

**WASTEWATER ENGINEERING– OBJECTIVES OF  
WASTEWATER TREATMENT, PRIMARY  
TREATMENT OF WASTEWATER**

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## **1.0 OBJECTIVES**

- To understand various terms used in wastewater treatment
- To understand basics of wastewater treatment
- To acquaint with different steps involved in primary treatment of wastewater.

## **1.1 INTRODUCTION**

It is the branch of environmental engineering in which the basic principles of science and engineering are applied to the problems of water pollution control.

So, as an overview, this wastewater engineering includes wastewater treatment, sludge disposal and reuse, wastewater reclamation and reuse, effluent disposal and the role of engineer.

Every community produces both solid and liquid wastes. The liquid waste is known as the wastewater.

It may be defined as liquid wastes collected in a sewer system and conveyed to a treatment plant for processing.

In view of their sources of generation it may be defined as a combination of the liquid or water carrying wastes removed from residences, institutions, commercial and industrial establishments together with ground water, surface water and storm water (may also be present).

In most of the communities, storm runoff water is collected in a separate sewer system and conveyed to the nearest water course for disposal without treatment. Several large cities have a combined wastewater collection system where both storm as well as sanitary wastes are collected in the same pipe system.

Storm wastewater means the wastes from rains or floods while sanitary or domestic wastewater refers to liquid collected from residences, business buildings and institutions. Municipal wastewater is the wastewater treated in a municipal treatment plant which comes from towns frequently containing industrial effluents from dairies, laundries, bakeries, factories and in large cities it may have wastes from major industries such as chemical manufacturing, breweries, meat processing, metal processing or paper mills etc.

In the old days, city residents used to place 'night soil' in buckets along the streets and workers emptied the waste into 'honey wagon' tanks. The waste was transported to rural areas for disposal over agricultural lands. The invention of flush practices in nineteenth century changed the waste disposal practices. Existing system for transporting urban wastes for disposal on agricultural lands were not adequate to handle the large volume of liquid generated by the flush toilets. Due to transportation problem, cities began to use natural drainage systems and storm sewers for wastewater carriage against the advice of Edwin Chadwick- rain to river and sewage to soil. Construction of combined sewer was common place in large cities during the later half of nineteenth century.

The first modern sewerage system for wastewater carriage was built in Hamburg, Germany in 1842 by an English Engineer named Lindley. Most of the improvement over 100 years in wastewater collection system

consists of improved materials and the inclusion of manholes, pumping stations and other appurtenances.

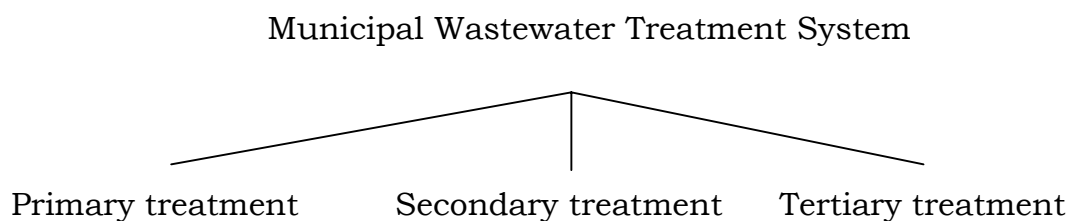
## 1.2 TERMINOLOGY IN WASTEWATER TREATMENT

Two methods are used for treatment of wastewater:

- i) Unit Operations: Removes contaminants by physical forces.
- ii) Unit Processes: Removes contaminants by biological or chemical reactions.

**Reactor:** It refers to vessel or containment structure alongwith all of its appurtenances in which the unit operation or unit process takes place. Although these two processes are natural phenomena but they may be initiated, enhanced or otherwise controlled by altering the environment in the reactor. Reactor designing is a very important aspect of wastewater treatment and requires a thorough understanding of the unit operations and unit processes involved.

**Wastewater Treatment System:** It is composed of a combination of unit operations and unit processes designed to reduce certain constituents of wastewater to an acceptable level.



**Primary Treatment:** Removal of solid materials from the incoming wastewater. Large debris may be removed by screening or may be reduced in size by grinding devices. Inorganic solids are removed by grit channels while suspended organic solids are removed by sedimentation.

**Secondary Treatment:** It consists of biological conversion of dissolved and colloidal organics into biomass that can be subsequently removed by sedimentation.

Two systems may be used in this treatment:

- a) *Activated Sludge System:* In this system, contact between micro-organisms and the organics is optimized by suspending the biomass in the wastewater. Recirculation of a portion of the biomass maintains a large number of organisms in contact with the wastewater and speeds up the conversion process.
- b) *Trickling Filter system:* In this system, contact between micro-organisms and organics is optimized by passing the wastewater over a film of biomass attached to solid surfaces. Stones or other solid media are used to increase the surface area for biofilm growth. Mature biofilms peel of the surface and are washed out to the settling basin with the liquid under flow.

Secondary systems produce excess biomass that is biodegradable through endogenous catabolism and by other micro-organisms. Secondary sludges are usually combined with primary sludge for further treatment by anaerobic digestion. The results are gaseous end products, mainly methane and CO<sub>2</sub>, liquids and inert solids. Liquids contain large concentrations of organic compounds and are recycled through the treatment plant. The solid residue has a high mineral content and may be used as a soil conditioner and fertilizer on agricultural lands.

**Tertiary Treatment:** It often involves further removal of suspended solids and or the removal of nutrients. Solids removal may be

accomplished by filtration and phosphorus & nitrogen compounds may be removed by combinations of physical, chemical and biological process.

### **1.3 OBJECTIVES OF WASTEWATER TREATMENT**

Methods of wastewater treatment first developed in response to the concern for public health and adverse conditions caused by discharge of wastewater to environment. Besides this, the enlargement of cities resulted in the deficiency of land available for wastewater disposal principally by irrigation and intermittent filtration so the purpose of developing other methods of treatment was to accelerate the forces of nature under controlled conditions in treatment facilities of comparatively smaller size.

In general from about 1900 to early 1970s, treatment objectives were concerned with:

- a) Removal of suspended and floatable material.
- b) Treatment of biodegradable organics.
- c) Elimination of pathogenic organisms.

Unfortunately these objectives were not uniformly met throughout the United States as is evidenced by the many plants that were discharging partially treated wastewater into wells since 1960s.

From early 1970s to about 1980, wastewater treatment objectives were based primarily on aesthetic and environmental concerns. The earlier objectives of biological oxygen demand (BOD), suspended solids and pathogenic organisms reduction continued but at higher levels. Removal of nutrients such as nitrogen and phosphorus also began to be addressed particularly in some of the inland streams and lakes. State and Federal agencies undertook a major effort to achieve more effective and widespread treatment of wastewater to improve the quality of surface waters. This effort resulted in part from (a) an increased understanding of

the environmental effects caused by wastewater discharges; (b) a developing knowledge of the adverse long term effects caused by discharge of some of specific constituents found in wastewater; (c) development of national concern for environmental protection. The result of these efforts was a significant improvement in the quality of surface waters.

Since 1980, because of increased scientific knowledge and an expanded information base, wastewater treatment has begun to focus on health concerns related to toxic and potentially toxic chemicals released to the environment. Water quality improvement objective of 1970s have continued but emphasis has shifted to the definition and removal of toxic and trace compounds that may cause long term health effects. As a consequence, while the early treatment objective remains valid today, the required degree of treatment has increased significantly and additional treatment objectives and goals have been added. The removal of toxic compounds such as refractory organics and heavy metals are examples of additional treatment objectives that are being considered. Therefore, the treatment objectives must go hand in hand with water quality objectives or standards established by federal, state and regional regulatory authorities.

#### **1.4 PRIMARY TREATMENT**

In primary treatment, a portion of the suspended solids and organic matter is removed from incoming wastewater. This removal is usually accomplished with physical operations such as screening, comminuting, grit chambers and sedimentation etc. The effluent from primary treatment will ordinarily contain considerable organic matter and will have a relatively high BOD (Biological Oxygen Demand). The principal function of primary treatment will continue to be as a precursor to secondary treatment.

## 1.4.1 Screening

It is the first operation in wastewater treatment to remove most of the bigger and longer visible objects such as trees, branches, sticks, rags, boards, animals etc present in raw water of surface water sources as the screens protect pumps and other mechanical equipments and to prevent clogging of valves and other appurtenances.

### 1.4.1.1 Types of Screens

Screens are of three types depending upon the size of opening- (a) Coarse screens; (b) Medium screens and (c) Fine screens.

**a) Coarse Screens:** They are also known as racks. Spacing between bars is 50 mm or more than this. These screens help in removing large floating objects from sewage. The material separated by coarse screens consists of rags, woods, sticks and paper etc. which will putrefy and must therefore be disposed of by incineration, burial or dumping.

Coarse screens consist of parallel iron rods placed vertically or at a slight slope of about 2 to 10 cm centre to centre. The coarse screens are also now normally kept inclined at about 45-60° so as to increase the opening area to reduce the flow velocity and thus making the screening more effective. Velocity of wastewater through screen should not be more than 0.8 to 1 m/sec. The material which is collected on the upstream side of screens is removed either manually or mechanically. In mechanically cleaned screens, a rack traverses the front of the screen either continuously or intermittently. Mechanical cleaning is done at large plants with mechanically operated rakes while manual cleaning is done at small plants with hand operated rakes.



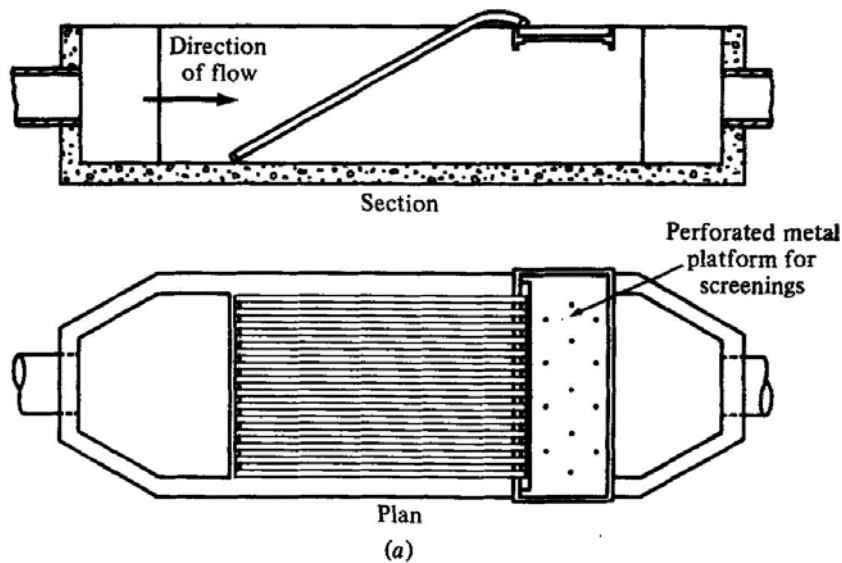


FIG. 1: SCREENING DEVICES USED IN WASTEWATER TREATMENT

**b) Medium Screens:** In this type of screen, spacing between the bars is 6-40 mm. These screens will ordinarily collect 30-90 litres of material per million litre of Sewage. Screenings (material removed by screens) usually contain some quantity of organic material which may putrefy and become offensive, therefore, be disposed off by incineration or burial (not by dumping).

Rectangular shaped coarse and medium screens, made up of steel are now-a-days widely used at sewage treatment plants. These are fixed parallel to one another at desired space on a rectangular steel frame and are called bar screens which are set in screen chamber. Now-a-days, these screens are generally kept at about 30-60° to the direction of flow so as to increase the opening area and to reduce the flow velocity and thus making the screen more effective. Screens can be either fixed or movable depending upon whether the screens are stationary or capable of motion. Fixed screens are permanently set in position while movable can be moved bodily for the purpose of cleaning.

**c) Fine Screens:** In this type of screen, spacing between bars is 1.5 mm to 3 mm size. It removes about 20% of suspending solids from

sewage. These screens are made up of fine wire, brass or bronze plates with openings less than 1 cm. Metal used should be resistant to rust and corrosion. They may be disc or drum type and operated continuously by electric motors. These screens often get clogged and are to be cleaned frequently. They are, therefore, used for treating industrial wastewater or for municipal waste containing industrial wastewater. Cleaning frequency is governed by head loss through the screen. More the screen openings clogged more will be the head loss.

#### **1.4.1.2 Characteristics of Screenings**

Screenings are the material retained on bar racks and screens. The smaller the screen opening, the greater the quantity of collected screenings will be. Although no precise definition of screenable material exists and no recognized method of measuring quantities of screenings is available. Screenings exhibit some common properties.

**Screenings retained on bar racks:** Coarse screenings (collected on racks or bars of about 5/8 inches or greater spacing) consist of debris such as rocks, branches, pieces of timber, leaves, paper, tree roots, plastics and rags and organic matter. The rag content can be substantial and has been visually estimated to comprise from 60 to 70% of the total screenings, volume of 1 and 4 inches (25 and 100 mm) screen respectively.

**Screenings retained on screens:** Fine screenings consist of materials that are retained on screens with openings less than 5/8 inches (15 mm). Screens with 0.09 to 0.25 inches openings remove 5 to 10% of effluent suspended solids whereas those with openings of 0.03 to 0.06 inches can remove 10 to 15%. Screenings from fine screens have been reported to have volatile solids content varying from 65 to 95%. In comparison to coarse screenings, their bulk densities are slightly lower

and moisture content is slightly higher. Fine screenings contain substantial grease and scum which requires similar care.

### **1.4.2 Comminutors or Shredders**

These are the patented devices which break larger sewage solids to about 6 mm. They consist of a revolving slotted drum through which sewage is screened. Cutters are mounted on drum which shear the collected screenings against a comb. They are usually arranged in pairs to facilitate repair and maintenance. They are of recent origin and eliminate the problem of disposal of screenings by reducing solids to a size which can be processed elsewhere in plant. Basic parts of a comminutor are screens and teeth, one of them is movable and other is stationary.

### **1.4.3 Grit removal**

Grit removal is done in grit chambers, channels/basins. Inorganic solids such as pebbles, sand, silt eggshells, glass and metal fragments, heavier organics such as bone chips, seeds etc. when collected together, constitute grit, are removed from wastewater to prevent damage to pumps and to prevent their accumulation in sludge digester. Grit chambers are in fact sedimentation tanks designed to separate heavier inorganics by sedimentation due to gravitational forces and to pass forward the lighter organic material. It may be placed either after or before the screen.

Most of the substances in grit are abrasive in nature and will cause accelerated wear on pumps and sludge handling equipments. Grit deposits in areas of low hydraulic shear in pipes, sumps and clarifiers may absorb grease and solidify. These materials are not biodegradable and occupy valuable space in sludge digester so they should be separated from organic suspended solids.

Because, infiltration is a major source of inorganics, the quantity of grit varies with the type, age and condition of pipe in the collection system.

Grit removal facilities basically consist of an enlarged channel area where reduced flow velocities allow grit to settle out. Two configuration of grit chambers are available - a) Channel type b) Aerated rectangular basin.

#### **1.4.3.1 Channel type**

These are horizontal flow grit chambers in which the horizontal velocity is maintained at approximately 0.3 m/sec. Even a 25% increase in horizontal velocity may result in washout of grit whereas 25% decrease may result in retention of non-target organics. So, horizontal velocity must be artificially controlled. It is installed at small plants.

Grit from this type of grit chamber, may contain a sizable fraction of biodegradable organics that must be removed by washing or must be disposed off quickly to avoid nuisance problems. Grit containing organics must either be placed in a sanitary landfill or incinerated alongwith screenings to a sterile ash for disposal.

#### **1.4.3.2 Aerated rectangular basin**

It is installed at large plants. In this, injection of compressed air creates turbulence and keeps lighter organic matter in suspension while the heavier grit falls to bottom. Here roll velocity is more important rather than horizontal velocity as it separates the non-target organics from the grit so artificial control of horizontal velocity is not required. Adjustment of air quantity provides settling control.

If sewage is anaerobic, aeration serves to strip noxious gases from liquid and to restore it to aerobic conditions which allows for better treatment. Aeration period is usually extended from 15 to 20 min.

#### **1.4.4 Sedimentation**

The screens and the grit chambers remove most of the floating materials like paper, rags, cloth, wood and tree branches etc and the heavy inorganic settleable solids from the sewage. However, a part of the suspended organic solids which are too heavy to be removed as floating matters and too light to be removed by grit chambers are generally removed by the sedimentation tanks. This process is called sedimentation. The sedimentation tanks are thus designed to remove a part of the organic matter from the sewage effluent coming out from the grit chambers.

In a complete sewage treatment, the sedimentation is in fact carried out twice - once before the biological treatment and once after the biological treatment.

##### ***1.4.4.1 Principle of Sedimentation***

Most of the suspended impurities (organic matter) present in water have a specific gravity greater than that of water. In still sewage, these impurities will therefore, tend to settle down by gravity whereas in a flowing sewage, they are kept in suspension because of turbulence in water. Hence as soon as the turbulence is retarded by offering storage to sewage, these impurities tend to settle down at the bottom of the tank offering such storages. This is the main principle behind sedimentation.

##### ***1.4.4.2 Theory of sedimentation***

The settlement of a particle by gravity in liquid, when brought to rest, is opposed by the following factors:

**1. Velocity of flow:** It carries the particle horizontally. Greater the flow area, lesser is the velocity and hence more easily the particle will settle down.

**2. Viscosity of water:** In this particle travels. Viscosity is inversely proportional to temperature. Warm water is less viscous and therefore, offers less resistance to settlement.

**3. Size, shape and specific gravity of the particle:** Greater the specific gravity, more readily a particle will settle. Size and shape of the particle also affect the settling rate e.g. the weight and volume of a spherically shaped particle varies with the cube of its diameter and its area varies with the square of the diameter.

**4. Sedimentation tanks:** The clarification of sewage by the process of sedimentation can be affected by providing conditions under which the suspended material present in sewage can settle out. This is brought about in specially designed tanks called sedimentation tanks. Out of the three forces which control the settling tendencies of the particles, two forces i.e., the velocity of flow, and the shape and size of the particles, are tried to be controlled in these settling tanks. The third force i.e. viscosity of sewage or temperature of sewage is left uncontrolled, as the same is not practically possible.

Velocity of flow can be reduced by increasing the length of travel and by detaining the particle for a longer time in the sedimentation basin. The size and shape of the particles can be altered by the addition of certain chemicals in water. But this is done only in chemical precipitation.

Sedimentation basins are thus designed for affecting settlement of particles by reducing the flow velocity or by detaining the sewage in them.

### 1.4.4.3 Types of sedimentation tanks

Sedimentation tanks may function either intermittently or continuously. In the intermittent type of sedimentation tanks, sewage is stored for a certain period and kept under rest. After 24 hours, the settlement of suspended particles at the bottom of tank, the clear supernatant (i.e. cleaner sewage) from top is drawn off and the tank is cleaned. Tank is again filled with raw sewage and process is repeated. It is used in old days.

In continuous flow type of sedimentation tank, flow velocity is only reduced and sewage is not brought to complete rest. The velocity is sufficiently reduced by providing sufficient length of travel. Velocity is adjusted in such a way that the time taken by the particle to travel from one end to another is slightly more than the time required for settlement of that particle.

Sedimentation tanks may be rectangular or circular.

$$\begin{aligned} \text{The detention time (t), for a rectangular tank} &= \frac{\text{Volume of tank}}{\text{Rate of flow}} \\ &= \frac{BLH}{Q} \end{aligned}$$

Where,      B- Width of basin  
                H- Depth of water in the tank  
                Q- Discharge entering the basin  
                L- Length of basin

$$\text{Detention time for a circular tank} = \frac{D^2(0.011L + 0.785H)}{Q}$$

Where,      D- Diameter of tank  
                H- Vertical depth at wall or side water depth.

Detention time usually ranges between 4 to 8 hrs for plain sedimentation. The width of tank is normally kept equal to 10 m and not

allowed to exceed 12 m. The length of the tank is not generally allowed to exceed 4 times the width. Cross-sectional area of the sedimentation tank is such as to provide a horizontal flow velocity ranging between 0.15 to 0.9 m/min, normally kept at about 0.3 m/min. The total amount of flow from the tank within 24 hrs generally equals the maximum daily demand of water.

### **1.4.5 Chemical Coagulation**

Very fine suspended particles present in wastewaters cannot be removed in plain sedimentation as their settling velocity is very low due to which detention period required to get them removed is very high and practical difficulties arise in holding water for such a long time. Besides this very fine colloidal or dispersed particles contain electric charges and they are continuously in motion known as Brownian motion and they are not settled down by gravity force.

Due to all these problems, coagulation is needed before sedimentation which is also known as forced sedimentation.

Very fine suspended particles, present in wastewaters cannot settle down in plain sedimentation tanks of ordinary detention periods. They can, however, be removed by increasing their size by changing them into flocculated particles. For this purpose, certain chemical compounds such as ferric chloride, ferric sulphate, alum etc. called coagulants are added to the wastewater which on thorough mixing form a gelatinuous precipitate called floc. The fine mud particles and other colloidal matter present in wastewater gets absorbed in these flocs, forming the bigger size flocculated particles. The process of addition and mixing of chemicals is called coagulation. The coagulated sewage is then passed through sedimentation tank where the flocculated particles settle down and are removed.



The use of coagulants is generally necessary for clarifying raw waters containing turbidities greater than 30 to 50 mg/l.

#### **1.4.5.1 Principle of Coagulation**

In coagulation, individual particles combine together. When a coagulant is used in water, it forms a spongy gelatinous precipitate which absorbs fine size particles in water and binds them together. The whole process results into bigger particles which are heavier and easily settleable.

#### **1.4.5.2 Properties of common coagulants**

A coagulant should possess following properties as under:

1. It should react quickly in water to give spongy gelatinous flocs.
2. It should be cheap material.
3. It should be easy to handle and store.
4. It should not deteriorate in quality with time.
5. It should be electrolyte in nature to give out positively charged electric ions for attracting the negatively charged colloidal impurities.
6. It should produce high valance ions for high absorptive efficiency.
7. It should react in the long range of pH.

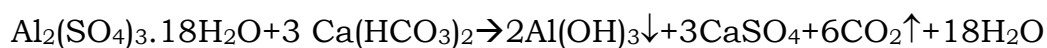
Overdosing of coagulants may reverse the electric charges in colloids which retard the coagulation.

#### **1.4.5.3 Chemicals used for coagulation**

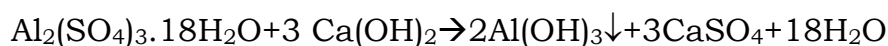
Various chemicals such as alum, iron salts like ferric chloride, ferric sulphate, ferrous sulphate, sodium aluminate are generally used as coagulants.

**1. Use of alum [Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub> 18H<sub>2</sub>O]:** Alum is the most widely used coagulant in water treatment. It reacts quickly giving excellent stable flocs. It is cheap and can be easily stored and handled. The alum when added to raw water, reacts with natural alkalinity in water (if that is insufficient, lime may be added) so as to form a gelatinous precipitate of aluminium hydroxide. It increases the sulphate hardness and corrosiveness of water to a small extent.

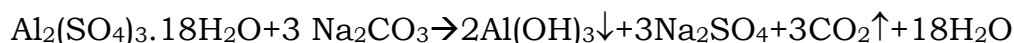
Another variety known as Black Alum, contains 2-5% of activated carbon. When it is used in coagulation helps in removal of taste and colour.



Floc



Floc

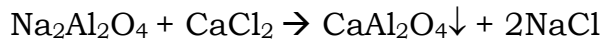


Floc

The amount of alum required for coagulation depends on the turbidity and colour of raw water. The dose of alum may vary from 5 mg/l for relatively clear water to 85 mg/l for highly turbid waters. The average normal alum dose is about 17 mg/l.

**2. Use of sodium aluminate (Na<sub>2</sub>Al<sub>2</sub>O<sub>4</sub>) as coagulant:** This is an alkaline compound sometimes used as coagulant. It can react in water which does not have natural alkalinity. This chemical when dissolved and mixed with water, reacts with salts of calcium and magnesium present in raw water, resulting in the formation of precipitates of calcium or magnesium aluminate. Thus it can reduce both carbonate and non-carbonate hardness in the process of coagulation and is, therefore, useful in treating hard, turbid waters.





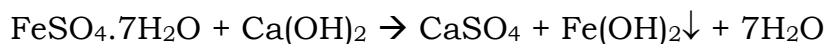
This coagulant is about 1.5 times costlier than alum and is therefore generally avoided for treating ordinary public supplies but however, it is very useful for treating water which do not have the natural desired alkalinity and thus cannot be treated with pure alum.

**3. Use of Iron salts as coagulant:** These are generally used for soft water having a low pH value. They also remove colour present in water. They can react in a longer range of pH values than alum except ferrous sulphate. They are quite cheap, react quickly and form heavy flocs. But as they are corrosive and deliquescent they are difficult to handle and store. They promote the growth of iron bacteria in the distribution system.

Ferric salts being good oxidizing agents, can remove hydrogen sulphide and the taste and odour.

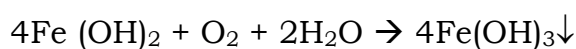
Iron salts are used as coagulants more for sewage than water treatment. Two types of iron salts are used as coagulants as under:

(a) *Use of copperas as coagulant:* Copperas is the name given to ferrous sulphate with its chemical formula as  $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ . Copperas is generally added to raw water in conjunction with lime. Lime is added either earlier to copperas or vice-versa. When lime is added earlier than copperas then following reaction takes place:



Copperas

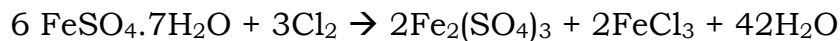
This ferrous hydroxide  $[\text{Fe}(\text{OH})_2]$  further gets oxidized forming ferric hydroxide as under:



Floc

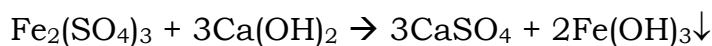
$\text{Fe}(\text{OH})_3$  forms the floc and thus helps in sedimentation. The quantity of copperas required is almost same as that of alum.

(b) *Use of chlorinated copperas as coagulant:* When chlorine is added to a solution of copperas (i.e. ferrous sulphate), the two, react chemically, so as to form ferric sulphate and ferric chloride:

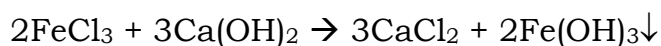


The resultant combination of ferric sulphate and ferric chloride is known as chlorinated copperas and is a valuable coagulant for removing colours, especially where the raw water has a low pH value.

Both constituents of chlorinated copperas along with lime are effective coagulants.



Floc



Floc

The resultant  $\text{Fe}(\text{OH})_3$  forms the floc and helps in sedimentation. Ferric sulphate is quite effective in the pH range of 4-7 and above 9 whereas ferric chloride is quite effective in the pH range of 3.5-6.5 and above 8.5.

The combination has therefore, proved to be very effective coagulant for treating low pH waters.

**Auxiliary Chemicals:** These chemicals are not primarily used for coagulation but they help it in the process of other treatments. Lime and sodium carbonate are used in controlling pH value of water. But with their use, floc formation is found to be better and minimum amounts of coagulants are consumed.

### 1.4.5.4 Determination of coagulant dose

The dose of chemical required for coagulation depends on the quality of water. The optimum dosage of coagulant is determined by the jar test method. The amount of coagulant is increased stepwise and all jars are mixed simultaneously for 10-30 minutes. The jar in which floc first makes its appearance, is assumed to have received the most economical dose.

Dose of chemical differs from time to time for the same source of water.

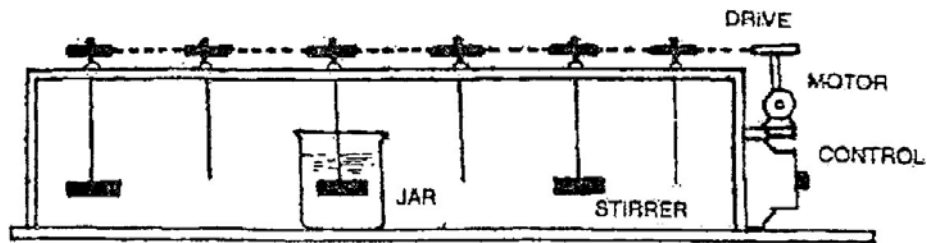


FIG. 2: JAR TEST APPARATUS

### PROPERTIES OF IMPORTANT COAGULANTS USED IN SEWAGE TREATMENT

Sr. No.	Name of coagulant	B.O.D. removed as percentage of total present	Suspended solids removed as percentage of total present	Dosage required in ppm	pH value required for proper functioning	Remarks
1	Ferric chloride	80-90	90-95	25-35	5.5-7.0	This coagulant is widely used for sewage treatment*, wherever, coagulation is adopted.
2	Ferric sulphate with lime	60	80	35-40	8.0-8.5	Ferric sulphate has been found to be more effective than chlorinated copperas, if used in conjunction with lime. Hence ferric chloride and ferric sulphate are mainly used, as coagulants in sewage.

3	Alum	60	80	40-90	6-8.5	It is generally not used in sewage** although used for treating water supplies on a large scale.
4	Chlorinated copperas	70-80	80-90	35-80	5.5-7.0 & 9.0 to 9.5	This coagulant is effective for producing sludge for activated sludge process.

\*Ferric chloride forms a dense heavy floc, which settles rapidly. The sludge formed is also not so bulky, and can be digested or dewatered easily. However, it is corrosive in nature and requires care in storing and handling.

\*\*Alums, although cheap and easy to handle, yet are not used, because they form a spongy floc which settles slowly. Moreover, the volume of sludge produced is also large.

#### **1.4.5.5 Advantages and Disadvantages of coagulation**

Coagulation process is generally not adopted in modern sludge treatment plants, mainly because of the following reasons:

- (i) The biological secondary treatments used these days for treating sewage are complete in themselves, and do not require coagulation. Moreover, coagulation rather makes some of these processes more difficult.
- (ii) The chemicals used in coagulation react with sewage, and during these reactions, they destroy certain micro-organisms, which are helpful in digestion of the sludge, thus creating difficulties in sludge digestion.
- (iii) Cost of chemicals is added to the cost of sedimentation without much use, and thereby making the treatment costlier.
- (iv) The process of coagulation and subsequent sedimentation produces larger quantities of sludge than that produced in plain sedimentation, and thus adding to the problems of sludge disposal.
- (v) The process of coagulation requires skilled supervision and handling of chemicals.

In view of all these disadvantages, the coagulation of sewage has become obsolete these days. It may still, however, be adopted in certain special cases, such as:

- (a) For treating sewage from industries, using some specific chemicals in their processes.
- (b) It is particularly advantageous, where there is large seasonal variation in sewage or as an emergency measure to increase the capacity of an overloaded plain sedimentation tank. It may, thus be of use at places, like hill stations, where flow may considerably go up during such seasons.

The various advantages offered by the coagulation process are:

- (i) Sedimentation aided with coagulation produces better effluent with lesser BOD and suspended solids, as compared to plain sedimentation.
- (ii) Coagulated settling tank requires less space than that required by an ordinary plain settling tank. Coagulation process may also remove the phosphates from sewage, which may help in controlling eutrophication of river, into which the effluent is being discharged.

## **1.6 SUMMARY**

Wastewater engineering is that branch of engineering in which the basic principles of science and engineering are applied to the problems of water pollution controls. Liquid wastes are collected in a sewer system and then conveyed to a treatment plant for processing. The first modern sewerage system for wastewater carriage was built in Hemburg, Germany in 1842 by an English engineer named Lindley. Wastewater treatment system is a combination of unit operations and processes designed to reduce constituents of wastewater to an acceptable level and it has 3

levels of treatment– primary, secondary and tertiary. *Primary* treatment is removal of solid materials from incoming wastewater. *Secondary* treatment is biological conversion of dissolved and colloidal organics into biomass that can be subsequently removed by sedimentation while *tertiary* treatment is the removal of suspended solids and nutrients such as nitrogen and phosphorus.

Primary treatment takes place in different steps-

*Screening*: which removes most of the bigger and longer visible object, such as trees, branches, sticks and rags etc. with the help of different screens.

*Comminuting*: It involves breaking of large sewage solids to about 6 mm size.

*Grit removal*: Inorganic solid, such as pebbles, sand, silt, heavier inorganics and other materials constituting grit are removed with the help of grit chambers.

*Sedimentation*: Removal of a part of organic solids which are too heavy suspended to be removed as floating matters and too light to be removed by grit chambers are generally removed by sedimentation tanks.

*Chemical coagulation*: For removal of very fine suspended particles present in wastewater (cannot be removed by sedimentation) and very fine colloidal or suspended particles containing electric charges and continuously in motion, chemical coagulation is needed.

## 1.7 KEYWORDS

**Wastewater**: The spent or used water from a home, community, farm or industry that contains dissolved or suspended matter.

**Screenings**: Materials retained on bar racks and screens.



**Grit:** Inorganic solids such as pebbles, sand, silt, eggshells, glass and metal fragments, heavier organics such as bone chips, seeds etc. when collected together constitute grit.

**Sedimentation tank:** Tanks in which sedimentation takes place.

**Coagulants:** Chemicals used for coagulation.

## 1.8 SELF ASSESSMENT QUESTIONS

1. What is the difference between unit operations and unit processes?
2. Define wastewater. Why do we want to treat it?
3. Write a note on different types of screens used in primary treatment of wastewater.
4. How many types of grit chambers can be used in primary treatment process?
5. What is the principle lying behind sedimentation?
6. Which qualities a chemical should possess for being a coagulant? Name few chemicals being used as coagulants, how will you determine coagulant dose for the treatment of wastewater?

## 1.9 SUGGESTED READINGS

1. Garg, S.K. and Rajeshwari Garg (1999): Sewage disposal and air pollution engineering. Khanna Publishers, New Delhi.
2. Metcalf and Eddy (2004): Wastewater engineering. Tata McGraw Hill Publishing Company Ltd., New Delhi.
3. Henze Harremoes La Cour Jansen, Arvin (1998): Wastewater treatment. Prentice Hall of India, USA.

4. Chatterjee, A.K. (1998): Water supply, waste disposal and environmental engineering. Khanna Publication, New Delhi.
5. Hammer M.J. (2000): Water and wastewater technology. Prentice Hall of India Pvt. Ltd., New Delhi.

**SECONDARY TREATMENT OF WASTEWATER**

**Dr. Asha Gupta**

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**STRUCTURE**

- 2.0 Objectives
- 2.1 Introduction
- 2.2 Filtration
  - 2.2.1 Contact beds
  - 2.2.2 Intermittent sand filters
  - 2.2.3 Trickling filters
    - 2.2.3.1 Construction and operation of trickling filter
    - 2.2.3.2 Types of trickling filters
    - 2.2.3.3 Merits and demerits of trickling filters
    - 2.2.3.4 Goals of trickling filters
- 2.3 Activated sludge process
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    - 2.3.2.1 Diffused air aeration or air diffusion
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  - 2.3.3 Bulking and foaming sludge in an activated sludge treatment plant Foam
  - 2.3.4 Advantages of an activated sludge process
  - 2.3.5 Disadvantages of activated sludge process
- 2.4 Rotating biological contractors (RBCs)
- 2.5 Summary
- 2.6 Keywords
- 2.7 Self assessment questions

## 2.8 Further readings

## 2.0 OBJECTIVES

- To give an idea about different processes like filtration, activated sludge process and use of rotating biological contactors involved in secondary treatment of waste water.

## 2.1 INTRODUCTION

The effluent from the primary sedimentation tank contains about 60-80% of the unstable organic matter originally present in sewage. This colloidal organic matter, which passes the primary clarifiers, without settling there, has to be removed by further treatment. This further treatment of sewage is called secondary treatment in which biological and chemical processes are used to remove most of the organic matter. The secondary treatment is directed principally towards the removal of biodegradable organics and suspended solids.

The secondary treatment is carried out by changing the character of the organic matter and thus converting it into stable forms. The character of sewage may be changed by different methods- broadly classified as under:

- i) Filtration
- ii) Activated Sludge Process.

These two processes help in changing the unstable organic matter into stable forms and thus ensuring their removal, when the effluent from these units is settled in secondary sedimentation tanks.

All secondary treatment processes are designed to work on aerobic bacterial decomposition as the aerobic decomposition does not produce bad smells and gases as are produced by the anaerobic decomposition

and besides this the aerobic bacteria are three times more active than anaerobic bacteria at 30°C.

## **2.2 FILTRATION**

In filtration, filter units are used which consist of open beds of coarse aggregates over which sewage is sprinkled intermittently. The necessary contact surface for the growth of aerobic bacteria is provided by aggregates in the bed and the aeration is provided by nature.

