Liquid waste treatment

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Waste water

- Wastewater is water that has been used and must be treated before it is released into another body of water, so that it does not cause further pollution of water sources.
- Wastewater comes from a variety of sources. Everything that you flush down your toilet or rinse down the drain is wastewater.
- Rainwater and runoff, along with various pollutants, go down street gutters and eventually end up at a wastewater treatment facility.
- Wastewater can also come from agricultural and industrial sources.
- Some wastewaters are more difficult to treat than others; for example, industrial wastewater can be difficult to treat, whereas domestic wastewater is relatively easy to treat.

Biological oxidation demand

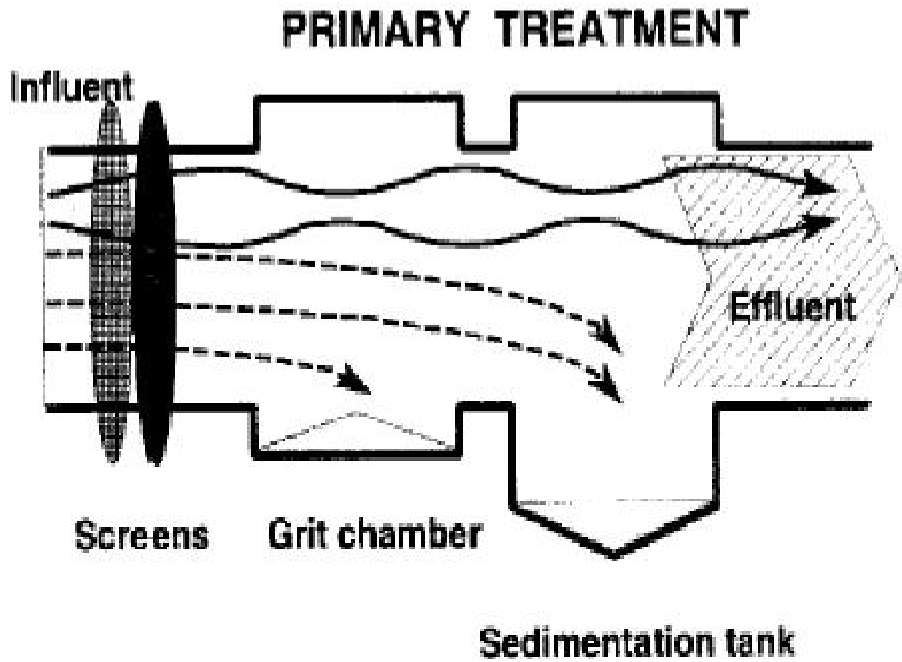
- In contemporary liquid waste treatment, the usual order of operation is the reduction of the biological oxidation demand (BOD) associated with suspended and dissolved organics, occasionally followed by the removal of inorganic nutrients and recalcitrant organics prior to the discharge of the effluent.
- BOD is a measure of O_2 consumption by the microbial oxidation of readily degradable organics and ammonia in sewage.
- 5-day BOD: O_2 consumption by microbes for degradation of a properly diluted sewage sample during 5 days of incubation at 20^oC.
- Chemical oxygen demand (COD): because some organics are not readily oxidized by microorganisms, and because microbial biomass is also formed, BOD is lower than the COD.
- Dissolved oxygen in natural water seldom exceeds 8 mg/l.

Wastewater treatment

- There are several levels of wastewater treatment: primary, secondary and tertiary treatment.
- The primary level of treatment uses screens and settling tanks to remove the majority of solids.
- This step is extremely important, because solids make up approximately 35 percent of the pollutants that must be removed.
- The screens usually have openings of about 10 millimetres, which is small enough to remove sticks, garbage and other large materials from the wastewater.
- This material is removed and disposed of at the landfill.
- The water is then put into settling tanks (or clarifiers), where it sits for several hours, allowing the sludge to settle and a scum to form on the top.
- The scum is then skimmed off the top, the sludge is removed from the bottom, and the partially treated wastewater moves on to the secondary treatment level.

Primary treatment

- The primary treatment generally removes up to 50 % of the BOD, around 90 % of suspended solids, and up to 55 % of fecal coliforms.
- While primary treatment removes a significant amount of harmful substances from wastewater, it is not enough to ensure that all harmful pollutants have been removed.



Secondary treatment

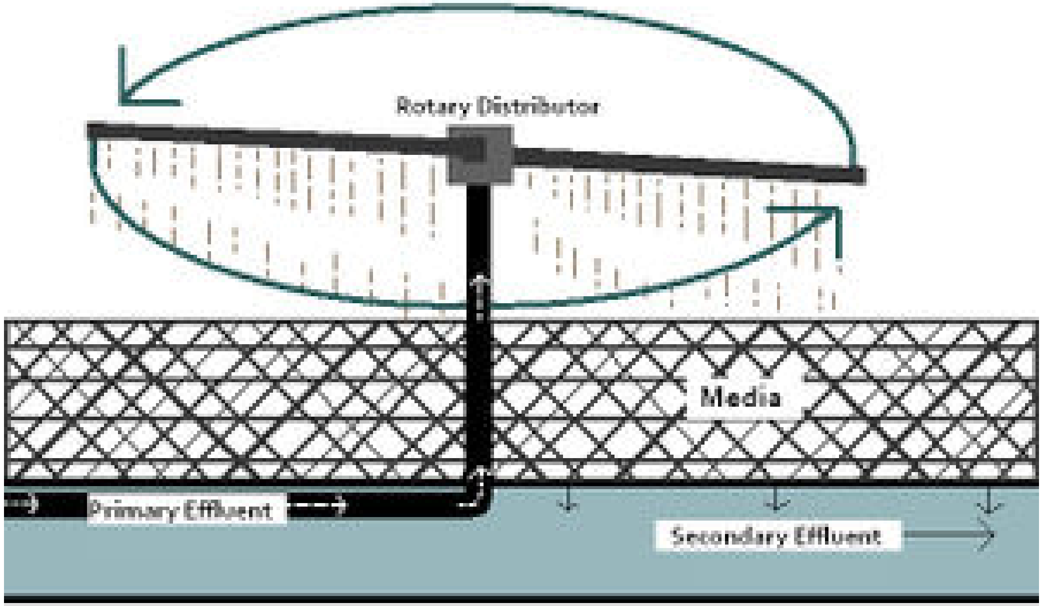
- The objective of secondary treatment is the further treatment of the effluent from primary treatment to remove the residual organics and suspended solids.
- Secondary treatment removes about 85 to 90 percent of BOD and suspended solid, and about 90 to 99 percent of coliform bacteria.
- In some devices used for secondary treatment, microbes associated with surface film; in others homogenously suspended.
- Most of the secondary treatment methods requires aerobic environment, while anaerobic systems are also in use.
- A combination of two of these processes in series (e.g., biofilter followed by activated sludge) is sometimes used to treat municipal wastewater containing a high concentration of organic material from industrial sources.

Fixed film sewage treatment systems

- **Trickling Filters:** the wastewater is dispensed upon a bed of media, such as rocks, stones, plastics, or salts.
- The effluent flows through the material at slow enough rates to allow microbial growth on the surface of the media creating a layer of film.
- The spacing of the media allows air to circulate throughout the trickling system.
- Once microbial growth takes place additional wastewater flow has contact with microorganisms; this contact ensures that the organic matter in the primary treatment effluent is broken down.
- The biofilm that falls off the media flows through the bed of material and will be transported to the secondary settling tank to remove excess microorganisms.
- The secondary effluent that settles will either enter a digester or re-enter the trickling system.

