CHAPTER 2

WASTE WATER TREATMENT

2.1 This chapter is concerned with liquid wastes as found at permanent locations. Although field-type wastes are mentioned in this chapter, they are discussed in more detail in part 2. Australian Defence Force health staff should coordinate with the appropriate overseas or domestic health authorities to ensure compliance with applicable health and environmental regulations.

2.2 The wastewater discussed in this section is predominantly of domestic origin. Varying amounts of industrial and laboratory wastewaters can be collected and treated with the sanitary sewage. The primary purpose of the treatment of sewage is to prevent the pollution of the receiving waters. Many techniques have been devised to accomplish this aim for both small and large quantities of sewage.

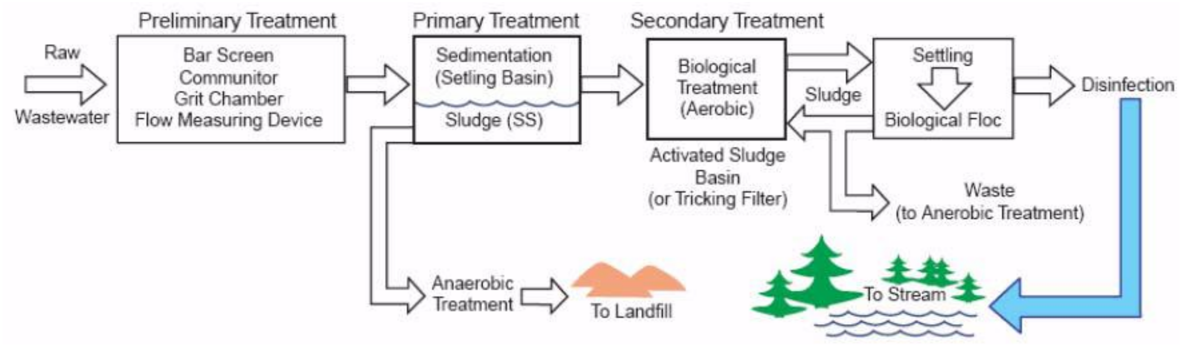


Figure 2–1: Schematic of a typical wastewater treatment plant

2.3 In general, these processes are divided into three stages: preliminary (physical), primary (physical) treatment and secondary (biological) treatment. Figure 2–1 provides a schematic of a typical wastewater treatment plant. Minimally, wastewater should receive primary (physical removal/settling) and secondary (biological) treatment, which can be followed by disinfection before discharge. More advanced processes (advanced or tertiary treatment) may be required for special wastes. When the effluent from secondary treatment is unacceptable, a third level of treatment, tertiary treatment, can be employed. There are many basic types of sewage treatment plants employing both primary and secondary treatment stages that are in use today for treating large quantities of sewage.

COLLECTION SYSTEM

2.4 The purpose of a sewage collection system is to remove wastewater from points of origin to a treatment facility or place of disposal. The collection system consists of the sewers (pipes and conduits) and plumbing necessary to convey sewage from the point(s) of origin to the treatment system or place of disposal. It is necessary that the collection system be designed so that the sewage will reach the treatment system as soon as possible after entering the sewer. If the length of time in the sewers is too long, the sewage will be anaerobic when it reaches the treatment facilities.

2.5 Sanitary sewage collection systems should be designed to remove domestic sewage only. Surface drainage is excluded to avoid constructing large sewers and treating large volumes of sewage diluted by rainwater during storms. Sewers which exclude surface drainage are called sanitary sewers, and those which collect surface drainage in combination with sanitary sewage are called combined sewers.

2.6 Except for force mains, sewers are laid to permit gravity flow of their contents. Unlike water in a water distribution system, the contents of a sewer do not flow under pressure. Usually the slope is such that a flow rate of 0.03 metre (m) per second or more is maintained when the line is flowing half full to full. This is a self-cleansing velocity and prevents solids from settling in the sewer pipes. To the maximum extent practical, sewers are laid in straight lines. Corners and sharp bends slow the flow rate, permit clogging, and make line cleaning difficult.

2.7 Pumping is necessary where the slope of the sewer does not produce the required minimum velocity of 0.03 m or where sewage must be lifted to a higher elevation. Sewage can be pumped from pumping stations through pressure lines (force mains) regardless of their slope, or it can be raised to a higher elevation at pumping stations (lift stations), so that gravity flow will again produce the required velocity.

2.8 For gravity flow lines, sewer pipes of vitrified clay tile, concrete, cement-asbestos, or bituminous-impregnated fibre may be used. For force mains and stream crossings, cast iron or cement-asbestos pipes are used.

2.9 Removing grease from sewage is essential to the proper functioning of sewage systems. At fixed installations, grease is collected by ceramic or cast iron grease interceptors installed at kitchens and other facilities that generate grease and by concrete or brick grease traps outside the building. Approximately 90 per cent of the grease will be removed from greasy wastes by properly maintained grease interceptors and traps.

2.10 Petrol and oil separators are installed in sewer lines from garages and shops where petrol and oil might be accidentally spilled. Separators are also installed under washing facilities to contain the oil in water. In areas where large amounts of volatile material are produced as waste, some other method must be provided. Volatile liquids accumulating in sewers can cause explosions and destroy sewer lines or the treatment plant.

WASTEWATER MANAGEMENT TRICKLING FILTER SYSTEM

2.11 A common type of treatment system used at military installations where extensive water collection systems handle large quantities of sewage is the trickling filter system (*see* figure 2–2). The trickling filter system employs the following units:

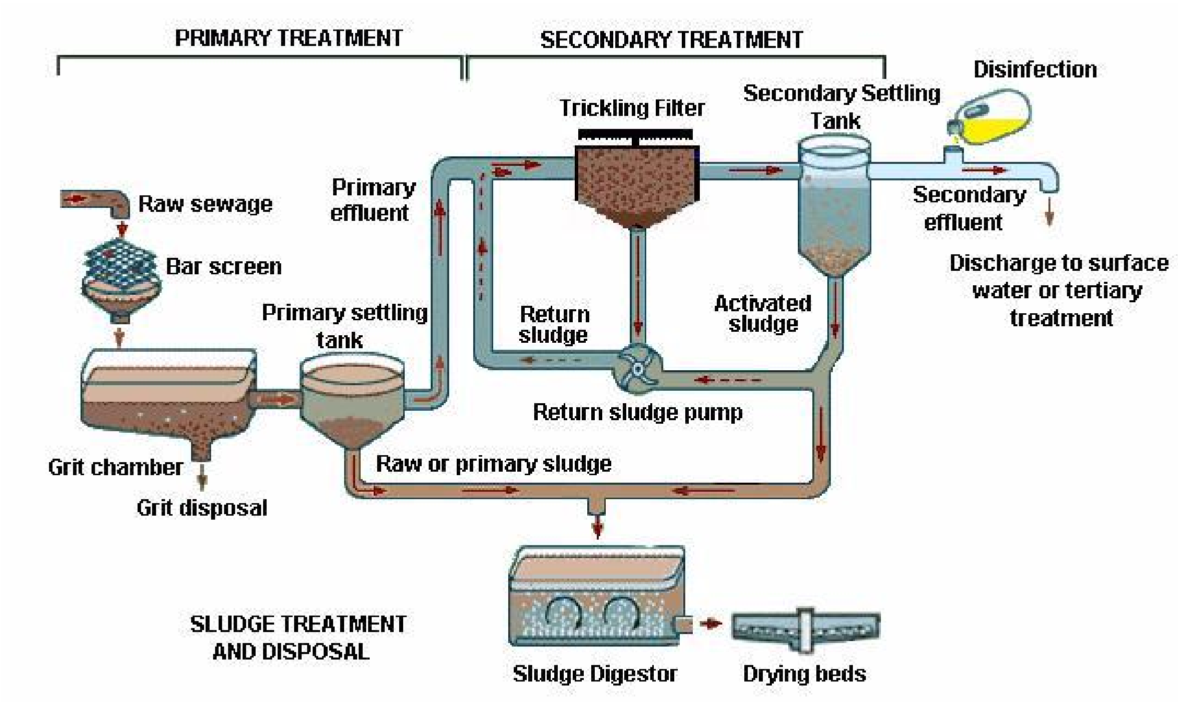


Figure 2–2: Wastewater treatment based on a trickling filter system

Bar screens

2.12 A grating of steel bars spaced about 2–4 cm on centres is placed at an angle to the flow of sewage through an open channel (*see* figure 2–3). The raw influent first goes through a self-cleaning screen and then into one end of a shallow and rather fast moving basin so that sand and gravel can settle out. Often skimmers rotate around the surface of the basin to remove oils that may have been flushed into the system. The screen removes coarse and floating solids from the sewage. The screen must be cleaned regularly and the removed solids must be burned, ground and digested, or buried. Many systems have a grinder known as a comminutor used either with or instead of a bar screen for grinding large particles which might clog the pumps.

Figure 2–3: Bar screen

Grit chamber

2.13 A chamber in which the velocity of waste flow is reduced to a point where the denser sand and other grit will settle out, but the organic solids will remain in suspension (refer figure 2–4). The settled material is buried or used for fill.

Figure 2–4: Grit chamber

Primary settling tanks (or basins)

2.14 These are usually large tanks in which solids settle out of water by gravity (refer figure 2–5 and 2–6) where the settle-able solids are pumped away (as sludge), while oils float to the top and are skimmed off. It operates by means of the velocity of flow is reduced to about 0.005 m so that the suspended material (organic settleable solids) will settle out. The usual detention time is 11/2–21/2 hours. Longer periods usually result in depletion of dissolved oxygen and subsequent anaerobic conditions. Removal of suspended solids ranges from 50–65 per cent, and a 30–40 per cent reduction of the five-day biochemical oxygen demand (BOD) can be expected. For more information on BOD, *see* paragraph 2.48.

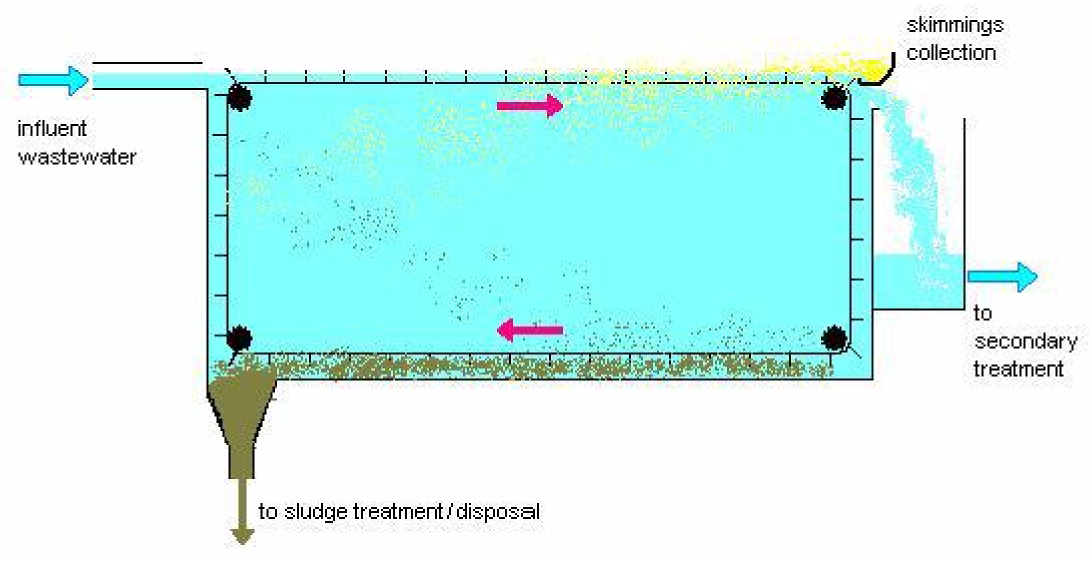


Figure 2–5: Primary settling tank schematic

Figure 2–6: Primary settling tank

Sludge digestors

2.15 The sludge which settles in the sedimentation basin is pumped to the sludge digestors (*see* figure 2–7) where a temperature of 30–35ºC is maintained. This is the optimum temperature for the anaerobic bacteria (bacteria that live in an environment that does not contain oxygen). The usual length of digestion is 20–30 days but can be much longer during winter months. Continual adding of raw sludge is necessary and only well-digested sludge should be withdrawn, leaving some ripe sludge in the digestor to acclimatise the incoming raw sludge.

Figure 2–7: Sludge digestors

Drying beds

2.16 Digested sludge is placed on drying beds of sand (*see* figure 2–8) where the liquid may evaporate or drain into the soil. The dried sludge is a porous humus-like cake which can be used as a fertiliser base.

Figure 2–8: Drying beds

Trickling filters

2.17 The liquid effluent from the primary settling tank is passed to the secondary part of the system where aerobic decomposition completes the stabilisation. For this purpose, a trickling filter (*see* figures 2–9 and 2–10) is used.

2.18 A trickling filter is a fixed bed, biological filter that operates under (mostly) aerobic conditions. Pre-settled wastewater is ‘trickled’ or sprayed over the filter. As the water migrates through the pores of the filter, organics are degraded by the biomass covering the filter material.

2.19 The Trickling Filter is filled with a high specific surface-area material such as rocks, gravel, shredded PVC bottles, or special pre-formed filter-material. A material with a specific surface area between 30 and 900m^2/m^3 is desirable. The filter is usually 1–3 m deep but filters packed with lighter plastic filling can be up to 12 m deep. Pre-treatment is essential to prevent clogging and to ensure efficient treatment. The pre-treated wastewater is ‘trickled’ over the surface of the filter. Organisms that grow in a thin bio-film over the surface of the media oxidize the organic load in the wastewater to carbon dioxide and water while generating new biomass.

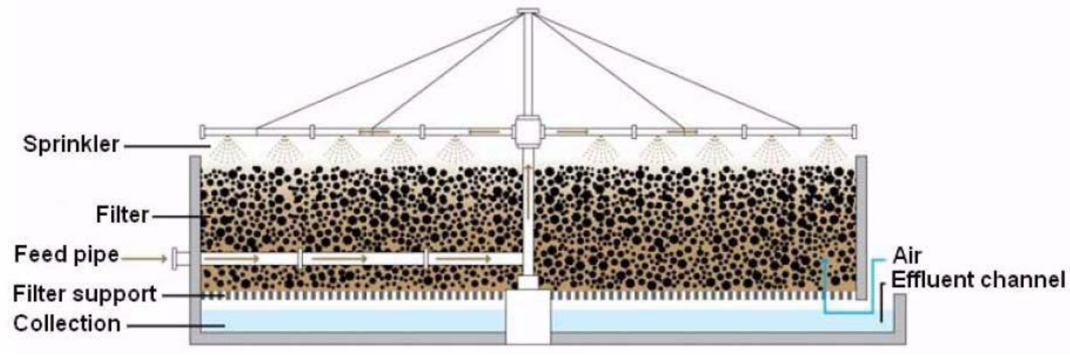


Figure 2–9: Trickling filter

2.20 The incoming wastewater is sprayed over the filter with the use of a rotating sprinkler. In this way, the filter media goes through cycles of being dosed and exposed to air. However, oxygen is depleted within the biomass and the inner layers may be anoxic or anaerobic.

Figure 2–10: Trickling filter

2.21 The ideal filter material has a high surface to volume ratio, is light, durable and allows air to circulate. Whenever it is available, crushed rock or gravel is the cheapest option. The particles should be uniform such that 95 per cent of the particles have a diameter between seven and 10 cm. Both ends of the filter are ventilated to allow oxygen to travel the length of the filter. A perforated slab that allows the effluent and excess sludge to be collected supports the bottom of the filter.

2.22 The bed consists of crushed rock or slag (1–2 m deep) through which the sewage is allowed to percolate. The stones become coated with a zoogloea film (a jelly-like growth of bacteria, fungi, algae, and protozoa), and air circulates by convection currents through the bed. Most of the biological action takes place in the upper 0.5 m of the bed. Depending on the rate of flow and other factors, the slime will slough off the rocks at periodic intervals or continuously, whenever it becomes too thick to be retained on the stones. A secondary settling basin is necessary to clarify the effluent from the trickling filter. The overall reduction of BOD for a complete trickling filter system averages around 80–90 per cent.

Secondary settling tank

2.23 With the majority of the suspended material removed from the sewage, the liquid portion flows over a weir at the surface of the secondary settling tank (*see* figure 2–11). Chlorination of the effluent from the secondary settling tank takes place in accordance with state and local laws. Depending on the location most laws require that a free available chlorine (FAC) residual (usually 0.2 mg/L) be maintained after a 30-minute contact period. This contact period is obtained through the use of chlorine contact chambers which are designed to provide a 30-minute detention time. From the chlorine contact chamber the treated sewage is normally discharged into a receiving body of water.

Figure 2–11: Secondary settling tank

Activated sludge system

2.24 Activated Sludge is a multi-chamber reactor unit that makes use of (mostly) aerobic microorganisms to degrade organics in wastewater and to produce a high-quality effluent. To maintain aerobic conditions and to the keep the active biomass suspended, a constant and well-timed supply of oxygen is required. Activated sludge systems (refer figures 2–12 and 2–13) normally make use of bar screens and/or comminutors, grit chambers, primary settling tanks, secondary settling tanks, and digesters, which are operated in the same manner as those of trickling filter systems. They differ from the trickling filter systems in that they make use of an aeration tank instead of a trickling filter.

2.25 Different configurations of the Activated Sludge process can be employed to ensure that the wastewater is mixed and aerated (with either air or pure oxygen) in an aeration tank. The microorganisms oxidize the organic carbon in the wastewater to produce new cells, carbon dioxide and water. Although aerobic bacteria are the most common organisms, aerobic, anaerobic, and/or nitrifying bacteria along with higher organisms can be present. The exact composition depends on the reactor design, environment, and wastewater characteristics. During aeration and mixing, the bacteria form small clusters, or flocs. When the aeration stops, the mixture is transferred to a secondary clarifier where the flocs are allowed to settle out and the effluent moves on for further treatment or discharge. The sludge is then recycled back to the aeration tank, where the process is repeated.

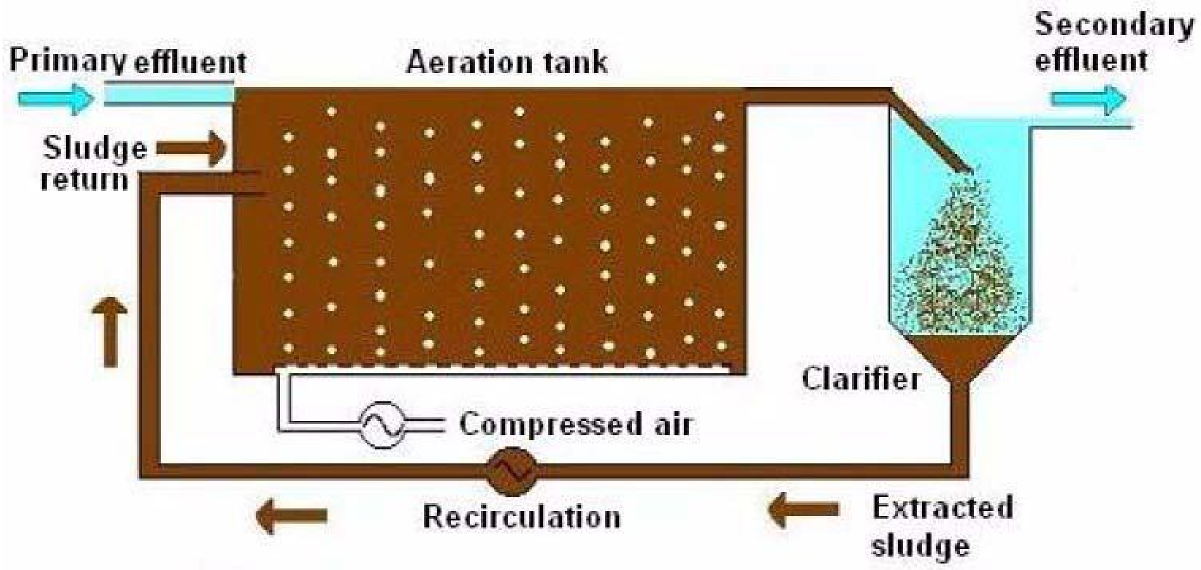


Figure 2–12: Activated sludge system example one

2.26 Compressed air is continually diffused into the sewage as it flows through the aeration tank. This provides both a source of oxygen for the aerobic bacterial floc that forms in the tank and the turbulence necessary to bring the waste and the bacteria into contact. Aerobic bacteria attack the dissolved and finely divided suspended solids not removed by primary sedimentation. Some of the floc is removed with the sewage that flows out of the aeration tank and carried into the secondary settling tank. Here the floc settles to the bottom of the tank, and is later pumped back into the aeration tank. The liquid portion then flows over a weir at the surface of the settling tank to be chlorinated and released to a receiving stream.

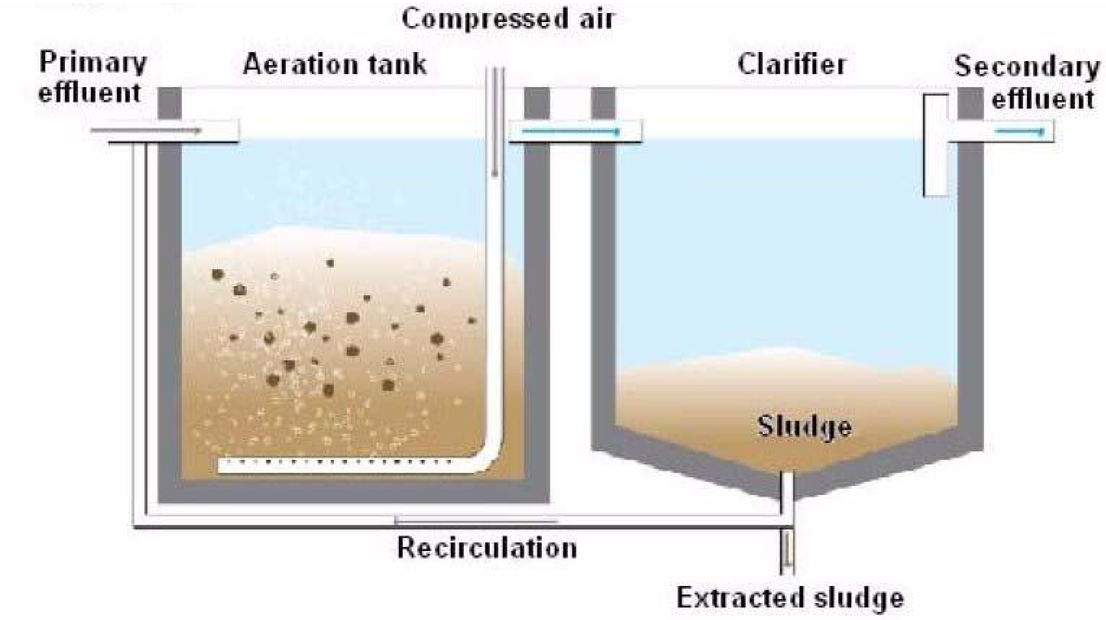


Figure 2–13: Activated sludge system example two

2.27 To achieve specific effluent goals for BOD, nitrogen and phosphorus, different adaptations and modifications have been made to the basic Activated Sludge design. Aerobic conditions, nutrient-specific organisms (especially for phosphorus), recycle design and carbon dosing, among others, have successfully allowed Activated Sludge processes to achieve high treatment efficiencies.

Rotating biological contactor system

2.28 Rotating biological contactor systems (refer figures 2–13, 2–14 and 2–15) normally make use of bar screens and/or comminutors, grit chambers, primary settling tanks, secondary tanks, and digesters, which are operated in the same manner as those of trickling filter systems. The rotating biological contactor (RBC) is a simple, effective method of providing secondary wastewater treatment. The system consists of biomass media, usually plastic, that is partially immersed in the wastewater. As it slowly rotates, it lifts a film of wastewater into the air. The wastewater trickles down across the media and absorbs oxygen from the air. A living biomass of bacteria, protozoa, and other simple organisms attaches and grows on the biomass media. The organisms then remove both dissolved oxygen and organic material from the trickling film of wastewater. Any excess biomass is sloughed-off as the media is rotated through the wastewater. This prevents clogging of the media surface and maintains a constant microorganism population. The sloughed-off material is removed from the clear water by conventional clarification. The RBC rotates at a speed of one to two rpm and provides a high degree of organic removal.

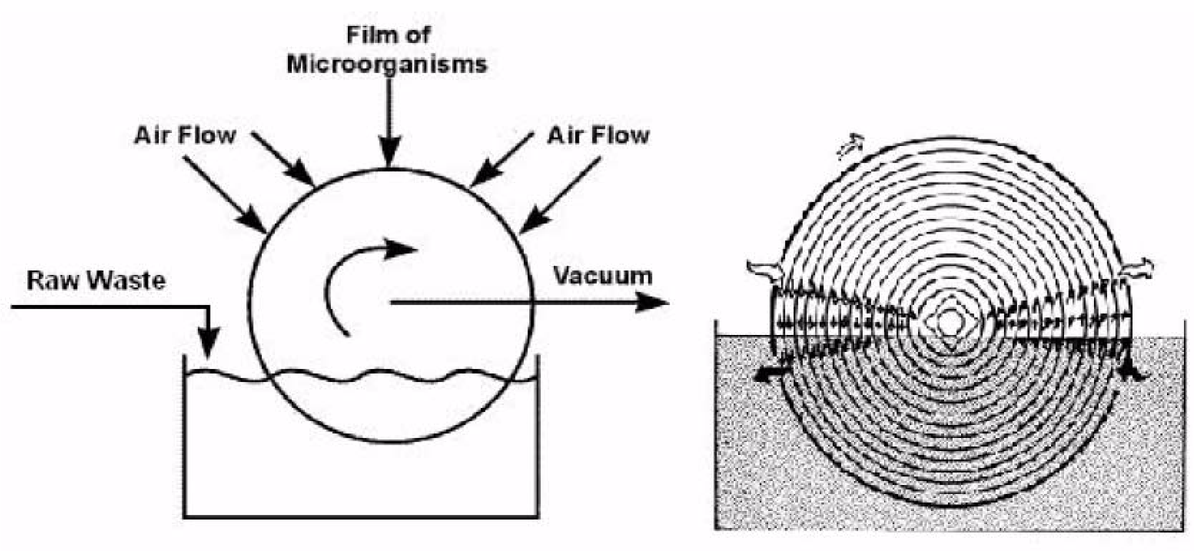


Figure 2–14: Rotating biological contactor

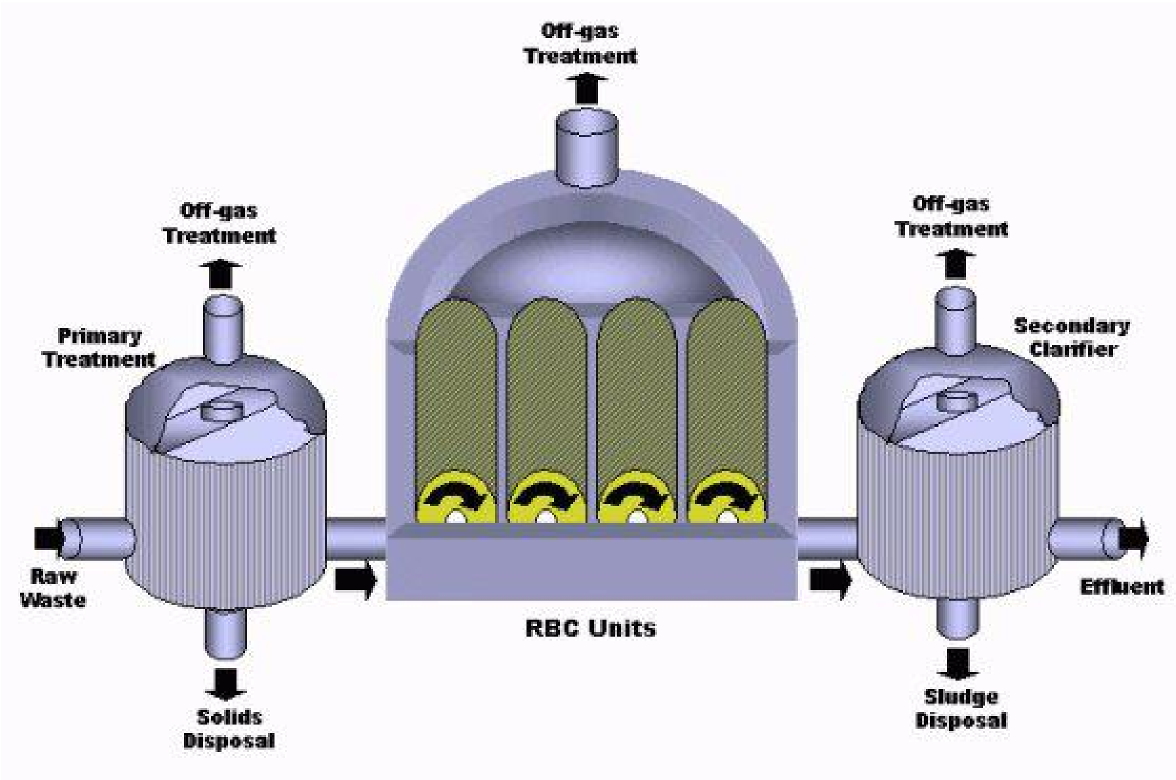


Figure 2–15: Rotating biological contactors preceded by pre-treatment and followed by secondary sedimentation

Figure 2–16: Rotating biological contactor

Imhoff tank system

2.29 Imhoff tank systems normally make use of bar screens and/or comminutors, grit chambers, primary settling tanks, secondary settling tanks, and digesters, which are operated in the same manner as those of trickling filter systems. An Imhoff tank is a combined sedimentation or settling tank and digestion tank (*see* figure 2–17). It consists of an upper compartment for settling out solids from slowly flowing sewage and a lower compartment for anaerobic digestion of the sludge. The upper compartment forms a channel with an approximately 20 cm slot in the bottom. Sides of the slot have a 1 horizontal to 1 1/2 vertical slope and are overlapped to prevent gases formed by digesting sludge from escaping into the upper or 'flowing-through' compartment.

2.30 With an average flow, solids settle in the upper compartment in two to two and a half hours, pass downward through the slot, and settle to the bottom of the lower compartment where they are digested. Accumulated solids are removed periodically through a sludge draw-off pipe having its inlet about 30 cm above the tank bottom. Design of the upper or 'flowing-through' compartment is based on the retention period. The lower or digestion compartment is designed to hold 85 litres per capita below a plane 45 cm beneath the bottom of the slot. If sludge from secondary settling is returned to this compartment for digestion, the capacity of the compartment must be increased to 130 L per capita.

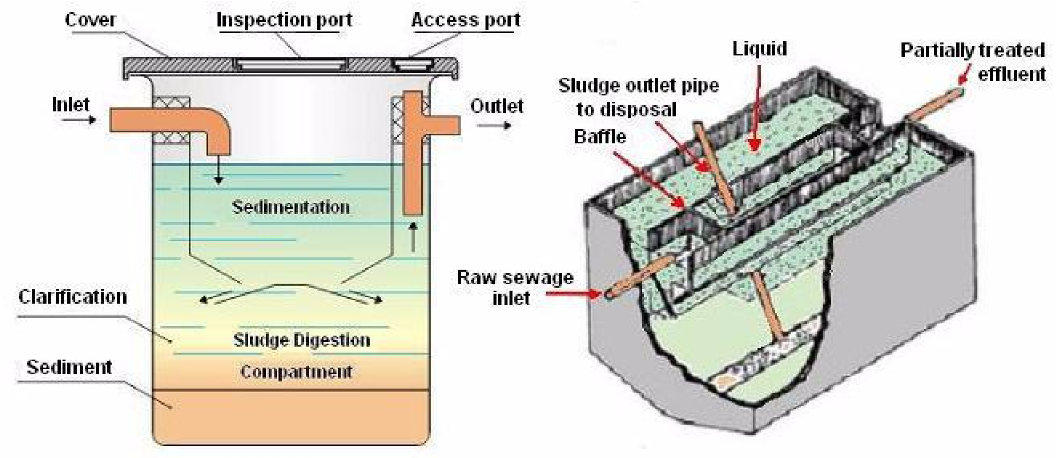


Figure 2–17: Imhoff tank schematic

Sewage oxidation ponds

2.31 Sewage oxidation ponds (lagoons) offer economical secondary sewage treatment with relatively low initial cost. These ponds are 0.8–1.2 m in depth, and may be used singly, in parallel, or in a series following primary treatment (*see* figures 2–18 and 2–19). Their use is particularly suited to locations with available land and warm climates. Their ability to absorb shock loads and ease of operation and maintenance make them desirable treatment units. Biological life in ponds use the organic and mineral matter in the sewage for food to produce more stable products. The products often stimulate abundant growth of algae and other vegetation. Solution of oxygen from the atmosphere, and the ability of vegetation to produce oxygen when exposed to sunlight, help maintain aerobic conditions. The lagoons will develop an odour similar to freshwater ponds in wooded areas. Allowable loading can vary from 125–2000 persons per hectare depending upon the location. Where complete treatment is to be provided by ponding, the cells are known as raw sewage lagoons, with depths of 1–1.5 m and reduced loading.

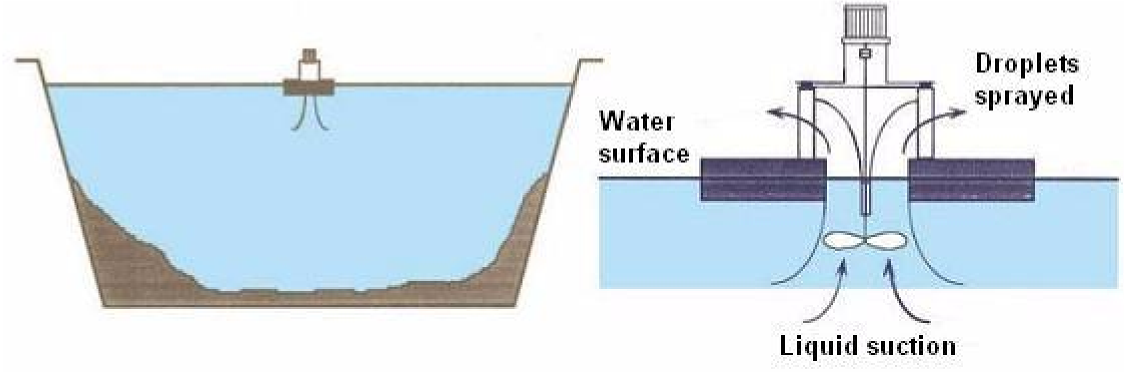


Figure 2–18: Sewage oxidation ponds schematic

Figure 2–19: Sewage oxidation ponds

Septic tank and tile drains

2.32 **Septic Tanks.** Septic tanks (*see* figure 2–20) may be used to serve small installations where the effluent can be disposed of through leaching wells, subsurface tile systems, or artificial subsurface filter systems. When sewage enters a septic tank an equal volume of liquid is discharged from the tank. The primary purpose of the septic tank is to condition the sewage so that the discharged liquid will not clog the disposal system.

2.33 A septic tank combines two processes. Sedimentation takes place in the upper portion of the tank, and the accumulated solids are digested by anaerobic decomposition in the lower portion. As sewage from a building enters a septic tank, its rate of flow is reduced so that the heavier solids sink to the bottom and the lighter solids including fats and grease rise to the surface. These solids are retained in the tank, and the clarified effluent is discharged. With good care and efficient operation, removal of solids maybe as high as 60 per cent, but at times the solid content of the effluent may equal or exceed that of the influent. Clogging of the disposal system will vary directly with the amount of suspended solids contained in the septic tank effluent.

2.34 Septic tanks do not accomplish a high degree of bacterial removal. Although the sewage undergoes treatment in passing through the tank, this does not mean that the infectious agents will be removed; hence, septic tank effluent cannot be considered safe. The liquid that is discharged from the tank is, in some respects, more objectionable than that which goes in; it is anaerobic and malodorous. However, this does not detract from the value of the tank. Further treatment of the effluent, including the removal of pathogens, is effected by percolation through the soil. In order not to disturb the bacterial action of the septic tank, disinfectants and bleach must never be flushed down toilets connected to septic tanks.

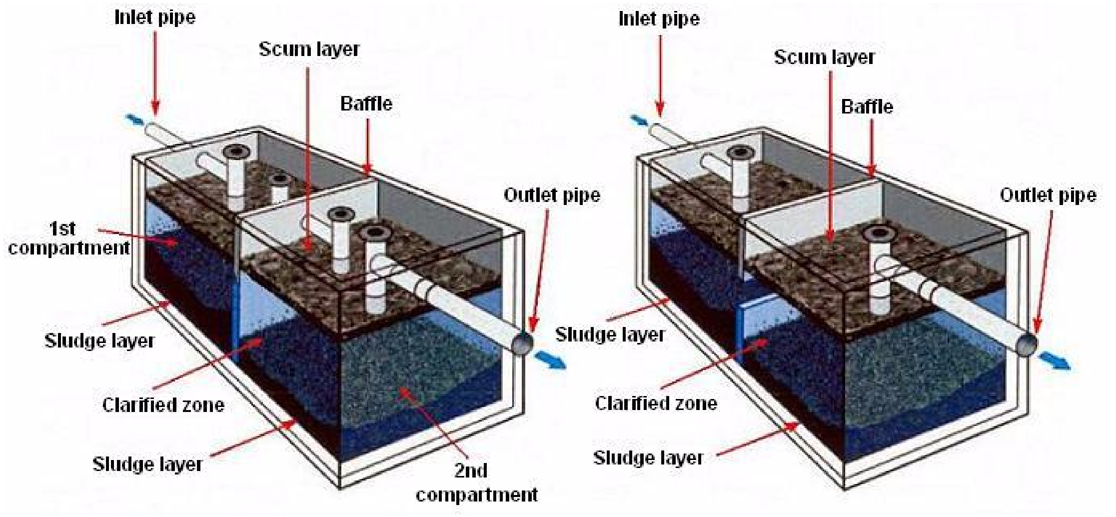


Figure 2–20: Typical septic tanks-dual chamber tank (left) and single chamber tank (right)

2.35 Septic tank capacity should equal a full days flow plus an allowance of from 15–25 per cent for sludge capacity. The minimum desirable size of the tank is 2000 litres. The tank's length should not be less than two or three times the width; liquid depth should not be less than 1.2 m for small tanks and 1.8 m for large tanks. Manholes should be provided over the inlet and outlet pipes for observation and maintenance. Baffles should be located approximately 45 cm from the ends of the tank, and should extend approximately 45 cm below and 30 cm above the flow line. Ells or tees may be used in place of wooden baffles. If these are used they should also extend at least 45 cm below the flow line. The elevations of the inlet and outlet pipes should provide free flow through the tank. This can be done by setting the bottom of the inlet pipe 8 cm above the water level. Some sludge from another operating septic tank or several shovels of fresh animal manure should be added to the new septic tank to facilitate its initial operation. A septic tank servicing an average size home of five people will need to be desludged every three to five years.