There are various kinds of filters that are commonly used either singly or in combination for giving secondary treatment to sewage. All these filters try to oxidize the unstable organic matter into stable forms mainly by aerobic decomposition. Different types of filters which may be used in sewage treatment are as under:

- a) Contact beds
- b) Intermittent sand filters and
- c) Trickling filters

### **2.2.1 Contact beds**

Also known as contact filters. In these filters, sewage is kept in contact with the filtering media for a certain period. As the sewage percolates through the filtering media, fine colloidal organic matter is trapped in the voids between the particles of filtering media due to which an organic film is produced around the particles of filtering media. A large number of bacteria present in this film will carry out the aerobic decomposition of organic matter present in this film. Filter is left empty for a certain period to make the sufficient oxygen available for the growth of aerobic bacteria. Filter during this period will absorb oxygen from the atmosphere and will complete the oxidation process. The stabilized organic matter produced during this cycle will be washed away by the fresh sewage in the next cycle of operation.

Although the contact beds produce satisfactory effluent and consume little head, still they are generally not adopted these days because their rate of loading is quite less and they thus require large land areas for their installation. Besides this, their intermittent operation requires continuous attendance. All these factors make them unsuitable for use in modern days.

### **2.2.2 Intermittent sand filters**

They were the earlier forms of biological units of sewage treatment but are now rarely used because of their large area requirement. They may still however, be used at certain places to give highly nitrified and polished effluent such as in case of treating sewage from tuberculosis hospitals.

They are more or less like contact beds with the difference that the contact media here is finer than that in the contact beds and also there is no concrete lining around the filter media as was in the contact beds.

Effluent obtained from these filters is of excellent quality with suspended solids less than 10 ppm and BOD less than 5 ppm. This effluent is better than that obtained from any other ordinary type of sewage treatment and can be disposed of even without dilution. However, these filters require large land areas and huge quantities of sands for their installations due to low rate of loading. These filters can not, therefore, be economically used at larger plants.

### **2.2.3 Trickling filters**

These filters are also known as sprinkling or percolating filters. The conventional trickling filters and their improved form known as high rate trickling filters are now almost universally adopted for giving secondary treatment to sewage.

Trickling filter is a bed of crushed stone, gravel or slag of relatively large size to which the settled sewage is applied by sprinkling on the surface. The applied sewage trickles in a thin film over the surface of filtering media which have become coated with a zoogloal film. This zoogloal film includes zoogloal forming and other bacteria, fungi, protozoa and algae. Both suspended and dissolved solids come in contact with this film. As the condition is aerobic, a large number of aerobic bacteria will inhabit the film, reacts with the organic solids either in suspended, colloidal or dissolved form. This bring about the reduction of biological oxygen demand (BOD), ammonia, organic nitrogen etc. In order to ensure the large .scale growth of the aerobic bacteria sufficient quantity of oxygen is supplied by providing suitable ventilation facilities in the body of the filter and also to some extent by the intermittent functioning of the filters. The contact between filter media and wastewater is allowed only for a short time. The bed is then drained and allowed to rest before the next cycle is repeated. A typical cycle requires 12 hours (6 hours for operation and 6 hours for resting). Temperature will affect the efficiency of tickling filters. In warm climate, the efficiency of BOD removal by a trickling filters is higher.

The effluent obtained from the filter must be taken to secondary sedimentation tank for settling out the organic matter, oxidized while passing down the filter. The sewage influent entering the filter must be given pretreatment including screening and primary sedimentation.

### ***2.2.3.1 Construction and operation of trickling filter***

Trickling filter tanks are generally constructed above the ground. They may either be rectangular or more generally circular. Rectangular filters are provided with a network of pipes having fixed nozzles, which sprays the incoming sewage into air, which then falls over the bed of the filter under gravity. While the circular filter tanks are provided with

rotary distributors having a number of distributing arms (generally four arms are used). These distributors rotate around a central support either by an electric motor or more generally by the force of reaction on the sprays. The rate of revolutions varies from 2 RPM for small distributors to less than  $\frac{1}{2}$  RPM per large distributors. The distributing arms should remain about 15-20 cm above the top surface of the filtering media in the tank.

There is an important difference between the action of rotary distributors and that of spray nozzles. With a rotary distributor, the application of sewage to filter is practically continuous whereas with spray nozzles, the filter is closed for 3-5 minutes and then rested for 5-10 minutes before the next application.

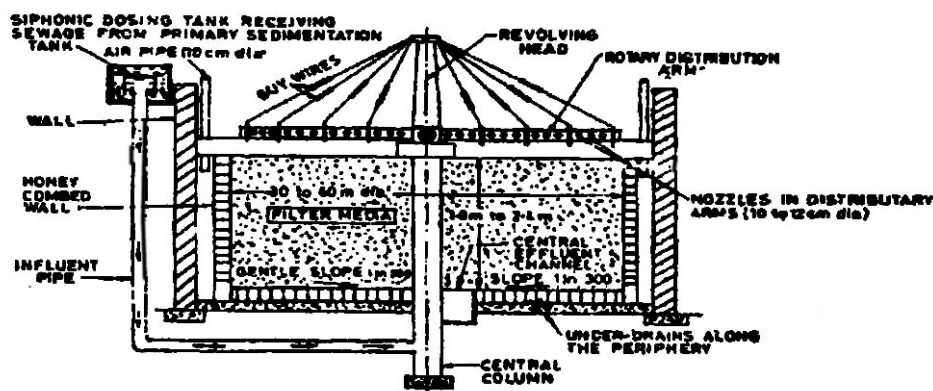


FIG. 3: TYPICAL SECTION OF A CONVENTIONAL TRICKLING FILTER WITH ROTARY DISTRIBUTORS

The closing tank for a filter with circular distributors will, however, be designed to have a smaller capacity (about 1- 3 minutes detention capacity), as against a higher capacity (about 5-10 minutes detention capacity) for filters with spray nozzles.

The filtering media consists of coarser materials like cubically broken stones or slag, free from dust and small pieces. The size of the material used may vary between 25-75 mm. The depth of filtering media



may be between 2-3 metres. The filtering material may be placed in layers, with coarsest stones used near the bottom and finer materials towards the top.

The walls of filter tanks are made honey combed or otherwise provided with openings for circulation of air. A satisfactory ventilation is achieved when properly designed under-drains having adequate openings are provided under the filter bed. Besides ensuring satisfactory drainage, such drains, will also ensure satisfactory ventilation and aeration of the filter bed. Vitrified clay blocks are generally used as under drains which have top openings of such size that the stone can be placed directly on them. These blocks are laid on a reinforced concrete floor (about 10-15 cm thick) which is sloped gently towards the main effluent rectangular channel. This main effluent channel may be provided adjoining the central column of the distributor or may be provided along the circular periphery of the filter. The slope of the channel should be sufficient to ensure a flow velocity of about 0.9 m/sec. The depth and width of this central channel should be such that maximum flow is carried below the level of the under drains.

### **2.2.3.2 Types of trickling filters**

They can be broadly classified into:

1. Conventional trickling filters or standard rate or low rate trickling filters.
2. High rate trickling filters.

All which we have discussed above is about conventional trickling filters. The high rate filters, more advanced filters, also function on the same lines and are having the same constructional details, but with the difference that provision is made in them for recirculation of sewage through the filter, by pumping a part of the filter effluent to the primary settling tank and re-passing through it and then filter. The high rate

filters make it possible to pass the sewage at greater loadings, thus requiring lesser space and lesser filter media.

### **2.2.3.3 Merits and demerits of trickling filters**

The various merits of trickling filters are:

1. Rate of filter loading is high, as such requiring lesser land areas and smaller quantities of filter media for their installations.
2. Effluent obtained, from the trickling filters is sufficiently nitrified and stabilized. They can remove about 75% BOD and 80% of suspended solids. The effluent can therefore be easily disposed off in smaller quantity of dilution water.
3. Flexible in operation, therefore, can' withstand the application of variety of sewages having different concentrations and compositions,
4. Working is very simple so does not require any skilled supervision.
5. They are self-cleaning.
6. Mechanical wear and tear is small as they contain less mechanical equipment.
7. Moisture content of obtained sludge from these filter is as high as 99%.
8. They have been- found to operate more efficiently in warm weather and produce an effluent appreciably -lower in BOD: Hence, they are of immense use in hot countries like- India.

Demerits of the trickling filters are

1. Head loss through these filters is high, making automatic dosing of the filters necessary.
2. Their cost construction is high.

3. They cannot treat raw sewage so primary sedimentation is must.
4. These filters pose a number of operational troubles such as:
  - a) *Fly nuisance*: The filter fly, psychoda, which develops in filter particles, may prove to be nuisance, as the same may be carried away into the habitation. This problem may be controlled by flooding the filter with sewage for 24 hours or more.
  - b) *Odour nuisance*: Odour, generally, do not prevail in trickling filters using rotary distributors, but however, when fixed nozzles are used, H<sub>2</sub>S and other odorous gases are frequently released from the sprays into the atmosphere. In this case, the remedy is to chlorinate the sewage to prevent formation of H<sub>2</sub>S gas, or to neutralize that already formed.
  - c) *Pounding trouble*: Sometimes, the voids in the filter media get clogged due to heavy growth of fungi and algae which may result in pounding of the sewage over the filter bed. This trouble can be controlled by chlorinating the sewage which kills the algae, thus causing unloading of the accumulated material.

#### **2.2.3.4 Goals of trickling filters**

1. Review the advantages and disadvantages of fixed film wastewater treatment systems.
2. Determine the operational control of trickling filter.
3. Investigate the application of synthetic media in trickling filter system.
4. Investigate nutrient removal in trickling filter systems.

## 2.3 ACTIVATED SLUDGE PROCESS

This is also a secondary or biological treatment process and may be used in place of trickling filter. The activated sludge process was developed in England in

1914 by Ardem and Lockett and was so named because 'it involved the production of an activated mass of micro-organisms capable of stabilizing a waste aerobically.

The activated sludge process provides an excellent method of treating either raw sewage or more generally the settled sewage. The sewage effluent from primary sedimentation tank, is mixed with 20-30% of own volume of activated sludge, which contains a large concentration of highly active aerobic microorganisms. In the aeration tank, the mixture of sewage and microorganisms are mixed together with large quantity of air for about 4-8 hours. Under these conditions, the moving organisms will oxidize the organic matter and the suspended and colloidal matter tends to coagulate and form a precipitate, which settle down readily in the secondary settling tank. The settled sewage (containing micro-organisms) called activated sludge is then recycled to the head of aeration tank to be mixed again with the sewage being treated.

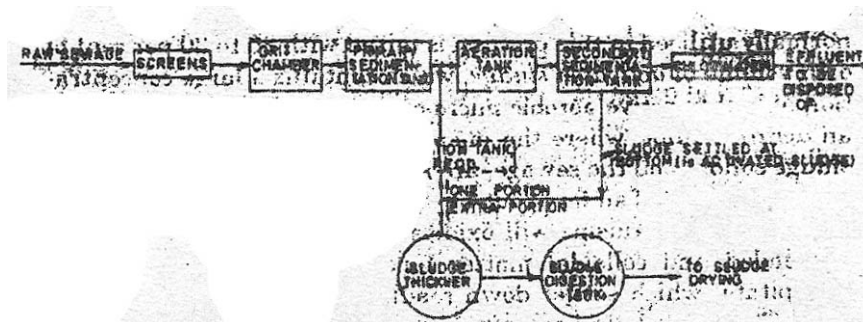
The activated sludge is a light to dark brown flocculent material which settles quickly, contains many filamentous and unicellular bacteria and protozoa and metazoan in the other part. The protozoa ingest and assimilate organic matter of the sewage and thereby contribute their own bodies and end products to the sludge. Sewage supplies nutrient to the living organisms and aeration provides oxygen to them.

The effluent obtained from a properly aerated activated sludge plant is of high quality, usually having a lower BOD than that of a

trickling filter plant. BOD removal is upto 80-95% and bacteria removal is upto 90-95%. Moreover, land area required is also quite less. But, however, in this process, a rather close degree of control is necessary in operation to ensure:

- a) That an ample supply of oxygen is present.
- b) That there is intimate and continuous mixing of the sewage and the activated sludge.
- c) That the ratio of the volume of activated sludge added to the volume of sewage being treated is kept practically constant.

When a new plant is put into operation, a period of about 4 weeks may be required to form a suitable return sludge and during this period, almost all the sludge from the secondary sedimentation tank will be returned through the aeration tank.



FLOW DIAGRAM FOR A CONVENTIONAL ACTIVATED SLUDGE PLANT  
GIVING HIGH DEGREE OF TREATMENT

As pointed out earlier, the removal of grit and larger solids by screening in grit chambers and primary sedimentation tanks respectively is generally considered necessary before aeration. The pre-removal of these settleable solids is helpful in preventing deposits on aeration devices, and thereby not reducing their efficiencies. Grit removal, screening and primary sedimentation are considered necessary for a conventional activated sludge process.

Since in this process, sewage is tried to keep as fresh as possible, a somewhat shorter detention period is provided in the primary sedimentation tanks than is required for most other treatment processes. This primary detention period may vary with the size of the plant and the characteristics of sewage, but tank size will generally provide an overflow rate of about 40,000 litres per s.q.m. of plan area per day. For a depth of about 2.4 m, the detention time will be about 1.4 hour.

### **2.3.1 Aeration tanks of an activated sludge plant**

The aeration tanks are normally rectangular tanks. 3-4.5 m deep, and about 4-6 m wide. The length may range between 20-200 m and the detention period between 4-8 hours for municipal sewage. Air is continuously introduced into these tanks.

### **2.3.2 Methods of aeration**

Basically there are two methods of introducing air into the aeration tanks i.e.

1. Diffused air aeration or air diffusion.
2. Mechanical aeration.
3. Combined diffused and mechanical aeration method-sometime used.

#### ***2.3.2.1 Diffused air aeration or air diffusion***

In this method, compressed air under a pressure of 0.35 to 0.7 kg/cm<sup>2</sup> is introduced into the aeration chambers, through diffusion plates or other devices, called diffusers- porous plates and porous tubes made up of quartz or crystalline alumina and capable of diffusing air in small bubbles, so as to provide the greatest possible efficiency of aeration. Plates are generally square in shape with dimensions of 30 cm × 30 cm and are usually 25 mm thick which are fixed at the bottom of

aeration tanks. Tube diffusers are generally 60 cm long with internal diameter of 75 mm and thickness of wall equal to 15 mm. These tubes are suspended in the aeration tank and can be taken out for cleaning, without emptying the tank. This type of aeration is achieved in different types of aeration tanks as under:

A) RIDGE AND FURROW TYPE AERATION TANKS

These tanks are long and narrow with ridges and furrows extending across and a row of diffusers at each furrow which gives good agitation and aeration but requires a relatively large proportion of the tank bottom in diffusion area. Diffusion is done with the help of diffusion plates made up of fused alumina. The tank dimensions may be between  $30 \times 5 \times 3$  to  $120 \times 10 \times 5$  in metres.

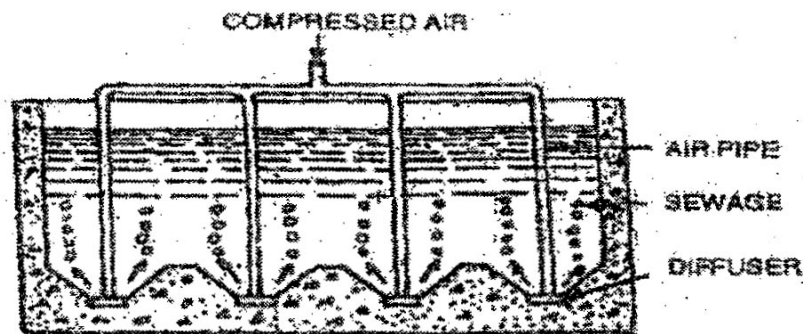


FIG. RIDGE AND FURROW TYPE AERATION TRUNK

B) SPIRAL FLOW TANKS

They have one or more TOWS of diffusers along one side of the aeration tank. The rising air sets up a spiral flow through the tanks and produces efficient agitation with less use of air.

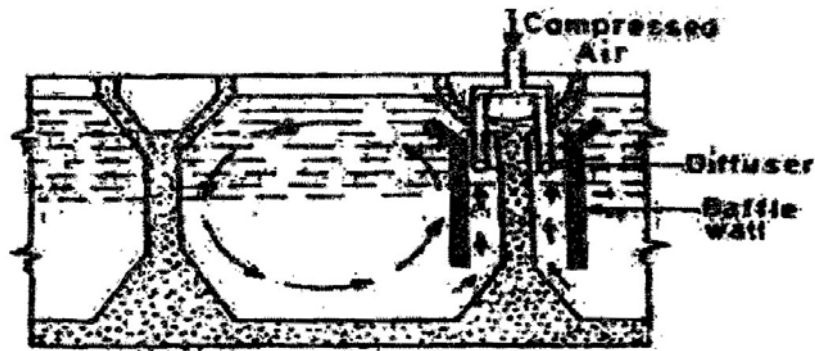


FIG.6: SPIRAL FLOW TANK

### **2.3.2.2 Mechanical aeration**

In the air diffusion method, a lot of compressed air (90-95%) gets wasted, as it simply escapes through the tank without giving oxygen to the sewage, although it helps in bringing about required agitation of sewage mixture. To combat this problem, in mechanical aeration method, atmospheric air is brought in contact with the sewage and sewage is stirred up by means of mechanical devices like paddles to introduce air into it from the atmosphere by continuously changing the surface of sewage by circulation of sewage from bottom to top. Aeration period depends on the mechanical process adopted for agitation and it generally varies between 6-8 hours. Two types of aerators are used in this type of aeration e.g.

#### **A) SIMPLEX TYPE AERATOR**

Here the sewage is collected in the tank and with the help of a central vertical tube, it is ejected in the atmosphere which in turn gets deflected by a horizontal plate and comes back to the tank entrapping oxygen from atmosphere.



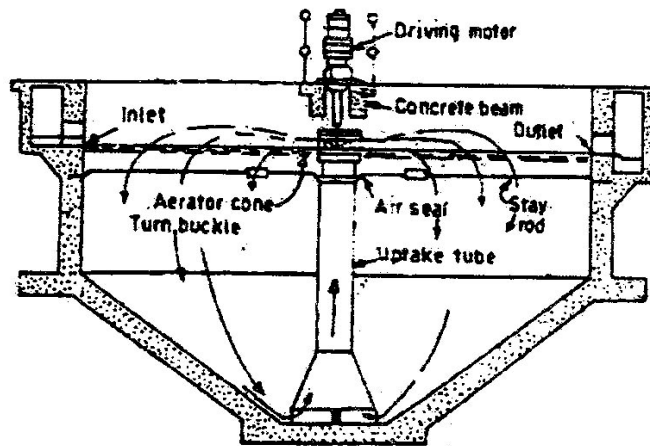


FIG. 7: SIMPLEX AERATOR

B) LINK BELT SYSTEM

In this system, aeration tank is about 4 m wide and 5 m deep. A paddle wheel is placed along the length of the tank near the surface. When the vanes rotate a wave action at the surface and a spiral motion inside will develop and sewage gets aerated.

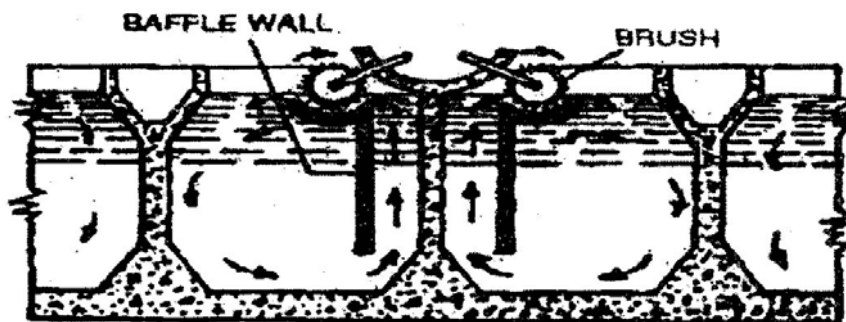


FIG. 8 LINK DEB SYSTEM

**2.3.2.3 Combined diffused and mechanical aeration**

In this method, the diffused air aeration as well as mechanical aeration are combined together in a single unit. A well known type of such an aerator unit is called Dorroco aerator. In this type of aerator, the aeration of sewage is achieved by diffusing air through bottom diffuser plates as well as by rotating paddles at the rate of 10-12 rpm. Spiral motion, so set up, bring about the required aeration.

Such an aerator is very efficient, detention period is smaller (3-4 hours) and requires less amount of compressed air as compared to the diffused air aeration.

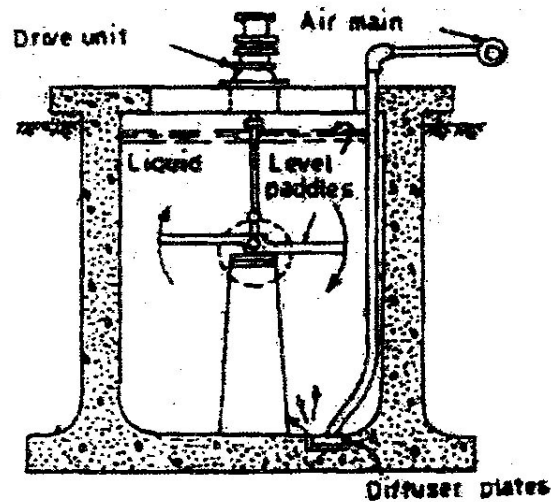


FIG.9: COMBINED AERATION TANK

### 2.3.3 Bulking and foaming sludge in an activated sludge treatment plant Foam

Form formation and poorly settling sludge are the two most common problems of the activated sludge process. A sludge that exhibits poor settling characteristics is called a bulking sludge. Filamentous micro-organisms such as fungi, filamentous sulphur bacteria and other types of bacteria such as *Nocardia amorae*, *Microthrix parvicella* etc. have been found to be responsible for a bulked sludge. This problem can be controlled by:

- (i) Reduction of the sludge age to less than 6 days.
- (ii) Chlorination of return activated sludge.

Classical control measures like adjustment of F: M (food: Microorganism) ration, raising or lowering of dissolved oxygen content or application of a disinfectant, removal of carbohydrate rich waters are found to help in controlling filamentous micro-organisms.

Another problem encountered in the secondary clarifiers of an activated sludge plant is the rising sludge caused by denitrification which results in the formation of nitrogen gas bubbles, which lifts up the settled sludge, thereby deteriorating the quality of the clarified effluent.

### **2.3.4 Advantages of an activated sludge process**

1. The initial cost is lower than trickling filter.
2. Compactness of design results in smaller land area requirement.
3. The effluent is a clearer sparkling liquid which is free from odour.
4. It gives freedom from fly nuisance.
5. Result gives very, high efficiency, over 90% removal of BOD and total solids.
6. The head required for operation is small as compared to trickling filter.

### **2.3.5 Disadvantages of activated sludge process**

1. The operational cost is high as compared to trickling filter.
2. The process is very sensitive and if goes out of order, it gives much trouble in settling it right.
3. Disposal of large quantity of sludge with high moisture content becomes a problem.
4. It requires a skilled attendance.

## **2.4 ROTATING BIOLOGICAL CONTRACTORS (RBCs)**

The rotating biological contractor's process of secondary waste water treatment has been recently developed and does not fit precisely into either the trickling filter or the activated sludge categories:, but does employ principle common to both of them.

A rotating biological contractor (RBC) is a cylindrical media made of closely mounted thin flat circular-plastic sheets or discs of 3-35 m in diameter, 10 mm thick and placed at 30-40 mm spacing mounted on a common shaft.

The RBCs are usually made in upto 8 m in length and may be placed in series or parallel in a specially constructed tank through which the wastewater is allowed to pass. The RBCs are kept immersed in wastewater by about 40% of their diameter. They are rotated around their central horizontal shaft, at a speed of 1-2 rpm by means of power supplied to the shaft. Approximately 95% of the surface area is thus alternatively immersed in the wastewater and then exposed to the atmosphere above the liquid.

When the process is operated, the micro-organisms of the wastewater begin to adhere to the rotating surfaces and grow there until the entire surface area of the discs gets covered with 1-3 mm thick layer of biological slime. As the discs rotate, they carry a film of wastewater into the air, where it trickles down the surface of the discs absorbing oxygen. As the discs complete their rotation, this film mixes with the wastewater in the tank, adding to the oxygen of the tank and mixing the treated and partially treated waste water. As the attached micro-organisms pass through the tank, they absorb other organics for breakdown. The excess growth of micro-organisms is sheared from the discs, as they move through the wastewater tank. The dislodged organisms are kept in suspension by the moving discs. This suspended growth finally moves down with the sewage flowing through the tank to a downstream settling tank for removal.

The effluent obtained from this process is of equal or even better quality than obtained from other secondary treatments. The quality of

effluent can further be improved by placing several contractors in series along the tank.

In this way, the RBCs serve the under mentioned purposes:

- a) They provide media for build up of attached microbial growth.
- b) They bring the growth of microbes in contact with the wastewater.
- c) They aerate the wastewater and the suspended microbial growth in the wastewater tank.

In this process, the attached growths are similar in concept to a trickling filter, except that here the micro-organisms are passed through the wastewater, rather than the wastewater passing over the microbes, as happens in a trickling filter. So this method realizes some of the advantages of both trickling filter and the activated sludge process.

## **2.5 SUMMARY**

Secondary treatment is the biological treatment which involves conversion of dissolved and colloidal organics into biomass that can be subsequently removed by sedimentation. The effluent from primary treatment plant is sent to secondary treatment plant for further treatment. Secondary treatment is carried out by changing the character of organic matter and thus converting it into stable forms mainly by two methods such as filtration and activated sludge process. Use of different types of filters such as contact beds, intermittent sand filters and trickling filters are well explained in this chapter. Activated sludge process is the biological treatment process and involves the production of activated mass of microorganism capable of stabilising waste aerobically. Initial cost of this process is lower than trickling filter but operational cost is higher than trickling filter. Rotating biological contractor is a cylindrical media made of closely mounted thin flat circular plastic sheets

or discs of 3-3.5 m in diameter, 10 mm thick and placed at 30-40 mm spacing mounted on a common shaft. RBG provide media for build up of attached microbial growth and bring the growth of microbes in contact with waste water. They aerate the wastewater and suspended microbial growth in the waste water tank.

## 2.6 KEYWORDS

**Aeration:** A process which promotes biological degradation of organic matter in water. The process may be active or passive.

**Aerobic:** A biological process that occurs in the presence of oxygen.

**Anaerobic:** A biological process that occurs in absence of oxygen.

**Trickling filter:** A bed of crushed stone, gravel or slag of relatively large size to which the settled sewage is applied by sprinkling on the surface.

**Activated sludge process:** Process involving the production of activated mass of micro-organisms capable of stabilizing waste aerobically is known as activated sludge process.

**Biomass:** Term used for the quantity of living plant and animal material in a given area.

**Biogas:** A methane rich gas which is produced from the fermentation of organic matter in an airtight container.

**Biological oxidation:** Degradation of organic matter with the help of living organism (microbes).

**Biological oxygen demand:** Amount of dissolved oxygen consumed by microorganisms as they decompose organic matter in polluted water.

## **2.7 SELF ASSESSMENT QUESTIONS**

1. What is the basic difference between primary and secondary treatment of wastewater?
2. How secondary treatment is carried out?
3. Write a note on different types of filters?
4. Which difficulties we do come across during the operation of a trickling filter? How they can be controlled?
5. Write a note on different modes of aeration in activated sludge process.
6. What is the difference between trickling filter and Rotating Biological Contractors (RBCs)?

## **2.8 FURTHER READINGS**

1. Garg, S.K. and Rajeshwari Garg (1999): Sewage disposal and air pollution engineering. Khanna Publishers, New Delhi.
2. Metcalf and Eddy (2004): Wastewater engineering. Tata McGraw Hill Publishing Company Ltd., New Delhi.
3. Henze Harremoes La Cour Jansen, Arvin (1998): Wastewater treatment. Prentice Hall of India, USA.
4. Chatterjee, A.K. (1998): Water supply, waste disposal and environmental engineering. Khanna Publication, New Delhi.
5. Hammer M.J. (2000): Water and wastewater technology. Prentice Hall of India Pvt. Ltd., New Delhi.

6. Woodard, F. (2001): Industrial Waste Treatment Handbook. Butterworth Heinemann, New Delhi.
7. Bristle, L.R. (1997): Theory and principles of water and wastewater treatment. John Willey and Sons, New Delhi.



**TERTIARY WASTEWATER TREATMENT**

**Dr. Asha Gupta**

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- 3.2 NUTRIENT REMOVAL
  - 3.2.1 Nitrogen removal
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3.8 SELF ASSESSMENT QUESTIONS

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### **3.0 OBJECTIVES**

To learn about advanced treatment of wastewater, wastewater disposal and reuse and disinfection of water.

## **Advanced Wastewater Treatment**

### **3.1 INTRODUCTION**

The quality of effluent provided by secondary treatment may not always be sufficient to meet discharge requirements. This is often the case when large quantities of effluent are discharged into small streams or when delicate ecosystems are encountered. In these instances, additional treatment to polish the effluent from secondary systems will be required, or an alternative method of wastewater disposal must be found.

Additional treatment, usually referred to as tertiary treatment, often involves the removal of nitrogen and phosphorus compounds, plant nutrients associated with eutrophication. Further treatment may be required to remove additional suspended solids, dissolved inorganic salts and refractory organics. Combinations of the above processes can be used to restore wastewater to potable quality, although at considerable expense.

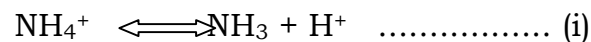
### **3.2 NUTRIENT REMOVAL**

Although the quantities of nutrients contributed by wastewater discharges may be less than those contributed by agricultural runoff and other sources, the point-source nature of wastewater discharges makes them more amenable to control techniques. Thus, wastewater treatment plants that discharge to water bodies that are delicately balanced with respect to nutrient loads may have nutrient limitations imposed on their effluents. The nutrients most often of interest are nitrogen and phosphorous compounds. Processes for removing these nutrients from

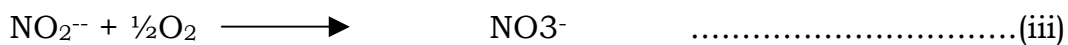
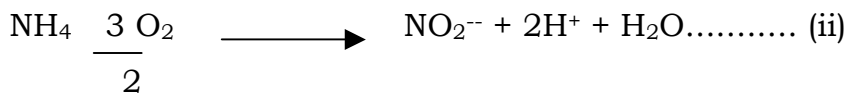
wastewater are discussed in the following paragraphs. **3.2.1**

### 3.2.1 Nitrogen Removal

In domestic wastewater, nitrogen compounds result from the biological decomposition of proteins and from urea discharged in body waste. This nitrogen may be bound in complex organic molecules and is referred to simply as organic nitrogen rather than by specific compound. Organic nitrogen may be biologically converted to free ammonia (NH<sub>3</sub>) or to the ammonium ion (NH<sub>4</sub><sup>+</sup>) by several different metabolic pathways. These two species, together termed as ammonia nitrogen, exist in equilibrium according to the following relationship :



Ammonia nitrogen, the most reduced nitrogen compound found in wastewater, will be biologically oxidized to nitrate as follows if molecular oxygen is present.



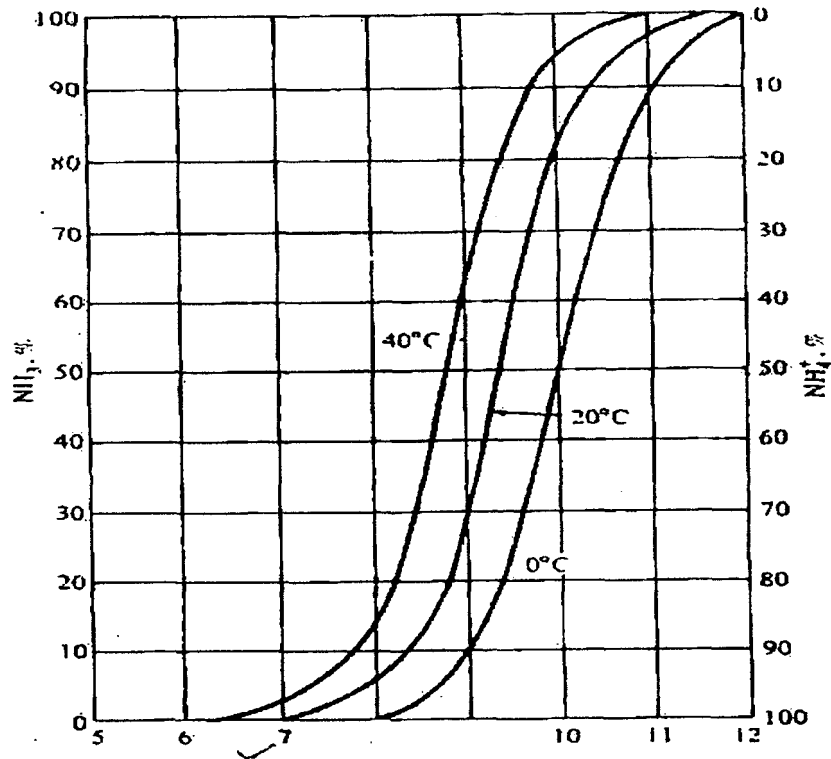
These reactions result in the utilization of about 4.6 mg of O<sub>2</sub> per each mg of NH<sub>4</sub><sup>+</sup>-N oxidized, with about 7.1 mg of alkalinity needed to neutralize the acid (I-T) produced.

In raw wastewater, the predominant forms of nitrogen are organic nitrogen and ammonia. Biological treatment may result in conversion to nitrate, provided the processes are aerobic and the treatment periods are long enough. Contact times in most secondary treatment systems, though sufficient to complete the conversion from organic nitrogen to ammonia,

may not be sufficient for significant nitrification. Because of oxygen demand exerted by ammonia and other environmental factors, removal of ammonia may be required. The most common processes for removing ammonia from wastewater are (i) stripping with air and (2) biological nitrification - denitrification.

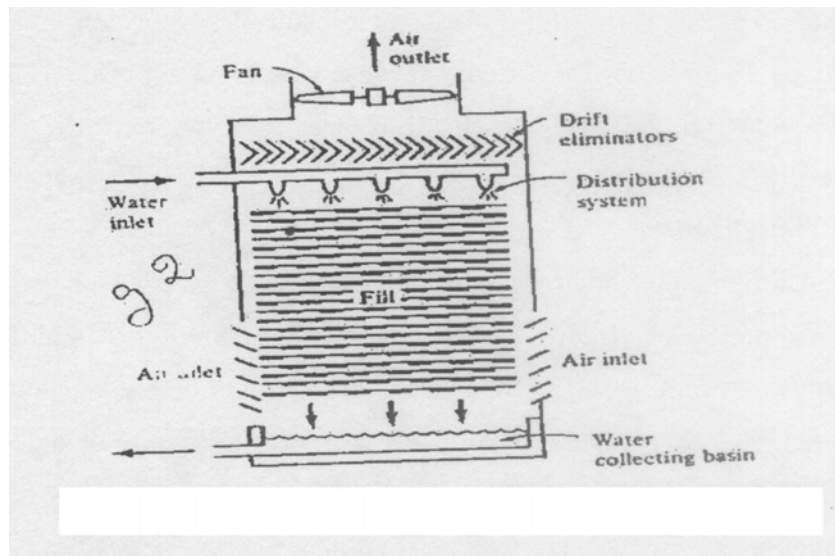
### **3.2.1.1 Air stripping**

Air stripping operations consist of converting ammonium to the gaseous phase and then dispersing the liquid in air, thus allowing transfer of the ammonia from the wastewater to the air. The gaseous phase  $\text{NH}_3$  and the aqueous phase  $\text{NH}_3$  exist together in equilibrium as indicated in Eq.(i). The relative abundance of the phases depends upon both the pH and the temperature of the wastewater. As seen in figure No. 1, the pH must be in excess of 11 for complete conversion to  $\text{NH}_3$ . Since this is well above the normal pH for wastewater, pH adjustment is necessary prior to air stripping. For economic reasons, lime is the most common means of raising the pH. An unavoidable consequence of lime addition is the softening of the wastewater. Enough lime must be added to precipitate the alkalinity and to add the excess  $\text{OH}^-$  ions for pH adjustment. An amount equivalent to the alkalinity plus 1.5 meq/L is usually sufficient to bring the pH to approximately 11.5.



**Fig. 1. Effects of pH and temperature on distribution of ammonia and ammonium ion in water.**

Once the conversion to ammonia has been completed, stripping, or degasification, can proceed. The most efficient reactor has been found to be a counter-current spray tower similar to the one shown in figure No.2. Large quantities of air are required, and a fan must be included to draw air through the tower. Packing is usually provided to minimize film resistance to gas transfer by continuously forming, splashing and reforming drops.



**Fig.2 Diagram of counter current tower for ammonia stripping**

Design parameters for ammonia stripping reactors include air to liquid ratios, over depth and loading rates. Common design practice is to use air to wastewater ratios ranging from about 2000 to 6000 m<sup>3</sup> of air per cubic meter of wastewater with more air being required at lower temperatures. Tower depths are seldom less than 7.5 m, and hydraulic loading rates vary from about 40 to 46 L/min per square meter of tower.

