STUDY MODULE- XIV

Wastewater Treatment

(The Fundamentals of Water Treatment Processes: Physical, Chemical, and Biological)

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Preface

Waste-water treatment is becoming more important in the light of diminishing water resources. The treatment of waste-water for reuse and disposal is particularly important for water scarce countries like Pakistan. The municipal sector consumes significant volumes of water, and consequently generates considerable amounts of waste-water discharge. Municipal waste-water is a combination of water and water-carried wastes originating from homes, commercial and industrial facilities, and institutions. Treatment of waste water is a complex process. Selection of treatment process is based on type of waste water composition and availability of resources. This module describes Fundamentals of wastewater treatment processes

Learning Objectives

- To describe the typical composition of raw wastewater.
- To understand the effects of wastewater discharges on the receiving stream.
- To understand basics of wastewater treatment process used in various wastewater techniques.

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UNIT 1:
INTRODUCTION TO WASTE WATER TREATMENT

1 INTRODUCTION TO FUNDAMENTALS OF WASTEWATER TREATMENT

Municipal waste-water is the combination of liquid or water-carried wastes originating in the sanitary Conveniences of dwellings, commercial or industrial facilities and institutions. Untreated waste-water generally contains high levels of organic material, numerous pathogenic microorganisms, as well as nutrients and toxic compounds. It thus entails environmental and health hazards and, consequently, must immediately be conveyed away from its generation sources and treated appropriately before final disposal. The ultimate goal of waste-water management is the protection of the environment in a manner commensurate with public health and socio-economic concerns.

1.1 Characteristics of Wastewater

Wastewater contains many substances that are considered impurities. Impurities are any substances that are not found in “pure” water Pure water is 2 parts hydrogen, 1 part oxygen. In nature, water contains many dissolved impurities.

In fact, water is referred to as “the universal solvent” due to its ability to dissolve many substances.

- Even distilled water and rainfall are not “completely” pure because they usually contain very low levels of dissolved substances such as ammonia, which are considered impurities.
- There are dissolved substances found in surface and ground water.
- As rain falls, nitrogen and other gasses are absorbed.
- Water, as it travels through the ground, can dissolve substances from the earth such as sodium, calcium, iron, phosphorus, magnesium, and sulfate.

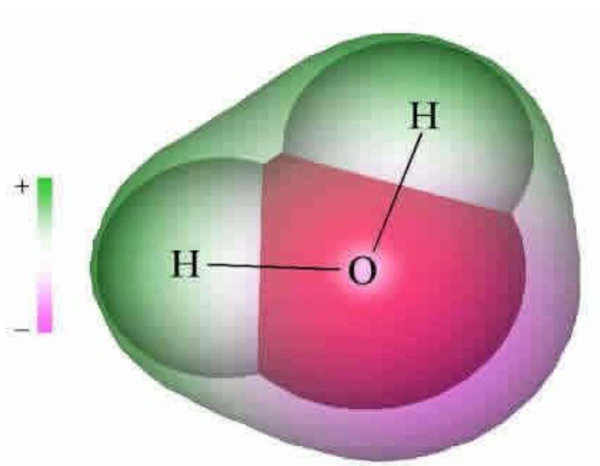

Figure 1: Structure of water molecule

1.2 Contaminants Typically Found in Untreated Wastewater

Fresh domestic untreated or raw wastewater has a musty odor, a pH range of 6.5 to 8.0 and is grayish brown in color. Types of contaminants typically found in untreated wastewater and the importance of each is presented in Table 1. These contaminants can be broadly categorized into four basic classes:

- Organic contaminants;
- Inorganic contaminants
- Pathogens; and
- Other contaminants.

1.2.1 Organic Contaminants

Organic contaminants are derived from animals and plants, or may be manufactured chemical compounds. However, all organics contain carbon. Organic contaminants can be biodegradable, which means that the contaminants can be consumed by bacteria and other microorganisms. In the process of being consumed, these organics will exert an oxygen demand which can be measured as the Biochemical Oxygen Demand (BOD) of the wastewater. Some organic contaminants (refractory organics) are resistant to biodegradation.

1.2.2 Inorganic Contaminants

Inorganic contaminants are not biodegradable, but may be nutrients necessary for microorganisms to live. These are typically chemical compounds (priority pollutants) or metals that are either present in the wastewater as suspended solids or as dissolved inorganics.

- Examples of inorganic contaminants include:
- The sodium chloride byproduct from the water softening process adds to the total dissolved solid content in water.
- Nutrients such as phosphorus and ammonia-nitrogen. Both of these nutrients are typically found in domestic sewage, internal recycle flows (belt press filtrate or anaerobic digester supernate), and trucked in wastes.
- The filter backwash from drinking water facilities is often high in suspended solids and low in organic loading.
- Street cleaning or sidewalk washing introduces soil, sand, or grit.
- Copper (a heavy metal) dissolved from household plumbing. • Other toxic metals from industrial processes.

1.2.3 Pathogens

Pathogens are disease-causing organisms including bacteria and viruses that can be deposited in the wastewater through human or animal wastes, or from improperly handled hospitals wastes. Proper hygiene is extremely important when working around wastewater.

Because the potential disease is so great, it is important that wastewater be treated and disinfected to inactivate the pathogens prior to discharge to the receiving stream. It is particularly important if the receiving stream is used for recreational purposes (e.g., boating, swimming and fishing) or as a drinking water source.

1.2.4 Solids

1.2.4.1 Total Solids

Total solids include both dissolved and suspended materials.

1.2.4.2 Suspended solids are those which cannot be dissolved in water like mud particles, straw etc. and include both non settle-able and settle-able materials.

1.2.4.3 Dissolved Solids will pass through a standard glass fiber filter. Dissolved solids weight is the difference in weight between total solids and suspended solids.

When a sample is filtered through fine mesh filter (example - 0.45 micron membrane filter), the suspended solids are captured on the filter pad and the dissolved solids will remain in the water passing through the filter.

Table 1: Typical contaminants of wastewater

Contaminant	**Effects**
Suspended solids	Suspended solids can lead to the development of sludge deposits and anaerobic conditions when untreated wastewater is discharged in the aquatic environment.
Biodegradable organics	Composed principally of proteins, carbohydrates, and fats, biodegradable organics are measured most common in terms of BOD (biochemical oxygen demand) and COD (chemical oxygen demand). If discharged untreated to the environment, their biological stabilization can lead to the depletion of natural oxygen resources and to the development of septic conditions.
Pathogens	Communicable diseases can be transmitted by the pathogenic organisms in wastewater.

Nutrients	Both nitrogen and phosphorus, along with carbon, are essential nutrients for growth. When discharged to the aquatic environment, these nutrients can lead to the growth of undesirable aquatic life. When discharged in excessive amounts on land, they can also lead to the pollution of groundwater.
Priority pollutants	Organic and inorganic compounds selected on the basis of their unknown or suspected carcinogenicity, mutagenicity, or high acute toxicity. The presence of these compounds in wastewater must be minimized for public health reasons and to protect the biological treatment processes.
Refractory organics	These organics tend to resist conventional methods of wastewater treatment. Typical examples include surfactants, phenols, and agricultural pesticides. Some of these may be toxic to the biological treatment processes.
Heavy metals	Heavy metals are usually added to wastewater from commercial and industrial activities and may have to be removed if the wastewater is discharged to a stream used as a potable water source. The presence of heavy metals may also impact the recycling of biosolids (stabilized waste sludge) on farmland.
Dissolved inorganics	Inorganic constituents such as calcium, sodium, and sulfate are added to the original domestic water supply as a result of water use and may have to be removed if the wastewater is discharged to a stream used as a potable water source.

1.3 Effects of Wastewater Discharges

A **discharge** is the release of treated or untreated wastewater into a receiving stream. A discharge may occur from a treatment plant or from an overflow in the collection system. Untreated wastewater discharge can create several undesirable conditions. These include:

1. Oxygen depletion and odor production in the stream.
2. Sludge and scum accumulations.
3. Other Effects

1.3.1 Oxygen Depletion and Odor Production

- The dissolved oxygen (DO) content of a stream will depend on the temperature and the flow characteristics.
- Cold water can retain higher dissolved oxygen content than warm water. As water temperatures increase, dissolved oxygen levels will decrease.
- Turbulent flow will add more dissolved oxygen to the stream than non-turbulent flow.
- The desired oxygen level to sustain living creatures (including aquatic life) is 5 mg/L.

Aerobic bacteria are bacteria that use dissolved oxygen to live and reproduce while anaerobic bacteria are bacteria that live and reproduce in an environment containing no Dissolved oxygen. The bacteria obtain oxygen by breaking down chemical compounds, which contain oxygen (organic matter, sulfate and nitrate).

- Organic waste is discharged to the receiving stream; bacteria numbers increase (as does oxygen use).
- When oxygen is used faster than it is replenished, aquatic life can die from insufficient oxygen.
- Anaerobic bacteria remove oxygen from sulfate; the sulfate is reduced to sulfide, which can combine with hydrogen in water to produce hydrogen sulfide (rotten egg odor).

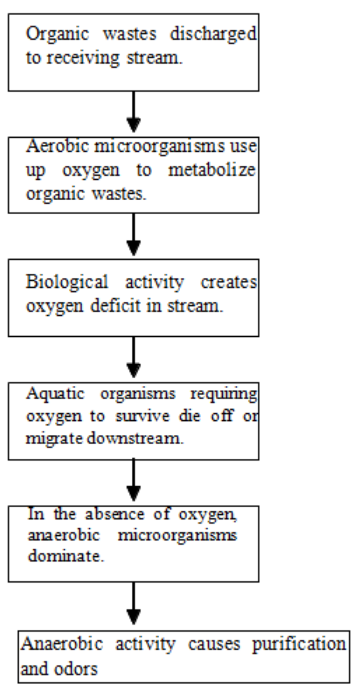

Figure 2: Oxygen utilization by aerobic microorganisms and odor production by anaerobic microorganisms.

1.3.2 Effects of Scum and Sludge Accumulation

Scum and sludge can accumulate in the receiving water banks or beds or can float on the water surface.

- Oxygen depletion occurs from metabolism of the organic matter contained in the sludge.
- Odors occur from continued biological activity after oxygen is depleted.

1.3.3 Other Effects

- Clarity and color determine if water is desirable for recreation.
- Changes in pH (acidic or alkaline water) can disrupt aquatic life.
- Toxic discharges (heavy metals such as lead, mercury, and chromium) or cyanide also impact aquatic life and domestic use.
- Bad taste and odor are undesirable for drinking water sources.
- Excessive Nutrients;
    - Support living plants and organisms (carbon, hydrogen, oxygen, etc.).
    - Encourage algae and plant growth, which interferes with domestic, industrial, and recreational uses.
    - Can lead to oxygen depletion in the receiving stream.
    - Eutrophication-An extreme result of excessive nutrient availability
    - A condition in a lake or pond characterized by an abundance of nutrients and organics.
    - Characterized by overgrowth of aquatic weeds and algae.
    - Often leads to oxygen deficits, compounded by large day-night swings in available dissolved oxygen brought on by photosynthesis and respiration.
    - Can be detrimental to aquatic life.

1.4 Wastewater Treatment Objective

The objective of wastewater treatment is to prevent oxygen-demanding entities from entering water.

Reduce nutrient load that promote eutrophication and

1.4.1 Wastewater Stabilization

Stabilization is the process of converting a waste to a form that resists change. Stabilized material usually does not give off bad odors.

- Organic material is stabilized when bacteria convert the material to new growth, carbon dioxide, and water.

1.4.2 Disinfection

Disinfection can be accomplished by addition of a disinfectant such as chlorine to the water or through ultraviolet radiation.

