

## Unit – IV

### Sludge:

- Sewage sludge is a kind of waste coming from municipal wastewater treatment plants. In these facilities, high quantities of water are treated every day to eliminate bacteria, viruses and pollutants. As main output, these plants produce treated water and sewage sludge.
- Sludge, which constitutes 1% of wastewater entering the plant, is digested anaerobically and dehydrated. Sewage sludge, at the outlet after mechanical drying, is made of approximately 80% moisture and 20% dry matter.
- The management of this product has become a serious problem in Europe over the last years because of legislation and environmental issues.
- Typical destinations for sewage sludge were agriculture, forestry, incineration, land building or landfills, but most of them have been banned or limited by recent EU and local laws.
- Sludge constituents are organic and inorganic compounds, including traces of heavy metals such as chromium, zinc, mercury, lead, nickel, cadmium and copper. These elements restrict the use of sludge in agriculture, because their accumulation is harmful to the environment and particularly to the food chain.

### Characteristics and types

The principal sources of solids and the types generated are reported in Table

Unit operation or process	Type of solids	Remarks
Screening	Coarse solids	Coarse solids are removed by mechanical and hand cleaned bar screens. In small plants, screenings are often continued for removal in subsequent treatment units.
Grit removal	Grit and scum	Scum-removal facilities are often omitted in grit-removal facilities.

Pre-aeration	Grit and scum	In some plants, scum-removal facilities are not provided in pre-aeration tanks. If the pre-aeration tanks are not preceded by grit-removal facilities, grit deposition may occur in pre-aeration tanks.
Primary sedimentation	Primary solids and scum	Quantities of solids and scum depend upon the nature of the collection system and whether industrial wastes are discharged to the system.
Biological treatment	Suspended solids	Suspended solids are produced by the biological conversion of BOD. Some form of thickening may be required to concentrate the waste sludge stream from the biological treatment system.
Secondary sedimentation	Secondary bio-solids and scum	Provision for scum removal from secondary settling tanks is a requirement of the U.S. EPA
Solids processing facilities	Solids, compost and ashes	The characteristics of the end products depend on the characteristics of the solids treated and operations and processes used. Regulations for the disposal of residuals are stringent.

Characteristics of sludge are determined by various tests for the determination of specific gravity, moisture content, volatile and fixed solids, colour, odour etc.,

#### **Sludge from PST :**

- It is gray- coloured, greasy, odourous slurry of settleable solids accounting for about 50 – 60% of SS applied and tank skimmings.
- It contains faecal matter, vegetable parrings and fine silt. The sludge is sticky and does not drain easily.
- Solids concentration in raw primary sludge are 6-8%, and the portion of volatile solids varies from 60 to 80%.

#### **Chemical precipitation:**

- It's properties same as PST, except it resembles less odour.

- It includes precipitated chemicals and entangled solids in more or less stoichiometric amount.
- It takes its colour from the coagulating chemicals used in the process and is slightly heavier also.

#### **Trickling Filter :**

- Sludge is dark brown in colour, flocculent and relatively less offensive when fresh.
- During unloading of filters that are operated at low rates, sludge contains many dead worms and its odour becomes quite offensive.
- It generally undergoes decomposition more slowly than other undigested sludges.
- TF sludge digests easily.
- This sludge exhibits good settleability, the precipitate does not compact to high density.
- The sludge has a solids content of 4 – 6% which is slightly thinner than residue with raw organics only.

#### **Activated Sludge:**

- Activated sludge generally has a golden-brown flocculent appearance. Inoffensive when fresh.
- If the colour is dark, the sludge may be approaching a septic condition. If the colour is lighter than usual, there may be under aeration with a tendency for the solids to settle slowly.
- It contains large percent of moisture about 98-99% and is most voluminous amongst the sludges.
- Thickness of return activated sludge is 0.5-2% SS with a volatile fraction of 0.7 - 0.8. Waste activated sludge can be thickened effectively by centrifugation or flotation.

#### **SLUDGE TREATMENT**

- To extract water from solids and dispose the dewatered residue through a combination of physical, chemical and biological operations.

- Sludge treatment may include different unit process:

1. Concentration or Thickening

- a. Gravity Thickening
- b. Centrifugation
- c. Air Flotation Thickening

2. Digestion or Stabilization

- a. Aerobic
- b. Anaerobic

3. Conditioning

- a. Elutriation
- b. Chemical Conditioning
- c. Heat Treatment

4. Dewatering

- a. Vacuum Filtration
- b. Centrifugation
- c. Pressure Filtration

5. Heat Drying

- a. Flash Drying
- b. Spray Drying
- c. Rotary Drying

6. Incineration

- a. Multiple Hearth Incineration
- b. Fluidized Bed Incineration

### c. Flash Combustion

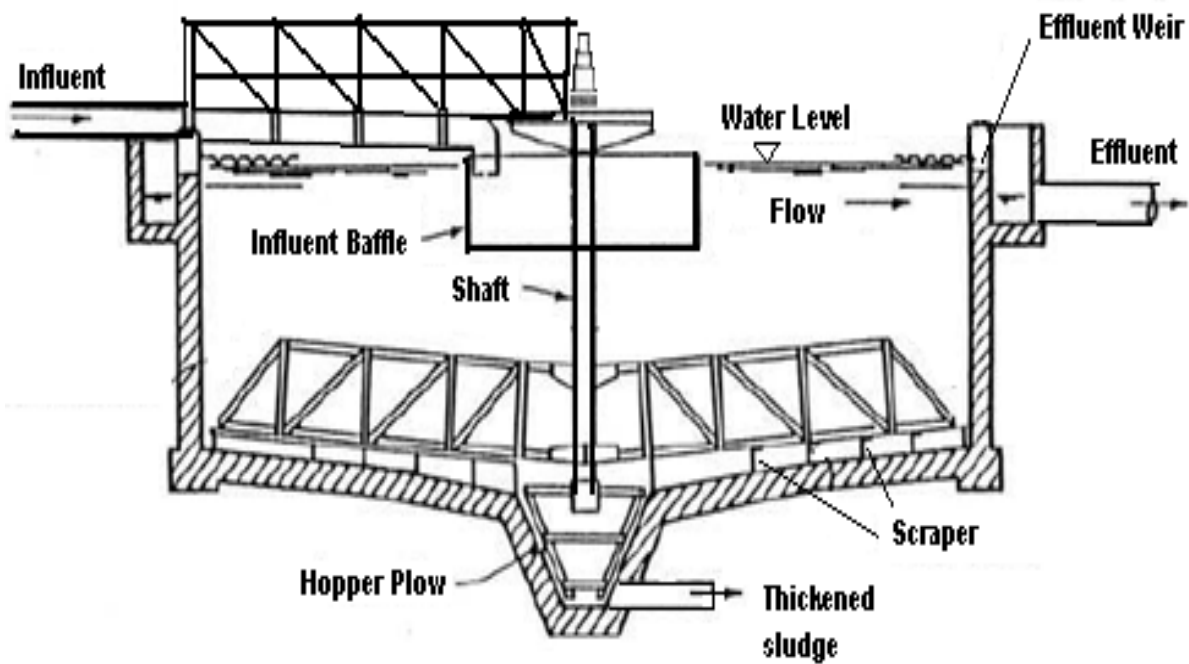
#### 1. Concentration or Thickening:

- To reduce moisture content of sludge and to increase the solids concentration. This is mainly adopted for the separation of greater amount of water from the sludge solids that can be attained in settling tanks.
- The volume reduction is done for the following purposes
  1. Increase feed solids concentration to vacuum filters,
  2. Economize transport and handling cost of sludge within the plant and final disposal,
  3. Minimize land required and handling cost for final disposal of the digested sludge on land, and save fuel if incineration is practiced.
- In sludge thickeners, greater amount of water is removed from the sludge than what could obtain from sedimentation tank. This reduces overall volume of the sludge considerably. The thickening of the sludge can be achieved either by gravity thickening, application of air floatation or by centrifugation.

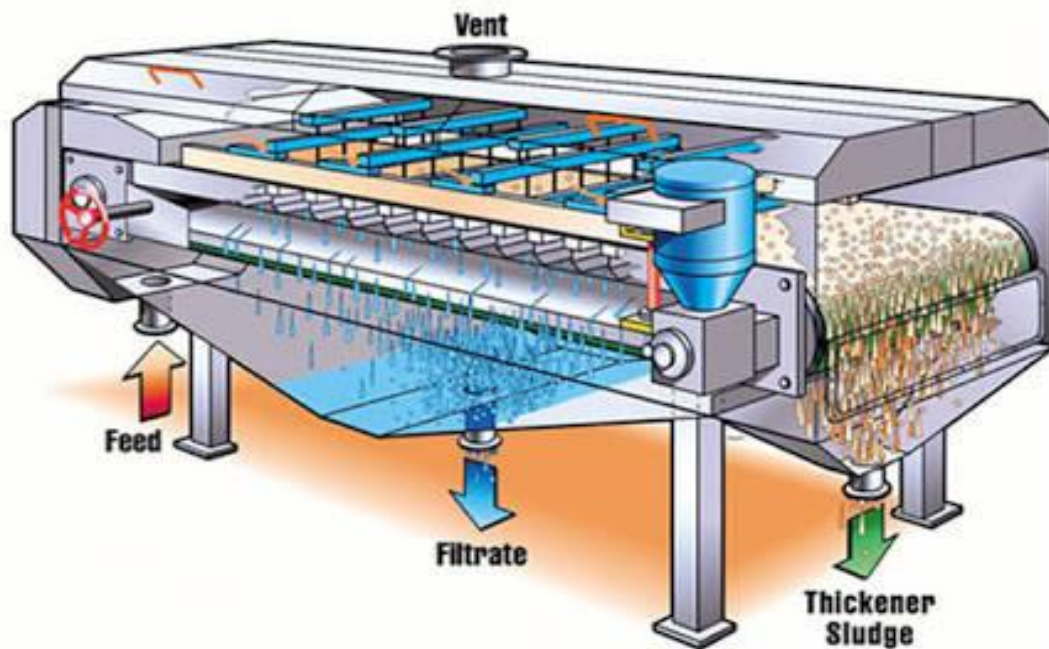
#### a. Gravity thickening:

- Gravity thickening is accomplished in a tank similar in design to a sedimentation tank. This is most commonly used for concentrating the sludge for achieving saving in the digester volume, sludge handling cost.
- This is used for primary sludge and for combine primary and secondary sludge, and it is not suitable for ASP sludge alone. When the ASP sludge is more than 40% (weight ratio) of the total combined sludge, gravity thickening is not effective and other methods of thickening have to be considered.
- This is simplest and least expensive.
- Gravity thickeners can be operated either as continuous flow or fill and draw type, with or without chemical addition.
- Continuous feed tanks are circular in shape with central feeding and overflow at the periphery. The feed sludge is allowed to settle at the bottom.

- The thickened sludge is withdrawn from the bottom of the tank and pumped to the digester. The supernatant is returned to the PST.



Schematic diagram of a gravity thickening unit



Different types of gravity belt thickening units

- A bridge fastened to the tank walls supports a truss type scrapper arm mounted on a pipe shaft equipped with a power lift device there by opening up channels for water escape and promoting densification. Use of slow stirring improves efficiency.
- The side water depth is kept about 3.0 m. Due to relatively high concentration of the solids, as compared to PST or SST, the settling in thickeners will follow hindered settling in the beginning and compaction at later stage.
- Concentration of the underflow solids is governed by the depth of sludge blanket up to 1 m beyond which there is very little influence of the blanket.
- Continuous flow tanks are designed for a hydraulic loading likely to give rise odour problems.
- Thickeners are designed for hydraulic loading of 20 to 25 m<sup>3</sup>/m<sup>2</sup>.d. Loading rates lesser than 12 m<sup>3</sup>/m<sup>2</sup>.d are likely to give very high solids concentration, which may require dilution with plant effluent for transporting.
- The underflow solid concentration will increase with increase in detention time, and detention time of about 24 h will produce maximum compaction.
- During peak condition, lesser detention time is allowed to keep the sludge blanket sufficiently below the overflow weirs to prevent excessive solids carryover.