2.36 **Tile fields.** Tile fields are also known as 'soak-aways', drain fields, drainage fields, leach fields and absorption fields. Tile fields (*see* figure 2–21 and 2–22) with lines of cement or clay tile laid at least 45 cm underground with open joints are used to dispose of settled sewage into the ground. Fibre pipe with holes bored in the lower portion to allow drainage may also be used for these drain lines. A distribution box is essential for every absorption-field system to ensure equal distribution of the effluent to the several lateral lines, and to prevent overloading and failure of one line while the others are left empty. At least two lateral lines should lead from the box, and enough additional laterals should be connected to the box to provide the required effective percolation area.

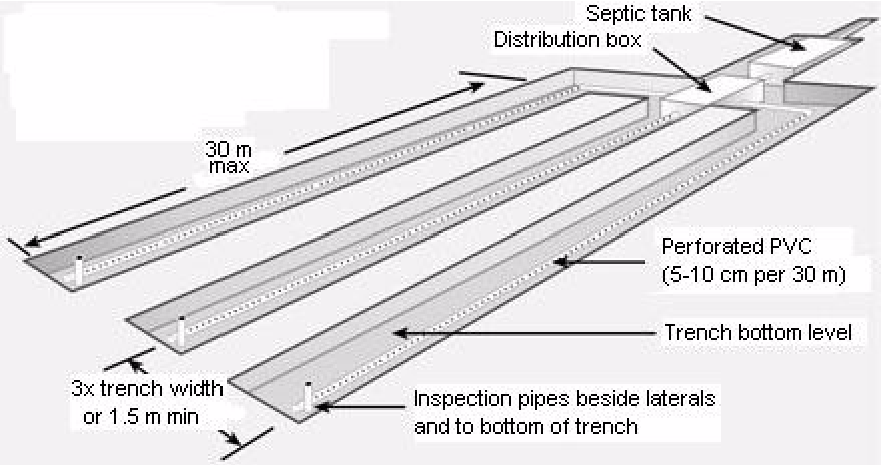


Figure 2–21: Tile field typical layout

2.37 The design of the system can be varied to meet most topographic conditions encountered, and to give proper grade and alignment for all laterals. Normally, the individual laterals should not be over 18 m long, with a maximum length of 30 m. The trench bottom and tile distribution lines should be laid at a grade of 5–10 cm per 30 m and never exceed 15 cm per 30 m. Use of more and shorter laterals is preferred because, if something should happen to disturb one line, most of the field will still be serviceable. Many different designs may be used in laying out subsurface disposal fields. The choice will depend on the size and shape of the available disposal area, the capacity required, and the topography of the disposal area.

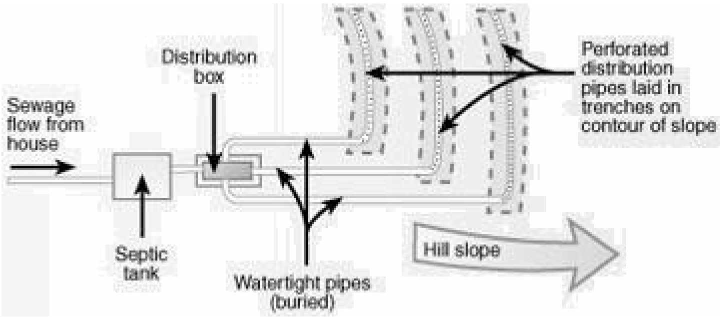


Figure 2–22: Tile field layout for a sloping site

2.38 Not all soils are porous enough to permit use of a tile field disposal system. First test the percolation rate of the soil in the proposed tile field area to determine the speed with which the settled sewage will pass into the soil. Also determine the total tile field area required to serve the installation adequately.

2.39 The required tile field area is determined by the soil percolation test. This test should be performed by qualified sanitary engineering personnel.

2.40 Once a tile field is constructed, all traffic must be excluded by fencing or posting to prevent crushing the tile. Planting shrubs or trees over the field is not a good practice, because the roots will clog the tile lines; however, grass over the lines assists in removing the moisture and keeping the soil open. Freezing rarely occurs in a carefully constructed system kept in continuous operation.

2.41 Leaching wells, sometimes called dry well or seepage pits, can be used with a septic tank. Leaching wells usually are dry-laid masonry or brick-lined wells without any masonry at the bottom; the sewage flows from the septic tank into them and leaches out into the soil. Floating solids collect in the top and settling solids in the bottom of the well. The well's leaching capacity is exhausted when the solids accumulate and clog the surrounding soil. The leaching well works on the same principle as the tile field, but leaching is a less desirable method for sewage disposal. Leaching wells are suitable where the ground-water table is below elevation. When located in fine sand, surrounding the walls with graded gravel increases the leaching area.

Aerated water treatment systems.

2.42 Aerated water treatment systems (AWTS) have superseded septic tanks in many parts of rural Australia, because they are much more efficient in reducing the organic load of domestic effluent.

2.43 The conventional AWTS treats blackwater (water containing human excrement from a toilet) and/or greywater (wastewater from a hand basin, bath, shower, kitchen, laundry) using aeration to produce treated effluent.

2.44 The conventional AWTS incorporates two plastic or concrete tanks, each with a capacity of about 2500 L (*see* figures 2–23 and 2–24). The process involves primary sedimentation, anaerobic and aerobic treatment, secondary sedimentation and clarification, and disinfection using chlorine or ultraviolet irradiation. The treated effluent is discharged into the environment via surface irrigation, absorption trench or mound.

2.45 The maximum AWTS design capacity is for effluent produced by 10 persons on domestic premises. Maximum loads are: a daily flow of 150 L per person, an average daily BOD of 70 g oxygen per person, an average daily suspended solids rate of 70 g per person, an average daily total nitrogen of 15 g per person, and an average daily total phosphorus of 2.5 g per person. Some AWTS use two aerobic biological treatment tanks and their maximum design capacity is significantly greater.

2.46 AWTS tanks should be desludged every three to five years.

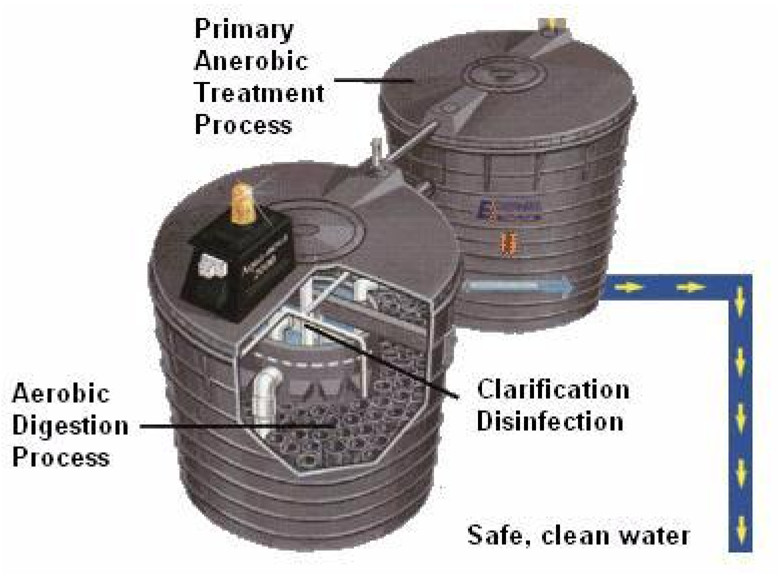


Figure 2–23: Dual tank aerated water treatment system

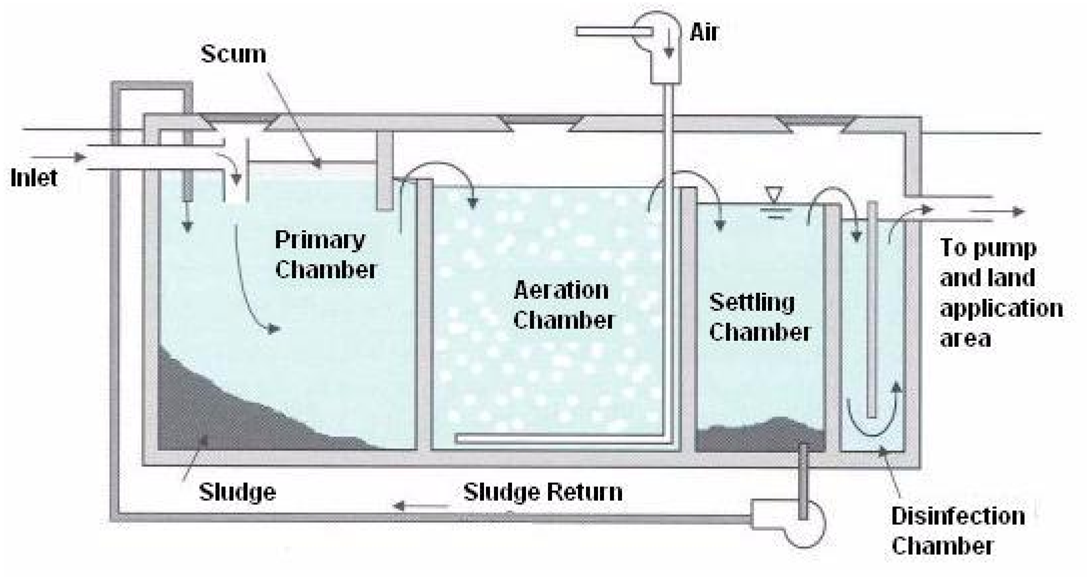


Figure 2–24: Fully encapsulated aerated water treatment system

Tertiary treatment

2.47 Increasingly, the effluent from secondary treatment systems is unacceptable because of increased recreational, domestic, and industrial requirements on the receiving body of water and more stringent stream standards. In such cases tertiary treatment can be employed to further reduce the solids and organic content of the effluent. This treatment can employ conventional processes with an increased detention time to allow for greater removals, or the operations installed for tertiary treatment can involve more exotic and expensive equipment such as electrodialysis units or ion exchange columns. In tertiary treatment, emphasis is placed on absorptive processes, such as the use of activated carbon; more efficient oxidation, as with ozone; foam separation of impurities; and demineralisation using reverse osmosis or distillation.

BIOCHEMICAL OXYGEN DEMAND CONCEPT

2.48 Sewage when ‘fresh’ has a musty odour, a grey colour, and contains both organic material and sufficient dissolved oxygen to support the growth of aerobic bacteria. Aerobic bacteria, as do humans, need a food supply and a source of free oxygen to survive. The food supply is furnished by the organic material in sewage, and the free oxygen is available as dissolved oxygen (DO). The DO is depleted as the aerobic bacteria attack the organic material contained in the sewage. Some of the DO can also be depleted through chemical action. The sewage will become ‘stale’ and then ‘septic’ as DO is depleted. Septic sewage contains no DO, and all bacterial action will be anaerobic.

2.49 The amount of oxygen necessary for the stabilisation (decomposition) of organic material in sewage under aerobic conditions is called BOD. It is an important indication of the amount of organic matter present in the sewage. The BOD test is a measure of the oxygen requirements of bacteria and other organisms as they feed upon and cause decomposition of organic matter. A high BOD will result in water becoming anaerobic (depleted of oxygen). BOD is therefore a measure of the organic load placed on the treatment facility. Industrial non-organic wastes can also deplete oxygen in the water, and this is measured by the chemical oxygen demand (COD) test.

2.50 COD is a measure of the oxidisability of waste, expressed as the equivalent amount in oxygen of a strong oxidizing agent consumed by the waste under fixed laboratory conditions. The dichromate reflux method is preferred over other methods using other oxidants such as potassium permanganate because of:

a. its superior oxidising ability,

b. applicability to a wide range of wastes, and

c. ease of use.

2.51 In the dichromate reflux method, a predetermined amount of waste is dissolved or dispersed in water and oxidised by potassium dichromate in a strong sulphuric acid medium with silver sulphate as the catalyst under reflux for two hours. The residual dichromate is determined by titration with standardised ferrous ammonium sulphate. In the case of wastes containing chlorine, mercuric sulphate is added to reduce chloride interference. The result of analysis for COD is expressed in mg/L (ppm).

2.52 BOD is normally expressed in mg/L or parts per million for a specified time and temperature, the standard being five days at 20ºC. The five-day, 20ºC BOD does not represent the total demand of a sample for oxygen. Only about two-thirds of the total oxygen demand of a domestic sewage sample is satisfied in five days at 20ºC, and almost all of the demand in 20 days at 20ºC. It would be very time-consuming to attempt to determine the total demand by incubating samples for 20 or more days. For this reason the five-day BOD test has been accepted as a practical standard.

2.53 The five-day BOD test is used as a control at nearly all sewage treatment facilities. The adequacy and degree of sewage treatment may be judged by the total reduction that occurs in the five-day BOD of the sewage as it flows through the sewage treatment facility. Also, standards are established by various governmental control agencies which set limits on the five-day BOD of treated sewage that may be legally discharged into a receiving stream.

2.54 Normally treated sewage effluent should have a suspended solids not exceeding 30 mg/L and a BOD not exceeding 20 mg/L. This standard is often referred to as the 30:20 standard. Sewage effluent discharged into a river should have a BOD not exceeding 4 mg/L. This can be achieved by diluting the effluent with clean water prior to discharge. Most rivers can easily assimilate affluent with a BOD of 4 mg/L without affecting fish and other aquatic life, so that effluent complying with the 30:20 standard is generally safe.

2.55 The general procedure for determining a BOD involves filling two BOD bottles with the water sample that has had its pH corrected to 7, and any chlorine present neutralized with three drops of a one per cent solution of sodium thiosulphate. DO is measured in the first bottle at time zero, and in the second bottle after five days storage in the dark at 20ºC. The difference between the two when multiplied by the dilution factor gives the BOD in mg/L or ppm. This is the oxygen consumed by microorganisms in the sample as they digest the organic matter present, over five days at 20ºC.

2.56 A rapid BOD can be determined in two and a half days at 37ºC and this has been determined to be equivalent to the five day test at 20ºC.

SEWAGE SAMPLING AND ANALYSIS

2.57 **General.** The purpose of sewage sampling and analysis is to ensure adequacy of sewage treatment or to identify problem areas in its operation. Normally, health personnel will not be equipped to analyse sewage samples, but they should know the purpose and procedures of conventional sewage analysis procedures.

2.58 **Sampling.** Sampling is conducted on the influent to a treatment system and the effluent after treatment. Sampling is also conducted at intermediate points or between components of the entire treatment system. There are two types of sampling techniques.

a. **Grab Sampling.** This is a sample of sewage taken at a designated time. It involves nothing more than collecting a designated amount of sewage in a container at a specific point in the system.

b. **Composite Sampling.** In as much as the quantity and quality of sewage vary significantly during a 24-hour period, a grab sample is not a good representation of the characteristics of sewage. The composite is taken by mixing together samples that have been collected at regular intervals (usually one-hour) over a 24-hour period. Because the quality and quantity of sewage vary throughout this period, the samples should be proportional in size approximately to the rate of flow at the time they are taken. The actual collection technique for either grab or composite samples is to use a dipper or can at least five cm in diameter to collect the sewage at mid depth in the sewer or conduit. Composite samples can also be collected automatically. A number of types of automatic samplers are available. Avoid excessive aeration of the composite sample and refrigerate the sample until it can be analysed. Analysis should be conducted as soon as possible, because sewage characteristics will vary with time.

2.59 **Sewage analysis**:

a. **Settleable and Suspended Solids (SS).** This measurement checks the efficiency of solids removal in treatment units. A similar term is non-filterable residues (NFR). Both SS and NFR are measured in mg/L.

b. **Biochemical Oxygen Demand.** This measurement indicates the amount of organic matter in sewage.

c. Other tests commonly used to evaluate the adequacy of treatment include pH, FAC, COD, and DO.

d. Refer to part 3 for additional information on sampling procedures.

POLLUTION

2.60 Pollution is one of the greatest abuses of our natural water resources. All foreign material added to a natural body of water is considered pollution. Overloading a natural body of water beyond its reserve or recuperative capacities with raw sewage, improperly treated sewage, or industrial wastes is a very serious matter. If the volume and velocity of the stream are not sufficient to handle the quantity of effluent being discharged great environmental damage can occur.

2.61 Everybody of water has a limited capacity for receiving sewage and other organic wastes by means of dilution. The full use of this capacity results in a loss of any reserve capacity and produces nuisances or reduces the quality of the stream. These detriments are classified as physical, chemical, and bacterial.

2.62 The physical detriments include the offensive odours of organic matter putrefaction; unsightliness of floating solids, oils, grease, scum, and debris; and turbidity and colour caused by dissolved and suspended matter. The body of water's ability to neutralise these effects is determined by its volume and velocity. For example, if a stream is flowing swiftly, bulky deposits will not appear, and the larger solids are broken up and carried downstream. However, debris and larger floating solids may still be a problem. Further dilution of these offending wastes as they are carried downstream likewise reduces odour and discolouration. Usually, these physical nuisances are not as important as the other types, and they are prevented by primary sewage treatment. However, a stream may be heavily overloaded by the effluent from a modern sewage treatment plant simply because the stream does not have the biological ability to handle the amount of organic matter being discharged from the plant.

2.63 Chemical detriments to a body of water include the depletion of oxygen in the water by the biochemical oxidation of organic matter. When total exhaustion of the dissolved oxygen occurs, odours and destruction of plant and fish life result. Secondly, other chemicals primarily from industrial wastes may be toxic, attack concrete structures, discolour the waters, destroy paints on boats, and more important, render the water unsuitable as a source of water supply by making it difficult or uneconomical to treat. For example, the discharge of phenols into a stream used as a water supply will not be removed with normal treatment methods, and with chlorination the water is rendered unpalatable by the formation of chlorophenols.

2.64 The last type of detriment is the microbial pollution caused by sewage effluent. A test for the most probable number of heat tolerant coliform organisms is of significance, particularly when the body of water is used as a source of water supply or as a bathing area, or if it passes over shellfish areas. A body of water's capacity to cope with this type of pollution is a function of dilution and distance from the point of discharge to the area of use. It has been found that most pathogenic bacteria die-off when released from the gastrointestinal tract into the marine or aquatic environments. The numbers of surviving bacteria tend to form a geometrical progression in time; that is, during an interval of time, the bacteria are reduced by a constant proportion of the number existing at the beginning of that interval. This phenomenon is called the geometric death rate.

2.65 With each of the three types of pollution mentioned, physical, chemical, and microbial , dilution in the stream volume is one indication of the receiving capacity of the stream. Microbial and organic chemical pollutants, however, are subject to other means of purification, and are the basis for what is known as self-purification of streams.

2.66 A polluted stream undergoing self-purification can be divided into four zones: zone of degradation, zone of active decomposition, zone of recovery, and zone of cleaner water.

2.67 Within the zone of degradation is where the pollutant has recently been introduced. The DO can be reduced to less than one-half of its original value; algae and fish life are declining; water is turbid; sludge deposits are forming on the stream bed; and typical bottom worms, together with sewage fungi, appear.

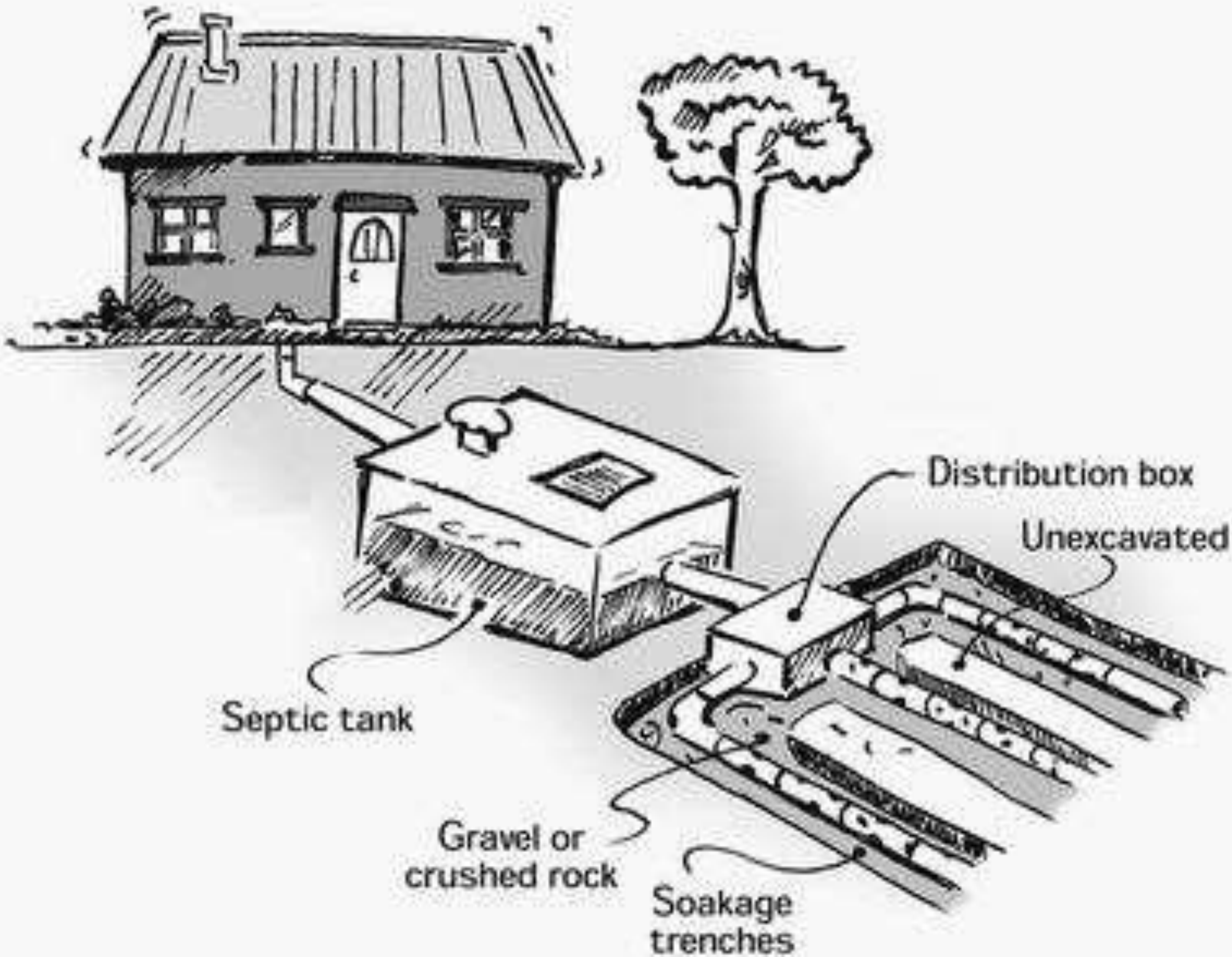
2.68 In the zone of active decomposition, the DO can be reduced to zero; fish life is absent; water is darker and greyish in colour; odours from putrefaction of organic matter including hydrogen sulphide and methane gases are given off; a scum may appear on the surface; and threadlike organisms of greyish, pink, and cream tints appear.

2.69 Through the zone of recovery the DO increases, the water is less turbid with reduced unpleasant odours given off, algae reappear, fungi disappear, and some of the hardier fish such as carp appear. Entering the zone of cleaner water, the DO approaches saturation, the natural stream conditions are restored, and trout and other game fish appear.

2.70 Although the physical appearance of the stream and the animal and plant life observed are important factors in judging stream pollution, it should be remembered that the indices (primarily pH, DO, BOD, SS, and nutrients) are the most significant measures of stream pollution.

a. The five day BOD for a very clean river is one or less; for a clean river 2 to <3; for a fairly clean river 3 to <5. For a river of doubtful condition 5 to <10, and for river in bad condition 10 or more.

b. The concentrations of oxygen in water at saturation, (at normal atmospheric pressure) at different temperatures, are: 14.66 mg/L (0ºC), 12.37 mg/L (5ºC), 10.92 mg/L (10ºC), 9.76 mg/L (15ºC), 8.84 mg/L (20ºC) and 8.11 mg/L (25ºC).


Distribution box
Unexcavated
Septic tank
Gravel or
crushed rock
Soakage
trenches

SEPTIC TANK

DISPOSAL OF EFFLUENT FROM THE SEPTIC TANK.

- Effluent contains 200 to 250mg/l of putrescible organic matter.
- BOD is high – 100 to 200mg/L
- Three methods of disposal

1. Soil absorption system
2. Biological filters
3. Upflow anaerobic filters.

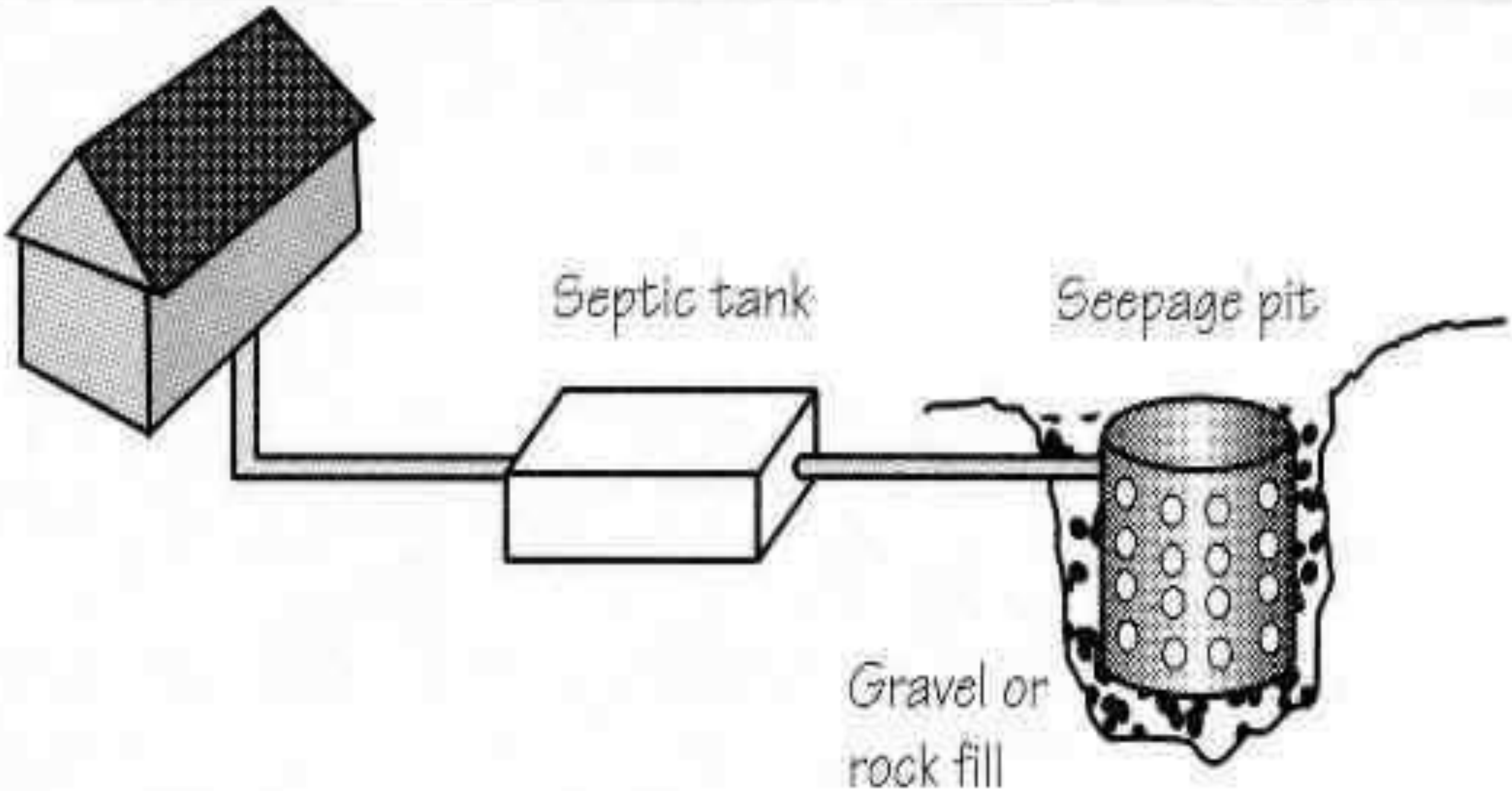


Illustration courtesy of the United States Environmental Protection Agency.

Schematic of a Seepage Pit (Dry Well)

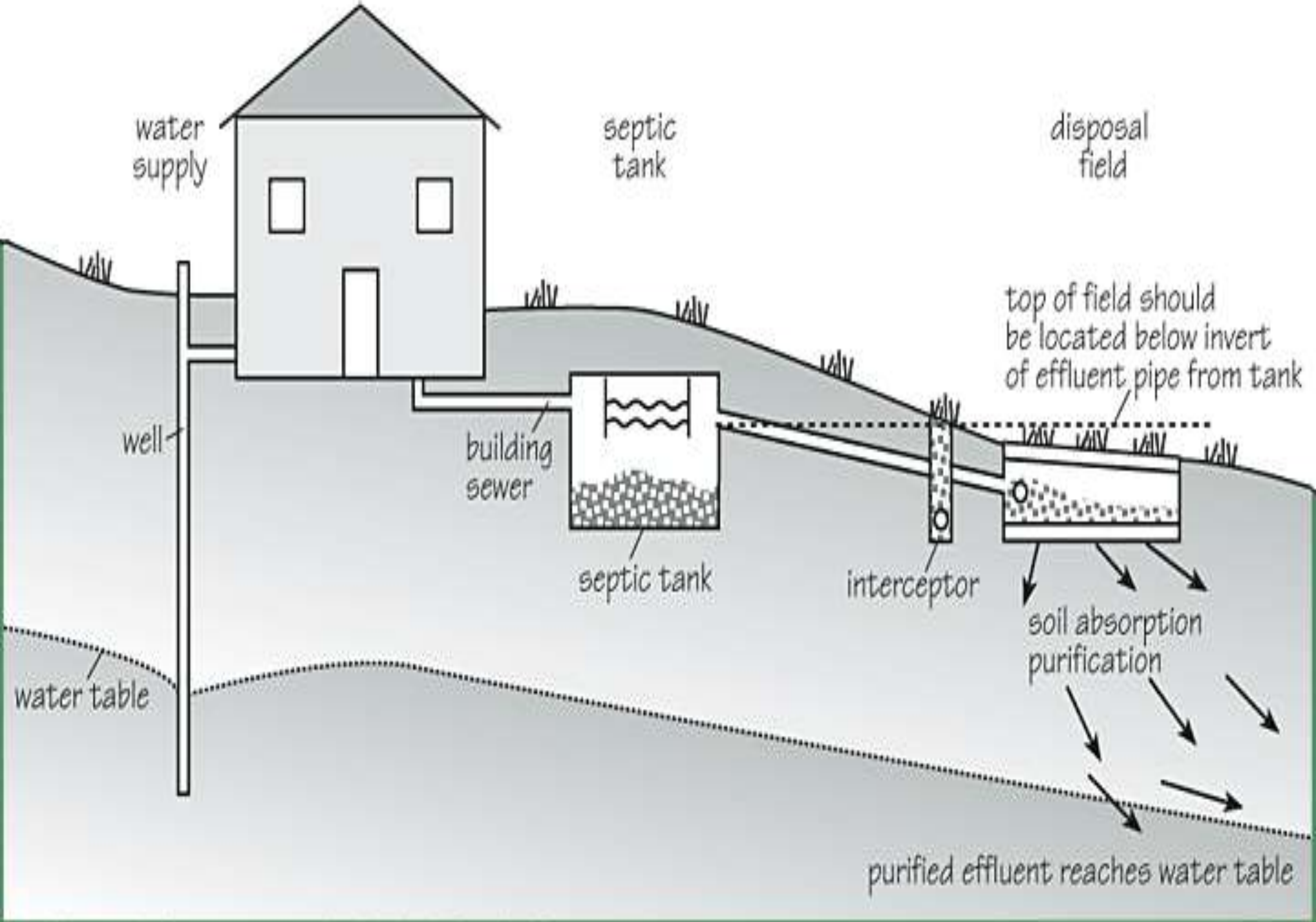
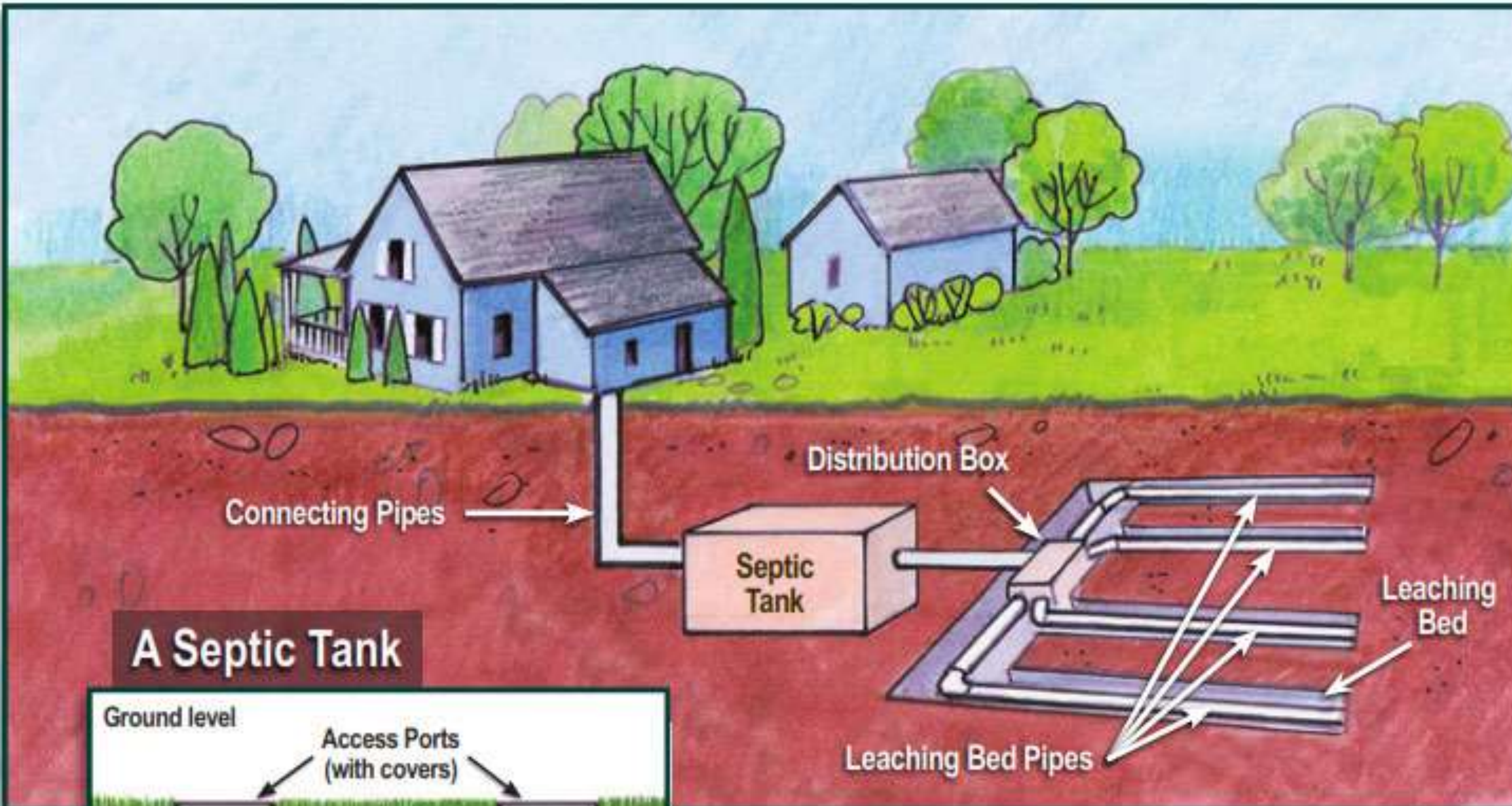
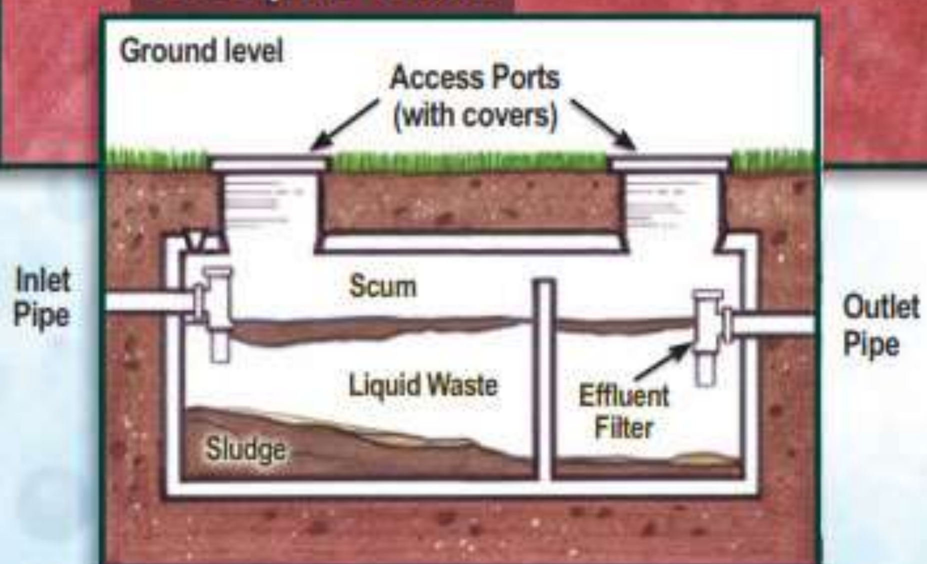


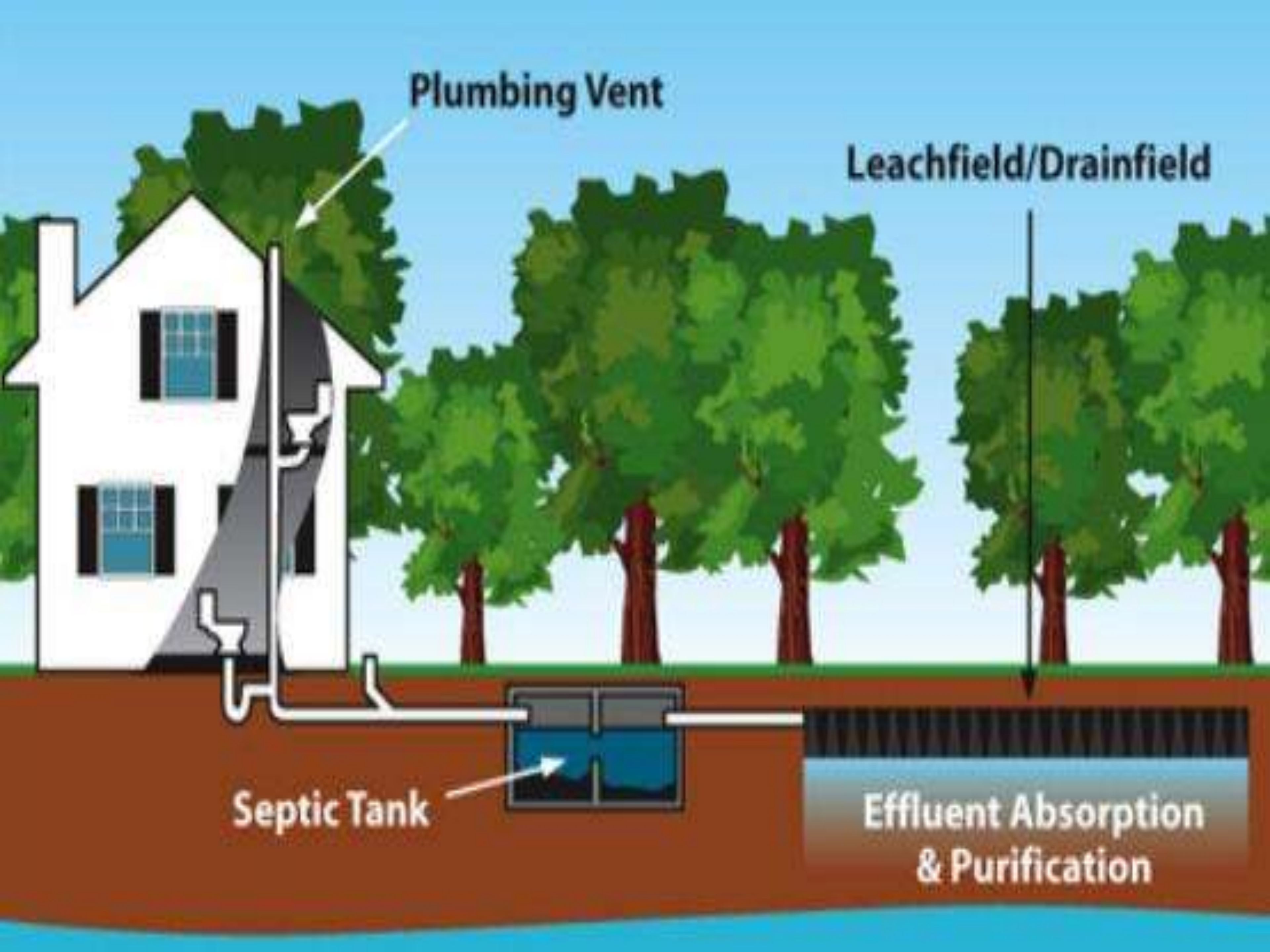
Figure 1 - Components of a Typical On-site System



A Septic Tank



A septic system is made up of connecting and leaching bed pipes, a septic tank and the leaching bed.