Air stripping is one of the most economical means of nitrogen removal, particularly if lime precipitation of phosphate is also required, because chemical conditioning can be concurrent. There are serious limitations to the process, however, as air temperature approaches freezing, a drastic reduction in efficiency is observed and preheating of the air is not practical because of the large volume required. Furthermore, towers cannot operate in subfreezing weather because of icing. In cold climates, alternative methods of nitrogen removal must be provided during winter.

Other problems associated with ammonia stripping include noise and air pollution and scaling of the packing media. Noise and odour problems caused by the roar of the fans and the dispersion of ammonia

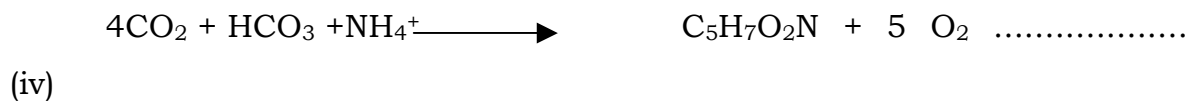
gas can be minimized by locating the facility away from the populated area. Precipitation of calcium carbonate scale on the packing media as a result of wastewater softening can be minimized by the use of smooth-surface polyvinyl chloride (PVC) pipe as packing material, though occasional cleaning of the packing media is still required.

### 3.2.1.2 Nitrification - Denitrification

Ammonia nitrogen can be converted to gaseous nitrogen, N<sub>2</sub>, by biological processes. In this form, nitrogen is essentially inert and does not react with the wastewater itself or with other constituents of the wastewaters. Since N<sub>2</sub> is the principal constituent of air, treated wastewater is likely to be already saturated with molecular nitrogen and the additional N<sub>2</sub> is simply released to the atmosphere.

Biological conversion of ammonia to nitrogen gas is not a direct process but consists of two separate steps. The ammonia must first be oxidized to nitrate and then reduced to molecular nitrogen. These reactions require different environmental conditions and must be carried out in separate reactors.

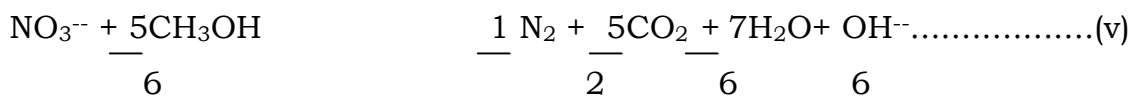
The organisms responsible for nitrification are the autotrophic bacteria, nitrosomonas and nitrobacteria. Equations (ii) & (iii) represent catabolic reactions that supply energy. Anabolic reactions use carbon dioxide and/or bicarbonate as a carbon source and may be represented by the following equation.



Although some ammonia is converted to biomass by this reaction, the catabolic reactions are the principal ammonia conversion processes.

Nitrification can be accomplished in both suspended culture and attached culture reactors. Under favourable circumstances, nitrification can be accomplished along with carbonaceous BOD removal in secondary treatment systems. In other cases it is more efficient to separate the processes and follow carbonaceous BOD removal with a separate reactor for nitrification. Operational parameters of importance include pH, DO, aeration periods, mean cell residence time, and carbon to nitrogen ratios. Temperature is an overriding variable that affects optimum ranges of all the above variables. Combined carbon oxidation and nitrification operations are possible at warmer temperatures, while colder wastewaters will require separate treatment systems in most cases.

In the denitrification process, nitrate is reduced to nitrogen gas by the same facultative, heterotrophic -bacteria involved in the oxidation of carbonaceous material. For reduction to occur, the dissolved oxygen level must be at or near zero, and a carbon supply must be available to the bacteria. Because a low carbon content is required for the previous nitrification step, carbon must be added before denitrification can proceed. A small amount of primary effluent, bypassed around secondary and nitrification reactors, can be used to supply the carbon. However, the unnitrified compounds in this water will be unaffected by the denitrification process and will appear in the effluent. When essentially complete nitrogen removal is required, an external source of carbon containing no nitrogen will be required. The most commonly used external carbon source is methanol, CH<sub>3</sub>OH. When methanol is added, the denitrification reaction is :





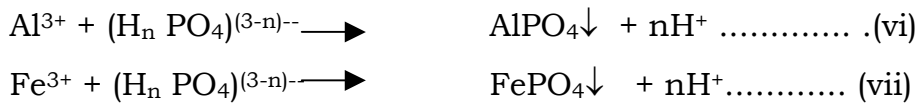
Theoretically, each milligram per liter of nitrate should require 1.9 mg/L of methanol. Under treatment plant conditions, however, about 3.0 mg/L of methanol is required for each milligram per liter of nitrate, making this process an expensive one. 3.2.2

### **3.2.2 Phosphorus Removal**

Phosphorus is a ubiquitous constituent of municipal wastewater, averaging around 10 mg/L in most cases. The principal forms are organically bound phosphorus, polyphosphates, and orthophosphates. Organically bound phosphorus originates from body and food waste and, upon biological decomposition of these solids, is released as orthophosphates. Polyphosphates are used extensively in synthetic detergents and often contribute up to one-half of the phosphorus in wastewater. Polyphosphates can be hydrolyzed to orthophosphates. Thus the principal form of phosphorus in wastewater is assumed to be orthophosphates, although the other two forms may coexist.

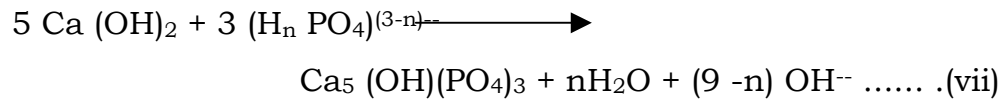
Orthophosphates consist of the negative radicals  $\text{PO}_4^{3-}$ ,  $\text{HPO}_4^{--2}$  and  $\text{H}_2\text{PO}_4^-$  and may form chemical combinations with cations or positive radicals. In most cases the compounds are quite soluble, and phosphate removal in conventional primary treatment is negligible. Because phosphorus is a component of microbial cells, some phosphate may be removed in the biomass in secondary treatment processes. However, microorganisms need relatively little phosphorus as compared with carbon and nitrogen, and less than 3 mg/L of phosphorus is usually removed in conventional secondary treatment. When effluent requirement necessitates greater removal efficiencies, additional treatment must be provided.

The principal means of phosphorus removal is chemical precipitation. At slightly acidic pH, orthophosphates combine with trivalent aluminum or iron cations to form a precipitate.



Because domestic wastewater usually contains only trace amounts of iron and aluminum, the addition of these materials is necessary.

At higher pH values, calcium forms an insoluble complex with phosphate. The addition of lime can provide both the calcium and the pH adjustment necessary.



This reaction requires a pH of at least 9.0 for significant phosphorus removal. Higher pH values generally increase removal efficiencies. However, recarbonation may be necessary to lower the pH after the precipitation process has removed the phosphorus.

Chemical requirements for phosphate precipitation exceed the stoichiometric requirements indicated in Eqs.(vi) through (vii). Aluminum and iron salts react with alkalinity in the wastewater to produce metallic hydroxide flocs [Al(OH)<sub>3</sub> and Fe(OH)<sub>3</sub> ] and may increase the required dosages by up to a factor of 3. Fortunately, this increase is not totally wasted, as the metallic hydroxides assist in the flocculation and removal of the metallic phosphate precipitate along with other suspended and colloidal solids in the wastewater, and are thus useful in the treatment process. At high pH values calcium reacts completely with wastewater alkalinity to form calcium carbonate. Lime additions equivalent to the alkalinity plus that required for phosphate precipitation and pH adjustment are required.

Phosphorus removal can be incorporated into primary or secondary treatment or may be added as a tertiary process. Selection of the point of

application depends on efficiency requirements, wastewater characteristics, and the type of secondary treatment employed. The advantages and disadvantages of each system are summarized in table where effluent phosphorus concentrations of up to 1.0 mg/L are acceptable, the use of iron or aluminum salts in the secondary system is often the process of choice, while high pH precipitation by lime in a tertiary unit is required to obtain very low levels of effluent phosphorus. Where nitrogen removal by ammonia stripping is also practiced, tertiary lime precipitation at a pH of 11.5 serves in both processes.

**Comparison of point of application for phosphorus removal systems**

<b>Primary</b>	<b>Secondary</b>	<b>Tertiary</b>
<b>Advantages</b>		
Applicable to all plants	Lowest capital	Lowest phosphorus in effluent
Increased BOD and suspended solids removal	Lower chemical dosage than primary	Most efficient metal use
Lowest degree of metal leakage	Improved stability of activated sludge	Lime recovery possible
	Polymer not required	Separation of organic and inorganic sludge
<b>Disadvantages</b>		
Least efficient utilization of metal	Careful pH control to get phosphorus <1 mg/L	Highest capital cost
Polymer required for flocculation	Overdose of metal may cause low pH toxicity	Highest metal leakage
Sludge more difficult to dewater than primary sludge	Cannot use lime because of excessive pH	

**3.3 SOLIDS REMOVAL**

Removal of suspended solids, and sometimes dissolved solids, may be necessary in advanced wastewater treatment systems. The solids removal processes employed in advanced wastewater treatment are

essentially the same as those used in the treatment of potable water, although application is made more difficult by the overall poorer quality of the wastewater.

### **3.3.1 Suspended Solids Removal**

As an advanced treatment process, suspended solids removal implies the removal of particles and flocs too small or too lightweight to be removed in gravity settling operations. These solids may be carried over from the secondary clarifier or from tertiary systems in which solids were precipitated.

Several methods are available for removing residual suspended solids from wastewater. Removal by centrifugation, air flotation, mechanical microscreening, and granular media filtration have all been used successfully. In current practice, granular media filtration is the most commonly used process. Basically, the same principles that apply to filtration of particles from potable water apply to the removal of residual solids in wastewater. Differences in operational modes for application of these principles to wastewater filtration vs. potable water filtration may range from slight to drastic, however, and the most commonly used wastewater filtration techniques are discussed below.

Sand filters have been used to polish effluents from septic tanks, Imhoff tanks, and other anaerobic treatment units for decades. Because they are alternately dosed and allowed to dry, the term intermittent sand filters has been applied to this type of unit. The process is essentially the slow sand filter. More recently, this type of filter has been applied to the effluent from oxidation ponds with considerable success. Effluent concentrations of less than 10 mg/L of BOD and suspended solids have been reported at filtering rates of 0.37 to 0.56 m<sup>3</sup>/m<sup>2</sup>.day.

Use of intermittent sand filters in tandem with conventional

secondary treatment has not been very successful. The nature of the solids from these processes results in rapid plugging at the sand surface, necessitating frequent cleaning and thus high maintenance costs. The use of intermittent filters for tertiary treatment is usually restricted to plants with small flows.

Granular media filtration is usually the process of choice in larger secondary systems. Dual or multimedia beds prevent surface plugging problems and allow for longer filter runs. Loading rates depend on both the concentration and nature of solids in the wastewater. Filtering rates ranging from 12 to 30  $m^3/m^2$  day have been used with filter runs of up to 1 day.

Other recent innovations in filtration practices hold promise for advanced wastewater treatment. Moving bed filters have been developed which are continuously cleaned, and the rate of cleaning can be adjusted to match the solids loading rate. Another modification called the pulsed bed filter, uses compressed air to periodically break up the surface mat deposited on a thin bed of fine filter media. Only after a thick suspension of solids has accumulated on the bed, requiring frequent pulsing, is the filter backwashed.

Both the moving bed and the pulsed bed filters have the capability of filtering raw wastewater. A much higher percentage of solids can be removed by filtration than can be removed in primary settling. The filter effluent, containing lower levels of mostly dissolved organics, responds very well to conventional secondary treatment. The filtered solids can be thickened and treated by anaerobic digestion with a resultant increase in overall methane production, a possible source of energy for use within the plant.

### **3.3.2 Dissolved Solids Removal**

Both secondary treatment and nutrient removal decrease the dissolved organic solids content of wastewater. Neither process, however, completely removes all dissolved organic constituents, and neither process removes significant amounts of inorganic dissolved solids. Further treatment will be required where substantial reductions in the total dissolved solids of wastewater must be made.

Ion exchange, microporous membrane filtration, adsorption, and chemical oxidation can be used to decrease the dissolved solids content of water. These processes were developed to prepare potable water from a poor quality raw water. Their use can be adopted to advanced wastewater treatment if a high level pretreatment is provided. The removal of suspended solids is necessary prior to any of the processes. Removal of the dissolved organic material (by activated carbon adsorption) is necessary prior to microporous membrane filtration to prevent the larger organic molecules from plugging the micropores.

Advanced wastewater treatment for dissolved solids removal is complicated and expensive. Treatment of municipal wastewater by these processes can be justified only when reuse of the wastewater is anticipated.

### **3.4 WASTEWATER DISPOSAL AND REUSE**

An insignificant volume of the influent wastewater accompanies sludges and other materials disposed of during wastewater treatment processes. The bulk of the wastewater remains to be disposed of after the treatment processes have been completed. Ultimate receptors of treated wastewaters include surface water and groundwater bodies, land surfaces, and, in some instances, the atmosphere. Recognition of the value of wastewater as a water resource has resulted in an increase in the reuse of treated effluents, particularly in water scarce regions. Portions of the

reused wastewater may appear as effluent for disposal after reuse.

Disposal sites or reuse facilities must be found within a reasonable distance of the wastewater treatment plant because of the cost of transporting the effluent over long distances. Because of the possibility that wastewater may contain a few viable pathogens even after extensive treatment, both disposal and reuse must be accomplished with due caution.

### **3.5 DISINFECTION**

Treatment of water is not complete unless the micro-organisms present in water is removed. The filtered water which is obtained either from the slow sand filters or rapid gravity filters, may normally contain some harmful pathogenic bacteria in it, so the killing of these pathogenic bacteria is must to make the water safe for drinking. The process of killing of pathogenic micro-organisms is known as sterilization or disinfection and chemicals used for this process are known as disinfectants.

This process of purification is the most important, because the bacterially contaminated waters may lead to spread of various diseases and their epidemics thus causing disasters to public life. The disinfection not only removes the existing bacteria from the water at the plant, but also ensures their immediate killing even afterwards, in the distribution system.

Disinfectants which are used for killing of pathogenic micro-organisms should possess the following qualities as under :

1. They should be able to destroy the expected bacteria in water.
2. They should be cheap and reliable.
3. They should not render water ionic or harmful to the consumers;
4. They should not impart any objectionable taste and odour within the required dose .

5. They should kill the bacteria quickly and within the time available for disinfection.
6. They should be easy to transport, easy to store, easy to handle and should not be dangerous to the operator if carefully managed.
7. They should last for fairly long time in the distribution system, thus take care of after growth.
8. They should possess such property that their strength can easily be determined at any point in the distribution system.

### **3.5.1 Minor methods of disinfection**

#### **3.5.1.1 Boiling of water**

The pathogenic bacteria present in water can be destroyed by boiling it for a long time. Although it is an effective method of disinfection but not practically possible because it is not possible to boil huge amounts of public water supplies. Moreover it can kill only the existing bacteria not the future possible contaminations. So not used for disinfection of public water supplies.

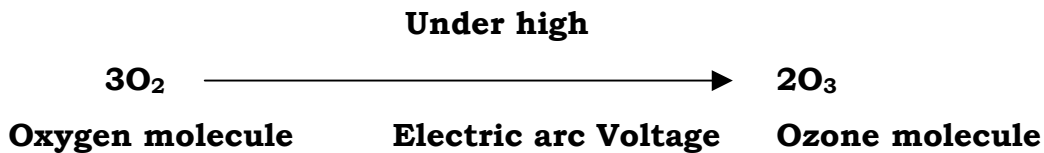
#### **3.5.1.2 Treatment with lime (excess lime)**

Lime is generally used at a water purification plant for softening (i.e. reducing hardness) the water supplies. But it has been found that if excess lime is added to the water, it can kill the bacteria also. An addition of 14-43 ppm of excess lime has been found to remove the bacterial load by about 99.3 - 100% from highly polluted water. Although this method is quite practical for disinfection, but it requires removal of excess lime from the water before supply to general public. Therefore, treatment like recarbonation should be used for lime removal after disinfection.

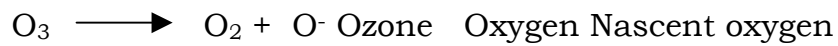


### 3.5.1.3 Treatment with ozone

Ozone, a faintly blue gas of pungent odour, an excellent disinfectant, is nothing but an unstable allotropic form of oxygen, with each of its molecule containing three oxygen atom. It can be produced by passing a high tension of electric current through a stream of air in a closed chamber. The chemical reaction takes place as under :



Because of its unstability, ozone readily breaks down into normal oxygen and releases nascent oxygen as below :



The nascent oxygen, so produced, is a powerful oxidizing agent and removes the organic matter as well as bacteria from the water.

About 2-3 ppm of ozone is generally consumed, so as to obtain a residual ozone of 0.10 ppm after a contact period of about 10 minutes.

Ozone and chlorine are quite competitive disinfectants, each having its merits and demerits over the other. Chlorine is, however, preferred and almost universally adopted, although ozone is also largely used in France and Russia and cities like Chandigarh in India.

#### **Advantages of using ozone as a disinfectant:**

1. Ozone being unstable, nothing remains in water, by the time it reaches the distribution system.
2. Ozone removes the colour, taste and odour from water, in

addition to removing bacteria from it.

3. The ozonised water becomes tasty and pleasant unlike the chlorinated water which becomes bitter to tongue.

#### **Disadvantages of using ozone as a disinfectant**

1. It is very costly ; much costlier than chlorination.
2. Ozone needs electricity for its manufacture and hence can be used only when electricity is available easily and cheaply.
3. No residuals can be maintained because it is highly unstable and thus its use does not ensure safety against possible future contamination.

#### **3.5.1.4 Treatment with iodine and bromine**

Addition of bromine or iodine to water helps in killing pathogenic bacteria and disinfect the same. Their quantities may be limited to about 8 ppm and a contact period of 5 minutes is generally enough. Now-a-days these are available in pills form and can be used for disinfecting only small water supplies.

#### **3.5.1.5 Treatment with ultra-violet rays**

Ultra violet (UV) rays having wavelength of 1000-4000  $\mu\text{m}$  are basically found in sunlight, but can also be produced by passing electric current through mercury enclosed in quartz bulbs.

These rays are highly effective in killing all types of bacteria so provide a true sterilized water. The water, to be sterilized, should be colourless and turbidity should not exceed 15 mg/L and depth of water over the bulb should not generally exceed 10 cm because these rays can effectively penetrate to this much of distance only.

Although sterilization with UV rays does not impart taste or odour

the water but still it is unsuitable for treating large public supplies, as it is very costly and needs technical expertise.

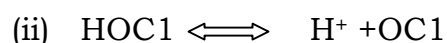
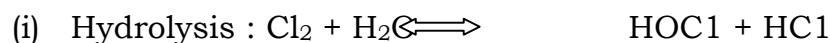
#### **3.5.1.6 Treatment with potassium permanganate**

Potassium permanganate is used as a popular disinfectant for treating water supplies in villages. Besides killing bacteria, it also helps in oxidizing the taste producing organic matter. The normal doses of this disinfectant varies between 1-2 mg/L with a contact period of 4-6 hours. Potassium permanganate, though cheap, handy and quite useful, yet cannot guarantee 100% removal of bacteria. So this method is not satisfactory and not recommended except for rural areas.

#### **3.5.2 Chlorination**

Chlorine in its various forms is invariably and almost universally used for disinfecting public water supplies. It is cheap, reliable, easy to handle, easily measurable and above all, it is capable of providing residual disinfecting effects for long periods, thus affording complete protection against future contamination of water in distribution system. Its only disadvantage is that it provides bitter taste to water so not liked by various people.

Action of chlorine for disinfection : When chlorine is added to water, it first gets hydrolyzed to form hypo-chlorous acid (HOCl) and hydrochloric acid (HCl). In the second stage, hypochlorous acid is ionized to hypochlorite ions (OCl) as under :



Below pH 5, chlorine exists as elemental chlorine. Above pH 5, it will

be a mixture of hypochlorous acid and hypochlorite ions. At about pH 10, it remains as hypochlorite only.

### **3.5.2.1 Classification of chlorination**

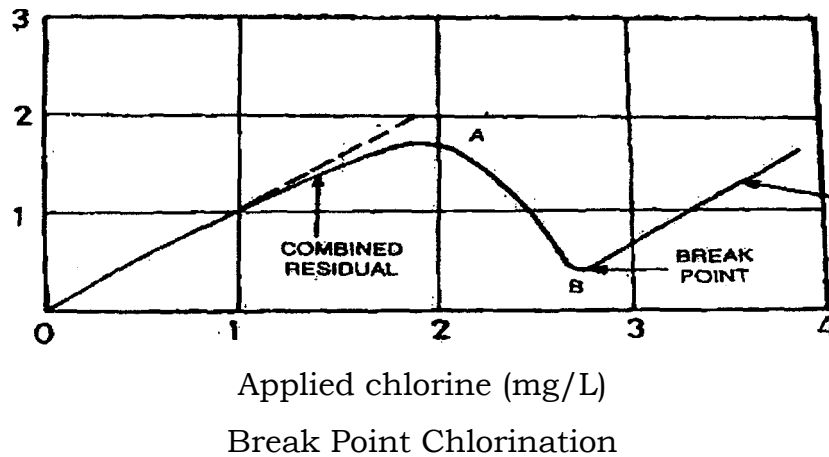
Chlorination can be classified in various way depending on the point of application or the extent of chlorination carried out as described below :

**a) Plain Chlorination** : In some cities only chlorine treated surface waters are used, although in some of these cities, long storage is given. Ground water many times does not require any other treatment except chlorination.

**b) Prechlorination** : When chlorination is used before coagulation, it is known as prechlorination. It may improve coagulation and will reduce taste and odours caused by sludge in the sedimentation tank. It keeps the filter sand cleaner and will increase the length of filter runs. This treatment is must for very highly polluted source.

**c) Postchlorination** : In this, chlorine is applied after the filtration unit. Dosage of chlorination will depend on the character of water and generally varies from 0.25 - 0.50 mg/L in order to obtain a consigned available residual of 0.2 mg/L.

**d) Break point chlorination** : When chlorine is added to water, it does not react until a certain stage is reached. When a certain proportion between the chlorine dosage and ammonia and organic impurities is reached, chlorine starts reacting and combining with them. So the residual chlorine drops down from A to B inspite of increase of chlorine dosage as in figure



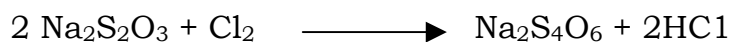
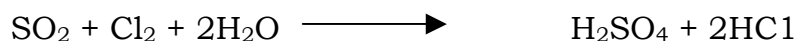
The portion OA shows the formation of chloramines and is known as combined residual. A to B shows the oxidation of chloramines. From the point B onwards, it is free residual chlorine.

**e) Superchlorination** : In this method, chlorine is added to water in high doses so as to get a free residual of 2 mg/L beyond the break point. It is not ordinarily employed but practiced only during the epidemic of water borne diseases. As it imparts strong odour and taste in water, dechlorination is needed after treatment.

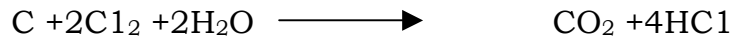
### 3.5.2.2 Dechlorination

This is employed to remove the taste and odour due to chlorine. This is done by following methods as under :

- (i) Addition of reducing chemicals : Common reducing agents are sulphur dioxide (SO<sub>2</sub>), sodium sulphate (Na<sub>2</sub>SO<sub>3</sub>) and sodium thiosulphate (Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub>).



- (ii) By passing water through bed of granular activated carbon, dechlorination can be done .



- (iii) Dechlorination can also be done by aeration.

### 3.5.2.3 Doses of chlorine

The requirement of chlorine dose depends on the following :

- (i) Organic load including microbial life
- (ii) pH value of water
- (iii) Amount of carbon dioxide present
- (iv) Temperature of water
- (v) Available time of contact.

In nutshell, the amount of chlorine required for disinfection of water depends upon the inorganic and organic impurities present in it, because when chlorine is added to water, it first of all reacts with the organic as well as inorganic impurities simultaneously. The amount of chlorine consumed reducing these impurities is called as chlorine demand of water. Once it gets satisfied, chlorine will appear as free chlorine.

The free chlorine as well as the combined chlorine will cause germicidal action in bacteria and pathogens. Free chlorine will instantaneously kill the pathogens while the combined chlorine will provide long term germicidal effect. In general, most of the waters are satisfactorily disinfected if the free chlorine residual is about 0.2 mg/L, 10 minutes after the chlorine is applied.

### 3.5.2.4 Various forms in which chlorine can be applied

Chlorine is generally applied in the following form as under :

- a) As **free chlorine** : In the form of liquid chlorine or as chlorine gas.
- b) As **combined chlorine** : In the form of hypochlorites or bleaching

powder, chloramines i.e. a mixture of ammonia and chlorine and in the form of chlorine dioxide.

### **3.6 SUMMARY**

To meet discharge requirements effluent sometimes may need advanced treatment in which removal of nitrogen, phosphorus, additional suspended solids, dissolved inorganic salts and refractory organics is done. Removal of nutrients such as nitrogen and phosphorus are well described in this chapter. Nitrogen is removed by air stripping. Besides the removal of nutrients, removal of solid, suspended as well as dissolved is also explained. After treatment wastewater is disposed off and it may be reused. Disinfection is purification of water and treatment of water is not complete under the micro-organisms present in water are removed. For disinfection of water, disinfectants are required. Minor methods of disinfection involve boiling of water, treatment with lime, ozone, iodine and bromine, UV-rays and potassium permanganate. Besides these methods, chlorination of water may also be done. In this process chlorine is used in various forms such as free chlorine and combined chlorine. Free chlorine is used in the form of liquid chlorine or as chlorine gas while combined chlorine is in the form of hypochlorite or bleaching powder, chloramines, i.e., a mixture of ammonia and chlorine and in the form of chlorine dioxide.

### **3.7 KEYWORDS**

**Advanced wastewater treatment:** Any treatment of sewage that goes beyond secondary or biological water treatment stage and includes removal of nutrients such as nitrogen and phosphorus and high percentage of suspended solids.

**Nutrient:** Any substance that is assimilated (taken in) by organisms and promotes growth.

**Air stripping:** A treatment system that removes volatile organic

compounds (VOCs) from contaminated groundwater or surface water by forcing an air-stream through water and causing the compounds to evaporate.

**Denitrification:** Bacterial degradation of nitrite to gaseous nitrogen under anaerobic conditions.

**Chlorination:** The application of chlorine to water for the purpose of disinfection.

### **3.8 SELF ASSESSMENT QUESTIONS**

1. What do you mean by tertiary treatment ? Why it is required ?
2. How will you remove phosphorus from wastewater ?
3. Write a note on air stripping
4. How different types of solids are removed from effluent coming from secondary treatment plant ?
5. Explain disinfection in detail.
6. Draw a flow diagram for conversion of wastewater into potable water.

### **3.9 SUGGESTED READINGS**

1. Garg, S.K. and Rajeshwari Garg (1999): Sewage disposal and air pollution engineering. Khanna Publishers, New Delhi.
2. Metcalf and Eddy (2004): Wastewater engineering. Tata McGraw Hill Publishing Company Ltd., New Delhi.
3. Henze Harremoes La Cour Jansen, Arvin (1998): Wastewater treatment. Prentice Hall of India, USA.
4. Chatterjee, A.K. (1998): Water supply, waste disposal and environmental engineering. Khanna Publication, New Delhi.
5. Hammer M.J. (2000): Water and wastewater technology. Prentice Hall of India Pvt. Ltd., New Delhi.
6. Woodard, F. (2001): Industrial Waste Treatment Handbook.



Butterworth Heinemann, New Delhi.

7. Bristle, L.R. (1997): Theory and principles of water and wastewater treatment. John Willey and Sons, New Delhi.

## INDUSTRIAL WASTEWATERS MANAGEMENT

Narsi Ram Bishnoi

### STRUCTURE

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- 1.9. REMOVAL OF SUSPENDED SOLIDS
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    - 1.9.2.1. Advantage of floatation as wastewater process
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  - 1.9.2. Sedimentation
- 1.10. REMOVAL OF COLLOIDAL SOLIDS
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- 1.11. SUMMARY
- 1.12. KEY WORDS
- 1.13. SELF ASSESSMENT QUESTIONS
- 1.14. SUGGESTED READINGS

## **1.0. OBJECTIVES**

After studying this unit, you will be able to understand about :

- The possible types of contaminants in industrial wastewater.
- Characteristics of the produced wastewater from different industries.
- The general standards for discharge of effluents.
- Methods for the treatment of industrial wastewater.

## **1.1 INTRODUCTION**

Wastewaters obtained from industries are generally much more polluted than the domestic or even commercial wastewaters. Still, however, several industries try to discharge their effluents into our natural

river streams, through unauthorized direct discharges; Such a tendency on the part of the industries may pollute the entire river water to a grave extent, thereby making its purification almost an impossible task. Sometimes, the industries discharge their polluted wastewaters into municipal sewers, thereby making the task of treating that municipal sewage, a very difficult and a costly exercise.

The industries are, therefore, generally prevented by legal laws from discharging their untreated effluents. It, therefore, becomes necessary for the industries to treat their wastewaters in their individual treatment plants, before discharging their effluents either on land or lakes or rivers, or in municipal sewers, as the case may be.

## 1.2 METHODS OF TREATING INDUSTRIAL WASTEWATERS

Industrial wastewaters usually contain several chemical pollutants and toxic substances in too large proportions as given in table 1.1.

**Table - 1.1 : Possible types of contaminants in the wastes**

Biological

- (a) Suspended solids
- (b) Dissolved solids and liquids

Non- Biological

- (a) Suspended solids
  - (i) Colloidal  
Emulsified oils and greases
  - (ii) Non colloidal  
Floating oils  
Metallic sludge (viscous or granular).

- (b) Dissolved solids and liquids

(i) Ionic

Acids	Carbonates	Phosphates
Bases	Chlorides	Sulphides
Metals	Ammonia	Nitrates
Cyanides	Sulphates	Thiocynides

- (ii) Non-ionic
  - (a) Chloride

(b) Volatile

Organics      Phenols  
Gasoline      Naptha  
Benzene      Solvents

(c) Non-volatile (hydrocarbons)

Chlorinated  
Phosphorated  
Metal complex organics

The characteristics of the produced wastewater will usually vary from industry to industry, and also vary from process to process even in the same industry (see table 1.2).

**Table-1.2 : Pollution Characteristics of different industries**

<b>Industry</b>	<b>Pollution characteristics</b>	<b>Suggested treatment methods</b>
Paper and Pulp industry	High BOD High BOD/COD ratio, high alkalinity, high sodium content	Biological treatment Chemical recovery, lime treatment for colour
Tannery	High BOD, High Salt, High dissolved solids, presence of sulphides lime and chromium, strong colour	Chemical treatment, biological treatment
Sugar Industry	High BOD high volatile solids, low pH	Biological treatment
Dairy	High dissolved solids, high suspended solids, high BOD, presence of oil and grease	Biological treatment
Distillery and Brewery	High chloride, high sulphate, very high BOD strong colour	Biological treatment
Petrochemical industry	Oil, high BOD/COD, high total solids	Chemical and biological treatment
Pharmaceuticals	High total solids, high BOD/COD ratio, high COD may be acidic or alkaline in reaction.	Chemical treatment, biological treatment
Fertilizer	High nitrogen content	Biological treatment

Coke oven	High ammonia content, high phenol content, high BOD, low S.S., high cyanide	Chemical and biological treatment
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Waste from living or previously living sources are called biological wastes, such wastes are generally treated quite differently from wastes from nonliving, non biological sources.

Non-biological wastes are from metal plating industries, aircraft industries, sheet metal industries etc. These industries commonly discharge which are known as spent up chemicals.

Biological wastes includes discharge from municipalities, tanneries, paper mills, food processing plants, slaughter house and textile units.

In Table 1.2, we have a cursory look and we can find the nature of pollutants from each industry and suggestive method of treatment.

Such industrial wastewaters cannot always be treated easily by the normal methods of treating domestic wastewaters, and certain specially designed methods or sequence of methods may be necessary.

In order to achieve this aim, it is generally always necessary and advantageous to isolate and remove the troubling pollutants from the wastewaters. before subjecting them to usual treatment processes. The sequence of treatment processes adopted should also be such as to help generate useful by products. This help economise the pollution-control measures, and will encourage the industries to develop such treatment plants.

Depending upon the quantum, concentration, toxicity and presence of non-biodegradable organics in an industrial wastewater, its treatment may consist of any one or more of the following processes :

- (1) Volume reduction ;
- (2) Strength reduction ;
- (3) Neutralization;
- (4) Equalization and proportions ;
- (5) Removal of suspended solids

- (6) Removal of colloidal solids
- (7) Removal of inorganic dissolved solids
- (8) Removal of organic dissolved solids

### 1.3. EFFLUENT STANDARDS

General standards for discharge of effluent is given in Table – 1.3

Table 1.3. General standards for discharge of effluents (CPCB, 1995)

	Standards			
	Inland surface water (a)	Public sewers (b)	Land for irrigation (c)	Marine coastal area (d)
Suspended solids mg/L max.	100	600	200	(a) For process waste water-100 (b) For cooling water effluent-10 per cent above total suspended matter of influent cooling water
Particle size of suspended solids	Shall pass 850 micron IS Sieve	-	-	(a) Floatable solids, Max.3mm (b) Settable solids max. 850 microns
Dissolved solids (inorganic), mg/L max	2100	2100	2100	
pH value	5.5-9.0	5.5-9.0	5.5-9.0	5.5-9.0
Temperature °C. Max	Shall not exceed 40 in any section of the stream within 15 metres down	45 at the point of discharge		45 at the point of discharge

	stream from the effluent outlet			
Oil and grease mg/L max.	10	20	10	20
Total residual Chlorine	1.0	-	-	1.0
Ammonical nitrogen (as N), mg/L Max.	50	50	-	50
Total Kjeldahl nitrogen (as N), mg/L Max.	100	-	-	100
Free Ammonia (as NH <sub>3</sub> ), mg/L Max.	5.0	-	-	5.0
Biochemical oxygen demand (5 days at 20 <sup>0</sup> C) mg/L Max.	30	350	100	100
Chemical Oxygen demand, mg/L Max.	250	-	-	250

Lead (as Pb), mg/L max.	0.1	1.0	-	2.0
Cadmium (as Cd), mg/L Max.	2.0	1.0	-	2.0
Hexavalent chromium (as Cr) <sup>+6</sup> mg/L Max.	0.1	2.0	-	1.0



Total chromium (as Cr.), mg/L Max.	2.0	2.0	-	2.0
Copper (as Cu), mg/L Max.	3.0	3.0	-	3.0
Zinc (as Zn), mg/L Max.	5.0	15	-	15
Selenium (as Se), mg/L Max.	0.05	0.05	-	0.05
Nickel (as Ni), mg/L Max.	3.0	3.0	-	5.0
Boron (as B), mg/L Max.	2.0	2.0	2.0	-
Residual sodium carbonate, mg/L Max.	-	-	5.0	-

Cyanide (as CN <sup>-</sup> ), mg/L Max.	0.2	2.0	0.2	0.2
Chloride (as Cl <sup>-</sup> ), mg/L Max.	1000	1000	600	-
Fluoride (as F <sup>-</sup> ), mg/L Max.	2.0	15	-	15
Dissolved Phosphates (as P), mg/L Max.	5.0	-	-	-
Sulphate (as SO <sub>4</sub> <sup>-2</sup> ), mg/L	1000	1000	1000	-

Max.				
Sulphide (as S), mg/L Max.	2.0	-	-	5.0
<b>Radioactive materials :</b>				
(a) Alpha emitters micro curie/ml	$10^{-7}$	$10^{-7}$	$10^{-8}$	$10^{-7}$
(b) Beta emitters micro curie/ml	$10^{-6}$	$10^{-6}$	$10^{-7}$	$10^{-6}$
Manganese (as Mn) mg/L	2.0	2.0	2.0	2.0
Iron (as Fe)	3.0	3.0	3.0	3.0
Nitrate Nitrogen (mg/L)	10	-	-	20

#### 1.4 VOLUME REDUCTION

In general, the first step in minimizing the effects of industrial wastes on receiving streams and treatment plants is to reduce the volume of such wastes. This may be accomplished by :

1. Classification of wastes
2. Conservation of wastewater
3. Changing production to decrease wastes
4. Reusing both industrial and municipal effluents as raw water supplies
5. Elimination of batch or slug discharges of process wastes.

##### 1.4.1 Classification of wastes

If wastes are classified, so that manufacturing process waters are separated from cooling waters, the volume of water required for intensive treatment may be reduced considerably. Sometimes it is possible to classify and separate the process waste themselves, so that only the most polluted ones are treated and the relatively uncontaminated are

discharged without treatment.

#### **1.4.2. Conservation of waste water**

Water conserved is waste saved. For e.g. a paper mill which recycles white water (water passing through a wire screen upon which paper is formed) and thus reduces the volume of wash waters. Concentrated recycled wastewaters are often treated at the end. Since usually it is impractical and uneconomical to treat the wastewaters as they complete each cycle. The savings are two folds : both water costs and waste treatment costs are lower.