**Surface Loading Rates and Solid Concentration Typically Achieved in Thickeners:**

Type of sludge	Thickened sludge solids concentration, % (g/L)	Solid surface loading (kg/m <sup>2</sup> .day)
Separate Sludge		
Primary	5 – 10 ( 50 - 100)	90 – 140
Activated	2.5 – 3.0 ( 25 – 30 )	25 – 30
Trickling filter	7 – 9 (70 – 90 )	40 – 45
Combined sludge		
Primary + Activated	4 – 8 (40 – 80 )	30 – 50

Primary + Trickling filter		50 – 60
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**b. Air floatation Thickening:**

- By applying air under pressure or vacuum, thickening of the sludge can be achieved. This process is known as dissolved air floatation or pressure type floatation.
- This is normally preferred for ASP sludge. This requires additional equipment, power for operation, skilled supervision for operation and maintenance, hence it is costly.
- However, better removal of oil and grease, solids, and odour control are the advantages offered by this method.
- Addition of alum, polyelectrolytes can increase the efficiency of the floatation unit. Alum will increase the sludge but polyelectrolyte will not increase the solids concentration but improves solids capture from 90 to 98%.
- The floatation units can be of two types
  - (i) Pressure type
  - (ii) Vacuum type.

**i. Pressure type floatation:**

- In pressure type floatation unit, a portion of the subnatant is pressurized from 3 to 5 kg/cm<sup>2</sup> and then saturated with air in the pressure tank.
- The effluent from the pressure tank is mixed with influent sludge immediately before it is released into floatation tank. Once the pressure is released, excess dissolve air rises up in the form of extremely small air bubbles, attaching themselves to the sludge particles.
- This imparts buoyancy to the sludge particles and forms sludge blanket ( 0.2m – 0.6 m ) at the top, which is skimmed off, while the unrecycled subnatant is returned to the wastewater treatment plant. Dissolved air floatation (DAF) offers significant advantages in thickening light sludge such as activated sludge.



- Effluent recycled at a rate of 30 – 150% of the influent flow through the air dissolution tank to the feed inlet. Recycle ratio is interrelated with.
  1. Feed solids concentration.
  2. Detention time
  3. Air solids ratio (0.01 to 0.03) is sufficient to achieve acceptable thickening of waste activated sludge. Surface overflow rates in floatation thickeners vary from 10 – 45 m/day at a retention time of 30 minutes to 1 hour.

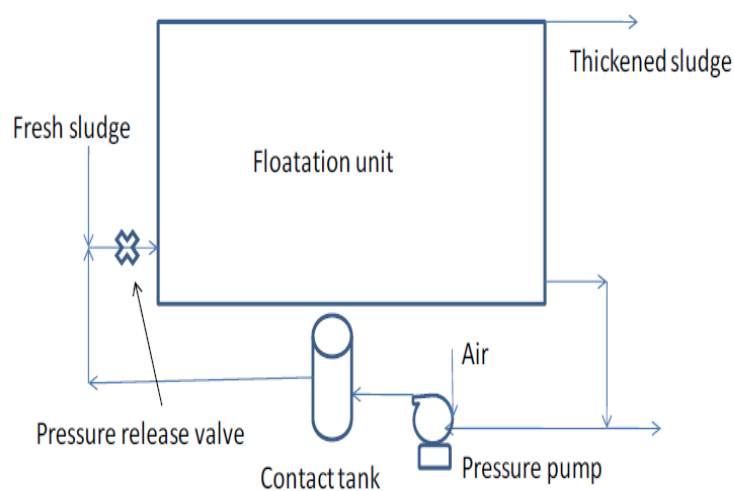


Fig: Working of Pressure Type Air Floatation Unit

## ii. Vacuum Type Floatation:

The vacuum type floatation unit employs the addition of air to saturation and applying vacuum to the unit to release the air bubbles which float the solids to the surface. The solids concentrated at the surface are skimmed off.

## c. Centrifugation:

Thickening by centrifugation is used only when the land available is limited and sludge characteristics will not permit adoption of other methods. Thickening by centrifugation involves the settling of sludge particles under the influence of centrifugal forces.

This will require high maintenance and operational and power cost. A centrifuge acts both ways to thicken and to dewater sludge. The centrifuge process separates liquid and solid by the influence of centrifugal force which is typically 50 to 300 times that of gravity.

Three basic type of centrifuges currently available for sludge thickening are

- i. Disc type
- ii. Solids Bowl
- iii. Basket Centrifuges

Disc centrifuges are prone to clogging while the latter types gives poor quality effluent.

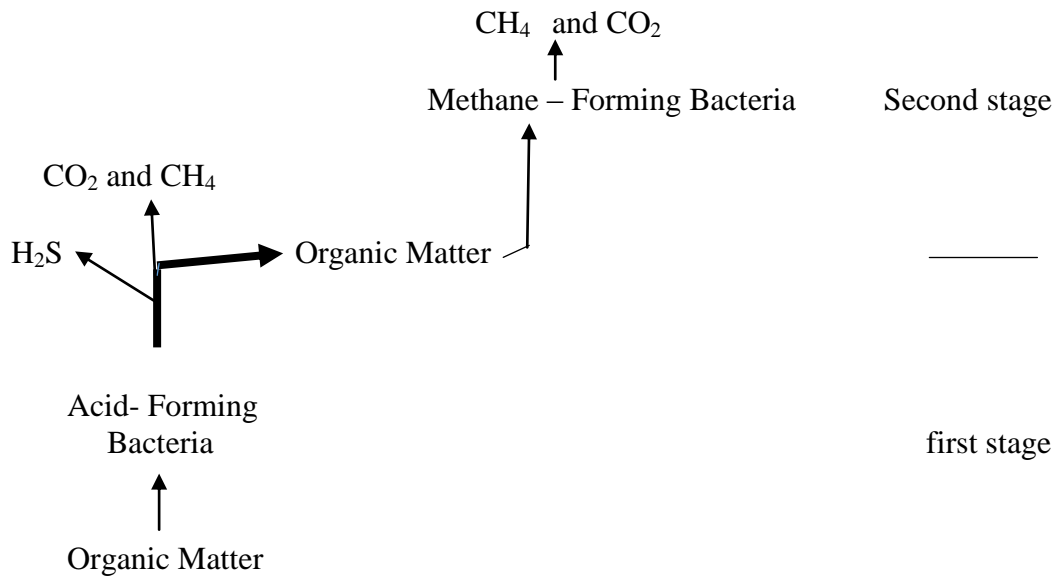
## **2. Digestion or Stabilization:**

### **a. Anaerobic Digestion**

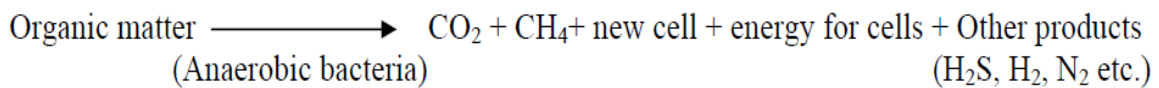
- Sludge digestion is a biochemical phenomenon involving organisms, enzymes, food and environment.
- Main objective of sludge digestion is to subject the organic matter present on the settled sludge of primary and final sedimentation tank to anaerobic or aerobic decomposition as to make it innocuous and amenable to dewatering on sand beds before final disposal.
- Anaerobic digestion produce gas which can be utilized wherever feasible, aerobic digestion does not produce any utilizable by product other than well stabilized sludge.
- Anaerobic digestion is the biological decomposition of organic matter in the absence of oxygen .
- Anaerobic digestion consists of two stages. 1. Acid Fermentation

#### 2. Methane Fermentation

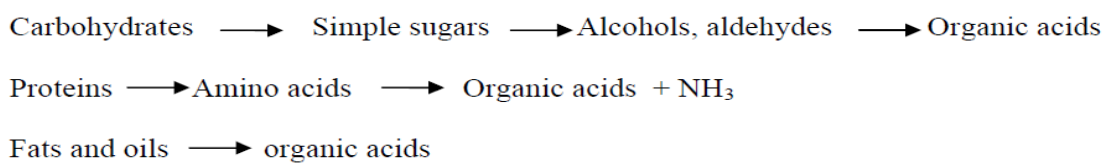
Acid fermentation consists of hydrolysis and liquefaction of high molecular- weight organic compounds and conversion of organic acids by acid forming bacteria. Acetic acid, propionic and butyric acid are the most common end products in the first stage.



Methane fermentation is gasification of the organic acids to methane and carbon dioxide by acid splitting methane forming bacteria.



Microbial action by anaerobic bacteria consists of three stages as 1) Liquefaction of solids, 2) Digestion of soluble solids, 3) Gas production. Organic acid forming heterotrophs use complex organic substrate such as carbohydrates, proteins, fats, oils and their degradation products and produce organic acids. The breakdown of three major organic matters is shown below:



- For the proper functioning of the process, it is necessary to have good balance between the reaction of two stages is maintained. So there is no accumulation of excess volatile acids, normal operating values of 200 to 400 mg/l with a maximum of 2000 mg/l.
- Due to low microbial growth rate, the production of biological sludge is very low. Major portion of organic waste is converted into gas.

### ***Advantages of anaerobic digestion***

- Methane recovered can be used as alternate fuel source.
- Reduce production of landfill greenhouse gases when otherwise these untreated sludge is disposed on landfill, which then broken down anaerobically to release methane into atmosphere.
- Reduction in volume of sludge and improving dewatering characteristics of the sludge makes it easy to dry.
- Reduces odour/ flies problem.
- Low operating cost, since energy is not require to supply oxygen being anaerobic process.

### **Disadvantages of anaerobic digestion**

- Accumulation of heavy metal and recalcitrant contaminants in the sludge.
- Narrow operating temperature control range.
- When heating is to be provided safely handling is required with electrical grid based heat management.