Plumbing Vent
Leachfield/Drainfield
Septic Tank
Effluent Absorption
& Purification

SEPTIC TANK

DISPOSAL OF EFFLUENT FROM THE SEPTIC TANK.

2. **Biological filters**

- ✓ Used where soil has high percolation rate (> 60min/cm)
- ✓ Used in water logged areas
- ✓ Septic tank effluent treated further by coating with organic medium.
- ✓ Much of the polluting matter gets oxidized.
- ✓ Requires ample ventilation and an efficient system of under drainage system.

3. **Upflow anaerobic filters**

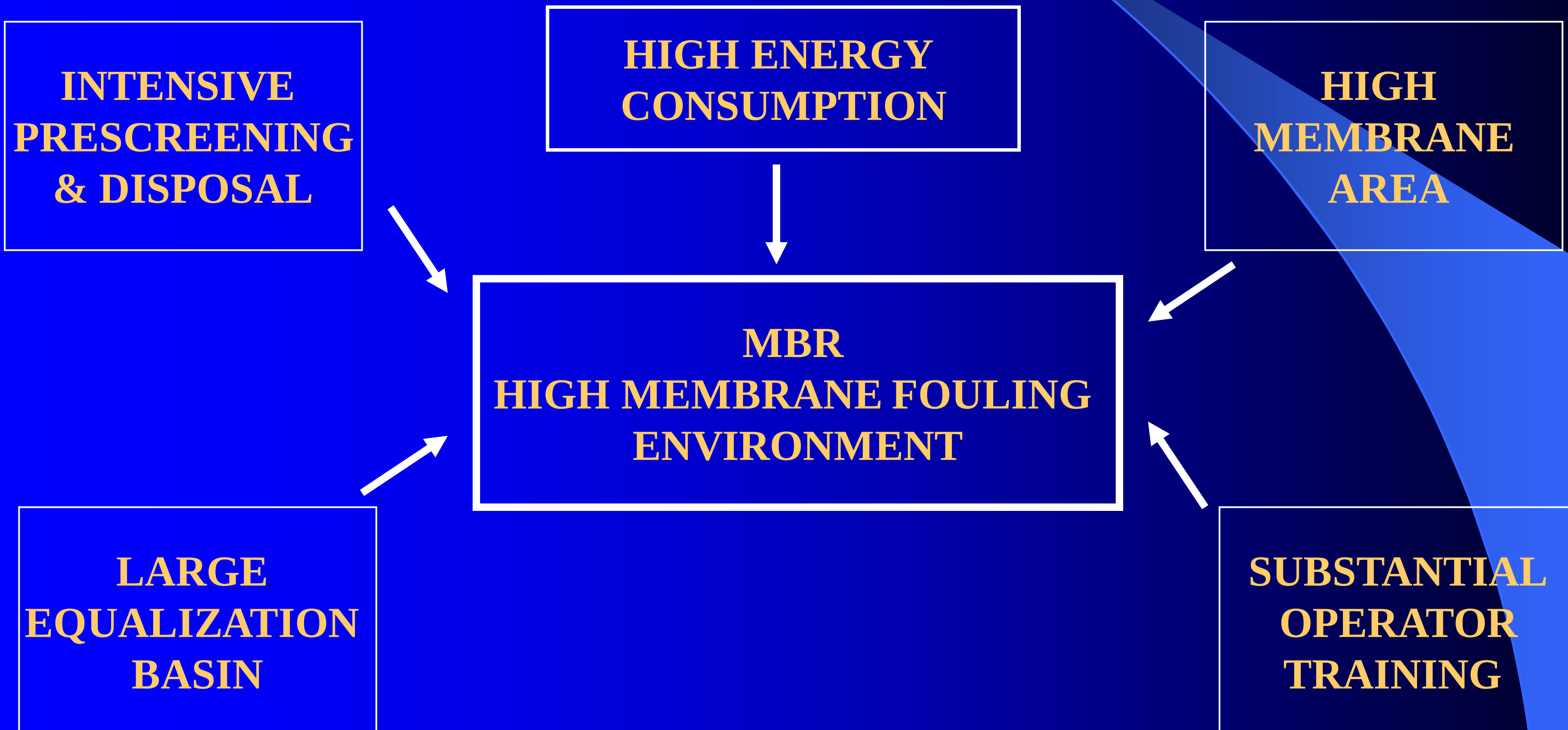
- ✓ Used where soil has high percolation rate (> 60min/cm)
- ✓ Used in water logged areas

MEMBRANE BIOREACTORS

AS - MBR PROCESS

- Conventional membrane bioreactors process immerses membranes directly into highly concentrated mixed liquor suspended solids.
- MLSS contains high levels of dispersed , small particles comprised of inert and colloidal material.
- High membrane fouling environment, which results in low membrane flux rates, which require large membrane surface area.

TO AVOIDE LOW FOULING CONDITIONS IN AS - MBR



AS - MBR LIMITATIONS

- MBR HAS LOW PEAK FLOW TOLERANCE.

WITH THE HIGH MEMBRANE FOULING ENVIRONMENT CONSTRAINING THE FLUX, THE MBR HAS VERY LOW PEAK FLOW TOLERANCE. HENCE IT REQUIRES LARGE EQUALIZATION TANK VOLUME.

AS - MBR LIMITATIONS

- MBR REQUIRES FINE SCREENING. (1 mm OR LESS)

FINE SCREENING REMOVES SUBSTANTIAL AMOUNT OF UNTREATED WASTE THAT MUST BE DISPOSED of. FINE SCREENING ALSO REQUIRES A LARGE AREAAND IS MORE EXPENSIVE THAN STANDARD WASTEWATER SCREENING.

AS - MBR LIMITATIONS

- MBR REQUIRES HIGH MLSS RECIRCULATION RATES.

- AS PERMEATE IS REMOVED THROUGH THE MEMBRANE, THE ALREADY HIGH CONCENTRATION OF SUSPENDED SOLIDS AT THE MEMBRANE SURFACE OF MBR INCREASES AND FOULING RATES ARE COMPOUNDED.
- THIS REQUIRES RECIRCULATING MLSS WITH IN THE BIOREACTOR AND THUS RESULTS IN LARGE AMOUNT OF ENERGY CONSUMPTION,

AS - MBR LIMITATIONS

- MBR REQUIRES HIGH MEMBRANE AIR SCOUR RATES.
- LARGE AMOUNTS OF ENERGY MUST BE INPUT TO GENERATE AIR TO TO SCOUR THE MEMBRANE SURFACE OF SUSPENDED SOLIDS.

AS - MBR LIMITATIONS

- MBR REQUIRES HIGH BIOREACTOR AERATION RATES.

- THE HIGH MLSS CONCENTRATION OF MBR REDUCES OXYGEN TRANSFER EFFICIENCY WITHIN THE BIOREACTOR, RESULTING IN A HIGHER ENERGY REQUIREMENT IN ORDER TO AERATE THE BIOREACTOR.

AS - MBR LIMITATIONS

- MBR HAS LOW MEMBRANE FLUX RATES.

- MEMBRANE COMPONENT COSTS CONTRIBUTE A VERY HIGH CAPITAL AND OPERATING COSTS.

UF FOLLOWED BY MBBR

- UF FOLLOWED BY MBBR MAINTAINS SEPARATE BIOLOGICAL AND MEMBRANE UNIT PROCESSES, ALLOWING FOR MAXIMUM TOTAL SYSTEM PERFORMANCE.
- EACH PROCESS IS INDIVIDUALLY CONTROLLED AND OPTIMIZED.
- MBBR MLSS PARTICLES SETTLE WELL AND EXIBIT LOW MEMBRANE FOULING.
- REDUCES THE MLSS TO THE UF MEMBRANE BY 97%
- THIS DIRECTLY INCREASES THE MEMBRANE FLUX.

CONTROLLING MEMBRNE FOULING RATES WITH MBBR - UF

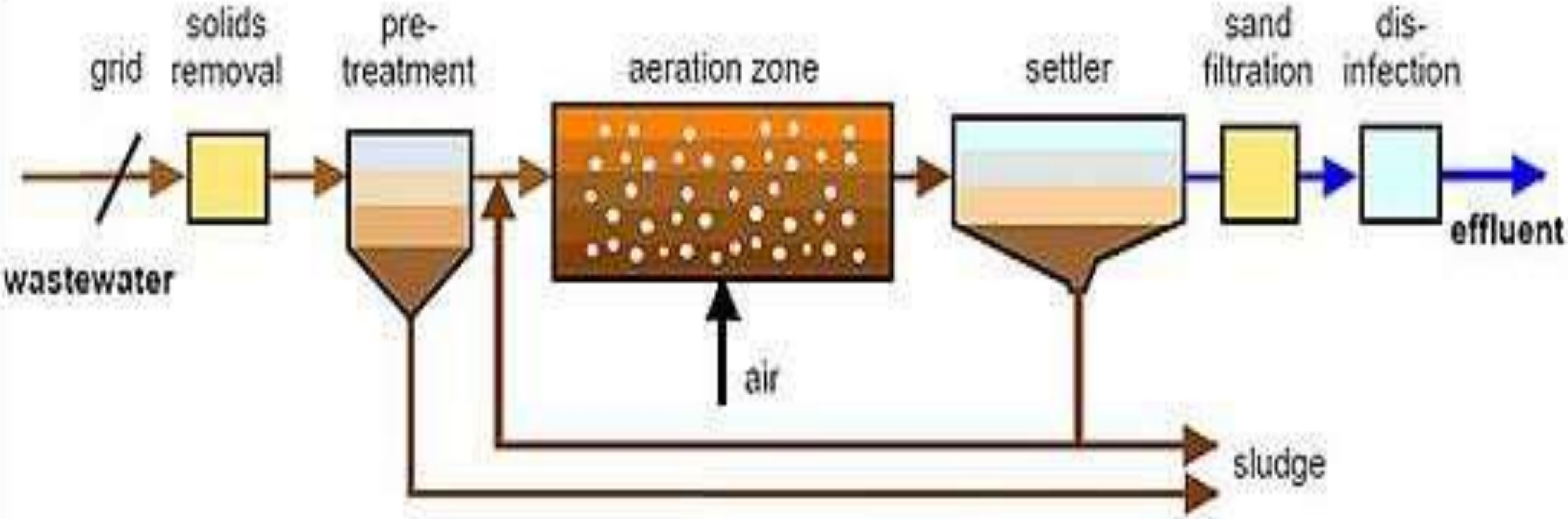
- CAN TOLERATE MODERATE PEAK FLOW RATES. WILL REQUIRE SMALLER EQUALIZATION TANK.
- NO FINE SCREENING REQUIREMENT.
- NO SLUDGE RECIRCULTION. ENERGY SAVING.
- NO AIR SCOURING REQUIRED. ENERGY SAVING.
- SINCE MLSS IS LOW IN MBBR, OXYGEN TRANSFER EFFICIENCY IS HIGH.
- FLUX RATES CAN BE MUCH HIGHER, SAVES COST OF MEMBRANES.
- SINCE MLSS IS VERY LOW, MEMBRANE FOULING MINIMUM.

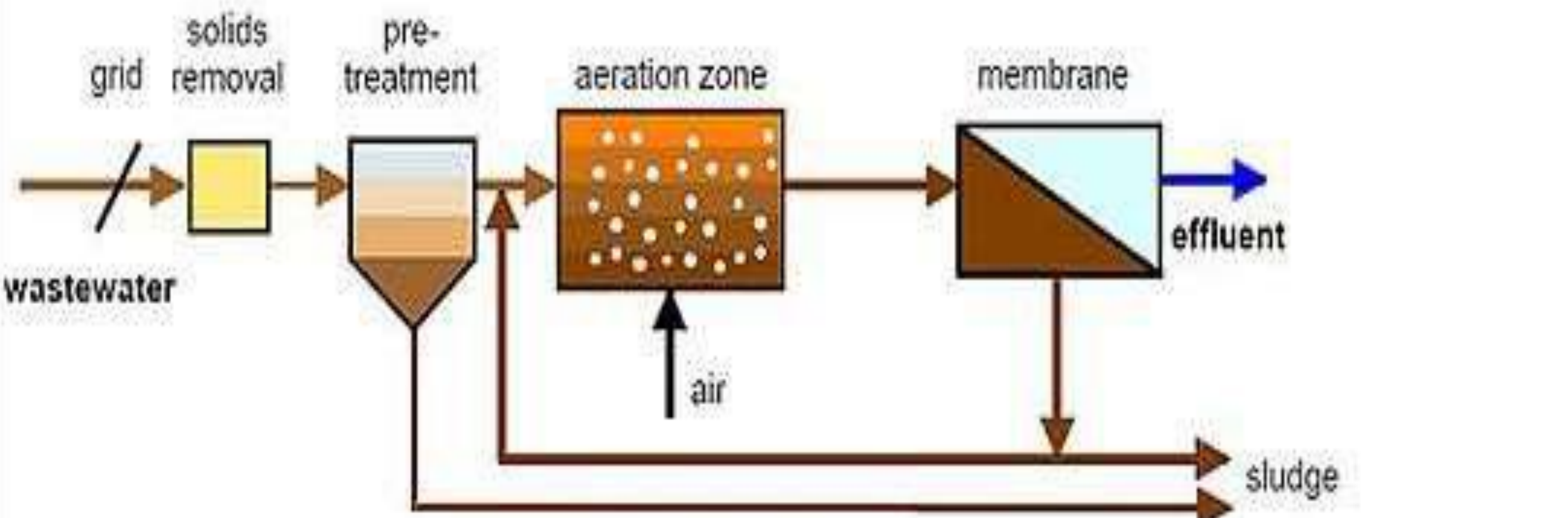
ENERGY CONSUMPTION COMPARISION

	AS - MBR	MBBR - UF
MEMBRANE AIR BLOWER	38%	NOT REQUIRED
RECIRCULTION PUMPS	18%	NOT REQUIRED
PROCESS AIR BLOWERS	35%	17%
MISCLLANEOUS	9%	9%
TOTAL	100%	26%

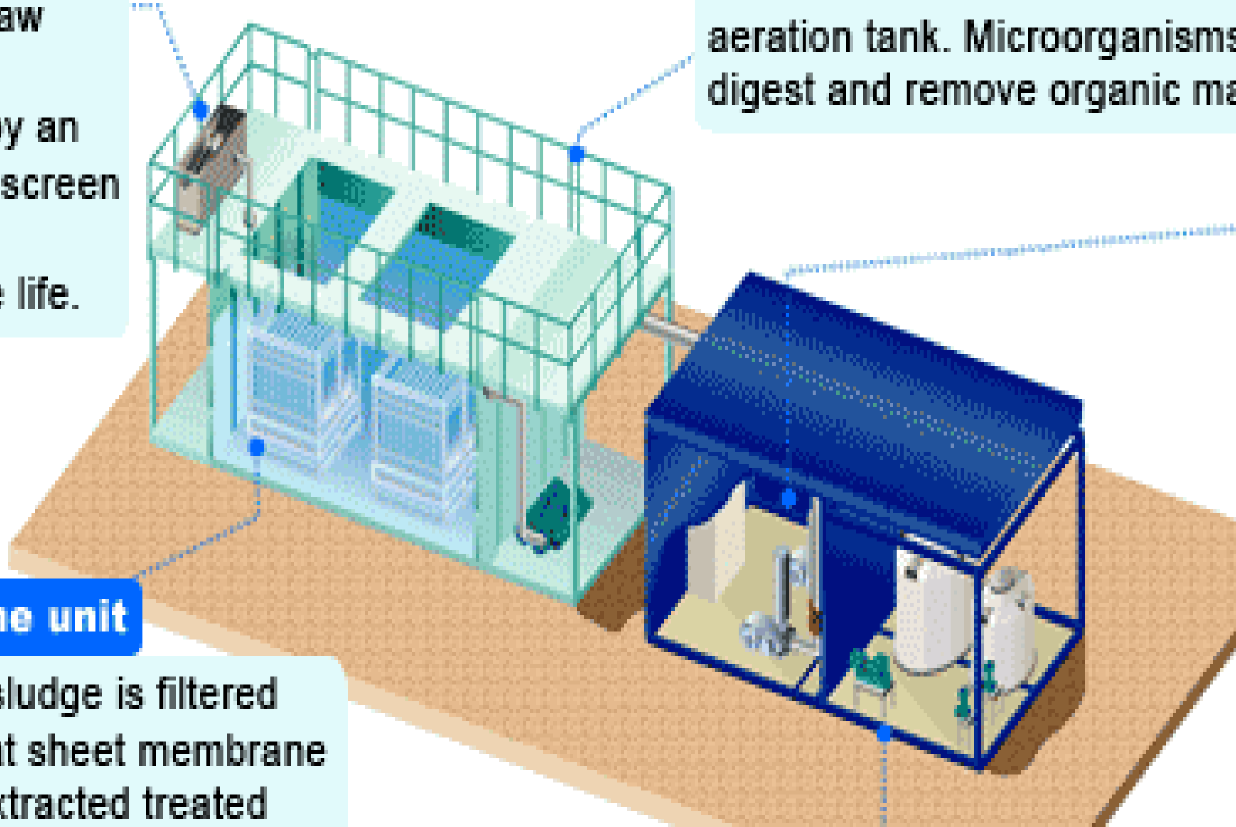
MBR AND MBBR – MBR COMPARISION

	AS - MBR	MBBR – UF
MLSS MEMBRANE FOULING	HIGH	LOW
MEMBRANE FLUX	LOW	MODERATE
MEMBRANE REQUIREMENT	HIGH	MODERATE
MEMBRANE COST	HIGH	MODERATE
RECIRCULATION ENERGY	HIGH	NIL
AIR SCOUR ENERGY	HIGH	NIL
OXYGEN TRANSFER EFF.	LOW	HIGH
SCREENING REQUIREMENTS	HIGH	LOW
PEAK F:OW TOLERANCE	LOW	MODERATE
FOOT PRINT	MODERATE	MODERATE


grid
solids removal
pre-treatment
aeration zone
settler
sand filtration
dis-infection
wastewater
effluent
air
sludge


grid
solids removal
pre-treatment
aeration zone
membrane
wastewater
effluent
air
sludge

MBR Plant Exploded View



Fine screen

Solids in raw water are removed by an automatic screen to extend membrane life.

Aeration tank

The membrane is immersed in activated sludge in the aeration tank. Microorganisms in the activated sludge digest and remove organic material .

Blower

The blower pumps air to clean the membrane and feed the bioreaction process. Blowers are covered by an acoustic enclosure to minimize noise.

Membrane unit

Activated sludge is filtered using a flat sheet membrane and the extracted treated sewage effluent is pumped to tanks prior to disposal. The membrane is produced in Japan by Hitachi using patented manufacturing techniques.

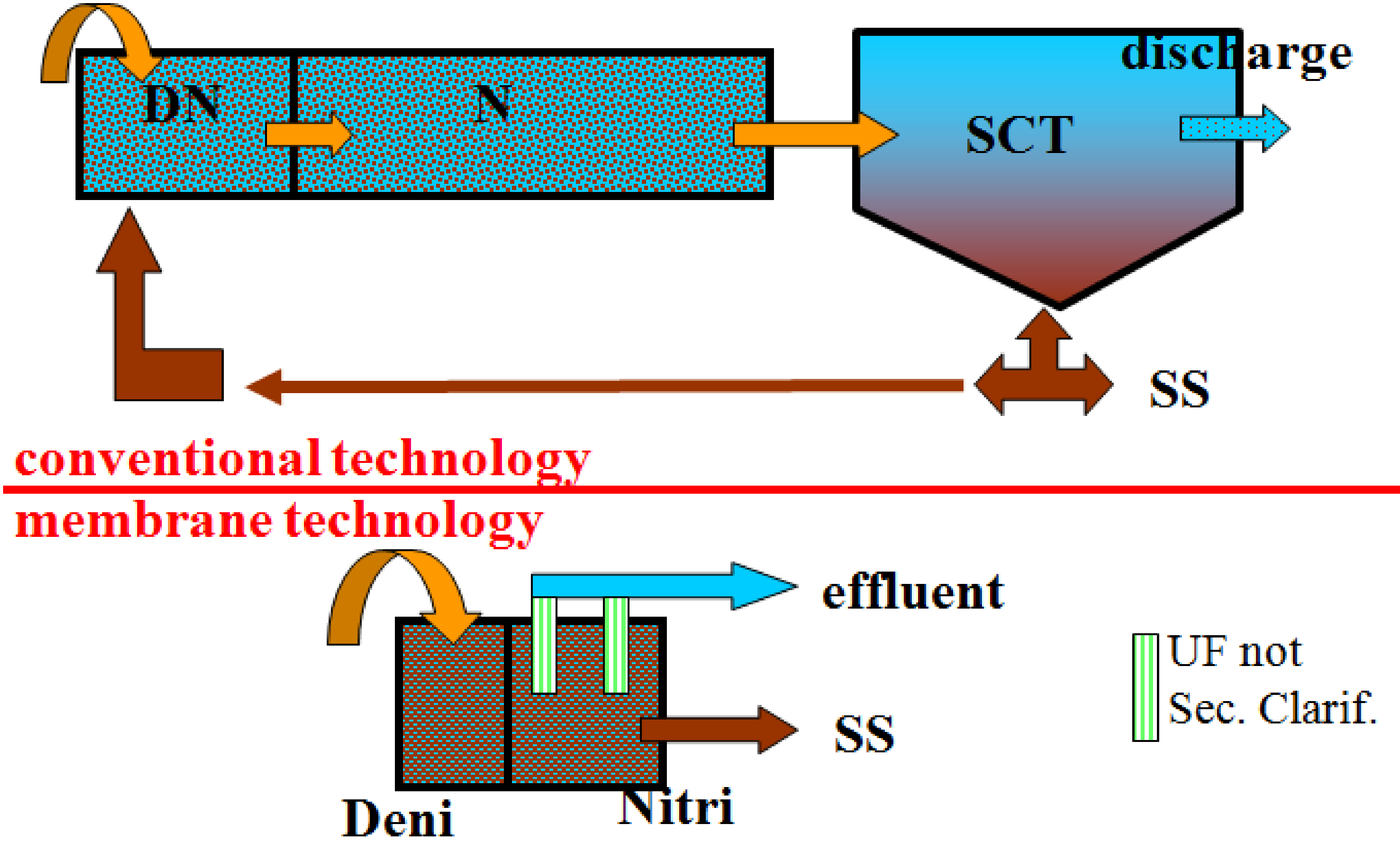
Chemical cleaning unit

A dosing chemical (Sodium hypochlorite) is used for membrane cleaning. Dosing frequency is approx once per 2 to 3 months, depending on the condition of the raw water and the throughput volume.

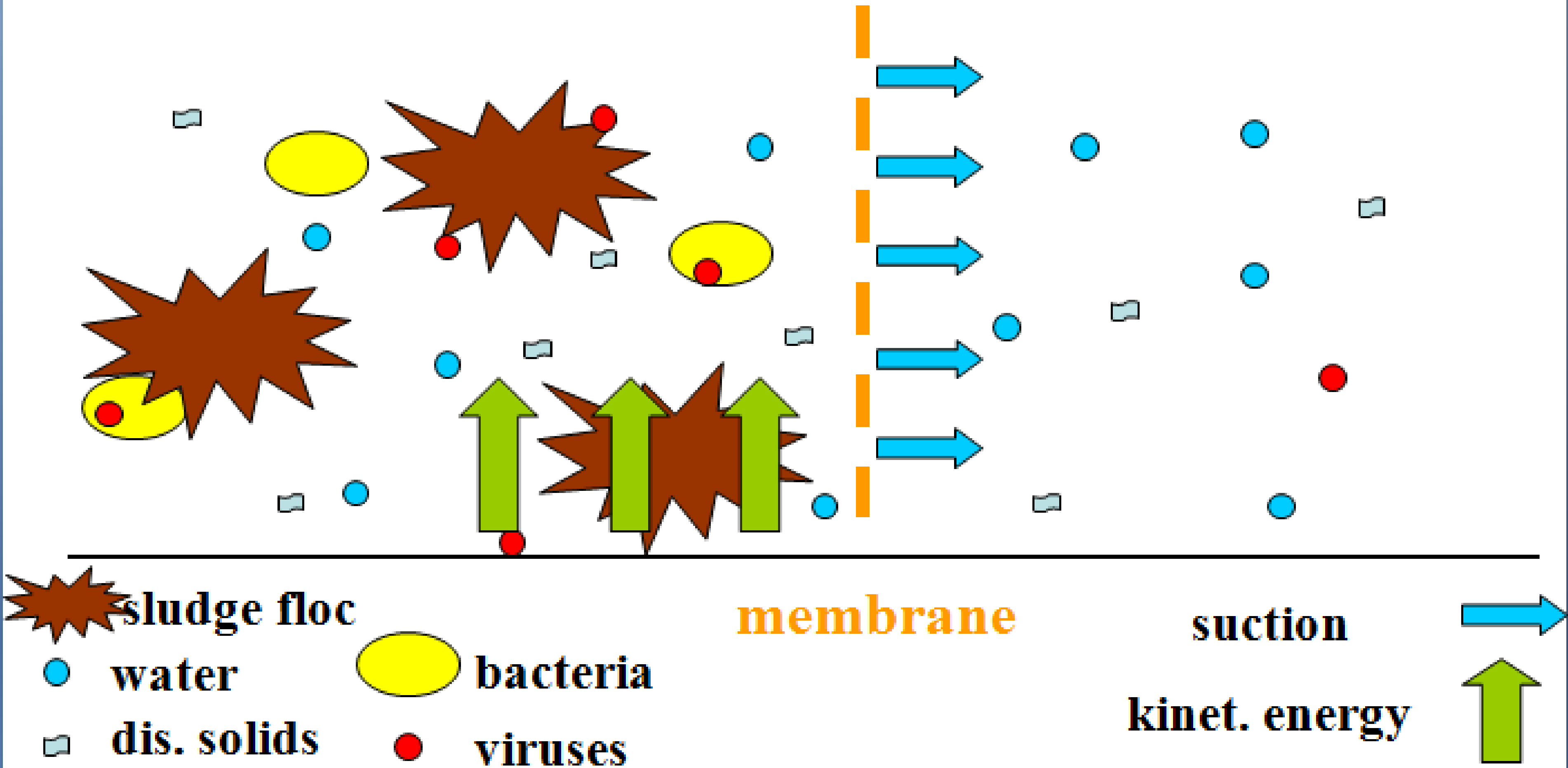
Membrane Bioreactors

- Employ biological reactor and membrane filtration as a unified system for the secondary treatment of wastewater
- Membranes perform the separation of the final effluent from the biomass through filtration
- Filtration takes place by the application of a pressure gradient

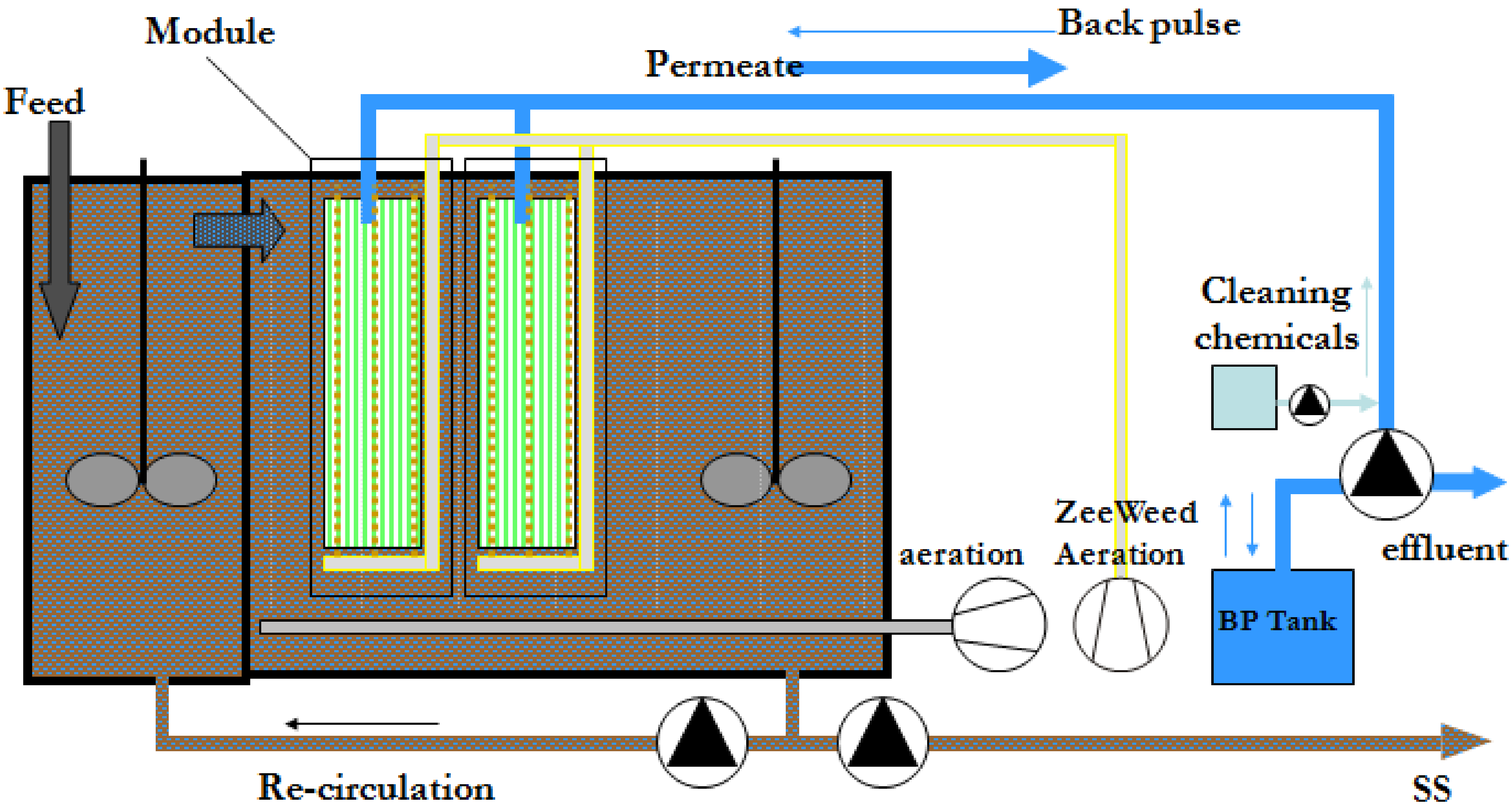
Process Basics



Process Basics



Submerged MBR System



Assessment of MBR Technology

- Advantages
  - High effluent quality
  - No sludge settling problems
  - Reduced volume requirements
- Disadvantages
  - Membrane fouling
  - Increased operational costs

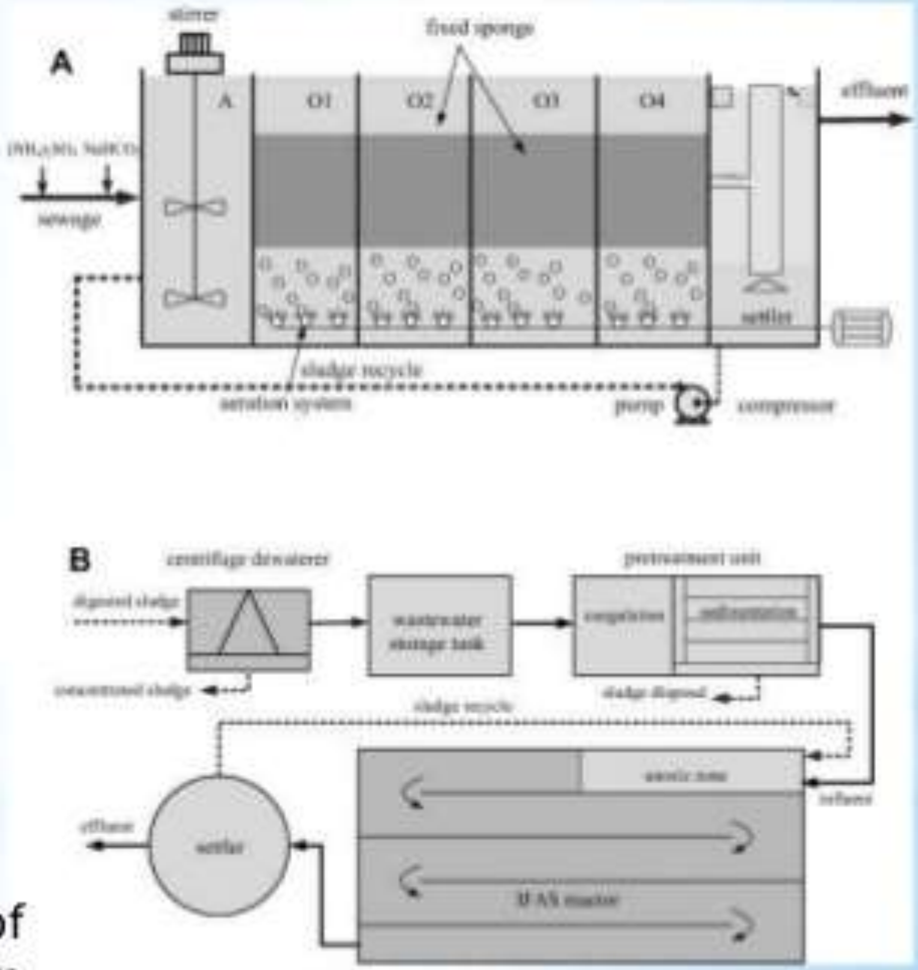
*Introduction

- Industry practice for upgrading WWTP usually focuses on increasing the bioreactor volume by building new reactors to meet the system needs.

What's Integrated Fixed-Film Activated sludge (IFAS)?

- IFAS is a modification of the conventional activated sludge process.
- It is achieved by adding media to the aeration tanks of the Activated sludge process.
- Creates a hybrid suspended- attached-growth system.

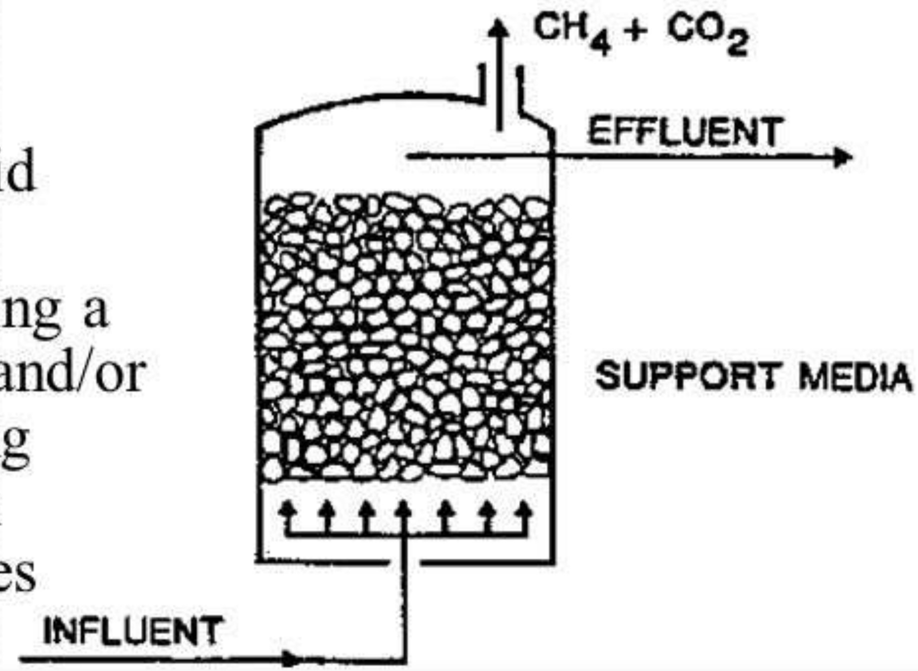
- Pilot and full-scale (IFAS) reactors were used.
- Full Scale Reactor treating sludge dewatering liquors (V = 500 m^3).
- The pilot-scale was tested in treating high ammonium wastewater.
- The biofilm carriers used in this study were cubic sponge polyesters.



The Fig. shows (A) Scheme of pilot-scale IFAS reactor used in the experiment. (B) Scheme of full-scale IFAS reactor.