Steel mills reuse cooling waters to quench ingots and coal processors reuse water to remove dirt and other non-combustible materials from coal.

#### **1.4.3 Changing production to decrease wastes**

This is an effective method of controlling the volume of wastes, but it is difficult to put into practice. It is hard to persuade production men to change their operations just to eliminate wastes. Normally, the operational phase of engineering is planned by the chemical, mechanical or industrial engineer, whose primary objective is cost savings. The sanitary engineer, on the other hand, has the protection of public health and the conservation of a natural resources as his main considerations. Yet there is no reason why both objectives cannot be achieved.

Waste treatment at the source should be considered an integral part of production. If a chemical engineer argues that it would cost the company money to change its methods of manufacture in order to reduce pollution at the source, the sanitary engineer can do more than simply enter a plea for the improvement of mankind's environment. The reduction in the amount of sodium sulfite used in dyeing ; or sodium cyanide used in plating, and of other chemical used directly in production has resulted in both reduction in quantify of wastewaters and saving of money. The balancing the quantities of acids and alkalis used in a plant often results in

a neutral waste, with saving of chemicals, money and time spent in waste treatment.

#### **1.4.4 Reusing both Industrial and Municipal effluents for raw water supplies**

Practiced mainly in areas where water is scarce and / or expensive, this is proving a popular and economical method of conservation, of all the sources of water available to industry, sewage plant effluent is the most reliable at all seasons of the year.

#### **1.4.5 Elimination of Batch or slug discharges of process wastes**

During manufacturing process, one or two steps are sometimes repeated. which results in production of a significantly higher volume and strength of waste during that period If this waste is discharged in a short period of time ; it is usually referred to as a slug discharge. This type of wastes because of its concentrated contaminants and / or surge in volume, can be troublesome to both treatment plants. and receiving streams. There are at least two methods of reducing the effects of these discharges :

- i) the manufacturing firm alters its practice so as to increase frequency and lessen the magnitude of batch discharges.
- ii) Sludge wastes are retained in holding basins from which they are allowed to flow continuously and uniformly over an extended ( usually 24 hours ) periods

### **1.5 STRENGTH REDUCTION**

Waste strength reduction is the second major objective in industrial waste management. The strength of waste can be reduced by :

1. Process change
2. Equipment modifications
3. Segregation of wastes
4. Equalization of wastes

5. By-product recovery
6. Proportioning wastes and
7. Monitoring waste streams.
8. Accidental spills.

### **1.5.1 Process change**

Many industries have resolved waste problems through process changes e.g. textile & metal-fabricating industries. Textile finishing mills are faced with a problem of disposal of highly polluted wastes from sizing, kiering, desizing and dyeing processes. Starch has been traditionally used as sizing agent. This starch after hydrolysis became a major source of waste pollutants. New substituent of starch; carboxymethyl cellulose has been developed to solve above problem which has reduced BOD value significantly.

In the metal-plating industries, several changes in the process have been suggested to eliminate or reduce cyanide strengths :

- i) Change from copper-cyanide plating solution to acid-copper solutions
- ii) Replace the  $\text{CuCN}_2$  strike before the copper-plating bath with a nickel strike
- iii) Substitute  $\text{H}_3\text{PO}_4$  for  $\text{H}_2\text{SO}_4$  in pickling of steel
- iv) Use alkaline derusters instead of acid solutions to remove light rust which occurs during storage (the overall pH will be raised nearer to neutrality by this procedure, which will also alleviate corrosive effects on piping and sewer lines)

Coal mining company has modified its process to wash raw coal with acid mine water rather than a public or private water supply. In this way. the mine drainage waste is neutralized, while the washed coal is free from any impurities.

### **1.5.2 Equipment modifications**

Changes in equipment can effect a reduction in the strength of the

waste. usually by reducing the amounts of contaminants entering the waste stream. For e.g. in pickle factories, screens placed over drain lines in the tanks prevents the escape of seeds and piece of vegetables and fruits which add to the strength and density of the waste. Similarly, traps on the discharge pipeline in poultry plants prevents emission of feathers and piece of fats. Waste strength reduction occurred in the dairy industry by redesigning the large milk-cans used to collect farmer's-milk. The new cans were constructed with smooth necks so that they could be drained faster and more completely. This prevented a large amount of milk waste from entering streams and sewage plants.

### **1.5.3 Segregation of wastes**

Segregation of wastes reduces the strength and / or the difficulty of treating the final waste from an industrial plant. For e.g. In metal finishing plants, which produce wastes containing both chromium and cyanide as well as other metals. It is necessary to segregate the cyanide-bearing waste, make them alkaline and oxidize them. The chromium waste, on the other hand, have to be acidified and reduced.

Two effluents can then be combined and precipitated in an alkaline solution to remove the metals. Without segregation, poisonous hydrogen cyanide gas would develop as a result of acidification. A textile mill manufacturing finished cloth produced the four types of waste such as Grey waste, white waste, dye waste and kier waste. The combined waste are quite strong, difficult and expensive to treat. However, when the strong liquid kierung waste was segregated from the other wastes, chemically neutralized, precipitated, and settled, the supernatant could be treated chemically and biologically along with the other three wastes, because the strength of the resulting mixture was considerably less than that of the original combined waste.

### **1.5.4 Equalization of wastes**

Main objectives of equalization are to stabilization of pH, BOD and

settling of solids and heavy metals. Plants which have many products, from a diversity of processes, prefer to equalize their waste. This requires holding wastes for a certain period of time, depending on the time taken for the repetitive processes in plant. For e.g., if a manufactured item, requires a series of operations that take eight hours, the plant needs an equalization designed to hold the wastes for that eight hour period. The effluent from an equalization basin is much more consistent in its characteristics than in each separate influent to that same basin. Stable effluents are treated more easily and efficiently than unstable, ones by industrial and municipal treatment plants. Sometimes equalization may produce an effluent which warrants no further treatment.

#### **1.5.5 By-product recovery**

This is the Utopian aspect of industrial-waste treatment; the one phase of the entire problem which may lead to economic gains. The industrial management should consider the possibility of building a recovery plant which will produce a marketable by-product and at the same time solve a troublesome waste problem. For e.g. (i) The dairy industry treats skim milk with dilute acid to manufacture casein. Casein manufacturers in turn utilize their waste to precipitate albumin. The resulting albumin waste is used in the crystallization of milk sugar, and the residue from this process is utilized as poultry feed ; (2) Yeast factories evaporate a portion of their waste and sell residue for cattle feed; (3) In sewage treatment plant. Methane gas from sewage digesters is commonly utilized for heat and power and some cities digested and dried sewage sludge is used as a manure ; (4) The sulphite waste liquor by

products from paper mills are used in fuel, road binder, cattle fodder, fertilizer, insulating compounds and in production of alcohol and artificial vanillin.

Once a by-product is developed and put into production, it is difficult to identify the new product with a waste-treatment process. For example, when sugar is extracted from sugar cane, a thick slurry known as molasses is left. It has many uses, one of the best known beings in the production of commercial alcohol.

#### **1.5.6 Proportioning Waste**

By proportioning its discharge of concentrated wastes into the main sewer, a plant can often reduce the strength of its total waste to the point where it will need a minimum of final treatment or will cause the least damage to the stream or treatment plant.

#### **1.5.7 Monitoring Waste Streams**

Remote sensing devices that enable the operator to stop, reduce, or redirect the flow from any process when its concentration of contaminants exceeds certain limits are an excellent method of reducing waste strengths. In fact, accidental spills are often the sole cause of stream pollution or malfunctioning of treatment plants these can be controlled.

#### **1.5.8 Accidental Spills**

Accidental discharges of significant process solutions represent one of the most severe pollution hazards. There are some measures that can be taken to reduce the likelihood of accidents and severity when and if they occur. Some suggestions for general use include the following :

- a) Make certain that all pipelines and valves in the plant are clearly identified.
- b) Allow only certain knowledgeable persons to operate these valves.
- c) Install indicators and warning systems for leaks and spills.



- d) Provide for detention of spilled wastewater in holding basins or lagoons until proper waste treatment can be accomplished.
- e) Monitor all effluents quantity and quality to provide a positive public record if necessary.

## 1.6 NEUTRALIZATION

Excessive acid or alkaline wastes should not be discharged without treatment into a receiving stream. There are many acceptable methods for neutralizing over-acidity or over-alkalinity of wastewaters such as :

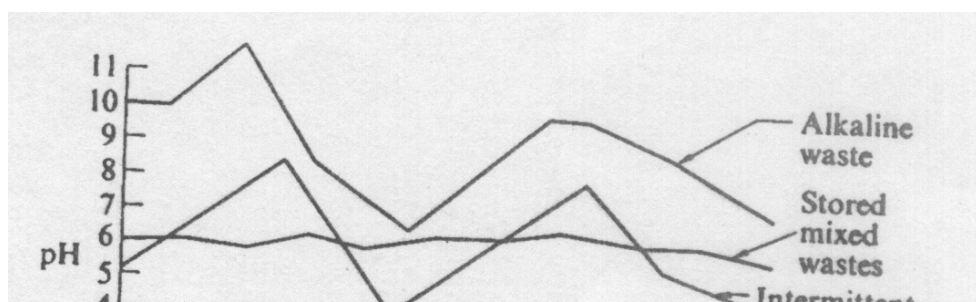
- i) Mixing wastes ;
- ii) Limestone treatment for acid waste ;
- iii) Lime slurry treatment for acid waste ;
- iv) Caustic Soda treatment for acid waste ;
- v) Waste-boiler - Flue-Gas ;
- vi) CO<sub>2</sub> treatment for alkaline waste ;
- vii) Producing CO<sub>2</sub> in alkaline wastes ; and
- viii) Sulfuric acid treatment for alkaline waste.

The volume, kind, and quantity of acid or alkali to be neutralized are the main factor to be kept in mind to decide, what kind of neutralizing agent is to be used.

In any lime neutralization treatment, adequate reaction time for an acid effluent should be given so that they can reach minimum pH value. Because during storage of alkaline wastes come in contact with air and CO<sub>2</sub>, which will slowly dissolve in the waste and lower the pH. Biological treatments are more efficient at pH value nearer to neutrality.

### 1.6.1 Mixing Wastes

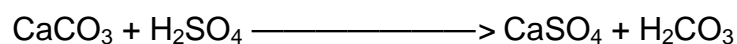
Mixing of wastes can be accomplished within a single plant operation or between neighbouring industrial plants. Acid and alkaline wastes may be produced. Individually within one plant and proper mixing of these waste at appropriate time. results in neutralization.



For example, if one plant produces an alkaline waste which can be pumped conventionally to an area adjacent to a plant discharging an acid waste, an economical and feasible system of neutralization results for each plant.

### **1.6.2 Lime stone treatment for acid wastes**

In this method, acid wastes is passed through beds of limestones ( $\text{CaCO}_3$ ) at a rate of about one gallon per minute per square feet (1 gpm/ft<sup>2</sup>). Neutralization takes place with following reaction :



This reaction will continue as long as excess limestone is available and in an active state. The first condition can be fulfilled by providing a sufficient quantity of limestone, the second condition is difficult to meet, because excess of acid will precipitate the calcium sulfate and cause subsequent coating and inactivation of the limestone.

Disposing of the used limestone beds can be a serious drawback to this method of neutralization. Since the used limestone must be replaced by fresh at periodic interval, frequency of replacement depending on the quantity and quality of acid wastes being passed through a bed. When there are extremely high acid loads, foaming may occur, especially when organic matter is also present in the waste.

### **1.6.3 Lime-slurry treatment for acid wastes**

Mixing acid wastes with lime slurries is an effective procedure for neutralization. The reaction is similar to that obtained with limestone beds. But the advantages of using lime slurry than lime stone beds are :

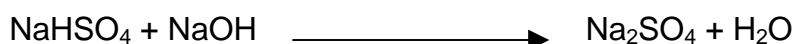
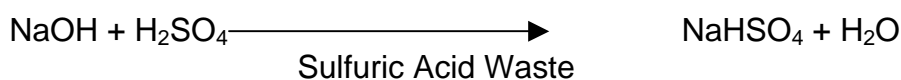
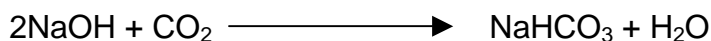
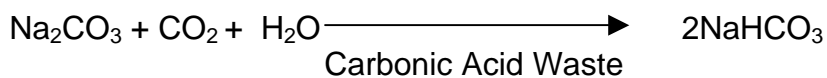
- i) In this case, lime is used up continuously because it is converted to  $\text{CaSO}_4$  and which is carried out in the waste ;
- ii) Lime possesses a high neutralizing power and its action can be hastened by heating or by oxygenating the mixture.
- iii) It is relatively inexpensive, but in large quantities the cost can be an important item.

Neutralization of nitric and sulfuric acid wastes in concentrations upto about 1.5 per cent ( in case of  $\text{H}_2\text{SO}_4$ ) was accomplished satisfactorily by using a burned dolomitic stone containing 47.5 per cent  $\text{CaO}$ , 34.3 percent  $\text{MgO}$ , and 1.8 per cent  $\text{CaCO}_3$ .

#### 1.6.4 Caustic-Soda treatment for acid wastes

Concentrated solutions of caustic soda or sodium carbonate cause neutralization of acid waste. These neutralizers are more powerful than lime or limestone and some agents are required in small volume. Another advantage is that the reaction products are soluble and thus they do not increase the hardness of receiving waters.

When sodium hydroxide is used as a neutralizing agent for carbonic and sulfuric acid wastes, the following reactions take place :

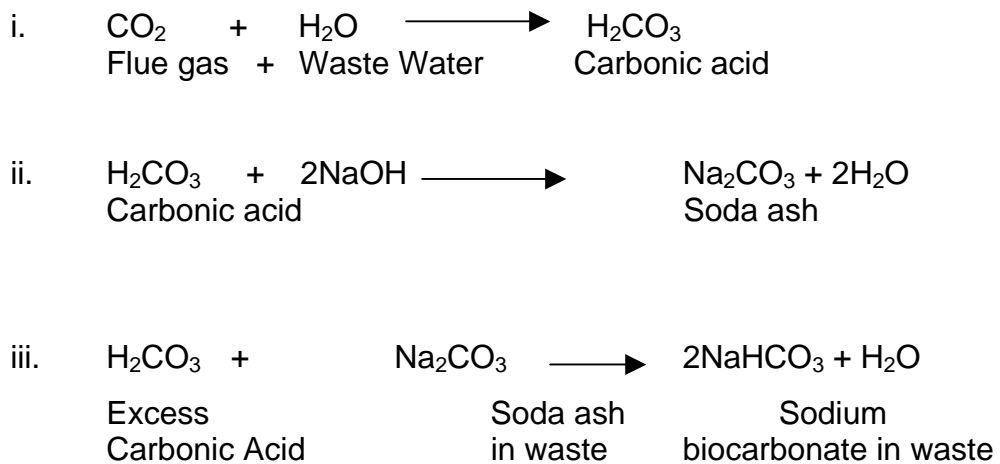


Both these neutralizations take place in two steps and the end-products depend on the final pH desired. For example, one treatment may

require a final pH of only 6, and the most of end product is NaHSO<sub>4</sub>. Another treatment may require a pH of 8, with most of product being Na<sub>2</sub>SO<sub>4</sub>.

### 1.6.5 Neutralization of Alkaline Wastes : Using Waste-Boiler-Fuel Gas

It is a most economical method for neutralization of alkaline waste. In this method, when waste boiler-flue gas (containing 14 percent CO<sub>2</sub>) is passed through the alkaline waste CO<sub>2</sub> dissolve in waste water and will form carbonic acid (a weak acid) which in turn reacts with caustic wastes to neutralize the excess alkalinity as follows :



### 1.6.6 Carbon - Dioxide Treatment for Alkaline Wastes

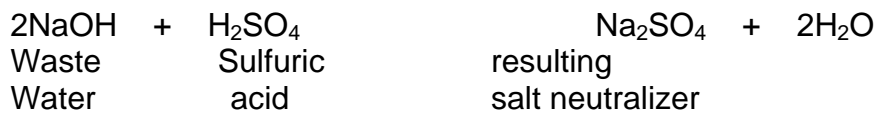
Bottled CO<sub>2</sub> is applied to wastewaters which neutralizes alkaline wastes on the same principle as boiler-flue gas [i.e. it forms a weak acid (carbonic acid) dissolved in water. When the quantity of alkaline waste is large, there is operational difficulty as well as high cost.

### 1.6.7 Producing Carbon-dioxide in Alkaline Wastes

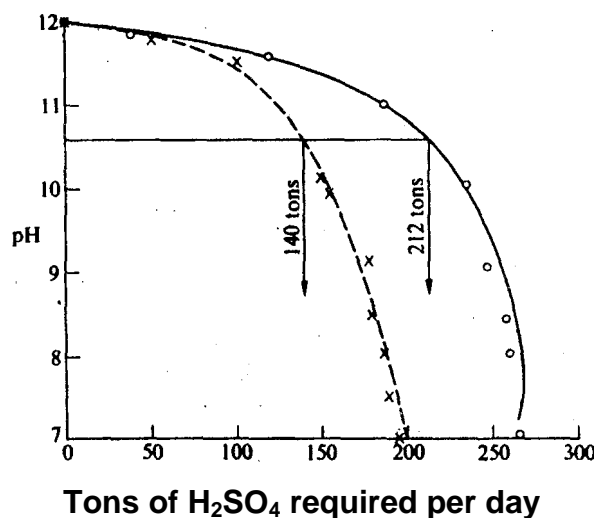
CO<sub>2</sub> produced by fermentation of an alkaline, organic waste help in neutralization of alkaline waste by decreasing the pH. Similar by fermenting alkaline fat-sugar wastes with yeast, CO<sub>2</sub> is produced which can be used for neutralization.

### 1.6.8 Sulfuric-Acid Treatment for Alkaline Wastes

The addition of sulfuric acid to alkaline wastes causes neutralization. In this method, storage and feeding equipment requirement are low due to high acidity value of N3804, but it is difficult to handle because of its corrosiveness. The neutralization reaction which occurs, when it is added to wastewater is as follows :



A titration curve of an alkaline waste neutralized with various amounts of  $\text{H}_2\text{SO}_4$  is helpful to determine the quantities of acid required for neutralization.



### 1.7 EQUALIZATION AND PROPORTIONING

Equalization is a method of retaining wastes in a basin so that the effluent discharged is :

- (i) Uniform in its sanitary characteristics (pH, color, turbidity, Alkalinity & BOD).
- (ii) Concentration of effluent contaminants lowered

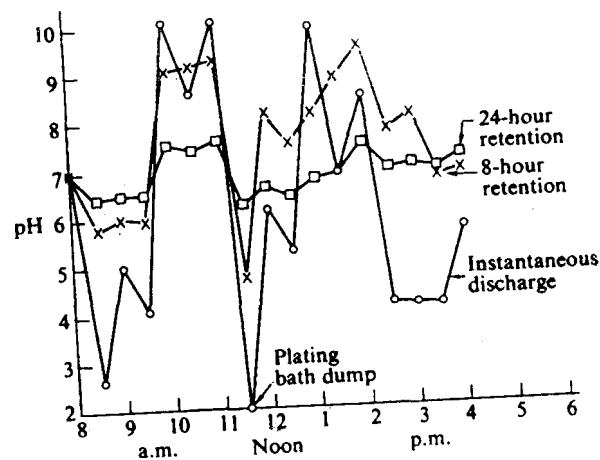
(iii) Physical, chemical, and biological reactions takes place.

Sometimes, air is injected into these basins to provide (1) better mixing ; (2) Chemical oxidation of reduced compounds (3) some degree of biological oxidation. and (4) agitation to prevent suspended solids from settling.

The size and shape of the basin vary with the quantity of waste and the pattern of discharge from the factory. Most basins are rectangular, square or triangular in shape. The capacity of the tank should be adequate to hold all the waste from the plant. Almost all industrial plants operate on a cycle basis, thus if the cycle of operations is repeated every two hours, an equalization tank which can hold a two-hour flow will usually be sufficient. If the cycle is repeated only each 24 hours, the equalization basin must be high enough to hold a 24 hours flow of waste.

The mere holding of waste however, is not sufficient to equalize it. Each unit volume of waste discharged must be adequately mixed with other unit volumes of waste discharged many hours previously. This mixing may be brought about in the following :

- (i) Proper distribution and baffling
- (ii) Mechanical agitation
- (iii) Aeration
- (iv) Combinations of all three.

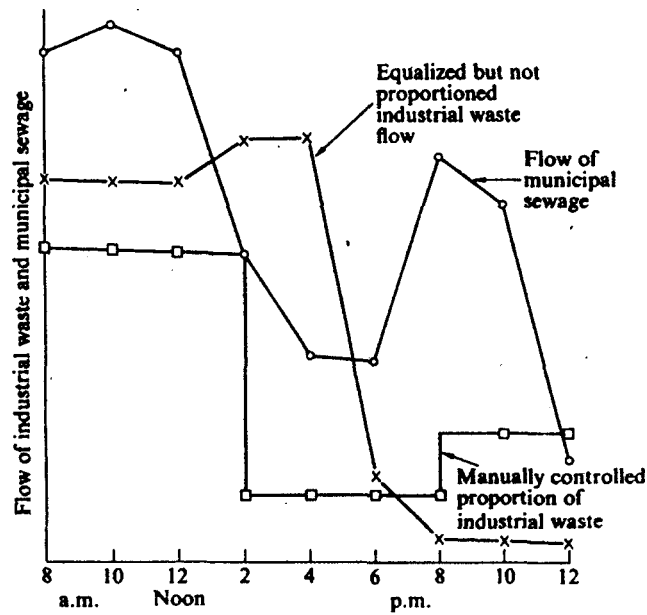


## 1.8 PROPORTIONING

Proportioning means the discharge of industrial wastes in proportion to the flow of municipal sewage in sewers. In most cases, it is possible to combine equalization and proportioning in the same basin. The objective of proportioning in sewers is to keep constant the percentage of industrial wastes to domestic sewage flow entering the municipal sewage plant. This procedure have several other purposes also :

- (i) To protect municipal sewage treatment plant using chemical by sudden overdose of chemicals contained in the industrial waste.
- (ii) To protect biological treatment devices from shock loads of industrial wastes, which may inactivate the bacteria
- (iv) To minimize fluctuations of sanitary standards in the treated effluents.

The rate of flow of industrial waste varies from instant to instant, as does the flow of domestic sewage, and both empty into the same sewage system. Therefore, the industrial waste must be equalized and retained, then proportioned to the sewer or stream according to the volume of domestic sewage or stream flow. To facilitate proportioning, an industry should construct a holding tank with a variable speed pump to control the effluent discharge. But in some cases, domestic sewage treatment plant is usually located some distance from an industry, hence signalling the time and amount of flow is difficult and sometimes quite expensive. To solve this problem, many industries have separate pipelines through which they pump their wastes to the municipal treatment plant. The wastes are equalized separated at the site of the municipal plant and proportioned to the flow of incoming municipal waste water. Separate lines are not ; of course, always possible or even necessary.



### 1.8.1 Discharge of industrial waste

There are two general methods of discharging industrial waste in proportion to the flow of domestic sewage at the municipal plant : (i) Manual control ; (ii) Automatic electronic control.

#### (i) Manual Control

It is lower in initial cost but less accurate. It involves determining the flow pattern of domestic sewage for each day in the week, over a period of months. Usually one does this by examining the flow records of the sewage plant or by studying the hourly water-consumption figures for the city.

#### (ii) Automatic Control

It involves placing a metering device, which registers the amount of flow at the most convenient main sewer connection. This device translates the rate of flow in the sewer to a recorder which is located near the industrial plant's holding tank. The pen on the recorder accelerates either a mechanical or a pneumatic (air) control system for opening or closing the diaphragm of the pump. The initial cost of this automatic control system is higher than that of manual control, they will usually return the investment many times by saving in labour costs.

Some industrial and municipal sewage-plant operations think that



the best time to release a high proportion of industrial waste to the sewer is at night ; when the domestic sewage flow is low. Whether night release is a good idea depends on the type of treatment used and the character of the industrial waste. If the treatment is primarily biological and the industrial wastes contain readily decomposable organic matter and no toxic elements discharging the largest part of the industrial waste to the treatment plant at night is indeed advisable, since, this ensures a relatively constant organic load delivered to the plant day and night.

## **1.9 REMOVAL OF SUSPENDED SOLIDS**

There are three methods for the removal of suspended solids, which are as follows :

1. Screening.
2. Flotation
3. Sedimentation

### **1.9.1 Screening**

Screening of industrial wastes is generally practiced on waste containing larger suspended solids of variable sizes. For e.g. from canneries, pulp and paper mills, or poultry processing plants. It is an economical and effective means of rapid separation of these larger suspended solids from the remaining waste material. In many cases screening alone will reduce the suspended solids to a low enough concentration to be acceptable for discharge into a municipal sewer or a nearby stream.

Screens are available in sizes ranging from coarse (10 or 20 mesh) to fine (120 to 320). In the industry, generally two types of screens are used :

- i) North Screen
- ii) Sweco Screen

**North screen** : They are generally rotary, self-cleaning gravity-type, units.

They have been used successfully in treating wastes from meat-packing, grain-washing, tanning, woolen and sea food plants.

**Sweco screen** : They are circular, vibratory screens. They have been quite effectively used for screening wastes from food-packing processes such as meat and poultry packing or fruit and vegetable canning.

### **1.9.2 Floatation**

The floatation process consists of creation of air bubbles in the waste body or tank by introducing air to the system. These air bubbles increase the buoyancy of the finer particles which could be easily lifted by skimming (i.e. the process of removing floating grease or scum from the surface of the effluent in a tank).

#### **1.9.2.1 Advantages of floatation as wastewater process**

- i). Grease, and light solids rising to the tops and grit and heavy solids settling to the bottom are all removed in one unit.
- ii). Odor nuisance are minimized, because of short detention period.
- iii). High overflow rates and short detention periods means smaller tank sizes, resulting in decreased space requirements and possible saving in construction costs.

#### **1.9.2.2 The disadvantages of floatation**

- i) The additional equipment required results in higher operating costs.
- ii) Floatation units generally do not give as effective treatment as gravity settling units, although the efficiency varies with the waste.
- iii) More skilled maintenance is required for a floatation unit than for a gravity settling unit.

### **1.9.3 Sedimentation**

Sedimentation processes are very effective in removing suspended solids in industrial wastewater. The efficiency of sedimentation tank depends, in general on the following factors :

- \* Detention periods.
- \* Wastewater characteristics
- \* Tank design.
- \* Particle size.
- \* Velocity & density of particles.

The clarifiers/tanks either rectangular or circular in shape are most commonly used in the application of sedimentation in wastewater treatment. The design of the clarifiers are based on several factors, which are as follows :

- \* Influent TSS concentration.
- \* Effluent TSS concentration.
- \* Surface loading
- \* Detention time.
- \* Sludge generation.

## **1.10 REMOVAL OF COLLOIDAL SOLIDS**

### **1.10.1 Introduction**

A colloids particles are extremely small size (1-200 millimicrons). These particles do not settle out on standing and cannot be removed by conventional physical treatment processes. Colloids are often responsible for a relatively high percentage of the color, turbidity, and BOD of certain industrial wastes. Thus it is

important to remove colloids from wastewater before they can reach into streams.

Colloids exhibit Brownian movement ; that is the continuous, random movement of tiny solid particles in liquids or gases. This is caused by the impact of moving liquid or gas molecules pushing at the solid particles

from all the side. They are essentially non-settleable because of their charge, small size and low particle weight. They are dialyzable through semipermeable membrane. Colloidal particles are generally electrically charged with respect to their surroundings. An electric current passing through a colloidal system causes the positive charges to migrate to the cathode and the negative one to the anode. Colloids exhibit Tyndall effect; that is the scattering of light from very small particles, as seen when a beam of sunlight passes through a dirty atmosphere. This gives bluish light. True solutions show no Tyndall effect, whereas colloidal solutions do.

**Table 11.1 : Types and characteristics of colloidal sols**

Characteristic	Lyophobic (hydrophobic)	Lyophilic (hydrophilic)
Physical state	Suspensoid	Emulsoid
Surface tension	The colloid is very similar to the medium	The colloid is of considerably less surface tension than the medium
Viscosity	The colloid suspension is very similar to the dispersing phase alone	Viscosity of colloid suspension alone is greatly increased
Tyndall effect	Very pronounced (ferric hydroxide is an exception)	Small or entirely absent
Ease of reconstitution	Not easily reconstituted after freezing or drying	Easily reconstituted
Reaction to electrolytes	Coagulated easily by electrolytes	Much less sensitive to the action of electrolytes, thus more is required for coagulation
Examples	Metal oxides, sulfides, silver halides, metals, silicon dioxide	Proteins, starches, gums, mucilages, and soaps.

### 1.10.2 Chemical Coagulation

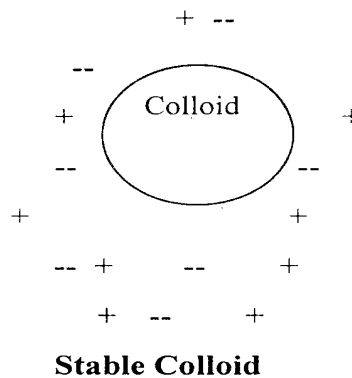
This is a process of destabilizing colloids, aggregating them, and binding them together for sedimentation. It involves the formation of chemical flocs that absorb, entrap, or otherwise bring together, suspended matter that is so finely divided as to be colloidal.

The chemicals most commonly used are : alum  $[Al_2(SO_4)_3 \cdot 18H_2O]$ , copperas,  $[FeSO_4 \cdot 7H_2O]$ , Ferric Sulfate,  $[Fe_2(SO_4)_3]$ , Ferric Chloride.  $FeCl_3$  and chlorinated copper as a mixture of ferric sulfate and chloride. Aluminum sulfate appears to be more effective in coagulating carbonaceous wastes, while iron sulfates are more effective when a considerable quantity of proteins is present in the wastes.

### 1.10.3 Coagulation by Neutralization of the Electrical Charges

This can be performed by :

- i) Lowering of the zeta potential of the colloids. (Figure ). Zeta potential is the difference in electrical charge existing between the stable colloid and the dispersing medium



- ii) Neutralizing the colloidal charge by flooding the medium with an excess of oppositely charged ions ; usually hydrous oxide colloids formed by reaction of the coagulant with ions in the water.

In this process, the coagulant colloids also become destabilized by the reaction with oppositely charged colloids and produce hydrous oxide, which is a floc-forming material.

From the stand point of electrical charges, there are two predominant types of colloid in wastewaters :

- i) Colloids naturally present, including several proteins, starch, hemicellulose, polypeptides and other substances, all possess negative charge ( mostly Lyophilic in nature ).

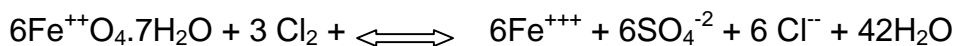
- II) Colloids artificially produced by coagulants usually the hydroxides of iron and aluminum (mostly lyophobic in nature) are mainly positively charged ions.

The charge on colloidal particle is due mainly to the preferential adsorption of ions ( $H_+$  or  $OH^-$ ) from the dispersing medium. The charge may also be due to, the direct ionization of a portion of its structure groups such as  $NH_2^+$  and  $COO^-$ .

Electrolytes and colloids react readily to changes in the pH of the waste waters. Most of the negatively charged colloids present in wastewaters. coagulate at an optimum pH value of less than 7.0 whereas on the other hand. Flocculent hydroxide colloids are insoluble only at pH value about 7.0 and usually over 9.0. Thus lime is normally added to raise the pH, as well as to aid in precipitation of colloids.

Alum has a pH range of maximum insolubility between 5 and 7, the ferric ion coagulates only at pH values above 4, and the ferrous ion only above 9.5. Copperas (  $FeSO_4 \cdot 7H_2O$ ) is a useful coagulants only in highly alkaline wastes.

Since the ferrous ion when oxidized to the ferric ion can also be used as a coagulant at low pH values, oxidation may be carried out by chlorination as follows:



#### 1.10.4 Removal of Colloids by adsorption

A large number of compounds which are not removed by coagulation and other treatments, may be removed from wastes by adsorption. For e.g. pesticide such as 2,4-D, herbicides and carbamate insecticides may be removed by adsorption of activated carbon. In addition, colloidal suspension of DDT, chlorobenzene, and p-chlorobenzene sulfonic acid resulting in DDT production may also be removed by activated carbon.

#### 1.11. SUMMARY

Industrial wastewater usually contains several chemical pollutants and toxic substances. The characteristics of the produced wastewater is vary from industry to industry and also vary from process to process even in the same industry. Industrial biodegradable wastewater can be reduced by the processes such as volume reduction, strength reduction, neutralization, equalization and proportions. There are several technologies for the removal of suspended solids, colloidal solids, inorganic dissolved solid, organic dissolved solids. The central pollution control board has fixed the general standards for discharge of industrial wastewater after pretreatment.

## **1.12. KEY WORDS**

### **Wastewater**

The spent or used water from a home, community, farm or industry that contains dissolved or suspended matter.

### **Industrial waste**

Unwanted materials from an industrial operation, may be liquid, sludge, solid or hazardous waste.

### **Chemical oxygen demand (COD)**

The amount of chemically oxidizable materials present in the wastewater.

### **Biochemical oxygen demand (BOD)**

The oxygen used in meeting the metabolic needs of aerobic microorganisms in water rich in organic matter.

### **Coagulation**

The neutralization of the charges of the colloidal matter.

## **1.13. SELF ASSESSMENT QUESTIONS**

1. What are the methods of reducing volume of the effluent ?
2. What advantage do we get by reducing the waste volume ?
3. How can we encourage water conservation in an industrial plant ?
4. What do you mean by strength reduction ? Why should we use it

?

5. How does segregation reduce the strength of the wastewater ?  
Give an example.
6. What do you mean by equalization to reduce the strength of wastewater ?
7. How can proportioning industrial wastes reduce their strength ?
8. Write down the name of the majors methods of neutralization of both alkaline and acid waste.
9. What effect can the storage of alkaline wastes have on pH and resulting neutralization ?
10. When would you use NaOH or Na<sub>2</sub>CO<sub>3</sub> for neutralization ?
11. What is the advantage of using lime slurry rather than limestone beds for neutralization ?
12. When would you are limestone beds for acid waste ?
13. What are the objectives of equalization and proportioning of industrial wastes?
14. What are the problems associated with proportioning industrial waste into municipal sewers.
15. What are three major methods of removing suspended solids ?
16. When should you use flotation for removal of suspended solids.
17. Why and when would you are screening for suspended solids removal ?
18. What are the important factors affecting industrial wastewater sedimentation?
19. Why is it important to remove colloids from wastes ?
20. What are colloids ?
21. Are colloids all of one type ? If of more than one type, what are the difference ?
22. What is meant by the zeta potential ?
23. For what reasons do we add lime to industrial wastes for colloidal solids removals.
24. Write down the name of the processes used for industrial



wastewaters treatment ?

#### **1.14. SUGGESTED READINGS**

1. Chatterji, A K. (2005). Introduction to environment biotechnology, PHI, New Delhi.
2. Cheremisinoff, N. P. (2003). Biotechnology for waste and wastewater treatment prentice Hall of India, New Delhi.
3. Spellman, F. R. (2004) Mathematics manual for water and wastewater treatment plant operators, CRC press, New York.
4. Venugopala Rao, P. (2005). Text book of environmental engineering. Prentice Hall of India, New Delhi.

## REMOVAL OF INORGANIC AND ORGANIC DISSOLVED SOLIDS

Narsi Ram Bishnoi

### STRUCTURE

#### 2.0. OBJECTIVES

#### 2.1. REMOVAL OF INORGANIC DISSOLVED SOLIDS

2.1.1. Introduction

2.1.2. Evaporation

2.1.3. Dialysis

2.1.4. Algae

2.1.5. Reverse osmosis

2.1.6. Ion exchange

2.1.7. Miscellaneous methods

#### 2.2. REMOVAL OF ORGANIC DISSOLVED SOLIDS

2.2.1. Introduction

2.2.2. Lagooning

2.2.3. Trickling filters

2.2.3.1. Recirculation

2.2.3.2. Hydraulic load

2.2.3.3. Organic (BOD) load

2.2.3.4. Efficiency

2.2.4. Activated sludge treatment

2.2.5. Modification of the activated sludge process

2.2.5.1. F/M ratio

2.2.5.2. Sludge setting

2.2.6. Contact stabilization

2.2.7. Rotating biological contactors (RBCs)

2.2.8. Anaerobic digestion

#### 2.3. SUMMARY

#### 2.4. KEY WORDS

## 2.5. REVISION QUESTIONS

## 2.6. SUGGESTED READINGS

### 2.0. OBJECTIVS

After studying this unit, the learners will be able to understand:

- The various methods for the removal of inorganic dissolved solids from industrial wastewater.
- About the processes used to reduce the concentration of organic dissolved solid from industrial wastewater.