### **Types of Anaerobic Digesters**

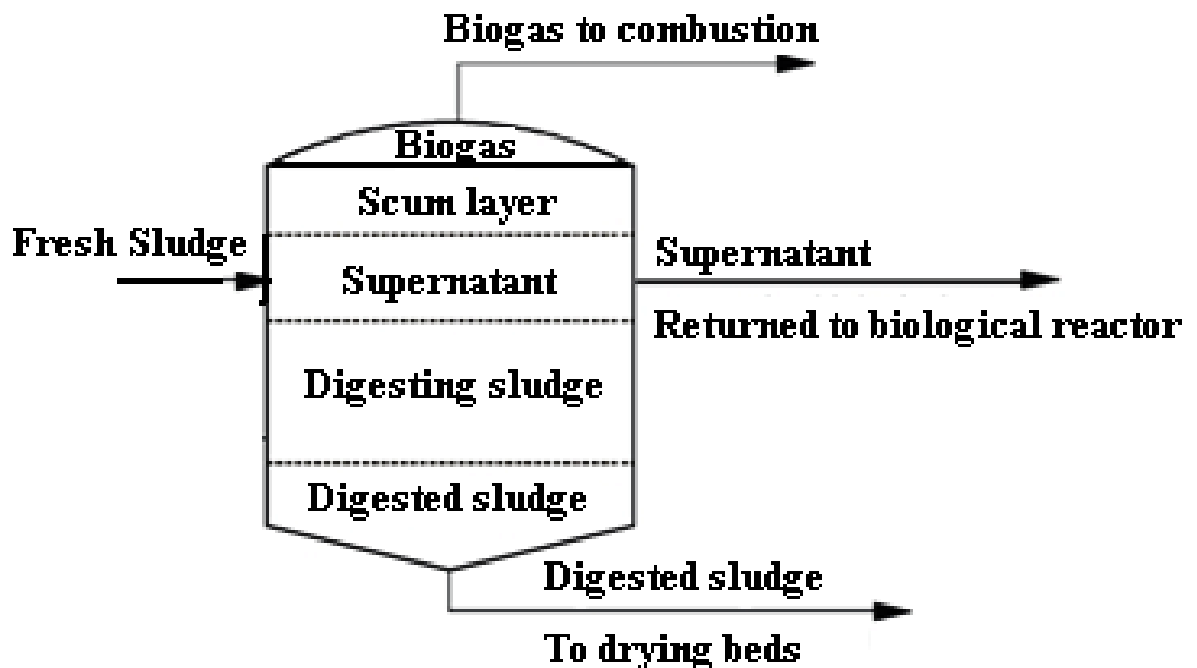
1. Standard rate or low rate
2. High rate digester

#### **1. Standard rate or low rate**

In the standard rate digestion process, the contents of the digester are usually unheated and unmixed. In this acidification, methane fermentation and sludge thickening takes place in single tank. Standard or low rate digesters have intermittent mixing, intermittent sludge feeding and intermittent sludge withdrawal. Detention time for this process vary from 30 to 60 days. When sludge is not being mixed, the digester contents undergo thermal stratification.

- Low-rate digestion is the oldest and simplest type of the anaerobic sludge digestion process.
- Essentially, it is a large cylindrically shaped tank with a sloping bottom and a flat or domed roof.
- An external heat source may or may not be provided.
- No mixing is provided.

- Although the gas generated and its rise to the surface provide some degree of mixing, the stabilization results in a stratified condition within the digester.
- Supernatant is drawn off and recycled to influent of STP. Stabilized biosolids, which accumulate and thicken at the bottom of the tank, are periodically drawn off for removal.
- CH<sub>4</sub> gas collects above the liquid surface and is drawn off through the cover.
- Low-rate digestion is characterized by a long detention time, 30 to 60 days, and is sometimes considered for small plants of less than 4000 m<sup>3</sup>/d, however, they are seldom built today.
- Three functions in a single stage floating cover digester are anaerobic digestion, gravity thickening and storage of thickened sludge.
- In this digesters much volume is wasted and sometimes acidification takes place in the top and middle layers while methane fermentation is confined to lower layers.
- This can lead to areas of low and high pH in the system which restricts the optimum biological activity. Chemical added for pH control are not dispersed throughout the tank and their effectiveness is limited.
- Gas break down is poor because of grease tends to float at the top of digester.
- Methane bacteria are removed with digested sludge and not recycled at the top.
- During progression from top to bottom of the tank, the sludge is compressed and gradually dewatered.



**Fig: Stratification in Conventional Digester**

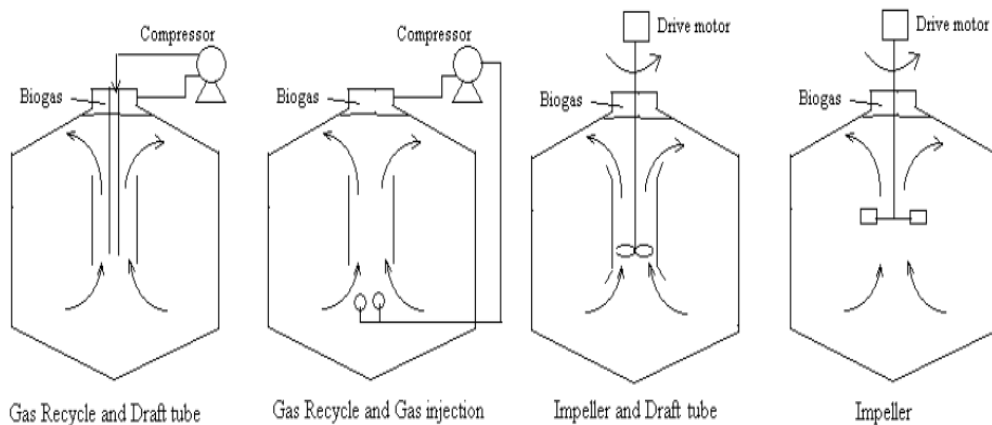
### **High Rate Digesters**

- In the 1950s, several improvements to low-rate digestion were developed, resulting in a high-rate system.
- Heating, auxiliary mixing, thickening the raw sludge, and uniform feeding, the essential elements of a high-rate digestion system, act together to create a uniform environment.
- As a result, the tank volume is reduced and the stability and efficiency of the process are improved.
- In HRD the sludge is more or less continuously added and vigorously mixed either mechanically or by recirculating a portion of digestion gas through a compressor. Mechanical mixing is normally accomplished by an impeller suspended from the cover of digester. Gas mixing may be 3 types.
  1. by injection of compressed gas through a series of small diameter pipes.
  2. by using a draft tube in the center of the tank.
  3. by supplying compressed gas to a number of diffusers mounted in the center at the bottom of tank

### **2. High Rate Digesters**

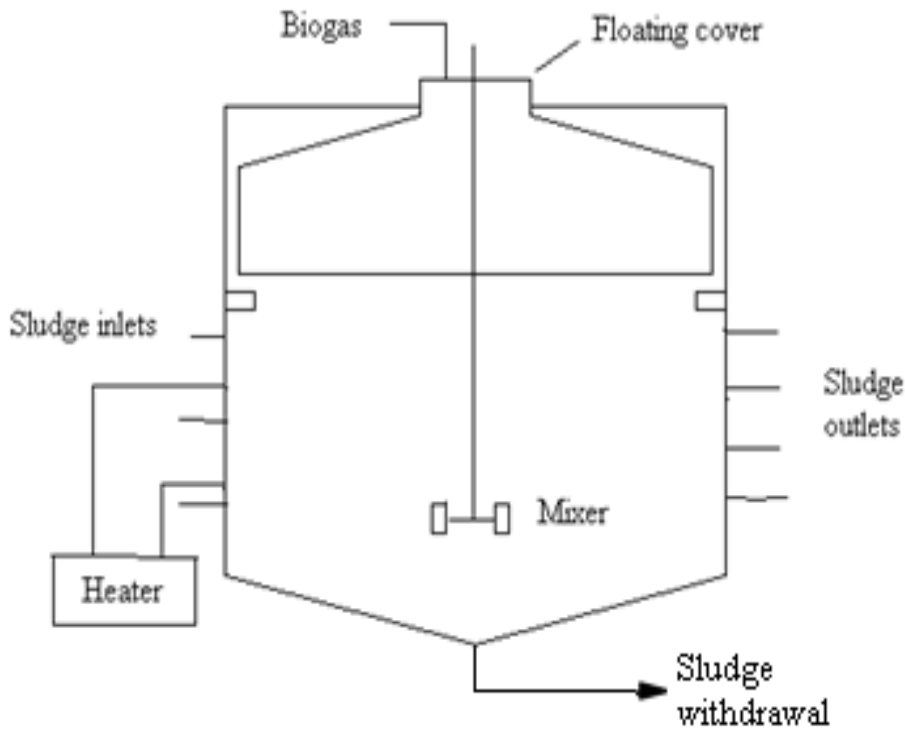
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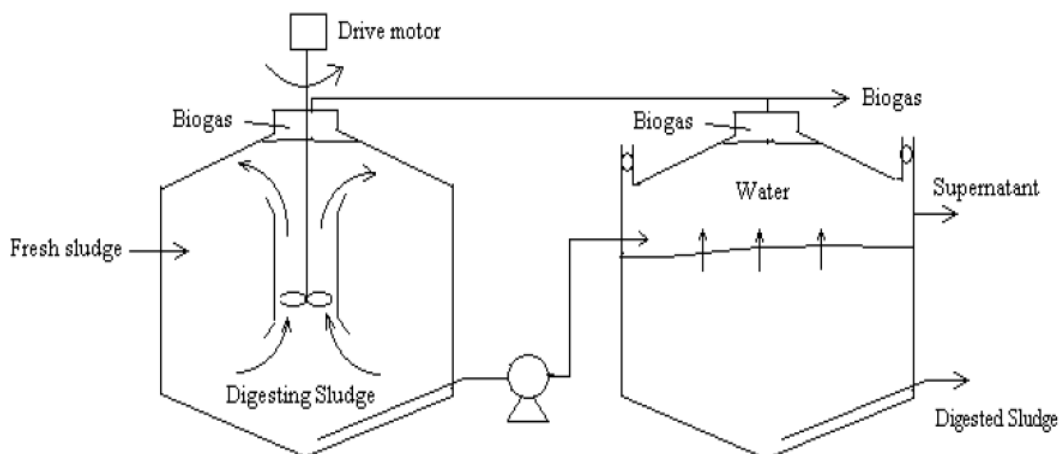


- In high rate digestion process, the contents of the digester are heated and completely mixed. Continuous or intermittent sludge feeding and withdrawal is practiced in these digesters.
- The required detention time is 10 - 15 days. The homogenous nature of the digested sludge in the high rate digester does not permit formation of supernatant and only 50% destruction of VS is achieved and also thickening cannot be performed in complete mix digester.
- Hence high rate digesters normally consists of 2 tanks.
- The first tank is provided for acidification and second for methane formation and thickening and supernatant formation.

- In single stage digester mixing is stopped and the contents are allowed to stratify before digested sludge and supernatant are withdrawn.
- The digestion tanks are circular and diameter ranges between 6 and 45 m. The depth of water ranges between 7.5 and 14 m. The minimum slope of the tank floor is 1 vertical to 4 horizontal.



**Fig: High Rate Digester, Continuous Flow Stirred Tank, Single Stage Process**



**Fig: High Rate Anaerobic Digester**

**Operation of Digesters:**



- Generally digesters are operated at temperature of 30 to 37°C and optimum pH of 7 to 7.2. The wide operating pH range could be 6.7 to 7.4.
- Lime may be added to control the pH. Drop in pH inhibits methanogenesis and reduces methane production.
- The digester gas produced from the process may be used for heating purpose. Heavy metals may inhibit digestion process so that it must be eliminated at source. Supernatant liquor has BOD<sub>5</sub> of about 2000 mg/L and SS of 1000 mg/L and it is recycled back to PST.
- Usually acidification will not occur if the dry solids added or withdrawn daily do not exceed 3 to 5 % of the dry solids in the digester. The degree of the digestion is measured by VSS reduction and amount of gas produced.

### **Aerobic Digestion:**

- Function of aerobic digestion is to stabilize waste sludge by long term action, there by reducing the BOD and destroying volatile solids.
- Aerobic digestion is generally defined as a process in which micro- organisms obtain energy by endogenous or auto- oxidation of their cellular protoplasm.
- The biologically degradable constituents of the cellular material are slowly oxidized to Carbon-dioxide, water and ammonia.
- Aerobic digestion produces volatile solids reduction compared to those in anaerobic digestion, which has low BOD in the supernatant, fewer operational problems and lower initial cost.
- This digestion can be accomplished in one or more tanks mixed by diffused aeration. Since aerated solids have a low rate of oxygen demand, the need for effective mixing rather than microbial metabolism usually governs the air supply required.
- Aerobic digesters are similar to conventional activated sludge tanks in that they are not covered and insulated.
- These are more economical to construct than to be covered.
- Long term aeration of waste- activated sludge creates a bulking material to thicken. This digestion can be used for secondary tank humus or for a mixture of primary and secondary sludges but not for primary sludges alone. Well suited for industrial sludge and for small municipal activated sludge plants.
- Factors to be Considered in the Design of Aerobic Digester:
  1. Detention time
  2. Loading criteria

3. Oxygen requirement – 1.7 to 1.9 gm/gm of volatile solids destroyed.

- It is also necessary to maintain DO of 1 to 2 mg/l in the system.