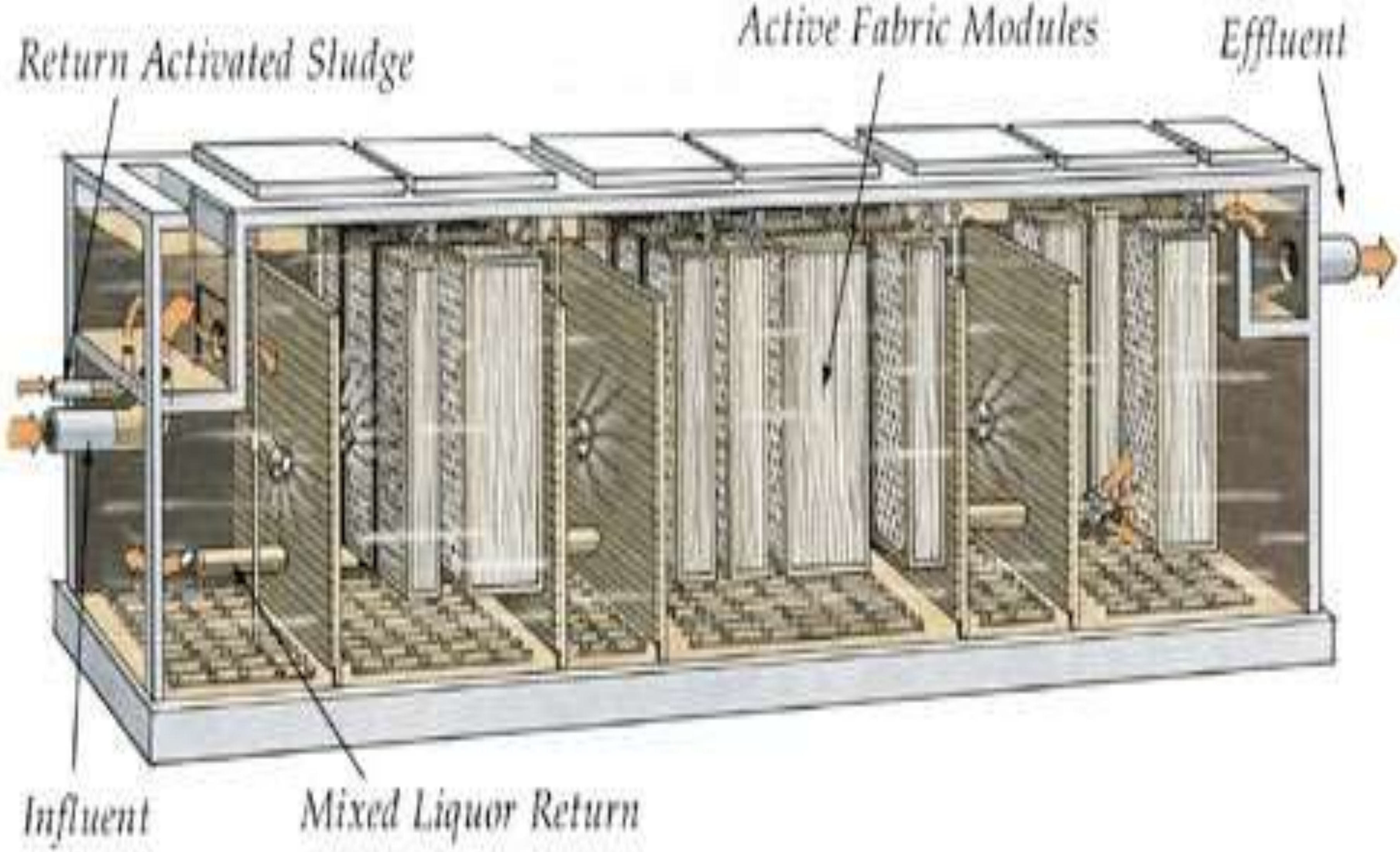
Anaerobic Fixed Film Reactor

- Sludge age: > 100 days
  VSS: > 20,000 mg/L
- Increased efficiency and rapid elution of toxic sludge
- Not good for wastes containing a large portion of particulates and/or carbohydrates due to clogging
- Possible to treat low strength waste at nominal temperatures economically



- Effluent recycle (sufficient alkalinity) to raise pH to 7
- Possible buildup of nonbiodegradable solids in reactor
- Loading rate: 0.42~3.4 kg COD/m^3·day at 25°C; 60~80% COD removal; e.g. Landfill leachate: pH 5.4, COD 54,000 mg/L, 45% fatty acids, loading 7.9 kg COD/m^3·day → 89% removal

Integrated Fixed Film/Activated Sludge Systems (IFAS)



Nitrification & Denitrification

Nitrification & Denitrification

Bacteria remove nitrogen from wastewater by a two step biological processes: nitrification followed by denitrification.

Technically, it is a three step process: ammonification precedes nitrification and denitrification.

Ammonification. While traveling through sewer pipes, the majority of the nitrogen contained in raw sewage (urea and fecal material) is converted from organic-nitrogen to ammonia through a process called hydrolysis.

Technically, in the majority of situations, more ammonium than ammonia is created during ammonification. The actual ratio is influenced by pH and temperature.

Nitrification. The biological conversion of ammonium to nitrate nitrogen is called Nitrification. Nitrification is a two-step process. Bacteria known as *Nitrosomonas* convert ammonia and ammonium to nitrite. Next, bacteria called *Nitrobacter* finish the conversion of nitrite to nitrate. The reactions are generally coupled and proceed rapidly to the nitrate form; therefore, nitrite levels at any given time are usually low.

These bacteria known as "nitrifiers" are strict "aerobes," meaning they must have free dissolved oxygen to perform their work. Nitrification occurs only under aerobic conditions at dissolved oxygen levels of 1.0 mg/L or more. At dissolved oxygen (DO) concentrations less than 0.5 mg/L, the growth rate is minimal. Nitrification requires a long retention time, a low food to microorganism ratio (F:M), a high mean cell residence time (measured as MCRT or Sludge Age), and adequate buffering (alkalinity). A plug-flow, extended aeration tank is ideal. Temperature, as discussed below, is also important, but not really.

The nitrification process produces acid. This acid formation lowers the pH of the biological population in the aeration tank and can cause a reduction of the growth rate of nitrifying bacteria. The optimum pH for *Nitrosomonas* and *Nitrobacter* is between 7.5 and 8.5; most treatment plants are able to effectively nitrify with a pH of 6.5 to 7.0. Nitrification stops at a pH below 6.0. The nitrification reaction (that is, the conversion of ammonia to nitrate) consumes 7.1 mg/L of alkalinity as $CaCO_3$ for each mg/L of ammonia nitrogen oxidized. An alkalinity of no less than 50-100 mg/L is required to insure adequate buffering.

Water temperature also affects the rate of nitrification. Nitrification reaches a maximum rate at temperatures between 30 and 35 degrees C (86^{o}F and 95^{o}F). At temperatures of 40^{o}C (104^{o}F) and higher, nitrification rates fall to near zero. At temperatures below 20 degrees C, nitrification proceeds at a slower rate, but will continue at temperatures of 10 degrees C and less. However, if nitrification is lost, it will not resume until the temperature increases to well over 10 ^{o}C.

Some of the most toxic compounds to nitrifiers include cyanide, thiourea, phenol and heavy metals such as silver, mercury, nickel, chromium, copper and zinc. Nitrifying bacteria can also be inhibited by nitrous acid and free ammonia.

The following equations describe the nitrification process.

Alkalinity buffering equation

$H_20 + CO_2 \leftrightarrow H_2CO_3 \leftrightarrow HCO_3 + H^+ \leftrightarrow CO_3 + 2H+$

Nitrification equations

$NH_4^+ + 1.5O_2 \longrightarrow 2H^+ + 2H_2O + NO_2^-$

$NO_2^- + 0.5O_2 \longrightarrow NO_3^-$

$NH_4^+ + 1.83\ O_2 + 1.98\ HCO3^- \longrightarrow 0.021\ C_5H_70_2N + 0.98\ NO_3^- + 1.041\ H_2O + 1.88\ H_2CO_3^-$

$NH_4+ + 1.9O_2 + 2HCO3^- \longrightarrow 1.9\ CO_2 + 2.9\ H_2O + 0.1\ CH_2$

From the above equations, it can be calculated that for every pound of ammonia oxidized to nitrate, the following occurs:

4.18 pounds of oxygen are consumed

7.14 pounds of alkalinity as calcium carbonate (as $CaCO_3$) is consumed

12 pounds of alkalinity as sodium bicarbonate ($NaHCO_3$) is consumed

Denitrification. The biological reduction of nitrate (NO_3) to nitrogen gas (N_2) by facultative heterotrophic bacteria is called Denitrification. “Heterotrophic” bacteria need a carbon source as food to live. “Facultative” bacteria can get their oxygen by taking dissolved oxygen out of the water or by taking it off of nitrate molecules.

Denitrification occurs when oxygen levels are depleted and nitrate becomes the primary oxygen source for microorganisms. The process is performed under anoxic conditions, when the dissolved oxygen concentration is less than 0.5 mg/L, ideally less than 0.2. When bacteria break apart nitrate (NO_3^-) to gain the oxygen (O_2), the nitrate is reduced to nitrous oxide (N_2O), and, in turn, nitrogen gas (N_2). Since nitrogen gas has low water solubility, it escapes into the atmosphere as gas bubbles. Free nitrogen is the major component of air, thus its release does not cause any environmental concern.

The formula describing the nitrification reaction follows:

$6NO_3- + 5CH_3OH \longrightarrow 3N_2 + 5CO_2 + 7H_2O + 6OH'$

A carbon source (shown in the above equation as CH_3OH) is required for denitrification to occur.

Optimum pH values for denitrification are between 7.0 and 8.5. Denitrification is an alkalinity producing process. Approximately 3.0 to 3.6 pounds of alkalinity (as $CaCO_3$) is produced per pound of nitrate, thus partially mitigating the lowering of pH caused by nitrification in the mixed liquor.

Since denitrifying bacteria are facultative organisms, they can use either dissolved oxygen or nitrate as an oxygen source for metabolism and oxidation of organic matter. If dissolved oxygen and nitrate are present, bacteria will use the dissolved oxygen first. That is, the bacteria will not lower the nitrate concentration. Denitrification occurs only under anaerobic or anoxic conditions.

Another important aspect of denitrification is the requirement for carbon; that is, the presence of sufficient organic matter to drive the denitrification reaction. Organic matter may be in the form of raw wastewater, or supplemental carbon. Conditions that affect the efficiency of denitrification include nitrate concentration, anoxic conditions, presence of organic matter, pH, temperature, alkalinity and the effects of trace metals. Denitrifying organisms are generally less sensitive to toxic chemicals than nitrifiers, and recover from toxic shock loads quicker than nitrifiers.

Temperature affects the growth rate of denitrifying organisms, with greater growth rate at higher temperatures. Denitrification can occur between 5 and 30°C (41°F to 86°F), and these rates increase with temperature and type of organic source present. The highest growth rate can be found when using methanol or acetic acid. A slightly lower rate using raw wastewater will occur, and the lowest growth rates are found when relying on endogenous carbon sources at low water temperatures.

Wastewater cannot be denitrified unless it is first nitrified.

Nitrogen Forms

Nitrogen exists in several forms. The principal nitrogen types of concern to wastewater treatment are: Total Nitrogen, Total Kejeldahl Nitrogen (TKN), Ammonia, Organic Nitrogen, Nitrate and Nitrite. Concentrations are reported in mg/L, as Nitrogen.

The relationships of the various forms is confusing, but important to understand.

total-Nitrogen (total-N). In order to determine the total-Nitrogen concentration, laboratory testing of TKN, Nitrate and Nitrite is required. The results of the three tests are added together.

Technically, if regulations allow, total-N may be determined by performing only two lab tests: TKN and nitrite+nitrate.

$$\text{Total-N} = TKN + NO_3 + NO_2$$

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Continued - Nitrification & Denitrification

Total Kejeldahl Nitrogen (TKN). TKN includes Ammonia and organic-Nitrogen. A municipal wastewater treatment plant with an effluent containing more than 5 mg/L TKN is not fully nitrifying.

$$TKN = NH_3 + org\text{-}N$$

Ammonia (NH_3 or NH_4). When the pH of the wastewater is acidic or neutral, the majority of the nitrogen is ammonium (NH_4^+). When the pH increases over 8.0, the nitrogen is mostly ammonia (NH_3). A municipal wastewater treatment plant with an effluent containing more than 2 or 3 mg/L NH_3 is not fully nitrifying.

organic-Nitrogen (org-N). A small fraction, typically one or two milligrams per liter, of the organic-Nitrogen is not amenable to biological treatment and passes through the treatment facility untreated as organic-Nitrogen. Quaternary ammonia (a form of organic-Nitrogen) is used as a bactericide by food handling businesses. At low concentrations, "quats" can be toxic to wastewater bacteria. Quaternary ammonia passes through treatment plants unchanged. A municipal wastewater treatment plant that is effectively nitrifying generally contains less than 3 mg/L organic-Nitrogen.

Nitrate (NO_3). Without additional information, the NO_3 concentration in municipal effluent is of little value. An effluent NO_3 concentration of less than 3 mg/L exists in wastewaters that are fully nitrified and denitrified as well as in effluent with no nitrogen removal at all. An effluent that is fully nitrified but has not been denitrified will generally contain an NO_3 concentration of approximately 20 mg/L.

Nitrite (NO_2). Municipal wastewater effluents generally contain less than 1 mg/L NO_2. Greater concentrations are generally found when a facility is partially nitrifying.

Nitrogen Gas (N_2). The air we breathe is 78% N_2 and only 21% oxygen. The remaining one percent is argon and other inert material.

The Basics of Phosphorus Removal

WHY THE CONCERN OVER

P

Phosphorus

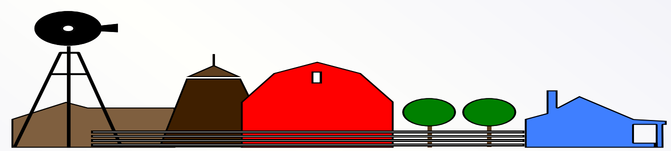
WHY IT'S REGULATED:

PHOSPHORUS IS A NUTRIENT

100:5:1 (C:N:P)

INCREASES PLANT GROWTH

Good for Food Crops



Phosphorus

WHY IT'S REGULATED:

PHOSPHORUS IS A NUTRIENT

100:5:1 (C:N:P)

INCREASES PLANT GROWTH

Good for Food Crops

Not Good for Aquatic Systems

Phosphorus

WHY IT'S REGULATED:

PHOSPHORUS IS A NUTRIENT

100:5:1 (C:N:P)

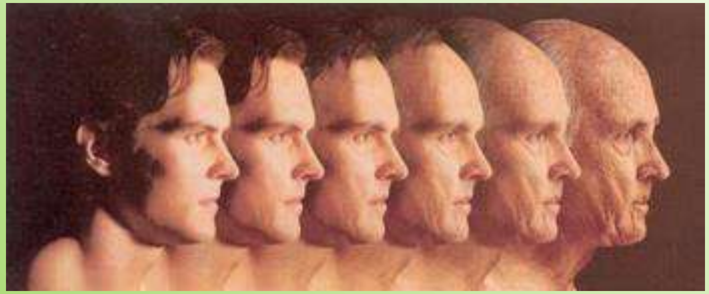
INCREASES EUTROPHICATION

Eutrophication

From the Greek word “Eutrophos”, meaning “well nourished”

Describes the biological reactions of aquatic systems to nutrient enrichment

Natural aging process



"I can assure you, this is the finest anti-aging formula money can buy. And I should know because I've been selling it for over 150 years."

Eutrophication

Classification of Lakes

Oligotrophic

Cold, Deep, Low Nutrients

Eutrophication

Classification of Lakes

Mesotrophic

Increasing in Nutrient Load

Eutrophication

Classification of Lakes

Eutrophic

Shallow, Warm, High Nutrient Load

Eutrophication

Classification of Lakes

Oligotrophic

Cold, Deep, Low Nutrients

Mesotrophic

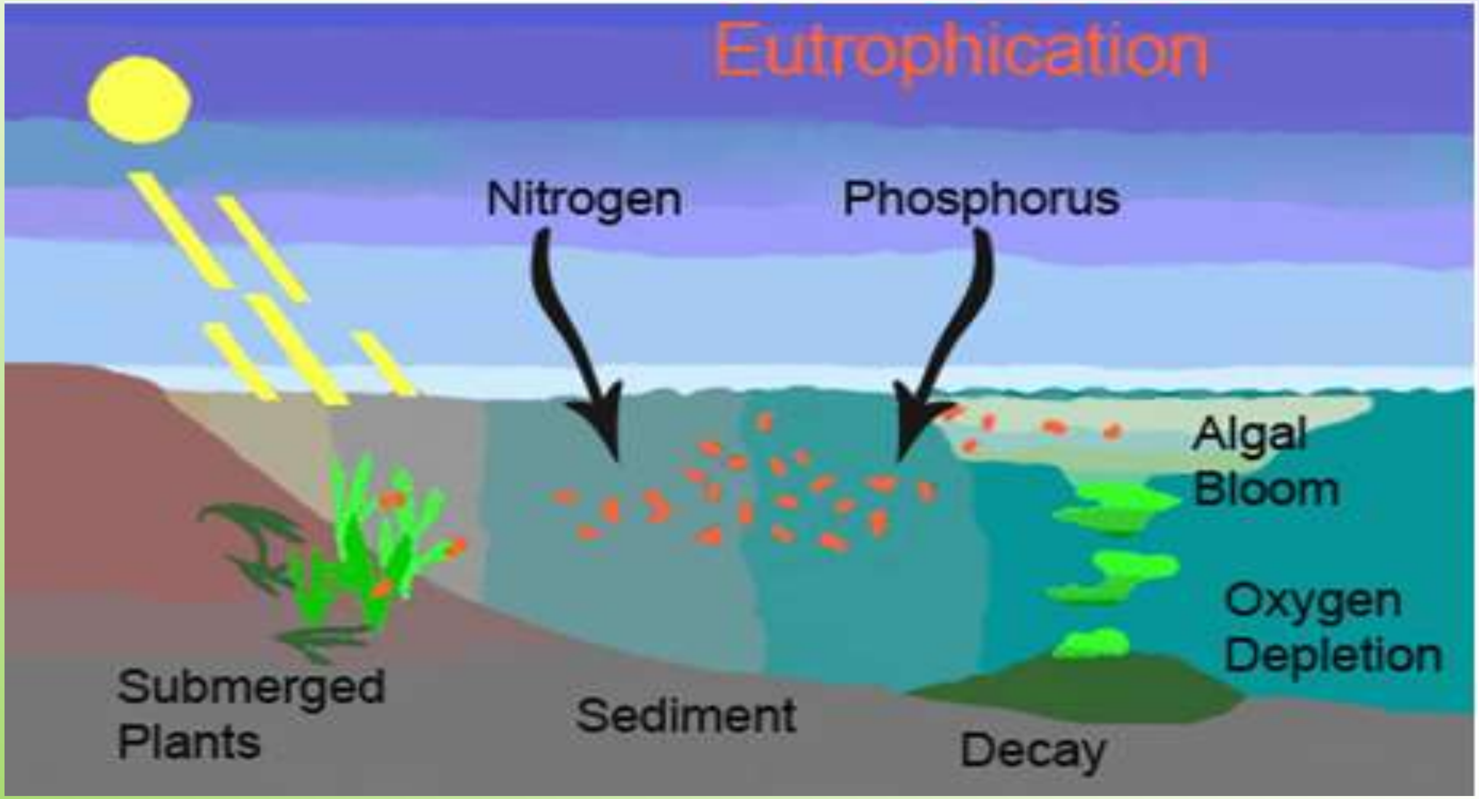
Increasing in Nutrient Load

Eutrophic

Shallow, Warm, High Nutrient Load

Control of Eutrophication

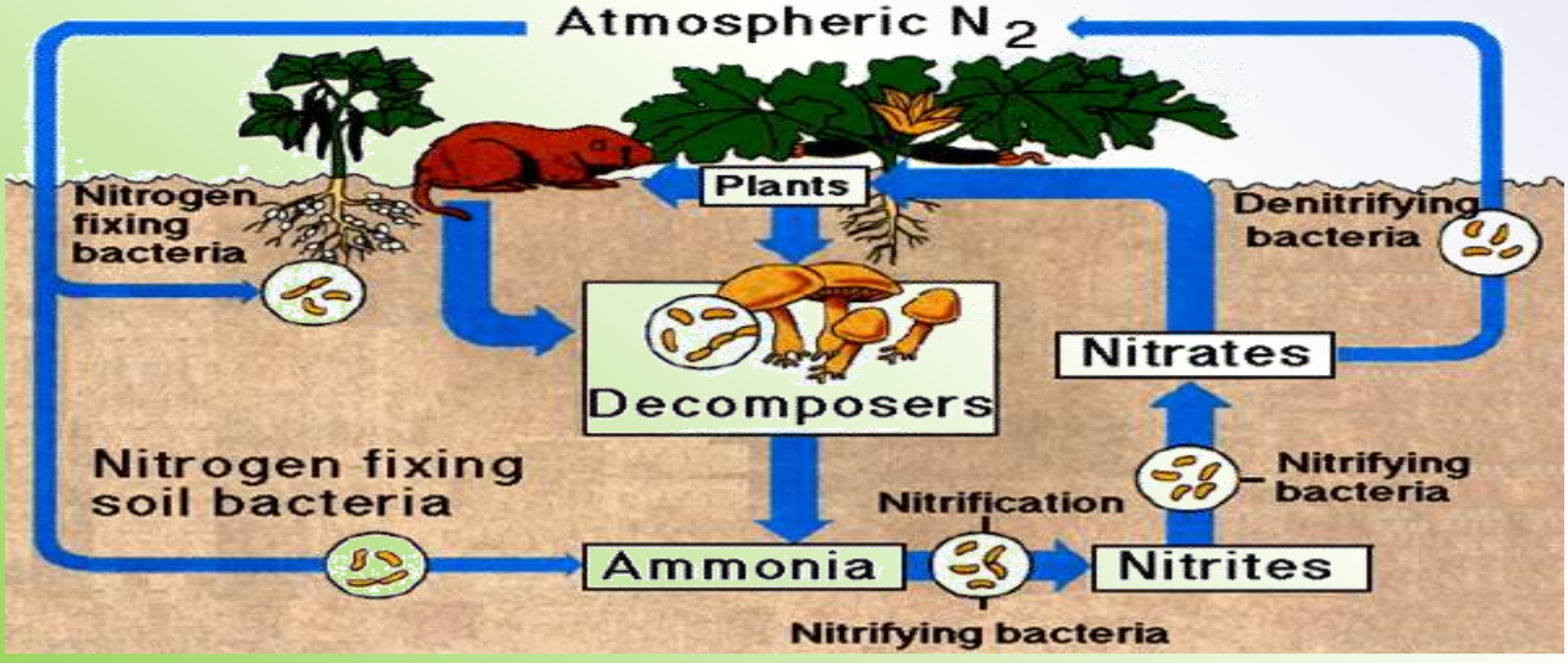
Control Nutrient Load



Control of Eutrophication

Nitrogen

Essential Nutrient
Very available in nature
Not practical to control



Control of Eutrophication

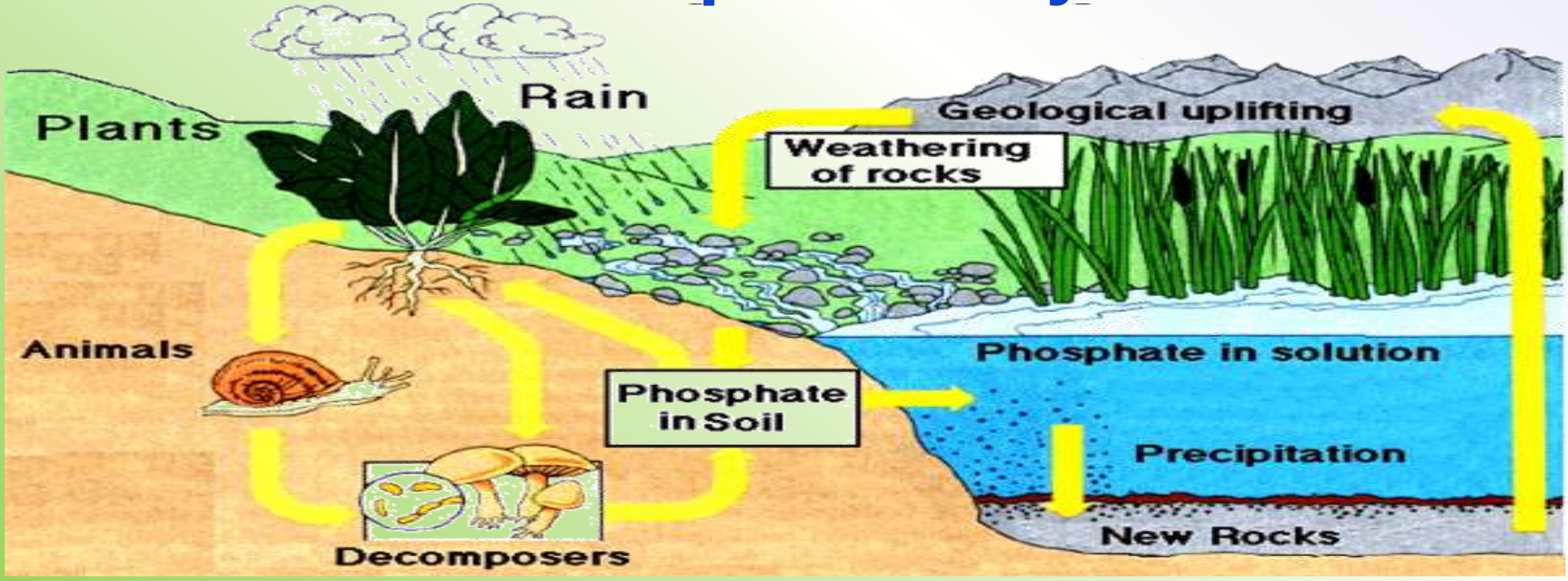
Phosphorus

Essential Nutrient

Not easily replaced in nature

P removal is practical

The Phosphorus Cycle

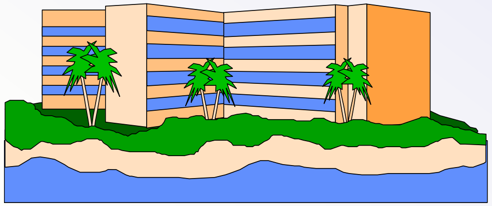


Eutrophication

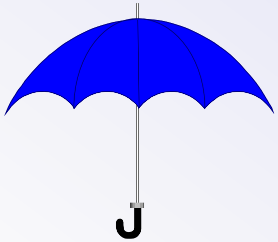
Rate of Eutrophication is increased by human activities

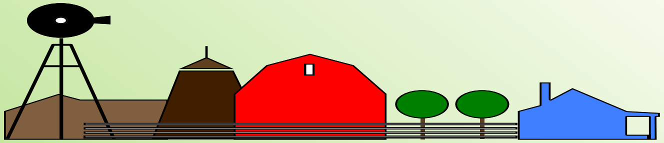
(Cultural Eutrophication)

Development



Stormwater Run-Off





Agriculture

Wastewater Discharges
- **WWTP**
- **On-Site Systems**
- **Combined Sewer Overflow**

Phosphorus

Wastewater Discharges

USUALLY LIMITED IN MICHIGAN TO 1 mg/L OR LESS IN DISCHARGES TO SURFACE WATER

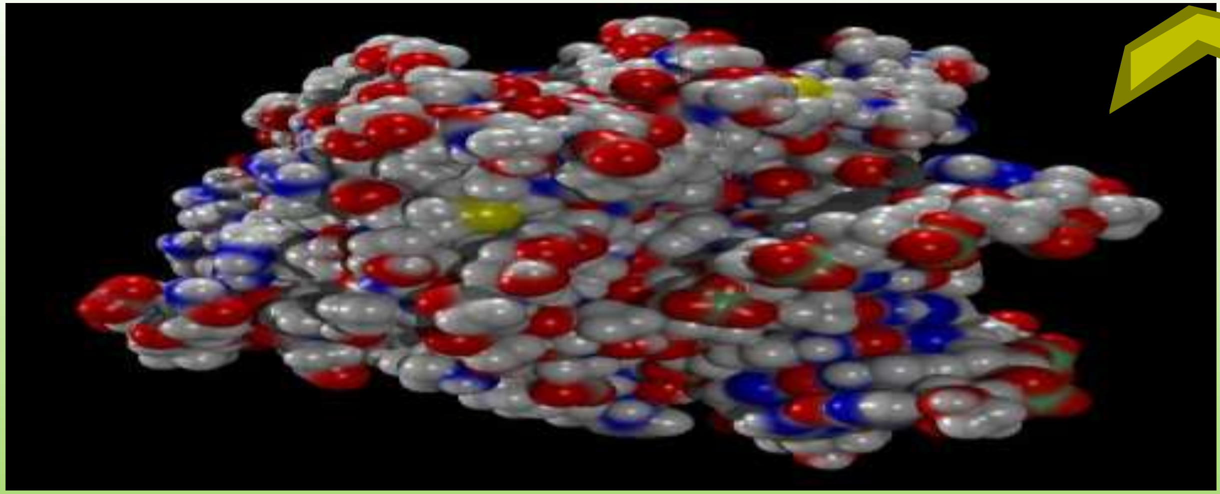
(Many Have Pounds Limit)

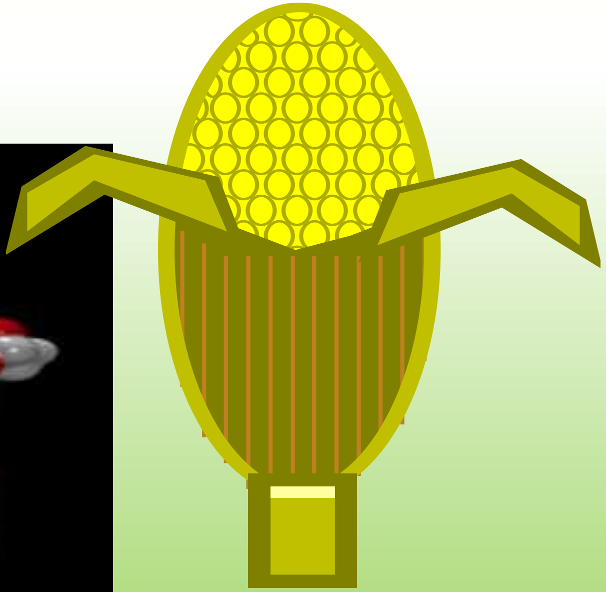
Limits Getting More Restrictive

Forms and Sources of Phosphorus

Organic Phosphorus

- complex organic compounds
- soluble or particulate
- decomposes to Ortho-P

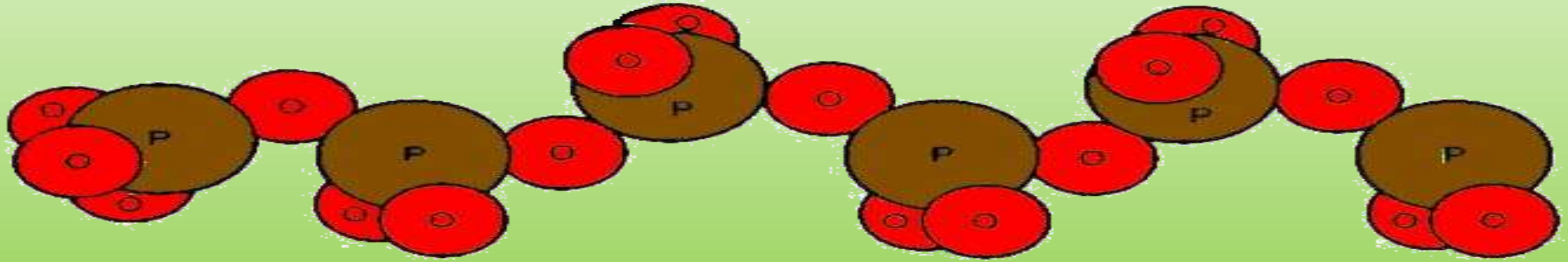




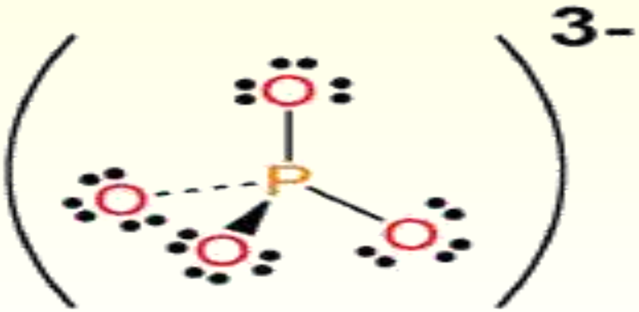
Forms and Sources of Phosphorus

Polyphosphate (condensed phosphate)

- chained molecules
- soluble
- home, industrial detergents
- potable water treatment
- decomposes to Ortho-P

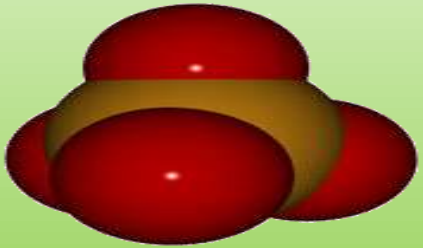


Forms and Sources of Phosphorus



Orthophosphate

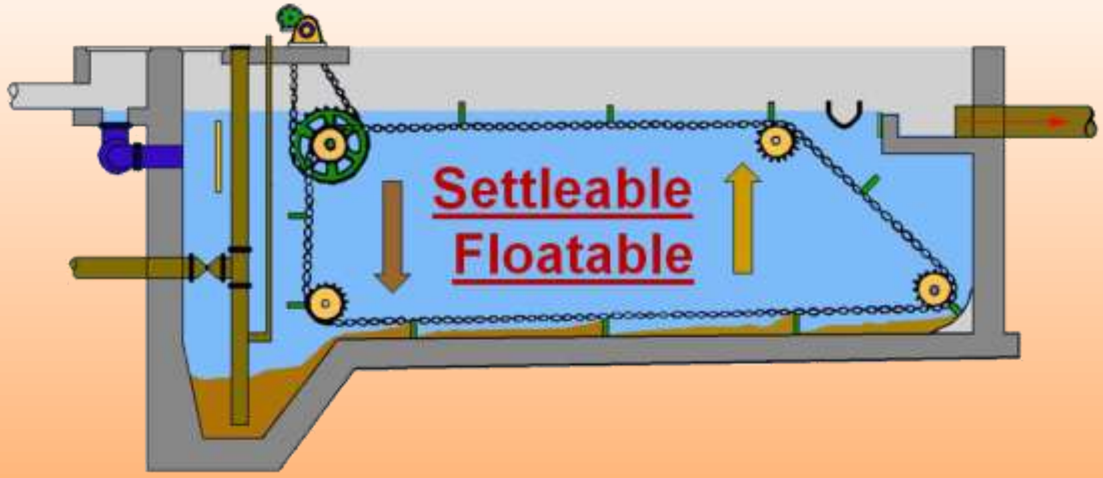
- Simple Phosphate, PO_4
- soluble
- household cleaning agents
- industrial cleaners;
- phosphoric acid
- conversion of organic and poly phosphate



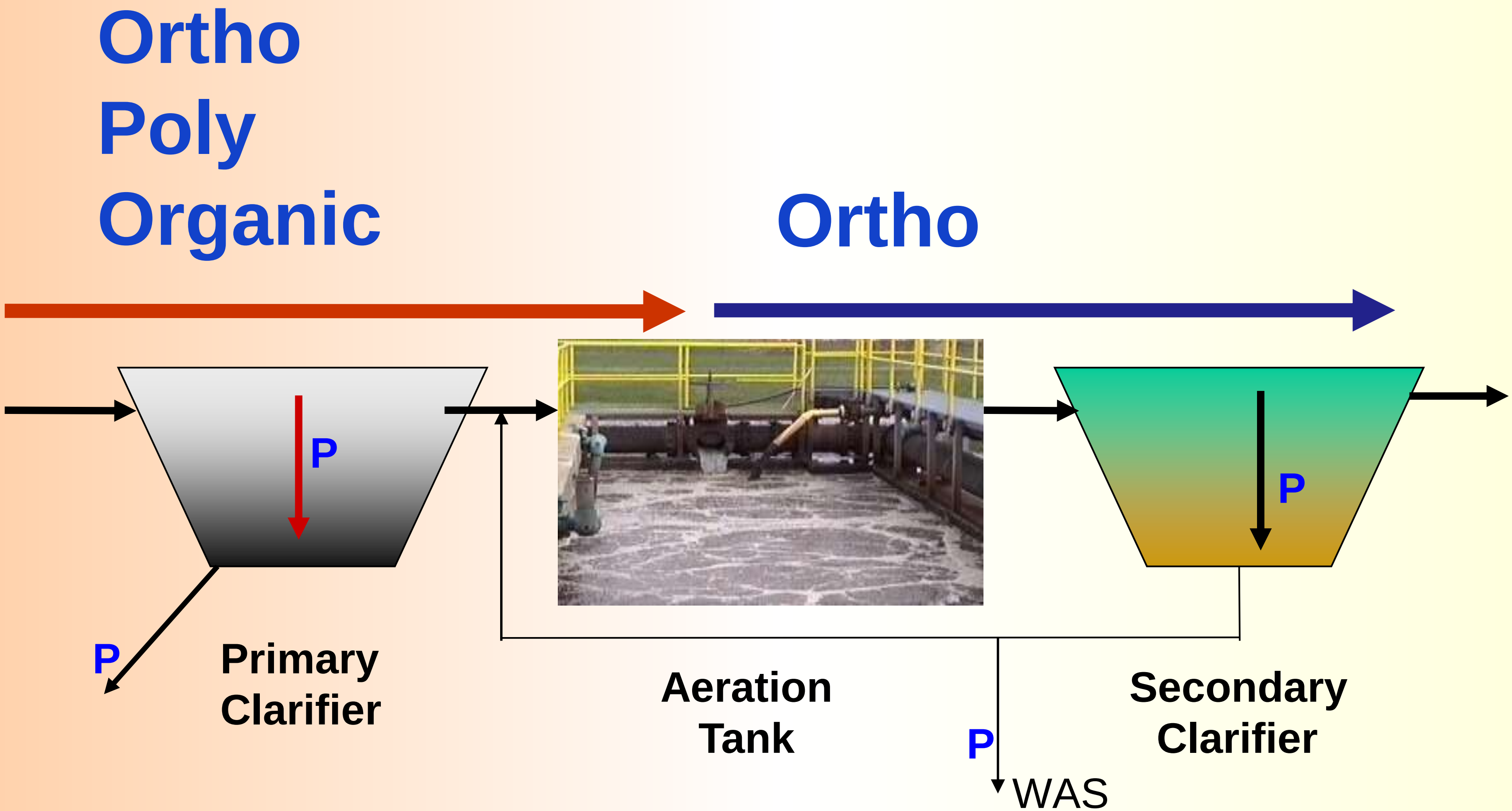
Phosphorus Removal

- **Removal of Settleable Solids Provides Some Phosphorus Removal**

Primary Sedimentation 5 - 15 %



Conversion to Ortho-P



Phosphorus Removal

- Biological Wastewater Treatment Systems Will Remove Phosphorus

  100:5:1 (C:N:P)
  Primary and TF 20 - 30 %
  Primary and AS 30 - 50 %

- Total Influent P Ranges from 2.5 to 6 mg/L

- NPDES Permits Limit Effluent P 1 mg/L and Lower

Most Facilities Will Require Additional Process for Phosphorous Removal

Phosphorus Removal

Removal of Ortho-P may Occur Through:

1. **Chemical Precipitation**

2. **Enhanced Biological Uptake**

Chemical Phosphorus Removal

Ortho Phosphate

(Soluble)

plus

Metal Salts

(Soluble)

form

Insoluble Phosphorus Compounds

Chemical Phosphorus Removal

Total Phosphorus

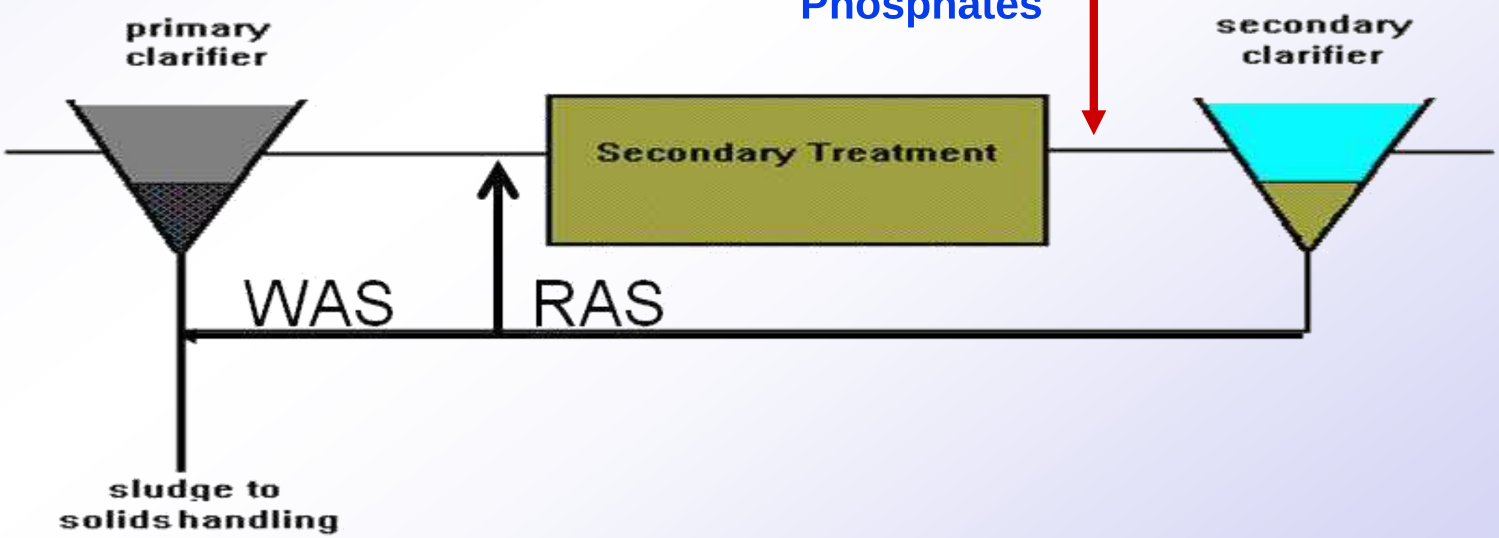
Organic Phosphorus

Condensed (Poly) Phosphates

Ortho Phosphates

Ortho Phosphates

Metal Salt Addition



Chemical Removal

$$M^{+3} + PO_4^{-3} \longrightarrow MPO_4 \downarrow$$

(M^{+3} = Metal in Solution)

PRECIPITATION

Metals used are:

Aluminum, Al

Iron, Fe

Chemicals Used for Phosphorous Precipitation

Most Common in Michigan:

Ferric Chloride
Ferrous Chloride
Alum

FERRIC IRON - Fe^{+3}

$$M^{+3} + PO_4^{-3} \rightarrow MPO_4 \downarrow$$

$$Fe^{+3} + PO_4^{-3} \rightarrow FePO_4 \downarrow$$

Weight Ratio

Fe^{+3} to P

1.8 : 1

$FeCl_3$: P

5.2 : 1

Starting Dosage 20-25 mg/L

ALUMINUM COMPOUNDS

Aluminum Sulfate (Alum)

$Al_2(SO_4)_3 \cdot 14H_2O$

Sodium Aluminate

$Na_2Al_2O_4$

Aluminum Chloride

$AlCl_3$

Alum Dosage Rates

$$Al_2(SO_4)_3 + 2PO_4^{-3} \longrightarrow 2AlPO_4 \downarrow$$

Weight Ratio

Al^{+3} : P

0.87 : 1

Alum to Phosphorus

9.6 : 1

Starting Dosage 40-50 mg/L

Chemical Phosphorus Removal

Total Phosphorus

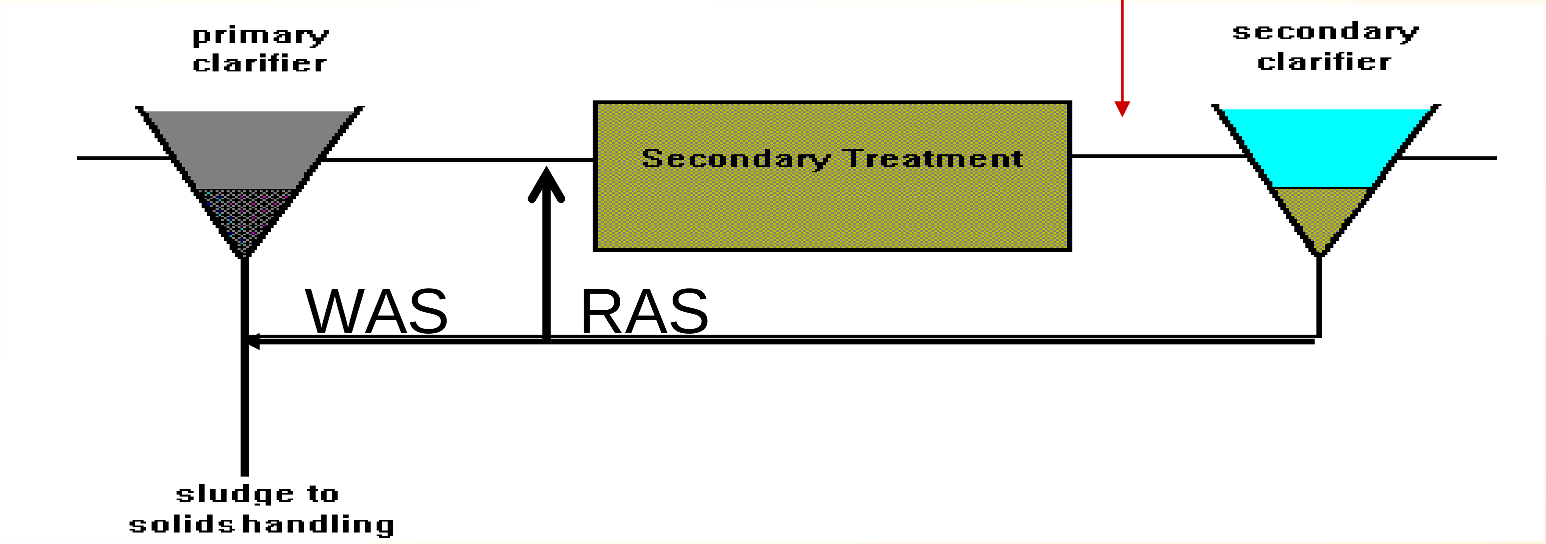
Organic Phosphorus

Condensed (Poly) Phosphates

Ortho Phosphates

Ortho Phosphates

Metal Salt Addition



Phosphorus Removal

Removal of Ortho-P may Occur Through:

1. **Chemical Precipitation**
2. **Enhanced Biological Uptake**

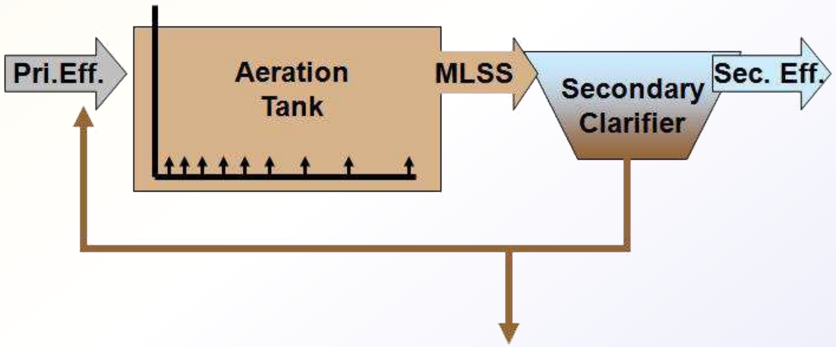
(EBPR)

Often Just Called
BIOLOGICAL P REMOVAL

Biological P Removal

All Biological Systems Take Up P

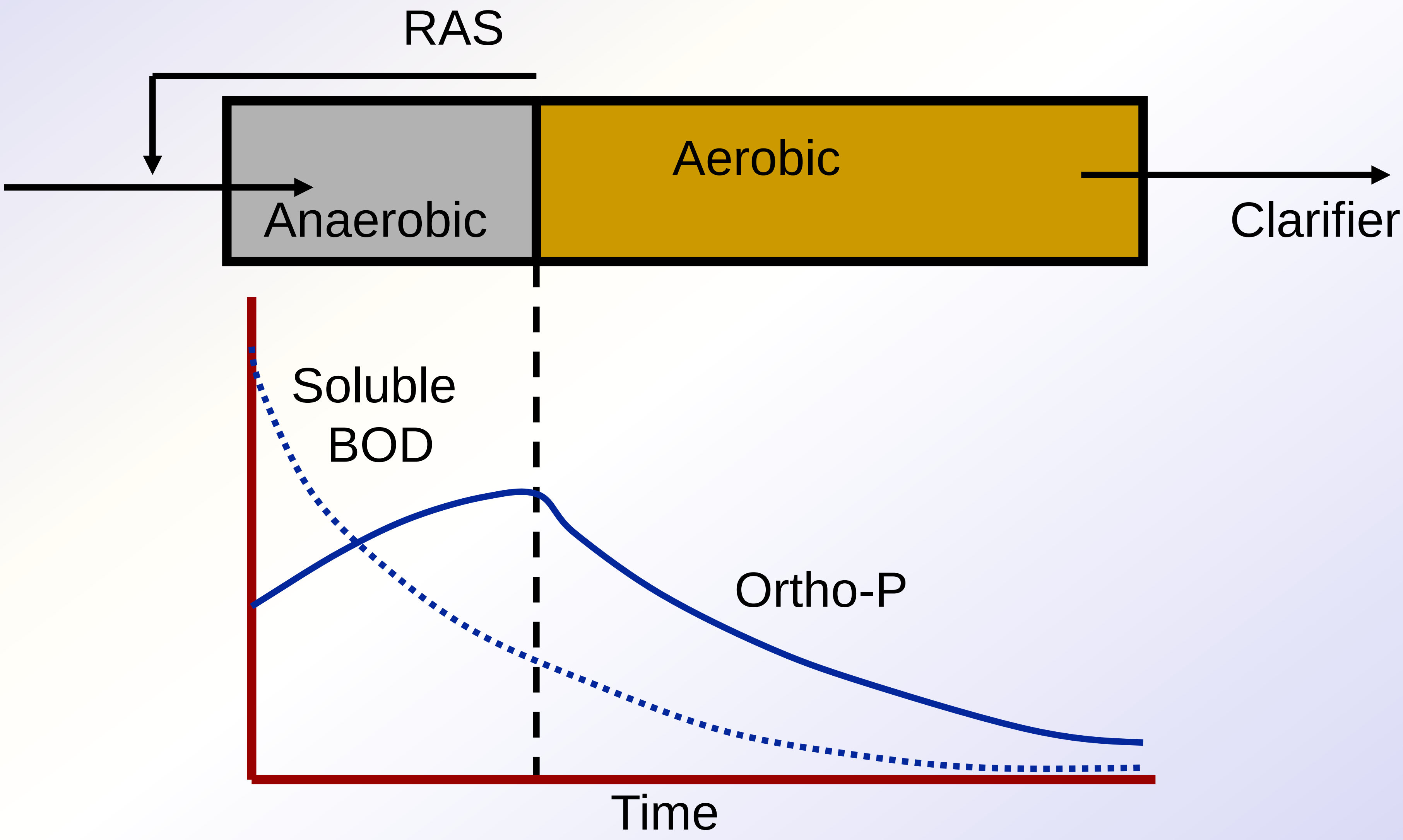
100:5:1
C:N:P



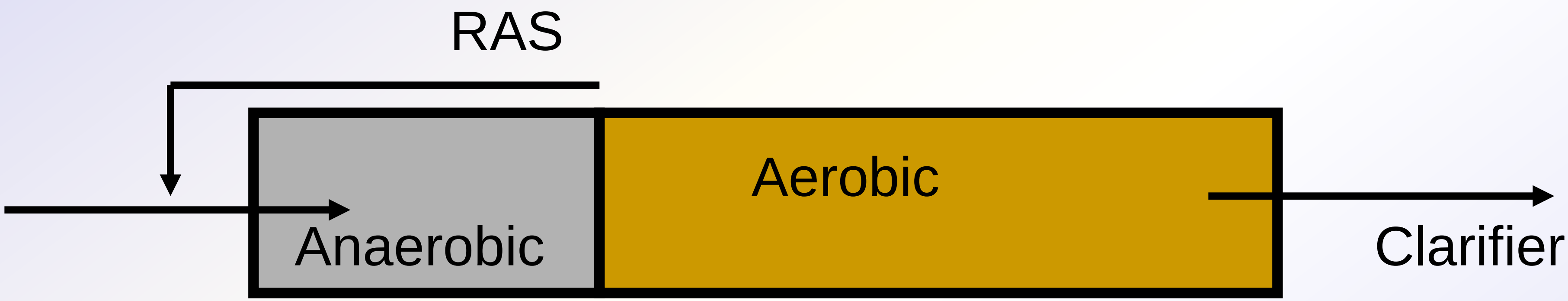
Some Facilities Removed More P Than 1P:100BOD

?

The MLSS in Those Facilities Cycled From <u>Anaerobic</u> to <u>Aerobic</u>



The MLSS in Those Facilities Cycled From Anaerobic to Aerobic



This Promoted the Accumulation of Bacteria that Uses P as an Energy Storage Mechanism

Acinetobacter (Assin Eato Back Ter)

& Other

Phosphate Accumulating Organisms (PAO)

Biological P Removal

Anaerobic Conditions

Heterotrophic Bacteria Break Down Organics

Fermentation

Volatile Fatty Acids (VFAs)

Acetate (Acetic Acid)

Also

Selection of PAO - Phosphate Accumulating Organisms

(Able to Out-Compete Other Aerobic Heterotrophic Bacteria for Food When Anaerobic)

Biological P Removal

Anaerobic Conditions

PAO Take Up VFAs and Covert them to Polyhydroxybutyrate (PHB)

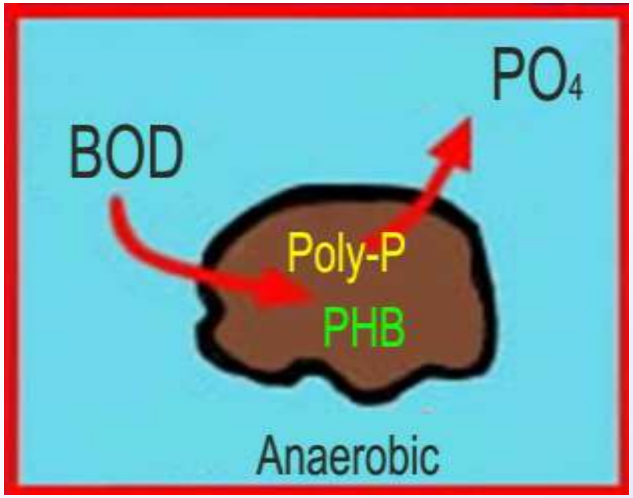
PAO Able to store soluble organics as Polyhydroxybutyrate (PHB)

Biological P Removal

Anaerobic Conditions

PAO Able to store soluble organics as Polyhydroxybutyrate (PHB)

PAO Break Energy-Rich Poly-P Bonds To Produce Energy Needed for the Production of PHB



Ortho-P is Released Into Solution

Biological P Removal

Aerobic Conditions

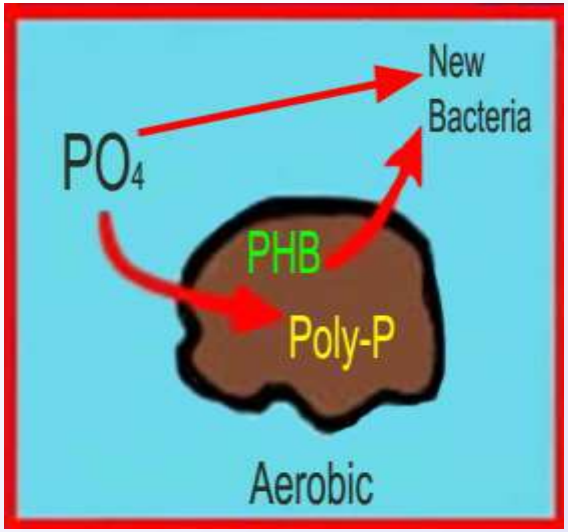
Rapid Aerobic Metabolism of Stored Food (PHB)

Producing New Cells

$\underline{PO_4}$ Used in Cell Production

Excess <u>Stored</u> as Polyphosphate

("Luxury Uptake")



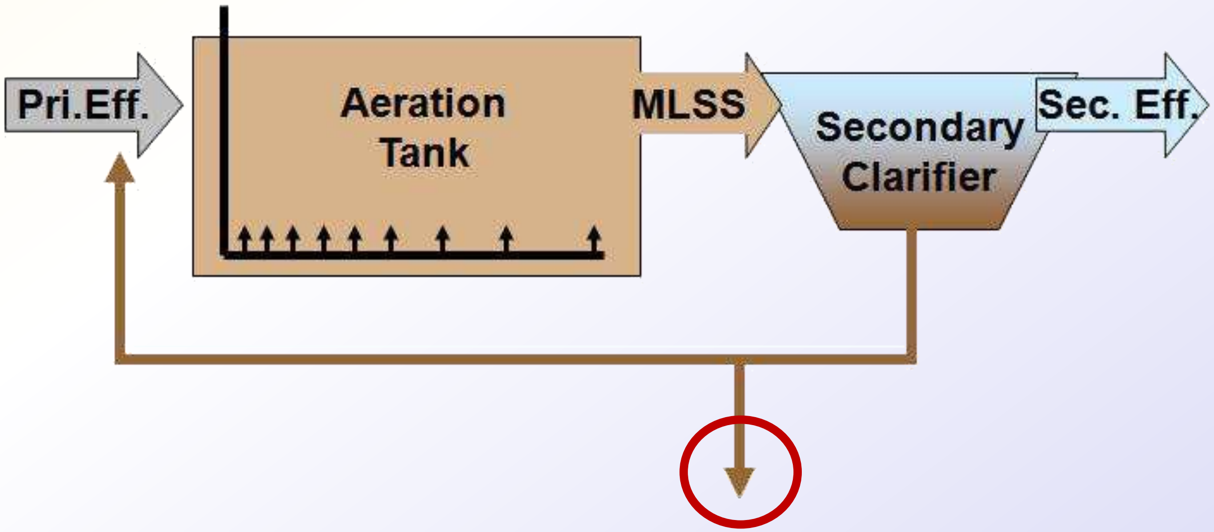
Biological P Removal

Aerobic Conditions

PO_4 Used in Cell Production
Excess Stored as Polyphosphate

Biomass Approximately 5 to 7% P by Weight
(Normal 1.5 to 2 %)

Sludge is Wasted When Loaded With P



Biological P Removal

EBPR

BSCOD

BOD

VFAs

PAO

PHB

Ortho-P

Poly-P

Luxury Uptake

Acinetobacter

Biological P Removal

Phosphorus Accumulating Bacteria (**PAO)**

Anaerobic

Fermentation

Acetate Production

Selection of Acinetobacter/PAO

P Released to Produce Energy

Biological P Removal

Phosphorus Accumulating Bacteria (**PAO)**

Anaerobic

Fermentation
Acetate Production
Selection of Acinetobacter/PAO
P Released to Produce Energy

Aerobic

Stored Food Consumed
Excess P Taken Up
Sludge Wasted

Biological P Removal

Most often Used Processes

A/O
Phostrip
A2/O
Concentric Ring Oxidation Ditch
Sequencing Batch Reactor

Definitions

Aerobic – Dissolved (Free) Oxygen Present – O_2

Oxic – Dissolved (Free) Oxygen Present – O_2

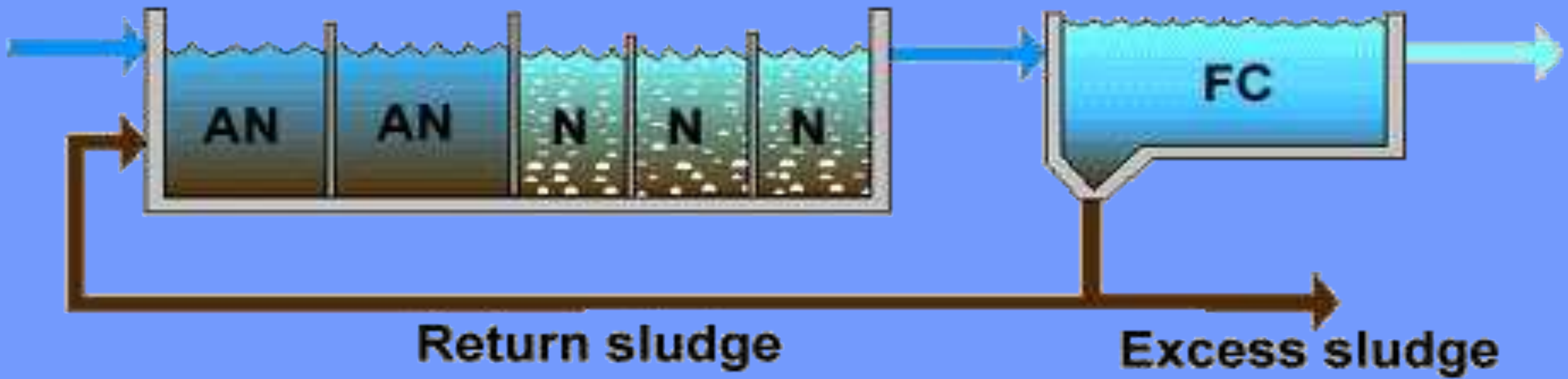
Anoxic – No Free Oxygen

(Combined Oxygen –Nitrates NO_2 and Nitrites NO_3)

Anaerobic – Oxygen Absent

A/O Process

(Anaerobic/Oxic)



Head End of Aeration Tank Baffled and Mechanically Mixed

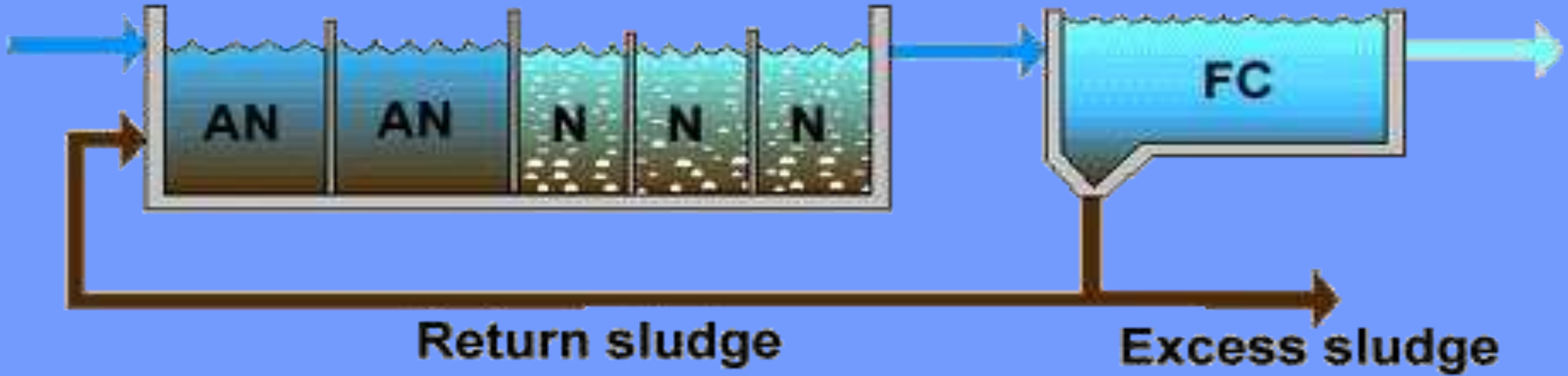
Primary Effluent and RAS Produce Anaerobic Conditions

Phosphorus Released

"Luxury Uptake" of Phosphorus in Aerated End

A/O Process

(Anaerobic/Oxic)



Studies in Florida and Pontiac, MI

At Pontiac (Cold Weather Testing)

Side by Side with Conventional

Cold Weather P removal achieved

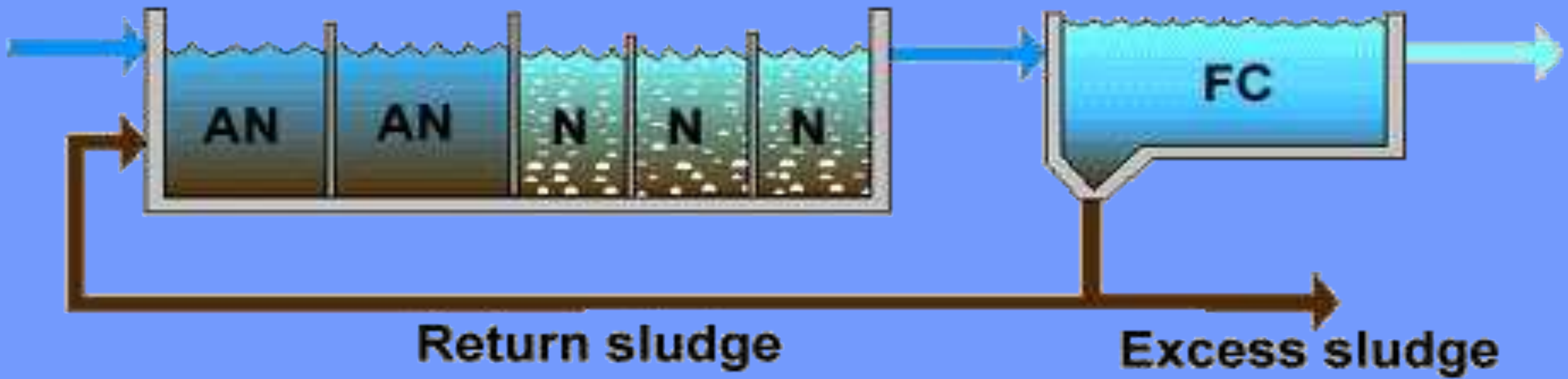
Nitrification process continued

Anaerobic Digester recycle not detrimental

A/O Process

A/O Process

(Anaerobic/Oxic)



Control Issues

Patented Process

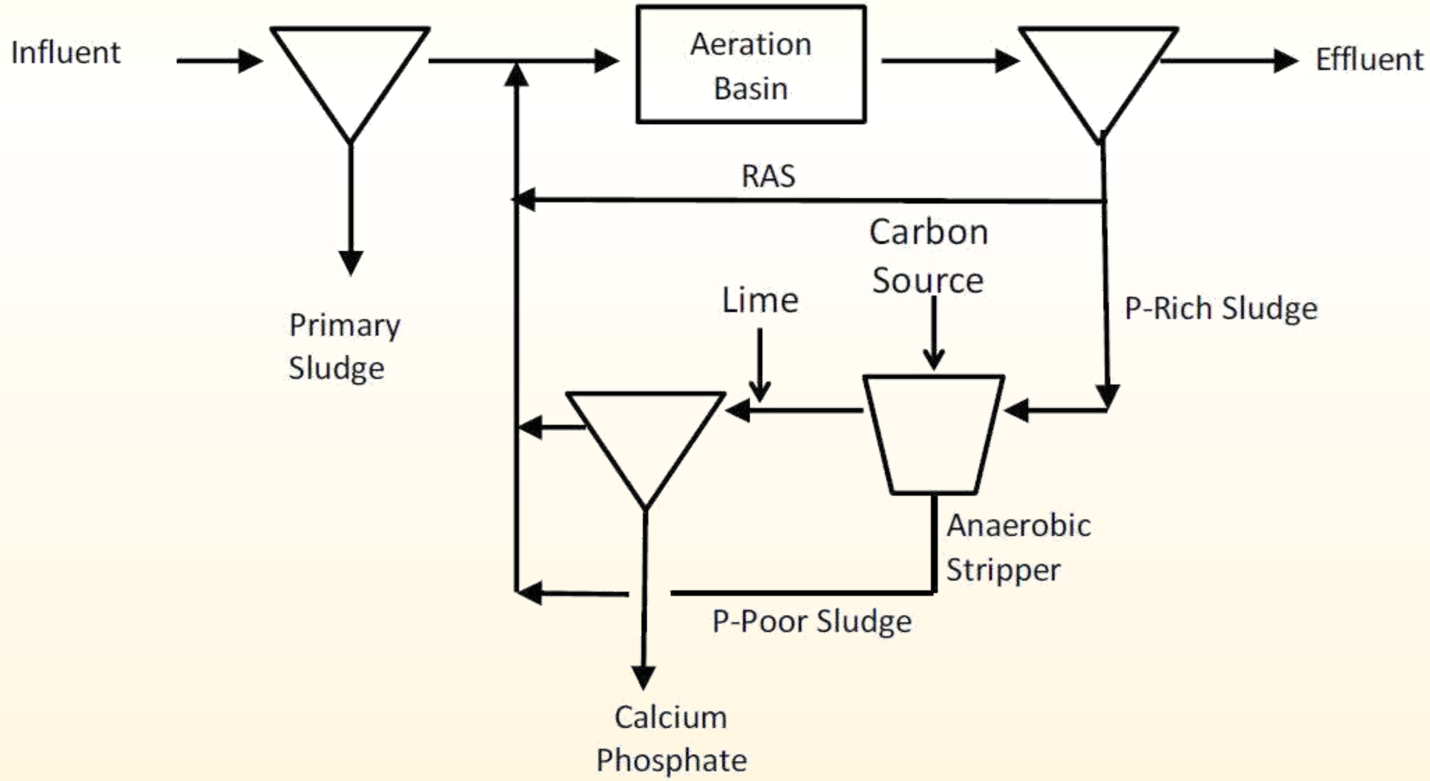
Phostrip

Some Return Sludge Diverted to Anaerobic Stripper

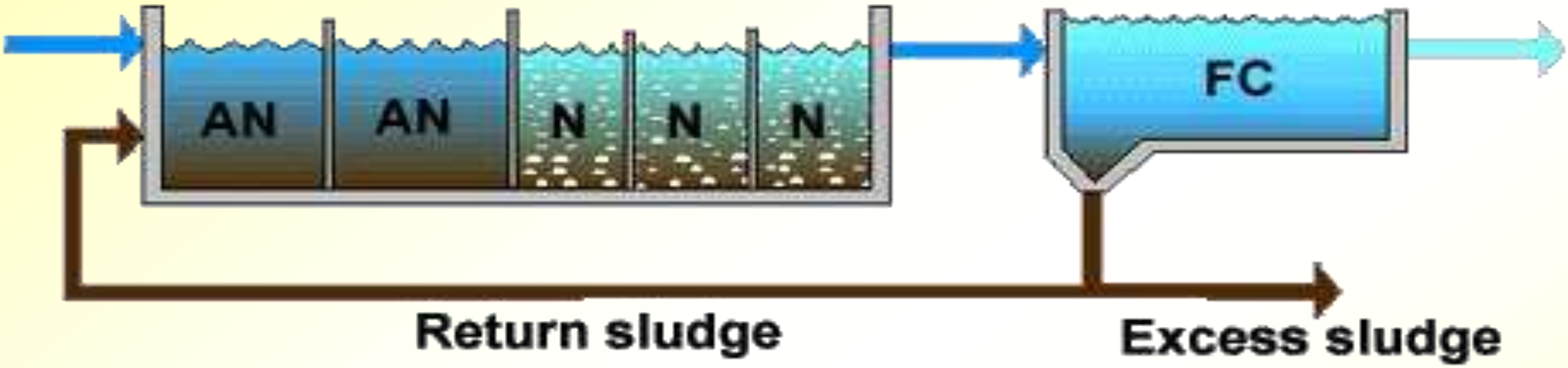
Phosphorus Released

Elutriated (Washed) to a Precipitation Tank

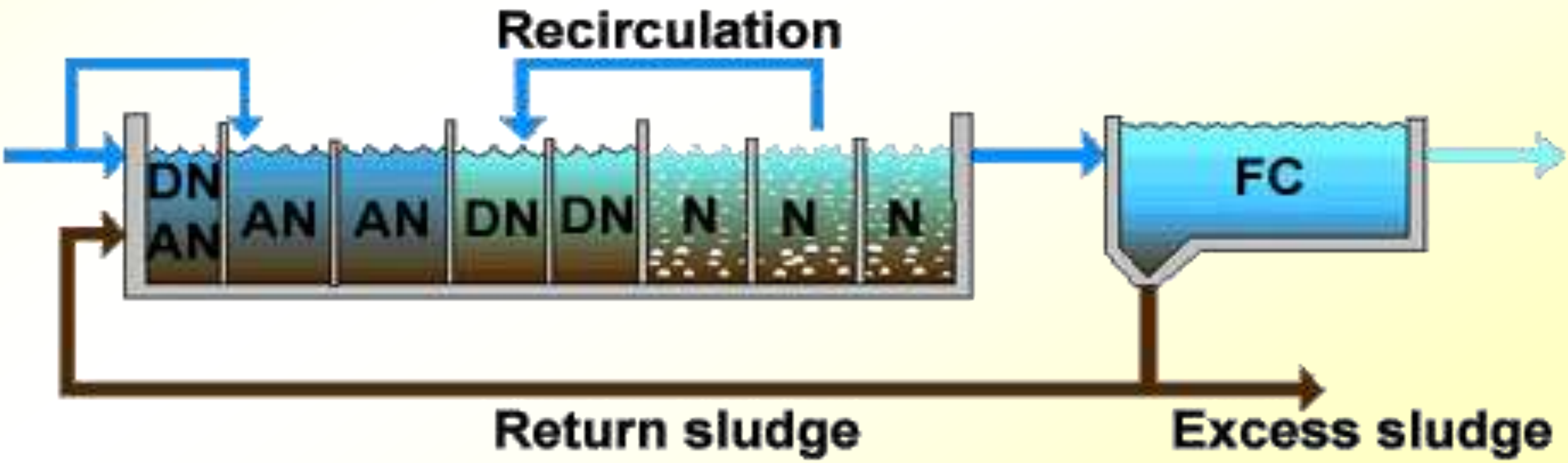
Precipitated With Lime – Sludge Removed



A/O Process (Anaerobic/Oxic)

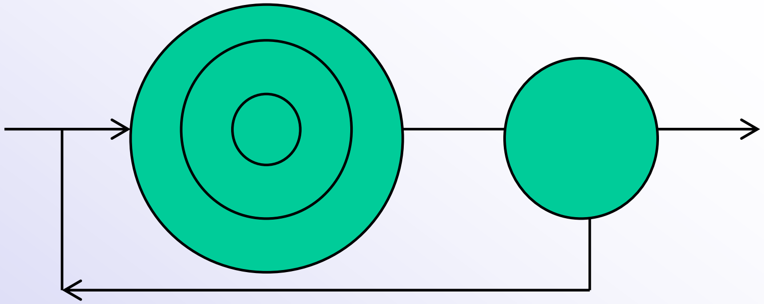


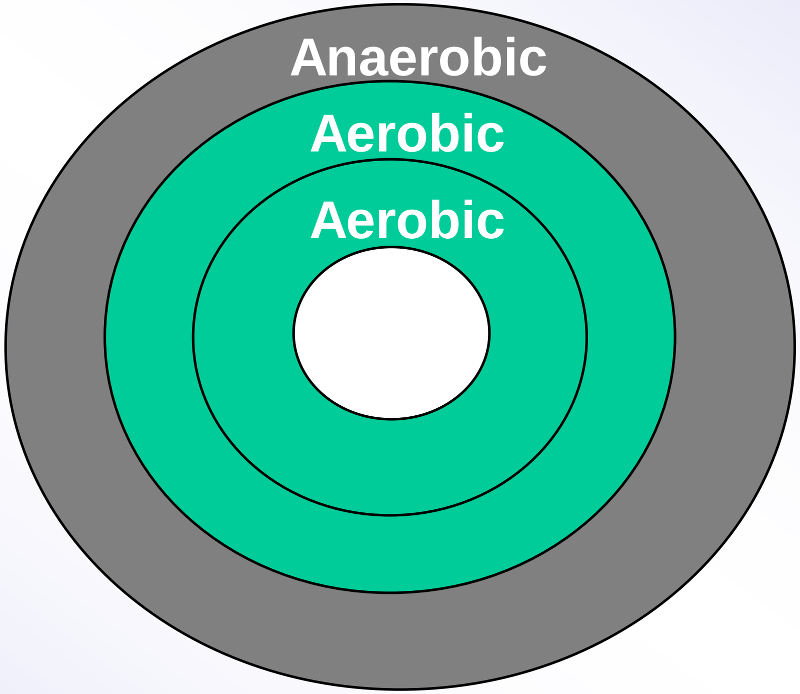
A2/O (Anaerobic/Anoxic/Oxic)