### 2.1. REMOVAL OF INORGANIC DISSOLVED SOLIDS

#### 2.1.1. Introduction

Little attention has been given to the removal of dissolved minerals from waste waters by waste treatment engineers, because minerals have been considered less polluting than organic matter and suspended solids. However, regarding the causes and effects of pollution, it is important to reduce the quantity of certain types of inorganic matter. Chloride, phosphates, nitrate and certain metals are examples of the significant inorganic dissolved solids. The various methods employed for removing inorganic matter are :

- i) Evaporation
- ii) Dialysis
- iii) Ion exchange
- iv) Algae
- v) Reverse osmosis
- vi) Miscellaneous

**2.1.2. Evaporation** :- This is a process of bringing wastewater to its boiling point and vaporising pure water. The vapor is either used for power production, or condensed and used for heating, or simply wasted to the

surrounding atmosphere. The minerals solids concentrate in the residue is reused either in production cycle or to be disposed of easily.

Chrome, nickel, and copper plating wastes may be reclaimed from the rinse tank by evaporation in glass-lined equipment or other suitable evaporators, and the concentrated solution returned to the plating system.

Efficiency of evaporation is directly related to heat-transfer rate-expressed in British thermal units per hour (Btu/hr)-through the heating surface. It is expressed as :

$$q = UA(t_s - t_w) = UA\Delta t$$

Where

$q$  = rate of heat transfer (Btu/hr)

$U$  = overall coefficient

$A$  = heating surface area.

$t_s$  = temperature of steam condensate

$t_w$  = boiling temperature of waste.

$\Delta t$  = overall temperature change between steam and waste.

**2.1.3. Dialysis** : It is the separation of solute by means of their unequal diffusion through membranes. It is most useful in recovering pure solutions for reuse in manufacturing processes for e.g. caustic soda in textile industry.

Dialysis work on the simple principle of passing a concentrated, impure caustic solution upward, counter current to a down stream water supply, from which it is separated by a semi-permeable membrane. The caustic soda permeates the membranes and goes into water more rapidly than the other impurities contained in the water.

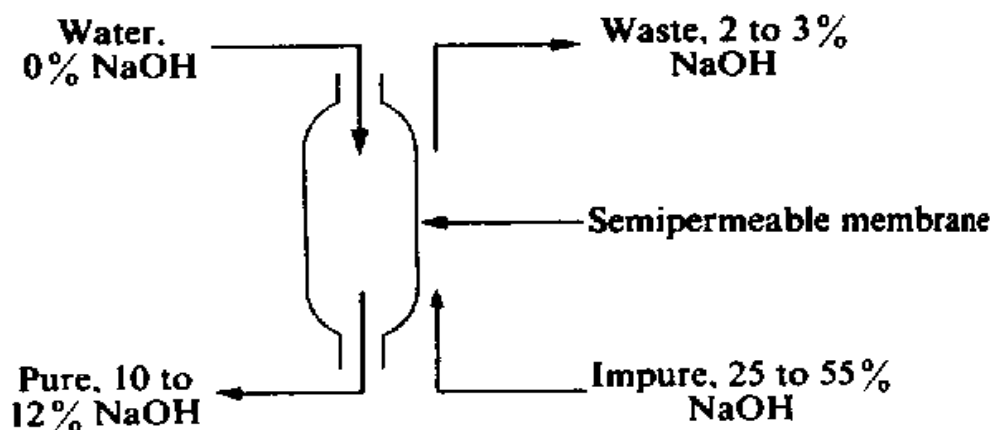


Figure 2.1. Typical dialysis flow diagram

The quantity of NaOH diffusing through the membrane diaphragm depends upon the time, the area of the dialyzing surface, the mean concentration difference and the temperature. These are expressed as

$$Q = KA t (\Delta C)$$

Where

K = overall diffusion coefficient.

A = area of dialyzing surface

t = time in minutes, and

$$\Delta C = \Delta C_{av} = \frac{(\Delta C_1 - \Delta C_2)}{2.3 \log_{10} \Delta C_1 / \Delta C_2}$$

where  $C_1$  and  $C_2$  are the difference in concentration between the two solutes at the top and bottom of the membrane diaphragm respectively.

Dialysis is an operation requiring very little operator attention and although its main role is to conserve raw materials and to reduce plant waste, at the same time it aids in waste treatment. With the introduction of acid resistant membranes, dialysis has been used successfully in the recovery of sulphuric acid in the copper, stainless steel and other industries. Some operation can recover as much as the 70 to 75% of the acid, but a recovery of as little as 20% may be justify the process. In

dialysis, the driving force of separation is natural diffusion because of concentration gradient. Electro dialysis is another form of dialysis in which the natural driving force is enhanced by the application of electrical energy. Electro-dialysis can achieve as much as 44 percent reduction in concentration of dissolved solids in industrial effluents.

**2.1.4. Algae** : The use of algae for removing minerals from waste water has been investigated. Although sedimentation and filtration do not remove any phosphorus, the algae actively growing in the ponds caused a reduction of about 42% of the phosphate content. *Chlorella* and *Scenedesmus* are most active algae in stabilized ponds; because they are very hardy.

**2.1.5. Reverse osmosis** : It is process for separating relatively pure water or some other solvent from a less pure solution. The solution is passed over the surface of a specific semi-permeable membrane at a pressure in excess of the effective osmotic pressure of the feed solution. The permeating liquid is collected as the product and the concentrated feed solution is generally discarded. The membrane must be (1) highly permeable to water (2) highly impermeable to solutes (3) capable of with standing the applied pressure without failure, (4) chemically inert, mechanically strong.

Although several types of membranes have been developed, two types of membranes are generally used in commercial equipment.

1. The first is a symmetric of skinned cellulose acetate membranes made in flat or Tubular forms.
2. The second type of membrane is an aromatic polyamide or polyamide hydrazide.

Reverse osmosis is an advanced unit operation in water treatment. Reverse osmosis membranes are capable of removing at least 90 per cent of the dissolved solids in water as well as organics, bacteria and others impurities.

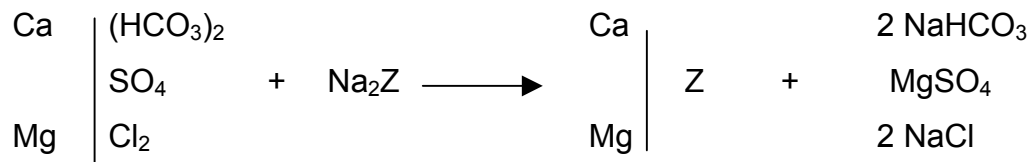
Osmosis can be defined as the spontaneous passage of a liquid from dilute to a more concentrated solution across an ideal semipermeable membranes which allows the passage of the solvent (water) but not the dissolved solids (solutes). The transport of the water from one side of the membrane to the other continues until the pressure ( $p$ ) is large enough to prevent any net transfer of the solvent (water) to the more concentrated solution. At equilibrium, the quantity of water passing in the either direction is equal, and pressure ( $p$ ) is then defined as the osmotic pressure of the solution having that particular concentration and make up of dissolved solids.

If a piston is placed on the more concentrated solution side of a semipermeable membrane and a pressure ( $P$ ) is applied to the solution, the following conditions can be realized :

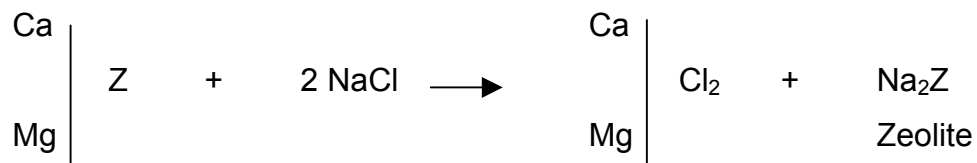
- (i)  $P$  is less than the osmotic pressure of the solution and solvent flows (in the same direction) spontaneously toward the more concentrated solution.
- (ii)  $P$  equals the osmotic pressure of the solution and solvent flows at the same rate in both direction; that is no net change in water levels.
- (iii)  $P$  is greater than the osmotic pressure of the solution and solvent flows from the more concentrated solution to the pure solvent side of the membrane leaving a higher concentration behind. This condition represents the phenomenon of reverse osmosis.

Substantial energy is needed to constantly pressurized the incoming salty water is one of the drawback of the reverse osmosis.

**2.1.6. Ion exchange :** Ion exchange is basically a process of exchanging certain undesirable cations and anions of the wastewater for sodium, hydrogen or other ions in a resinous materials. The resins, both natural and artificial are commonly referred to as Zeolites. The reactions involved is as



Where z is the symbol for the zeolite radical. When the ability of the zeolite bed to produce soft water is exhausted, the softener is temporarily cut out of service. It is then backwash to clean and hydraulically regrade the bed, regenerated with a solution of common salt; which remove the calcium and magnesium in the form of their soluble chlorides and restores the zeolite to its original conditions, rinsed free of these and the excess salt, and finally returned to service. Reaction is



**2.1.7. Miscellaneous methods** : Chemical precipitation or coagulation have been used to remove some inorganic matter from wastewater. Oxidation reduction chemical reactions are used in certain cases to alter inorganic matter and thus enhance its removal. For example, chromate must be reduced, usually with ferrous sulfate or sulfur dioxide under acid conditions, to the trivalent form and precipitate with lime and subsequent removed as a chromic-hydroxide sludge likewise. Cyanides must be completely oxidized, usually with chlorine under alkaline conditions, to split them up into harmless and volatile nitrogen gas and carbonate ions. The ultimate disposal of salts has always been and still remains a major problem to the environmental engineer. One solution is the addition of salt solutions with atleast 10 percent salt content to the warm surface water of lakes. The increased density of there warm surface waters tends to cause them to sink to the bottom, where they stay and serve as an reservoir for



hot water energy. The hot water energy is pumped out periodically to drive turbines to produce electrical energy. The hot water can also be used for space heating or for agricultural or industrial process.

## **2.2. REMOVAL OF ORGANIC DISSOLVED SOLIDS**

### **2.2.1. Introduction**

The removal of dissolved organic matter from waste waters is one of the most important tasks of the waste engineer. These solids are usually oxidized rapidly by microorganisms in the receiving stream, resulting in loss of dissolved oxygen and the accompanying ill effects of deoxygenated water. They are difficult to remove because of the extensive detention time required in biological process and often expensive equipment required for other methods. In general, biological methods have proved more effective since the microbes including bacteria and protozoa, consume the organic pollutants as food. They metabolize the biodegradable organics, converting them into carbon dioxide, water and energy for their growth and reproduction. To keep the microbe healthy and productive in their task of wastewater treatment, they must be provided with enough oxygen, adequate contact with the organic material in the effluent suitable temperatures and other favorable conditions. The design and operation of a biological treatment plant is accomplished with these factors in mind.

There are many varieties of biological treatments, each adopted to certain types of wastewaters and local environmental conditions such as temperature and soil type. Some specific processes for treating organic matter are :

- i) Lagooning in oxidation ponds.
- ii) Activated – sludge treatment
- iii) Contact stabilization
- iv) Trickling filter.
- v) Biodisc or Rotating biological contactor

vi) Anaerobic digestion.

**2.2.2. Lagooning** : Lagooning in oxidation ponds is a common means of both removing and oxidizing organic matter and wastewaters as well. The most common type of lagoon used for treating wastewaters is facultative pond. In a facultative pond, which is generally about 2m (6ft) deep, both aerobic and anaerobic biochemical reactions take place (Fig. 2.2).

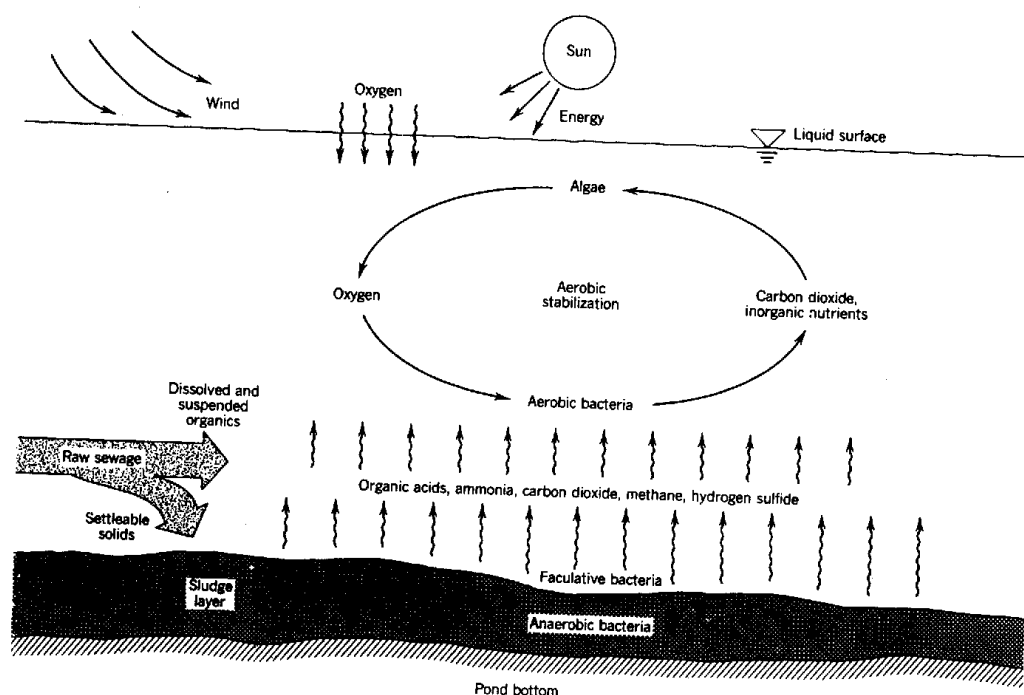


Figure 2.2. Schematic diagram of the complex biochemical reactions that take place in a wastewater stabilizations pond or lagoon.

Raw wastewater enters the pond eliminating the need for primary treatment. Organic solids that settle to the bottom decompose anaerobically, producing such substances as methane, organic acids, ammonia, carbon dioxide and hydrogen sulfide. In the liquid above the sludge zone of the pond, incoming organics and the products of anaerobic microorganisms are stabilized by facultative bacteria as well as by aerobic microorganisms. Facultative bacteria can grow in either aerobic or anaerobic environments. The average sewage detention time in a facultative pond may be 60 days or more. Oxygen is added to the

wastewater in the pond by wind action and mixing at the surface and from the day light metabolism of algae taking place. This oxygen supports the aerobic reactions. The mutually dependent relationship between the algae and bacteria in a stabilization pond is very important. Using energy from sunlight, the algae grow and multiply by consuming the carbon dioxide and other inorganic compounds released by the bacteria. The bacteria use both the oxygen released by the algae and the organics from the waste water.

Although the algae play an important role in the purification process in a lagoon, they can also cause a problem. When, they die, they impose a secondary organic loading on the pond. Another disadvantage is a seasonal one : algae are less effective in winter. Beside this, lagoons are used with increasing frequency in areas where land is readily available. The low construction, operational and maintenance cost and negligible energy costs offer distinct advantages for this natural purification system.

**2.2.3. Trickling filters :** The trickling filter is a type of fixed growth system : The microbes remain fixed or attached to a surface, while the wastewater flows over the surface to provide contact with the organics. Thus the trickling filter may be define as a process by which biological units are coated with slime growths from the bacteria in the wastes. These growths adsorb and oxidize dissolved and colloidal organic matter from the wastes applied to them.

A trickling filter consists basically of a layer or bed of crushed rock about 2 m (6ft) deep. It is usually circular in shape and may be built as large as 60 m (200 ft) in diameter (Fig. 2.3). Crushed stones may be of granite and limestone or sometime other materials, such as plastic rings, may also be used, because plastic media, are light weight, chemical resistant. The trickling filters are always preceded by primary treatment to remove coarse and settleable solids. The primary effluent is sprayed over the surface of the crushed stone bed and trickles downward through the bed to an under-drain system.

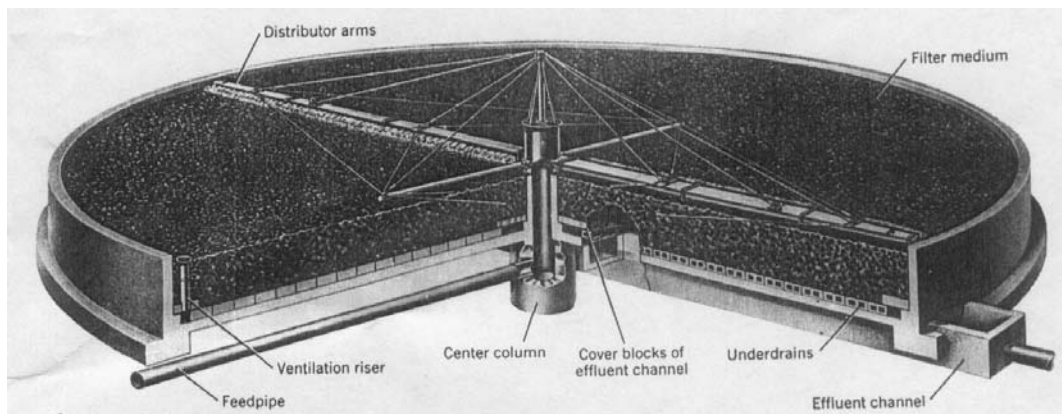


Figure 2.3. Cutaway view of a trickling filter

A rotary distributor arm with nozzles located along its length is usually used to spray the effluent, although sometime fixed nozzles are used.

The under-drain system serves to collect and carry away the waste water from the bottom of the bed and to permit air circulation upward through the stones as long as topography permits, the effluent flows from the primary tank to the trickling filter by the force of gravity, rather than by pumping.

As the primary effluent trickles downward through the beds of stones, a biological slime of microbes develops on the surfaces of the rocks. The continuing flow of the wastewater over these fixed biological growths provides the needed contact between the microbes and the organics. The microbes in the thin slime layer adsorb the dissolved organics, thus removing oxygen – demanding substances from the wastewater. Air circulating through the void spaces in the bed of stones provides the needed oxygen for stabilization of the organics by the microbes.

As the microorganisms grow and multiply, the slime layer gets thicker. Eventually, it gets so thick that the flowing wastewater washed it off the surfaces of the stones. This is called *sloughing*. The slime layer (humus) collected on the filter bed surfaces is sloughed off continuously.

There is a need to provide settling time for the trickling filter effluent, in order to remove the sloughed biological solids. These solids consists basically of billions of microorganisms that have absorbed the dissolved organics into their bodies.

The trickling filter effluent is collected in the under-drain system and then conveyed to a sedimentation tank called a secondary clarifier, which is similar in most respects to the primary clarifier, although there are differences in detention time, over flow rate, water load and other details.

To maintain a relatively uniform flow rate through the trickling filter and to keep the distributor arm rotating even during periods of low effluent flow, some of the wastewater may be re-circulated. In other words, a portion of the effluent is pumped back to the trickling filter inlet so that it will pass through the bed of stones more than once (See fig. 2.4.).

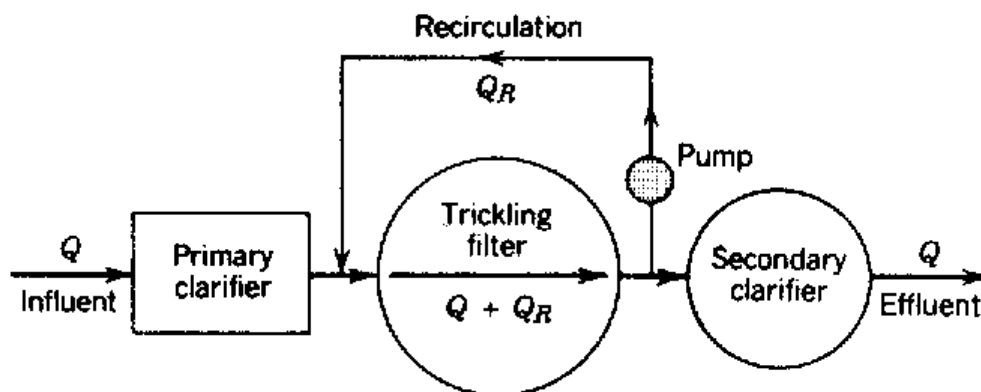


Figure 2.4. Schematic diagram showing recirculation of flow through a trickling filter.

Recirculation can also serve to improve the pollutant removal efficiency, it allows the microbes to remove organics that flowed by them during the previous pass through the bed. There are many recirculation patterns and configurations of trickling filter plants. One common pattern called direct recirculation is shown in the above diagram.

**2.2.3.1. Recirculation** : The amount of recirculation can vary. It is characterized by a *recirculation ratio*, which is the ratio of recycled flow to the raw wastewater flow. In formula form it is

$$R = \frac{Q_R}{Q}$$

Where R = recirculation ratio

$Q_R$  = recirculated flow rate

Q = Raw sewage flow rate

The recirculation ratio R, is generally in the range of 0.0 to 3.0

**2.2.3.2. Hydraulic load** : The rate at which the wastewater flow is applied to the trickling filter surface is called the hydraulic load. The hydraulic load includes the recirculated flow  $Q_R$  the total flow through the trickling filter is equal to  $Q+Q_R$ . In formula form, it is

$$\text{Hydraulic load} = \frac{Q+Q_R}{A_S}$$

Where Q = raw sewage flow rate

$Q_R$  = recirculated flow rate

$A_S$  = trickling filter surface area (plan view)

Hydraulic load may be expressed in terms of cubic meters per day per square meter of surface area, or  $\text{m}^3/\text{m}^2 \cdot \text{d}$ . It also may be expressed in terms of million gallons per acre of surface area per day, or mil gal/ac/d. A typical value for a conventional trickling filter is  $20 \text{ m}^3/\text{m}^2 \cdot \text{d}$ . (19 mil gal/ac/d).

**2.2.3.3. Organic (BOD) load** : The rate which organic material is applied to the trickling filter is called the organic or BOD load. It does not include the BOD added by recirculation. Organic load is expressed in terms of kilograms of BOD per cubic meter of bed volume per day or  $\text{kg}/\text{m}^3 \cdot \text{d}$ . A typical value for organic load on a trickling filter is  $0.5 \text{ kg}/\text{m}^3 \cdot \text{d}$ . In formula form, the organic load may be expressed as

$$\text{Organic load} = \frac{Q \times \text{BOD}}{V}$$

(S. I. metric units)

where Q = raw wastewater flow, ML/d (mgd)

BOD = BOD<sub>5</sub> in the primary effluent, mg/L (ppm)

V = volume of trickling filter bed, m<sup>3</sup>/(ft<sup>3</sup>)

**2.2.3.4. Efficiency** : BOD removal efficiency of a trickling filter unit depends primarily on the organic load, the recirculation ratio, and the temperature of the wastewater. Generally, the efficiency increases with decreasing organic load, increasing recirculation and increasing temperature. For example, with no recirculation (R=0) and a temperature of 20<sup>0</sup>C, a typical trickling filter will have an efficiency of about 60 per cent when the organic load is about 2 kg/m<sup>3</sup>.d. But if the organic load is 0.5 kg/m<sup>3</sup>.d. At the same conditions of recirculation and temperature, the efficiency will be 75 percent.

Furthermore, at the 0.5-kg/m<sup>3</sup>. d loading, a recirculation of R=1 instead of R=0 could raise the efficiency to about 80 percent. And if the temperature increased to 22<sup>0</sup>C, the efficiency would be raised to about 85 percent. Because of the marked effect of temperature on treatment efficiency, trickling filters in northern climates are often enclosed under fiberglass domes to provide protection against wind and snow and to reduced the rate of heat loss from the waste water.

#### **2.2.4. Activated sludge treatment**

The activated sludge process is probably versatile and effective of all wastewater treatment processes. It is quite effective in the treatment of domestic sewage, as well as a few industrial waste from large plants. The basic component of an activated sludge sewage treatment system include an aeration tank and a secondary settling basin or clarifier. Primary effluent is mixed with settled solids that are recycled from the secondary

clarifier and then introduced into the aeration tank. Compressed air is injected continuously into the mixture through porous diffusers located at the bottom of the tank along one side (Fig. 2.5).

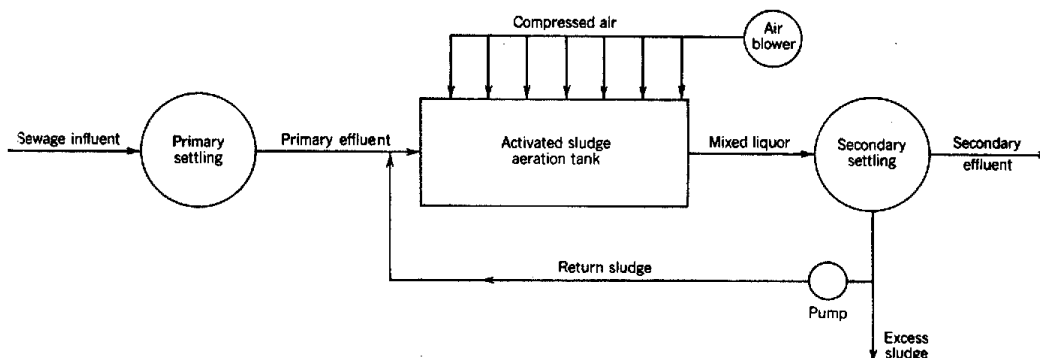


Figure 2.5. A flow diagram for a conventional activated sludge plant.

In the aeration tank, microorganisms consume the dissolved organic pollutants as food and convert organic materials in wastewater to microbial biomass and  $\text{CO}_2$  by using  $\text{O}_2$  provided in the air compressor (Fig. 2.6). The organic nitrogen is converted to ammonium ion or nitrate. Organic phosphorus is converted to orthophosphate. In addition to provide oxygen, the compressed air thoroughly mixes the microbes and wastewater together as it rapidly bubbles up to the surface from the diffusers.

The aerobic microorganisms in the tank grow and multiply, forming an active suspension of biological solids called *activated sludge*. The combination of the activated sludge and wastewater in the aeration tank is called the *mixed liquor*. In basic or conventional activated sludge treatment system, a tank detention time of about 6h is required for thorough stabilization of most of the organics in the mixed liquor.

After about 6h of aeration, the mixed liquor flows to the secondary or final clarifier, in which the activated sludge solids settle out by gravity. The clarifier water near the surface, called the supernatant is discharged



over an effluent weir, the settled sludge is pumped out from a sludge hopper at the bottom of the tank. This is illustrated in figure 2.6.

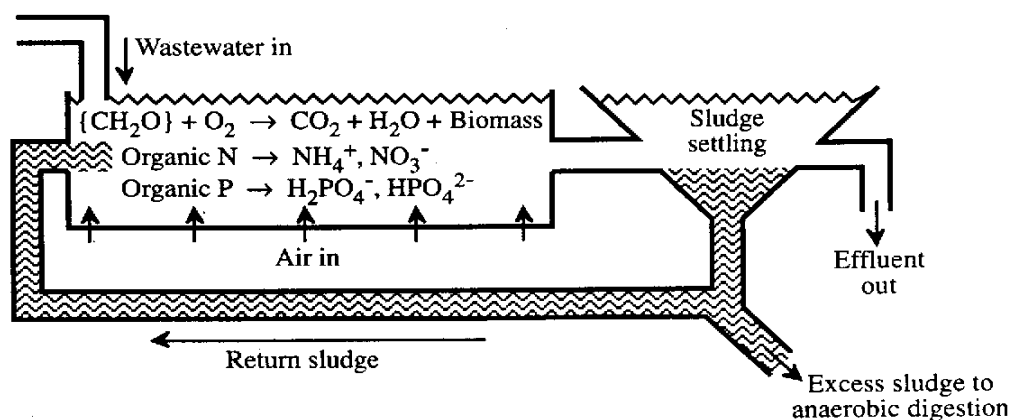


Figure 2.6. Activated sludge process

Recycling a portion of the sludge back to the inlet of the aeration tank is an essential characteristic of this treatment process. The settled sludge is in an active state. In other words, the microbes are well acclimated to the wastewater and given the opportunity, will readily absorb and decompose more organics by their metabolism.

By pumping about 30 percent of the wastewater flow from the bottom of the clarifier back to the head of the aeration tank, the activated sludge process can be maintained continuously. When mixed with the primary effluent, the hungry microbes quickly begin to absorb and metabolize the fresh food in the form of BOD causing organics. Since the microbes multiply and increase greatly in numbers it not possible to recycle or return all the sludge to the aeration tank. The excess sludge, called waste activated sludge, must eventually be treated and disposed off.

### 2.2.5. Modification of the activated sludge process

Several modification of the conventional activated sludge process have been developed. The objective is to supply the maximum of air to the sludge when it is in optimum condition to oxidize adsorbed organic matter.

In step aeration process, the sewage is introduced along the length of aeration tank in several steps; while the return sludge is introduced at the head. (Fig. 2.7). Such an arrangement result in the uniform air requirement along the entire length of tank. The process enables a large reduction in the size of aeration tank.

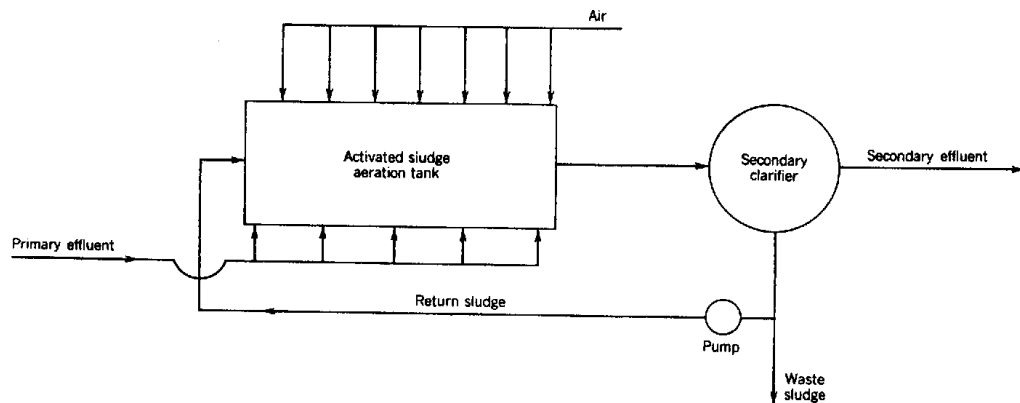


Figure 2.7. Flow diagram for the step aeration modification of activated sludge process.

There are two important distinctions between step aeration system and a conventional system. First, screened sewage is directed into the step aeration tank without any primary setting. Second, the detention time or aeration period is about 30 h, whereas the conventional system's detention time to about 6h.

**2.2.5.1. F/M ratio :** An important factor used in the design and operation of activated sludge systems is known as the food-to-microorganism (F/M) ratio. The food is measured in terms of kilograms (pounds) of BOD added to the tank per day. And since the suspended solids in the mixed liquor consist mostly of living microorganisms, the suspended solids concentration is used as a measure of the amount of microorganisms in the tank. This concentration is called the mixed liquor suspended solids, or MLSS.

The F/M ratio is an indicator of the organic load on the system, with respect to the amount of biological solids in the tank. For conventional

aeration tanks, the ratio is in the range of 0.2 to 0.5. It can be computed from the following formula :

$$F/M = \frac{Q \times BOD}{MLSS \times V}$$

Where

F/M = food-to-microorganism ratio, in units of kilograms of BOD per kilogram of MLSS per day

Q = raw sewage flow rate, ML/d (mgd)

BOD = applied 5-day BOD, mg/L (ppm)

MLSS = mixed liquor suspended solids, mg/L

V = volume of aeration tank, ML (million gal)

**2.2.5.2. Sludge setting** : In the activated sludge process, the organic pollutants are absorbed by the billions of microorganisms in an aeration tank. These microorganisms essentially are the activated sludge. But without proper clarification or separation of the sludge from the liquid portion of the mixed liquor, the treatments process will not be effective at all. For this reason, gravity settling in the secondary clarifier is a most important part of the activated sludge treatment system. If the sludge does not settle fast enough, some of it will be carried over the effluent weirs of the clarifier and cause pollution of the receiving body of water.

### **2.2.6. Contact stabilization**

It is another modification of the activated sludge process and is similar to some respects in the step-aeration process, but generally require less air and plant space than these other two methods.

In the contact stabilization process, raw waste is mixed by aeration with return activated sludge for only about 30 minutes. The short contact of 30 minutes is sufficient for the microorganisms to absorb the organic pollutants but not to stabilize them.

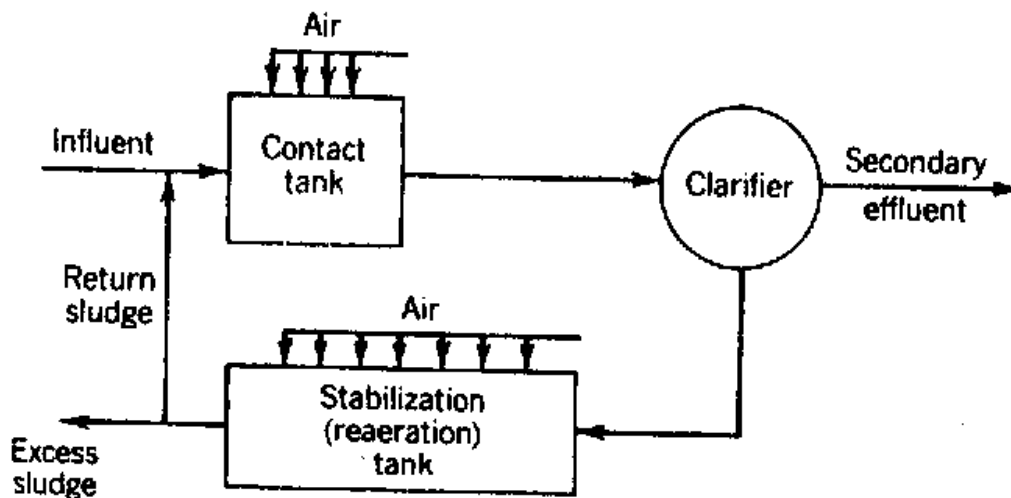


Figure 2.8. The contact stabilization modification of the activated sludge process.

After the short contact time, the activated sludge and raw waste mixture is then clarified by setting for about two hours in the clarifier after which the settled sludge (consists of activated sludge floc with absorbed impurities from raw water) goes through intense biological oxidation in the stabilization tank for an aeration period of one to two hours (Fig. 2.8). It then return to the mixing tank and is again mixed with raw waste, so that it can adsorb and absorb added organic matter and so on, in a continuous process. Excess or waste sludge can be taken from the system after either the clarifying or stabilizing steps, of an aerobic digestion or for dewatering on vacuum filter.

### 2.2.7. Rotating biological contactors (RBCs)

It consists of a series of large plastic discs mounted on a horizontal shaft. The light weight discs are about 3 m (10ft) in diameter and are spaced about 40 mm (1.5mm) apart on the shaft. The discs are partially submerged in settled sewage (primary effluent). As the shaft rotates, the disc surface are alternately in contact with air and with wastewater. Consequently, a layer of biological slime grows on each disc and the attached microbes that form the slime absorb the organic material in the

wastewater. This process is similar to the trickling filter system, except that the attached microbial growth is passed through the wastewater, instead of the wastewater being sprayed over the microorganisms.

The speed of rotation and the number of discs can be varied to achieve specific levels of pollutant removal. With several stages of discs, it is possible to remove nitrogenous as well as carbonaceous BOD. This is because growths of nitrifying bacteria predominate in the microbial population of the final disc stages.

In RBC system, there is no need to recycle sludge. But a secondary clarifier is needed to settle out the excess biological solids that slough off the discs as the slime layer thickens. Like the trickling filter, the efficiency of the biodisc process is adversely affected by low temperature. This is because the rate of metabolism of the microbes slows down when the temperature drops.

#### **2.2.8. Anaerobic digestion**

It is a process for oxidizing organic matter in closed vessels in the absence of air. The process has been highly successful in conditioning sewage sludge for final disposal. It is also effective in reducing the BOD of soluble organic liquid wastes such as yeast, slaughterhouse, dairy, and paper mill waste. Generally anaerobic processes are less effective than aerobic processes, mainly because of the small amount of energy that results when anaerobic bacteria oxidize organic matter. Anaerobic processes are therefore slow and require low daily loading and long detention periods. However, since little or no power need be added, operating cost is very low. Where liquid waste volume are small and contain no toxic matter and there are high percentages of readily oxidized dissolved organic matter, this process has definite advantages over aerobic system. The pH in the digester must be controlled to near the neutral point.

#### **2.5. SUMMARY**

Industrial wastewater contain various types of inorganic as well as organic dissolved solids. The various methods employed for removing inorganic matter are : evaporation, dialysis, ion exchange, adsorption, reverse osmosis etc. The organic dissolved solids are generally removed by biological methods in which the microbes including bacteria and protozoa, metabolize the biodegradable organics, converting them into CO<sub>2</sub>, water and energy for their growth and reproduction. There are many types of biological treatments for treating organic matter i.e., activated sludge processes, rotating biological contactor, trickling filter, contact stabilization, lagooning, oxidation pond and anaerobic digestion.

## **2.6. KEY WORDS**

### **Evaporation**

It is the process that heats the liquid, venting the vapours to the atmosphere and concentrating the pollutants into a slurry.

### **Electrodialysis**

A process that uses electrical current applied to permeable membranes to remove minerals from water.