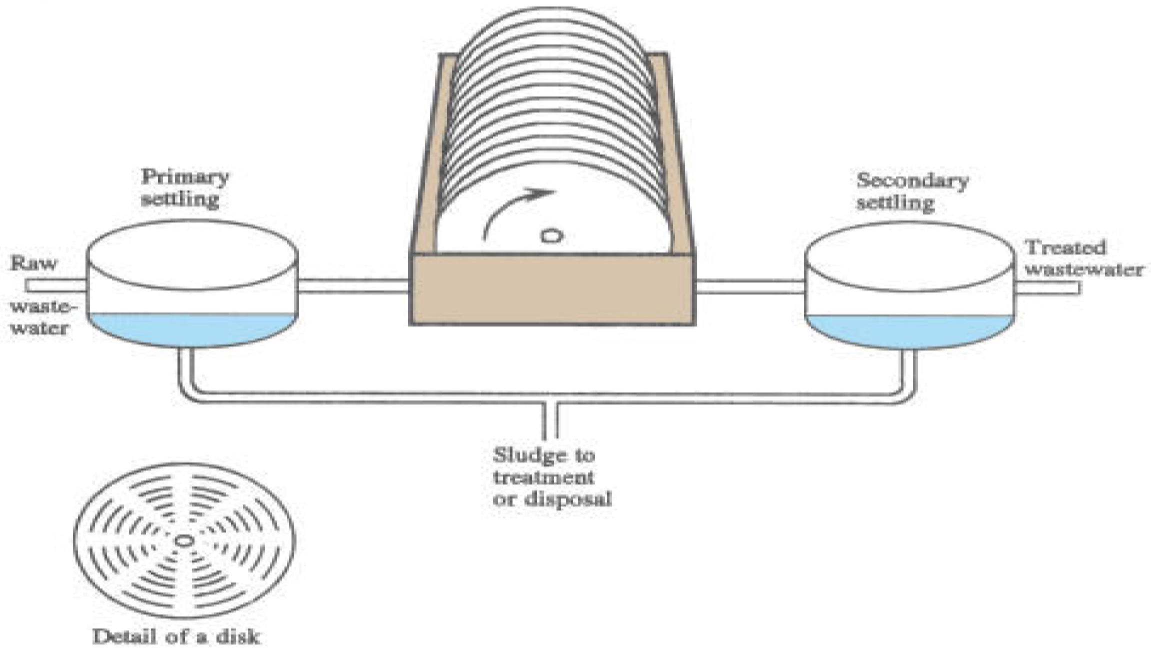
Trickling filter

- Secondary effluent that re-enters the trickling filter serves several purposes, the following are examples; 1. further treatment, 2. preventing the microorganism from drying out, and 3. diluting or supplementing primary effluent.
- This method is associated with nuisance created by insects in nearby areas; hence continuous rather than intermittent operation of trickling filter is recommended.



Rotating biological contactor (RBC) or Biodisc system

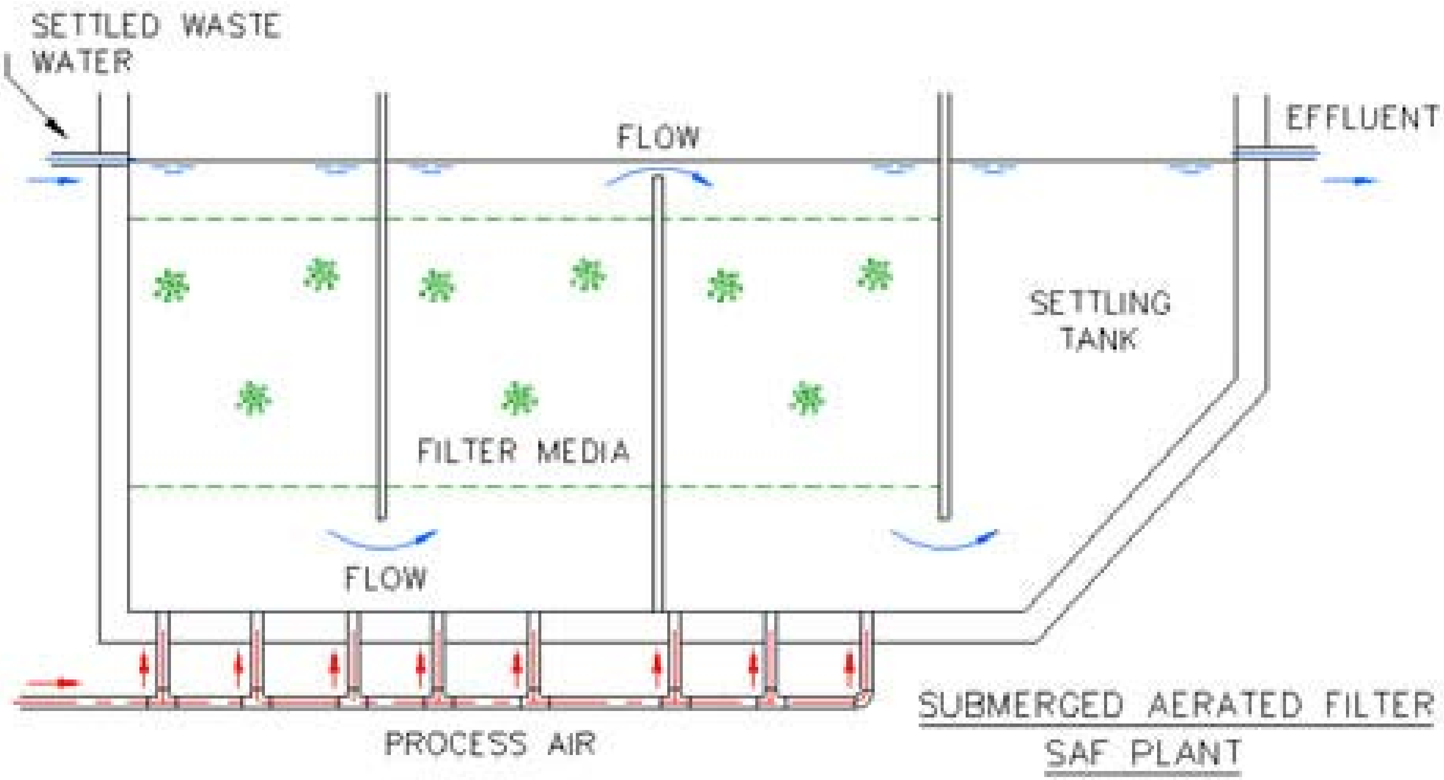
- In this treatment system a series of large plastic disks mounted on a horizontal shaft are partially submerged in primary effluent.
- As the shaft rotates, the disks are exposed alternately to air and wastewater, allowing a layer of bacteria to grow on the disks and to metabolize the organics in the wastewater.