Concentric Ring Oxidation Ditch

Three Aeration Tanks in Concentric Rings





Concentric Ring Oxidation Ditch

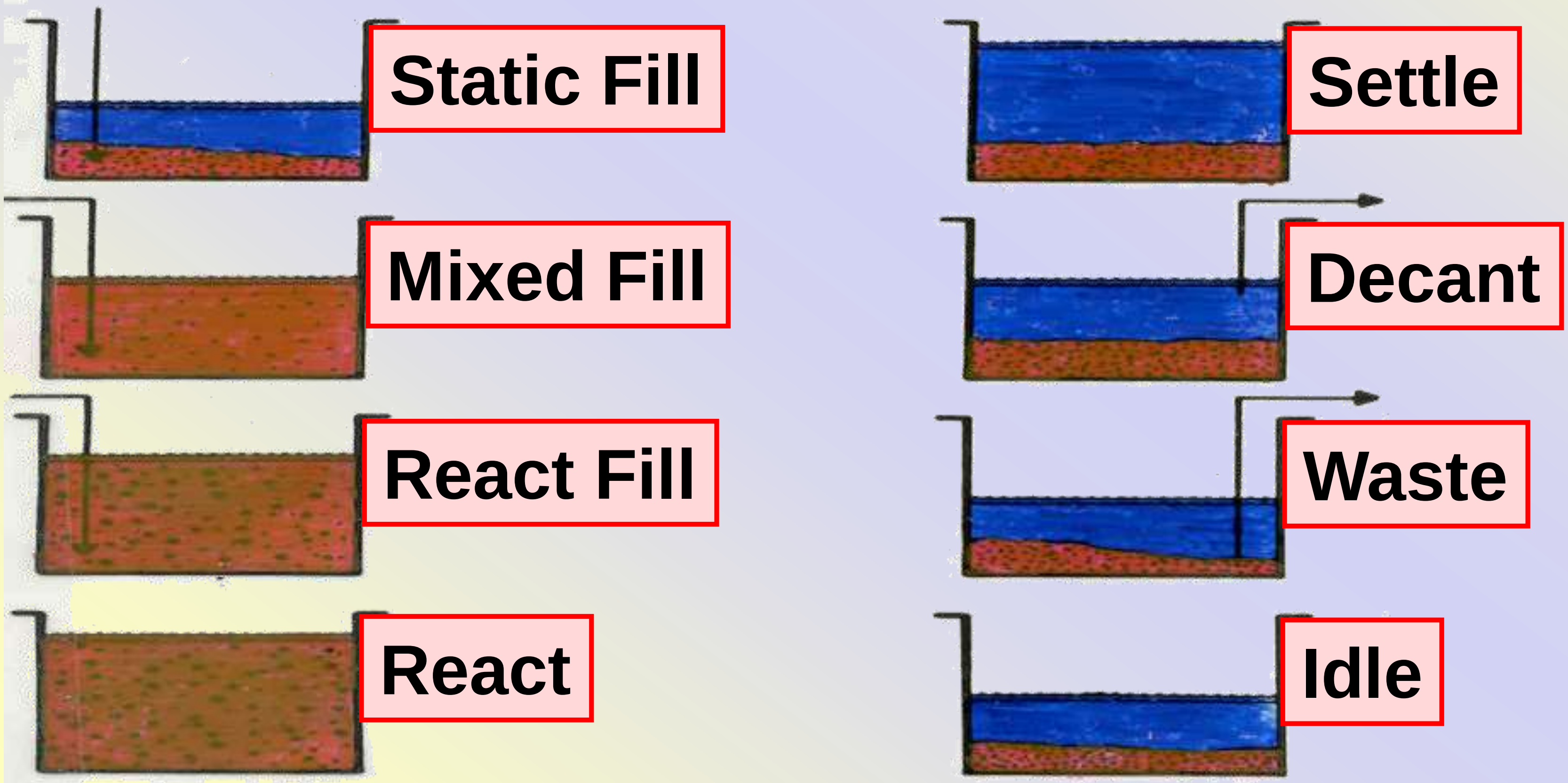
Three Aeration Tanks in Concentric Rings

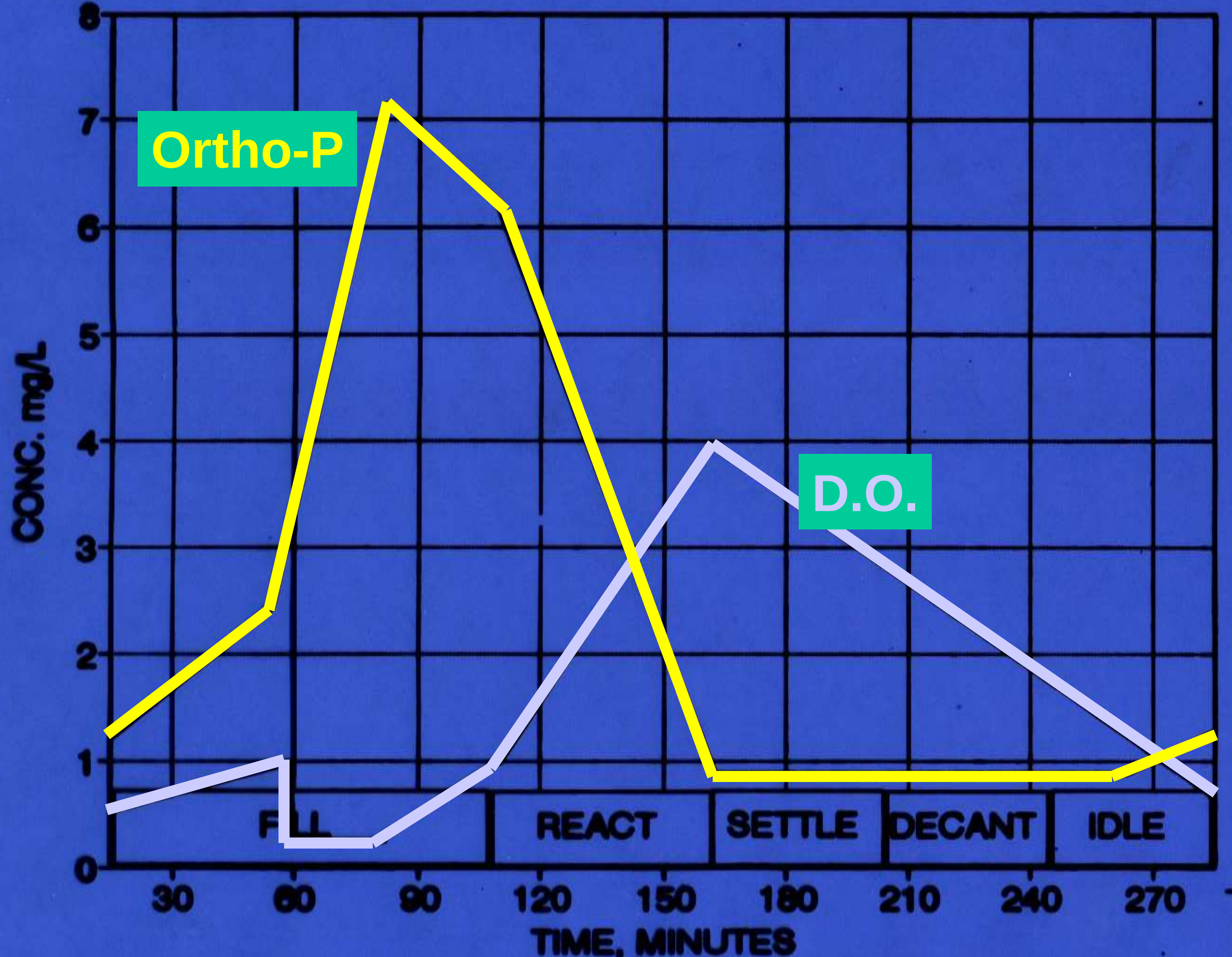
Wasting Aerobic the Bio-solids Removes Phosphorus

Sequencing Batch Reactor

Sequencing Batch Reactor

Batch Treatment in Sequence of Steps

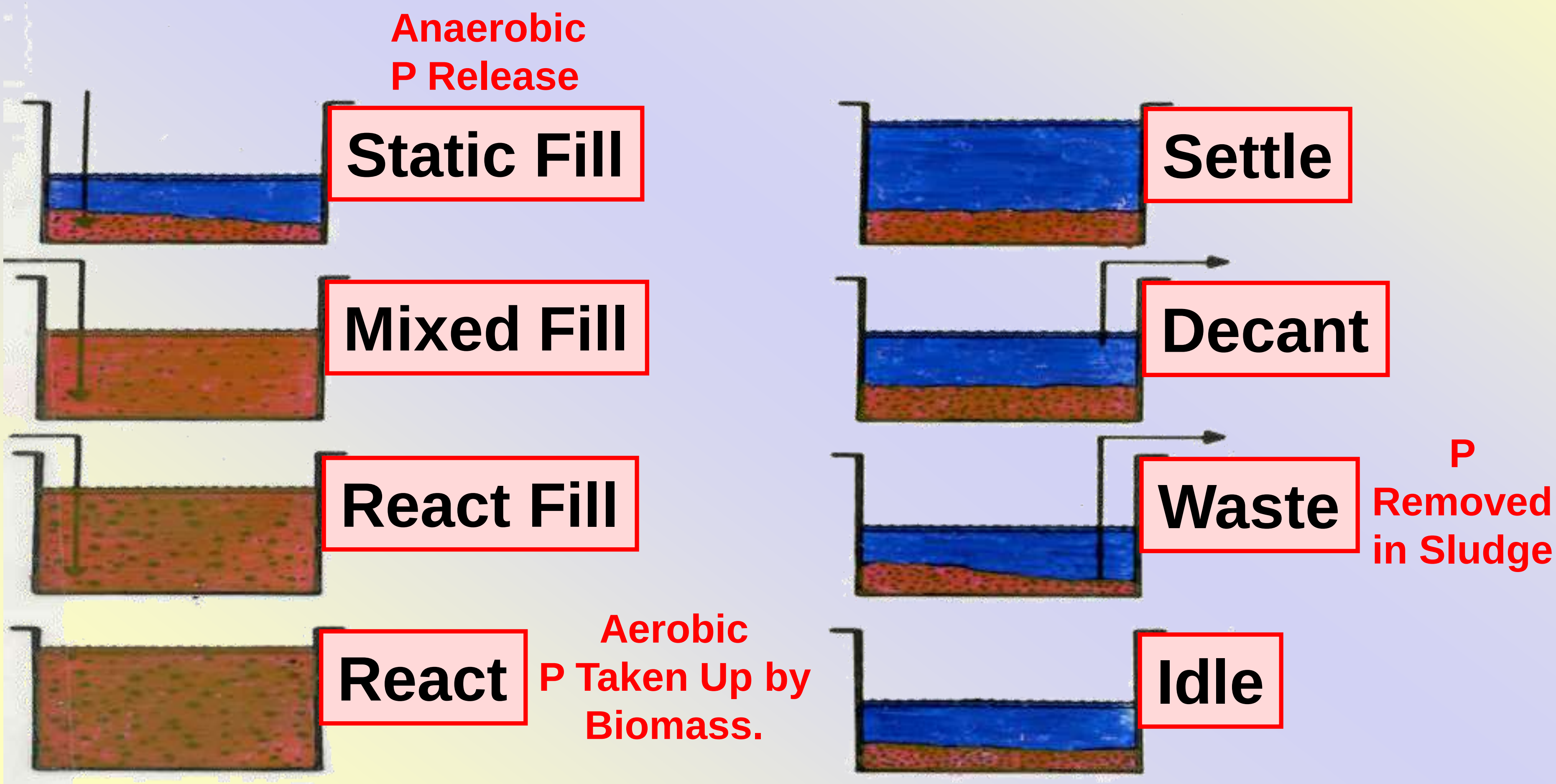




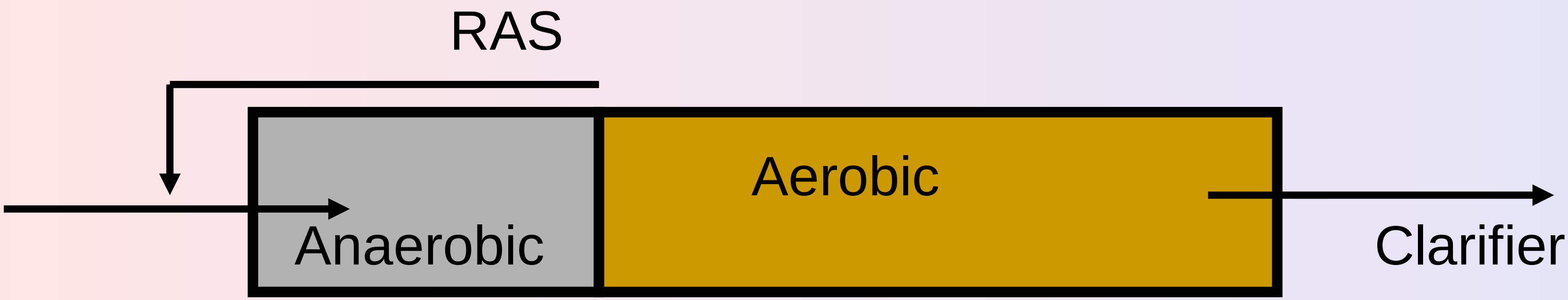
Ortho-P
D.O.
CONC. mg/L
0
1
2
3
4
5
6
7
8
FILL
REACT
SETTLE
DECANT
IDLE
30
60
90
120
150
180
210
240
270
TIME, MINUTES

Sequencing Batch Reactor

Batch Treatment in Sequence of Steps



Biological P Removal



The MLSS Cycles From Anaerobic to Aerobic

This Promotes
Phosphate Accumulating Organisms (PAO)

Anaerobic
Fermentation
Acetate Production
P Released to Produce Energy

Aerobic
Stored Food Consumed
Excess P Taken Up
Sludge Wasted

Biological P Removal

Important Considerations

Adequate Influent BOD

(Enough O_2 demand to achieve anaerobic conditions)

BOD:P
20:1

Adequate Anaerobic Detention Time 1-3 hrs

(Not so long as to reduce sulfate to sulfide-septicity)

Adequate Aerobic Detention Time 4-5 hrs.

(Enough time for BOD removal & Nitrification)

Biological P Removal

Important Considerations

Low Effluent Suspended Solids

Below 20 mg/L (SS result in P in effluent)

Nitrification –Nitrate

(Adds O_2 in Anaerobic Zone)

Sludge Handling

(Supernatant P can overload P removal system)

Biological P Removal

Benefits

No Chemical Feed (Usually, Sometimes)

- Lower Cost
- Safety
- No Tramp Metals
- No Chemical Sludge Produced

Inhibits Growth of Filamentous Organisms

(Cycling between Anaerobic & Aerobic)

Biological P Removal

Unbenefits

Probably Need Chemical System Too

DO requirements Opposes Nitrification

Sludge Handling More Critical

Effluent Solids More Critical

Close Control Required

P in Anaerobic and Aerobic
D.O. in Anaerobic and Aerobic

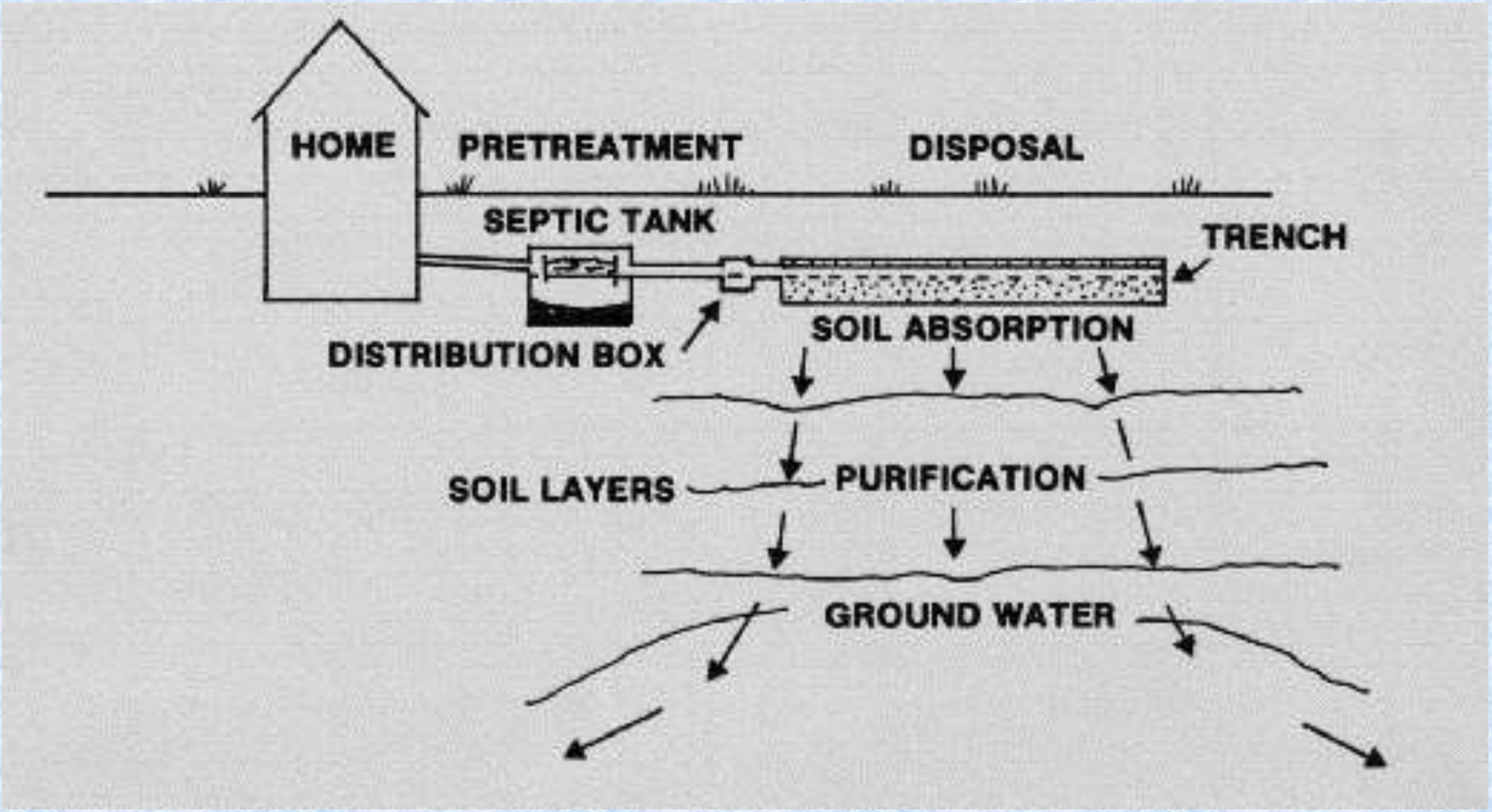
May be Patented Process

OTHER TREATMENT PROCESSES

Other processes include:

- **Septic tank**
- Imhoff tank
- Ponds
- Lagoons
- Ditches

TREAT SEWAGE SO THAT IT IS MADE HARMLESS.



SEPTIC TANK

- ***Process:***
  - Horizontal continuous flow bed tank (with longer detention time)
  - Extended sedimentation tank
  - 12-36 hours detention
  - Closed tank – Anaerobic decomposition of settled sludge
  - Three purposes
    - Sedimentation
    - Digestion tank
    - Storage of digested sludge

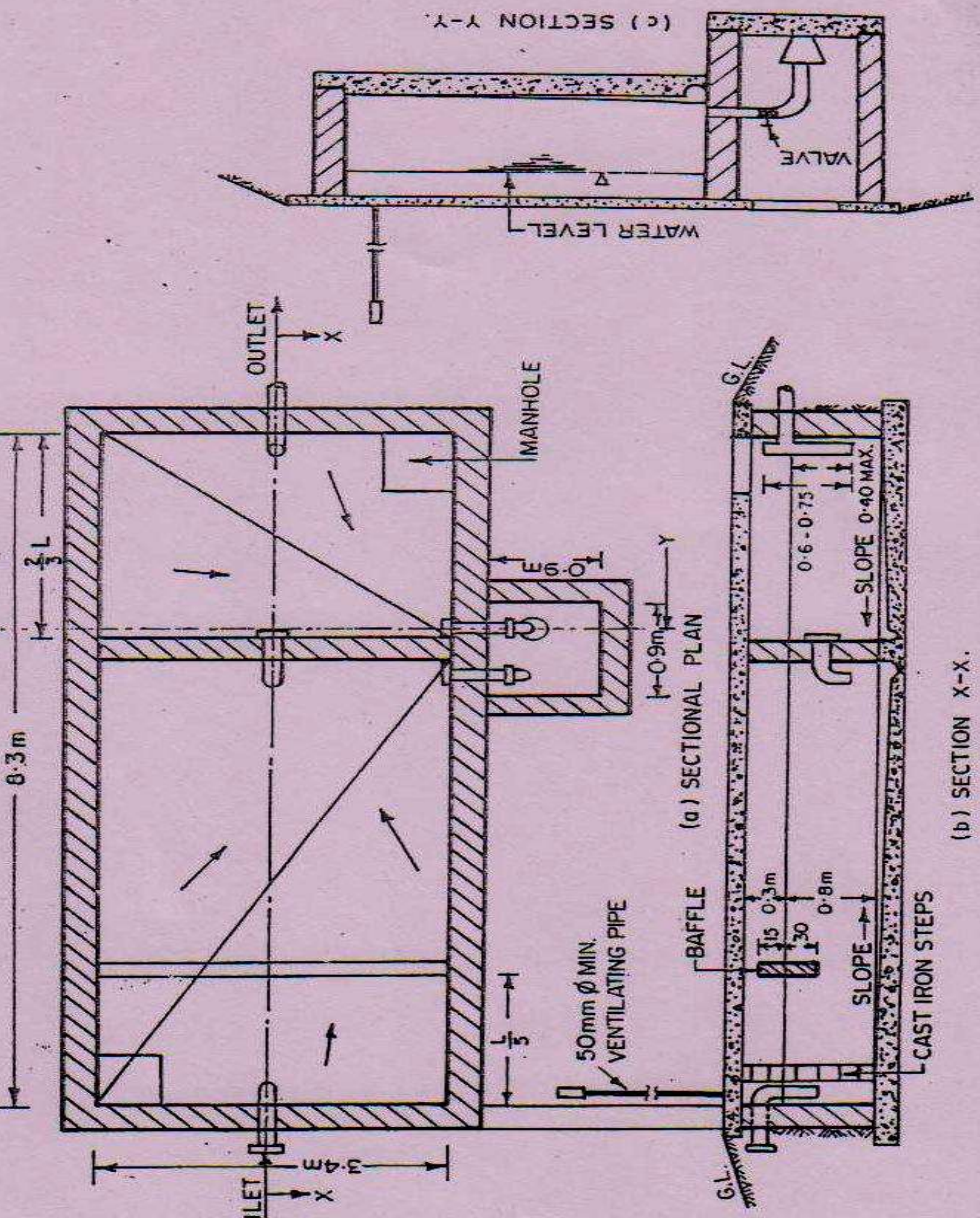
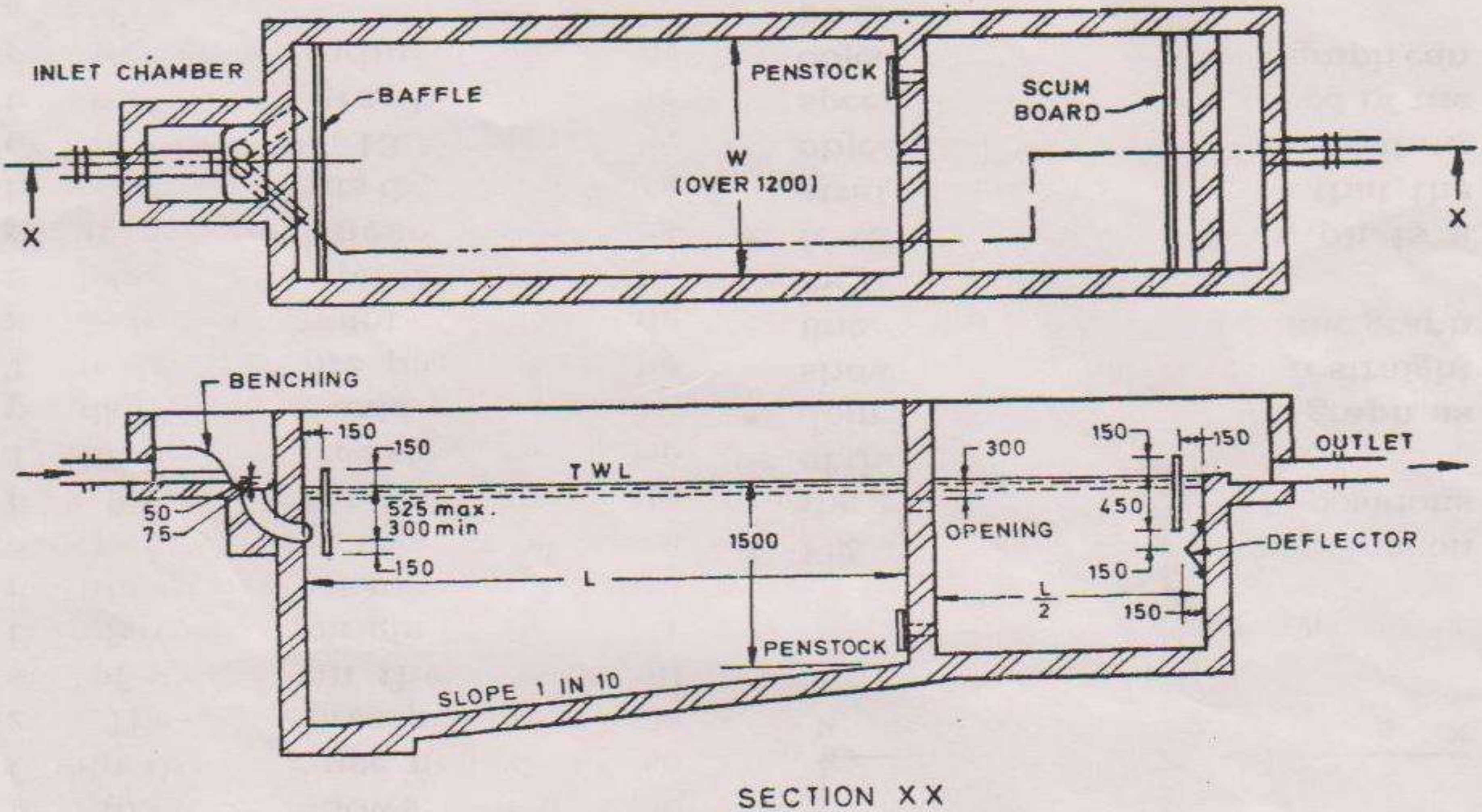


FIG. 17.2. DETAILS OF A SEPTIC TANK



All dimensions in millimetres.

FIG. 4 TYPICAL SKETCH OF TWO COMPARTMENT SEPTIC TANK FOR POPULATIONS OVER 50

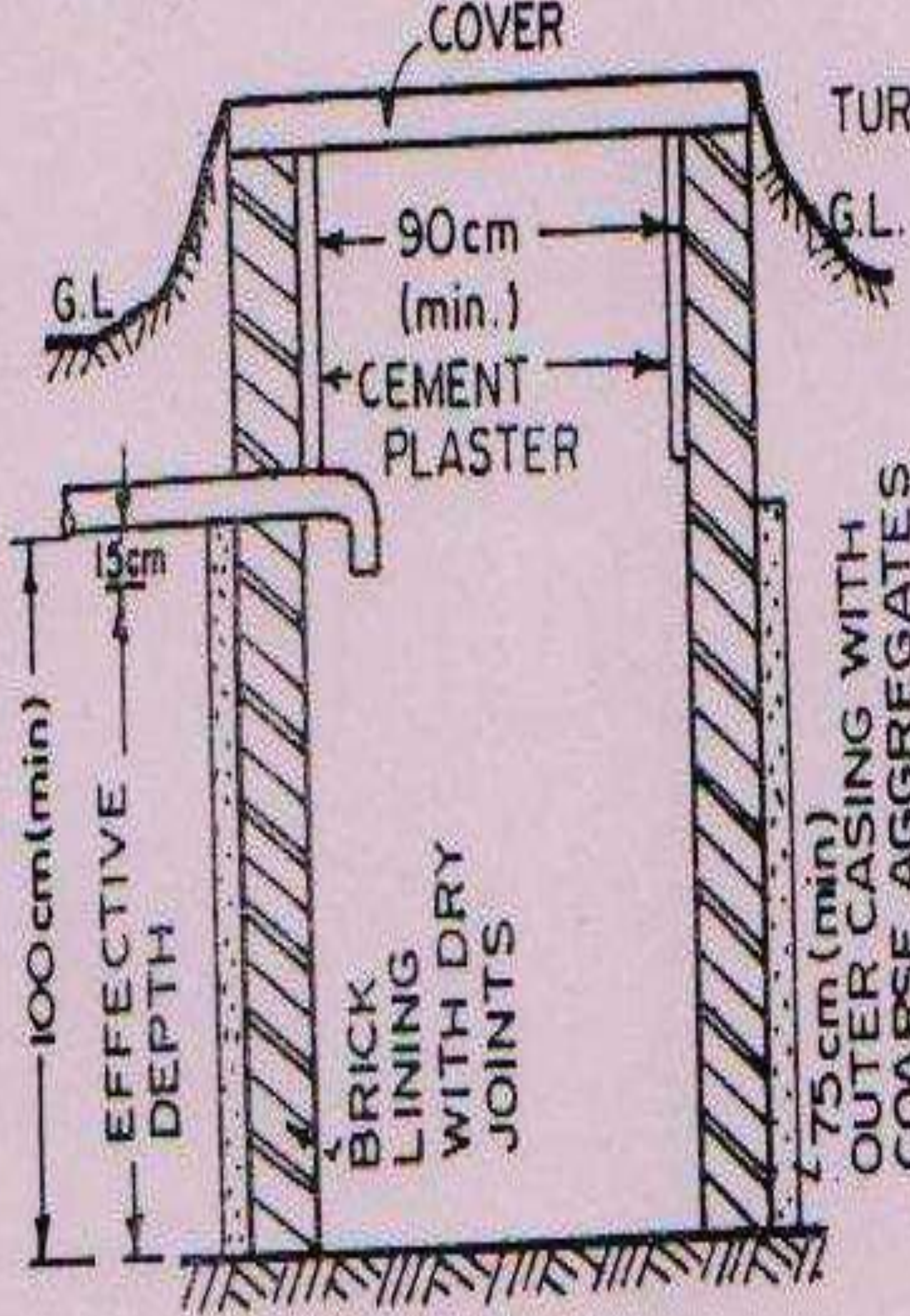
- Digestion - Evolution of gases – gas vent
- Cleaning/ Removing digested sludge – once in a year (6 months to 2 years)
- Thus Two processes-*Sedimentation* and *Anaerobic Sludge digestion*

***Construction details*:**

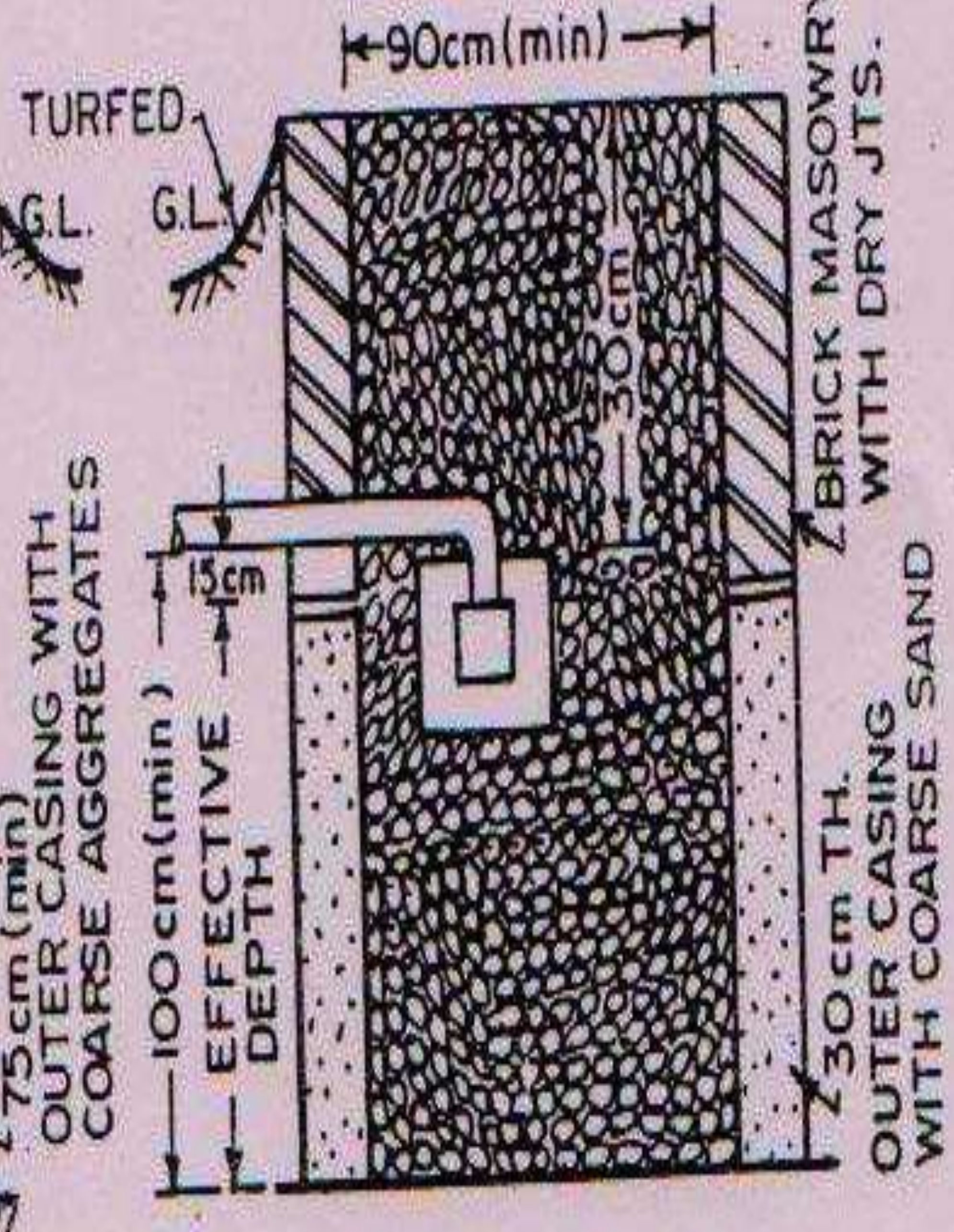
- Long, continuous flow tank of RCC and sides water proof.
- Facility for gas vent through vent pipe.
- Bottom (slope) to facilitate pumping of sludge.
- Manhole with for removal of sludge
- Inlet and outlet, Tee's will be provided
- Sometimes baffles to reduce disturbances.

Septage:

- Effluent from septic tank *disposal*
- Soak pit/ Cess pool
  - A closed circular or rectangular pit through which effluent will be soaked or absorbed into the surrounding soil
  - Two- Filled or Empty type
- Under drain /absorption /dispersion trenches.
  - 3-4 distributions@2m spacing, L shall not be more than30cm



(a) LINED SOAKPIT



(b) UNLINED SOAKPIT

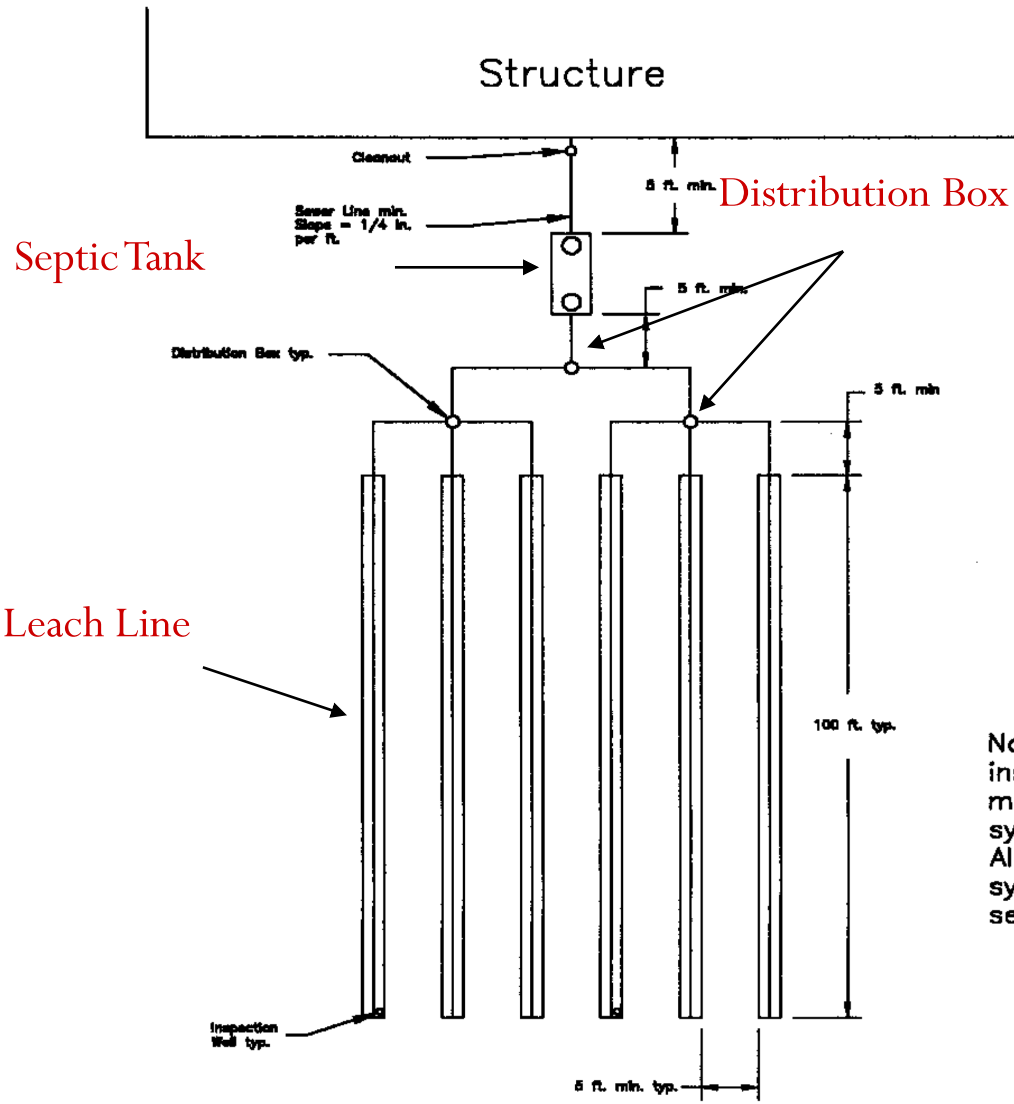
Design criteria(Septic Tank):

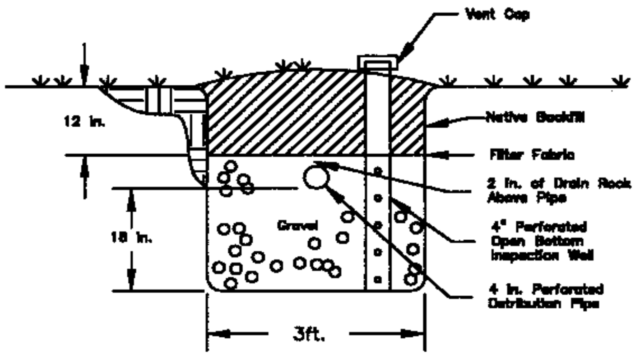
- Quantity of sludge -**30 l/capita/ years** - Sludge storage
- Depth - **1.2 – 1.8 m**
- Length: Breadth - **2-4** times
- Min width - **120cm**
- Outlet ~ in let level difference = 5-7.5 or up to 15 cm
- Detention time = **24 hours**
- Free board**: 30cm**

Design criteria for *absorption system*:

- Calculation of Total subsurface soil area required for soak pits/ dispersion trenches
- **Lq = 130/√t**
  - **t-** standard percolation rate for the soil min/cm
  - **Lq-**Maximum rate of effluent application in Lpd/m^2 of leaching surface
- **Total trench area required = Total flow per day/ Lq**

COMPONENTS OF A SEPTIC SYSTEM





Standard Trench

N.T.S.