### **Adsorbate**

The material being removed by the adsorption process.

### **Adsorbent**

The materials that is responsible for removing the undesirable substance in the adsorption process.

### **Adsorption**

The process by which chemicals or ions are held on the surface of a mineral or soil particles.

### **Activated sludge process**

The term used for a biological treatment of sewage waters in which micro-organisms are encouraged to grow under favourable conditions of

oxygenation and nutrients and in doing so, cleans the waters. Dissolved or suspended organic matter in the polluted water acts as nutrients for the microorganisms which feed on the organic pollutants and secrete enzymes to digest and oxidize the absorbed material and so purify the waste.

### **Osmosis**

It is the process where a solvent (e.g. water) moves from an area of low concentration to high across a semipermeable membrane. Which does not allow the dissolved solids to pass.

### **Reverse osmosis**

A pressure greater than the osmotic pressure is applied so the flow is reversed. Purewater will then flow through the membrane from the concentrated solution.

### **Ion exchange process**

A process used to remove hardness from water.

## **2.7. SELF ASSESSMENT QUESTIONS**

1. Name major methods where by inorganic ions can be removed.
2. Describe the principles and problem in using evaporation and its major use.
3. Describe the principle and problems in using dialysis and its major use.
4. What are algae used for and when are they most useful in waste treatment?
5. What miscellaneous methods are also available for removing minerals ?
6. What are the advantage and disadvantages of lagooning ?
7. Briefly describes the configuration and operation of a trickling filter unit.
8. What is the purpose of recirculation in a trickling filter?
9. What is meant by hydraulic and organic load ?
10. How does temperature affect a trickling filter and biological rotatory contactor operation?

11. Sketch a flow diagram of an activated sludge treatment process.
12. Briefly describe the configuration and operation of a biological rotatory contactor. In what way is it similar to a trickling filter system.
13. What is meant by the term mixed liquor ?
14. What is waste activated sludge?

## **2.8. SUGGESTED READINGS**

1. Bhatia, S.C. (2001). Environmental pollution and control in chemical process industries. Khanna Publishers, New Delhi.
2. Birdie, G.S. and Birdie, J.S. (2000). Water supply and sanitary engineering. Dhanpat Rai Publishing Company, New Delhi.
3. Chatterjee, A.K. (2001). Water supply, water disposal and environmental engineering. Khanna Publishers, New Delhi.
4. Doble, M. and Kumar Anil (2005). Bio-treatment of industrial effluent. Elsevier, New York.
5. Nathanson, J.A. (2000). Basic environmental technology – water supply, waste management and pollution control. IIIrd Edition. Printice Hall, New Delhi.
6. Rao, C.S. (2001). Environmental pollution control. Engineering. New Age International Publishers Limited, New Delhi.
7. Spellman, F.R. (2003). Handbook of water and wastewater treatment plant operation. Lewis Publication, CRC Press, New York.
8. Trivedi, P.R. and Ray, G. (2005). Industrial pollution control. Deep Publishing House, New Delhi.
9. Wang, L.K.; Hung, Y.T.; Lo, H.M. and Yapijabes (2006). Waste treatment in the process industries. Taylor and Francis, CRC Press, New York.
10. Woodard and Curran (2006). Industrial Waste treatment handbook. Elsevier, New York.



**SOLID WASTES****Dr. Asha Gupta**

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**STRUCTURE**

- 1.0 Objectives
- 1.1 Introduction
- 1.2 Types & sources of solid waste
  - 1.2.1 Municipal-Wastes
  - 1.2.2 Industrial wastes
  - 1.2.3 Hazardous Wastes
- 1.3 Properties of solid wastes
  - 1.3.1 Physical Properties
  - 1.3.2 Chemical Properties
- 1.4 Summary
- 1.5 Keywords
- 1.6 Self assessment questions
- 1.7 Suggested readings
- 1.8 Annexure-1

**1.0 OBJECTIVES**

- To introduce with concept of solid waste, types and sources of solid wastes and properties of solid wastes.

**1.1 INTRODUCTION**

Solid wastes are all the wastes arising from human and animal activities that are normally solid and that are discarded as useless or unwanted.

“Solid wastes” is the term now used internationally to describe non-liquid waste material, arising from domestic, trade, commercial, industrial, agriculture and mining activities and from the public services.

An appropriate definition of solid wastes is “matter in the wrong place,” implying that a material becomes waste only when a specific owner ceases to have a use for it. Yesterday’s newspaper is waste to the man who bought it, but it could be the raw material for a paper mill.

Solid wastes comprise countless different materials just as food wastes, packaging in the form of paper, metals, plastics or glass, discarded clothing and furnishings, garden wastes, and hazardous and radioactive wastes. The sources of solid wastes have been (1) municipal street sweepings, sewage treatment plant wastes, wastes from schools and other institutions, (2) domestic-garbage, rubbish, and occasional large wastes from homes, (3) commercial- from stores and offices, (4) industrial -from manufacturing plants, (5) mining- from coal mining, strip mining etc. and (6) agricultural.

## **1.2 TYPES & SOURCES OF SOLID WASTE**

In order to understand their composition and properties, and to chalk out their management programmes, treatment and disposal methods, solid wastes in general can be classified into three categories, namely, (i) Municipal wastes, (ii) Industrial wastes and (iii) hazardous wastes (including hospital wastes). The details with respect to their sub-categories and generation sources are described below:

### **1.2.1 Municipal-Wastes**

The solid waste generated in residential and commercial areas by activities other than industrial production are termed as “municipal wastes”. The municipal wastes include all kinds of solid and semi-solid

waste products e.g. food wastes, rubbish, ashes and residues, demolition and construction wastes, street sweeps etc. The description of these components is given in Table 1 which may serve, as a guide for municipal wastes, whereas sources for these wastes are given in Table 2.

It is important to note that the definitions of terms and the classifications used to describe the components of solid waste vary greatly in practice. There are different sources of the municipal solid waste: domestic, markets and community facilities etc. The amount of municipal solid wastes (MSW) generated is dependent on the public habits e.g. the per capita production of MSW is much greater in the USA in comparison to other, western as well as Asian countries. In India per capita MSW production in metropolitan cities are significantly high in comparison to the towns and villages. Average MSW production is about, 0.33 kg/capita/day in India.

TABLE 1: CLASSIFICATION OF MATERIALS COMPRISING  
MUNICIPAL SOLID WASTE

<b>Component</b>	<b>Description</b>
Food wastes	The animal, fruit or vegetable residues (also called garbage) resulting from the handling, preparation, cooking, and eating of foods. Because food-wastes are putrescible, they will decompose rapidly, especially in warm weather.
Rubbish	Combustible and non-combustible solid wastes excluding food wastes or other putrescible materials. Typically, combustible rubbish consists of materials such as paper, cardboard, plastics, textiles, rubber, leather, wood, furniture, and garden trimmings. Non-combustible rubbish consists of items such as glass, crockery, tin cans, aluminium cans, ferrous and nonferrous, metals, dirt, and construction wastes.
Ashes and residues	Materials remaining from the burning of wood, coal, coke, and other combustible wastes.

<b>Component</b>	<b>Description</b>
	Residues from power plant, normally are not included in this category. Ashes and residues are normally composed of fine, powdery materials, cinders, clinker, and small amounts of burned and partially burned materials.
Demolition and construction wastes	Wastes from razed buildings and other structures are classified as demolition wastes. Wastes from the Construction, remodelling and repairing of residential, commercial and industrial buildings and similar structures are classified as construction wastes. These wastes may include dirt, stones, concrete bricks, plaster, lumber, shingles, and plumbing, heating, and electrical parts.
Special wastes	Wastes such as street sweepings, roadside litter, catch-basin debris, dead animals, and abandoned vehicles are classified as special wastes.
Treatment plant wastes	The solid and semi-solid wastes from water, wastewater and industrial waste treatment facilities are included in this classification.

TABLE 2: GENERAL SOURCES OF MUNICIPAL SOLID WASTES

Source	Typical facilities, activities or locations where wastes are generated	Types of solid wastes
Residential	Single-family and multifamily dwellings, low, medium and high-rise apartments, etc.	Food wastes, rubbish, ashes, special wastes
Commercial	Stores, restaurants, markets, office buildings, hotels, motels, print shops, auto repair shops, medical facilities and institutions	Food wastes, rubbish, ashes, demolition and construction wastes, special wastes, occasionally hazardous wastes etc.
Open areas	Streets, alleys, parks, vacant lots, playgrounds, beaches, highways, recreational areas etc.	Special wastes, rubbish

Treatment	Water, wastewater, and industrial plant sites treatment processes etc.	Treatment-plant wastes, principally composed of residual sludges
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### 1.2.2 Industrial wastes

Industrial wastes are those wastes, which arise from industrial activities and typically include rubbish, ashes, demolition, construction wastes, special wastes and hazardous wastes. Industrial wastes generated from source of major industries along with generation processes are given in Table 3. The industrial grouping has been done as per Standard Industrial Classification (SIC).

TABLE 3: SOURCES AND TYPES OF INDUSTRIAL WASTES

<b>SIC group classification</b>	<b>Waste generating processes</b>	<b>Expected specific wastes</b>
Ordnance and accessories	Manufacturing, assembling	Metals, plastic, rubber, paper, wood, cloth, chemical residues.
Food and kindered products	Processing, packaging, shipping	Meats, fats, oils, bones, offal, shipping, vegetables, fruits, nuts and shells, cereals
Textile mill products	Weaving, processing, dyeing, shipping	Cloth and filter residues
Apparel and other finished products	Cutting, sewing, sizing, pressing	Cloth, fibres, metals, plastics, rubber

<b>SIC group classification</b>	<b>Waste generating processes</b>	<b>Expected specific wastes</b>
Timber and wood	Sawmills, millwork plants, wooden containers, miscellaneous wood products, manufacturing	Scrap wood, shavings, sawdust, in some instances metals, plastics, fibre, glues sealers, paints, solvents
Furniture, wood	Manufacture of household and office furniture, partitions, office and store fixtures, mattresses	Those listed under code 24 of SIC classification in addition to cloth and padding residues.
Furniture metal	Manufacture of household and office furniture, lockers, springs, frames	Metal, plastics, resins, glass, wood, rubber, adhesives, cloth paper
Paper and allied products	Paper manufacture, conversation of paper and paper-board, manufacture of paperboard boxes and containers	Paper and fibre residues, chemicals, paper coatings and fillers, inks, glues, fasteners
Printing and publishing	Newspaper publishing, printing lithography, engraving bookbinding	Paper, newsprint, cardboard, metals, chemicals, cloth and glues.
Chemicals and related products	Manufacture and preparation of inorganic chemicals (ranging from drugs and soaps to paint and varnishes and explosives)	Organic and inorganic chemicals, metals, plastics, rubber, glass, oils, paints, solvents, pigments.
Petroleum refining and related industries	Manufacture of paving and roofing materials	Asphalt and tars, felts, asbestos, paper, cloth, fibre
Rubber and miscellaneous plastic products	Manufacture of fabricated rubber and plastic products	Scrap rubber, plastics, lampback, curing compounds, dyes

<b>SIC group classification</b>	<b>Waste generating processes</b>	<b>Expected specific wastes</b>
Leather and leather products	Leather tanning and finishing, manufacture of leather belting and packing	Scrap leather, thread, dyes, oils, processing and curing compounds
Stone, clay, and glass products	Manufacture of flat glass, fabrication or forming of glass; manufacture of concrete, gypsum, and plaster products; forming and processing stone and stone products, abrasives, asbestos and miscellaneous non-mineral products	Glass, cement, clay, ceramics, gypsum, asbestos, stone paper, abrasives.
Primary metal industries	Melting, casting, forging, drawing, rolling, forming, extruding operations	Ferrous and non-ferrous metals scrap, slag, sand cores patterns, bonding agents
Fabricated metal products	Manufacture of metal cans, hand tools, general hardware non-electrical heating apparatus, plumbing fixtures, fabricated structural products, wire, farm machinery and equipment, coating and engraving of metal	Metals, ceramics, sand, slag, scae, coatings solvents, lubricants, pickling liquors
Machinery (except electrical)	Manufacture of equipment for construction, mining, elevators, moving stairways, conveyors, industrial trucks, trailers, stackers, machine tools, etc.	Slag, sand, cores, metal scrap, wood plastics, resins, rubber cloth, paints, solvents, petroleum products
Electrical	Manufacture of electric equipment, appliances, and communication apparatus, machining, drawing, forming, welding, stamping, winding, painting, plating, baking, firing operations	Metal scrap, carbon, glass, exotic metals, rubber, plastics resins, fibres, cloth residues.

<b>SIC group classification</b>	<b>Waste generating processes</b>	<b>Expected specific wastes</b>
Transportation equipment	Manufacturer of motor vehicles, truck and bus bodies, motor-vehicle parts and accessories, aircraft and parts, ship and boat building, repairing motorcycles and bicycles and parts etc.	Metal scrap, glass, fibre, wood, rubber, plastics, cloth, paints solvents, petroleum products
Professional scientific controlling instruments	Manufacture of engineering, laboratory, and research instruments and associated equipment	Metals, plastics, resins, glass, wood, rubber, fibres abrasives
Miscellaneous manufacturing	Manufacture of jewellery silverware, plated ware, toys, amusement, sporting, and athletic goods, costume brooms, brushes, signs, advertising displays	Metals, glass, plastics, resins, leather, rubber, composition, bone, cloth straw, adhesives

### 1.2.3 Hazardous Wastes

Waste that poses a substantial danger immediately or over a period of time to human, plant or animal life are classified as hazardous wastes. A waste is classified as hazardous if it exhibits any, of the following characteristics: (i) ignitability (ii) corrosivity (iii) reactivity or (iv) toxicity. Hazardous wastes have often been grouped into five categories namely, (i) radioactive substances (ii) chemicals (iii) biological wastes (iv) flammable wastes and (v) explosives. The chemical category includes wastes that are corrosive, reactive or toxic. The principal sources of biological wastes are hospitals and biological research laboratories.

In order to manage the generation/storage/transportational disposal of hazardous wastes in effective manner Ministry of Environment & Forests, Govt. of India, has identified 18 categories of hazardous solid wastes (Table 4) under Waste Management & Handling Rules, 1989 of EP



Act, 1986. A person handling any of these hazardous wastes, beyond stipulated quantity has to seek authorization or consent from regulatory agency primarily State Pollution Control Boards. Certain guidelines have also been laid down under these rules to be followed up by concerned occupier/generator/transporter/owner/operator (Annexure- 1).

TABLE 4: CLASSIFICATION OF HAZARDOUS WASTE CATEGORIES (SCHEDULE) ALONG WITH HAZARD CLASS LABELS

Waste categories number	Type of waste	Hazard class labels (As per motor vehicle Act, 1988)*
1	Cyanide waste	Poisonous
2, 3, & 4	Heavy metal bearing waste	Poisonous, corrosives, oxidising substance
5	Non-halogenated hydrocarbon including solvents	Combustible, poisonous, flammable liquid
6.	Halogenated hydrocarbon including solvents	Combustible, poisonous flammable liquid
7.	Waste from paint, pigment, glue, varnish and printing inks	Flammable solids, combustibles
8.	Wastes from dyes and dye intermediate containing inorganic chemical compounds	Poison, flammable solids, corrosive
9.	Wastes from dyes and dye intermediate containing organic chemical compounds	Poison, flammable solids, dangerous when wet
10.	Waste oil and oil emulsions	Flammable liquid
11.	Tarry waste from refining and tar residues from distillation or pyrolytic treatment	Flammable solids/liquid, combustible
12.	Sludges from waste water treatment including incineration ash	Poison, dangerous when wet

13.	Phenols	Poisonous
14.	Asbestos	Poisonous
15.	Wastes from pesticide and herbicide manufacturing and residues from formulation units	Flammable solids/liquid, poison, combustible
16.	Acid/Alkaline/Slurry wastes	Corrosive, oxidising substance
17.	Off-specification and discarded products	Poisonous
18.	Discarded containers and liners of hazardous and toxic chemicals and wastes	Dangerous

#### HOSPITAL WASTES

In recent years, emphasis on proper treatment and disposal of hazardous wastes particularly hospital wastes has gained momentum. It is because the amount of waste generated is increasing with growth of their services and the increased uses of disposal items. Ministry of Environment and Forests has also accorded due priority to hospital wastes and rules are being made for their effective and safe disposal. The solid wastes generated in hospitals can be categorised into- (a) general wastes, and (b) biomedical wastes.

- a) **General Wastes:** These include wastes from packing materials, garbage, kitchen waste which are not infectious or hazardous in nature. Such wastes can be handled along with the municipal wastes and disposed off at the common dumping sites..
- b) **Biomedical Wastes:** These are generated from the hospital activities including laboratories and other associated areas. They are potentially dangerous/infectious and can further be classified into following types

- i) *Chemical wastes*: The discarded material from diagnostic -and experimental work, cleaning, house keeping and disinfecting work comprise of chemical wastes.
- ii) *Pathological wastes*: The tissues, organic body parts and human foetuses form the pathological wastes. These may be infectious waste requiring special care and disposal
- iii) *Highly infectious wastes*: These contain pathogens in sufficient quantity and exposure to such wastes could result in diseases. This includes cultures and stock of infectious agents from laboratories, wastes from surgery and autopsy on patients with infectious diseases, wastes from infected patients in isolation wards, wastes from the animals inoculated with infectious agents etc.
- iv) *Sharp objects*: The needles, syringes, scalpels, blades, broken glasses, nails and other instruments used in minor surgeries comprise of sharp objects.
- v) *Pharmaceutical wastes*: These include the pharmaceutical products, drugs and chemicals that are returned from the wards or have spilled or contaminated or out dated or discarded for any other reasons.
- vi) *Pressurized containers*: The containers used for demonstration or instrumental purposes containing innocuous or inert gas and aerosol can form hazardous wastes that require specialized treatment and .disposal.
- vii) *Laboratory wastes*: The waste which arises during storage, use and spillage of drugs and chemicals in

laboratory may have toxic constituents and would require safe disposal.

### **1.3 PROPERTIES OF SOLID WASTES**

Information on properties of solid wastes is important in evaluating alternative equipment needs, systems and management programmes and plans especially with respect to implementation of disposal and resource/energy-recovery options.

#### **1.3.1 Physical Properties**

We, in general, go for following four physical properties for solid wastes to get the requisite meaningful information. These properties are (1) identification of individual component, (ii) analysis of particle size, (iii) moisture content and (iv) density. In order to understand these properties more closely in relation to individual component of solid wastes, the data given in Table-5 may be examined. It provides us typical composition (components) of municipal wastes along with data on their range of typical values of mass percent, moisture content percent and density.

Table 5 provides an indication of range of essential physical properties. However, to be accurate, particle size of a solid waste sample can be determined by sieve method, moisture content by weighing the sample before (mass a) and after heating it up at 77°C for 24 hours (mass b) and using following formula express moisture content as % of wet mass.

$$\text{Moisture Content \%} = \left\{ \frac{a - b}{a} \right\} \times 100$$

Since density represents ratio of mass and volume, it varies significantly with geographic location, season of the year and length of

time in storage. Hence figures for it presented above may not be true representative for certain cases/locations.

In general, it could be stated that following is the range of common physical properties of solids wastes on per capita basis, which may be valid on a world wide scale:

Weight	250-1000 gm
Volume	0.5-1.0 litre
Density	100-600 kg/mJ

In solid-wastes management, particularly municipal wastes, being voluminous and heterogeneous in nature, the problem generally being confronted is of proper sampling. However, samples are being taken from different points of solid wastes collection zone and physical properties like identification of individual components along with their mass and volume are determined to reach to a representative sample with range/average values for these properties. It is this representative sample, which is being further referred to determine chemical properties.

TABLE 5: COMMON COMPONENTS OF MUNICIPAL WASTES AND THEIR PHYSICAL PROPERTIES

Item/ Component	Mass Percent		Moisture Percent		Density kg/ mJ	
	Range	Typical	Range	Typical	Range	Typical
Food wastes	6-26	14	50-80	70	120-480	290
Paper	15-45	34	4-10	6	30-130	85
Cardboard	3-15	7	4-8	5	30-80	50
Plastics	2-8	5	1-4	2	30-130	65
Textiles	0-4	2	6-15	10	30-100	65
Rubber	0-2	0.5	14	2	90-200	130
Leather	0-2	0.5	8-12	10	90-260	160

Garden trimmings	0-20	1.2	30-80	60	60-225	105
Wood	1-4	2	15-40	20	120-320	240
Misc. organics	0-5	2	10-60	25	90-360	240
Glass	4-16	8	1-4	2	160-480	195
Tin cans	2-8	6	2-4	3	45-160	90
Nonferrous metals	0-1	1	2-4	2	60-240	160
Ferrous metals	1-4	2	2-6	3	120-1200	320
Dirt, ashes, brick etc	0- 10	4	6-12	8	320-960	480
Municipal solid wastes			15-40	20		
Uncompacted					90-180	130
Compacted (in compactor truck)					180-450	300
In landfill (compacted normally)					350-550	475
In landfill (well compacted)					600-750	600

### 1.3.2 Chemical Properties

Chemical properties of solid wastes are determined with a purpose to utilize them for beneficial use as enlisted below:

1. Recovery of materials such as paper, cardboard, plastic glass & rubber etc.
2. Recovery of metals: ferrous and non-ferrous (aluminium).
3. Generation of energy
4. Generation of energy and biogas.

In case of recovery of materials/metals, the percentage content of that particular constituent in solid wastes is an important criteria to make the recovery techno-economically feasible.

The generation of energy/biogas is dependent upon the calorific value (energy content) of the solid wastes in question and this energy content can be determined in two ways.

Energy content kJ/kg of each of the component generally present in municipal solid wastes are known figures as given in Table 6. Thus if we know the contents of the solid wastes in terms of their individual mass then energy content of that solid wastes can be calculated.

TABLE 6: TYPICAL DATA ON INERT RESIDUE AND ENERGY CONTENT OF MUNICIPAL SOLID WASTES

<b>Component</b>	<b>Inert residue* (percent)</b>		<b>Energy* (kJ/Kg)</b>	
	<b>Range</b>	<b>Typical</b>	<b>Range</b>	<b>Typical</b>
Food wastes	2-8	5	3,500-7,000	4,650
Paper	4-8	6	11,600-18,600	16,750
Cardboard	3-6	5	13,950-17,450	16,300
Plastics	6-20	10	27,900-37200	32,600
Textiles	2-4	2.5	15,100-18,600	17,450
Rubber	8-20	10	20,900-27,900	23,250
Leather	8-20	10	15,100-19,800	17,450
Garden trimmings	2-6	4.5	2,300-18,600	6,500
Wood	0.6-2	1.5	17,450-19,800	18,600
Misc. organics	2-8	6	11,000-26,000	18,000

Glass	66-99+	9.8	100-250	150
Tin cans	96-99+	98	250-1,200	700
Non-ferrous metals	90-99+	96		
Ferrous metals	94-99+	98	250-1,200	700
Dirt, ashes, brick, etc.	60-80	70	2,300-11,650	7,000
Municipal solid wastes			9,300-12,800	10,500

\*After combustion

+As discarded basis

If the energy values of the contents present in solid waste are not available, then energy content (Q in kJ/kg) of that solid waste can be determined by using following formula, (modified Dulong formula), for which chemical analysis in quantitative terms need to be carried out for carbon, hydrogen, oxygen and sulphur.

$$Q = 337C + 1428 \left( H - \frac{O}{8} \right) + 95 S$$

(Where C, H, O and S are percentage of carbon, hydrogen, oxygen and sulphur present in the solid wastes).

In addition to energy content, it is also important to determine moisture (loss at 105°C for 1 hr), volatile matter (additional loss on ignition at 950°C), ash (residue after burning), fixed carbon and fusing point of ash in evaluating energy recovery options. Biogas generation becomes a viable option, if the solid waste is rich in organic matter.



TABLE 7: PROXIMATE AND ULTIMATE CHEMICAL ANALYSIS OF  
MUNICIPAL SOLID WASTE

<b>Proximate analysis</b>	<b>Value, percent*</b>	
	<b>Range</b>	<b>Typical</b>
Moisture	15-40	20
Volatile matter	40-60	53
Fixed carbon	5-12	7
Non-combustibles	15-30	20
<b>Ultimate analysis (combustible components)</b>		
Carbon	40-60	47
Hydrogen	4-8	6
Nitrogen	0.2-1.0	0.8
Sulfur	0.05-0.3	0.2
Ash	1-10	6.0
Heating value+ of organic fraction, kj/kg	12,000- 16,000	14,000
Total kj/kg	8,000- 12,000	10,500

\*Biomass + As discarded basis.

## 1.4 SUMMARY

A solid waste is matter in wrong place and implies that a solid material becomes waste only when a specific owner ceases to have a use for it. Solid wastes are of different types such as municipal, industrial and hazardous. Different sources for these types of solid wastes are well explained in this chapter. Among physical properties of solid wastes such as identification of individual components, analysis of particle size, moisture content and density are discussed. Chemical properties of solid

wastes are determined with a purpose to utilize them for beneficial use such as recovery of materials such as paper, cardboard, plastic, glass and rubber etc., recovery of ferrous and non-ferrous metals; recovery of energy and generation of energy and biogas.

## 1.5 KEYWORDS

**Solid waste:** All wastes arising from human and animal activities that are normally solid and are discarded as useless or unwanted.

**Rubbish:** Solid waste excluding food wastes and ashes from homes, institutions and work places.

**Hazardous wastes:** Wastes that pose a danger immediately or over a period of time to human, plant or animal life.

**Ignitable:** Capable of burning or causing a fire.

**Toxic waste:** Any discarded material commonly from industrial or commercial process, capable of causing injury or deaths to living organisms.

## 1.6 SELF ASSESSMENT QUESTIONS

1. What do you mean by solid wastes?
2. Enumerate different types of solid wastes.
3. Define hazardous wastes. What are sources of these wastes?
4. How many types of wastes are produced in a hospital?
5. What are the sources of municipal wastes?

## 1.7 SUGGESTED READINGS

1. Vesilind, P.A. and William A (2003): Solid waste Engineering. Tata McGraw Hill, New Delhi.
2. Trivedi, P.R. and Gurdeep (2000): Solid waste pollution, Akashdeep Publisher, New Delhi.
3. Irena, T. (2004): Waste Management Series. Elsevier Publishers.
4. Plavy, H.S., Rowe, D.R. Technoanoglous, G. (1985): Environmental engineering. Tata McGraw Hill, New Delhi.

## **1.8 ANNEXURE-1**

### **Salient Features of the Guidelines**

The regulatory authorities are expected to accomplish the following in respect of implementing the guidelines

- I. GUIDELINES FOR OCCUPIER/GENERATOR OF HAZARDOUS WASTES
  1. To allow the Occupier/Generator to store a maximum quantity of 10,000 kilograms or a truck load whichever is less of hazardous waste on-site for a maximum period of 90 days. They may extend the storage period under unforeseen circumstances on case to case basis.
  2. The occupier/generator may be allowed to store their hazardous wastes only in closed specified containers in the designated protected area.
  3. The authorities should ensure that the occupier/generator sends a copy of the manifest to them as soon as the hazardous waste is shipped for ultimate treatment and disposal.
  4. To ensure that the occupier/generator disposes-their waste only in the notified disposal facilities.
  5. To inspect the on-site storage areas or proper storage.
- II. GUIDELINES FOR TRANSPORTATION OF HAZARDOUS WASTES
  1. To register the authorized transporters for transportation of hazardous wastes.
  2. To ensure that the occupier/generator transport their hazardous waste only in the specified transport vehicles.
  3. The transporters should be asked to train the drivers and helpers of hazardous waste transport vehicles to handle the wastes under emergency situations.

### III. GUIDELINES FOR OWNER/OPERATOR OF HAZARDOUS WASTE STORAGE, TREATMENT & DISPOSAL FACILITY

1. To issue license to the owner/operator of Hazardous Waste Management facility for storage, treatment and disposal after having satisfied with their technical, financial and managerial capabilities.
2. To allow such facilities on the approved sites.
3. To inspect the facility at the time of construction, operation and closure of landfill facility.
4. To inspect the hazardous waste storage areas for proper storage facilities and containment systems.
5. To identify and establish standards for Principal Organic Hazardous constituents (POHC) for stack emissions from incinerator.
6. To monitor the stack emissions, effluent and ground water quality regularly.
7. To approve emergency/contingency plan of the waste management facility.
8. To inspect the facility after any incident for appropriate measures taken in order to avert such incidents.
9. To check the records of the facility periodically.

To ensure that the copy of the manifest reaches the authorities after receiving the hazardous waste from the occupier/generator. The owner/operator should indicate the proposed treatment and disposal scheme to be followed for the hazardous wastes. The copy of the manifest should be linked with the copy of the manifest sent by the occupier/generator.

**SOLID WASTE MANAGEMENT**

**Dr. Asha Gupta**

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**STRUCTURE**

- 2.0 Objectives
- 2.1 Introduction
- 2.2 Materials flow in society
- 2.3 Methods of solid wastes management
  - 2.3.1 Reduction in raw materials usage
  - 2.3.2 Reduction in Solid-Waste Quantities
  - 2.3.3 Reuse of Solid-Waste Materials
  - 2.3.4 Materials Recovery
  - 2.3.5 Generation of energy or recovery of energy from conversion products
  - 2.3.6 Generation of Energy/Biogas
  - 2.3.7 Conversion into Useful Products (fertilizers & fuel pellets)
  - 2.3.8 Reduction of Solid Wastes Quantities (by incineration/pyrolysis)
  - 2.3.9 Disposal of Solid Wastes (land filling)
- 2.4 Summary
- 2.5 Keywords
- 2.6 Self assessment questions
- 2.7 Suggested readings
- 2.8 Appendices

## **2.0 OBJECTIVES**

- To understand materials flow in society and various methods used for management of solid wastes.

## **2.1 INTRODUCTION**

Recognizing that our world is finite and that the continued pollution of our environment will, if uncontrolled, be difficult to rectify in the future, the subject of solid-waste management is both timely and important. The overall objective of solid-waste management is to minimize the adverse environmental effects caused by the indiscriminate disposal of solid wastes, especially of hazardous wastes. To assess the management possibilities it is important to consider: Materials flow in society, reduction in raw materials usage, reduction in solid wastes quantities, reuse of materials, materials recovery, energy recovery and day-to-day solid wastes management.

## **2.2 MATERIALS FLOW IN SOCIETY**

An indication of how and where solid wastes are generated in a technological society is shown in the simplified materials-flow diagram presented in Fig. 1. Solid wastes (debris) are generated at the start of the process, beginning with the mining of raw materials. Thereafter, solid wastes are generated at every step in the process as raw materials are converted to goods for consumption. It is apparent from Fig. 1 that one of the best ways to reduce the amount of solid wastes to be disposed is to reduce the consumption of raw materials and to increase the rate of recovery and reuse of waste materials. Although the concept is simple, effecting this change in a modern technological society has proved extremely difficult.

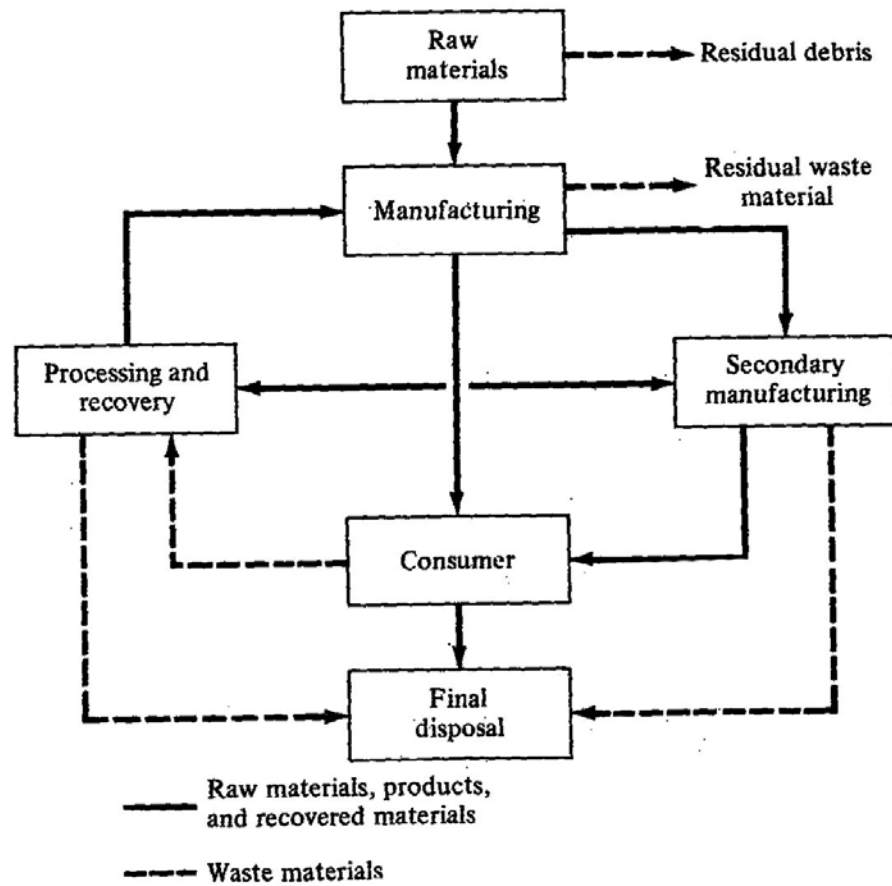


FIG. 1: GENERALIZED FLOW OF MATERIALS AND THE GENERATION OF SOLID WASTES IN SOCIETY

## 2.3 METHODS OF SOLID WASTES MANAGEMENT

Several methods can be used for the effective management of solid wastes. Few of them are as under:

### 2.3.1 Reduction in raw materials usage

The general relationships shown in Fig. 1 can be quantified relatively as shown in Fig. 2. To satisfy the principle of conservation of mass the input must equal the output. Clearly, if a reduction in the usage of raw materials is to occur either the input or output must be reduced. Raw materials usage can be reduced most effectively by reducing the quantity of municipal and industrial wastes. For example, to meet EPA mileage restrictions, American cars are now (1984) on the



average, 20 percent smaller than they were in the late 1950s and early 1960s. This reduction in size has also reduced the demand for steel by about 20 per cent. The reduced demand for steel has in turn resulted in less mining for the iron ore used to make steel. While most people would agree that it is desirable to reduce the usage of raw materials, others would argue that as the usage of raw materials is decreased jobs in those industries also are decreased.

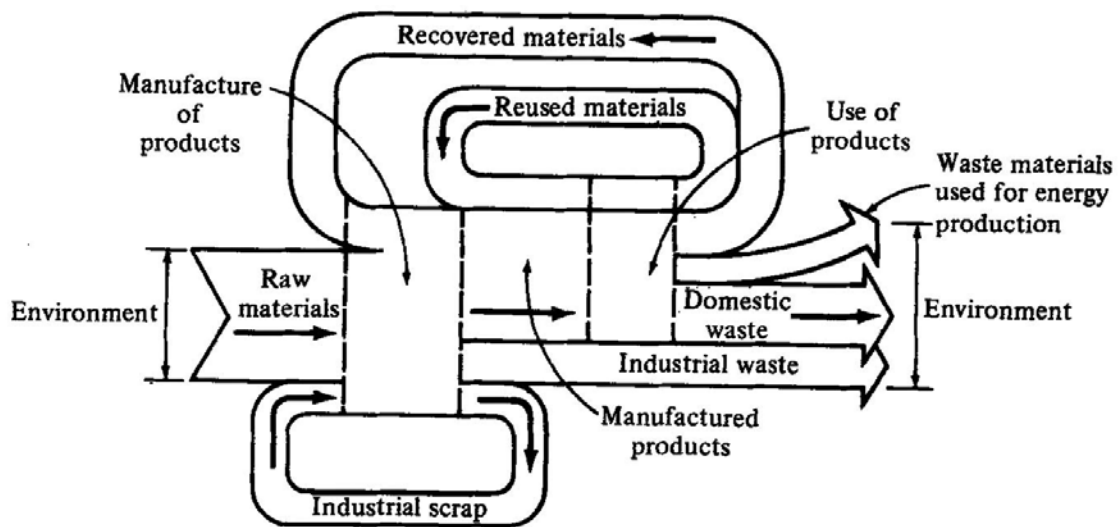


FIG. 2: FLOW OF MATERIALS IN A TECHNOLOGICAL SOCIETY

Clearly, the question of reduced raw materials usage is closely related to national policies. In more recent times, it has become clear that such usage is also related to the world economy. For example, the increase in oil prices has led to more usage of wood as an alternative source of energy.

### 2.3.2 Reduction in Solid-Waste Quantities

Reductions in the quantities of waste can occur in several ways: (1) the amount of material used in the manufacture of a product can be reduced, (2) the useful life of a product can be increased, and (3) the amount of materials used for packaging and marketing of consumer goods can be reduced. For example, the quantity of automobile tires now

disposed of on an annual basis could be cut almost in half if their useful life (or mileage) were doubled.