Submerged aerated filter or SAF

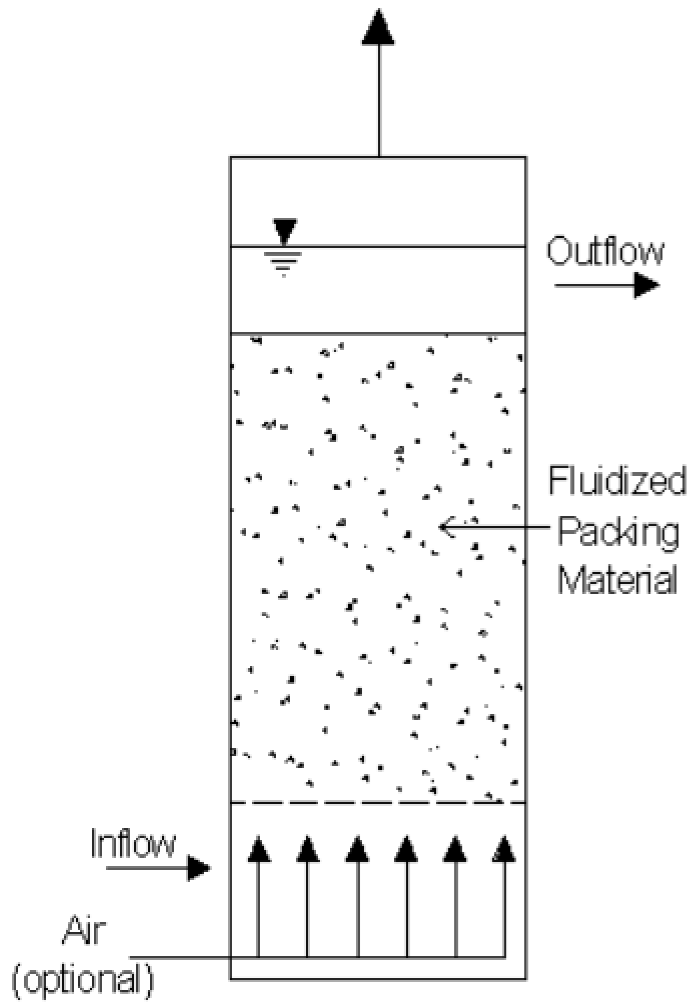
- The process employs a structured, support media and this forms an ideal place for the biomass to attach itself.
- The media a non clogging structure, fixed in place and with a very high surface area for the volume it occupies.
- It sits submerged in the biozone.
- The water passes through the cross fluted media in a very precise manner, flowing through every part ensuring excellent contact with the biomass.
- Air in introduced underneath and the media ensures very high oxygen transfer rates.
- After the biozone a standard settlement tank is used to clarify the water of any biomass that has detached itself from the support matrix.

Submerged Aerated Filter or SAF



Fluidized bed reactors or Expended bed reactors

- Fluidization is a process in which the upward flow of a fluid suspends a bed of particles.
- Fluidization offers many advantages, including excellent mixing, increased mass transfer, large specific surface area, and uniform particle and temperature distributions.
- Fluidized beds combine the best features of activated sludge and trickling filtration into one process.
- Offering a fixed film and a large surface area, stability and ease of operation of the trickling filter as well as the greater operating efficiency of the activated sludge process.



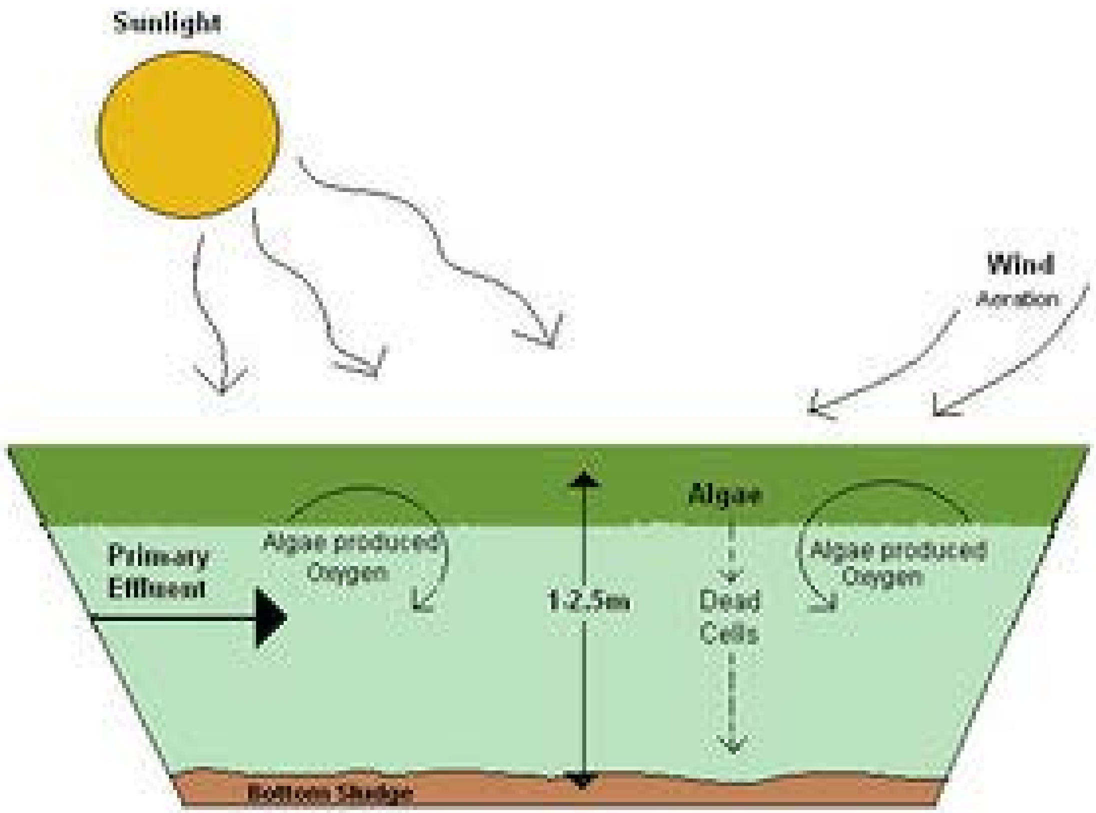
Suspended cell sewage treatment system

- **Oxidation pond:** also called lagoons or stabilization ponds, are large, shallow ponds designed to treat wastewater through the interaction of sunlight, bacteria, and algae.
- Oxidation ponds are large and shallow; a typical depth would range from 1-2.5m.
- The ponds are composed of microorganisms, which feed on the organic matter received from primary effluent.
- Algae deliver a steady flow of oxygen to the bacteria.
- The algae require sunlight to produce oxygen via photosynthesis, re-aeration created by wind delivers air flow when sunlight is not available.
- Overall the process is slow and requires large areas of land.
- Typically oxidation ponds are used in areas with small populations where land is readily available.

Oxidation ponds

Cons:

- Occupies a large area
- Possible odors
- Slow process
- Long retention times
- Climate dependent



Activated sludge treatment

- During the activated sludge process primary effluent flows into an aeration tank, where it is mixed with microorganisms.
- The aeration tank injects a steady supply of oxygen or air into the wastewater, ensuring that the organisms have an adequate supply of oxygen needed to breakdown the organic matter that remains in the effluent.
- The process takes advantage of aerobic micro-organisms that can digest organic matter in sewage, and clump together (by flocculation) as they do so.
- It thereby produces a liquid that is relatively free from suspended solids, organic material, and flocculated particles that will readily settle out and can be removed.
- The effluent then flows into secondary settling tanks. At this point the sludge goes in one of two directions;:
  - 1. back to the aeration tank, this is because the return sludge contains a large amount of microorganisms that will rapidly breakdown organic matter,
  - 2. to the sludge digester.
- The treated water will enter the tertiary treatment stage; here it will go through the final treatment stage before it is released into a natural water system.

Activated sludge

- This material, which in healthy sludge is a brown floc, is largely composed of saprotrophic bacteria (*Enterobacter,* pseudomonads, *Achromobacter, Flavobacterium, Zooglea, Arthrobacter, Micrococcus,* various coryneforms.
- But also has an important protozoan flora component mainly composed of amoebae, Spirotrichs, Peritrichs and a range of other filter-feeding species. Other important constituents include motile and sedentary Rotifers.
- The presence of attached ciliates is critical for removal of portion of BOD consisting of dispersed bacteria that would be otherwise discharged with effluent.
- Fungi usually low in number.
- In poorly managed activated sludge, a range of mucilaginous filamentous bacteria can develop including *Sphaerotilus natans* which produces a sludge that is difficult to settle
- *Salmonella, Shigella, E. coli* population 90-99% lower in the effluent of this process than in the incoming raw sewage.