- Works best if wastewater is treated to remove solids and other contaminants prior to disinfection.

1.4.3 Removal of Accumulations of Scum and Sludge

Scum and sludge can accumulate in the receiving water banks or beds or can float on the water surface.

- Remove sludge and scum before it can reach receiving waters.

1.5 Wastewater Treatment Processes

Waste Water Treatment primarily consists of Physical, Chemical and Biological methods used to remove contaminants from waste-water. In order to achieve different levels of contaminant removal, individual waste-water treatment procedures are combined into a variety of systems, classified as primary, secondary, and tertiary waste-water treatment. More rigorous treatment of waste-water includes the removal of specific contaminants as well as the removal and control of nutrients. Natural systems are also used for the treatment of waste-water in land-based applications. Sludge resulting from waste-water treatment operations is treated by various methods in order to reduce its water and organic content and make it suitable for final disposal and reuse.

Waste-water treatment methods are broadly classifiable into physical, chemical and biological processes.

Table 2: Wastewater treatment unit operations and processes

Physical Process	Screening Comminution Flow equalization Sedimentation Flotation Granular-medium filtration
Chemical Process	Chemical precipitation Adsorption Disinfection DE chlorination Other chemical applications
Biological Process	Activated sludge process Aerated lagoon Trickling filters Rotating biological contactors Pond stabilization Anaerobic digestion Biological nutrient removal

Activity:

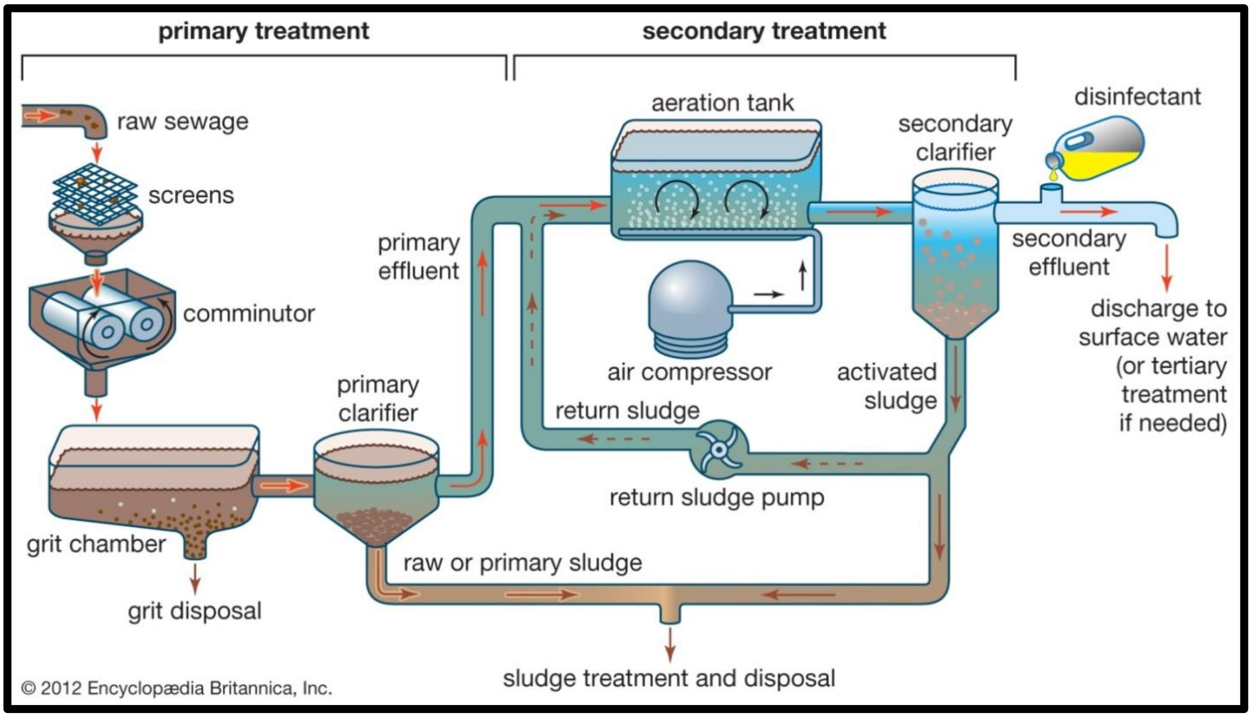

Figure 3: Wastewater treatment plant

1. Detailed description of wastewater treatment processes displayed in model
2. Identify and enlist process and stages of shown in wastewater model
3. Name two physical process used in waste water treatment model
4. Draw schematic diagram of waste water model
5. Quiz and Worksheet

UNIT 2:
PHYSICAL PROCESS
IN WASTE WATER TREATMENT

2 PHYSICAL PROCESS IN WASTEWATER TREATMENT

2.1 Introduction Physical Process

Among the first treatment methods used are physical unit operations, in which physical forces are applied to remove contaminants. They still form the basis of most process flow systems for wastewater treatment. The most commonly used physical unit operations are.

1. Screening
2. Flow equalization
3. Sedimentation
4. Flotation
5. Granular-medium filtration

2.1.1 Screening

The screening of waste-water, one of the oldest treatment methods, removes gross pollutants from the Waste stream to protect downstream equipment from damage, avoid interference with plant operations and prevent objectionable floating material from entering the primary settling tanks.

Figure 4: (Left) floating and suspended solids in wastewater; (Right), Bar screens

Screening devices may consist of parallel bars, rods or wires, grating, wire mesh, or perforated plates, to intercept large floating or Suspended material. The openings may be of any shape, but are generally circular or rectangular. The material retained from the manual or mechanical cleaning of bar racks and screens is referred to as

Screenings, and is either disposed of by burial or incineration, or returned into the waste flow after grinding. The principal types of screening devices are listed in table 2.1

2.1.1.1 Coarse Screen

The coarse screen category includes manually or mechanically cleaned bar screens and trash racks.

Bar screens consist of vertical or inclined steel bars distributed equally across a channel through which wastewater flows. They are used ahead of mechanical equipment including raw sewage pumps, grit chambers, and primary sedimentation tanks. Trash racks, are constructed of parallel rectangular or round steel bars with clear openings. They are usually followed by regular bar screens or comminutors. Criteria used in the design of coarse screens include bar size, spacing, and angle from the vertical, as well as channel width and wastewater approach velocity.

2.1.1.2 Fine Screens

Fine screens consist of various types of screen media, including slotted perforated plates, wire mesh, woven wire cloth and wedge-shaped wire. Due to their tiny openings, fine screens must be cleaned continuously by means of brushes, scrapers, or jets of water, steam, or air forced through the reverse side of the openings. The efficiency of a fine screen depends on the fineness of the openings as well as the sewage flow velocity through those openings.

Table 3: Different types of screen and application

Screen category	Size of openings (millimeters)	Application	Types of screens
Coarse screens	≥ 6	Remove large solids, rags, and debris.	Manually cleaned bar screens/trash racks Mechanically cleaned bar screens/trash racks o Chain or cable driven with front or back cleaning Reciprocating rake screens Catenary screens Continuous self-cleaning screens
Fine screens	1.5-6	Reduce suspended solids to primary treatment levels	Rotary-drum screens Rotary-drum screens with outward or inward flow Rotary-vertical-disk screens Inclined revolving disc screens Traveling water screens Endless band screen Vibrating screens
Very fine screens	0.2-1.5	Reduce suspended solids to primary treatment levels	
Micro screens	0.001-0.3	Upgrade secondary effluent to tertiary standards	

2.2 Flow Equalization

Flow equalization is a technique used to improve the effectiveness of secondary and advanced wastewater treatment processes by levelling out operation parameters such as flow, pollutant levels and temperature over a period of time. Variations are damped until a near-constant flow rate is achieved, minimizing the downstream effects of these parameters. Flow equalization may be applied at a number of locations within a waste-water treatment plant, e.g. near the head end of the treatment works, prior to discharge into a water body, and prior to advanced waste treatment operations.

2.3 Sedimentation

Sedimentation, a fundamental and widely used unit operation in waste-water treatment, involves the gravitational settling of heavy particles suspended in a mixture. This process is used for the removal of grit, particulate matter in the primary settling basin, biological floc in the activated sludge settling basin, and chemical flow when the chemical coagulation process is used. Sedimentation takes place in a settling tank, also referred to as a clarifier. There are three main designs, namely, horizontal flow, solids contact and inclined surface. In designing a sedimentation basin, it is important to bear in mind that the system must produce both a clarified effluent and a concentrated sludge.

Four types of settling occur, depending on particle concentration, namely, discrete, flocculent, hindered and compression.

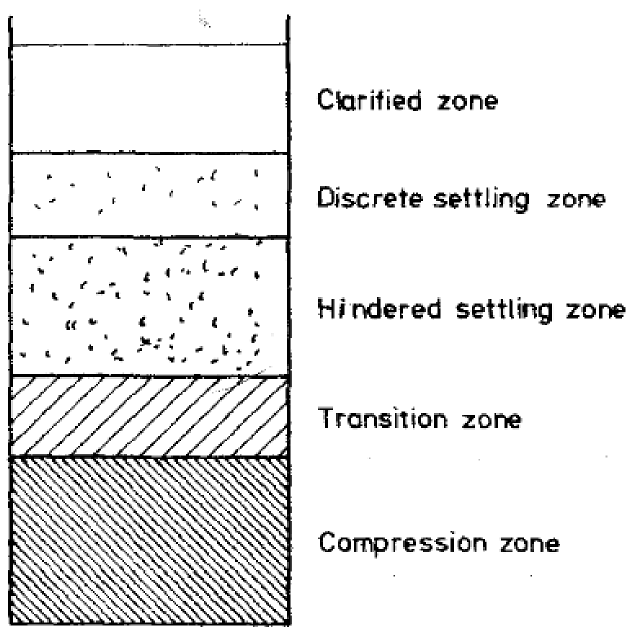

Figure 5: Illustration of zones in settling

It is common for more than one type of settling to occur during a sedimentation operation.

2.3.1 Horizontal Flow

Horizontal-flow clarifiers may be rectangular, square or circular in shape. The flow in rectangular basins is rectilinear and parallel to the long axis of the basin, whereas in Centre-feed circular basins, the water flows radially from the Centre towards the outer edges. Both types of basins are designed to keep the velocity and flow distributions as uniform as possible in order to prevent currents and eddies from forming, and thereby keep the suspended material from settling. Basins are usually made of steel or reinforced concrete. The bottom surface slopes slightly to facilitate sludge removal. In rectangular tanks, the slope is towards the inlet end, while in circular and square tanks; the bottom is conical and slopes towards the Centre of the basin.

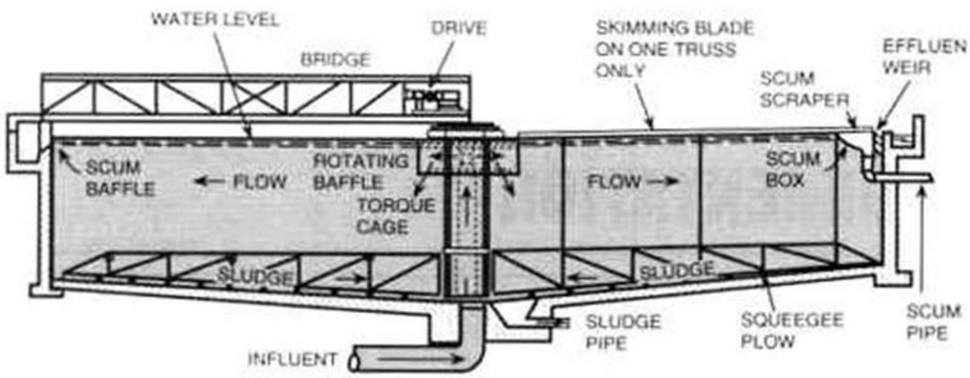

Figure 6: Horizontal flow clarifier

2.3.2 Solid Contact Clarifiers

Solid contact clarifiers bring incoming solids into contact with a suspended layer of sludge near the bottom that acts as a blanket. The incoming solids clustered and remain entangled within the sludge blanket, whereby the liquid is able to rise upwards while the solids are retained below.