The many opportunities to reduce the quantities of municipal and industrial wastes, major reductions will occur with changes in our national priorities or as a result of the effects of external economic forces beyond our control. Although this view is somewhat pessimistic it adequately reflects the current situation with respect to the reduction of solid wastes. Further, this view is not meant to minimize the important efforts of individuals and concerned citizen groups.

### **2.3.3 Reuse of Solid-Waste Materials**

Reuse (recycling) of waste materials now occurs most commonly in those situations where a product has utility in more than one application. For example, the paper bags used to bring home groceries are used to store household wastes prior to placing them in the containers used for their storage for collection. Soup and vegetable containers are used to store used cooking grease. Newspapers are used to start fires in fireplaces; they are also tightly rolled and used as logs for burning.

While all of the above uses are important, their impact on the generation of solid wastes is minimal. A much larger impact would occur if beverage containers were to be recycled. It has been estimated that about 60 billion beer and soft-drink containers are sold annually in the United States. Referring to Table-1, it can be seen that glass and nonferrous metals (mostly aluminium cans) constitute 9 percent of the total waste stream. Recycling of these containers would have a major impact on the quantity of wastes that must be disposed on an annual basis.

### 2.3.4 Materials Recovery

A number of materials present in municipal and industrial solid wastes are suitable for recovery and reuse. Referring to the percentage distribution of the waste components reported in Table-3, it would appear that paper, cardboard, plastics, glass, nonferrous metals, and ferrous metals are the most likely candidates. With the exception of plastics, the above materials are those most commonly recovered from solid wastes. The estimated recovery of these materials is reported in Table-4. The materials/metals recovered from solids waste in United States even about 20 years back in 1975 are given in Table-4, which shows recovery is certainly beneficial.

TABLE 1: MATERIALS RECOVERY IN THE UNITED STATES IN 1975 BY CATEGORY

Material Category	Gross discards	Quantity	Percent
Paper	44.1	6.8	15.4
Brass	13.7	0.4	2.9
Metals	12.7	0.6	4.7
Ferrous	11.3	0.5	4.4
Aluminium	1.0	0.1	10.0
Other non-ferrous	0.4	0.0	0.0
Plastics	4.4	0.0	0.0
Rubber	2.8	0.2	7.1
Leather	0.7	0.0	0.0
Textiles	2.1	0.0	0.0
Wood	4.8	0.0	0.0
Other	0.1	0.0	0.0
Total non-food product waste	85.4	8.0	9.3
Food waste	22.8	0.0	0.0
Non-food waste	26.0	0.0	0.0
Miscellaneous inorganic wastes	1.9	0.0	0.0
Total	136.1	8.0	5.9

### 2.3.5 Generation of energy or recovery of energy from conversion products

Once the conversion products i.e. Thermal conversion products (that can be derived from solid wastes including heat, gases, a variety of oils, and various related organic compounds) and Biological conversion products (that can be derived from solid wastes include compost, methane, various proteins and alcohols, and a variety of other intermediate organic compounds) have been derived from solid wastes. The next step includes their 'storage and/or use. If energy is to be produced, then an additional conversion step is required.

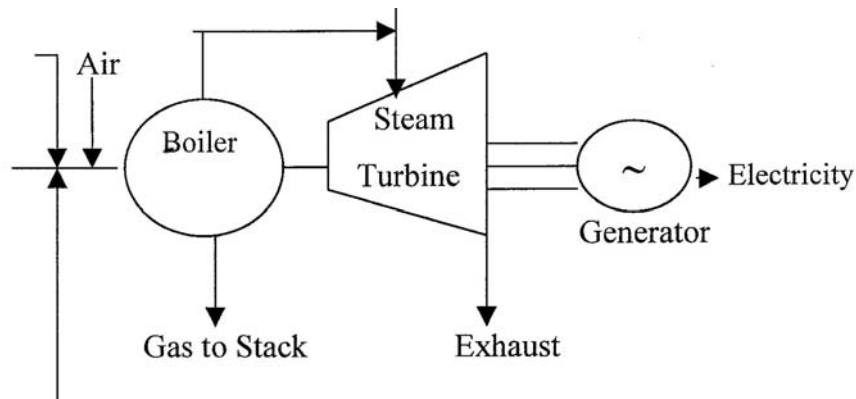
**Energy Recovery Systems:** The principal components involved in the recovery of energy from heat, steam, various gases and oils and other conversion products are boilers for the production of steam, steam and gas turbines for motive power, and electric generators for the conversion of motive power in to electricity. Typical flow sheets for alternative energy recovery systems are shown in Fig. 3. Perhaps the most common flow sheet for the production of electric energy involves no use of a steam turbine generator combination (see in Fig. 3). As shown, when solid wastes are used as the basic fuel sources, four operational modes are possible. A flow sheet using a gas turbine generator combination is shown in Fig. b. The low energy gas is compressed under high pressure so that it can be used more effectively in the gas turbine.

*Option-1:* Steam from shredded and classified solid wastes, or solids fuel pellets fired directly in boiler, or from solid wastes mass-fired in water-walled boiler. With mass-fired units auxiliary fuel may be required.

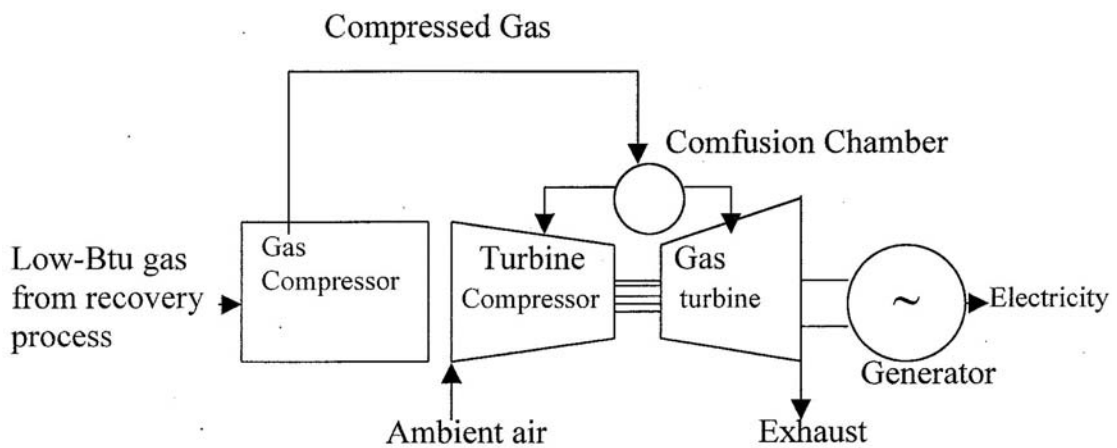
*Option 2:* Low- Btu gas from recovery process

*Option 3:* Low Btu gas methanated to pipeline quality

*Option 4:* Oil from recovery process



(a) Options with Steam turbine - generator



(b) Options with gas compressor gas turbine generator

FIG. 3: ENERGY-RECOVERY SYSTEMS

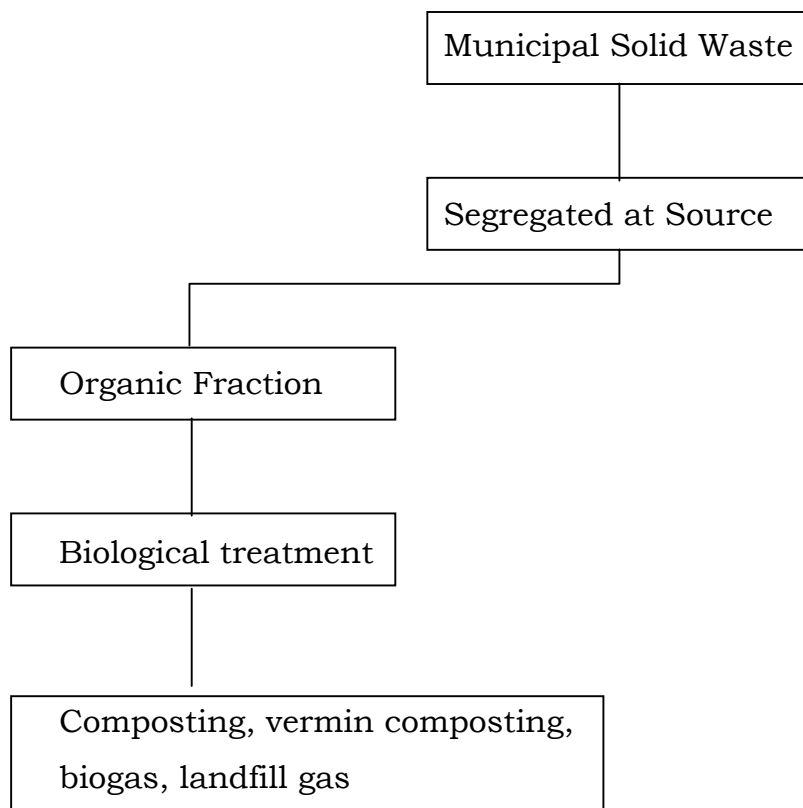
### 2.3.6 Generation of Energy/Biogas

As discussed in the section on chemical properties, the solid wastes could be utilized for generation of energy depending upon their calorific value (energy content) and other relevant parameters. The solid wastes rich in organic sites could also be used for generation of biogas. The common method adopted for generation of energy and biogas is anaerobic digestion. In some cases, energy is also being obtained through incineration of solid wastes as discussed ahead.

Anaerobic digestion is the process most frequently used for biological decomposition of organic wastes in the absence of oxygen. In

this process the organic wastes are hydrolysed, liquefied and gasified. As a result of it, a well mineralized residue is obtained. The gases liberated can be used for fuel and lighting. A mineralized residue can be used as rich manure. There is an appreciable saving in recurring costs because of utilization of this biogas, manure and electricity.

From several decades, tremendous progress has been made in converting animal waste into biogas and many community plants have gone into operation in rural areas of India. Khadi and Village Industries Commission have been marketing conventional plants, Gobar Gas Research Station set up in Lucknow, D.P. has been contributing in making more economical community plants. A similar research center has been working at Boriuti, Bombay, under the management of Kora Kendre. Individual or laboratory fronts studies are being conducted to tap biogas by treating municipal waste in similar way as gobar gas with some modifications in the technique. NEERI at Nagpur has also been successful in preparing laboratory plants.



### **2.3.7 Conversion into Useful Products (fertilizers & fuel pellets)**

Solid wastes rich in organic wastes could also be converted into organic fertilizer/manure through composting or by using vermiculture biotechnology. For composting, high vegetative-putrescible content wastes are ideally suitable for conversion into organic fertilizer rich in nitrogen, phosphate and potash. Besides rich manure, low investment and low price of compost are important propositions of this conversion method. However, in recent years, the vermiculture biotechnology particularly for converting solid wastes into organic rich manure, has gained momentum.

Vermiculture denotes culturing of earthworm. Thus “vermiculture biotechnology” is an aspect of biotechnology which involves the use of earthworm as versatile natural bioreactor for effective recycling of non-toxic organic solid wastes. Biodegradable wastes such as kitchen waste including all vegetable and non-vegetable materials, paper etc. could be used here. This technology has also now been indigenised.

The only pre-requisite of this process is to separate non-biodegradable materials like plastic, broken glass, metals etc. by keeping a separate container for them in the house or segregating at the dumping site before putting in the bin for treatment by this technique. The advantages of this technique are (i) the sites don't stink, (ii) good quality manure, (iii) low capital and operational cost and (iv) easiness to scale up.

It is a potential alternative which offers an ideal low solid waste-processing scheme with little capital and energy consumption. Also, it provides a valuable byproduct, the vermi-casting, a rich manure for use in agriculture and horticulture. Biotechnology involves efficient utilization of biosystems for economic and effective processing of materials to produce value added products.

In addition, solid wastes, depending upon their carbon content can be used to make fuel pellets through the process of pelletization. Fuel pellets are small cubes made out of garbage and the calorific value of these is quite close to coal. Therefore, these pellets can be a good substitute for coal, wood etc.

The cost efficient fuel pellets apart from replacing coal can also replace petroleum products for both domestic and industrial use. In India, an indigenous technology for this has already been developed by Department of Science & Technology, Govt. of India. Certain industrial wastes have even much wider areas of application.

### **2.3.8 Reduction of Solid Wastes Quantities (by incineration/ pyrolysis)**

Each option as mentioned above need to be worked out carefully to see whether some useful materials/metals can be recovered or solid wastes can be used for beneficial purpose (energy, biomass, fertilizer and fuel pellets etc.).

It may be that a part of solid wastes could easily be utilized for beneficial use, the remaining one or otherwise need to be disposed off, for which the most commonly used method is landfilling. As landfill is a continuous operation, it becomes necessary for effective solid waste management to reduce the quantum of solid wastes to be disposed off. The commonly used process to reduce the quantum of solid wastes is incineration/pyrolysis. Incineration refers to controlled burning of wastes at high temperature, may be 500-1200°C, in a furnace especially designed for this purpose and the product of incineration are ashes and gases. Whereas, pyrolysis refers to destructive distillation at high temperature in an oxygen free atmosphere. Hydrocarbons, such as cellulose, plastic and rubber, which are long chain compounds are main bulk of the solid wastes. On exposure to high temperature, these are



broken down into gases (like CO<sub>2</sub>, CO, H<sub>2</sub>, C<sub>2</sub>H<sub>4</sub>, CH<sub>4</sub>) and liquids (like tar, light oil, liquid and water soluble distillate) and solid tar. In addition, we can also obtain energy by using these hot gases to operate turbine generators/by employing work heat recovery systems.

**Operation of Incinerators:** All incineration systems can be generalised to include the following four basic unit operations:

1. In the first stage, the waste is prepared, stored and transported to the incinerator in a physical form conducive to the combustion process.
2. The incinerator furnace itself is designed on the basis of the physicochemical properties of the wastes being handled. Under controlled conditions of combustion, the toxic organics are thermally oxidised to form flue gases.
3. These gases are now cooled directly through quenching or dilution devices or indirectly by employing waste heat recovery systems and special types of boiler.
4. The final step removes the pollutants in the flue gases by subjecting them to venturi scrubbing, mass transfer operations, filtration etc. to reduce the emission to acceptable levels before letting them out into the atmosphere.

**Technological Advances in Incinerators:** Fluidized Bed Incinerators (FBI) to burn solid wastes have now come up as a simple and less expensive system to replace traditional rotary kiln incinerators. The costs of FBI's are generally one tenth the cost of rotary kiln incinerators.

Even a much cheaper alternative than FBI, that is, catalytic incinerators are gaining momentum for toxic fume destruction. Mobile

incinerators for industrial estate, where individual industries are too small to afford their own incinerator do provide an effective alternative to incinerate their low quantum of solid wastes which may be toxic.

**Efficiency of Incinerators:** Efficiency of incinerators, particularly at shut down, start-up and operational phase should be determined by percentage conversion of principal organic hazardous constituents (POHC).

Destruction & Removal efficiency (DRE) =

$$\frac{\left( \text{Mass feed rate} \right) - \left( \text{Mass emission rate} \right)}{\text{Mass feed rate of POHC}} \times 100$$

of POHC                      of POHC

This efficiency should be 99.9%.

### **2.3.9 Disposal of Solid Wastes (land filling)**

The main objective in management of solid waste is that the options which are techno-economically feasible need to be exercised so as to get the “bare minimum” wastes at the last step, which ultimately has to be disposed off usually at land fill site.

All such options referred above for handling of solid wastes after their generation are, in other words, also, meant for reducing their quantity. Thus such options including incineration are significant in minimization of problems that otherwise are confronted in disposal of voluminous wastes.

All types of solid waste when not put through any of the option meant for reducing their quantity effectively, pose problems in their disposal. Municipal and industrial wastes could be difficult to handle because of their voluminous quantity, whereas hazardous wastes may pose problems due to their toxicity.

The main problems that are generally faced in landfill disposal of such type of municipal and industrial wastes are availability of land itself, pollution of water and soil. Both these problems to some extent could be minimized if the landfill area is properly compacted and clay lined before dumping of wastes and these wastes are also compacted vis-a-vis with dumping.

In case of hazardous wastes, their toxicity in soil and water systems could be minimized effectively only when they are treated properly through physical/ chemical/biological methods before being dumped in landfill areas or disposed off in containers, in underground/ocean.

The disposal scenario of different types of solid waste, in summarized form, has been mentioned above. There are two important considerations which one must know before disposal of any type of solid wastes in landfill areas. These important aspects are (i) site selection and (ii) movement and control of gases and leachates in landfill area.

**Site Selection:** Factors that must be considered in evaluating potential solid waste disposal sites are summarized in Table 2. Results of engineering design, cost studies and environmental impact assessment are generally the deciding factors in site selection. The objectives in selection of these disposal sites are to (i) minimize health risks, (ii) minimize adverse environmental impacts, (iii) minimize costs and (iv) maximize public acceptability.

In order to minimize environmental impacts including contamination of surface/and ground water, certain specified areas need to be avoided for disposal of solid wastes and more particularly for hazardous wastes. These are:

- Areas enlisted in guidelines for siting of industries
- Existing zones of development

- Prime agriculture land
- Fresh water wetlands
- Visual corridors of scenic rivers
- Riverine and dam related areas

TABLE 2: FACTORS THAT MUST BE CONSIDERED IN EVALUATING POTENTIAL LANDFILL SITES

Factor	Remarks
Available land area	Site should have a useful life greater than 1 year (minimum value)
Haul distance	Will have significant impact on operating costs
Soil conditions and topography	Cover material must be available at or near the site
Surface water hydrology	Impact drainage requirements
Geologic and hydrogeologic	Probably most important factors in establishment of landfill site, especially with respect to site preparation
Climatologic conditions	Noise, odour, dust, vector, and aesthetic factors control requirements.
Local environmental conditions	Affects long-term management for site
Ultimate use of site	

#### **Movement and Control of Gases and Leachates in Landfill**

**Areas:** When the solid wastes are put into landfill area they undergo a series of biochemical decomposition, which prominently may be biological decay of organic materials either aerobically or anaerobically and chemical oxidation of waste materials etc. These series of interactions result in production of gases and liquids (leachates) in the landfill area.

The dominant gases in the landfill area are methane and carbon dioxide produced from anaerobic decomposition of the organic solid

waste compounds. Methane, being lighter than air, can easily escape out to atmosphere by providing proper venting system. However carbon dioxide being 1.5 times as dense as air, tends to move towards the bottom of the landfill. The downward movement of gases can be controlled by installing perforated pipes at the bottom (gravel layer) of the landfill.

Liquids released due to bio-chemical reactions of solid wastes in landfill areas are generally referred as leachates. In addition, it may be the liquid that has entered into the landfill area from external source (surface drainage, rainfall, ground water and water from underground springs). The liquids in landfill area or leachates can easily percolate through solid wastes in landfill area and can extract dissolved or suspended material from them.

Depending upon the soil characteristics, especially when the clay content is less, the leachates can percolate through the underlying strata, and can pollute the underground water which becomes a serious proposition in case of hazardous wastes. Thus it becomes necessary to collect and treat the leachates.

Collection and treatment of leachates is a costly affair, which may not be economically feasible for non-toxic municipal and industrial wastes. Thus for these wastes clay could be used for reducing or eliminating the percolation of leachates. Further the chemical and biological constituents of the leachates also get removed by filtering and absorptive action of material of the strata. However, sanitary land-fill method should used without fail for dumping of these wastes. In case of hazardous wastes, we have to collect and treat the leachates for which lining of landfill area and collection system are a prerequisite.

**Sanitary Landfill:** Sanitary landfilling is defined as a method of disposing of refuse on land without creating nuisance or hazards to

public health or safety, by utilizing the principles of engineering to confine the refuse to smallest practical area, to reduce it to the smallest practical volume and to cover it with a layer of earth at the conclusion of each day's operation or at such more frequent intervals as may be necessary. This method has the virtue of being a method of disposal which confers environmental improvement by restoring man-made surface dereliction such as disused surface of mineral excavation or improving natural contours like raising the level of low-lying land to enable it to be used for cultivation or industrial development.

**Design of Landfill Areas for Hazardous Wastes:** The landfill area for safe disposal of hazardous wastes should have two perfectly designed systems: the impervious linear system and leachate management system. The design aspects of the prevalent models are given here at Figures 4, 5 & 6. It is necessary that liner system should be of material that have appropriate chemical properties and sufficient strength and thickness to prevent any leakage/seepage due to accident/failure where as leachate system is designed to collect and remove the leachate generated from landfill. It should not get collapsed or degenerated/rusted due to interaction of hazardous wastes.

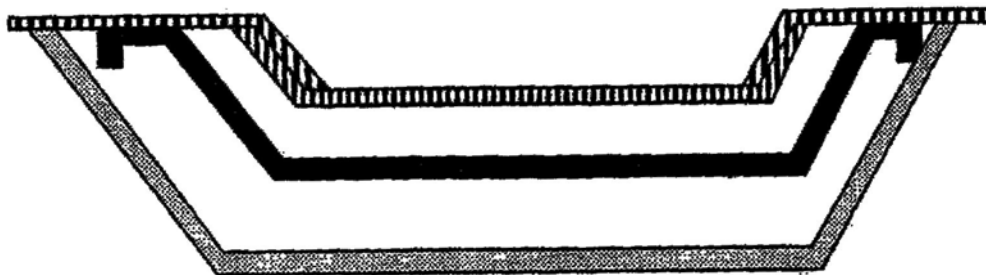


FIG. 4: SCHEMATIC DIAGRAM OF COMPOSITE DOUBLE LINER SYSTEM FOR A LANDFILL

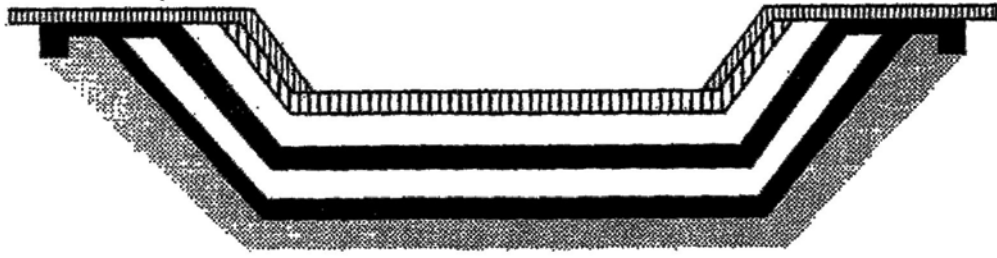


FIG. 5: SCHEMATIC DIAGRAM OF A HSWA DOUBLE LINER SYSTEM AND AN EPA SYNTHETIC/CLAY LINER FOR A LANDFILL

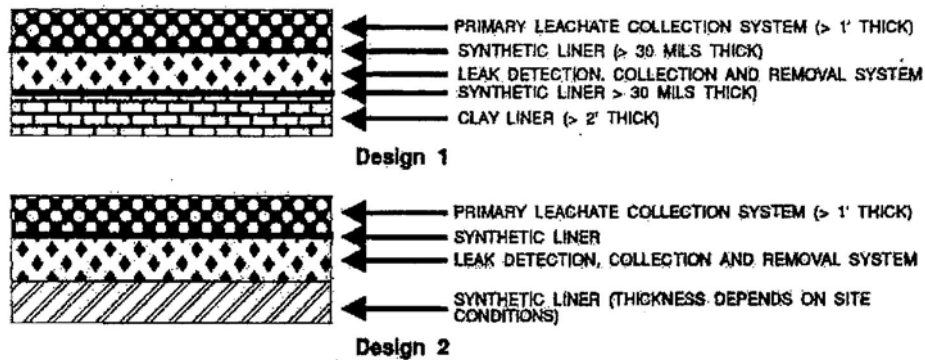


FIG. 6: SCHEMATIC DIAGRAM OF TWO DOUBLE LINER DESIGNS FOR LANDFILLS

## 2.4 SUMMARY

Materials flow in a society leads to generation of solid wastes. These solid wastes can be managed in different ways such as by reduction in raw materials usage, reduction in solid waste quantities, reuse of solid waste materials, recovery of material from solid waste, generation of energy/biogas from solid waste, recovery of energy from conversion products, conversion of solid wastes into useful products e.g. fertilizers and fuel pellets, reduction of solid waste by incineration/pyrolysis and then final disposal of solid waste in the form of land filling.

## 2.5 KEYWORDS

**Recycling:** Recovery and reuse of material from wastes.

**Resource:** Any commodity such as water, oxygen, chemical nutrients and territory required by living organisms in order to complete their life-cycle.

**Rubbish:** Solid wastes excluding food waste and ashes from homes, institutions and work places.

**Pyrolysis:** Transformation of a compound or material into one or more substances by heat alone.

**Fermentation:** Decomposition of organic material to alcohol, methane by organisms such as yeast or bacteria.

**Incineration:** Destruction of solid, liquid or gaseous wastes by controlled burning at high temperature.

**Incinerator:** A furnace for burning waste under controlled conditions.

**Industrial waste:** Unwanted materials from an industrial operation; may be liquid, sludge, solid or hazardous waste.

**Landfill:** Refers to the disposal of domestic or industrial waste in sites such as former quarries, disused mine workings and gravel or clay-pits.

## 2.6 SELF ASSESSMENT QUESTIONS

1. What do you mean by solid wastes management?
2. Which methods can be used in solid wastes management?
3. How will you reduce the quantity of solid wastes?
4. How solid wastes can be converted into fertilizers?



5. Which gas is produced from anaerobic digestion of solid waste?
6. How will you recover energy from conversion products?

## **2.7 SUGGESTED READINGS**

1. Vesilind, P.A. and William A (2003): Solid waste Engineering, Tata McGraw Hill, New Delhi.
2. Prabhakar, V.K. (2001): Solid waste management, Anmol Publishers, New Delhi.
3. Trivedi, P.R. and Gurdeep (2000): Solid waste pollution, Akashdeep Publishers, New Delhi.
4. Khyner, C. (1995): Waste management and resource recovery, Lewis Publishers, USA.
5. Wardowsky T.T. (2004): Waste Management Series, Elsevier Publication, USA.
6. Plavy, H.S., Donald, R. R. and Technoanoglous G. (1985): Environmental engineering, Tata McGraw Hill, New Delhi.

## 2.8 APPENDICES

### ANNEXURE-I

#### SOME INDUSTRIAL WASTES & THEIR AREAS OF APPLICATION

<b>Waste</b>	<b>Areas of Applications</b>
Flyash	Manufacture of Portland pozzolana cement
	Manufacture of pozzolana metallurgical cement, slag-flyash cement and low heat cement
	Raw material in OPC manufacture
	Manufacture of oil-well cement
	Making sintered fly ash light weight aggregates
	Cement/silicate bonded flyash/clay-binding bricks and insulating bricks.
	Cellular concrete bricks and blocks, lime and cement flyash concrete
	Precast flyash concrete building units.
	Structural fill for roads, construction on sites, land reclamation etc.
	As filler in mines, in bituminous concrete
	As plasticizer.
	As water reducer in concrete and sulphate resisting concrete.
	Amendment and stabilization of soil.
Blast furnace slag	Manufacture of slag cement, super sulphated cement, metallurgical cement.
	Non-portland cement
	Making expansive cement, oil-well, coloured cement and high early strength cement.
	In refractory and in ceramic as sital.
	As a structural fill (air coiled slag).
	As aggregates in concrete
Ferro-alloy and other Metallurgical slag	As structural fill
	In making pozzolana metallurgical cement.

<b>Waste</b>	<b>Areas of Applications</b>
Byproduct gypsum	In making of gypsum paster, plaster, plaster boards and slotted tiles.
	As set controller in the manufacture of Portland cement.
	In the manufacture of expensive or non-shrinking cement, super sulphated and anhydride cement.
	As a hydraulic binder
	As mineralizer
	Simultaneous manufacture of cement and sulphuric acid.
Lime sludge (phosphor- and sugar sludges)	Manufacture of lime pozzolama chalk, paper bricks/binders.
	As a sweetener for lime in cement manufacture
	For recycling in parent industry
	Manufacture of building lime
	Manufacture of masonry cement
	As a raw material for mini cement plants
Chromium sludge	As a raw material component in cement Manufacture
	Manufacture of coloured cement as a chromium bearing material.
Red mud	As a corrective material
	As a binder
	Making construction blocks
	As a cellular concrete additive
	Coloured composition for concrete
	Making heavy clay products and red must bricks
	In the formation of aggregate
	In making floor and all tiles
Pulp & paper	Lignin

ANNEXURE-II  
 APPLICABILITY OF PHYSICAL AND CHEMICAL PROCESSES TO  
 HAZARDOUS WASTES

Treatment process	Hazardous waste streams							Form of waste							
	Corrosive	Cyanides	Halogenated solvents	Nonhalogenated organics	Chlorinated organics	Other organics	Oily wastes	PCBs	Aqueous with metals	Queous with organics	Reactives	Contaminated soils	Liquids	Solids/sludges	Gases
Separation/ filtration	X	X	X	X	X				X	X			X		X
Chemical precipitation	X								X				X		
Photolysis									X				X		
Chemical oxidation/ reduction		X											X		
Dehalogenation			X		X			X				X	X	X	
Ozonation		X		X		X					X		X		X
Evaporation			X	X	X	X	X						X	X	
Solidification	X	X										X	X	X	

ANNEXURE-III  
MICROBIAL SPECIES FOR DETOXIFICATION OF SELECTED  
HAZARDOUS CHEMICALS

<b>Hazardous pollutants</b>	<b>Microbial species</b>
Phenols	Archromobacter, Alcaligenes, Acinetobacter, Arthrobacter, Azotobacter, bacillus cereus, Flavobacterium, Pseudomonas putida, P. aeruginosa, Nocardia, Canadida tropicalis, Trichosporon cuntaneum, Aspergillus, Penicillium and Neurospora
Dyes and dye intermediates	Bacillus sp., Flarabaderium sp., Pseudomonas sp.
Hydrocarbons	Escherichia coli, P. putida, P. aeruginosa and Candida
<b>PESTICIDES</b>	
DDT	P. aeruginosa
Linuron	B. sphaericus
2,4-D	Arthrobacter and P. cepacia
2,4,5-T	P. cepacia
Parathion	Pseudomonas sp., E. coli, P. stutzeri and P. aeruginosa
Cynide	Bacillus megatherium, B. subtilis, Pseudomonas sp., Arthrobacter sp., Nocardia, Fusarium solani, Aspergillus niger, Rhizopus nigricans and Rhizoctonia solani
Dioxins	Mutant strain of Pseudomonas sp. (NCIB9816 Strain II)
Pentachlorophenol (PCP)	Phanerochaete chrysosporium

**Noise and Air Pollution Control-I**  
**Dr. Krishan Kumar**

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**STRUCTURE**

- 1.0 Objectives**
  - 1.1 Introduction**
  - 1.2 Particulate Control Devices**
    - 1.2.1 Electrostatic Precipitators**
    - 1.2.2 Fabric Filters**
  - 1.3 Strategies for Noise Pollution Control**
    - 1.3.1 Silencers**
  - 1.4 Summary**
  - 1.5 Key words**
  - 1.6 Review Questions**
  - 1.7 Suggested readings**
- 

**1.0 Objectives**

To sensitize the students about the following major devices for the control of air and noise pollution

- Electrostatic precipitators
- Fabric Filters
- Silencers

**1.1 Introduction**

Air pollutants are of two types: gaseous and particulates. *Gaseous pollutants* are the pollutants in gas phase. They have the property of filling any available space until their concentrations reach equilibrium by diffusion. If the space is too large, the resulting concentration may be negligible. On the other hand, if space is small, the resulting concentration may reach significant levels e.g. concentrations of carbon dioxide due to continuous running of a motor vehicle in a closed garage.

Particulates are finely divided solids and liquids, such as dusts, fumes, smoke, fly ash, mist and spray.

- *Dusts* are small particles (1.0 to 1000 $\mu\text{m}$ ) of solids created from the break up of larger particles by operations such as crushing, grinding and blasting.
- *Fumes* are fine solid particles (0.03 to 0.3 $\mu\text{m}$ ) that condense from vapors of solid materials.
- *Smoke* is unburned carbon (0.5 to 1.0  $\mu\text{m}$ ) that results from the incomplete combustion of carbon containing substances.
- *Fly ash* (1.0 to 1000 $\mu\text{m}$ ) is the noncombustible particle admixed with combustion gases in the burning of coal.
- *Mists* are the particles (0.07 to 10 $\mu\text{m}$ ) formed from the condensation of liquid vapors.
- *Sprays* are particles (10 to 1000 $\mu\text{m}$ ) formed from the atomization of liquids through nozzles.

*Air pollution control* may be defined as the various measures taken to meet certain emission standards. These measures may include changes in processes/raw materials or modification of equipment. Another method is the installation of devices at the end of process equipment to treat the exhaust gas stream. These devices are called *air pollution control equipment*. In the coming section, we shall focus on the equipments that are used for the control of particulate matter.

## **1.2 Particulate Control Devices**

There are three general types of particulate control equipment: force-field settlers, fabric filters, and scrubbers. Force-field settlers are equipments that use a field of force for the collection of particulate. There are three types of force fields: gravitational, centrifugal, and electrical. Equipments that make use of gravitational

field for settling particulates are called *gravitational settling chambers*. Settlers that utilize centrifugal force for the collection of particulates are called *centrifugal collectors*. Devices, which utilize an electric field of force to collect particulates, are called *electrostatic precipitators (ESPs)*. *Fabric filters* are devices that use the principle of filtration for the removal of particulates. *Scrubbers* remove particulates from the exhaust gas stream by using water droplets for capturing them. Of all the devices mentioned above, electrostatic precipitators (ESPs) and the *fabric filters* possess the highest collection efficiencies. Particularly, they are very effective for the collection of small particulates that can be respired by human beings. Other devices mentioned above are often used for pretreatment of the effluent gas before directing it ESPs or fabric filters.

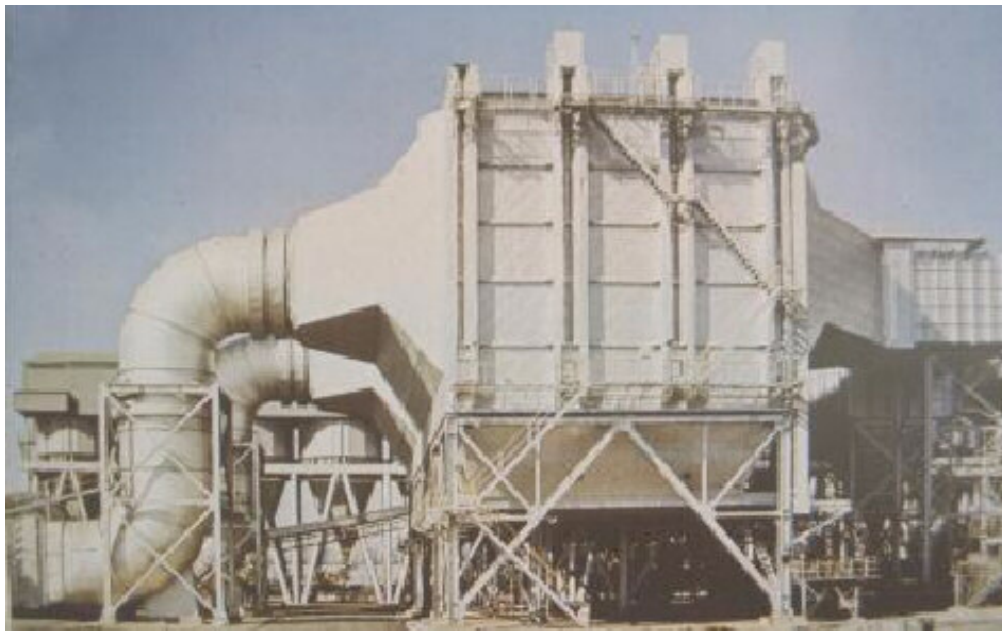
### **1.2.1 Electrostatic Precipitators**

Electrostatic precipitators make use of electric field force for the collection of particulate matter. This is done by applying a high voltage pulsating direct current to an electrode system consisting of a small diameter discharge electrode which is usually negatively charged, and a collection plate electrode which is grounded. This produces a unidirectional, nonuniform electric field whose magnitude is highest near the discharge electrode. A corona (a kind of glow) is generated near the discharge electrode, a condition that is essential for the process of charging. The electric field near the wire (discharge electrode) accelerates electrons present in the gas to velocities sufficient to cause ionization of the gas in the region near the wire. The ions produced as a result of the corona migrate toward the collection electrode and in the process collide with and become attached to particles suspended in the gas stream. The attachment of ions results in a build up of electric charge, the magnitude of which is determined by the number of ions attached.



The charge on the particles in the presence of an electric field results in a new force in the direction of the collection electrode. The magnitude of the force is dependent upon the charge and the field. This force causes particles to be deposited on the collection electrode where they are held by a combination of mechanical, electrical and molecular forces.

Once the particles are collected, they can be removed by coalescing and draining, in case of the liquid aerosols, or by periodic impact or rapping, in case of solid material. In case of rapping, a sufficiently thick layer of dust must be collected so that it falls into the hopper in coherent masses to prevent excessive re-entrainment of the particles in the gas stream.