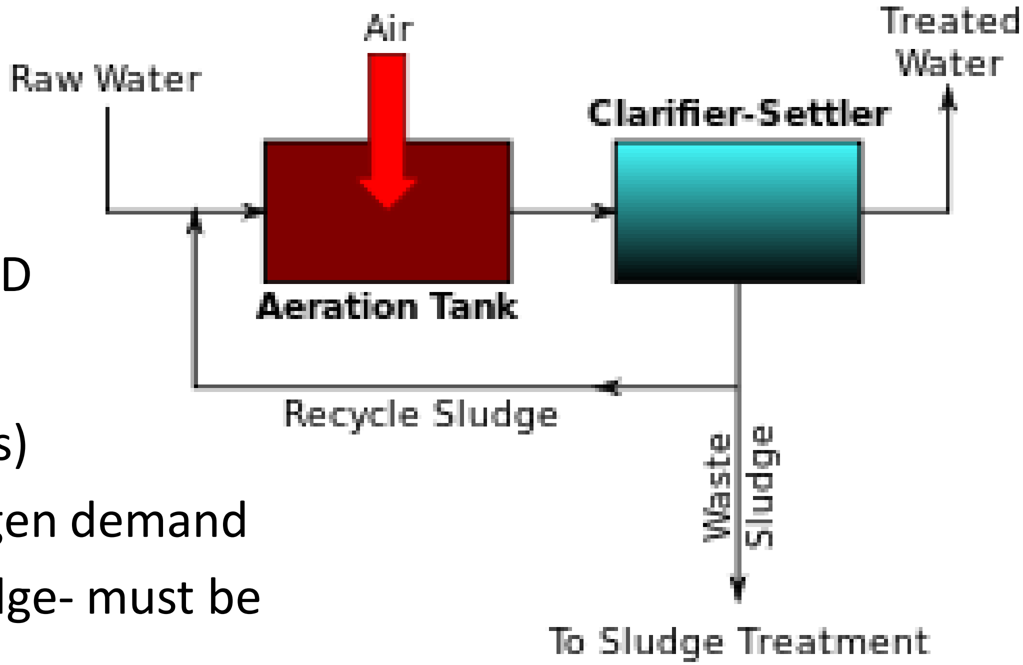
...Activated sludge treatment

Pros:

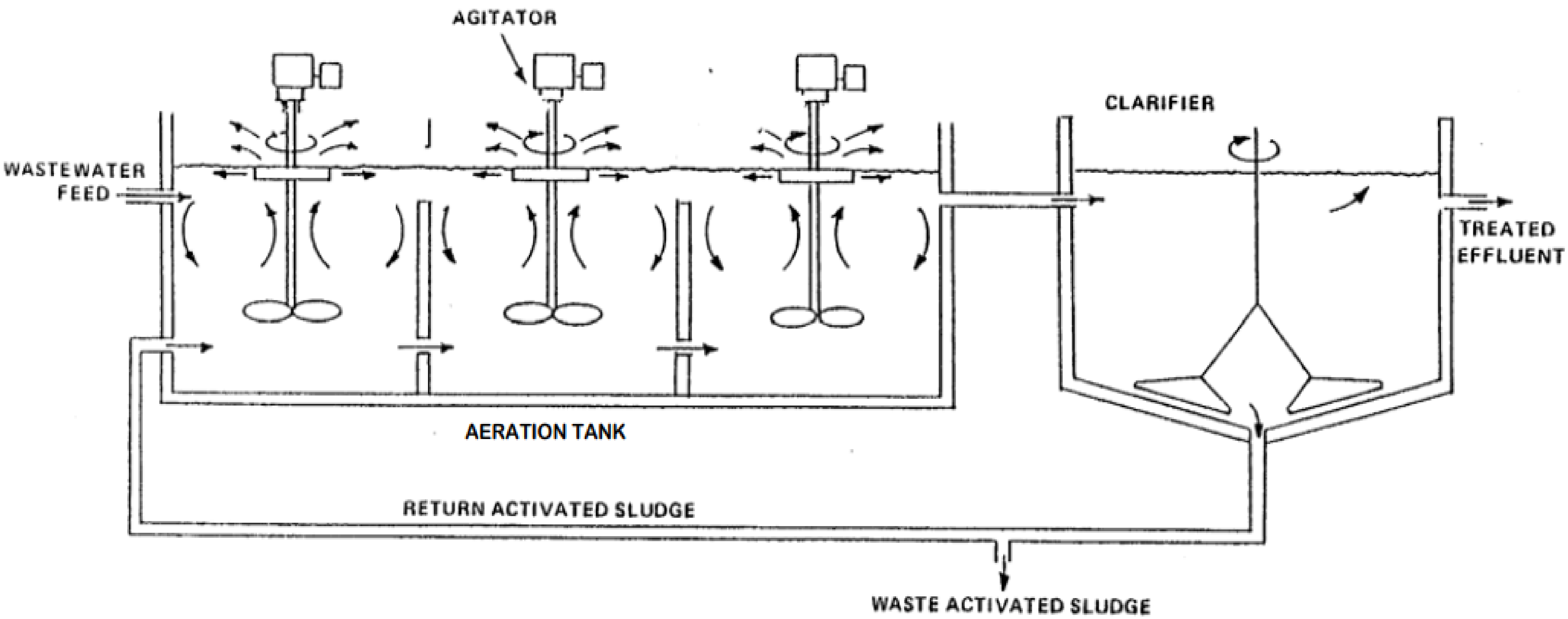
- Low construction cost
- Occupies small area
- Relatively low odour
- Removes a high percent of BOD

Cons:

- High operating cost (air pumps)
- High energy expenses for oxygen demand
- Produces large amount of sludge- must be disposed by other means.



...Activated sludge treatment system



Advanced activated sludge treatments

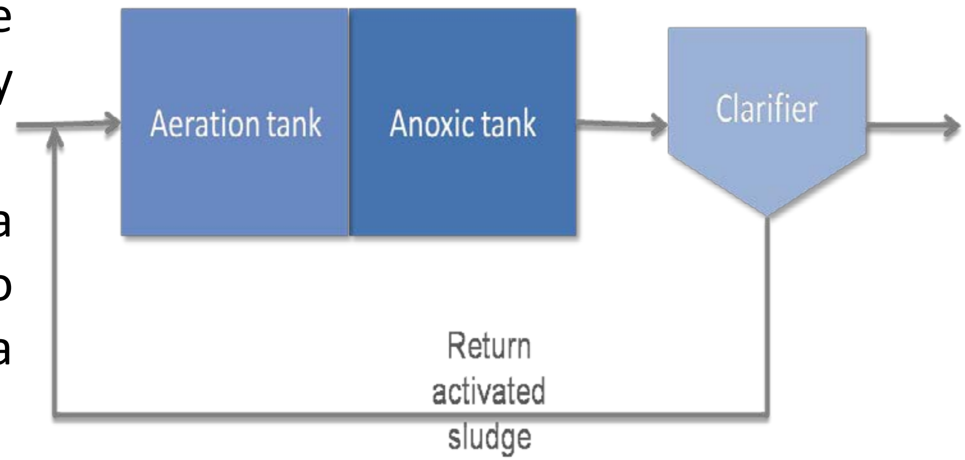
- Nutrients may be removed chemically, physically (through filtering) or biologically.
- Both phosphorus and nitrogen can be removed biologically.
- In both cases, it is generally more cost effective to use biological nutrient removal technology than chemical or physical removal.
- Treatment of nitrogenous matter or phosphate involves additional steps where the processes are managed to generate an anoxic zone so that phosphates can be solubilised in the reducing environment and oxides of nitrogen can be reduced to ammonium ion.