4. Mixing and process operation.

- The volatile solids destroyed in aerobic digestion in about 10 to 12 days time with a temperature of 20°C would be 35 to 45%. Higher temperature will result in reduction in the period of digestion.

**Advantages:**

1. Lower BOD concentration in the digester supernatant.
2. Production of odourless and easily dewaterable biologically stable sludge.
3. Recovery of more basic fertilizer value in digested sludge
4. Lower capital cost.
5. Fewer operational problems.

**Disadvantages:**

1. Higher power costs generate higher operating costs compared to anaerobic digesters.
2. No methane gas is produced for recovery as a by-product.
3. Some aerobically digested sludges do not dewater easily in vacuum filtration.

**3. Conditioning:**

Sludge is conditioned to improve its dewatering characteristics.

Methods to Condition the Sludge

1. Chemical conditioning
2. Heat treatment.

Elutriation is a physical washing operation is used to reduce chemical conditioning requirements.

**i. Chemical conditioning**

- Chemical conditioning may be applied to sludge which have been digested or to raw sludges. Chemical conditioning is the process of adding chemicals to the enable coalescence of sludge particles facilitating easy extraction of moisture.
- Many chemicals have been used such as sulfuric acid, alum, chlorinated copperas, ferrous sulfate, and ferric chloride with or without lime, and others.
- There are two mechanisms involved in chemical conditioning:
  1. Neutralization of charge (double layer theory)

2. Bridging of individual particles into a floc structure (polymer bridge formation which incorporates the individual particles into a lattice structure with sufficient rigidity and porosity to permit water to escape)

- Digested sludge because of its high alkalinity exerts a huge chemical demand and therefore the alkalinity has to be reduced to save the high chemicals consumption. This can be achieved by elutriation.
- The choice of chemicals depends upon pH, ash content of sludge, temperature and other factors.
- There is no one best pH value for all sludges. Different sludges such as primary, various secondary and digested sludge and different sludges of the same type have different optimum pH values which must be determined for each sludge by trial and error.
- Dosage of ferric chloride and alum for elutriated digested sludge are 1.0 kg/m<sup>3</sup> of sludge
- Alum when vigorously mixed with sludge reacts with the carbonate salts and releases CO<sub>2</sub> which causes the sludge to separate and the water drains out more easily.
- Feeders are also necessary for applying the chemicals needed for proper chemical conditioning.
- The most frequently encountered conditioning practice is the use of ferric chloride either alone or in combination with lime.
- Mixing of sludge and coagulant is essential for proper conditioning ( not more than 20 to 30 seconds)
- Chemical conditioning can reduce the 90 to 99% incoming moisture content to 65-85%, depending on the nature of the solids to be treated. Chemical conditioning results in coagulation of the solids and release of the absorbed water.

### **Factors Affecting Chemical Conditioning**

Wastewater sludge consists of primary, secondary, and/or chemical solids with various organic and inorganic particles of mixed sizes. Depending on the sources, they have various internal water contents, degree of hydration, and surface chemistry. Sludge characteristics that affect thickening or dewatering and for which conditioning is employed include the following:

- Source

- Solids concentration
- Particle size and distribution
- pH and alkalinity
- Surface charge and degree of hydration
- Other physical factors

## **ii. Elutriation**

- It is washing process of sludge. It is a unit operation in which a solid or semi-solid mixture is intimately mixed with a liquid for the purpose of transferring certain components to the liquid.
- This is achieved with dilution with water of lower alkalinity followed by sedimentation and decantation.
- Some end products of digestion such as ammonium bicarbonate which exert increased demand of chemicals in conditioning are removed in this process.
- 3 methods of elutriation are there. They are
  1. Single Stage
  2. Multi Stage
  3. Counter Current Washing.
- For a given alkalinity reduction single stage elutriation requires 2.5 times as much water as the two stage and 5 times as much water as counter-current washing.
- Hence single stage washing is used only in small plants.
- Water requirement also depends upon alkalinity of dilution water, alkalinity of sludge and desired alkalinity of elutriated sludge.
- Sludge and water are mixed in a chamber with mechanical mixing arrangement. Detention period is 20seconds.
- A maximum surface loading on settling tank of about  $40 \text{ m}^3/\text{m}^2/\text{day}$  and a detention period of 4 hours are adopted.

## **iii. Thermal Conditioning**

- There are two basic processes for thermal treatment of sludges.
- One, wet air oxidation, is the flameless oxidation of sludges at temperatures of 450 to 550°F.
- The other type, heat treatment, is similar but carried out at temperatures of 350 to 400°F.

- Wet air oxidation reduces the sludge to an ash and heat treatment improves the dewaterability of the sludge. At the lower temperature and pressure, heat treatment is more widely used than the oxidation process.
- When the organic sludge is heated, heat causes water to escape from the sludge. Thermal treatment systems release water that is bound within the cell structure of the sludge and thereby improves the dewatering and thickening characteristics of the sludge.
- The oxidation process further reduces the sludge to ash by wet incineration.
- Sludge is ground to a controlled particle size and pumped to a particular pressures . Compressed air is added to the sludge (wet air oxidation only), the mixture is brought to a temperature of about 350°F by heat exchange with treated sludge and direct steam injection, and then is processed (cooked) in the reactor at the desired temperature and pressure.
- The hot treated sludge is cooled by heat exchange with the incoming sludge. The treated sludge is settled from the supernatant before the dewatering step. Gases released at the separation step are passed through a catalytic after-burner at 650 to 705°F or deodorized by other means.

**Advantages:**

- More readily dewaterable sludge is produced than with chemical conditioning.
- The process also provides effective disinfection of the sludge.

**Disadvantages:**

- The heat treatment process ruptures the cell walls of biological organisms, releasing not only the water but some bound organic material.
- Creates a problem of separation, treating this highly polluted liquid from the cells. Treatment of this water or liquor requires careful consideration in design of the plant because the organic content of the liquor can be extremely high.

**4. Sludge Dewatering:**

- Sludge dewatering is a physical unit operation used to reduce the moisture content of sludge, and thus to increase the solids concentration.
- Dewatering is accomplished either by air drying in the sludge drying beds or by mechanical means such as vacuum filtration, centrifugation, pressure filtration.

**Purposes of Dewatering:**

1. Cost of trucking sludge to ultimate disposal site is reduced, because of reduced sludge volume consequent to dewatering.
2. Ease in handling dewatered sludge.
3. Increase in calorific value of sludge by removal of moisture, prior to incineration.
4. Rendering the sludge totally odourless and non-putrescible.
5. Dewatering is commonly required prior to land filling to reduce leachate production at landfill.

### **Sludge Drying Beds:**

- This method is dewatering and drying the sludge is specially suitable for those locations where temperature are higher.
- This method consists of applying the sludge on specially prepared open beds of land.
- Sludge drying beds usually consists of bottom layer of gravel of uniform size which is laid on clean sand bed.
- Open jointed drains are laid in the gravel layer to provide positive drainage as the liquid passes through sand and gravel.
- Underdrains are made of vitrified clay pipes or tiles of at least 10cm dia. laid with open joint. Underdrains are placed not more than 6m apart.
- Graded gravel is placed around the underdrains in layers upto 30cm with a minimum of 15cm above the top of under drains.
- Atleast 8cm of the top layer should consist of gravel 3 – 6 mm size.
- Clean sand of effective size of 0.5 to 0.75 mm and uniformity coefficient not greater than 4 is placed.
- The depth of sand may vary from 15 – 30 cm.
- Drying beds of width 6 – 8 m and length of 30 – 45 m are used.
- The area needed for dewatering digested sludge is dependent on total volume of sludge, climate, temperature and location.
- Areas required for drying beds range from 0.1 to 0.15 m<sup>2</sup>/capita with dry solids loading of 80 to 120 kg/m<sup>2</sup> of bed per year for digested primary sludge.
- Sludge should be deposited evenly to a depth of not greater than 20 cm. when the sludge deposited on a well drained bed of sand, the dissolved gases tend to buoy up and float the solids leaving a clear liquid at the bottom.
- The major portion of the liquid drains off in a few hours.

- The sludge cake shrinks producing cracks which accelerates evaporation from the sludge surface
- Dried sludge can be removed by using shovels or forks when the moisture content is less than 70%.
- When the moisture content reaches 40%, the cake becomes lighter and suitable for grinding.



**Fig: Starting the Drying Process**

**Mechanical Methods:**

- Vacuum filtration is the most common mechanical methods of dewatering, filter press and centrifugation being other methods.
- Chemical conditioning is normally required prior to the mechanical methods of dewatering.
- Mechanical methods used may be used to dewater raw or digested sludges.

**Vacuum filters:**

- Vacuum filter consists of a cylindrical drum over which is laid a filtering medium of wool, cloth, synthetic fiber or plastic or stainless steel mesh or coil springs.
- The drum is suspended horizontally so that on quarter of its diameter is submerged in a tank containing sludge.
- Valves and piping are arranged to apply a vacuum on the inner side of the filter media as the drum rotates slowly in the sludge.



**Fig: Vacuum Filters**

- The vacuum holds the sludge against the drum as it continues to be applied as the drum rotates out of sludge tank.
- This pulls water away from the sludge, leaving a moist cake mat at the outer surface. The sludge cake on the filter medium is scrapped from the drum just before it enters the sludge tank again.
- The filtration rate is expressed in kg of dry solids per square meter of medium per hour.

**Centrifugation:**

- Centrifugation is a process of forced solid/liquid separation by centrifugal forces. In this first stage is known as clarification, sludge solids particles settle at a much higher speed they would simply by gravity.
- In second stage compaction occurs and the sludge loses part of its capillary water. The cake is removed from the process after this latter stage.
- As in sludge thickening, centrifugation is a sedimentation process originating from the difference of density between a particle and the surrounding liquid.
- The process may be described by stokes law, which express the settling velocity of a solid particle in a liquid.

$$V = [ g ( \rho_s - \rho_L ) d^2 / ( 1800 \cdot \mu ) ]$$

Where V = settling velocity

g = gravitational constant (m/sqm)



$\rho_s$  = particle density (kg/m<sup>3</sup>)

$\rho_L$  = liquid density (kg/m<sup>3</sup>)

d = avg. particle diameter (m)

$\mu$  = liquid viscosity (kg/m.s)

### **Types of centrifuges:**

1. Vertical shaft centrifuges
2. Horizontal shaft centrifuges (solid bowl type)
  - a. Counter current
  - b. Decanter type

### **Filter press:**

- Filter press were developed aiming at industrial use and later changed them suitable for wastewater sludge dewatering.
- They operate through batch feeding which demands skilled operators. Main advantages of filter press are:
  1. Cake with higher solids concentration than any other mechanical equipment
  2. High solids capture
  3. Quality of liquid effluent

### **Working: (3 stages)**

1. **Filling:** Pumped sludge is admitted into empty gaps between consecutive filter plates. The filling period may reach 20 min, but usual time intervals are 5 – 10 min. The filling pump pressure is sufficient to immediate initiate the solid/liquid separation processes in filter cloth.
2. **Filtration under maximum pressure:** During filtration phase, the applied pressure may reach 170 kPa.