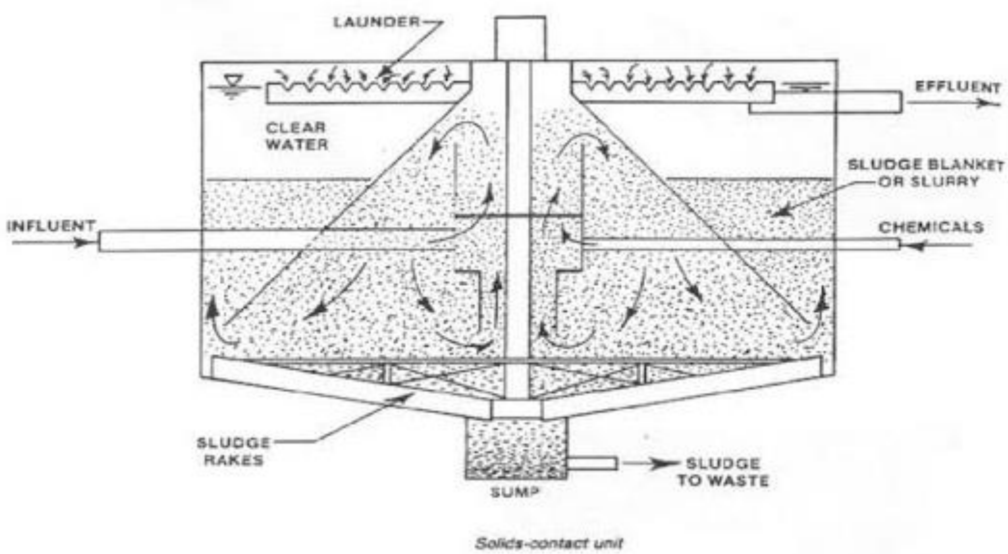

Figure 7: Solid contact clarifiers

2.3.3 Inclined Surface Basins

Inclined surface basins, also known as high-rate settlers, use inclined trays to divide the depth into shallower sections, thus reducing particle settling times. They also provide a larger surface area, so that a smaller-sized clarifier can be used. Many overloaded horizontal flow clarifiers have been upgraded to inclined surface basins. Here, the flow is laminar, and there is no wind effect.

Settling basin with horizontal flow:

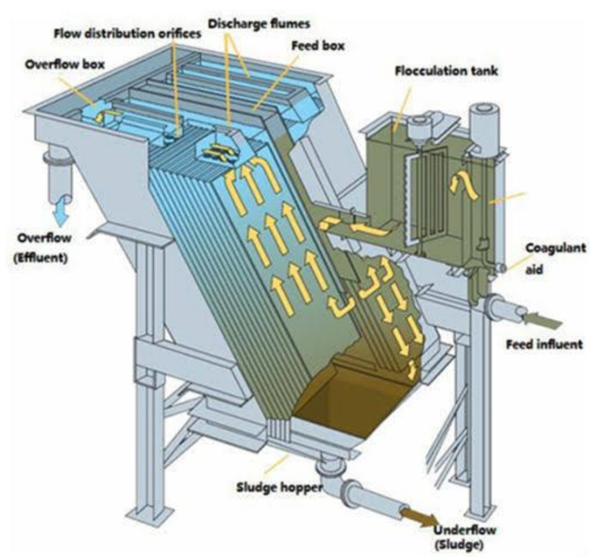

Figure 8: Inclined surface basins

2.4 Flotation

Flotation is a unit operation used to remove solid or liquid particles from a liquid phase by introducing a fine gas, usually air bubbles. The gas bubbles either adhere to the liquid or are trapped in the particle structure of the suspended solids, raising the buoyant force of the combined particle and gas bubbles. Particles that have a higher density than the liquid can thus be made to rise. In waste-water treatment, flotation is used mainly to remove suspended matter and to concentrate biological sludge. The chief advantage of flotation over sedimentation is that very small or light particles can be removed more completely and in a shorter time. Once the particles have been floated to the surface, they can be skimmed out. Flotation, as currently practiced in municipal waste-water treatment, uses air exclusively as the floating agent. Furthermore, various chemical additives can be introduced to enhance the removal process. The various flotation methods are described in table 4, while a typical flotation unit is illustrated in figure 9

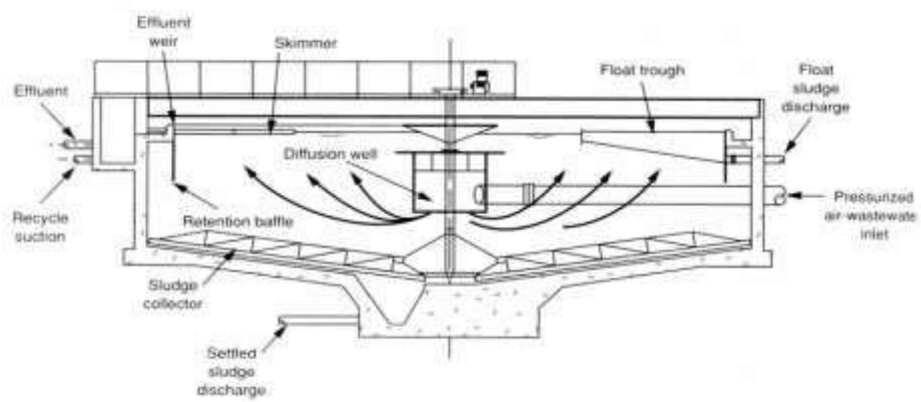

Figure 9: General flotation process

Table 4: Different types of flotation methods

Process	Description
Dissolved-air flotation	The injection of air while waste-water is under the pressure of several atmospheres. After a short holding time, the pressure is restored to atmospheric level, allowing the air to be released as minute bubbles
Air flotation	The introduction of gas into the liquid phase directly by means of a revolving impeller or through diffusers, at atmospheric pressure
Vacuum flotation	The saturation of waste-water with air either directly in an aeration tank or by permitting air to enter on the suction side of a waste-water pump. A partial vacuum is applied, causing the dissolved air to come out of solution as minute bubbles which rise with the attached solids to the surface, where they form a scum blanket. The scum is removed by a skimming mechanism while the settled grit is raked to a central sump for removal
Chemical additives	Chemicals further the flotation process by creating a surface that can easily adsorb or entrap air bubbles. Inorganic chemicals (aluminum and ferric salts and activated silica) and various organic polymers can be used for this purpose

2.5 Granular Medium Filtration

The filtration of effluents from waste-water treatment processes involves removal of suspended solids from waste-water effluents of biological and chemical treatment processes, in addition to the removal of chemically precipitated phosphorus.

The complete filtration operation comprises two phases:

1. Filtration

   The waste-water to be filtered is passed through a filter bed consisting of granular material (sand, anthracite), with or without added chemicals. Within the filter bed, suspended solids contained in the waste-water are removed by means of a complex process involving one or more removal mechanisms such as straining, interception, impaction, sedimentation, flocculation and adsorption.

2. Cleaning or Backwashing

   In Cleaning/backwashing phase, washing liquids are passed backward through filter materials. Filtering and cleaning operations occur sequentially.

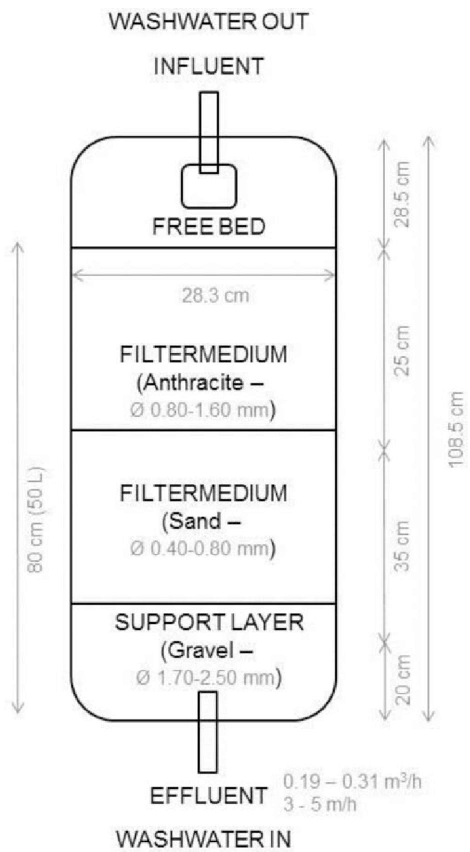

Figure 10: Granular medium filtration

Activity:

1. Identification of grit in waste water
2. Screening of wastewater from coarse and fine screens.
3. Sedimentation of Primary of primary sludge from waste water
4. Flocculation of primary effluent (**if aeration pumps will be available**)
5. Filtration of waste water from coarse sand or activated carbon.
6. Quiz.

UNIT 3: CHEMICAL PROCESS IN WASTE WATER TREATMENT

3 CHEMICAL PROCESSES

Chemical processes used in waste-water treatment are designed to bring about some form of change by means of chemical reactions. They are always used in conjunction with physical unit operations and biological processes. In general, chemical unit processes have an inherent disadvantage compared to physical operations in that they are additive processes. That is to say, there is usually a net increase in the dissolved constituents of the waste-water. This can be a significant factor if the waste-water is to be reused.

The main chemical unit processes, including;

1. Chemical precipitation
2. Adsorption
3. Disinfection chlorination

3.1 Chemical Coagulation and Precipitation

Coagulation: Particles that aggregate with themselves e.g. by the influence of a change in pH.

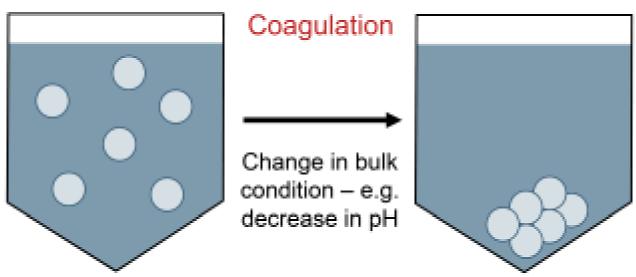

Figure 11: Coagulation

Chemical coagulation of raw waste-water before sedimentation promotes the flocculation of finely divided solids into more readily settle-able flocks, thereby enhancing the efficiency of suspended solid, BOD_5 and phosphorus removal as compared to plain sedimentation without coagulation. The degree of clarification obtained depends on the quantity of chemicals used and the care with which the process is controlled.

Table 5: Removal efficiency of plain sedimentation vs. chemical precipitation

Parameter	Percentage removal	
	Plain sedimentation	Chemical precipitation
Total suspended solids (TSS)	40-90	60-90
BOD_5	25-40	40-70
COD	---	30-60
Phosphorus	5-10	70-90
Bacteria loadings	50-60	80-90

Source: Bhargava, 2016

Coagulant selection for enhanced sedimentation is based on performance, reliability and cost.

Performance evaluation uses jar tests of the actual waste-water to determine dosages and effectiveness.