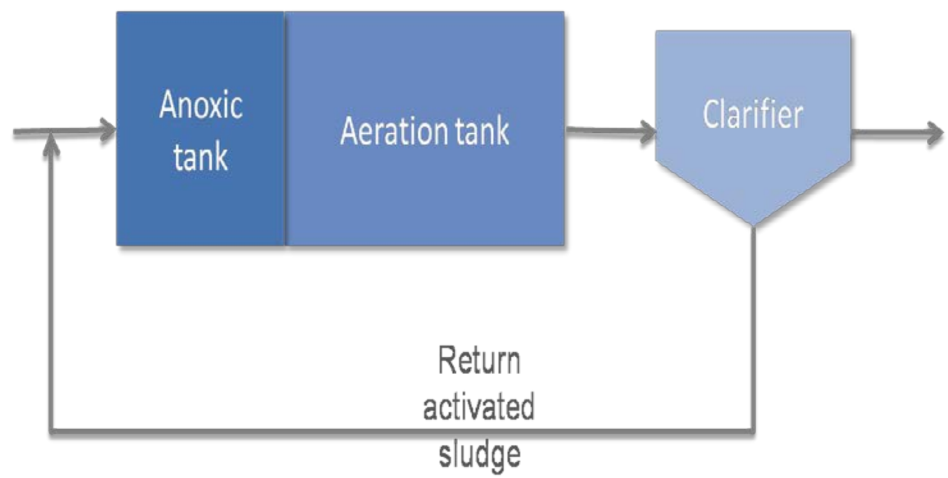
Biological nitrogen removal

- Biological nitrogen removal is a two-step process that involves nitrification and denitrification.
- Nitrification is an oxidizing process that occurs in the presence of oxygen under aerobic conditions using bacteria (often *Nitrosomonas*) to oxidize ammonia to nitrite, and then using another type of bacteria (often *Nitrobacter*) to oxidize the nitrite (NO_2^-) to nitrate (NO_3^-).
- Denitrification is a reducing process that occurs in the absence of oxygen under anoxic conditions using heterotrophic bacteria (usually *Pseudomonas*) to reduce nitrate to nitric oxide, nitrous oxide and nitrogen gas.
- The net removal of nitrogen is accomplished by stripping the nitrogen gas formed during denitrification out of the wastewater in a subsequent aeration process.

Single sludge nitrification system

- **A Wuhrmann Process** is a single sludge nitrification system followed by an anoxic zone for denitrification.
- This system is limited by the lack of a carbon source in the anoxic zone also requires more alkalinity to maintain a steady pH in the aeration tank.
- Nitrogen gas in the clarifier inhibits settling.
- A **Ludzack-Ettinger (LE) process** places the anoxic zone upstream of the nitrification reactor to take advantage of the carbon source in the influent.
- Nitrates are introduced to the anoxic tank through the RAS.
- The system is limited by the amount of nitrate returned in the RAS.





Upgraded system for higher nitrogen removal

- A **Modified Ludzack-Ettinger process** adds a mixed liquor recycle from the end of the aeration tank to the beginning of the anoxic tank.
- This returns more nitrates to the anoxic zone increasing the nitrogen that is removed.

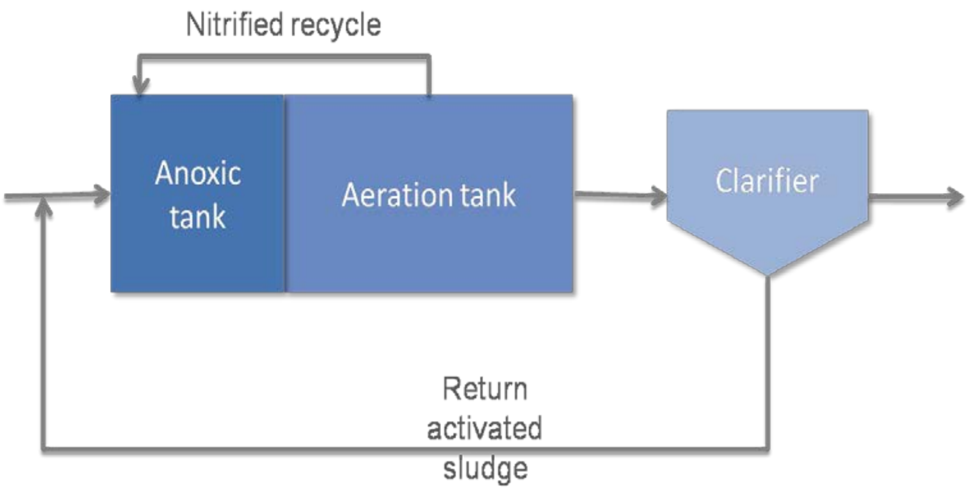
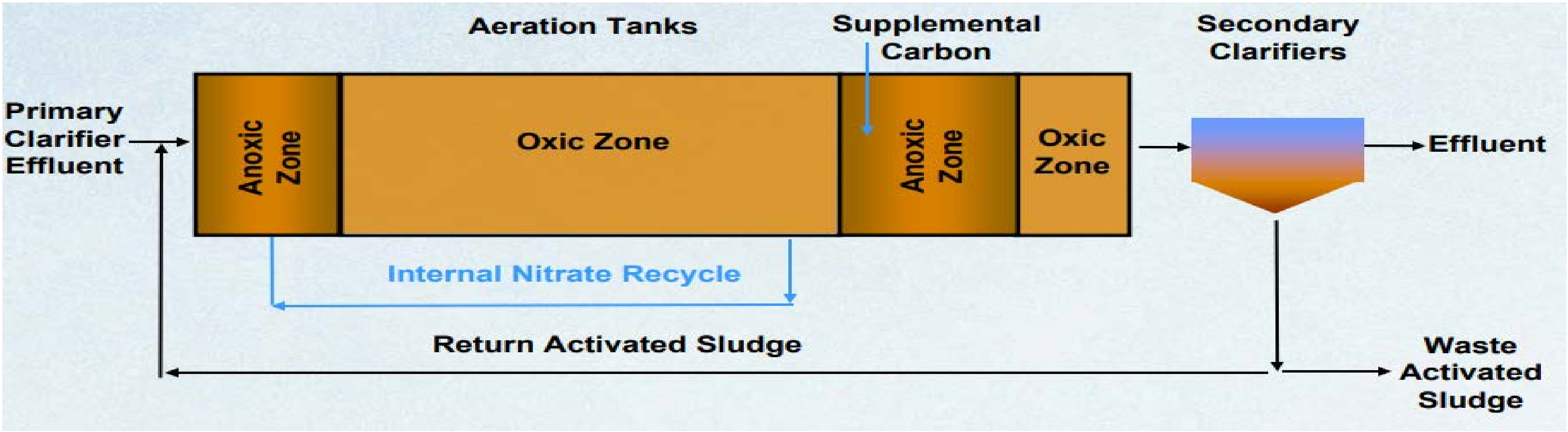