Note: The sewage disposal system must be installed so that all minimum setbacks are maintained between individual components of the system and conditions existing on the property. All plans submitted for review must show the system drawn to scale, meeting all minimum setbacks, and installed on contour.

Solano County Stabndard Detail		
Figure 8: Standard Sewage Dispsoal System		
DATE: 5.19.2000	SCALE: NTS	DRAWN BY: JLC

Problem:

- Design a septic tank for the hostels of the Engineering college:
  - Number of Hostels = 3
  - Students / Hostel = 200
  - Water supply = 120 lpcd
  - Assume Detention period 24 hours and
  - Sludge volume = 30l/cap/year

Solution:

Design for one hostel:

- Waste water = 200x120x80/100 = 19.2 m^3
- Let us assume that sludge withdrawal once in a year
- Volume required for sludge storage for one year

  = 200x30

  = 6000*l*= 6m^3
- Capacity of septic tank = 25.2 m^3
- Assuming a depth of 1.8 m , Area = 25.2/1.8=14 m^2

  $3B^2 = 14m^2$,

  $B^2 = 14/3$,

  B = 2.16 say 2.20m
- Length = 6.60m

- Dimension = 6.6x2.2x2.1m (1.8m+0.3m free board)
- 26.16m^3 > 25.2 m^3
- Assuming 1.5m depth, Area = 16.8 m^2
- $3B^2$= 16.8, B= 2.36 say 2.4 m
- Provide 7.2x2.4x1.8m septic tank

Design of absorption system:

Lq = $130/\sqrt{t}$

Say t=20min/cm

Lq = $130\sqrt{20}$ = 29*l*pd/m^2

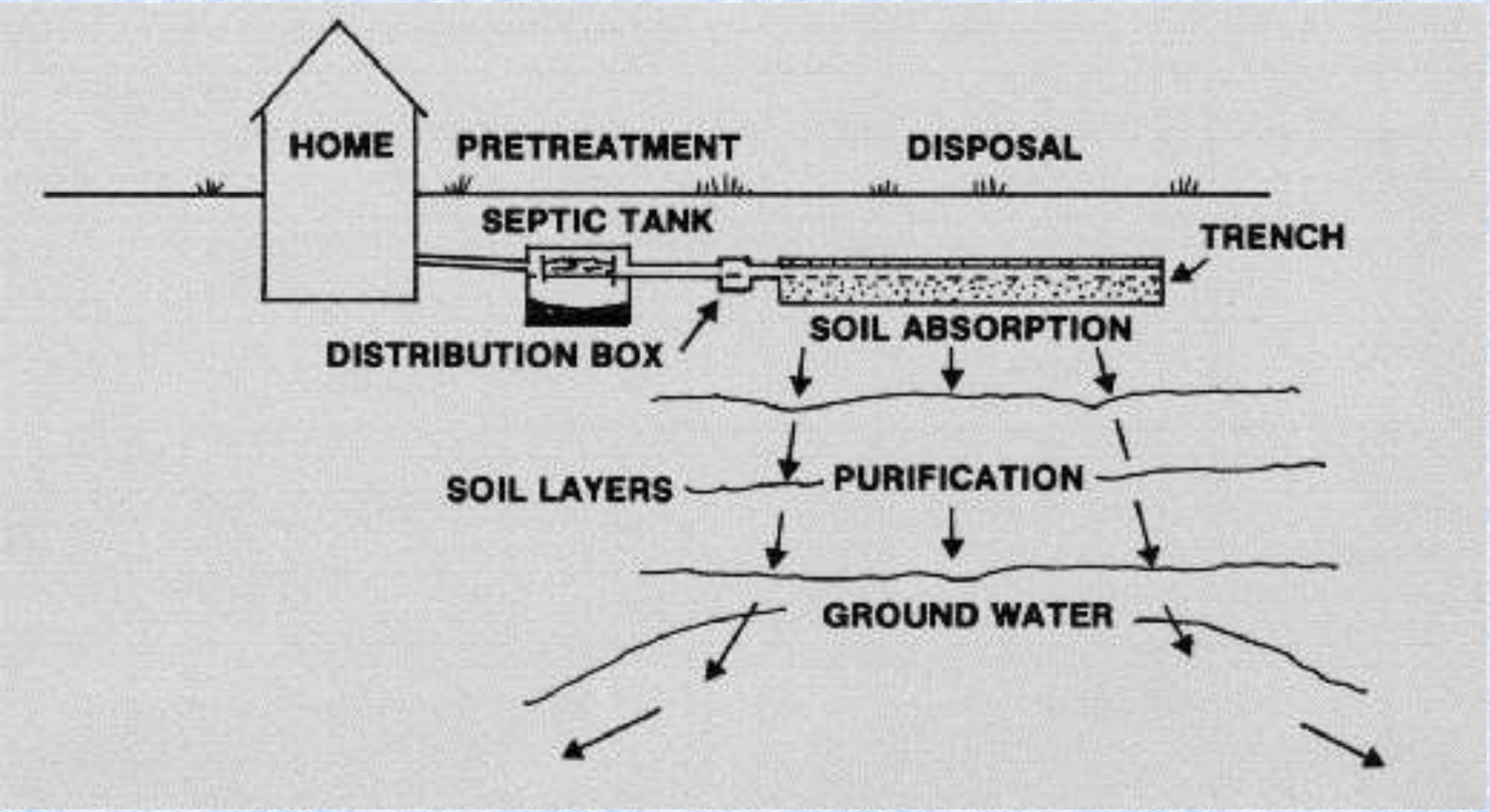
Area required = 200x120x0.8/29 = 662m^2

L = 30m

W=1m

TREAT SEWAGE SO THAT IT IS MADE HARMLESS.

DISPOSE OF SEWAGE (MAKE IT GO AWAY)

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UASB Water Treatment Process

Introduction

The total volume of water on Earth is about 1.4 billion km3. The volume of freshwater resources is around 35 million km3, Of these freshwater resources, about 24 million km3 or 70 percent is in the form of ice and permanent snow cover in the Antarctic and Arctic regions.

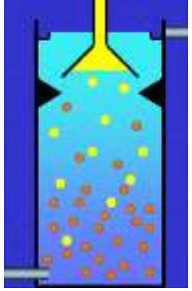
Domestic households, industrial and agricultural practices produce wastewater that can cause pollution of many lakes and rivers.

Industry is a huge source of water pollution, it produces pollutants that are extremely harmful to people and the environment.

Up flow Anaerobic Sludge Blanket digestion

One of the more interesting new processes is the up flow anaerobic sludge blanket process (UASB), which was developed by Lettinga and his co-workers in Holland in the early 1970's

Anaerobic granular sludge bed technology refers to a special kind of reactor concept for the "high rate" anaerobic treatment of wastewater.



- Sewage is greatest source of aquatic pollution & public health concern in urban areas of developing countries.
- *Domestic sewage* is defined as human excreta, urine, and the associated sludge (collectively known as blackwater), as well as, kitchen wastewater and wastewater generated through bathing (collectively known as greywater.

Several technology in the field of wastewater treatment:

***Conventional aerobic treatment in ponds**

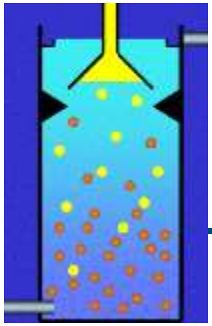
***Trickling Filters ,RBC ,ASP**

***Anaerobic treatment**

***Combination of Anaerobic And Aerobic Treatment**

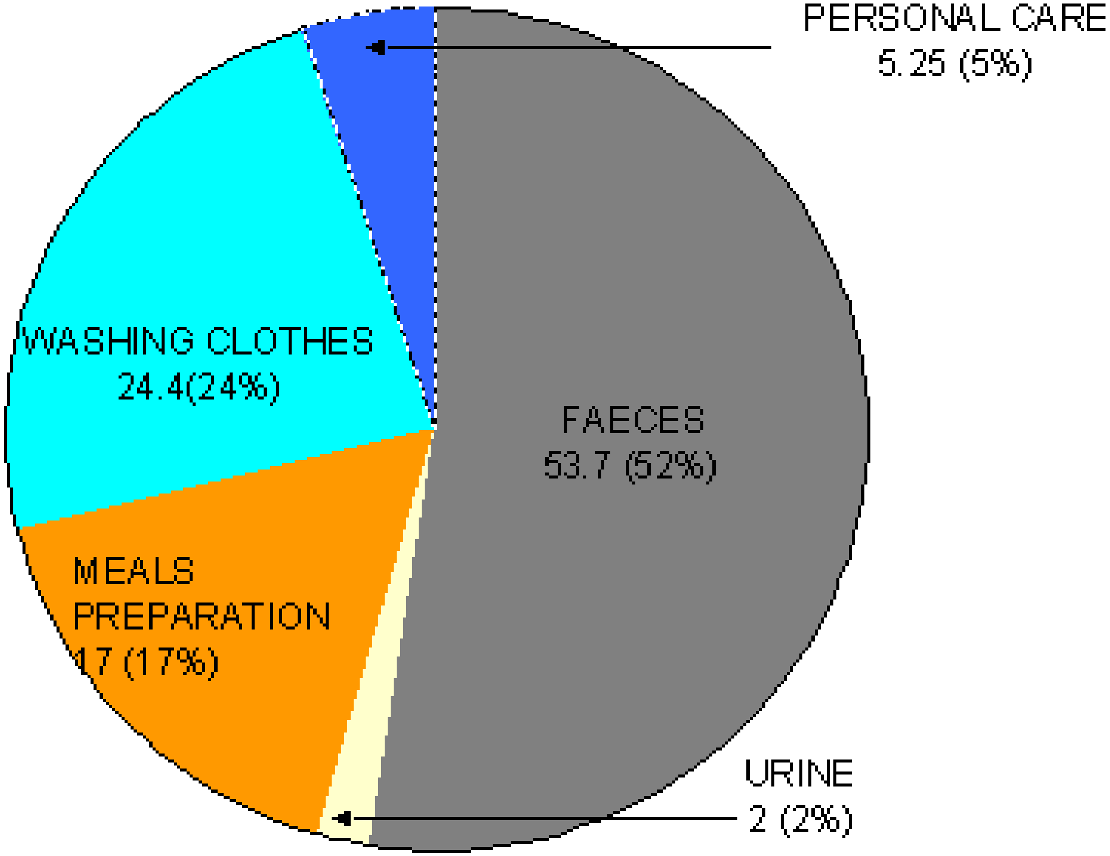
Adequate treatment system have to be :

- **Simple in design**
- **Efficient in removing the pollutants**
- **Energy consumption should be low**
- **Re use of water for use purpose**
- **Use of sophisticated equipment must be kept to a minimum.**

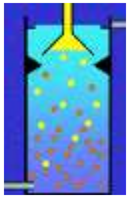


ORGANIC MATTER IN DOMESTIC WASTEWATER

(gCOD/p/d)



Anaerobic Waste Treatment : An Overview

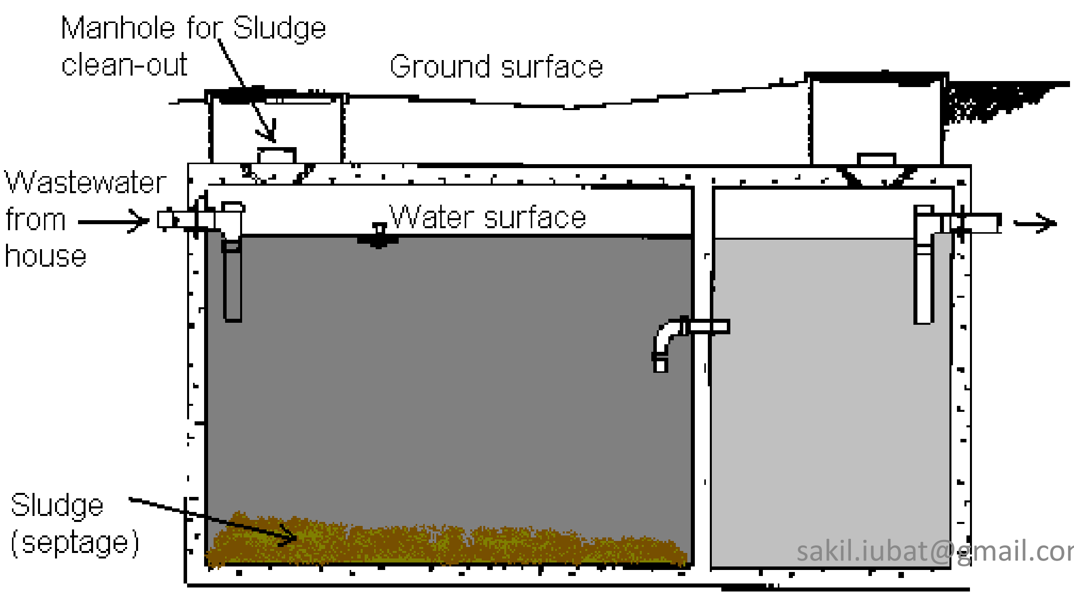


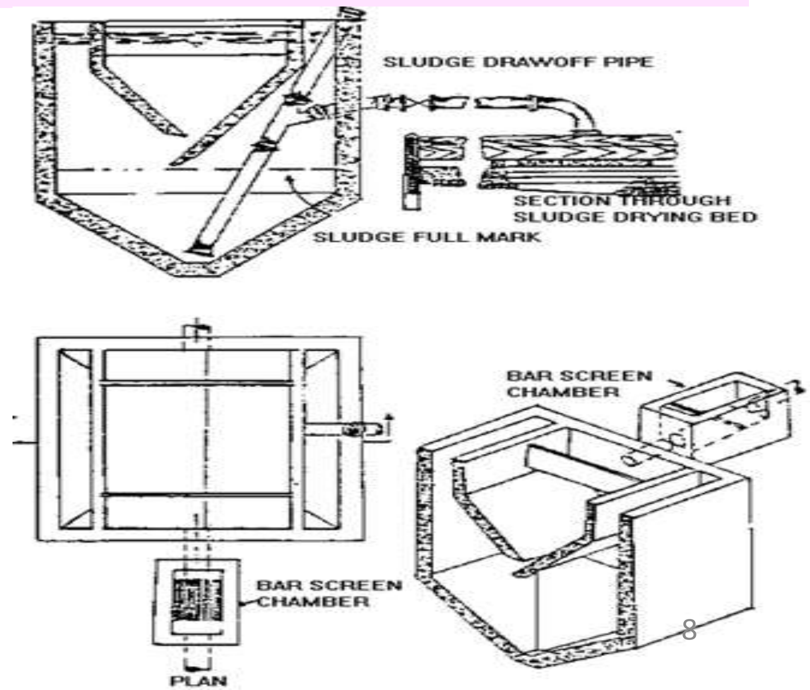
Historical development:

Mainly used for reducing mass of high solids wastes, e.g. human waste (night soil), animal manure, agricultural waste and sludge

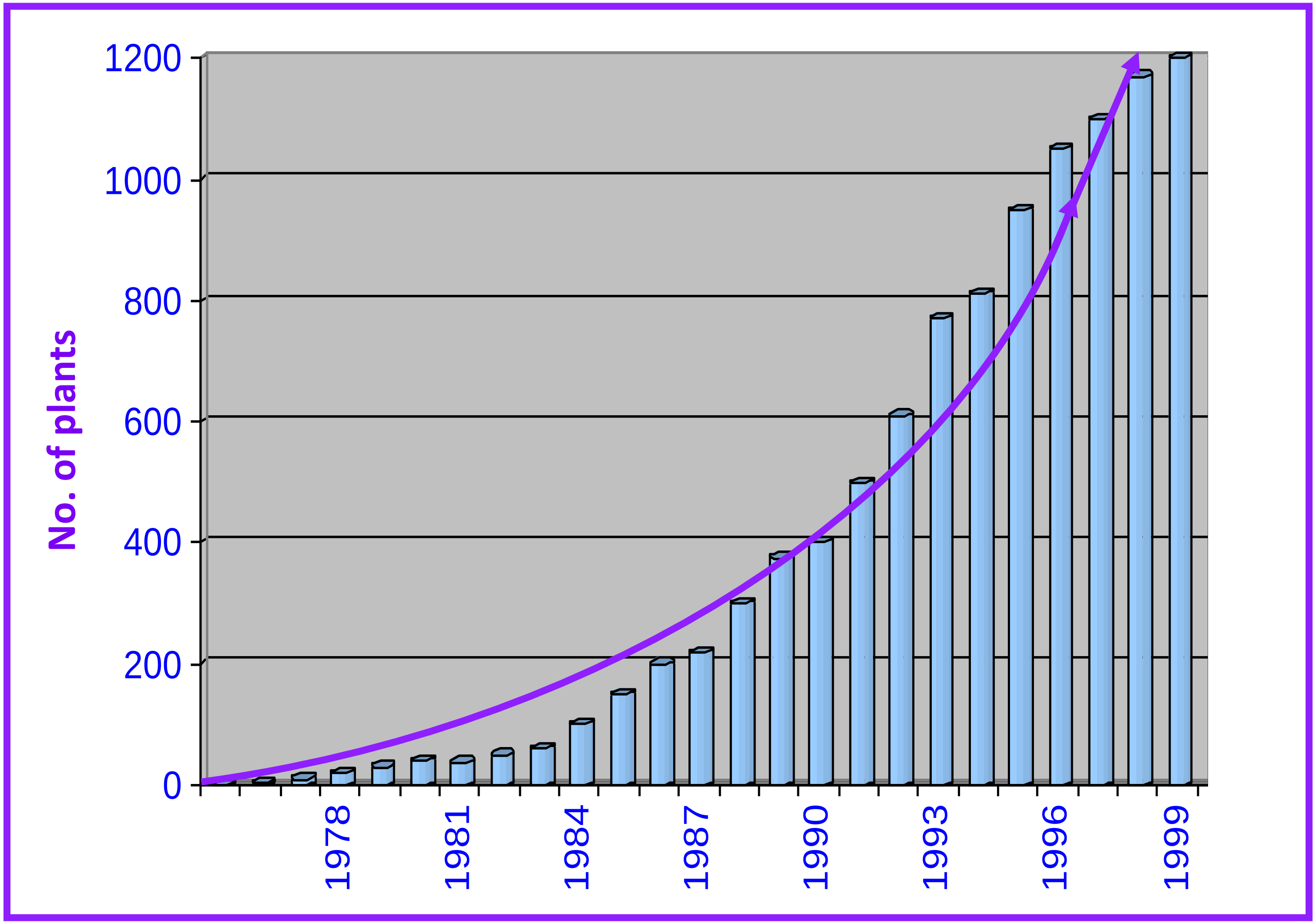
Early applications of anaerobic waste treatment include:

Mouras automatic scavenger - cited in French journal *cosmos* in 1881
Septic tank- developed by Donald Cameron in 1895 (England)
Imhoff tank: developed by Karl Imhoff in 1905 (Germany)



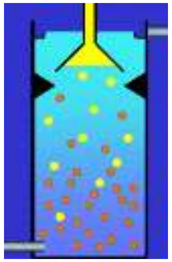


Aerobic treatment process - considerable progress in short span of time. Anaerobic technology: energy crisis in 70 and 80’s- a renewed interest in anaerobic process



sakil.iubat@gmail.com

Anaeroic treatment plants for industrial applications (Source: Frankin, 2001)



Anaerobic Waste Treatment

Definition:

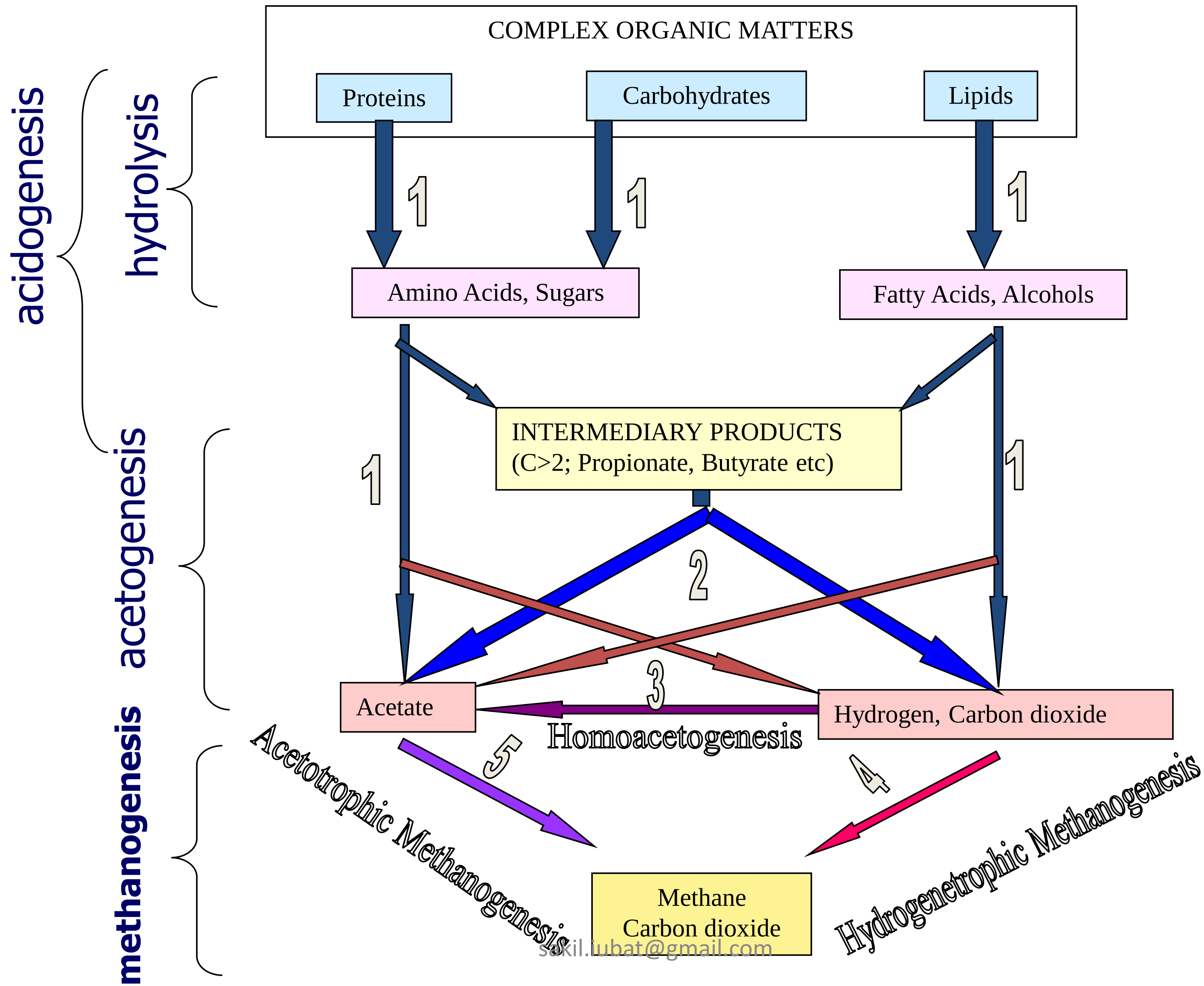
Anaerobic treatment is a biological process carried out in the absence of O_2 for the stabilization of organic materials by conversion to CH_4 and inorganic end-products such as CO_2 and NH_3.

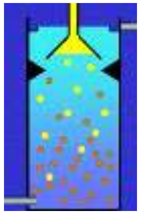
$$\textit{Organic materials} + \textit{Nutrients} \xrightarrow{\textit{Anaerobic microorganisms}} CH_4 + CO_2 + NH_3 + \textit{Biomass}$$

Anaerobic processes

- Anaerobic fermentation
- Anaerobic respiration

Overview Anaerobic Biodegradation

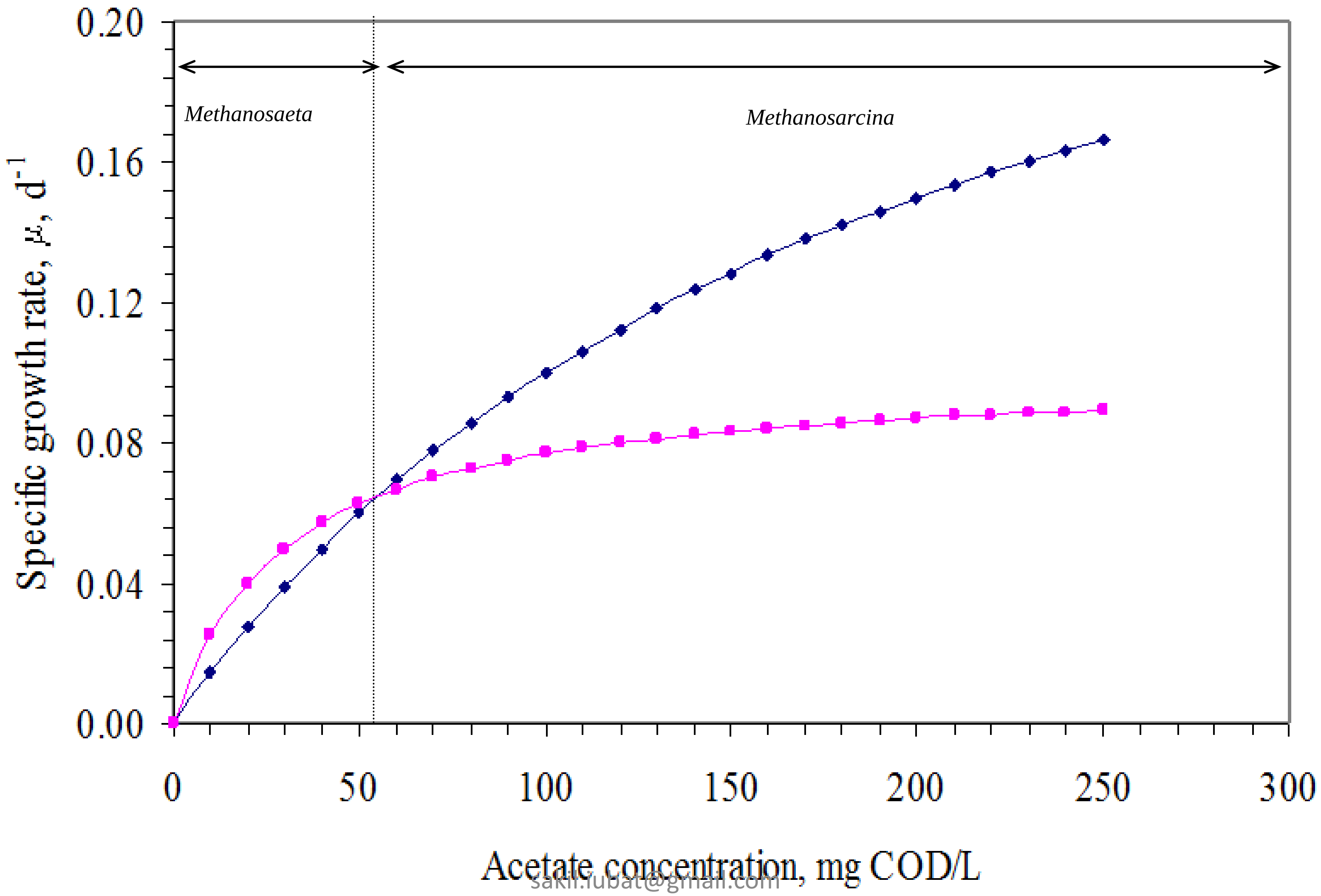




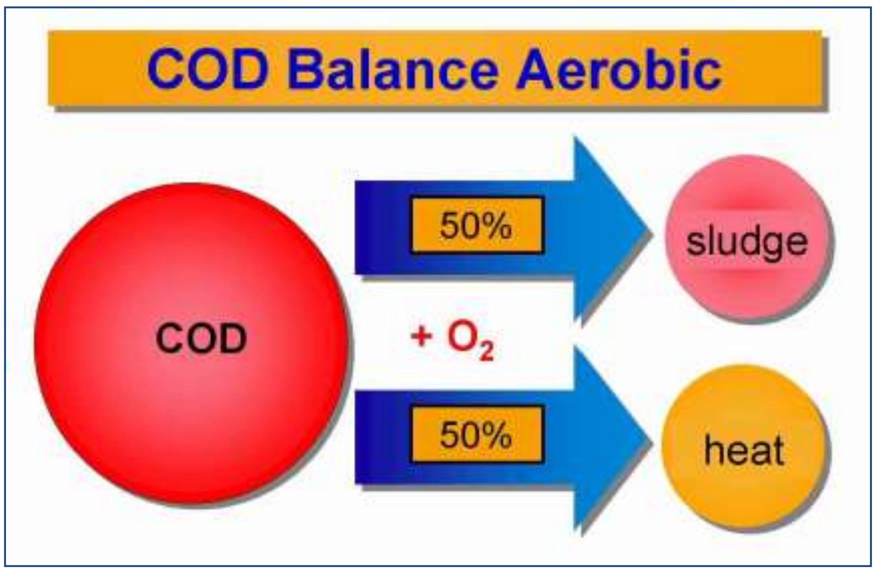
Kinetic Parameters Anaerobes

	Doubling Time days	Cell Yield g VSS g-1 COD	Cell Activity g COD g-1 VSS d-1	ks mM
Active Sludge (sugar)				
Aerobic Bacteria	0.030	0.40	57.8	0.25
Acidification (sugar)				
Fermentative Bacteria	0.125	0.14	39.6	ND
Acetogenesis (fatty acids)				
Acetogenic Bacteria	3.5	0.03	6.6	0.4
Methanogenesis				
Autotrophic (H2)	0.5	0.07	19.6	0.004
Acetoclastic (acetate)				
Methanosarcina	1.5	0.04	11.6	5.0
Methanosaete	7.0	0.02	5.0	0.3

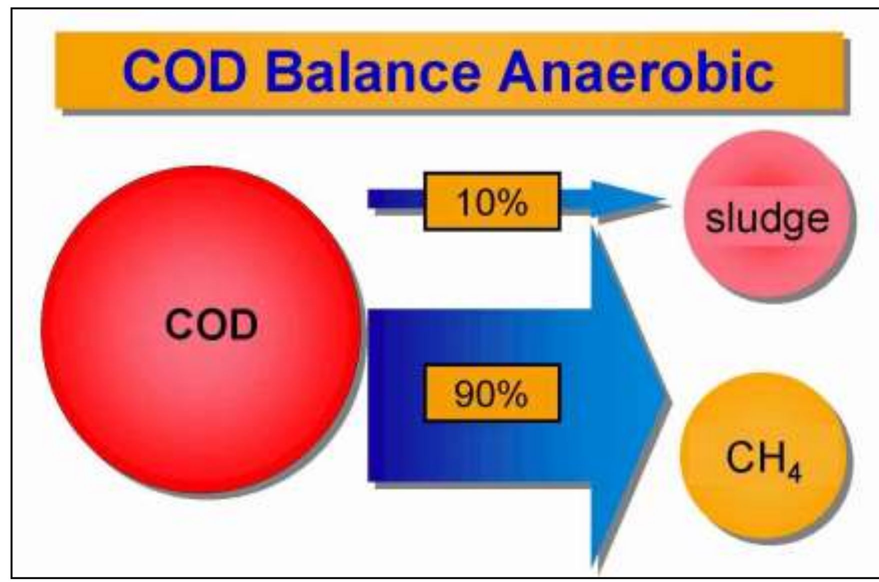
Growth kinetics of *Methanosarcina* and *Methanosaeta*



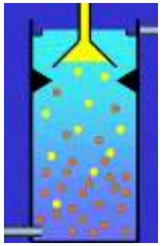
COD Balance Aerobic Biodegradation



COD Balance Anaerobic Biodegradation

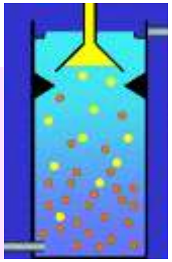


Essential conditions for efficient anaerobic treatment



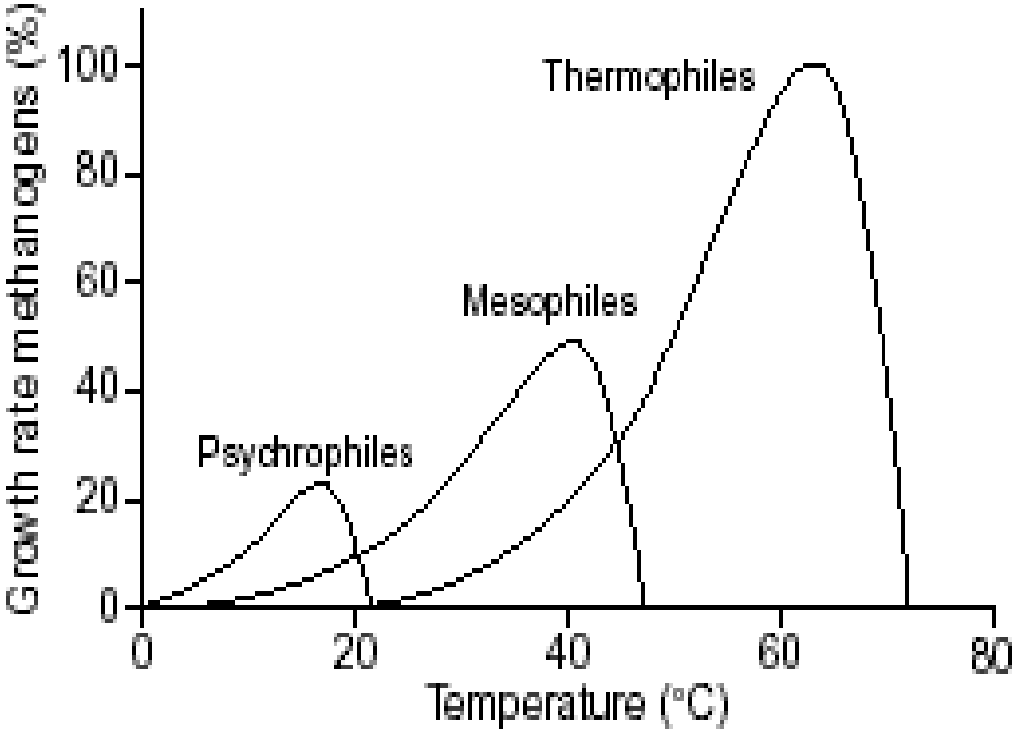
- Avoid excessive air/O_2 exposure
- No toxic/inhibitory compounds present in the influent
- Maintain pH between 6.8 –7.2
- Sufficient alkalinity present
- Temperature around mesophilic range (30-38 ^oC)
- Enough nutrients (N & P) and trace metals especially, Fe, Co, Ni, etc. COD:N:P = 350:7:1 (for highly loaded system) 1000:7:1 (lightly loaded system)

Environmental factors



The successful operation of anaerobic reactor depends on maintaining the environmental factors close to the comfort of the microorganisms involved in the process.

Temperature

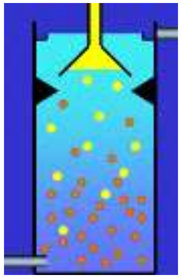


Psychrophilic (5 - 15°C)

Mesophilic (35 – 40 °C)

Thermophilic (50-55 °C)

Rule of thumb: Rate of a reaction doubles for every 10 degree rise in temperature



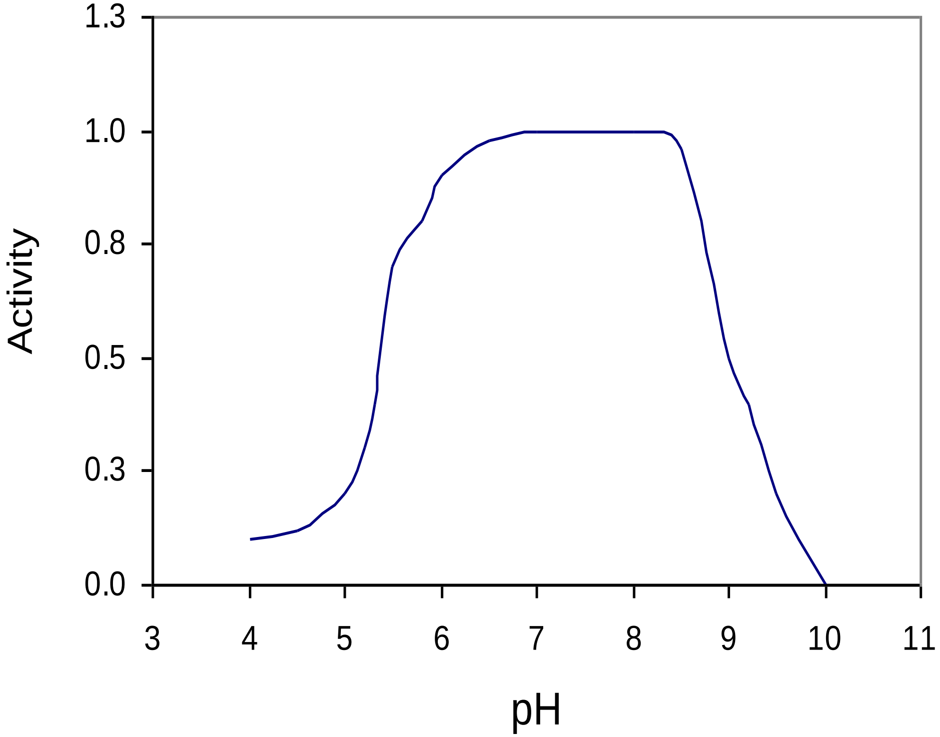
pH

pH range for acidogens is 5.5 – 6.5

Methanogensis 7.8 – 8.2.

operating pH for combined cultures is 6.8-7.4 with neutral pH being the optimum

Relative activity of methanogens to pH



Since methanogenesis is considered as a rate limiting step, It is necessary to maintain the reactor pH close to neutral.

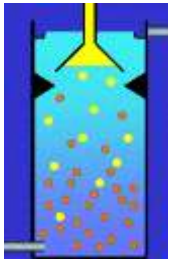
Nutrients and trace metals

All microbial processes including anaerobic process requires macro (N, P and S) and micro (trace metals) nutrients in sufficient concentration to support biomass synthesis. In addition to N and P, anaerobic microorganisms especially methanogens have specific requirements of trace metals such as Ni, Co, Fe, Mo, Se etc. The nutrients and trace metals requirements for anaerobic process are much lower as only 4 - 10% of the COD removed is converted biomass.

COD:N:P = 350:7:1

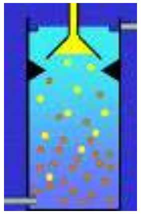
Inhibition/Toxicity

The toxicity is caused by the substance present in the influent waste or byproducts of the metabolic activities. Ammonia, heavy metals, halogenated compounds, cyanide etc. are the examples of the former type whereas ammonia, sulfide, VFAs belong to latter group.