### **3. Cake Discharge**

- The liquid sludge is pumped into the recessed plates, enveloped by filter cloths. Pumping of sludge increases the pressure in the space between plates, and the solids are left attached to the media as the liquid sludge passes through the filter cloth.

- After that a hydraulic piston pushes the steel plate against the polyethylene plates, compressing the cake.
- The filtrate passes through the filter cloth is collected by filtrate channels, the cake is easily removed by pneumatic piston moves back and the plates are separated each other.

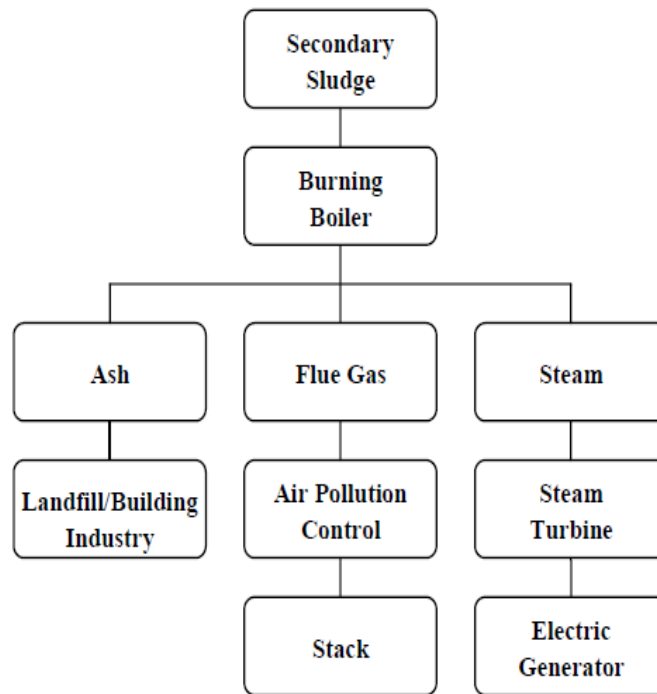
## 5. Incineration:

- Incineration process is the controlled combustion of waste with the recovery of heat to produce steam that in turn produces power through steam turbines.
- The sludge is fed into the boiler, which could be rotary kiln, fixed bed furnace or, common in the paper industry, a fluidized-bed incinerator.
- The incinerator yields products of steam and by-products of ash and flue gas .
- Ash can be disposed directly into the nearest landfill or it can be used as the raw materials of light-weight aggregate and constructional brick in the building industry.
- The flue gas requires treatment through air pollution control before discharge through the stack. However, specifically designed fluidized-bed combustors produce fewer pollutants through the flue gas.
- For power generation the steam is directed through steam turbines, which work to produce power through the electric generator.
- Alternatively steam can be used locally for process steam reducing the mill's dependence on costly fossil fuels for steam production. Typical fluidized bed operating temperature is between 700-900°C.
- Depending on specific waste regulations in Europe 850°C must be achieved for at least 2 seconds, in order to reduce the formation of the toxic compounds such as polychlorinated dibenzodioxins.
- Incineration of residues (both rejects and sludge), combined with power and steam generation, is one of the most commonly applied disposal methods
- Sludge incineration is widely practiced method. Thermal treatment through incineration of sludge for energy recovery is favourable both economically and environmentally.
- In a sludge incineration process, water in the sludge is completely evaporated and the organic matter in the sludge is effectively oxidized at high temperatures to CO<sub>2</sub> and H<sub>2</sub>O, as shown in the following two reactions:

Evaporation:  $\text{H}_2\text{O} (l) \longrightarrow \text{H}_2\text{O} (g)$

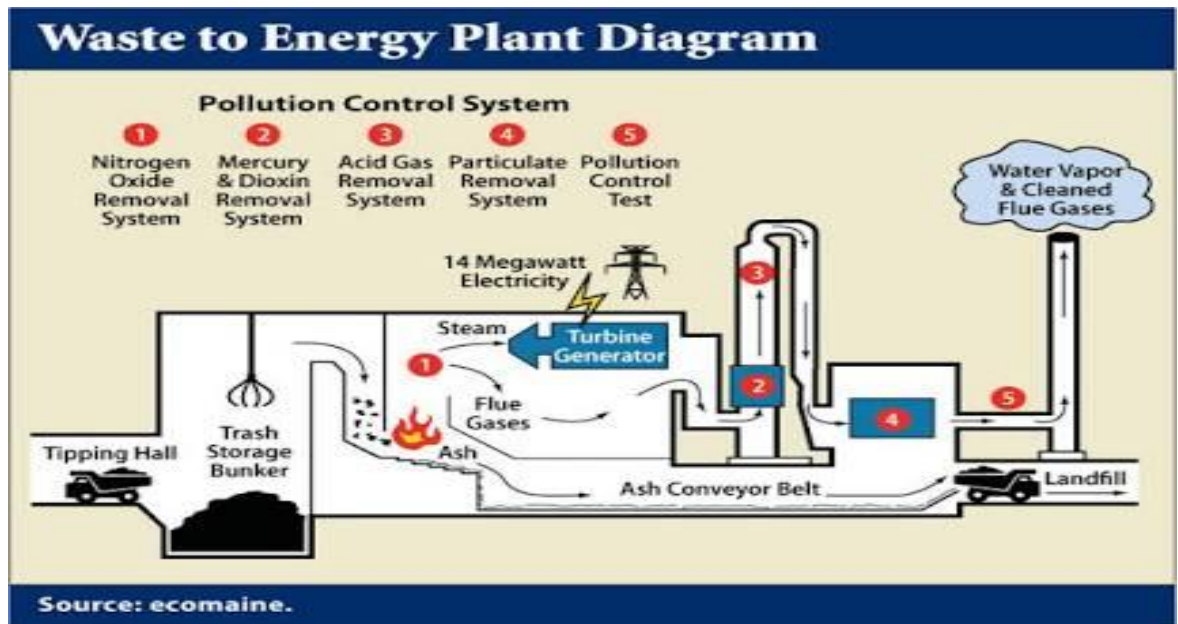
Oxidation and combustion:

sludge solids/organics +  $\text{O}_2 \longrightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{ash} + \text{heat}$



**Fig: Flow Diagram of Incineration**

- Since the water evaporation reaction is highly endothermic, in order to sustain the combustion for sludge with a low TS content, dewatering of the original sludge must be conducted or additional fuels (bark, wood waste and oil, etc.) shall be added containing approximately > 25% combustible/organic content and an ash content of 0-60%, where additional fuels are not necessary. Evaporation, oxidation and combustion occur simultaneously.
- Energy input is required to raise the temperature of the sludge from drying temperature of 105°C to an average reactor temperature of 800°C. The further energy input can be estimated at 2753 kJ per kg of the sludge with 10% total solids (TS). Approximately 30% of the solids remain in the ash, therefore 70% is combusted.



### Multiple Hearth Furnace:

- A Multiple Hearth Furnace is usually employed when a large volume of material needs to be thermally processed, provided that the material is:
  1. Moderately uniform in content
  2. Steady, continuous feed
- Multiple Hearth Furnace can be operated at a wide range of temperatures.
- The hearths allow for zoning of the atmospheres, including temperatures.
- Multiple Hearth Furnaces use burners to heat the furnace, and dry-out the refractory before feed is initiated. Then burners are used to maintain temperatures as needed.
- The burners can burn any fuel. Most common are fossil fuels (Natural Gas, Propane, Oil) but other fuel sources are possible.
- A furnace consisting of several round, stacked hearths. The hearths are basically floors within a large cylinder.
- The hearths alternate between in-hearths and out-hearths.
- In hearths have a large hole in the center, for material to pass through to the hearth below.
- Out-hearths, have holes around the perimeter of the hearth for material to pass through to the hearth below.

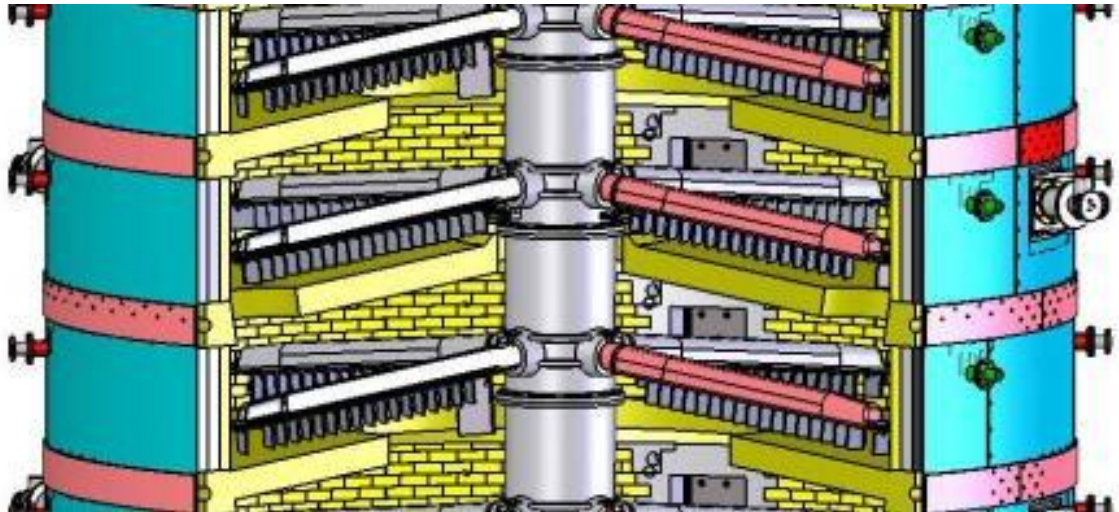


Fig: Multiple hearth furnace

- The multiple hearth furnace consists of a cylindrical lined steel jacket, horizontal layers, and a rotating sleeve shaft with attached agitating arms. The furnace is lined with refractory bricks. The number of trays for drying, incineration, and cooling is determined based on the residual material characteristics. The multiple hearth furnace is also equipped with a start-up burner, sludge dosing mechanism, circulation-, sleeve shaft- and fresh air - blowers.
- Sewage sludge is fed at the top of the furnace and moves downwards through the different hearths counter current to the combustion air, which is fed at the bottom of the furnace. The upper hearths of the furnace provide a drying zone, where the sludge gives up moisture while the hot flue-gases are cooled.
- The material to be incinerated is supplied at the highest furnace layer. It is captured by agitators prockets, divided, and forced through the furnace layers through constant rotation. In a counter direction to the sludge, hot flue-gas is conducted from the highest incineration layer via the drying layers.
- The sludge is dried by the flue-gas and heated to ignition temperature. The circulating air is augmented with steam and volatile particles during the drying process. It is lead towards the lowest incineration layer.
- The incineration mainly takes place on the central hearths. The incineration temperature is limited to 980 °C, as above this temperature the sludge ash fusion temperature will be reached and clinker will be formed. In order to prevent leakage of

hot toxic flue-gases, multiple hearth furnaces are always operated at a slight vacuum pressure.

- The conversion of organic sludge particles into CO<sub>2</sub> and H<sub>2</sub>O occurs at temperatures of between 850 and 950 °C. If the desired incineration temperature cannot be reached independently, a start-up burner is used for support incineration. As an alternative, solid auxiliary fuel can be added to the sludge.
- The ash is cooled to approximately 150 °C at the lower layers of the furnace with counter-flowing cool air and the ash is removed via the ash system. Carbon compounds that have not been converted are oxidised here.