Figure 10: Modified Ludzack-Ettinger process

- **Four-stage Bardenpho process**



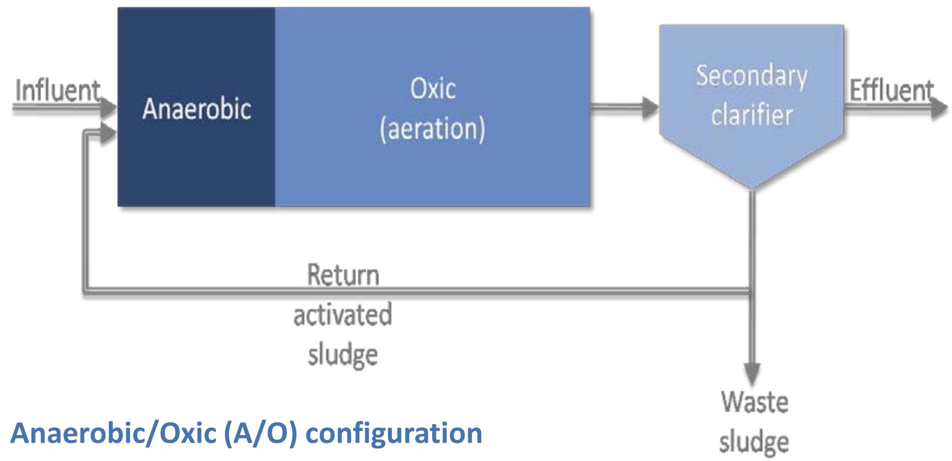
Biological phosphorus removal

- Under anaerobic conditions, the ‘phosphorus-accumulating organisms’ (PAOs) use stored polyphosphate as a source of energy for taking up and storing food.
- During the process of taking up and storing food, the polyphosphate used for energy is split apart into molecules of orthophosphate.
- These molecules cannot cross the cell membrane by themselves because they are negatively charged (anions).
- However, during the process they bond with magnesium and potassium, which are positively charged (cations).
- During bonding, the charges are neutralized; then they can cross the cell membrane and pass from the cell into the wastewater.
- This process, called *phosphorus release*, also releases magnesium and potassium into the wastewater.
- Under aerobic conditions, PAOs take up orthophosphate and convert it to polyphosphate, which is stored in their cell. PAOs take up more orthophosphate than they released under anaerobic conditions.
- This is called *luxury uptake*.

Enhanced biological phosphorus removal design configurations

Anaerobic/oxic (A/O) configuration

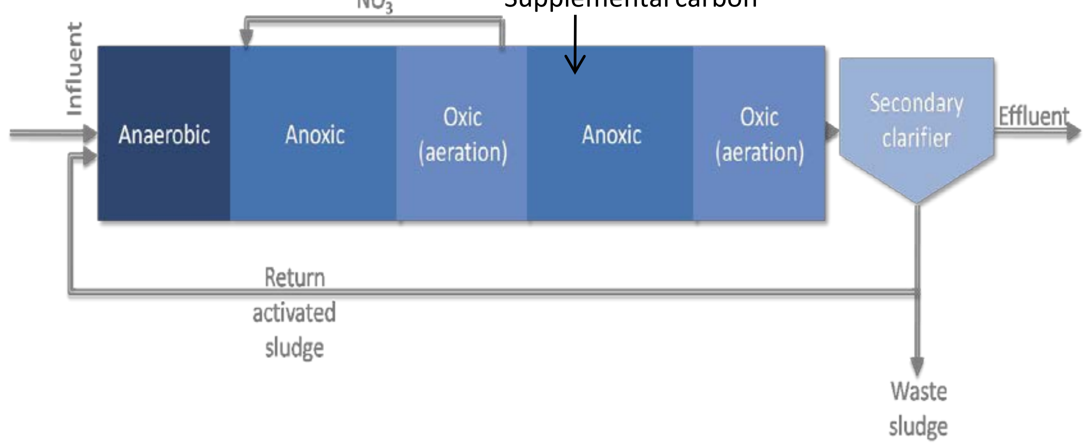
- This is similar to a conventional activated sludge process with an anaerobic zone at the head of the secondary train.
- This system is used where ammonia removal is not required so nitrates (nitrate inhibits fermentation in anoxic chamber-interfere with PHB accumulation) are not being returned to the anaerobic zone.



Anaerobic/Oxic (A/O) configuration

Modified Bardenpho configuration

- Effluent from primary clarifiers flows to the biological reactor, which is physically divided into five zones.
- In sequence these zones are: (i) anaerobic fermentation zone (characterized by very low dissolved oxygen levels and the absence of nitrates); (ii) anoxic zone (low dissolved oxygen levels but nitrates present); (iii) aerobic zone (aerated); (iv) secondary anoxic zone; and (v) final aeration zone.

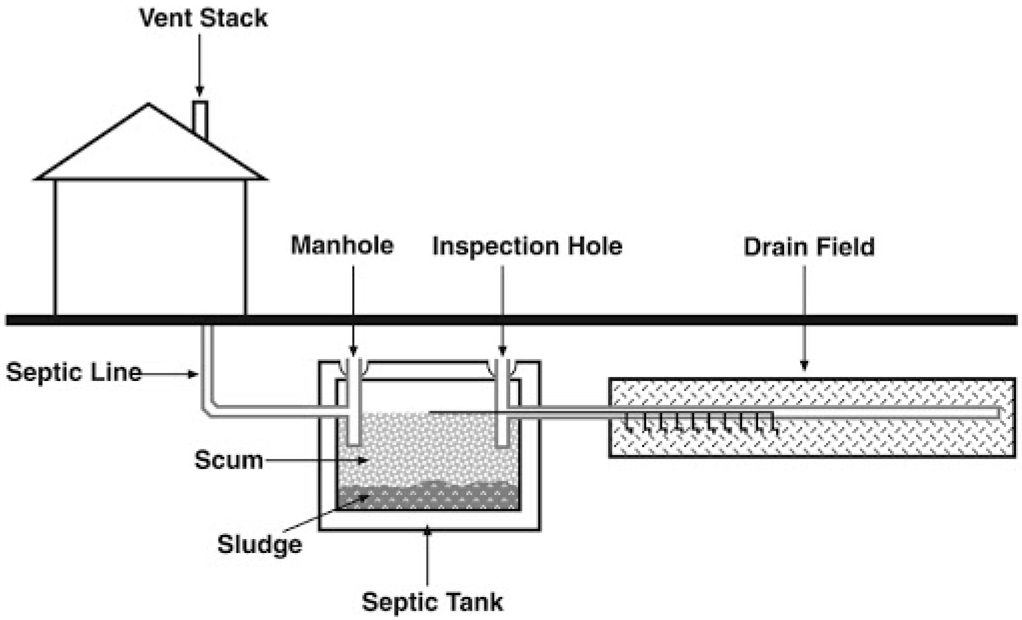


Anaerobic digesters

- Anaerobic digestion is the biological degradation of organic matter in the absence of free oxygen.
- During this process, much of the organic matter is converted to biogas (methane, carbon dioxide and water).
- Also known as methane fermentation or anaerobic sludge stabilisation, this process can reduce the organic matter content of sludge by 40 and 50 %.
- The two basic anaerobic digesters are:
  - Septic tank
  - Imhoff tank

Septic tank

- Septic systems work by receiving wastewater from the house.
- When wastewater passes through the septic tanks, heavier solids sink to the bottom and undergo bacterial digestion.
- This reduces the quantity of solids and also changes its composition to sludge, which builds up in the bottom of the tank.
- Materials such as grease and oil float to the surface in the tanks to form a crust over the liquid.