Chemical coagulants that are commonly used in waste-water treatment include

1. Alum ($Al_2 (SO_4)_3$.14H2O)
2. Ferric chloride ($FeCl_3$.6H2O),
3. Ferric sulfate (Fe2 $(SO_4)_3$),
4. Ferrous sulfate ($FeSO_4.7H_2O$) and
5. Lime (Ca (OH)

3.1.1 Chemical Treatment System

Suspended solids removal through chemical treatment involves a series of three unit operations:

1. Rapid Mixing, first, the chemical is added and completely dispersed throughout the waste-water by rapid mixing for 20-30 seconds in a basin with a turbine mixer.
2. Flocculation and Coagulated particles are then brought together via flocculation by mechanically inducing velocity gradients within the liquid. Flocculation takes 15 to 30 minutes in a basin containing turbine or paddle-type mixers.
3. Settling. The final step is clarification by gravity.

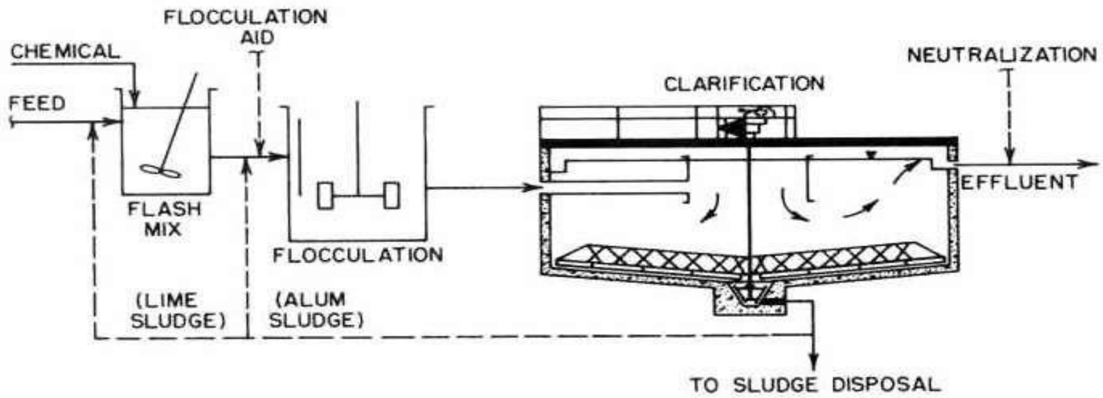

Figure 12: Chemical treatment: Coagulation

Advantages:

The advantages of coagulation include

1. greater removal efficiency,
2. the feasibility of using higher
3. Overflow rates, and more consistent performance.

Disadvantages:

On the other hand, coagulation results in

1. a larger mass of primary sludge that is often more difficult to thicken and dewater.
2. It also entails higher operational costs and
3. Demands greater attention on the part of the operator.

3.2 Adsorption with Activated Carbon

Adsorption is the process of collecting soluble substances within a solution on a suitable interface. In Wastewater treatment, adsorption with activated carbon—a solid interface usually follows normal Biological treatment, and is aimed at removing a portion of the remaining dissolved organic matter. Particulate matter present in the water may also be removed. Activated carbon is produced by heating char to a high temperature and then activating it by exposure to an oxidizing gas at high temperature. The gas develops a porous structure in the char and thus creates a large internal surface area. The activated char can then be separated into various sizes with different adsorption capacities. The two most common types of activated carbon are granular activated carbon (GAC), which has a diameter greater than 0.1 mm, and powdered activated carbon (PAC), which has a diameter of less than 200 mesh.

Waste-water treatment using PAC involves the addition of the powder directly to the biological treatment effluent or the physiochemical treatment process, as the case may be. PAC is usually added to Waste-water in a contacting basin for a certain length of time. It is then allowed to settle to the bottom of the tank and removed.

A fixed-bed column is often used to bring the waste-water into contact with GAC. The water is applied to the top of the column and withdrawn from the bottom, while the carbon is held in place.

Backwashing and surface washing are applied to limit head loss build-up. A schematic of an activated carbon Contactor is shown in figure.

Expanded-bed and moving-bed carbon contactors have been developed to overcome the problem of head loss build-up. In the expanded-bed system, the influent is introduced at the bottom of the column and is allowed to expand. In the moving-bed system, spent carbon is continuously replaced with fresh carbon. Spent granular carbon can be regenerated by removal of the adsorbed organic matter from its surface through oxidation in a furnace. The capacity of the regenerated carbon is slightly less than that of the virgin carbon.

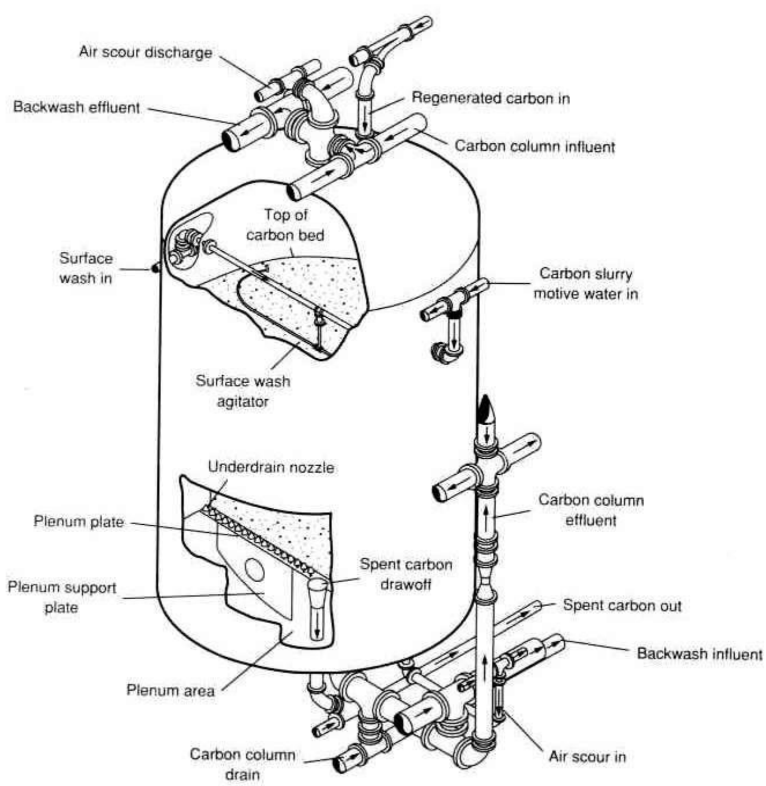

Figure 13: A typical granular activated carbon contactor

3.3 Disinfection

Disinfection refers to the selective destruction of disease-causing micro-organisms. This process is of importance in waste-water treatment owing to the nature of waste-water, which harbours a number of microorganisms that are associated with various waterborne diseases.

Commonly used means of disinfection include the following:

1. Physical agents such as heat and light;
2. Mechanical means such as screening, sedimentation, filtration, and so on;
3. Radiation, mainly gamma rays;
4. Chemical agents including chlorine and its compounds, bromine, iodine, ozone, phenol and various alkalis and acids are widely used.

Disinfectants act through one or more of a number of mechanisms, including damaging the cell wall, altering cell permeability, altering the colloidal nature of the protoplasm and inhibiting enzyme activity. In applying disinfecting agents, several factors need to be considered: contact time, concentration and type of chemical agent, intensity and nature of physical agent, temperature, number of organisms, and nature of suspending liquid. Table 6 shows the most commonly used disinfectants and their effectiveness

3.4 De-chlorination:

De-chlorination is the removal of free and total combined chlorine residue from chlorinated wastewater effluent before its reuse or discharge to receiving waters. Chlorine compounds react with many organic compounds in the effluent to produce undesired toxic compounds that cause long-term adverse impacts on the water environment and potentially toxic effects on aquatic micro-organisms. De-chlorination may be brought about by the use of activated carbon, or by the addition of a reducing agent such as sulfur dioxide (SO_2), sodium sulfite (Na_2SO_3) or sodium metabisulfite ($Na_2S_2O_5$). It is important to note that de-chlorination will not remove toxic by-products that have already been produced.

Table 6: Characteristics of common disinfecting agents

Characteristic	Chlorine	Sodium hypochlorite	Calcium hypochlorite	Chlorine dioxide	Bromine chloride	Ozone	Ultraviolet light
Chemical formula	Cl2	NaOCl	Ca(OCl)2	ClO2	BrCl	O3	N/A
Toxicity to microorganisms	High	High	High	High	High	High	High
Solubility	Slight	High	High	High	Slight	High	N/A
Stability	Stable	Slightly unstable	Relatively stable	Unstable, must be generated as used	Slightly unstable	Unstable, must be generated as used	Must be Generated as used
Toxicity to higher forms of life	Highly toxic	Toxic	Toxic	Toxic	Toxic	Toxic	Toxic
Effect at ambient temperature	High	High	High	High	High	High	High
Penetration	High	High	High	High	High	High	Moderate
Corrosiveness	Highly corrosive	Corrosive	Corrosive	Highly corrosive	Corrosive	Highly corrosive	N/A
Deodorizing ability	High	Moderate	Moderate	High	Moderate	High	None
Availability/cost	Low cost	Moderately low cost	Moderately low cost	Moderately low cost	Moderately low cost	Moderately high cost	Moderately high cost
Form	Liquid, gas	Solution	Powder, pellets or 1 percent solution	Gas	Liquid	Gas	UV energy

Table 7: Other chemical applications in waste-water treatment and disposal

Application	Chemical used	Remarks
Grease removal	Cl_2	Added before pre-aeration
BOD reduction	Cl_2, O_3	Oxidation of organic substances
pH control	KOH, NaOH, $Ca(OH)_2$	
Ferrous sulfate oxidation	Cl_2	Production of ferric sulfate and ferric chloride
Filter - ponding control	Cl_2	Residual at filter nozzles
Filter - fly control	Cl_2	Residual at filter nozzles, used during fly season
Sludge-bulking control	Cl_2, H_2O_2, O_3	Temporary control measure
Digester supernatant oxidation	Cl_2	
Ammonia oxidation	Cl_2	Conversion of ammonia to nitrogen gas
Odour control	Cl_2, H_2O_2, O_3	
Oxidation of refractory organic compounds	O_3	
Disposal		
Bacterial reduction	Cl_2, H_2O_2, O_3	Plant effluent, overflows, and storm water
Odour control	Cl_2, H_2O_2, O_3	

Activity

1. Determent the effects of different coagulants on waste water using (Jar test)
2. Calculation of Alum dosage for coagulation

Problem statement:

Find out the quantity of alum required to treat 18 million liters of water per day. The dosage of alum is 14mg/lit. Also work out the amount of CO_2 released per liter of treated water.

Solution:

$$\text{Weight of alum required } = \frac{18 * 10^6 * 14}{10^6} = 252 \text{ kg}$$

The chemical reaction of alum is given by:

$Al_2(SO_4)_3.18H_2O + 3Ca(HCO_3)_2 \rightarrow 2Al(OH)_3\downarrow + 3CaSO_4 + 6CO_2 + 18H_2O$

Calculate the molecular weight of alum and carbon dioxide:

Molecular weight of alum ($Al_2(SO_4)_3.18H_2O$) = 2*27 + 3*32 + 16* (4*3 + 18) + 36*1 = 666

Molecular weight of carbon dioxide: ($6CO_2$) = 6*44 = 264

666 mg of alum releases 264 mg of carbon dioxide.

Therefore, 252 kg of alum will release

$$\frac{264}{666} * 252 = 99.89 \cong 100 \text{ kg of } CO_2 \text{ per day}$$

UNIT 4:
BIOLOGICAL PROCESS
IN WASTEWATER TREATMENT

4 BIOLOGICAL PROCESS IN WASTEWATER TREATMENT

4.1 Biological Process

In waste water treatment process secondary treatment can be defined as “treatment of wastewater by a process involving biological treatment with a secondary sedimentation”. In other words, the secondary treatment is a biological process. The settled wastewater is introduced into a specially designed bioreactor where under aerobic or anaerobic conditions the organic matter is utilized by microorganisms such as bacteria (aerobically or anaerobically), algae, and fungi (aerobically). The bioreactor affords appropriate bioenvironmental conditions for the microorganisms to reproduce and use the dissolved organic matter as energy for themselves. Provided that oxygen and food, in the form of settled wastewater, are supplied to the microorganisms, the biological oxidation process of dissolved organic matter will be maintained.