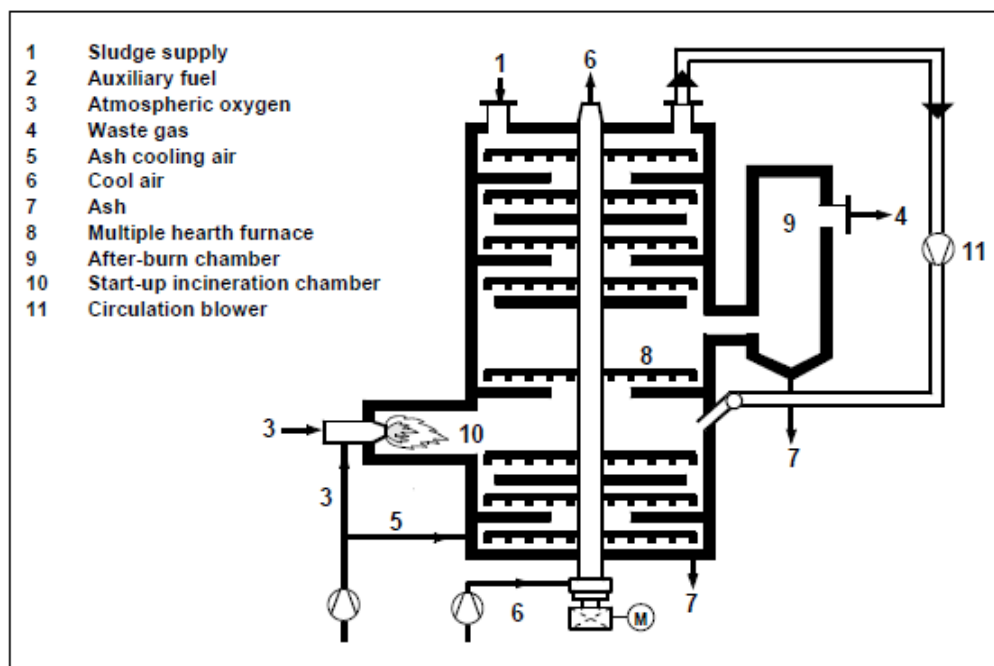
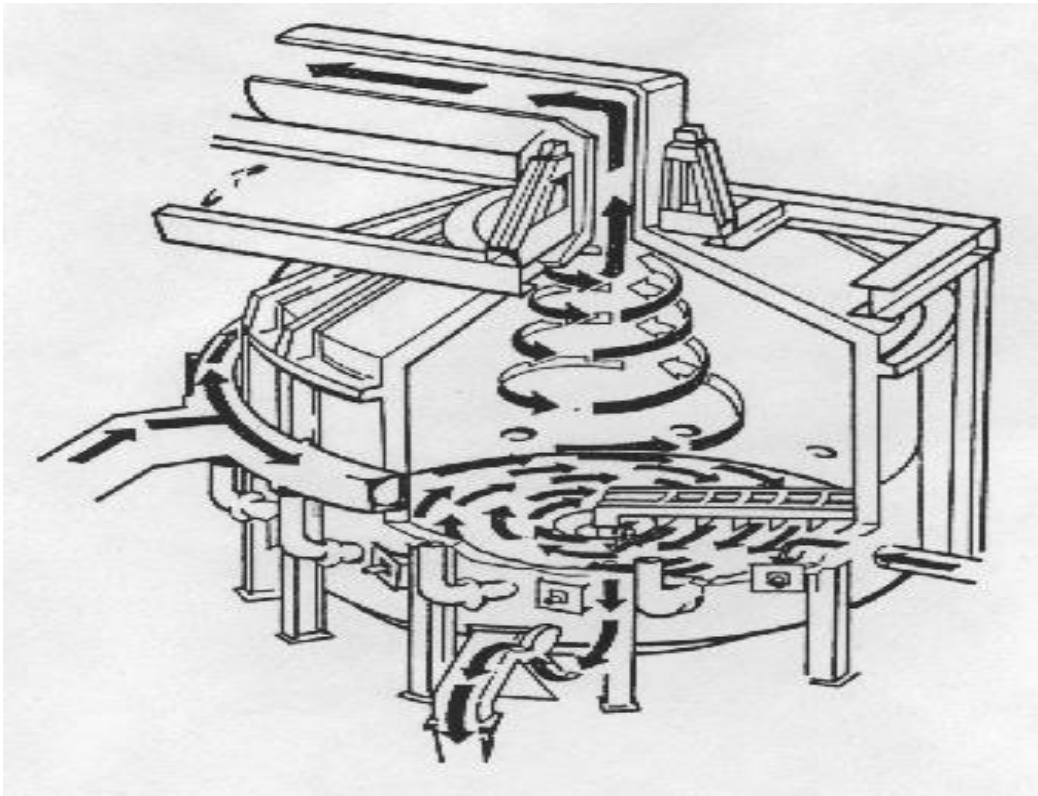


Fig: Multiple hearth furnace

### Cyclone Incineration:

- The cycloid incineration chamber was originally developed for incinerating old coke derived from flue-gas cleaning at waste incineration plants but is now also used for the thermal disposal of sewage sludge. The optimal particle size for fuel ignition lies between 1 and 5 mm.
- Therefore, only dried sewage sludge granules can be used.

- The fuel granules are supplied gravimetrically via a radial chute into the lower part of the incineration chamber, which is designed as a metallic air-cooled hopper. Atmospheric oxygen is blown into the incineration chamber at various air levels:
- The primary air enters the furnace at an angle through the lower part of the hopper, and the secondary air is injected on different levels through tangentially placed jets above the fuel feed. The distribution of primary and secondary air varies according to the specific fuel characteristics.
- The incineration of sewage sludge requires an even temperature distribution of between 900 and 1000 °C throughout the entire incineration chamber. Using this method, the temperature of the ash is maintained under its softening point.
- Flying dust is removed along with flue-gas from the incineration chamber. The coarse kernels circulate in the tangential flow field until they are incinerated to the point that they can be removed as fine kernels. Crude ash, remaining coke, or metallic parts will be removed in a downward direction via a lock system.



**Fig: Cyclone Incineration**

**SLUDGE UTILIZATION AND DISPOSAL:**

Sludge (either wet, dry or incinerated) can be finally disposed off by the following methods :

1. Spreading on farm land
2. 2 Dumping.
3. Land filling
4. Sludge lagooning
5. Disposing in water or sea.

**1. Spreading on farm land:** Dewatered sludge may be disposed of by spreading over farm land and ploughing under after it has dried.

- Wet dewatered sludge can be incorporated into soil directly by injection. Usually a number of shallow trenches, 50 to 90 cm wide and 0.3 to 0.4 m deep are provided about 1 to 1.5 m apart and wet sludge is discharged into it. After a sludge cake is formed due to evaporation of water, it is covered with dry earth.
- After about a month, the whole land is ploughed and used for cultivation. In general, digested sludges are of moderate but definite value as a source of slowly available nitrogen and some phosphate. They are comparable to farmyard manure except for deficiency in potash.
- They also contain many essential elements to plant life and minor nutrients in the form of trace metals.
- The sludge humus also increases the water holding capacity of soil and reduces soil erosion making an excellent soil conditioner specially in arid region by making available needed humus content which results in greater fertility.

**2. Dumping:** Dumping in an abandoned mine quarry can be resorted to only for sludges and solids that have been stabilized to that no decomposition or nuisance conditions will result. This method can be safely adopted for digested sludge, clean grit and incinerator residue.

**3. Disposal by Land filling:** If a suitable site is convenient, a sanitary landfill can be used for disposal of sludge, grease, grit and other solids, whether stabilised or not. However, dewatering is recommended before such disposal, so that the cost of hauling the sludge is reduced. In a true sanitary landfill, the wastes are deposited in a designated area, compacted in place with a tractor or roller and covered with 30 cm



layer of clean soil. The sanitary land fill method is most suitable if it is also used for disposal of the other solids wastes of the community. However, drainage from the site that would cause pollution of ground water supplies or surface streams must be guarded against

- 4. Sludge lagooning:** A lagoon is a shallow earth basin into which untreated or digested sludge is deposited. Untreated-sludge lagoons stabilize the organic solids by anaerobic and aerobic decomposition, which may give rise to objectionable odours. Hence the lagoons should be located away from the town.
  - The depth of the lagoon may vary from 0.5 to 1.5 m.
  - The depth of the lagoon and its area should be about twice that is required for sand drying under comparable conditions.
  - Agricultural tile drains of about 10 cm dia. are placed at 3 m centres at the bottom of the lagoon, and a 15 cm thick layer of ashes or clinker is placed over it to facilitate drain of water from wet sludge
  - . The detention time may vary from 1 to 2 months.
  - After the sludge has been stabilized and the moisture is drained/evaporated, the contents of the lagoon are dug out to about half of its volume and used as manure.
- 5. Disposal in water or sea:** This is not commonly used method of disposal because it is contingent on the availability of a large body of water adequate to permit dilutions.
  - At some sea coast sites, the sludge either raw or digested may be barged to sea far enough to make available the required dilution and dispersion.
  - The method requires careful consideration of all factors for proper design and siting to outfall to prevent any coastal pollution or interference and navigation.

## **TERTIARY SEWAGE TREATMENT**

### **INTRODUCTION**

- Secondary treatment removes 85 to 95 percent of BOD and TSS and minor portions of nitrogen, phosphorus and heavy metals. Tertiary treatment is the next wastewater treatment process after secondary treatment.
- This treatment is sometimes called as the final or advanced treatment and consists of removing the organic load left after secondary treatment for removal of nutrients from sewage and particularly to kill the pathogenic bacteria.

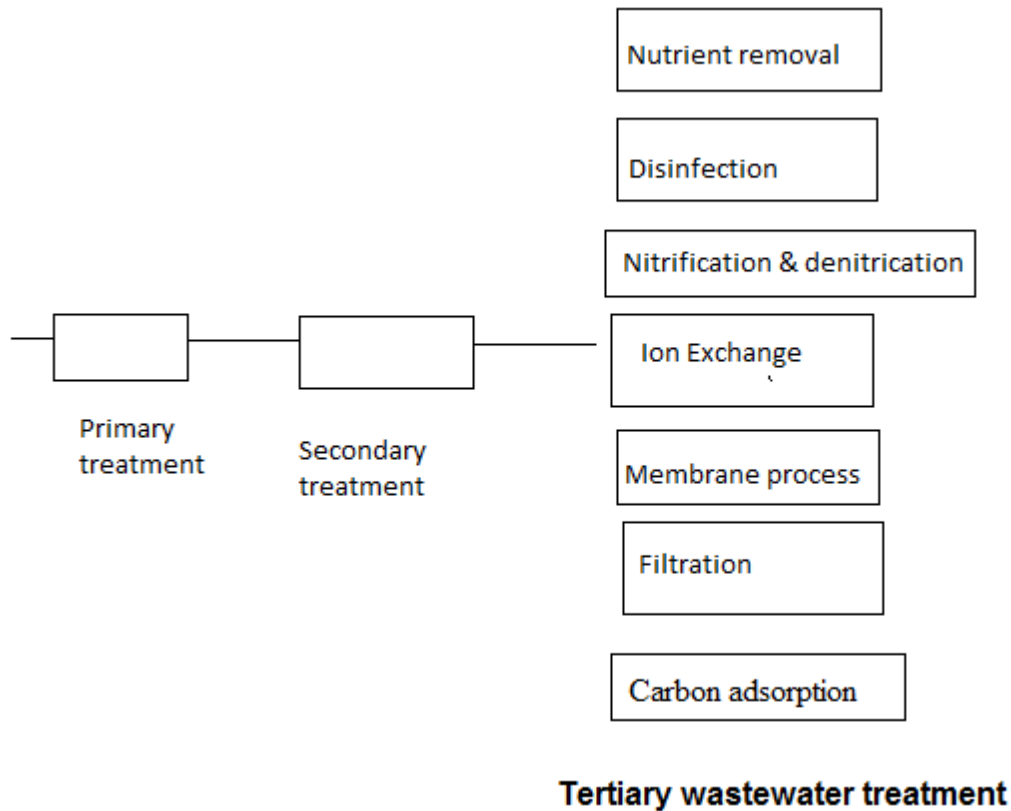
- The effluents from secondary sewage treatment plants contain both nitrogen (N) and phosphorus (P). N and P are ingredients in all fertilizers. When excess amounts of N and P are discharged, plant growth in the receiving waters may be accelerated which results in eutrophication in the water body receiving such waste.
- Algae growth may be stimulated causing blooms which are toxic to fish life as well as aesthetically unpleasing. Secondary treated effluent also contains suspended, dissolved, and colloidal constituents which may be required to be removed for stipulated reuse or disposal of the treated effluent.
- The purpose of tertiary treatment is to provide a final treatment stage to raise the effluent quality before it is discharged to the receiving environment such as sea, river, lake, ground, etc., or to raise the treated water quality to such a level to make it suitable for intended reuse.
- This step removes different types of pollutants such as organic matter, SS, nutrients, pathogens, and heavy metals that secondary treatment is not able to remove. Wastewater effluent becomes even cleaner in this treatment process through the use of stronger and more advanced treatment systems.
- It includes sedimentation, coagulations, membrane processes, filtration, ion exchange, activated carbon adsorption, electro dialysis, nitrification and denitrification, etc. Tertiary treatment is costly as compared to primary and secondary treatment methods.