- The remaining liquid, called effluent, flows from the tanks into the drainage receptacles to soak into the surrounding soil where it may undergo further natural treatment processes.
- Septic tanks or their disposal systems must be installed to ensure minimum clearance distances from:

  -the highest groundwater level

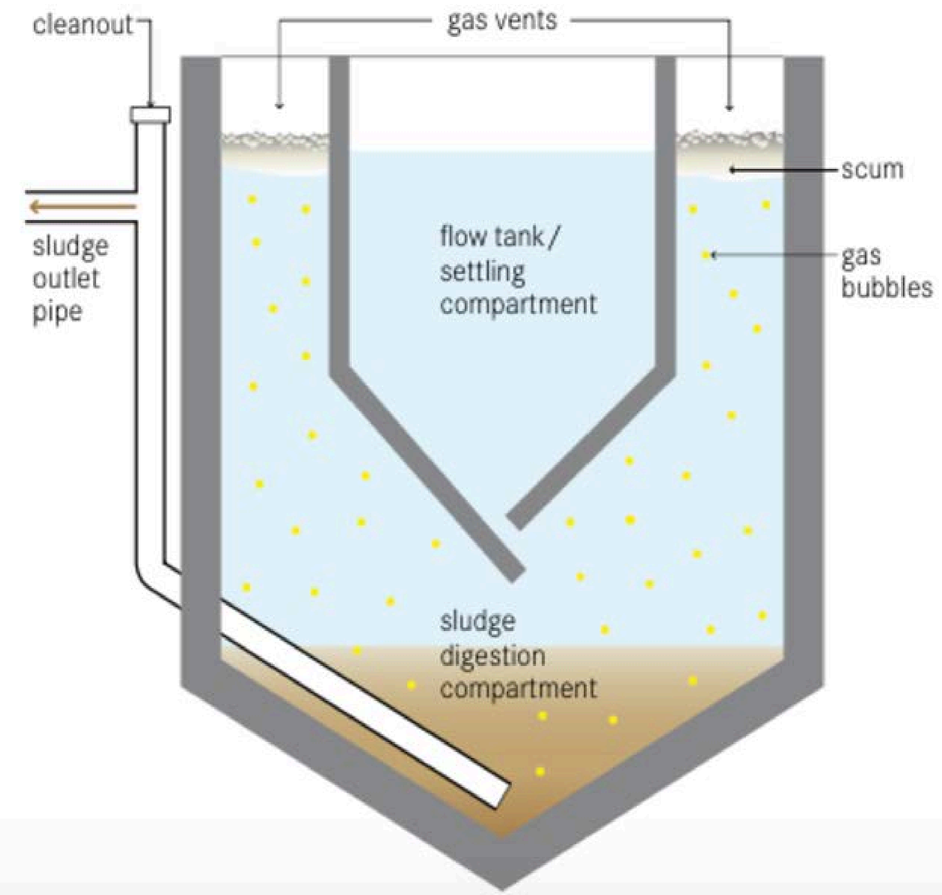
  - water supplies such as bores, creeks, dams etc.

  - buildings and boundaries

  - subsoil and open drainage channels

Imhoff tank

- The Imhoff tank is a robust and effective settler that causes a suspended solids reduction of 50 to 70%, COD reduction of 25 to 50%, and leads to potentially good sludge stabilisation – depending on the design and conditions.
- The settling compartment has a circular or rectangular shape with V-shaped walls and a slot at the bottom, allowing solids to settle into the digestion compartment, while preventing foul gas from rising up and disturbing the settling process. Gas produced in the digestion chamber rises into the gas vents at the edge of the reactor.
- It transports sludge particles to the water surface, creating a scum layer.
- The sludge accumulates in the sludge digestion chamber, compacted and partially stabilised through anaerobic digestion.



Tertiary treatments

- Tertiary treatment is any practice beyond secondary.
- Tertiary treatment are aimed at the removal of non-biodegradable organic pollutants and mineral nutrients.
- Methods includes:
  - Activated carbon absorption
  - Ion exchange
  - Ammonia stripping
  - Breakpoint chlorination
  - Phosphate precipitation (chemical treatment)

...Tertiary methods

- **Activated carbon absorption**– A physical process that is typically applied as tertiary treatment to remove low concentrations of contaminants from water that are difficult to remove by other means.
- Activated carbon has been processed to make it extremely porous, thereby creating a very large surface area available for adsorption of contaminants.
- Activated carbon may have a surface area as great as 1500 m^2/g.
- **Ion exchange** – Ion exchange is a reversible chemical reaction used to remove ions from water and wastewater.
- An ion in solution, such as ammonium, copper, calcium, magnesium, and many others, is exchanged for a similarly charged ion attached to an immobile solid ion exchange particle.
- These solid ion exchange particles are either naturally occurring inorganic zeolites or synthetically produced organic resins.

Ammonia Stripping

- Ammonia Stripping is the removal of nitrogen from wastewater when the nitrogen is in gaseous ammonia form.
- Ammonia is a volatile substance, which means that it has a tendency to leave the wastewater and enter the atmosphere.
- Ammonia (NH_3) and ammonium (NH_4^+) exist in equilibrium with each other based on the pH.
- Most of the ammonia-nitrogen in municipal wastewater is in the ammonium form because of its neutral pH range (between 6 and 8).
- Therefore, chemicals such as lime or sodium hydroxide must be added to raise the pH to the 10.5 to 11.5 range.
- This will effectively “convert” the ammonium in the wastewater to ammonia.
- The stripping effect is achieved by introducing the high pH wastewater into the top of a tower packed with fixed media (or “packing”).
- Air is blown into the bottom of the tower and flows in a counter current fashion with the incoming wastewater.
- The intimate contact between wastewater droplets and fresh air encourages the ammonia to volatilize from the wastewater to the exiting air stream.

Breakpoint chlorination

- Breakpoint chlorination is the chemical oxidation ammonia to nitrogen gas (N2) by the addition of chlorine.
- The "breakpoint" is the chlorine dosage, which results in an increase in the free chlorine residual with increasing chlorine dosages.

(1) $HOCl + NH_3 \longrightarrow NH_2Cl + H_2O$

Hypochlorous acid Monochloramine

(2) $HOCl + NH_2Cl \longrightarrow NHCl_2 + H_2O$

Dichloramine

(3) $2NHCl_2 + H_2O \longrightarrow N_2 + HOCl + 3H^+ + 3Cl^-$

- Breakpoint chlorination requires relatively high chlorine dosages per unit of ammonia present in the wastewater. In general, about 10 pounds of chlorine are required to oxidize one pound of ammonia-nitrogen.
- Because of the high chlorine demand, breakpoint chlorination is not used as the primary ammonia (or nitrogen) removal process.
- In activated sludge, biological methods, such as nitrification/denitrification, are used to remove the bulk of the nitrogen and breakpoint chlorination is used as a final polishing step to remove the residual nitrogen.

Chemical Treatment to Remove Phosphorus

- Chemical treatment for phosphorus removal involves the addition of metal salts to react with soluble phosphate to form solid precipitates that are removed by solids separation processes including clarification and filtration.
- The most common metal salts used are in the form of alum (aluminum sulfate), sodium aluminate, ferric chloride, ferric sulfate, ferrous sulfate, and ferrous chloride.

Disinfection

- Disinfection is a process where a significant percentage of pathogenic organisms are killed or controlled.
- As an individual pathogenic organism can be difficult to detect in a large volume of water, disinfection efficacy is most often measured using “indicator organisms” that coexist in high quantities where pathogens are present.
- The most common indicator organism for wastewater evaluation is fecal coliform but there has been discussion regarding the use of Escherichia coli (*E. coli*) or Total Coliform.
- A variety of physical and chemical methods are used to disinfect wastewater prior to it being released into natural waterways.
- Historically, the chemical agent of choice for municipal wastewater treatment has been chlorine, due to its disinfecting properties and low cost.
- However, the rising cost of chlorine and concerns that low chlorine concentrations can still be toxic to fish and other wildlife, has given rise to more physical methods of wastewater disinfection being adopted such as ozonation or ultraviolet (UV) light.