The overall objectives of the biological treatment of domestic industrial and agricultural wastewater are to

1. Transform (i.e., oxidize) dissolved and particulate biodegradable constituents into acceptable end products,
2. Capture and incorporate suspended and non-settleable colloidal solids into a biological floc or biofilm,
3. Transform or remove nutrients, the concentration of organic and inorganic compounds such as nitrogen and phosphorus, and that are capable of stimulating the growth of aquatic plants. And are potentially harmful for human health

The microorganisms may be *aerobic* (requiring free oxygen), *anaerobic* (not requiring free oxygen), *or facultative* (growing with or without oxygen). Processes in which microorganisms use bound oxygen (from NO_3 for de-nitrification, for example) are often called *anoxic* rather than anaerobic. The microbial population may be maintained in the liquid as suspended growth, referred to as *mixed liquor suspended solids* or *volatile suspended solids* (MLSS or MLVSS), or it may be attached to some medium in a fixed-film process.

4.1.1 Bacterial Growth Curve

Most of the organic matter in wastewater can serve as food (substrate) to provide energy for microbial growth. This is the principle used in biological waste treatment, where organic substrate is converted by microorganisms, primarily bacteria (with the help of protozoa), to carbon dioxide, water, and more new cells.

The rate of microbial growth varies directly with the amount of available substrate. In a batch culture when food is not limiting, the microbial population, after an initial lag period, grows rapidly at a logarithmic rate. As food decreases, growth slows until, at some point, growth stops and the number of new cells produced is balanced by the number of old cells that are dying. When the substrate is exhausted, the number of microorganisms declines as old cells decompose (lyse) releasing their nutrients for use by new microorganisms. These four phases, referred to as the lag (1), log growth (2), Stationary growth (3), and endogenous (death) phase (4), are shown in Figure 14.

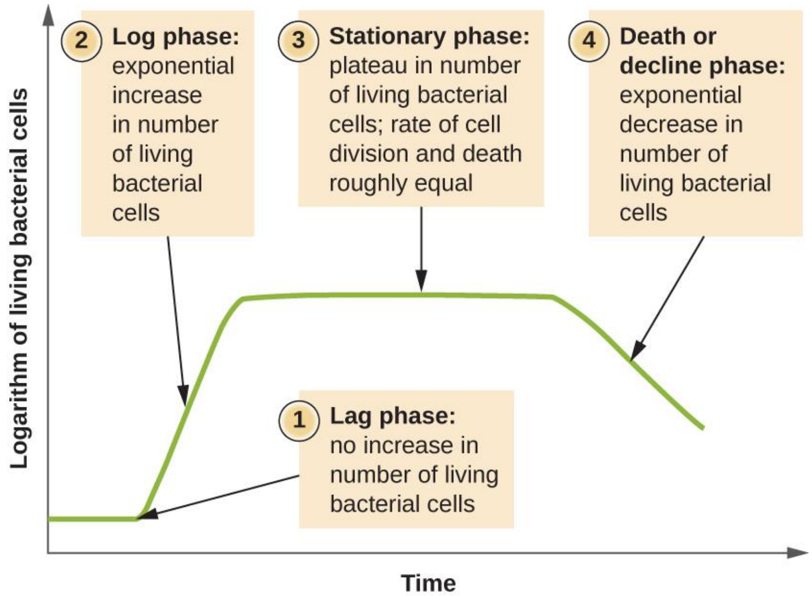

Figure 14: Bacterial growth curve

4.2 Biological Oxidation and Biosynthesis

The microorganisms are able to decompose the organic matter through two different biological processes: biological oxidation and biosynthesis Figure 15.

The biological oxidation forms some end-products, such as minerals, that remain in the solution and are discharged with the effluent (Eq. 1).

Oxidation:

(Organic matter)+O_2+ Bacteria→CO_2+NH_3+Energy +Other end products E1.

The biosynthesis transforms the colloidal and dissolved organic matter into new cells that form in turn the dense biomass that can be then removed by sedimentation (Eq. 2).

Biosynthesis:

(Organic matter)+O_2 + Bacteria→ (New cells)` E2.

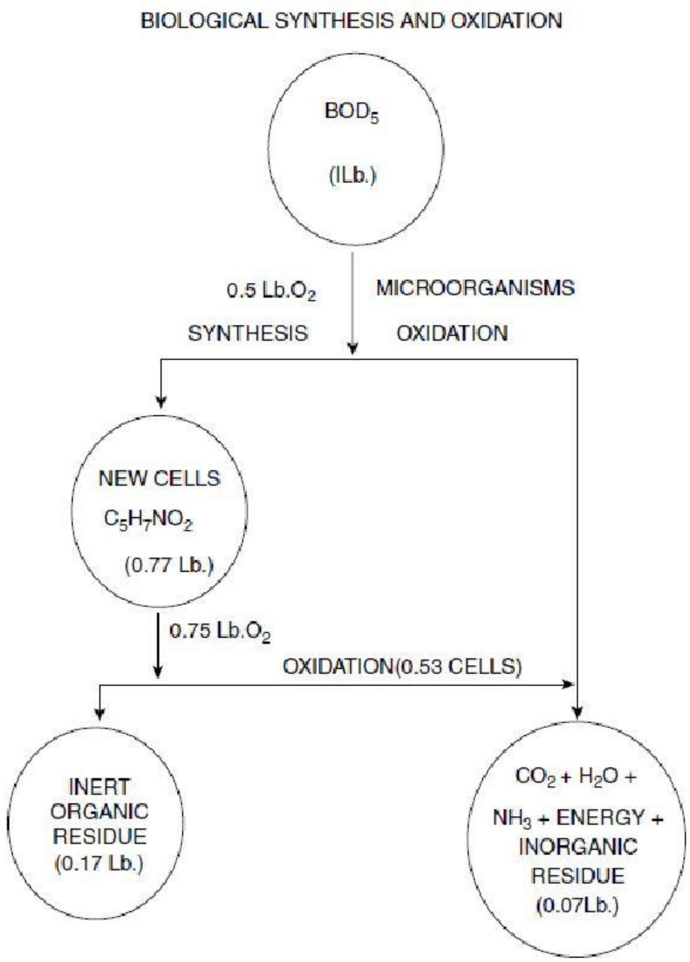

Figure 15: Biological processes: biological oxidation and biosynthesis

4.3 Factors Effecting Bacterial Activity

Several bioenvironmental factors affect the activity of bacteria and the rate of biochemical reactions. The most important factors are:

1. Temperature
2. Dissolved oxygen,
3. Nutrient concentration, and
4. Toxic materials.

All these factors can be controlled within a biological treatment system and/or a bioreactor in order to ensure that the microbial growth is maintained under optimum bioenvironmental conditions.

4.3.1 Temperature

The majority of biological treatment systems operate in the optimal temperature ranges from 20°C to 40°C.

The biological systems are very sensitive for extreme variations in hydraulic loads. Variations of greater than 250% are problematic because they will create biomass loss in the clarifiers.

The growth rate of microorganisms is highly dependent on temperature. A 10°C reduction in wastewater temperature dramatically decreases the biological reaction rates to half.

4.3.2 Dissolved Oxygen

The biological treatment is effective in removing up to 95% of the BOD but if food to microorganism ratio, is disturbed the organic load increase the Bacterial groeth then the DO will decrease and halt further aerobic digestion.

4.3.3 Nutrient Concentration

The carbon:nitrogen: phosphorus (C:N:P) ratio of wastewater is usually ideal. The C:N:P ratio of industrial wastewaters should range from 100:20:1 to 100:5:1 for a most advantageous biological process.

If the C:N:P ratio of the wastewater is strong in an element in comparison to the other elements, then poor treatment will result. This is especially true if the wastewater is very strong in carbon. The wastewater should also be neither very weak nor very strong in an element; although very weak is acceptable, it is difficult to treat.

Oils and solids cannot be handled in a biological treatment system because they negatively affect the treatment process. These wastes should be pretreated to remove solids and oils.

4.3.4 Toxic Material

Toxic and biological-resistant materials require special consideration and may require pretreatment before being introduced into a biological treatment system.

Although the capacity of the wastewater to utilize oxygen is unlimited, the capacity of any aeration system is limited in terms of oxygen transfer.

4.3.5 Basic Biological Processes in Wastewater Treatment

The principal biological processes used for wastewater treatment can be divided into two main categories: suspended growth and attached growth (or biofilm)

4.3.6 Suspended Growth Processes

In suspended growth processes, the microorganisms responsible for treatment are maintained in liquid suspension by appropriate mixing methods. Many suspended growth processes used in municipal and industrial wastewater treatment are operated with a positive dissolved oxygen concentration (aerobic), but applications exist where suspended growth anaerobic (no oxygen present) reactors are used, such as for high organic concentration industrial wastewaters and organic sludges.

The most common suspended growth process used for municipal wastewater treatment is the activated-sludge process. The activated-sludge process was so named because it involved the production of an activated mass of microorganisms capable of stabilizing a waste under aerobic conditions. In the aeration tank, contact time is provided for mixing and aerating influent wastewater with the microbial suspension, generally referred to as the mixed liquor suspended solids (MLSS) or mixed liquor volatile suspended solids (MLVSS). Mechanical equipment is used to provide the mixing and transfer of oxygen into the process. The mixed liquor then flows to a clarifier where the microbial suspension is settled and thickened. The settled biomass, described as activated sludge because of the presence of active microorganisms, is returned to the aeration tank to continue biodegradation of the influent organic material. A portion of the thickened solids is removed daily or periodically as the process produces excess biomass that would accumulate along with the non-biodegradable solids contained in the influent wastewater. If the accumulated solids are not removed, they will eventually find their way to the system effluent. An important feature of the activated-sludge process is the formation of floc particles, ranging in size from 50 to 200 µm, which can be removed by gravity settling, leaving a relatively clear liquid as the treated effluent. Typically, greater than 99 percent of the suspended solids can be removed in the clarification step.