### **Need of Tertiary treatment**

Tertiary treatment may be provided to the secondary effluent for one or more of the following contaminant further.

- To remove total suspended solids and organic matter those are present in effluents after secondary treatment.
- To remove specific organic and inorganic constituents from industrial effluent to make it suitable for reuse.
- To make treated wastewater suitable for land application purpose or directly discharge it into the water bodies like rivers, lakes, etc.
- To remove residual nutrients beyond what can be accomplished by earlier treatment methods.
- To remove pathogens from the secondary treated effluents.

- To reduce total dissolved solids (TDS) from the secondary treated effluent to meet reuse quality standards.
- One or more of the unit operation/ process will be used for achieving this tertiary treatment. (shown in below fig.)



**Figure:** Process involved in tertiary wastewater treatment

## Tertiary Treatments

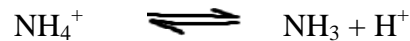
In advanced wastewater treatment, treatment options or methods are dependent upon the characteristics of effluent to be obtained after secondary treatment to satisfy further use or disposal of treated wastewater.

### Nitrogen removal

Wastewater containing nutrients includes sewage, agriculture runoff and many of the industrial effluents. The nutrients of most concerned are N and P. The principal nitrogen compounds in domestic sewage are proteins, amines, amino acids, and urea. Ammonia nitrogen in sewage results from the bacterial decomposition of these organic constituents.

- The nitrogen compounds results from the biological decomposition of proteins and from urea discharged in body waste. This nitrogen is in complex organic molecules and is referred simply as organic nitrogen. Organic nitrogen may be biologically

converted to free ammonia ( $\text{NH}_3^0$ ) or to the ammonium ion ( $\text{NH}_4^+$ ) by one of several different metabolic pathways. These two exist in equilibrium as



- Ammonia nitrogen is the most reduced nitrogen compound found in wastewater, which can be biologically oxidized to nitrate if molecular oxygen is present (under aerobic condition). In wastewater, the predominant forms of nitrogen are organic nitrogen and ammonia. The nitrification may take place in biological treatment units provided the treatment periods are long enough. Generally, for the HRT used in secondary treatment conversion of organic nitrogen to ammonia is significant and nitrification may not be significant. Because of oxygen demand exerted by ammonia (about 4.6 mg of  $\text{O}_2$  per mg of  $\text{NH}^+$ -N oxidized) and due to other environmental factors, removal of ammonia may be required. The most common processes for removal of ammonia from wastewater are

- i) Air stripping,
- ii) Biological nitrification and denitrification.

#### **i. Air stripping**

It consists of converting ammonium to gaseous phase and then dispersing the liquid in air, thus allowing transfer of the ammonia from wastewater to the air. The gaseous phase  $\text{NH}_3^0$

and aqueous phase  $\text{NH}_4^+$  exist together in equilibrium. The relative abundance of these phases depends upon both the pH and the temperature of the wastewater. The pH must be greater than

11 for complete conversion to  $\text{NH}_3$ . Since, this pH is greater than pH of normal wastewater, adjustment of pH is necessary prior to air stripping. Addition of lime is the most common means for raising the pH. Enough lime must be added to precipitate the alkalinity and to add the excess  $\text{OH}^-$  ions for pH adjustment.

The most important and efficient reactor for air stripping is counter current spray tower. Larger quantity of air is required, and fan must be installed to draw air through tower. Packing is provided to minimize the film resistance to gas transfer by continuously forming, splashing and reforming drops. The air to wastewater ratio ranging from 2000 to 6000  $\text{m}^3$  of air/ $\text{m}^3$  of wastewater is used for design. Air requirement is more at lower temperature. Tower depths are generally less than 7.5m, and hydraulic loading vary from 40 to 46  $\text{L}/\text{min}.\text{m}^2$  of tower. The limitation to this process occurs at temperature close to freezing temperature.

Drastic reduction in efficiency is observed and preheating of gas is not possible because of high volume.

The other problems associated with this include noise and air pollution and scaling of the packing media. Noise pollution problem is caused by roar of the fan. The odour problem is due to dispersion of ammonia gas in atmosphere, due to which this technique may not be permitted at some location. This problem 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 PVC pipe as packing material. The occasional cleaning of packing media is still required.

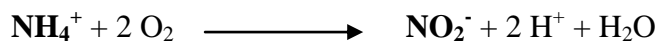
### **Biological Nitrification and De-nitrification:**

Bacteria remove ammonia nitrogen from wastewater by a two-step biological processes: Nitrification followed by de-nitrification to convert it finally to gaseous nitrogen. In this gaseous form  $N_2$  is inert and does not react with the wastewater itself or with other constituents present in wastewater. Since, treated wastewater is likely to be saturated with molecular nitrogen, the produced  $N_2$  is simply released to the atmosphere. These two steps involved require different environmental conditions and hence generally they are carried out in separate reactors.

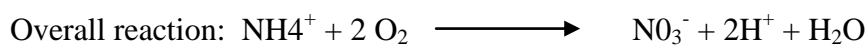
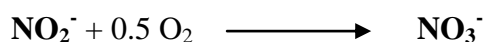
### **Nitrification**

It has important role in nitrogen removal from wastewater during treatment. The biological conversion of ammonium to nitrate nitrogen is called Nitrification. It is autotrophic process i.e. energy for bacterial growth is derived by oxidation of nitrogen compounds such as ammonia. In this process, the cell yield per unit substrate removal is smaller than heterotrophs. Nitrification is a two-step process. In first step, bacteria known as Nitrosomonas can convert ammonia and ammonium to nitrite. These bacteria known as nitrifiers are strictly aerobes. This process is limited by the relatively slow growth rate of Nitrosomonas. Next, bacteria called Nitrobacter finish the conversion of nitrite to nitrate.

Conversion of Ammonia to Nitrite (*Nitrosomonas*)



Conversion of Nitrite to Nitrate (*Nitrobacter*)



*Nitrosomonas* and *Nitrobacter* use the energy derived from the reactions for cell growth and maintenance. Some of ammonium ions are assimilated into cell tissues.

Neglecting this ammonium ion used in cell synthesis the  $O_2$  required to oxidize ammonia to nitrate is 4.57 mg

$O_2$ /mg ammonium nitrogen. If the ammonium used in cell,  $O_2$  required is considered it is 4.3 mg  $O_2$ /mg ammonium nitrogen and about 7.14 mg of alkalinity is needed to neutralize the  $H^+$  produced. Nitrification may be used to prevent oxygen depletion from nitrogenous demand in the receiving water. Nitrification requires a long retention time, a low food to microorganism ratio (F/M), a high mean cell residence time (MCRT), and adequate alkalinity. Wastewater temperature and pH affects the rate of nitrification.

Under favourable conditions, carbon oxidation and nitrification may occur in a single reactor called single stage under favourable conditions. In separate stage carbon oxidation and nitrification occur in different reactors. It can be accomplished in both suspended and attached growth process such as trickling filter, ASP, rotating disc biological contactor (RBC), SBR, etc. Also, nitrifying organisms are present in almost all aerobic process sludge but they are less in number. In nitrification, when ratio of  $BOD_5$  to TKN is greater than 5, the process is called as combined carbon oxidation and nitrification, whereas, when ratio of  $BOD_5$  to TKN is less than 3, the process is called as separate stage carbon oxidation and nitrification.

For single stage carbon oxidation and nitrification, plug flow, completely mixed and extended aeration ASP can be used. Oxidation ditch is also one of option for this process. The attached growth processes like TF and RBC are commonly used. Nitrification can be achieved by reducing applied loading rate, increasing the mean cell residence time ( $\theta_c$ ) and air supply.

Nitrifying bacteria are sensitive organisms. A variety of organic and inorganic agents can inhibit the growth and action of these organisms. High concentration of ammonia and nitrous acid can be inhibitory.

The effect of pH is also significant with optimal range of 7.5 to 8.6. The system acclimatize to lower pH can also work successfully. The temperature also has considerable impact on growth of the nitrifying bacteria. Dissolved oxygen concentration above 1 mg/L is essential for nitrification. Below this DO, oxygen becomes the limiting nutrients and nitrification slows down or ceases.

### **De-nitrification**

In some applications, such as discharge of effluent into enclosed water bodies or recycle to water supplies, nitrification may not be sufficient. When nitrogen removal is required, one of the available methods is to follow biological nitrification with de-

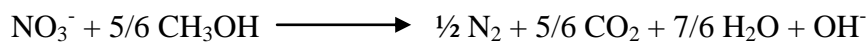
nitrification. De-nitrification is accomplished under anaerobic or near anaerobic conditions by facultative heterotrophic bacteria commonly found in wastewater. Nitrates are removed by two mechanisms: (1) conversion of  $\text{NO}_3^-$  to  $\text{N}_2$  gas by bacterial metabolism and (2) conversion of  $\text{NO}_3^-$  to nitrogen contained in cell mass which may be removed by settling. De-nitrification occurs when oxygen levels are depleted and nitrate becomes the primary electron acceptor source for microorganisms.

Nitrate,  $\text{NO}_3^- \longrightarrow$  Nitrite,  $\text{NO}_2^- \longrightarrow$  Nitric oxide,  $\text{NO} \longrightarrow$  Nitrous oxide,  $\text{N}_2\text{O} \longrightarrow \text{N}_2$

Denitrifying bacteria are facultative organisms, they can use either dissolved oxygen or nitrate as an oxygen source for metabolism and oxidation of organic matter. This is carried out by

heterotrophic bacteria such as *pseudomonas*, *spirillum*, *lactobacillus*, *bacillus*, *microaoccus*, etc.

For reduction to occur, the DO level must be near to zero, and carbon supply must be available to the bacteria. Because of low carbon content is required for the previous nitrification step, carbon must be added before de-nitrification can proceed. A small amount of primary effluent, by passed around secondary and nitrification reactor can be used to supply the carbon. However, the un-nitrified compounds in this water will be unaffected by the de-nitrification process and will appear in effluent. When complete nitrogen removal is required, an external source of carbon containing no nitrogen will be required. The most commonly used external source of nitrogen is methanol. When methanol is added the reaction is



For treatment plant above 3 mg/L of methanol is required for each milligram per litre of nitrate, making this process an expensive. Alkalinity is generated in this process. De-nitrification can be carried out as attached growth (anaerobic filter) and suspended growth process (expanded bed or UASB reactor).