Chlorination

- Chlorine can be used as liquid or gas form. It is a very strong, oxidizing agent.
- Both the forms (liquid and gas) can be stored and used from gas cylinders under pressure.

$$Cl_2 + H_2O \longrightarrow HOCl + HCl$$

$$HOCl \longrightarrow H^+ + OCl^-$$

- Hypochlorous acid and hypochlorite ions are formed when chlorine is mixed with water.
- The hypochlorous acid is a better disinfectant which is formed in greater concentration at low pH concentrations.
- The hypochlorite ions and hypochlorous acid will be present in equal concentrations at pH 7.3.
- At pH above 8.3, the hypochlorite ion predominates which is not a better disinfectant. So, better disinfection is achieved at low pH.

...Chlorination

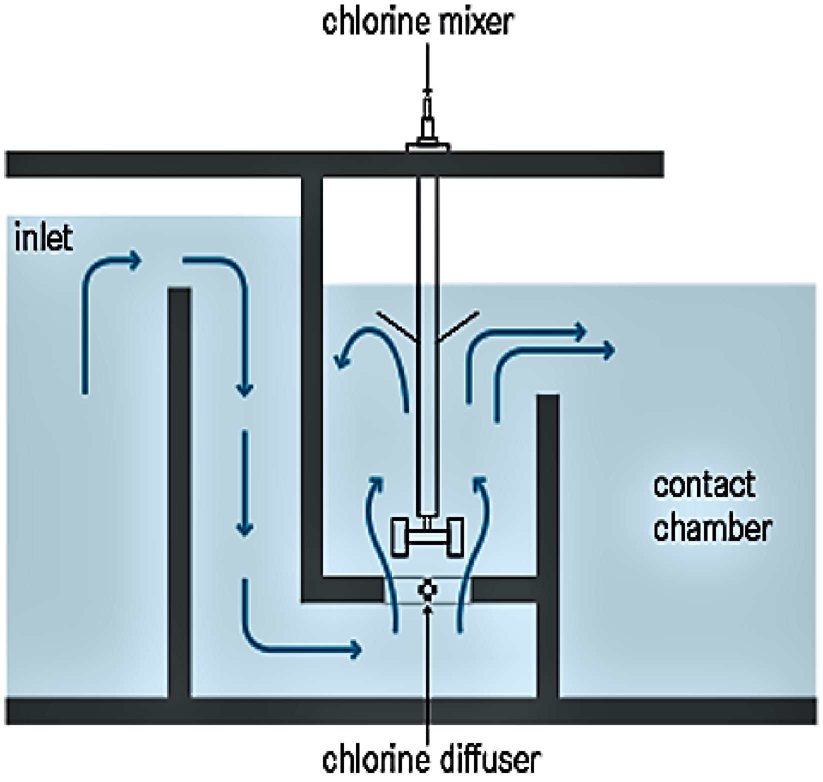
- **Sodium hypochlorite** can also be used as a disinfectant.
- Both sodium hypochlorite and chlorine gas shows similar disinfection effectiveness.

$$NaOCl + H_2O \longrightarrow HOCl + NaCl$$

- As compared to chlorine gas, sodium hypochlorite disinfection reduces the hazards in storing and handling.
- **Calcium hypochlorite** is an essential solid that can be used in replacement of NaOCl (liquid).

$$Ca(OCl)_2 + 2H_2O \longrightarrow 2HOCl + Ca(OH)_2$$

- As a disinfectant, it has similarity with NaOCl but it is much safer to handle.
- However, contamination or improper use of $Ca(OCl)_2$ may lead to explosion, fire, or the release of gases (toxic gases).



Ozonation

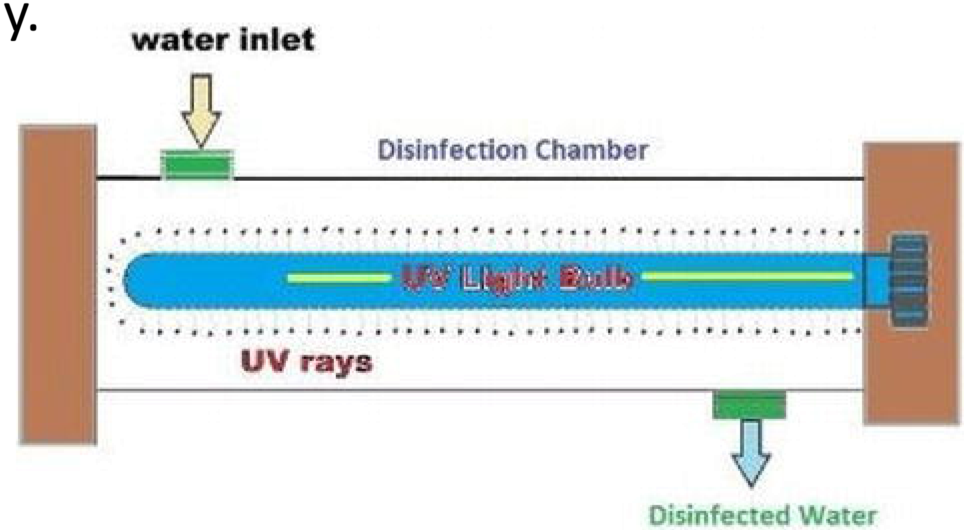
- Ozone is a powerful oxidant, degrades both organic and inorganic pollutants, including odour-producing agents.
- Ozone disinfects by oxidizing the cell walls of microorganisms, which then disintegrates (lyse), destroying the microorganism.
- Ozone gas (O_3) is formed by passing oxygen through a high voltage electric field.

$$3O_2 \rightarrow 2O_3$$

- Nowadays ozone is the widely used disinfectant after chlorine.
- Similar to chlorine, the formation of unwanted by-products is one of the problems associated with the use of ozone as a disinfectant.

Ultraviolet light (UV)

- UV treatment can be used for treating waste water, drinking water, and aquaculture.
- The UV light causes disinfection by changing the biological components of microorganisms specifically breaking the chemical bonds in DNA, RNA, and proteins.
- UV radiation can also be generated through special lamps, which can be installed in a channel or pipe.
- No change in taste and color occur that is an advantage of this method. The contact time is also very short as these rays kill the pathogenic bacteria quickly.



Questions

- What is biological oxygen demand? Explain waste water treatment methods for BOD reduction.

  Ans. Explain primary, secondary and tertiary treatments.
- Write an essay on municipal waste water treatment.

  Ans. Explain primary, secondary, tertiary and disinfection treatments
- What was the purpose of secondary treatment of waste water. Explain in detail various secondary treatment methods.

  Ans. Fixed film and suspended cell sewage treatment system, and anaerobic digesters.
- Explain activated sludge treatment methods in detail. Discuss advanced activated sludge treatment methods.
- What is tertiary treatment of waste water? Explain various tertiary treatment methods in detail.
- Write short note on:
  - Biological oxygen demand
  - Trickling filters
  - Fixed film sewage treatment systems
  - Activated sludge treatment
  - Advanced activated sludge treatments (Ans. biological nitrogen and phosphorus removal)
  - Biological removal of nitrogen from waste water
  - Biological removal of phosphorus from waste water
  - Anaerobic digesters
  - Septic tank
  - Imhoff tank
  - Ammonia stripping
  - Breakpoint chlorination
  - Removal of nitrogen from waster water (Ans. Biological method, stripping and breakpoint chlorination)
  - Removal of phosphorus from waster water (Ans. Biological and chemical methods)
  - Disinfection