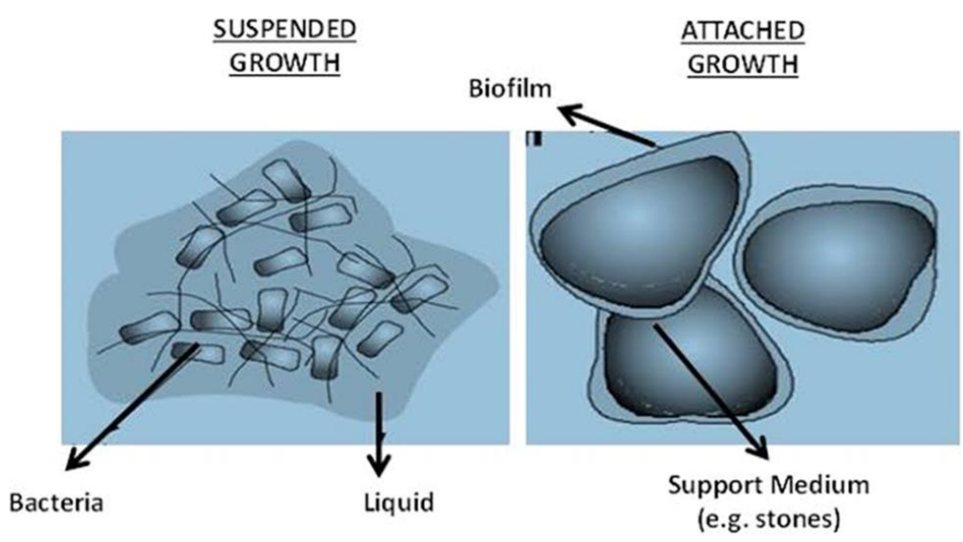

Figure 16: Bacterial growth types (left) Suspended Growth (Right) Attached Growth

4.3.7 Attached Growth Processes

In attached growth processes, the microorganisms responsible for the conversion of organic material or nutrients are attached to an inert packing material. The organic material and nutrients are removed from the wastewater flowing past the attached growth also known as a biofilm. Packing materials used in attached growth processes include rock, gravel, slag, sand, redwood, and a wide range of plastic and other synthetic materials. Attached growth processes can also be operated as aerobic or anaerobic processes. The packing can be submerged completely in liquid or not submerged, with air or gas space above the biofilm liquid layer. The most common aerobic attached growth process used is the trickling filter in which wastewater is distributed over the top area of a vessel containing non-submerged packing material. Historically, rock was used most commonly as the packing material for trickling filters, with typical depths ranging from 1.25 to 2 m

4.4 Microbial Assisted Waste Water Treatments

4.4.1 Aerobic Treatment

Aeration has been used to remove trace organic volatile compounds (VOCs) in water. It has also been employed to transfer a substance, such as oxygen, from air or a gas phase into water in a process called “gas adsorption” or “oxidation”, i.e., to oxidize iron and/or manganese. Aeration also provides the escape of dissolved gases, such as CO_2 and H_2S. Aeration has been also utilized effectively to remove NH_3 from wastewater and to remove volatile and other such substances in water. Aerobic treatment with bio-wastes is effective in reducing harmful gaseous emissions as greenhouse gases (CH_4 and N_2O) and ammonia.

4.4.1.1 Oxidation ponds

Oxidation ponds are aerobic systems where the oxygen required by the heterotrophic bacteria (a heterotroph is an organism that cannot fix carbon and uses organic carbon for growth) is provided not only by transfer from the atmosphere but also by photosynthetic algae. The algae are restricted to the euphotic zone (sunlight zone), which is often only a few centimeters deep. Ponds are constructed to a depth of between 1.2 and 1.8 m to ensure maximum penetration of sunlight, and appear dark green in color due to dense algal development.

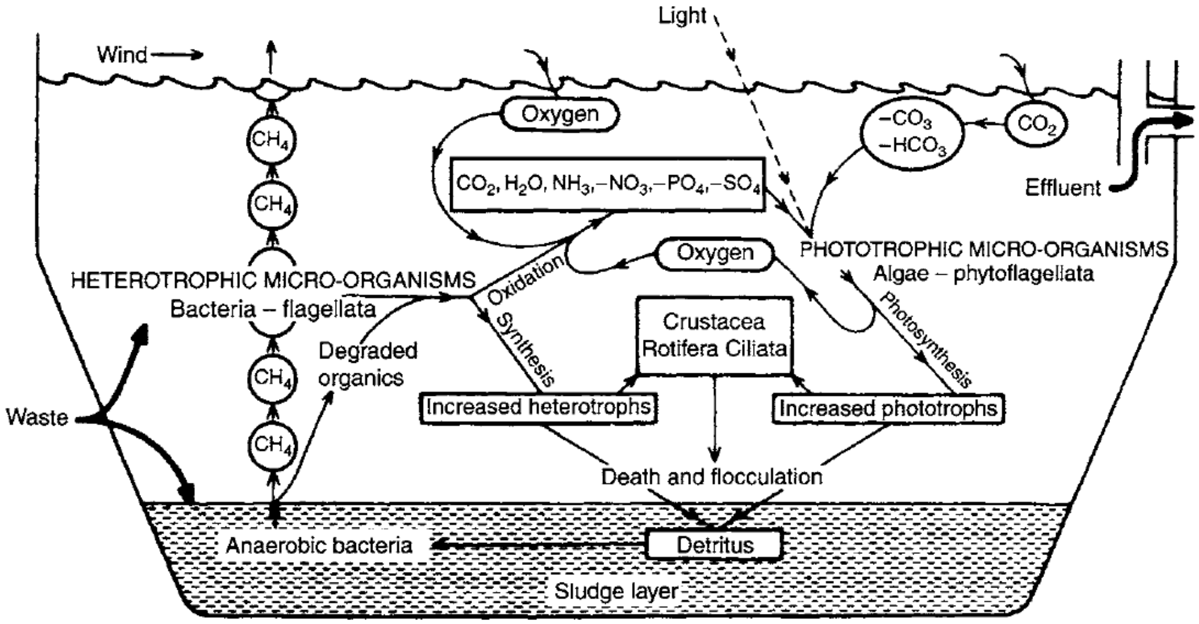

Figure 17: Aerobic system/oxidation pond

In oxidation ponds, the algae use the inorganic compounds (N, P, CO_2) released by aerobic bacteria for growth using sunlight for energy. They release oxygen into the solution that in turn is utilized by the bacteria, completing the symbiotic cycle. There are two distinct zones in facultative ponds: the upper aerobic zone where bacterial (facultative) activity occurs and a lower anaerobic zone where solids settle out of suspension to form a sludge that is degraded anaerobically.

4.4.1.2 Aeration Lagoons

Aeration lagoons are 3–4 m deep, compared to oxidation ponds, where oxygen is provided by aerators but not by the photosynthetic activity of algae as in the oxidation ponds. The aerators keep the microbial biomass suspended and provide sufficient dissolved oxygen that allows maximal aerobic activity. On the other hand, bubble aeration is commonly used where the bubbles are generated by compressed air pumped through plastic tubing laid through the base of the lagoon. A predominately bacterial biomass develops and, whereas there is neither sedimentation nor sludge return, this procedure counts on adequate mixed liquor formed in the tank/lagoon. Therefore, the aeration lagoons are suitable for strong but degradable wastewater such as wastewaters of food industries. The hydraulic retention time (HRT) ranges from 3 to 8 days based on treatment level, strength, and temperature of the influent. Generally, HRT of about 5 days at 20°C achieves 85% removal of BOD in household wastewater. However, if the temperature falls by 10°C, then the BOD removal will decrease to 65%

Figure 18: Aerated Lagoons

4.4.2 Anaerobic Treatment

The anaerobic treatments are implemented to treat wastewaters rich in biodegradable organic matter (BOD >500 mg L-1) and for further treatment of sedimentation sludges. Strong organic wastewaters containing large amounts of biodegradable materials are discharged mainly by agricultural and food processing industries. These wastewaters are difficult to be treated aerobically due to the troubles and expenses of fulfillment of the elevated oxygen demand to preserve the aerobic conditions. In contrast, anaerobic degradation occurs in the absence of oxygen. Although the anaerobic treatment is time-consuming, it has a multitude of advantages in treating strong organic wastewaters. These advantages include elevated levels of purification, aptitude to handle high organic loads, generating small amounts of sludges that are usually very stable, and production of methane (inert combustible gas) as end-product.

4.4.2.1 Anaerobic Digesters

Anaerobic digestion is a complex multistep process in terms of chemistry and microbiology.

Suitable wastewaters include livestock manure, food processing effluents, petroleum wastes (if the toxicity is controlled), and canning and dyestuff wastes where soluble organic matters are implemented in the treatment. Most anaerobic processes (solids fermentation) occur in two predetermined temperature ranges: mesophilic or thermophilic. The temperature ranges are 30–38°C and 38–50°C, respectively. In contrast to aerobic systems, absolute stabilization of organic matter is not achievable under anaerobic conditions. Therefore, subsequent aerobic treatment of the anaerobic effluents is usually essential. The final waste matter discharged by the anaerobic treatment includes solubilized organic matter demonstrating the possibility of installing collective anaerobic and aerobic units in series

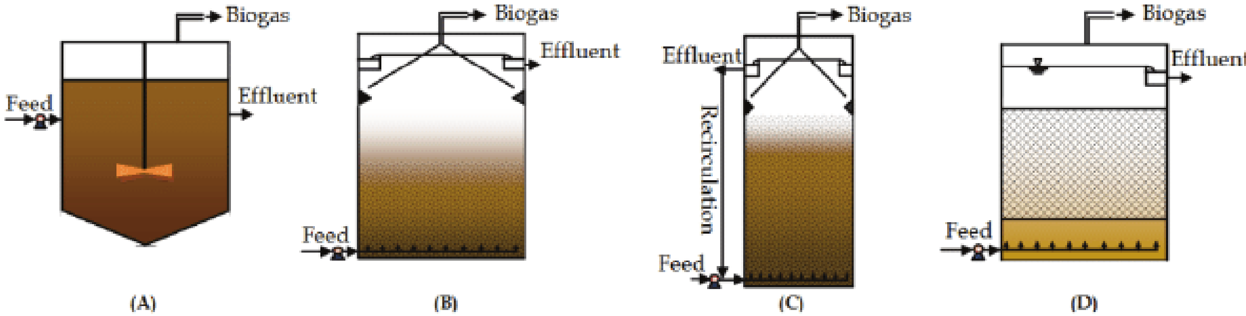

Figure 19: Anaerobic digester in series

4.4.2.2 Anaerobic Lagoon

An anaerobic lagoon is a deep lagoon, fundamentally without dissolved oxygen, that enforces anaerobic conditions. The anaerobic process occurs in deep ground ponds, and such basins are implemented for anaerobic pretreatment. The anaerobic lagoons are not aerated, heated, or mixed. The depth of an anaerobic lagoon should be typically deeper than 2.5 m, where deeper lagoons are more efficient. Such depths diminish the amount of oxygen diffused from the surface, allowing anaerobic conditions to prevail.

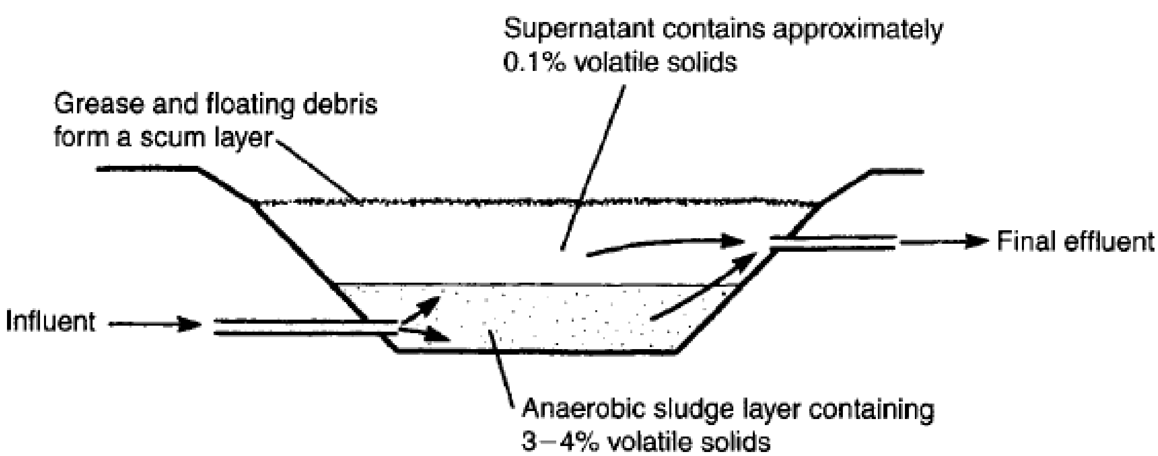

Figure 20: Anaerobic lagoon for strong wastewater treatment, such as meat processing wastewater

4.5 Membrane Bioreactor (MBR)

MBRs are commonly designed for nitrogen removal, using membranes for liquid-solids separation following the anoxic and aerobic zones instead of conventional clarification. Membranes can be submersed in the biological reactor or located in a separate stage or compartment. Low-pressure membranes (ultrafiltration or microfiltration) are commonly used. Systems can be pressure driven or vacuum. All systems use an air scour technique to reduce buildup on the membranes