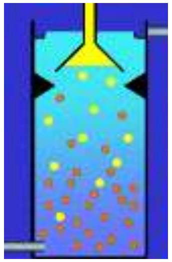
Comparison between anaerobic and aerobic processes

Anaerobic	Aerobic
Organic loading rate:	
High loading rates:10-40 kg COD/m^3-day (for high rate reactors, e.g. AF,UASB, E/FBR)	Low loading rates:0.5-1.5 kg COD/m^3-day (for activated sludge process)
Biomass yield:	
Low biomass yield:0.05-0.15 kg VSS/kg COD	High biomass yield:0.37-0.46 kg VSS/kg COD
(biomass yield is not constant but depends on types of substrates metabolized)	(biomass yield is fairly constant irrespective of types of substrates metabolized)
Specific substrate utilization rate:	
High rate: 0.75-1.5 kg COD/kg VSS-day	Low rate: 0.15-0.75 kg COD/kg VSS-day
Start-up time:	
Long start-up: 1-2 months for mesophilic : 2-3 months for thermophilic	Short start-up: 1-2 weeks



Continue……

Anaerobic	Aerobic
SRT:	
Longer SRT is essential to retain the slow growing methanogens within the reactor.	SRT of 4-10 days is enough in case of activated sludge process.
Microbiology:	
Anaerobic process is multi-step process and diverse group of microorganisms degrade the organic matter in a sequential order.	Aerobic process is mainly a one-species phenomenon.
Environmental factors:	
The process is highly susceptible to changes in environmental conditions.	The process is less susceptible to changes in environmental conditions.



Advantage of anaerobic process

1. Less energy requirement as no aeration is needed

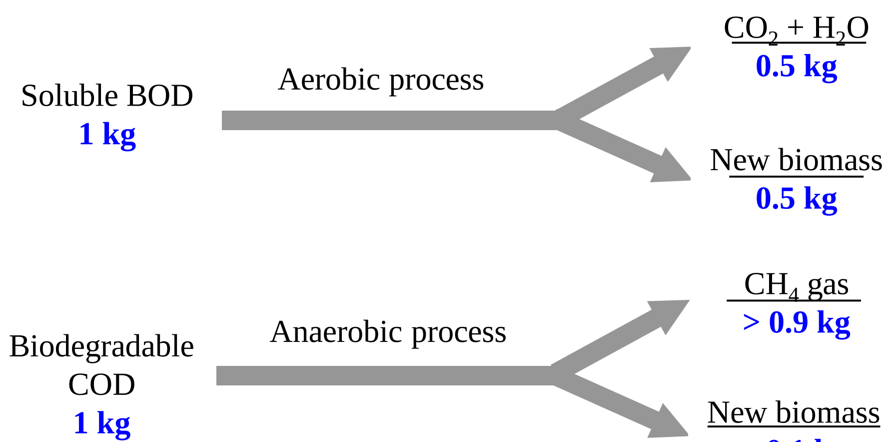
0.5-0.75 kwh energy is needed for every 1 kg of COD removal by aerobic process

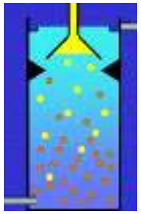
2. Energy generation in the form of methane gas

1.16 kwh energy is produced for every 1 kg of COD removal by anaerobic process

3. Less biomass (sludge) generation

Anaerobic process produces only 20% of sludge that of aerobic process





4. Less nutrients (N & P) requirement

Lower biomass synthesis rate also implies less nutrients requirement : 20% of aerobic

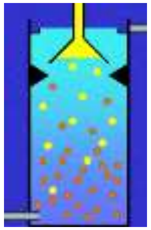
5. Application of higher organic loading rate

Organic loading rates of 5-10 times higher than that of aerobic processes are possible

6. Space saving

Application of higher loading rate requires smaller reactor volume thereby saving the land requirement

7. Ability to transform several hazardous solvents including chloroform, trichloroethylene and trichloroethane to an easily degradable form



Limitations of anaerobic processes

1. Long start-up time

Because of lower biomass synthesis rate, it requires longer start-up time to attain a biomass concentration.

2. Long recovery time

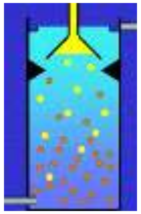
If an anaerobic system subjected to disturbances either due to biomass wash-out, toxic substances or shock loading, it may take longer time for the system to return to normal operating condition.

3. Specific nutrients/trace metal requirements

Anaerobic microorganisms especially methanogens have specific nutrients e.g. Fe, Ni, and Co requirement for optimum growth.

4. More susceptible to changes in environmental conditions

Anaerobic microorganisms especially methanogens are prone to changes in conditions such as temperature, pH, etc.



5. Treatment of sulfate rich wastewater

The presence of sulfate not only reduces the methane yield due to substrate competition but also inhibits the methanogens due to sulfide production.

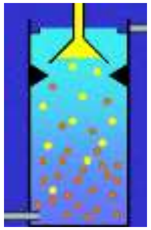
6. Effluent quality of treated wastewater

The minimum substrate concentration (S_{min}) from which microorganisms are able to generate energy for their growth and maintenance is much higher for anaerobic treatment system. Owing to this fact, anaerobic processes may not able to degrade the organic matter to the level meeting the discharge limits for ultimate disposal.

7. Treatment of high protein & nitrogen containing wastewater

The anaerobic degradation of proteins produces amines which are no longer be degraded anaerobically. Similarly nitrogen remains unchanged during anaerobic treatment. Recently, a process called ANAMMOX (ANaerobic AMMonium OXididation) has been developed to anaerobically oxidize NH_4^+ to N_2 in presence of nitrite.

$$NH_4^+ + NO_2^- \longrightarrow N_2 + 2H_2O$$



Types of anaerobic reactors

Low rate anaerobic reactors

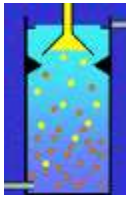
- **Anaerobic pond**
- **Septic tank**
- **Imhoff tank**
- **Standard rate anaerobic digester**

Slurry type bioreactor, temperature, mixing, SRT or other environmental conditions are not regulated. Loading of 1-2 kg COD/m3-day.

High rate anaerobic reactors

- **Anaerobic contact process**
- **Anaerobic filter (AF)**
- **Upflow anaerobic slugde Blanket (UASB)**
- **Fluidized bed Reactor**
- **Hybrid reactor: UASB/AF**
- **Anaerobic Sequencing Batch Reactor (ASBR)**

Able to retain very high concentration of active biomass in the reactor. Thus extremely high SRT could be maintained irrespective of HRT. Load 5-20 kg COD/m^3-d COD removal efficiency : 80-90%

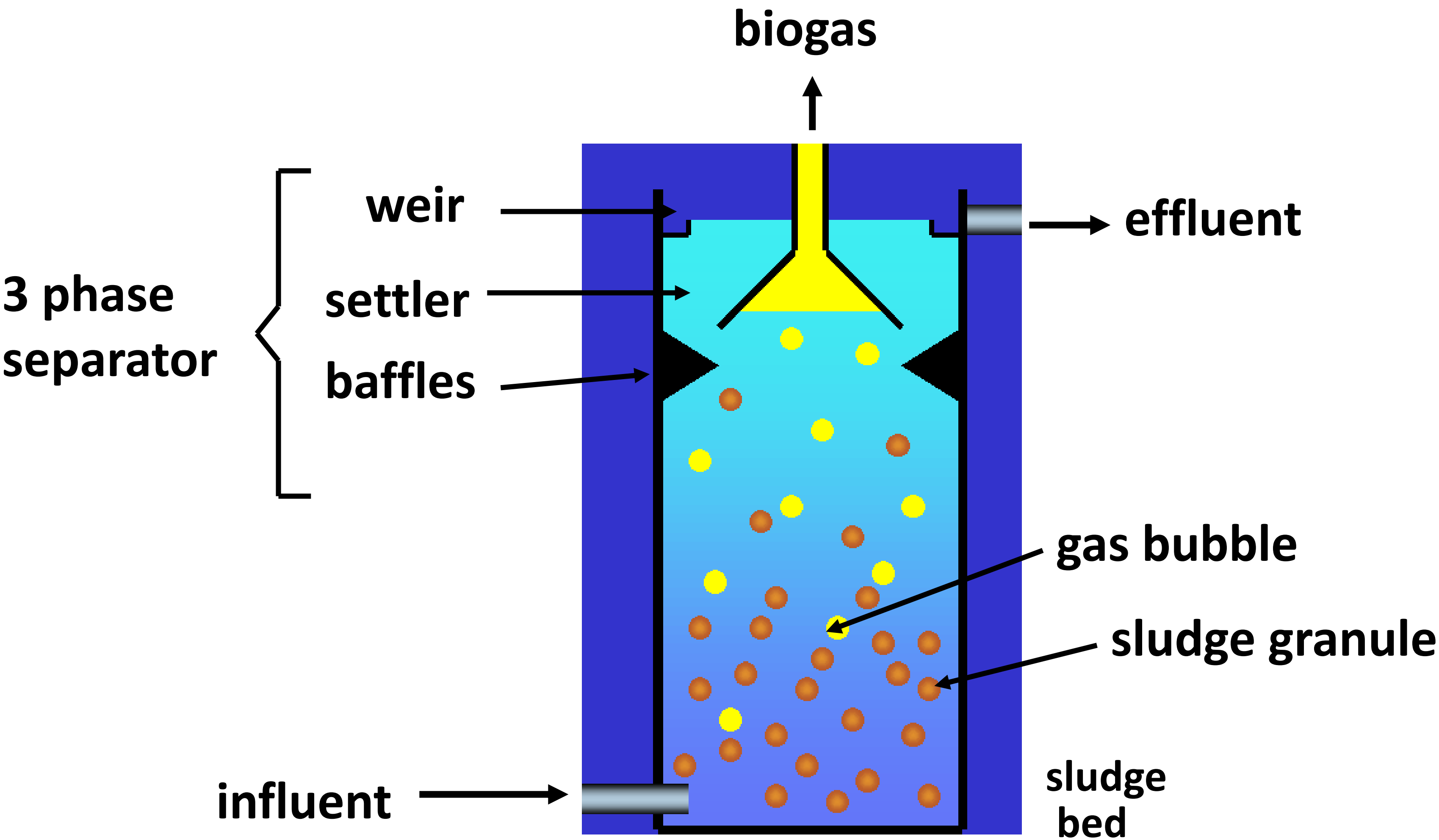


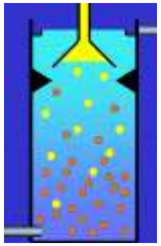
Upflow Anaerobic Sludge Blanket (UASB)

UASB was developed in 1970s by Lettinga in the Netherlands.
UASB is essentially a suspended growth system in which proper hydraulic and organic loading rate is maintained in order to facilitate the dense biomass aggregation known as granulation. The size of granules is about 1-3 mm diameter. Since granules are bigger in size and heavier, they will settle down and retain within the reactor. The concentration of biomass in the reactor may become as high as 50 g/L. Thus a very high SRT can be achieved even at very low HRT of 4 hours.

The granules consist of hydrolytic bacteria, acidogen/acetogens and methanogens. Carbohydrate degrading granules show layered structure with a surface layer of hydrolytic/fermentative Acidogens. A mid-layer comprising of syntrophic colonies and an interior with acetogenic methanogens.

Upward-flow Anaerobic Sludge Blanket





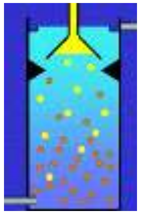
Anaerobic Sludge Granules

Physical:

- dense compact biofilms
- high settleability
- high mechanical strength

Microbial:

- balanced microbial community
- syntrophic partners closely associated
- high methanogenic activity (0.5 to 2.0 g COD/g VSS.d)
- protection from toxic shock



The spaghetti theory of granulation

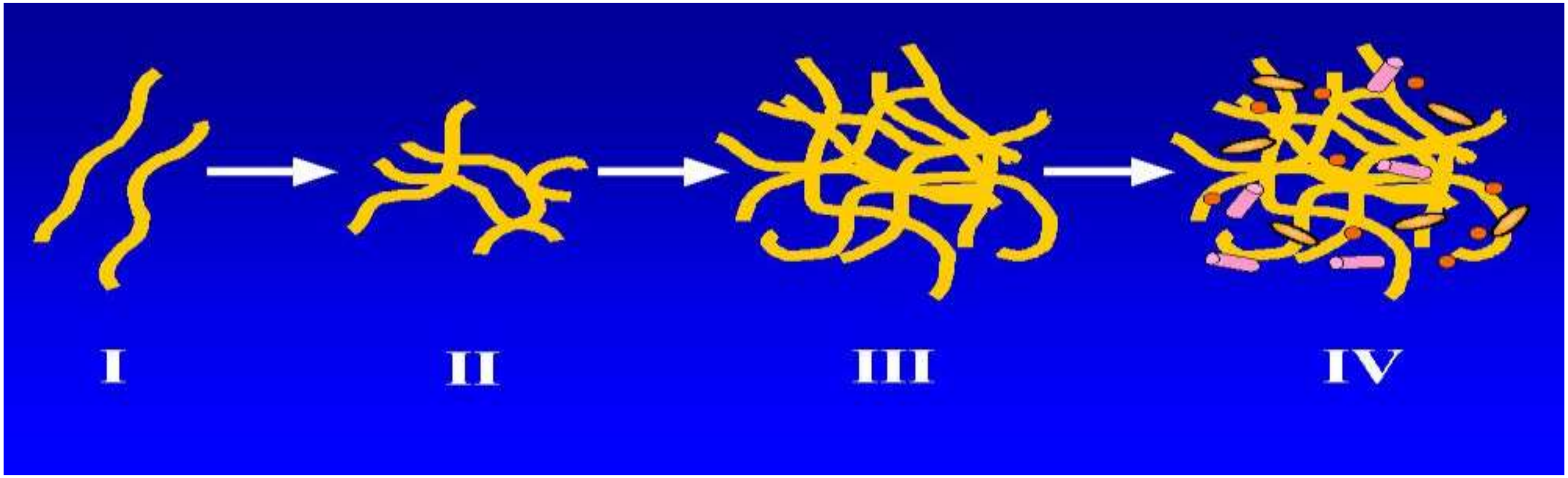
proposed by Dr. W. Wiegant

I) disperse methanogens (filamentous *Methanosaeta*

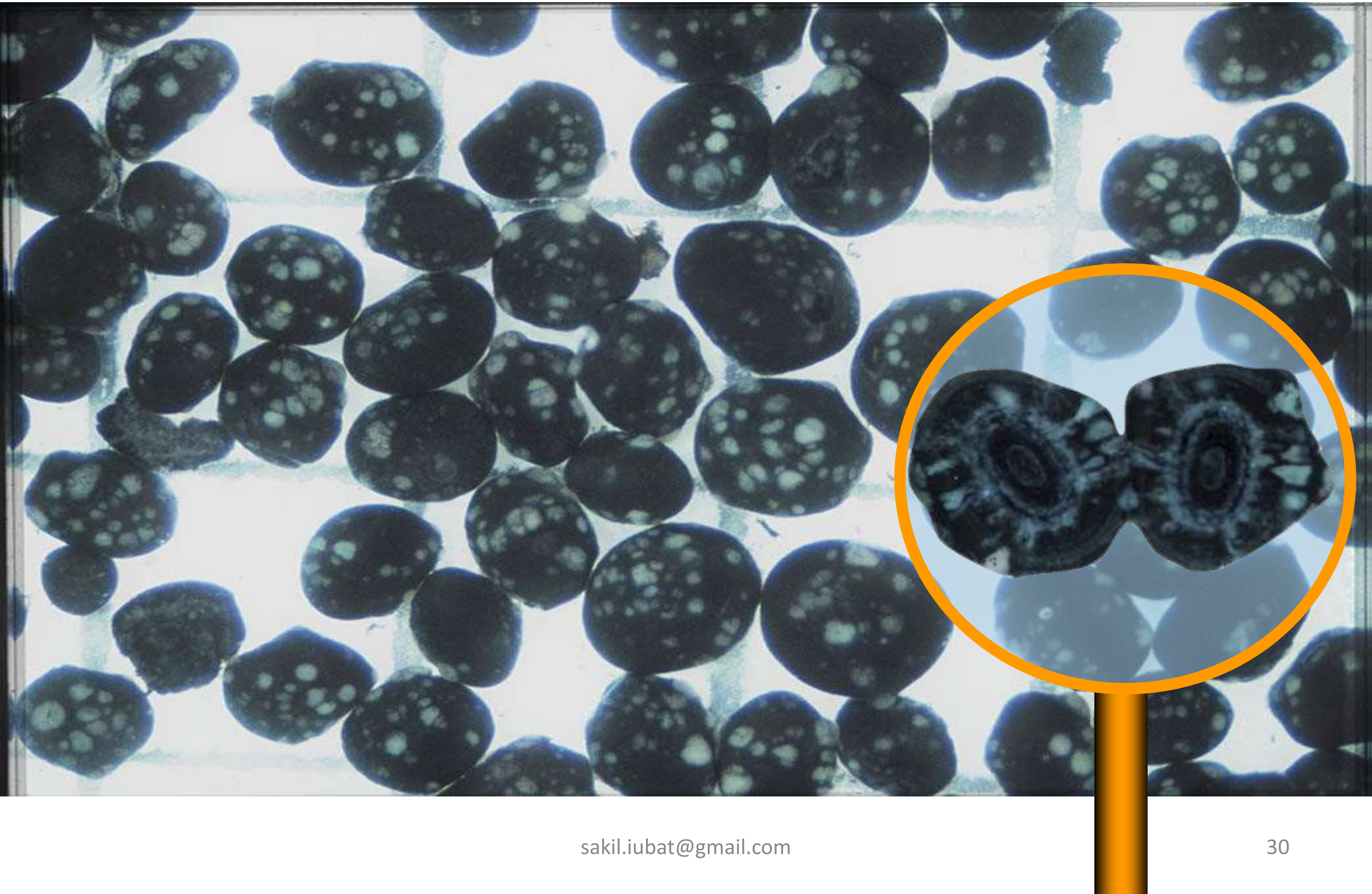
II) floccule formation via entanglement

III) pellet formation ("spaghetti balls");

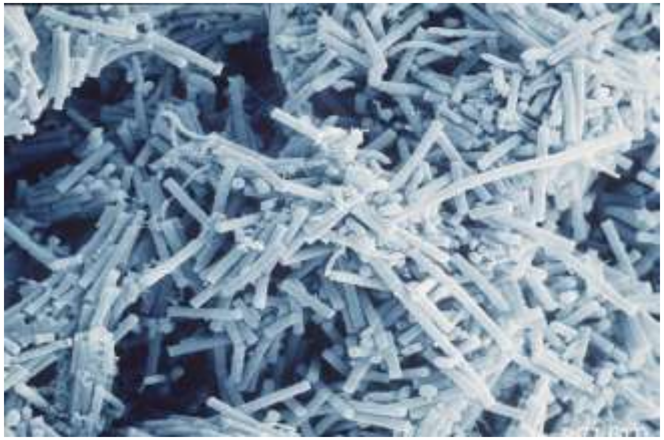
IV) mature granules,
with attachment of other anaerobic microorganisms onto the pellet.



Anaerobic Sludge Granules (close up)



Anaerobic Sludge Granules (SEM)

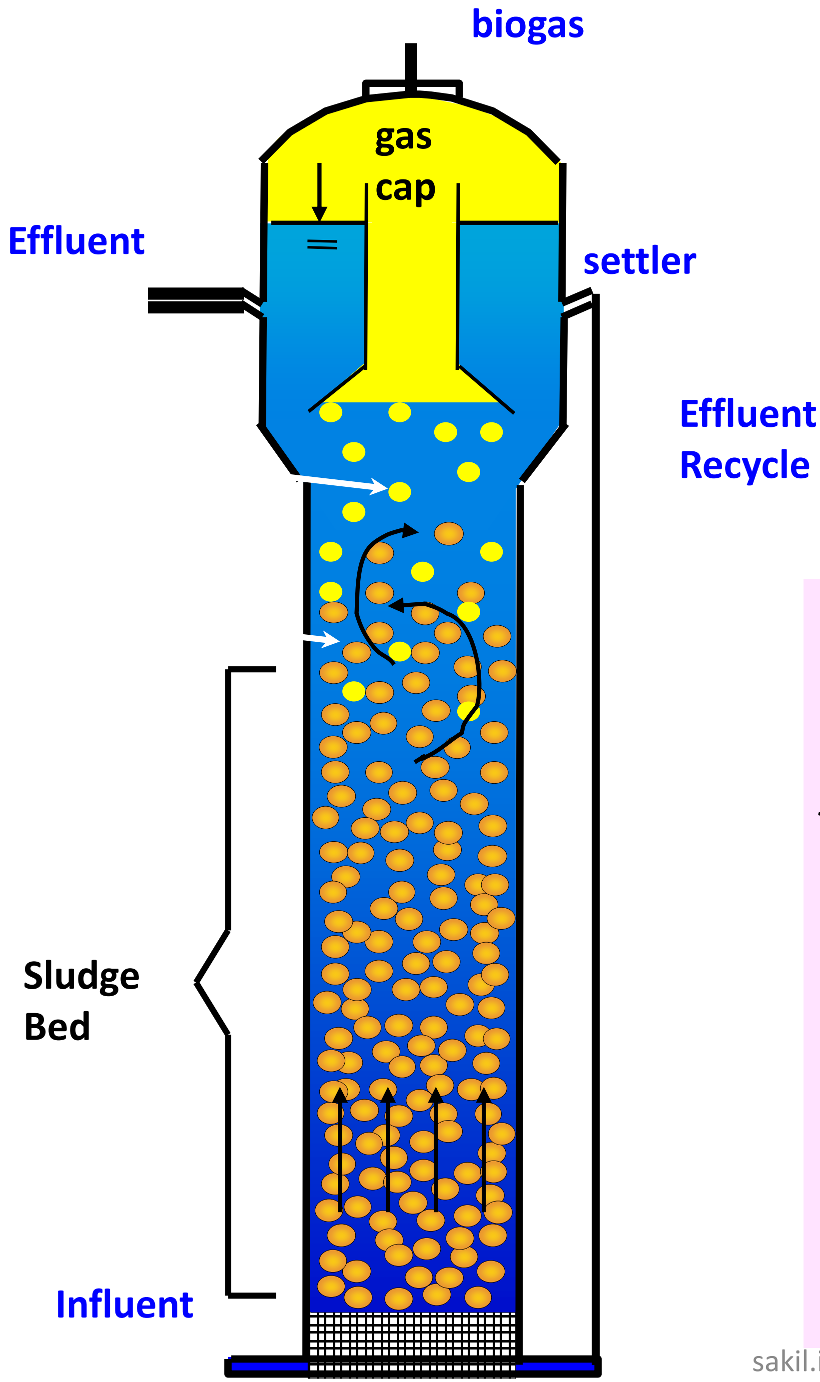


Acetate as Substrate (*Methanosaeta*)

Sucrose as Substrate (mixed culture)

Anaerobic Sludge Granules (settling)

granular flocculent dispersed

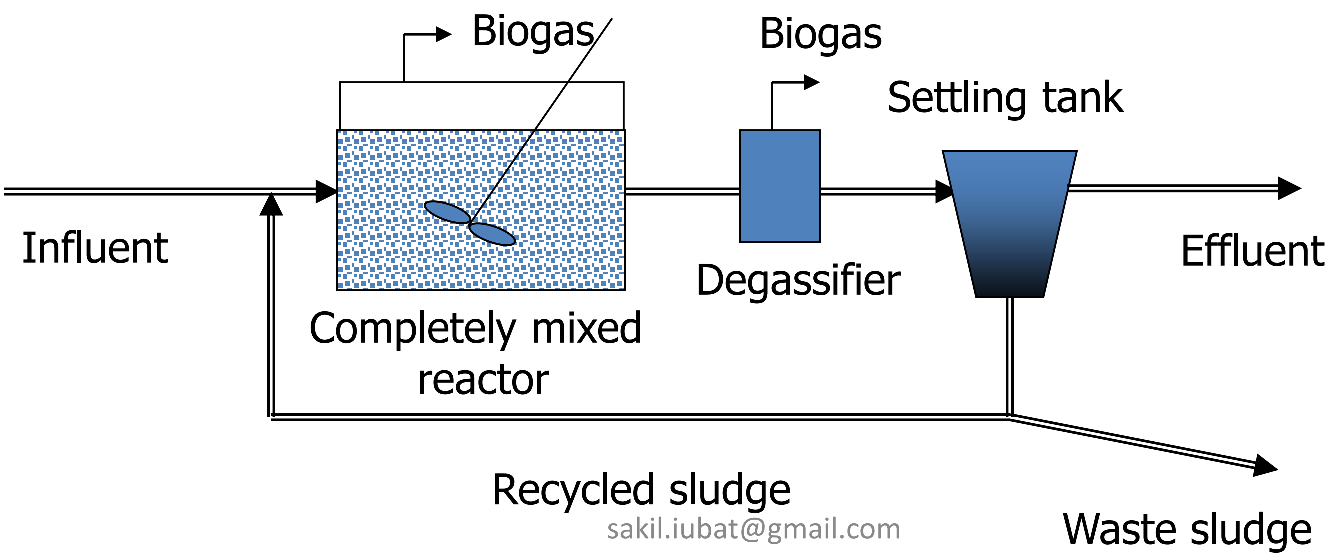


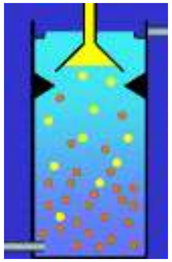
Expanded Granular Sludge Bed

An expanded granular sludge bed (EGSB) reactor is a variant of the UASB concept (Kato et al. 1994). The distinguishing feature is that a faster rate of upward-flow velocity is designed for the wastewater passing through the sludge bed. The increased flux permits partial expansion (fluidization) of the granular sludge bed, improving wastewater-sludge contact as well as enhancing segregation of small inactive suspended particle from the sludge bed. The increased flow velocity is either accomplished by utilizing tall reactors, or by incorporating an effluent recycle

Anaerobic contact process (ACP)

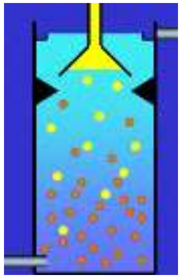
Anaerobic contact process is essentially an anaerobic activated sludge process. It consists of a completely mixed reactor followed by a settling tank. The settled biomass is recycled back to the reactor. Hence ACP is able to maintain high concentration of biomass in the reactor and thus high SRT irrespective of HRT. Degassifier allows the removal of biogas bubbles (CO_2, CH_4) attached to sludge which may otherwise float to the surface.



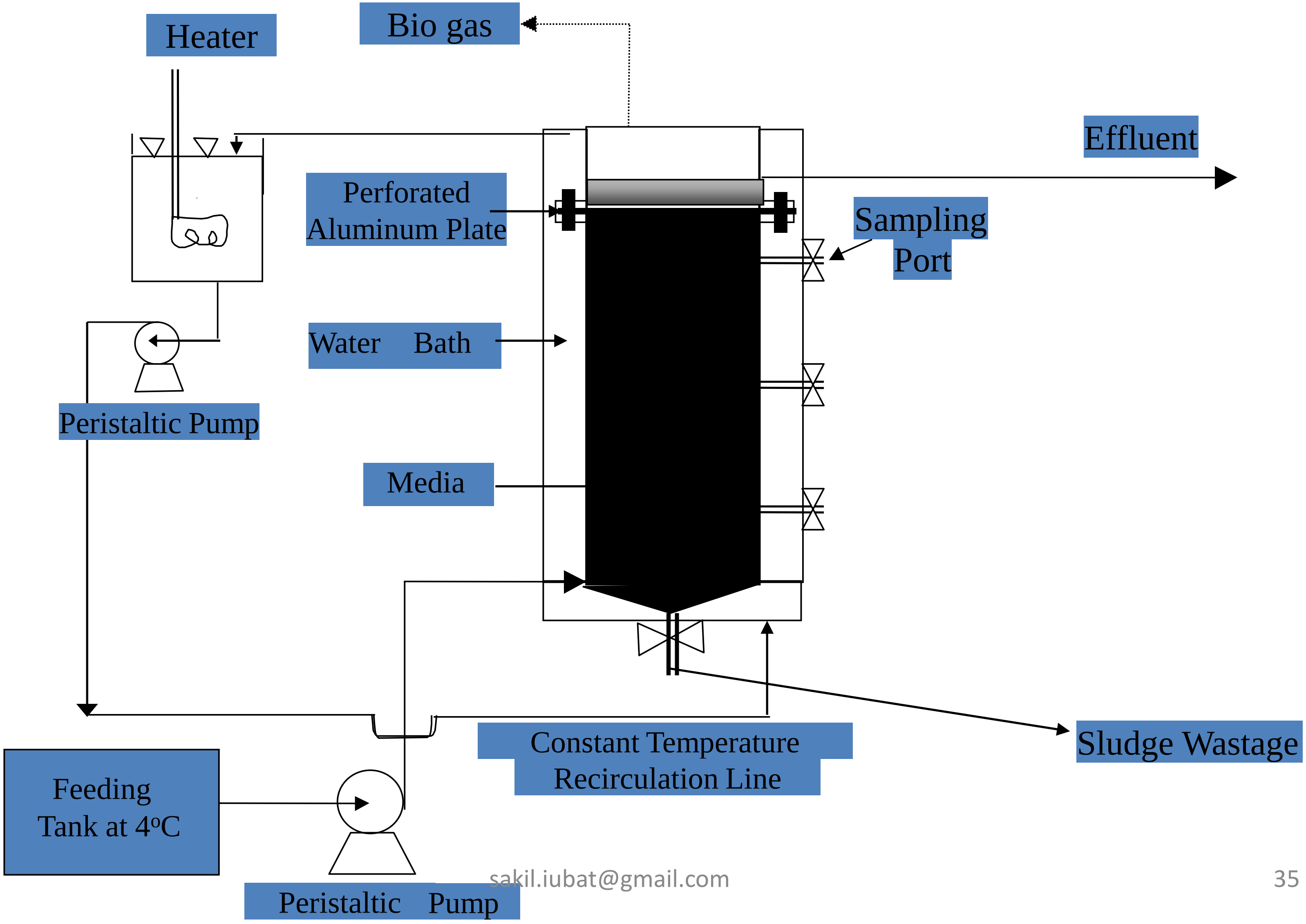


Anaerobic filter

- **Anaerobic filter:** Young and McCarty in the late 1960s for treat dilute soluble organic wastes.
- The filter was filled with rocks similar to the trickling filter.
- Wastewater distributed across the bottom and the flow was in the upward direction through the bed of rocks
- Whole filter submerged completely
- Anaerobic microorganisms accumulate within voids of media (rocks or other plastic media)
- The media retain or hold the active biomass within the filter
- The non-attached biomass within the interstices forms a bigger flocs of granular shape due to rising gas bubble/liquid
- Non-attached biomass contributes significantly to waste treatment
- Attached biomass not be a major portion of total biomass.
- 64% attached and 36% non-attached



Upflow Anaerobic Filter



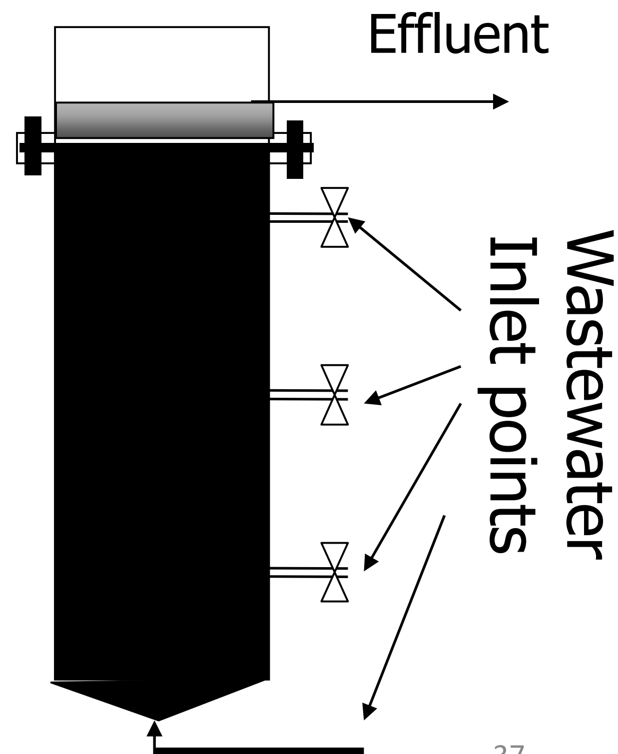
Originally, rocks were employed as packing medium in anaerobic filter. But due to very low void volume (40-50%), serious clogging problem was witnessed. Now, many synthetic packing media made up of plastics, ceramic tiles of different configuration have been used in anaerobic filters. The void volume in these media ranges from 85-95 %. Moreover, these media provide high specific surface area typically 100 m^2/m^3 or above which enhance biofilm growth.

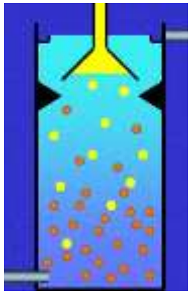
Since anaerobic filter is able to retain high biomass, long SRT could be maintained. Typically HRT varies from 0.5 – 4 days and the loading rates varies from 5 - 15 kg COD/m^3-day. Biomass wastage is generally not needed and hydrodynamic conditions play important role in biomass retention within the void space

Multi-fed Up Flow Anaerobic Filter (MUAF)

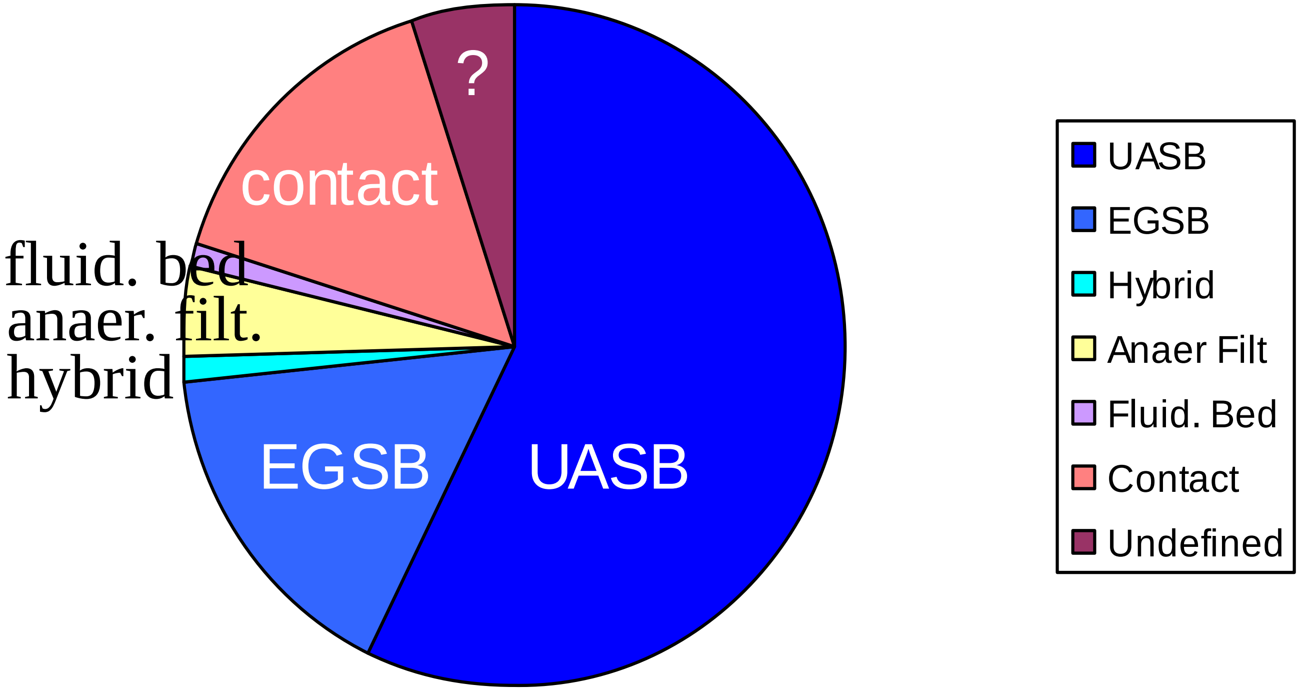
Waste is fed through several points along the depth of filter. Such feeding strategy has unique benefits:

1. Homogeneity in biomass distribution
2. Maintenance of completely mixed regime thus preventing short - circuiting and accumulation of VFA.
3. Uniform substrate concentration within the reactor and prevent heavy biomass growth at bottom thus avoids clogging
4. Effective utilization of whole filter bed

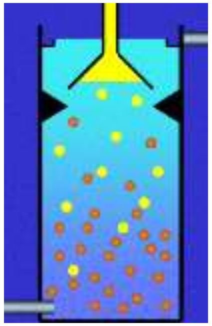




Market-Share Granular Sludge Reactors



EGSB+UASB = 72%



OPTIONS FOR POST-TREATMENT OF ANAEROBIC REACTOR EFFLUENTS

Beginning with a typical municipal raw wastewater, this level of treatment will generally result in an "enhanced primary" effluent quality, intermediate between primary and secondary (between 30-70 mg/l for BOD5). Post-treatment should be designed to improve the effluent quality in the following parameters.

pathogen contamination (measured by the index of E. coli);
**residual organic material (COD/BOD5);*
**oxygen demand from the reduced forms of N and S;*
**residual suspended solids (TSS)*
**inorganic N and P (nutrients)*

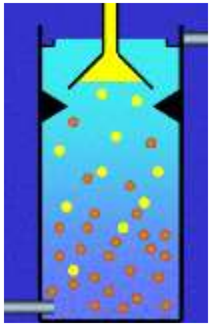
basic types of post treatment processes are:

Pond systems

Constructed wetlands

duckweed

Mechanical aerated post treatment



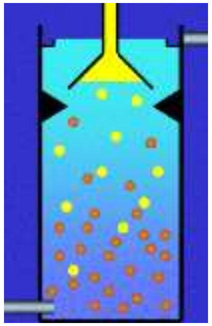
Indian Scenario

The government of India has made a major commitment to anaerobic treatment technology in its national river basin improvement program. As of 1996, thirteen new anaerobic treatment plants, with an aggregate treatment capacity of over 306 MLD are under construction in India. The treatment plants described below have been in operation long enough to be able to evaluate their treatment effectiveness and their financial and economic costs and benefits:

A 5 MLD plant in Kanpur, in the state of Uttar Pradesh, built in the late 1989,

A 14 MLD plant in Mirzapur, Uttar Pradesh, based on the Kanpur pilot plant design, was commissioned in 1991,

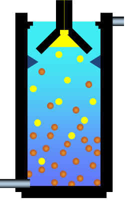
A 36 MLD plant in Kanpur reached full performance in 1994, treating a mixture of up to 75 percent municipal wastewater and 25 percent tannery effluent.



Concluding remarks

The UASB-process represents one important option for sewage purification in countries with warm climates as it meets the above mentioned basic necessities for a sustainable operation of wastewater treatment plants in developing countries like

- Low investment costs,
- Low maintenance demand,
- Good performance,
- Low sludge production
- Net energy production.



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Thanks

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