### **REMOVAL OF PHOSPHORUS:**

Normally secondary treatment can only remove 1-2 mg/l of phosphorus, so a large excess of phosphorus is discharged in the final effluent, causing eutrophication of lakes and natural water bodies. Generally it appears as orthophosphate, polyphosphate and organically bound phosphorus. Phosphorus is required for microbes for cell synthesis and energy transport, maintenance as well as it is stored for subsequent use by microbes. During secondary treatment process about 10 to 30 % of influent phosphorus is removed (Metcalf &

Eddy, 2003). Phosphate removal is currently achieved largely by chemical precipitation, which is expensive and causes an increase of sludge volume by up to 40%. An alternative is the biological phosphate removal (BPR), which is accomplished by sequencing and producing the appropriate environmental condition in the reactors.

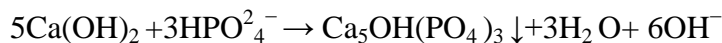
*Acinetobacter* organisms are helpful for removal of phosphorus from effluent. Under anaerobic conditions, phosphorus accumulating organisms (PAO) assimilate fermentation products (i.e. volatile fatty acids) into storage products within the cells with the concomitant release of phosphorus from stored polyphosphates (Gray, 2005). Release of phosphorus occurs under anoxic condition. The BPR requires both aerobic and anaerobic zones in reactors for efficient treatment. Generally, lime precipitation is most commonly used for phosphorus removal. Phosphorus is removed in the waste sludge from the system.

Treatment technologies presently available for phosphorus removal include:

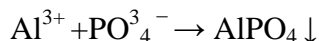
1. Physical:
  - a. Filtration for particulate phosphorus
  - b. Membrane technologies
2. Chemical:
  - a. Precipitation
  - b. Other (mainly physical-chemical adsorption)
3. Biological

#### **Phosphate removal (chemical treatment):**

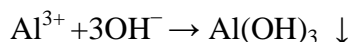
Phosphate may be removed chemically or biologically. The most popular chemical methods use lime,  $\text{Ca}(\text{OH})_2$  and alum,  $\text{Al}_2(\text{SO}_4)_3$ . Under alkaline conditions, the calcium will combine with phosphate to form calcium hydroxyapatite, a white insoluble precipitate that is settled out and removed from waste water. Insoluble calcium carbonate is also formed and removed.



The aluminium ion from alum precipitates as very slightly soluble aluminium phosphate,



and also forms aluminium hydroxide.



which forms sticky flocs that help to settle out phosphates.



### **Phosphorus removal (biological treatment)**

- Biological phosphorous removal does not require the addition of chemicals. In this process, the aeration tank in the activated sludge system is subdivided into zones, some of which are not aerated.
- In these zones, the aerobic microorganisms become solely stressed because of the lack of oxygen.
- If these microorganisms are then transferred to an aerated zone, they try to make up for lost time and assimilate organic matter (as well as phosphorous) at a rate much higher than they ordinarily would.
- Once the microorganisms have adsorbed the phosphorous, they are removed as waste activated sludge, thus carrying with them high concentrations of phosphorous. Using such sequencing of non-aerated and aerated zones, it is possible to remove as much as 90% of the phosphorous.

### **REMOVAL OF SUSPENDED SOLIDS:**

This treatment implies the removal of those materials that have been carried over from a secondary treatment settler. Many methods were proposed of which two methods were commonly used. The two methods are micro-straining and chemical coagulation followed by settling and mixed media filtration.

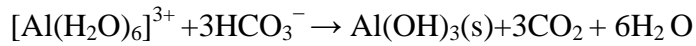
#### **Microstraining:**

It is a special type of filtration procedure which makes use of filters over from stainless steel wires with opening only 60-70  $\mu\text{m}$  across to remove very small particles. High flow rates and low back pressures are normally achieved.

#### **Coagulation and flocculation:**

The object of coagulation is to alter these particles in such a way as to allow them to adhere to each other. Most colloids of interest in water treatment remain suspended in solution because they have a net negative surface charge that causes the particles to repel each other. The intended action of the coagulant is to neutralise that charge, allowing the particles to come together to form larger particles that can be more easily removed from the raw water.

The usual coagulant is alum [ $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$ ], though  $\text{FeCl}_3$ ,  $\text{FeSO}_4$  and other coagulants, such as polyelectrolytes, can be used. Alum when added to water, the aluminium in this salt hydrolyses by reactions that consume alkalinity in the water such as:



The gelatinous hydroxide thus formed carries suspended material with it as it settles. In addition, however, it is likely that positively charged hydroxyl-bridged dimers such as and higher polymers are formed which interact specifically with colloidal particles, bringing about coagulation. Metal ions in coagulants also react with virus proteins and destroy upto 99% of the virus in water.

Anhydrous iron (III) sulphate can also act as effective coagulant similar to aluminium sulfate. An advantage with iron (III) sulfate is that it works over a wide range of pH.

### **Filtration:**

If properly formed, the addition of chemicals for promoting coagulation and flocculation can remove both suspended and colloidal solids. After the flocs are formed, the solution is led to a settling tank where the flocs are allowed to settle. While most of the flocculated material is removed in the settling tank, some floc do not settle. These flocs are removed by the filtration process, which is usually carried out using beds of porous media such as sand or coal. The current trend is to use a mixed-media filter which consists of fine garnet in the bottom layer, silica sand in the middle layer and coarse coal in the top layer which reduces clogging.

### **REMOVAL OF HEAVY METALS:**

Heavy metals are elements having atomic weights between 63.5 and 200.6, and a specific gravity greater than 5.0. Most of the heavy metals are dangerous to health or to the environment. Heavy metals in industrial wastewater include lead, chromium, mercury, uranium, selenium, zinc, arsenic, cadmium, silver, gold, and nickel. The main threats to human health from heavy metals are associated with exposure to lead, cadmium, mercury and arsenic. These metals have been extensively studied and their effects on human health regularly reviewed by international bodies such as the WHO. Acute heavy metal intoxications may damage central nervous function, the cardiovascular and gastrointestinal (GI) systems, lungs, kidneys, liver, endocrine glands, and bones. Chronic heavy metal exposure has been implicated in several degenerative diseases of these same systems and may increase the risk of some cancers.

### **Various Conventional Methods of Heavy Metal Removal**

#### **Chemical precipitation**

Chemical precipitation processes involve the addition of chemical reagents, followed by the separation of the precipitated solids from the cleaned water. Precipitation of metals is achieved by the addition of coagulants such as alum, lime, iron salts and other organic polymers. 80% removal of Zn, Cu, and Pb, and up to 96.2% removal of oil from industrial wastewaters by using a joint hydroxide precipitation and air floatation system has been noticed.

### **Electrodialysis**

Electro Dialysis (ED) is a membrane process, during which ions are transported through semi permeable membrane, under the influence of an electric potential. The membranes are cation- or anion-selective, which basically means that either positive ions or negative ions will flow through. Cation -selective membranes are polyelectrolytes with negatively charged matter, which rejects negatively charged ions and allows positively charged ions to flow through.

### **Coagulation/ flocculation**

Coagulation and flocculation are an essential part of drinking water treatment as well as wastewater treatment. Coagulation is the chemical reaction which occurs when a chemical or coagulant is added to the water. The coagulant encourages the colloidal material in the water to join together into small aggregates called “flocs”. Suspended matter is then attracted to these flocs. Flocculation is a slow gentle mixing of the water to encourage the flocs to form and grow to a size which will easily settle out.

### **Ultrafiltration**

Ultrafiltration is a separation process using membranes with pore sizes in the range of 0.1 to 0.001 micron. Typically, ultrafiltration will remove high molecular-weight substances, colloidal materials, and organic and inorganic polymeric molecules. It is a pressure-driven purification process in which water and low molecular weight substances permeate a membrane while particles, colloids, and macromolecules are retained. The primary removal mechanism is size exclusion, although the electrical charge and surface chemistry of the particles or membrane may affect the purification efficiency.

### **Reverse osmosis**

In the reverse osmosis process cellophane-like membranes separate purified water from contaminated water. RO is when a pressure is applied to the concentrated side of the membrane forcing purified water into the dilute side, the rejected impurities from the concentrated side being washed away in the reject water. Applications that have been reported for RO processes include the treatment of organic containing wastewater,

wastewater from electroplating and metal finishing, pulp and paper, mining and petrochemical, textile, and food processing industries, radioactive wastewater, municipal wastewater, and contaminated groundwater.

### **Adsorption**

Adsorption is a process that occurs when a gas or liquid solute accumulates on the surface of a solid or a liquid (adsorbent), forming a molecular or atomic film (the adsorbate). Adsorption is operative in most natural physical, biological, and chemical systems, and is widely used in industrial applications such as activated charcoal, synthetic resins and water purification. Among these methods, adsorption is currently considered to be very suitable for wastewater treatment because of its simplicity and cost effectiveness. Adsorption is commonly used technique for the removal of metal ions from various industrial effluents. Activated carbon is the most widely used adsorbent. It is a highly porous, amorphous solid consisting of micro crystallites with a graphite lattice, usually prepared in small pellets or a powder. It can remove a wide variety of toxic metals. Some widely used adsorbents for adsorption of metal ions include activated carbon, clay minerals, biomaterials, industrial solid wastes and zeolites. Natural material or certain waste from industrial or agricultural operation is one of the resources for low cost adsorbents. Generally, these materials are locally and easily available in large quantities. Therefore, they are inexpensive and have little economic value. Scattered research has already been conducted on a wide variety of sorbents. Some of the reported low-cost sorbents include bark/tannin-rich materials, lignin, chitin/chitosan, dead biomass, seaweed/algae/alginate, xanthate, zeolite, clay, ash, peat moss, bone gelatin beads, leaf mould, moss, iron-oxide-coated sand, modified wool, modified cotton.

## **REMOVAL OF PATHOGENIC BACTERIA:**

### **Disinfection**

The wastewater normally contain some harmful disease producing bacteria in it. These bacteria must be killed in order to make the water safe for drinking. The process of killing these pathogenic bacteria is known as Disinfection.

### **Methods of Disinfection:**

1. **Boiling:** The bacteria present in water can be destroyed by boiling it for a long time. However it is not practically possible to boil huge amounts of water. Moreover it cannot take care of future possible contaminations.
2. **Treatment with Excess Lime:** Lime is used in water treatment plant for softening. But if excess lime is added to the water, it can in addition, kill the bacteria also. Lime when added

raises the pH value of water making it extremely alkaline. This extreme alkalinity has been found detrimental to the survival of bacteria. This method needs the removal of excess lime from the water before it can be supplied to the general public. Treatment like re-carbonation for lime removal should be used after disinfection.

3. **Treatment with Ozone:** Ozone readily breaks down into normal oxygen, and releases nascent oxygen. The nascent oxygen is a powerful oxidising agent and removes the organic matter as well as the bacteria from the water.

4. **Chlorination:** The germicidal action of chlorine is explained by the recent theory of Enzymatic hypothesis, according to which the chlorine enters the cell walls of bacteria and kill the enzymes which are essential for the metabolic processes of living organisms.

#### **REMOVAL OF REFRACTORY ORGANICS:**

- Refractory organics are removed by activated carbon method.
- Dose is determined by freundlich isotherm

$$x/m = k C^{1/n}$$

where x = amount of refractory organics adsorbed in mg.

m = Mass of activated carbon in g

k = Bonding Energy

n = Constant of adsorption

C = Equilibrium concentration in mg/l

Just like jar test, add coagulants to the six beakers, stir it for 30 min. and resting period of 6 hrs is given for the sample in beakers.