Membrane materials are either organic polymers or inorganic materials such as ceramics. They are designed in modular units and are typically configured as either hollow fiber bundles or plate membranes

One of the main differences is that the MBR systems operate at a higher MLSS concentration which results in smaller tanks and smaller space requirements. In addition, membrane separation provides for greatly reduced TSS in the effluent, typically below 1.0 mg/L, and hence slightly greater removal of nitrogen and phosphorus. Operational issues include potential for membrane bio-fouling and increase pumping costs

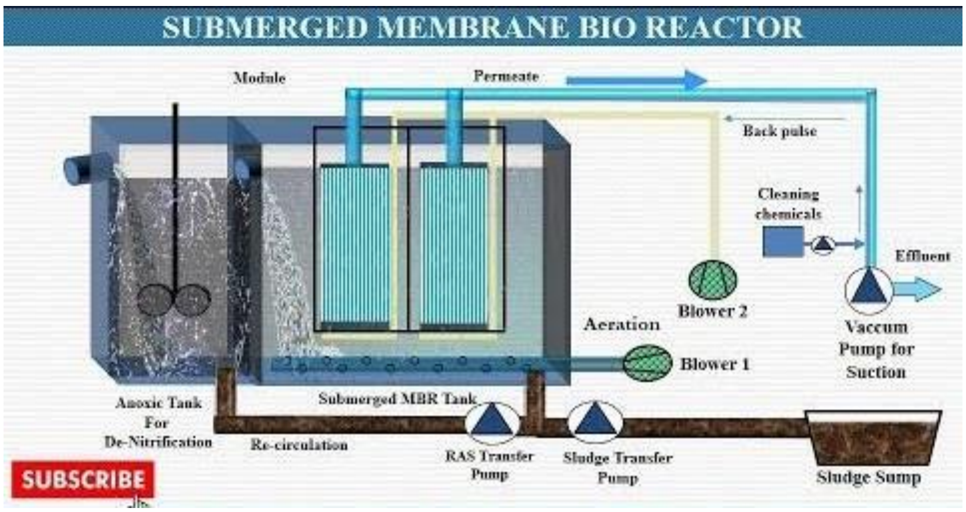

Figure 21: Submerged membrane bioreactors

4.5.1 Membrane Bioreactor Technology - An Overview

(i) Membrane Bioreactor Technology is based on Biological Treatment followed by membrane separation, system comprising of an intense activated sludge process with the biomass separation stage carried out by membrane cassettes located outside the aeration tank in a separate membrane tank.

(ii) The Membranes replace the settlement stage in conventional activated-sludge systems and effectively revolutionize the process.

(iii) Membrane fibers have billions of microscopic pores on the surface The pores form a barrier to impurities, while allowing pure water molecules to pass.

(iv) Water is drawn through the pores using gentle suction

(v) Two main process configurations of biomass rejection MBRs are as follows:

(vi) Submerged or Immersed MBR (MBR) In the submerged MBR (SMBR) process, the membrane is submerged directly in the aeration tank. By applying low vacuum or by using the static head of the mixed liquor, effluent is driven through the membrane leaving the solids behind.

(vii) (ii) External / Sidestream MBR (EMBR) In the external MBR (EMBR), the mixed liquor is pumped from the aeration tank to the membrane at flow rates that are 20–30 times the product water flow to provide adequate shear for controlling solids accumulation at the membrane surface. The high cost of pumping makes EMBR system impractical for full-scale municipal wastewater treatment plants

4.5.2 STRUCTURE OF MEMBRANE UNIT

(viii) Normally, systems are built with two different compartments.

(ix) The first section is the screening stage where the wastewater enters the unit.

(x) In this area; heavy solids are first separated subsequently traversing to another compartment which houses the membranes. The initial screening is of high importance, as the larger molecules (scum and grit) will not trap the surface of the membrane and lead to fouling.

(xi) In the second compartment, the biological process takes place involving vigorous agitation, coming from air bubbles generated from a blower system. This acts to scour and clean the surface of the membrane to prevent buildup of material on the and also to provide sufficient oxygen concentration for biological action that supports growth of bacteria. Depending on how the system is designed to ensure efficient air to water oxygen transfer, the household MBR is capable to support up to 4000ppm of MLSS level while large-scale industrial wastewater treatment plant bioreactor scan handle up to 20000ppm.

(xii) A complete unit usually comes equipped with a backflush system whereby discharged wastewater will now move counter flow from the permeate side back again to the system to dislodge trapped material accumulating on the surface. During this process, air scouring will still continue to run to help increase removal efficiency.

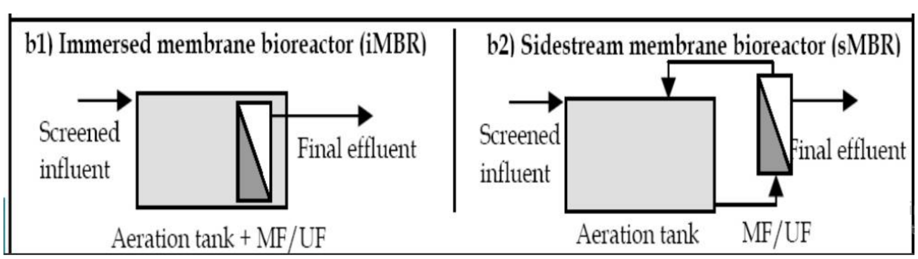

Figure 22: Types of membranes in MBR

4.6 Biological Removal of Nitrogen

The nitrification and de-nitrification processes are responsible for N_2O production Figure 23 shows a nitrification/de-nitrification system for biological removal of nitrogen.

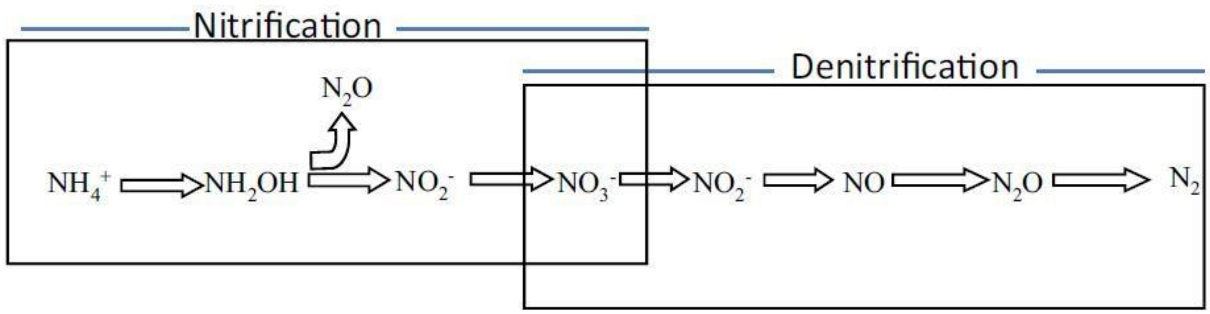

Figure 23: Schematic illustration of nitrification and de-nitrification processes that are responsible for N_2O release

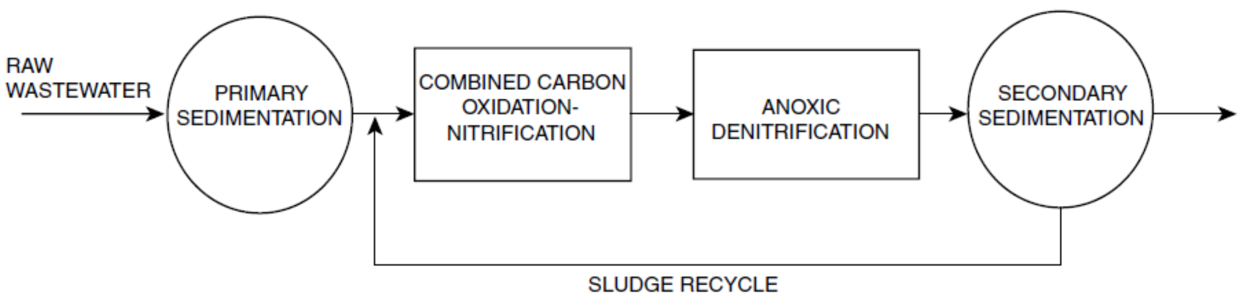

Figure 24: Nitrification/de-nitrification system for biological removal of nitrogen

UNIT 5:
WASTE WATER TREATMENT THROUGH PHYTOREMEDIATION

5 PHYTOREMEDIATION OR CONSTRUCTED WETLANDS

5.1 Introduction to Phytoremediation

Phytoremediation is a treatment process that solves environmental problems by implementing plants that abate environmental pollution without excavating the pollutants and disposing them elsewhere. Phytoremediation is the abatement of pollutant concentrations in contaminated soils or water using plants that are able to accumulate, degrade, or eliminate heavy metals, pesticides, solvents, explosives, crude oils and its derivatives, and a multitude of other contaminants and pollutants from water and soils. The incorporation of heavy metals, such as mercury, into the food chain may be a deteriorating matter. Phytoremediation is useful in these situations, where natural plants or transgenic plants are able to phyto-degrade and phyto-accumulate these toxic contaminants in their above-ground parts, which will be then harvested for extraction. The heavy metals in the harvested biomass can be further concentrated by incineration and recycled for industrial implementation.

Figures below show the designs of constructed wetlands where the phytoremediation takes place.

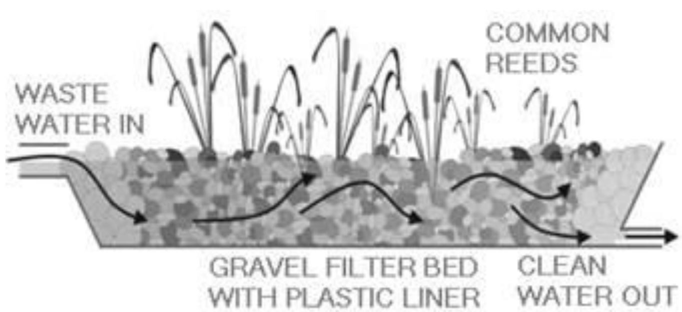

Figure 25: Cross-sectional view of a typical subsurface flow constructed wetland

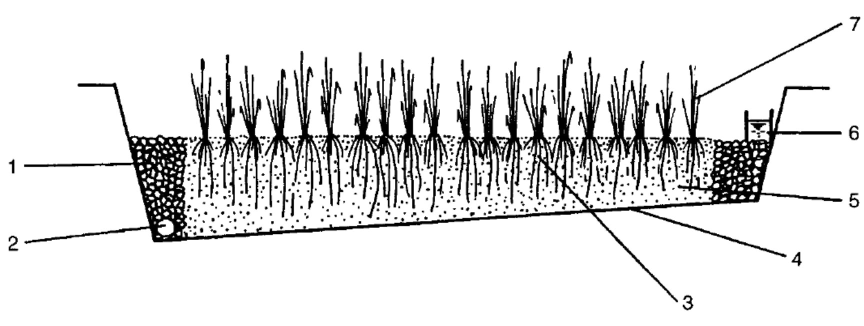

Figure 26: Components of a horizontal flow reed bed:

(1) drainage zone consisting of large rocks, (2) drainage tube of treated effluent, (3) root zone, (4) impermeable liner, (5) soil or gravel, (6) wastewater distribution system, and