**Fig.1.1 A typical ESP installed in an industrial set up**

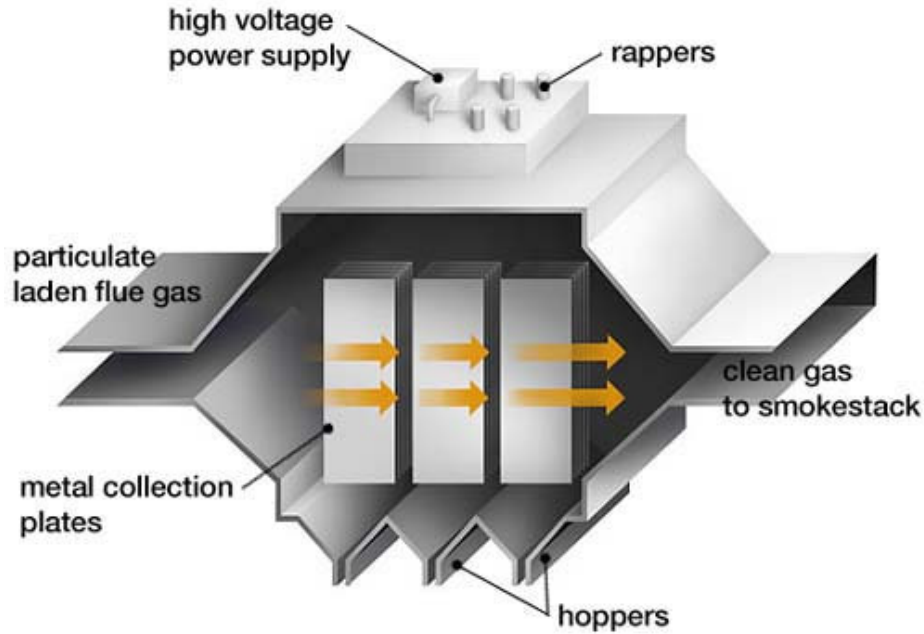


Fig 1.2 Schematic diagram of an Electrostatic Precipitator

### 1.2.1.1 Components of Electrostatic Precipitator

An electrostatic precipitator is composed of the following components:

(i) **Discharge Electrodes**

The discharge electrodes are thin round wires varying from 0.05 to 0.15 inch (0.13 to 0.38 cm.) in diameter. Most common designs use wires approximately 0.1 inch (0.25 cm) in diameter. The discharge electrodes consist of vertically hung wires supported at the top and held taut and plumb by the weight at the bottom. The wires are usually made from high-carbon steel, or of stainless steel, copper, titanium alloy and aluminum. The weights are made of cast iron and are generally 11.4 Kg or more. The weights at the bottom are attached to guide frames to help maintain wire alignments.

## **(ii) Collecting Electrodes**

Most precipitators use plate collection electrodes. The plates are generally made of carbon steel, stainless steel, or some kind of alloy, depending upon the gas stream conditions. The plates range from 0.02 to 0.08 inch (0.05 to 0.2cm) in thickness. Plates are spaced from 4 inch (10 cm) to 12 inch (30 cm) apart. Normal spacing for high efficiency units is 20-23 cm. Plates are usually 20 to 50 ft (6 to 15 m ) high.

## **(iii) Shells**

The shell structure encloses the electrodes and supports the precipitator component in a rigid frame. This is done to maintain proper electrode alignment and configuration. Providing supporting structures to the precipitator component is a very important aspect of design. Collecting plates and discharge electrodes are supported at the top so that elements hang vertically under the force of gravity. This allows the elements to expand or contract with temperature changes without binding or distorting.

## **(iv) Rappers**

Removal of accumulated dust deposit on collection electrode is accomplished by rapping. Dust deposits are dislodged by mechanical impulses or vibrations imparted to the electrodes. A rapping system is designed so that rapping intensity and frequency can be adjusted for varying operational conditions. Rapping of collection plates can be done by a number of methods. One of the popular methods of mechanical rapping uses hammers mounted on a rotating shaft. As the shaft rotates,

hammers drop by gravity and strike anvils attached to the collection plates. Rapping intensity is governed by the weight of hammers and length of the hammer mounting arm. The frequency of rapping can be changed by altering the speed of the rotating shafts.

**(v) Transformer-Rectifier Sets**

The T-R sets are required to control the strength of electric field generated between the discharge and collection electrodes. They step up the normal service voltages from 400 to 480V to approximately 50,000V and convert alternating to direct current.

**1.2.1.2 Efficiency Of Electrostatic Precipitator**

The efficiency of an electrostatic precipitator is given by the Deutsch-Anderson equation given below:

$$E = 1 - e^{(-wA / Q)}$$

Where E is the collection efficiency of the precipitator, A is the effective collecting plate area of the precipitator, Q is the gas flow rate of the precipitator and w is the drift velocity i.e. the velocity with which particles migrate towards the collecting electrode.

The efficiency of an electrostatic precipitator is greatly affected by the particle resistivity. Therefore, discussion about the performance of electrostatic precipitator would remain incomplete if no mention is made about it. Resistivity refers to the resistance offered by the collected dust layer to the flow of electric current. By definition, resistivity is the electrical resistance of a dust sample 1.0

cm<sup>2</sup> in cross-sectional area, 1.0 cm thick, and recorded in units of ohm.cm. Dust resistivity values can be classified roughly into three groups:

1. Between  $10^4$  and  $10^7$  ohm.cm – low resistivity
2. Between  $10^7$  and  $10^{10}$  ohm.cm – normal resistivity
3. Above  $10^{10}$  ohm.cm – high resistivity

Particles that have low resistivity are difficult to collect since they are easily charged and lose their charge upon arrival at collection electrode. This happens very fast and the particles can take on the charge of collection electrode. Particles thus bounce off plates and are re-entrained in the gas stream.

Particles that have normal resistivity do not rapidly lose their charge upon arrival at collection electrode. These particles leak their charge to ground and are retained on the collection plates by intermolecular adhesive and cohesive forces. This allows a particulate layer to build up, which is then dislodged into hopper through rapping. At this range of resistivity (i.e.  $10^7$  to  $10^{10}$  ohm.cm ), therefore, particles are collected most efficiently.

Particles that exhibit high resistivity are difficult to charge. Once they are finally charged, they do not readily give up the acquired negative charge upon arrival at the collection electrode. As the dust layer builds up on the collection electrode, the layer and the electrode form a high potential electric field.. This produces a condition called as back corona which produces small holes or craters in the dust layer, from which back corona discharges occur. Positive ions are generated within the dust layer and are accelerated toward the negative (discharge) electrode. This counteracts the process of ion generation at the discharge electrode and thus results in the reduction of collection efficiency.

### 1.2.2 Fabric Filters

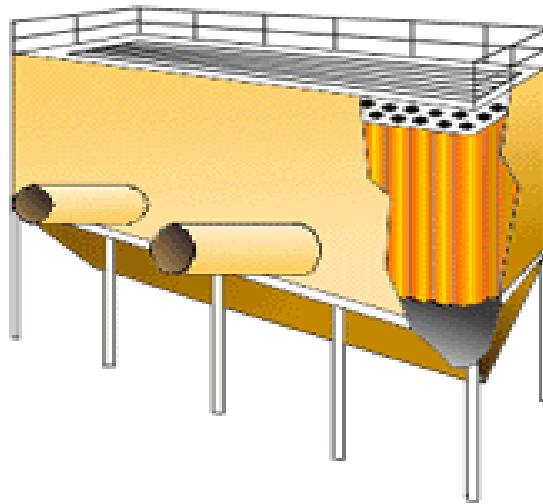
Fabric filters remove dust from a stream of gas by means of a porous fabric and a cake of dust as the filter media. These systems are commonly called as *baghouses* since the fabric is usually configured in cylindrical bags installed within a housing. The basic principle of baghouse operation involves the removal of dust from the dust laden gas by passing the dirty gas through a filtration medium. The cleaned gas emerges from one side of the medium while the dust is collected on the other side. Periodically, the collected dust is removed from the fabric.

The type of filter fabric used depends on the temperature and acidity of the gas stream, the characteristics of the dust, the gas-to-cloth filtration ratio, and the type of bag cleaning used.

Because all baghouses impose extra pressure drop on any operating process, a fan, blower, or compressor of some kind must be used to draw the process gases through the system. Usually, such devices are installed on the baghouse outlet, which is the clean side of the filtration process. This location has the advantage that it does not subject the fan to the dust so that the possibility of dust leakage into the clean gas coming out of the baghouse is reduced. This becomes particularly important when the dust is toxic.

There are a number of mechanisms through which the fabric filter traps the dust. Interception takes place when a particle traveling along a stream line in a gas stream approaches a fiber in the filter. The path of the particle is such that it strikes the fiber and gets stuck on it. In case of inertial impaction, a gas stream bends its direction if it comes across a fiber in its path. However, the dust particle being heavy, can not change its path (due to the property of inertia) and bangs the fiber where it gets stuck. This collection mechanism is effective for particles about  $10\mu\text{m}$  or larger. For particles below  $10\mu\text{m}$ , this is not a very effective mechanism.

For smaller particles, there is another mechanism that is effective. This is the process of diffusion. When the particles are too small, their motion can be affected by collisions with gas molecules. Frequent collisions with gas molecules make the path of a small particle erratic or random. The random motion of these small particles continues until they bump into the fiber and collected. Electrical entrapment can be another mechanism through which particles are collected in a fabric filter. Often, fibers and particles, both are charged. If these charges are of opposite sign, the particles are attracted to the fiber and collected on it. Another mechanism is sieving in which the particles larger than the pore size of the fabric cannot pass through the fabric. Sieving is a very important mechanism particularly after the building of dust cake on the surface of fabric. Without the dust cake, the efficiency of a fabric filter would be just 60 to 70%. It is the dust cake on the surface of the fabric, which reduces the pore size and thereby, increases the efficiency of a fabric filter to 99 percent.



**Fig. 1.3 A typical baghouse assembly**

### **1.2.2.1-Types of Fabric Filters**

Fabric filters can be classified into different groups in a number of ways. One such is to group the fabric filter designs by their cleaning methods. There are three major cleaning methods: shakers, reverse-air, and pulse jets. Another approach is to group fabric filters as per their capacity to deal different volumes of exhaust gases. There are three groupings: low volume, medium volume and high volume fabric filters. Yet another way is to classify the fabric filters according to the type of filter media they use i.e. woven or felted. Still another way is to categorize on the basis of temperature applications i.e. high temperature ( $>400^{\circ}\text{F}$ ), medium temperature ( $200$  to  $400^{\circ}\text{F}$ ) and low temperature ( $<200^{\circ}\text{F}$ ) applications group.

### **1.2.2.2-Cleaning Methods of Fabric Filters**

#### **(i) Shakers**

Shakers remove the collected dust from the surface of bag by mechanically shaking it. This is done manually in small dust collectors. In large size collectors, this process is motorized. The bag is generally open at the bottom and close at the top where it is attached to the shaking mechanism. In this configuration, the dust is collected on the inner sides of the bags. Shaking is done at a frequency of several cycles per second with the amplitude of a fraction of an inch to a few inches. The duration of shaking may be 30s to a few minutes. Common bag diameters are 5, 8 and 12 inches. The operation of shaking is performed in the off-stream mode.



**(ii) Reverse\_Flow Cleaning**

Reverse-air cleaning involves the removal of dust from the bags by backflushing them with a low-pressure reverse flow. In the case of high temperature applications, the just cleaned hot gas is employed to backflush rather than the ambient air. Woven filter media are generally employed in conjunction with reverse-air cleaning. Dust is collected on the inner side of the bags, which are closed at the bottom and open at the top. Most often, reverse flow systems are comprised of isolatable compartments. Normally, cleaning is done one compartment at a time. Duration of cleaning may vary from 1-2minutes. Cleaning is performed in the off-stream mode. Common bag diameters are 8, 12 inch.

**(iii) Pulse Jet Cleaning**

Pulse-jet cleaning employs high pressure compressed air, with or without a venturi, to backflush the bags vigorously. This method creates a shock wave that travels down the bag, knocking the dust away from filter medium. This method is generally employed in conjunction with felted filter media. The duration of cleaning is lower than that of other two methods. The pulse/shock wave lasts only for a fraction of a second. The baghouse is often not subdivided into compartments when pulse-jet cleaning is employed. The bag is closed at the bottom and open at the top. Dust is collected on the outside of the bag. Usually, a row of bags is cleaned simultaneously by introducing compressed air briefly at the top of each bag.

**1.2.2.3-Baghouse Selection**

A baghouse is selected on the basis of certain basic information about the process, the gas stream, and the dust to be collected. Following are the

factors that go behind the selection of a baghouse for a particular application:

- (i) Description of Application – What is the application? It is important to know fully the application for which the fabric filter is required.
- (ii) The gas volume - An important aspect is the gas flow rate to be filtered. Normal gas flow, as well as surges and maximum flows, must be established in order for a properly sized baghouse.
- (iii) The gas temperature – Maximum and minimum temperatures determine to a large degree the selection of bag fabric and other materials of construction.
- (iv) Chemical properties of the gases – It is important to identify the corrosive gases, combustible gases, and condensable vapors at inlet conditions. These inputs can greatly influence the selection of fabric and materials of construction.
- (v) Description of dust – Knowledge of dust concentration (grains per cubic feet of gas), properties of dust such as particle size distribution, shape, chemical composition, tendencies to agglomerate or develop electrostatic charges, abrasive characteristics, and bulk density are all very important factors in the selection of baghouse and auxiliary equipment.
- (vi) Available space – Availability of space is another important criterion that determines the size of a baghouse to be installed for a particular application.
- (vii) Other equipment in the dust collection system – The dust collection system may include other equipment, which may influence the selection of baghouse.

Selection of filter media is another very important aspect of baghouse selection. The filter media should be able to withstand temporary heat surges. Depending upon the specific applications, a particular filter media may be selected. The fiber must also be able to resist degradation from exposure to acids, alkalies, solvents or oxidizing agents found in the dust laden gas stream. Dimensional stability of the filter medium is another important factor. The fiber may shrink or stretch within the application environment. However, these effects must be controlled to maintain the dimensional stability of the fiber. Finally, cost of the fiber is a very important factor in the selection of filter medium. Generally, the least costly selection that satisfies the above mentioned requirements, is preferred. Table 1.1 presents the characteristics of some of the widely used filtration media.

**Table 1.1- Characteristics of some common fabric filter media.**

<b>Fabric</b>	<b>Max. Temp.</b>	<b>Acid Resistance</b>	<b>Fluoride Resistance</b>	<b>Alkali Resistance</b>	<b>Abrasion Resistance</b>
Cotton	180°F	Poor	Poor	Good	Very Good
Polypropylene	200°F	Excellent	Poor	Excellent	Very Good
Polyester	275°F	Good	Poor to Fair	Good	Very Good
Nomex	400°F	Poor to Fair	Good	Excellent	Excellent
Teflon	450°F	Excellent	Poor to Fair	Excellent	Fair
Fiberglass	500°F	Fair to Good	Poor	Fair to Good	Fair

#### **1.2.2.4 Performance of a Baghouse**

Despite several sophisticated formulae that have been developed, there is no satisfactory set of published equations that allows a designer to calculate the efficiency of a prospective baghouse. One parameter that helps the baghouse designers is the Gas-to –Cloth (G/C) ratio. This is a measure of the amount of gas driven through each square foot of fabric in the baghouse. It is given in terms of the number of cubic feet of gas per minute passing through one square foot of cloth. Factors influencing the appropriate G/C ratio for a baghouse include the cleaning method, filter media, dust size, dust density, dust loading, and other factors that are unique to each situation. Because of their variability, however, it has not been possible to satisfactorily quantify each of these factors for application. One approach to overcome this problem is to collect all empirical data available for the source in question. If there are no data for the industry at hand, then go to a similar industry, which is using a baghouse and determine the G/C range successfully employed in that industry and conservatively apply it to your case.

### **1.3 Strategies for Noise Pollution Control**

There are four general methods of controlling noise: enclosing the noise source, enclosing the noise receiver, putting a barrier between the noise source and the receiver, and controlling the noise generator.

Noise is transmitted by vibration. Hence the property of the enclosure must be such that it should not vibrate when a sound wave hits its surface; otherwise, the enclosure itself becomes the source of noise. Since vibration is inversely related to the mass of the material, in the use of enclosures, the effectiveness of control is, therefore, a function of the mass of the enclosure. Thus, by the mass law, the ideal enclosure is the heavy enclosure (materials of high density). Table 1.2 shows surface densities of some common materials of construction.

**Table 1.2 – Densities of some common materials of construction.**

<b>Material</b>	<b>Surface Density in kg/m<sup>2</sup>/cm of thickness</b>
Brick	19-23
Concrete Blocks	15
Dense Concrete	23
Wood	4-8
Common glass	29
Lead sheets	125
Gypsum board	10
Steel	108-112

Putting a barrier between the source and the receiver is generally used for controlling highway noise. The effectiveness of a barrier is dependent on the geometry of the source, barrier and receiver, and on the ground cover. Studies on different kind of noise barriers reveal that noise attenuation up to 8-14 dBA may be achieved using barriers 8ft high and 4 inches thick.

### **1.3.1 Silencers**

Control of noise at points of generation may be done with the help of mufflers or silencers and isolation of noise source by vibration control. There are three basic types of silencers:

**(i) Absorptive Silencers**

In these silencers, a lining of some acoustic material is provided directly on the interior of the duct. The duct may be straight or may have bends, or the duct may be expanded into plenum lined with the acoustic material. The acoustic material absorbs the noise, thus attenuating it. The absorptive silencer is a type of *dissipative muffler* since it dissipates the noise by absorbing it.

**(ii) Reactive Silencers**

These have no lining of absorptive acoustic materials. In them, attenuation of noise is achieved by reflecting the sound waves so as to cancel the waves of incoming noise. This process is called *destructive interference*. Reactive silencers are found in trucks and automobiles.

**(iii) Diffusers**

High velocity mass of air impinging on stationary air or solid objects produces noise due to the turbulence created. *Diffusers* attenuate noise by reducing this velocity. The source flow is diffused out into a multitude of tiny flows having lower velocities using some appropriate mechanism. The diffuser is an exhaust muffler, since it attenuates noise by installing it at the end of a duct or pipe.

#### **1.4 Summary**

Due to their obvious adverse effects on the physiological as well as psychological health of human beings, air and noise pollution control are two of the major components of any pollution management program. Control of particulate matter, emitting from an industrial process, is one of the important objectives of any air pollution control initiative. Two of the most efficient devices used for this purpose are the Electrostatic Precipitators (ESP's) and Fabric Filters or the Baghouses. Whereas, electrostatic precipitators work on the principle of electrostatic charging and subsequent collection of particles by employing a strong non-uniform electric field, fabric filters use the simple mechanisms of inertial impaction, diffusion, and sieving for trapping particulate matter. As far as control of noise pollution is concerned, two of the main strategies in this regard are (i) controlling noise at the source itself and (ii) isolating the source from the receiver using a barrier. Silencers and mufflers are important devices used for controlling the noise at the source itself. Different types of silencers use different principles for controlling noise.

## 1.5 Key Words

**Particulates:** Finely divided solids and liquids, such as dusts, fumes, smoke, fly ash, mist and spray.

**Electrostatic Precipitator:** A device that makes use of a strong non-uniform electric field for the removal of particulate matter from the effluent gas.

**Baghouse:** Systems consisting of assemblies of bags which remove dust by means of a porous fabric and a cake of dust as the filter media.

**Silencers:** Devices consisting of ducts designed to reduce the level of sound.

## 1.6 Review Questions

1. What is the principle on which electrostatic precipitator works?
2. What are different components of an electrostatic precipitator? Explain their significance.
3. How do you calculate the efficiency of an electrostatic precipitator?
4. What is resistivity? How does it affect the efficiency of a precipitator?
5. What are different mechanisms through which a baghouse traps dust?
6. What are different types of cleaning methods used for the removal of dust from the fabric in the baghouse filters?
7. What are the factors that must be considered before selecting a baghouse for a particular application?
8. What are different ways of achieving noise control?
9. What are different types of silencers used for noise control?

## 1.7 Suggested readings

1. Masters, G. M. (1998), "Introduction to Environmental Engineering and Science" – Prentice Hall of India
2. Boubel, R.W., Fox, D.L., Turner, B. and Stern, A.C. (2005), "Fundamentals of Air Pollution" – Academic Press.
3. Bell, L. H. and Bell, D. H. (1994), "Industrial Noise Control", Marcel Dekker, Inc.
4. Stephens, R. W. B. (1986), "Noise Pollution Effects and Control", SCOPE John Wiley and Sons.
5. Singal, S. P. (2005), "Noise Pollution and Control Strategy", Narosa Publishing House.



**AIR POLLUTION CONTROL**

**Prof. C.P. Kaushik**

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**STRUCTURE**

2.0 OBJECTIVES

2.1 INTRODUCTION

2.2.1 AMBIENT AIR QUALITY MONITORING

2.2.1.1 Selection of Sampling Site & Sampling Duration

2.2.1.2 Suspended Particulate Matter Sampling (SPM)

2.2.1.3 Sampling of Gaseous Pollutants

2.2.2 PREVENTION AND CONTROL OF POLLUTION

2.2.2.1 Sulfur-di-oxide Emissions

a) Preventive Measures

b) Control Measures

2.2.2.2 Nitrogen-oxide Emissions

a) Preventive Measures

b) Control Measures

2.2.3 MEASURES TO CONTROL VEHICULAR POLLUTION

a) Preventive Measures

b) Control Measures

2.3 SUMMARY

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2.5 SELF-ASSESSMENT QUESTIONS

2.6 SUGGESTED READINGS

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## **2.0 OBJECTIVES**

After going through this unit you would understand the following :

- \* What is the need for ambient air sampling?
- \* What are the major considerations for selection and duration of air sampling?
- \* What are the procedures for sampling the suspended particulate matter and gaseous pollutants?
- \* What are the control measures for air pollutants?
- \* What are the control measures for vehicular pollution?

## **2.1 INTRODUCTION**

Ambient air quality monitoring is very important for environmental management. The selection of site for air monitoring and sampling duration are considered based on many factors. High volume sampler is used to collect particulate matter and gaseous pollutants. Gaseous pollutants are collected by absorption in the absorbing media for different gases. Air pollution can be controlled by preventive methods which emphasize on various methods which decrease/prevent generation/emission of air pollutants. Control measures for various pollutants emphasize on removing the pollutants after the production by employing various types of control measure equipments/devices.

### **2.2.1 AMBIENT AIR QUALITY MONITORING**

Monitoring of ambient air quality is done to assess the level of air pollution. This helps in environmental management. The primary pollutants present in the air including suspended particulate (SPM), commonly called as dust and other hazardous gases like SO<sub>2</sub> NO<sub>x</sub> etc. which if present in large concentrations can cause several problems for man, materials and vegetation. Assessment of ambient air quality is very important because any future planning of industrial and residential areas

can be done carefully based on this assessment only. The sampling should be carried out long enough and at a rate that allows collection of an analytically measurable and prominently representative sample. High volume air sampler is used to collect particulate matter as well as gaseous pollutants such as NO<sub>x</sub>, SO<sub>2</sub> etc.

#### **2.2.1.1 Selection of sampling site & sampling duration**

One of the important objectives in air monitoring is to obtain a representative sample. Hence the site of sampling should be able to meet all the conditions of a particular study. The necessary number of sampling stations and their locations depend on several factors including the objectives of the programme, the size of the study area, the proximity of sources of pollution, topographical feature and weather, and the fact that concentrations of pollutants vary with altitude. For example, the results shown by sampling on the roofs of tall buildings may differ substantially from conditions at ground or breathing level.

Sampling duration should be selected in such a way that the information required for each specific problem can be provided. Some of the important factors governing the choice of sampling period are as follows:

- nature of the compound under study and its stability to oxidation.
- light or other factors such as sensitivity, accuracy and precision of the analytical method to be used for the measurement of pollutant. Depending upon the extent of surveys, the frequency of sampling is fixed and generally a 24 hour sampling period is prescribed to determine the average pollutant concentration.

#### **2.2.1.2 Suspended Particulate Matter (SPM) Sampling**

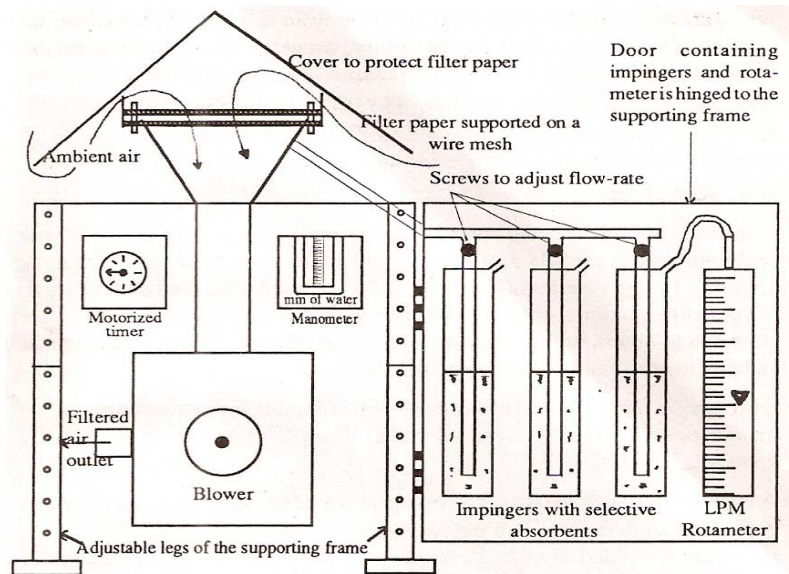
Atmospheric particulate matter is grouped generally into those that settle out due to the force of gravity and those that remain suspended as

aerosols. Large particles of size greater than 10  $\mu\text{m}$  in diameter can be collected using sedimentation techniques, whereas suspended particles of smaller size are collected by more sophisticated techniques like filtration, impingement and electrostatic and thermal precipitation. Out of these, high volume filtration method is popular for measurement of the mass concentration of SPM smaller than 10  $\mu\text{m}$ . The sampler is universally known as "Hi-Vol".

A known volume of air is sucked by a high speed blower through a fine filter paper. Such filter paper is folded twice by keeping the rough side facing up and then dried in a hot air oven at (105°C) for about 30 minutes, cooled and weighed. The pre weighed filter paper should be placed in the sampler keeping rough surface upwards, only at the site just before starting the high-volume sampler in order to avoid the deposition of dust and damage during transportation. The sampling is done for 24 hours and during this time over 2000  $\text{m}^3$  of air is sucked through the filter. Keeping the rotameter reading constant at 2 LPM the manometer reading is recorded every hour throughout the sampling period. For each manometric reading ( $H=H_1 - H_2$ , in mm of  $\text{H}_2\text{O}$ ) the corresponding flow rate in  $\text{m}^3/\text{min}$  is found out from the calibration curve supplied by the equipment manufacturer and the average flow-rate is found. The filter paper, after sampling, is removed gently and transferred carefully to the laboratory. Final weight is taken after drying at 105°C for half an hour.

### **2.2.1.3 Sampling of gaseous pollutants**

There are several methods available for collection of gaseous air pollutants, such as  $\text{SO}_x$  and  $\text{NO}_x$  from ambient air. The most common methods are grab sampling and absorption in liquid. Absorption separates the desired pollutants from air either through direct solubility in the absorbing media or by chemical reaction. Many different types of collectors are available for high degree of gas liquid contact.



**Fig. 1 A Typical High Volume Air Sampler**

Mostly, the midjet impinger is used as the collector in which the gas stream impinges with high velocity onto a flat surface providing good contact between gas and liquid. The absorbing solutions used for  $\text{SO}_2$  and  $\text{NO}_x$  (3%) and  $\text{NaOH}$  (4 g/lit) respectively. These solutions are bubbled at a rate of 2 LPM for 4 hrs. These solutions after sampling are taken to laboratory for analysis.

## **2.2.2 PREVENTION AND CONTROL OF AIR POLLUTION**

### **2.2.2.1 Sulfur Dioxide ( $\text{SO}_2$ ) Emissions**

#### **a) Preventive measures**

- ❖ Converting coal into a gas or liquid by gasification and liquefaction technologies, respectively. This would be expensive and low in net energy yield.
- ❖ Improving energy efficiency and shifting to less polluting fuels.
- ❖ Burning low sulfur coal. This would be especially useful for new power industrial plants located near deposits of such coal.

- ❖ Removing sulfur from coal. This would be fairly inexpensive. Current methods (mostly washing) remove 20-50%, but scientists hope to develop bacteria capable of removing sulfur more efficiently and cheaply. **Thiobacillus desulfuricans** is one such bacterium capable of removing the sulphur from coal before burning it. The sulfur thus removed must also be taken care of not to pollute the water bodies or ground water.
- ❖ Converting coal to a liquid or gas fuel through coal liquefaction or gasification, which burns relatively cleaner but has lower heating value.
- ❖ Removing sulfur during fluidized bed combustion of coal. This would remove up to 90% of the SO<sub>2</sub> and reduce CO<sub>2</sub> by 20%. It is commercially available for small to medium sized plants.
- ❖ Removing sulfur during limestone injection multiple burning of powdered coal. This is still in the development and testing stage; the sulfur removed must be dealt with.
- ❖ Improving energy efficiency and shifting to less polluting fuels, like non-conventional energy sources.

**b) Control Measures**

- ❖ Using smokestacks tall enough to pierce the thermal inversion layer. This would decrease pollution near power or industrial plants but increase pollution levels in downwind areas.
- ❖ Removing pollutants after combustion using a flue gas scrubber. This would remove 70-95% of SO<sub>2</sub> and 99.9% of suspended particulate matter (but not the more harmful fine particles). It can be used in new plants and added to most existing large plants; however it is expensive and leaves sludge that must be disposed off safely.

- ❖ Removing SO<sub>2</sub> after combustion using organic amine salt scrubbers. This would remove 99% of SO<sub>2</sub> and be about one-third cheaper than flue gas scrubbing. Organic amine salt can be regenerated by heating. It is still being developed.
- ❖ Taxing each unit of SO<sub>2</sub> emitted. This would encourage development of more efficient and cost effective methods of emission control, however, it is opposed by industry because it costs more than tall smokestacks and requires polluters to bear more of the costs now passed on to society. In 1990 France became the first nation to impose such a tax.

#### **2.2.2.2 Nitrogen Oxide (NO<sub>x</sub>) Emissions**

So far little emphasis has been placed on reducing NO<sub>x</sub> emissions from stationary sources because control of SO<sub>2</sub> and particulates was considered more important. Now it is clear that NO<sub>x</sub> emissions are a major contributor to acid deposition and that they increase tropospheric levels of ozone and other photochemical oxidants that can damage crops, trees, and materials.

##### **a) Preventive Measures**

- ❖ Removing NO<sub>x</sub> using fluidized bed combustion. This would remove 50-75% NO<sub>x</sub>.
- ❖ Removing NO<sub>x</sub> during limestone injection multiple burning. This would remove 50-60% NO<sub>x</sub>. However, the technology needs improvement.
- ❖ Reducing NO<sub>x</sub> emissions by decreasing combustion temperatures. This well established technology would reduce production of these gases by 50-60%. However, this may reduce energy conversion efficiency, thereby increasing CO<sub>2</sub> emissions.
- ❖ Improving energy efficiency and shifting to less polluting fuels.

## **b) Control Measures**

- ❖ Increasing the height of smokestacks.
- ❖ Tax levying on each unit of NO<sub>x</sub> emitted.
- ❖ Removing NO<sub>x</sub> after combustion by reburning. This would remove 50% or more but is still under development for large plants.
- ❖ Removing particulates from stack exhaust gases. This approach is widely used in electric power and industrial plants. Several methods are in use like electrostatic precipitators, bag-house, cyclone separators and wet scrubbers. All produce hazardous materials that must be disposed off safely and except for cyclone separators all methods are expensive.

### **2.2.3 MEASURES TO CONTROL/MINIMIZE VEHICULAR POLLUTION**

#### **2.2.3.1 Preventive Measures**

- ❖ To adopt means of mass rapid transport system (MRTS) which should be trouble free and accident free, car pooling and use of bicycles which would help reduce the magnitude of vehicular pollution.
- ❖ Appropriate operating conditions including speed to ensure maximum burning of fuel and minimum pollutant emission.
- ❖ Shifting to less polluting automobile engines. Examples include the stratified charge engine, the hydrogen powered engine, the electric motor etc.
- ❖ Shifting to less polluting fuels especially solar produced hydrogen.
- ❖ Improving fuel efficiency. This would be the quickest and most cost effective approach.



- ❖ Modifying the internal combustion engine to reduce emissions. Burning gasoline using a lean, or more air rich, mixture would reduce carbon monoxide and hydrocarbon emissions but increase NOx emissions; a lean burn engine that reduces NOx emissions by 75-90% may be available in about 10 years.
- ❖ Partial shifting to CNG (compressed natural gas) buses, cars and autorikshaws.

**Table-1. Emission reduction using CNG in 5 years old-car**

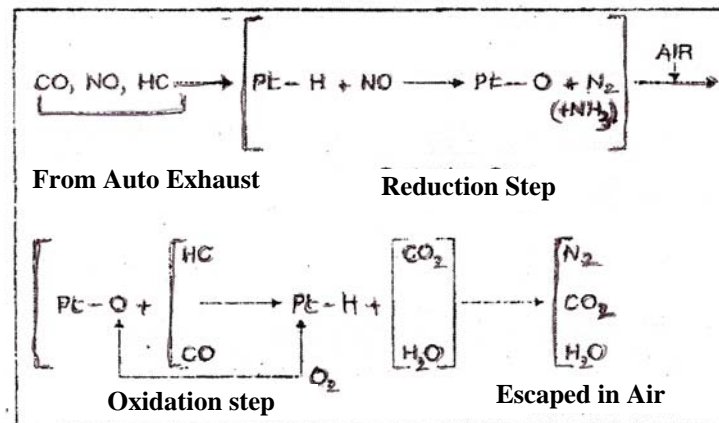
	CO (gm/km)		HC (gm/km)	
	Petrol	CNG	Petrol	CNG
Best performance in CNG car	13.4	0.5	1.7	0.6
Least best performance in CNG car	21.5	0.8	6.4	4.3

*Source: Chandrashekhar (1995)*

- ❖ Partial phasing out of the diesel run heavy vehicles by gasohol (gasoline + alcohol) run vehicles.
- ❖ Raising annual registration fees on older, more polluting cars or offering owners cash payments or rebates to retire such cars. Getting old vehicles off the road which would result in a much greater reduction in auto emissions.
- ❖ Taxing the manufacturer for each new car based on the amount of key pollutants emitted by the engine.
- ❖ Giving subsidies to automakers for each low or non-polluting, energy efficient car they sell. The manufacturers should comply with the standards of pollutant emissions.
- ❖ Giving buyers rebates or incentives when they buy low or nonpolluting energy efficient cars and charging them fees when they buy more polluting energy inefficient cars.
- ❖ The state authorities should ensure compliance of these standards of pollutant emission on uniform basis.

## b) Control Measures

Using emission control devices. This is the most widely used approach. However, current catalytic converters are poisoned by the lead in leaded gasoline (still used in most less developed countries).



**Fig. 2 Steps involved in vehicular catalytic converter**

Requiring car inspections frequently after a fixed interval of time. For cars exceeding the standards, an emission charge based on the grams of pollutants emitted per kilometer and the number of kilometers driven since the last inspection should be imposed. This would encourage drivers not to tamper with emission control devices and to keep them in good working order.

## 2.3 SUMMARY

Ambient air quality assessment is important for future planning of industrial and residential areas. High volume sampler is used for monitoring the particulate matter and the gaseous pollutants.

Sampling duration and site selection is done very carefully in order to provide the required information. It should take into consideration the source of pollution, topographical features, weather and altitude. Generally a 24-hr sampling is prescribed for average pollutant concentration.

The suspended particulate matter (SPM) smaller particulates are collected by sophisticated techniques. SPM can be collected on a fine filter paper.

The gaseous air pollutants such as NO<sub>x</sub>, SO<sub>x</sub> can be collected by absorption in liquid media, after passing at a fixed rate.

Various control measures can be adopted to prevent and control pollution. The methods could be preventive for emission or the emission of pollutants can be controlled by physical, chemical or biological techniques.

Vehicular pollution can be minimized/controlled by preventive measures and by control of emission. Catalytical converters should be employed to control the pollutants from vehicular.

## **2.4 KEY WORDS**

- Ambient air : The air surrounding us.
- Air pollutants : Substances present in air in such concentration that are harmful to humans, animals, plants and materials.
- Gasohol : A fuel which is a mixture of gasoline and alcohol.

## **2.5 SELF ASSESSMENT QUESTIONS**

1. Discuss the methods of sampling particulate matter and pollutant gases in the atmosphere.
2. Discuss the important preventive and control measures to minimize air pollution due to SPM, NO<sub>x</sub> and SO<sub>x</sub>.
3. How can pollution due to vehicular emissions be minimized?

## **2.6 SUGGESTED READINGS**

Gilbert M Masters (1994) Introduction to Environmental Engineering and Science.

Murali Krishna KVSG (1995) : Air Pollution and Control.