) Reactor***: In this reactor, the fluid particles pass through the tank and are discharged in the same sequence in which they enter in the tank. The particles remain in the tank for a time equal to theoretical detention time. There is no overtaking or falling behind; no intermixing or dispersion. Longitudinal dispersion is considered as minimum and this type can occur in high length to width ratio of the tanks. For example, grit chamber, aeration tank of ASP with high length to width ratio.

c) ***Continuous-flow Stirred Tank (Complete – mixed) reactor***: In this reactors, particles are dispersed immediately throughout the tank as they enter the tank. Thus, the content in the reactor are perfectly homogeneous at all points in the reactor. This can be achieved in square, circular or rectangular tank. The particles leave the tank in proportion to their statistical population. The concentration of the effluent from the reactor is the same as that in the reactor.

d) ***Arbitrary Flow***: Any degree of partial mixing between plug flow and completely mixing condition exists in this reactor. Each element of the incoming flow resides in the reactor for different length of time. It is also called as intermixing or dispersed flow and lies between ideal plug flow and ideal completely mixed reactor. This flow condition can be used in practice to describe the flow conditions in most of the reactors.

e) ***Packed Bed Reactor***: They are filled with some packing medium, such as, rock, slag, ceramic or synthetic plastic media. With respect to flow they can be anaerobic filter, when completely filled and no air is supplied, or aerobic (trickling filter) when flow is intermittent or submerged aerobic filter when compressed air is supplied from the bottom.

f) ***Fluidized Bed Reactor***: This reactor is similar to packed bed except packing medium is expanded by upward movement of fluid (or air) than resting on each other in fixed bed. The porosity or degree of fluidization can be controlled by controlling flow rate of fluid (wastewater or air).

13.7.5 Flow Patterns of Reactors

The flow pattern in the reactors depends on mixing conditions in them. This mixing in tern depends upon the shape of the reactor, energy spent per unit volume of the reactor, the size and scale of the unit, up-flow velocity of the liquid, rate of biogas generation (in an anaerobic reactors) or the rate of gas supplied (in an aerobic reactor), etc. Flow pattern affect the time of exposure to treatment and substrate distribution in the reactor. Depending upon the flow pattern the reactors can be classified as:

(a) Batch reactors,

(b) Ideal plug flow reactors,

(c) Ideal completely-mixed flow reactors,

(d) Non –ideal, dispersed flow reactors, and

(e) Series or parallel combinations of the reactors.

The hydraulic regime in the reactor can be defined with respect to the 'Dispersion number', which characterizes mixing condition in the reactor (Arceivala and Asolekar, 2007).

Dispersion Number = D/UL

Where,

D = Axial or longitudinal dispersion coefficient, L^2/t

U = Mean flow velocity along the reactor, L/t

L = Length of axial travel path, L

For ideal plug flow D/UL = 0, since, dispersion is zero by definition.

$D/UL \le 0.2$ indicate the regime approaching plug flow conditions.

$D/UL \ge 3.0$ to 4.0 indicates approaching completely mixed conditions.