(7) reeds

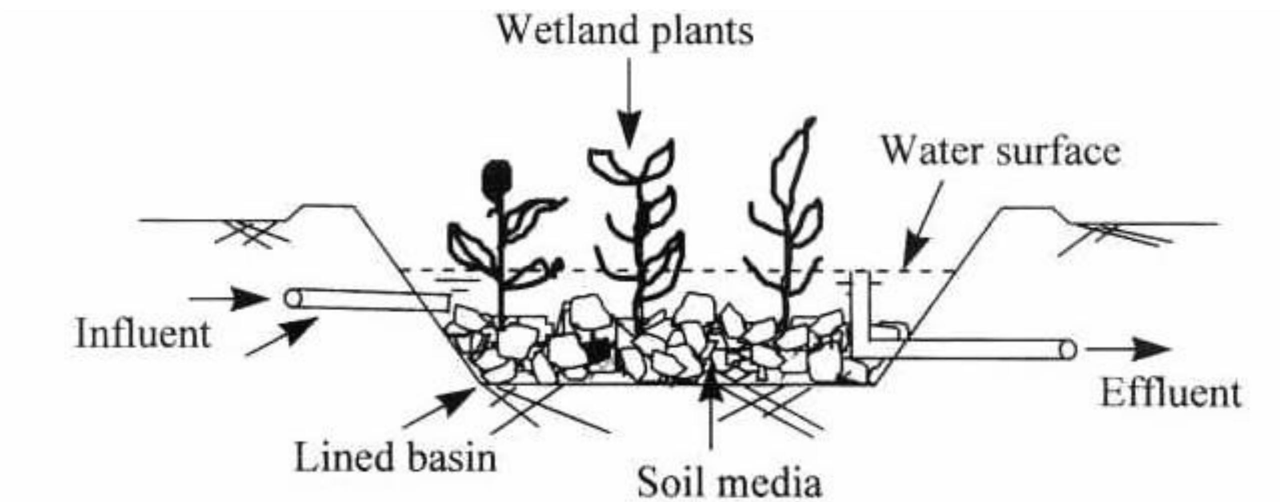

Figure 27: Free water surface flow system

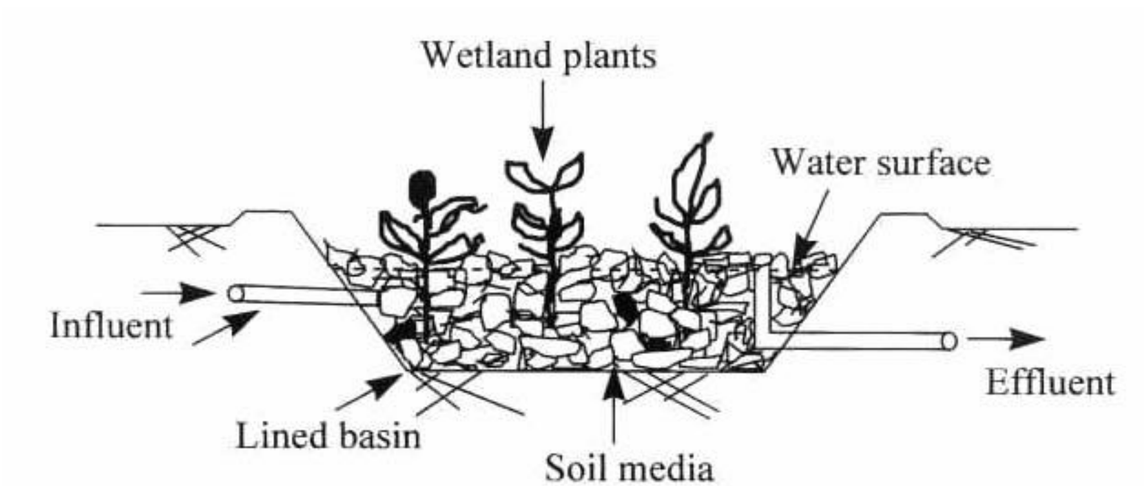

Figure 28: Sub-surface flow system.

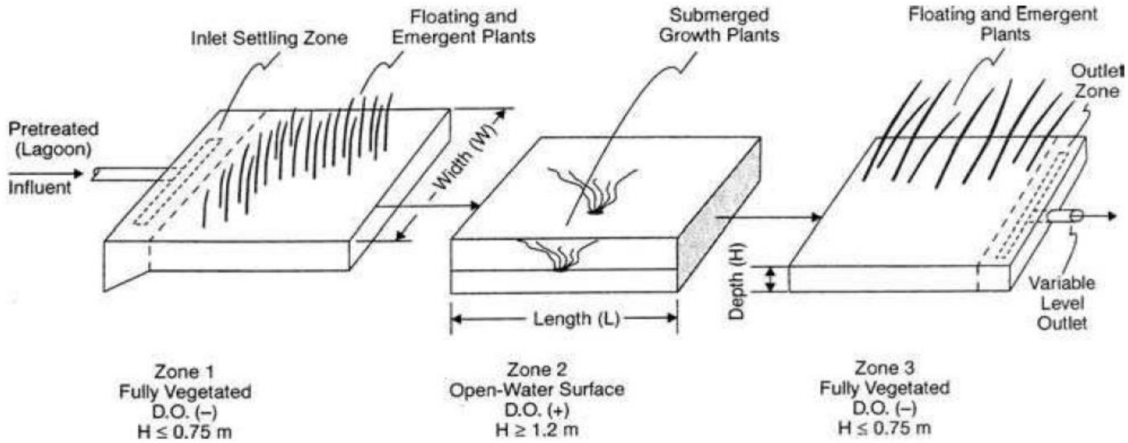

Figure 29: Components of a free water surface constructed wetland

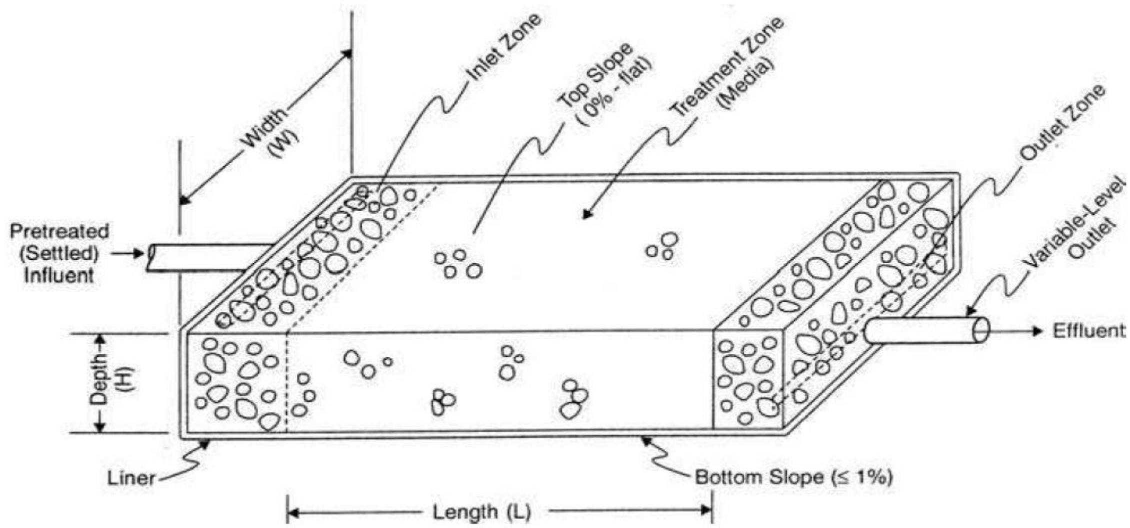

Figure 30: Components of a vegetated submerged bed system

5.2 Rhizofiltration

Rhizofiltration is a sort of phytoremediation that involves filtering wastewater through a mass of roots to remove toxic substances or excess nutrients. Phytoaccumulation or phytoextraction implements plants or algae to remove pollutants and contaminants from wastewater into plant biomass that can be harvested. Organisms that accumulate over than usual amounts of pollutants from soils are termed hyperaccumulators, where a multitude of tables that show the different hyperaccumulators are available and should be referred to. In the case of organic pollutants, such as pesticides, explosives, solvents, industrial chemicals, and other xenobiotic substances, certain plants render these substances non-toxic by their metabolism and this process is called phytotransformation. In other cases, microorganisms that live in symbiosis with plant roots are able to metabolize these pollutants in wastewater. shows the tissues where the rhizofiltration, phytodegradation, and phytoaccumulation take place.

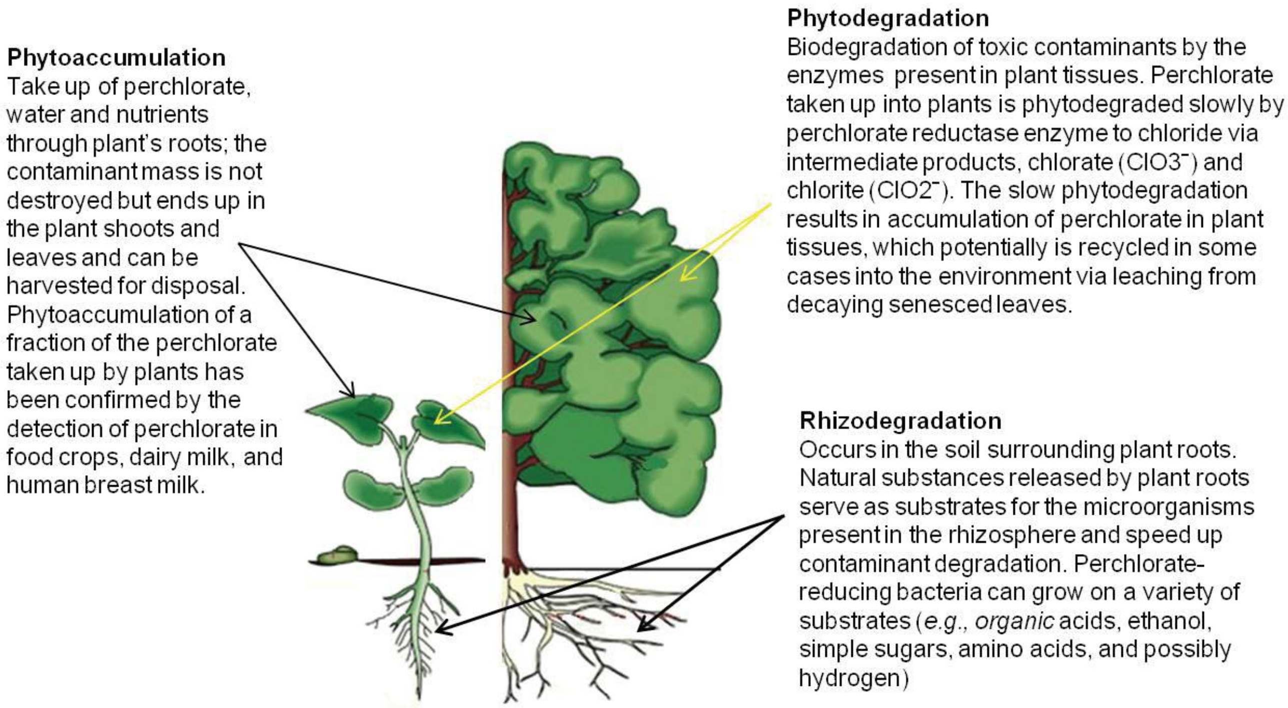

Figure 31: Rhizofiltration, phytodegradation, and phytoaccumulation

Activity:

Sludge seeding

Model development of constructed wetland for waste water treatment.

6 REFERENCES:

Bhargava, Dr. akshey. (2016). Physico-Chemical Waste Water Treatment Technologies: An Overview. International Journal Of Scientific Research And Education. 10.18535/ijsre/v4i05.05.

Metcalf and Eddy, Inc., Wastewater Engineering, 3rd edition

https://www.intechopen.com/books/wastewater-treatment-engineering/biological-and-chemical-wastewater-treatment-processes#B1