Wastewater Treatment Plants

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Najib Nicolas Gerges, Ph.D., P.E.

CED engineering.ca CANADA
CPD FOR THE PROFESSIONAL

Continuing Education and Development, Inc.

P: (877) 322-5800
info@cedengineering.ca

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Introduction

Wastewater Treatment is a process that removes and eliminates contaminants from wastewater and converts this into an effluent that may be returned to the original water system. Once returned to the water system, the effluent creates an “acceptable” impact on the environment or is reused for various purposes (also known as water reclamation).

Wastewater (or waste water) is water that is generated after the use of freshwater, raw water, drinking water, or saline water in a variety of deliberate applications or processes. Another definition of wastewater is "used water from any combination of domestic, industrial, commercial or agricultural activities, surface runoff / stormwater, and any sewer inflow or sewer infiltration". *Contamination* is the presence of any constituent, impurity, or some other undesirable element that renders a substance unsuitable, unfit, or harmful for both physical body, natural environment, workplace, and others.

The Treatment Process takes place in a facility called wastewater treatment plant. There are several kinds of wastewater which are treated at the appropriate type of wastewater treatment plant. For domestic wastewater (also called municipal wastewater or sewage), the treatment plant is called a Sewage Treatment Plant. For industrial wastewater, treatment either takes place in a separate Industrial Wastewater Treatment Plant, or in a Sewage Treatment Plant (usually after providing some form of pre-treatment).

Further types of wastewater treatment plants include Agricultural Wastewater Treatment and Leachate Treatment Plants.

Treatment plants are used to:

- Treat sewage water resulted from households and industries.
- Prevent waterborne diseases.
- Protect aquatic life.
- Conserve water resources.
- Reduce pollution in the environment.

Types of Treatment Plants

Wastewater treatment plants may be classified by the type of wastewater to be treated. There are numerous processes that can be used to treat wastewater depending on the type and extent of the amount of contamination. The treatment steps include physical, chemical, and biological treatment processes.

The types of wastewater treatment plants include:

- Sewage (or Domestic) treatment plants.
- Industrial wastewater treatment plants.
- Agricultural wastewater treatment plants.
- Leachate treatment plants.

Sewage (Domestic) Treatment Plants

Sewage (Domestic) Treatment Plants: Sewage treatment (or domestic wastewater treatment, municipal wastewater treatment) is a type of wastewater treatment which aims to remove the contaminants from the sewage in order to produce an effluent that is deemed suitable to discharge to the surrounding environment or an intended reuse application, thereby preventing the water pollution from the raw sewage discharges.

Sewage contains wastewater from households and businesses, and possibly pre-treated industrial wastewater. There are high numbers of sewage treatment processes to choose from, which may range from decentralized systems (including on-site treatment systems) to large centralized systems involving network of pipes and pump stations (called sewerage) which convey the sewage to a treatment plant. For cities that have a combined sewer system (both stormwater and sewerage), the sewers will also carry urban runoff (stormwater) to the sewage treatment plant.

Sewage treatment often involves two main stages, known as primary and secondary treatment, while advanced treatment also incorporates a tertiary treatment stage with polishing processes and nutrient removal. Secondary treatment can reduce organic matters (measured as biological oxygen demand) from sewage, using aerobic or anaerobic biological processes. A so-called quaternary treatment step (sometimes referred to as advanced treatment) can also be added for the removal of organic micropollutants, such as pharmaceuticals. This has been implemented in full-scale in Sweden.

Many sewage treatment technologies have been developed, mostly using biological treatment processes. The design engineers and decision makers need to consider the technical and economic criteria of each alternative when choosing a suitable technology. The main criteria for the selection of the appropriate technology are as follows: the desired effluent quality, the expected construction and operating costs, the availability of land, the sustainability aspects, and the energy requirements.

In developing countries and in rural areas with low population densities, sewage is often treated by various on-site sanitation systems and not conveyed in sewers. These types of systems include septic tanks that are connected to drain fields, on-site sewage systems (OSS), vermifilter systems, and many more. On the other hand, advanced and relatively expensive sewage treatment plants may include tertiary treatment with disinfection and possibly even a fourth treatment stage to remove micropollutants.

At the global level, an estimated 52% of sewage is treated. However, sewage treatment rates are highly unequal for different countries around the world. For example, while high-income countries treat approximately 74% of their sewage, developing countries treat an average of just 4.2%.

Industrial Wastewater Treatment Plants

Industrial Wastewater Treatment Plants: Industrial wastewater treatment describes the processes used for treating wastewater that is produced by industries as an undesirable byproduct. After treatment, the treated industrial wastewater (or effluent) may be reused or released to a sanitary sewer or to a surface water in the environment. Several industrial facilities generate wastewater that can be treated in appropriate sewage treatment plants.

Most industrial processes, such as petroleum refineries, chemical, and petrochemical plants have their own specialized facilities to treat their wastewaters so that the pollutant concentrations in the treated wastewater comply with the regulations regarding the disposal of wastewaters into sewers or into rivers, lakes, or oceans. This applies to industries that generate wastewater with high concentrations of organic matter (e.g. oil and grease), toxic pollutants (e.g. heavy metals, volatile organic compounds), or nutrients such as ammonia. Several industries install a pre-treatment system to remove some pollutants (e.g., toxic compounds) and then discharge the partially treated wastewater to the municipal sewer system.

Most industries produce wastewater. Recent trends have been to minimize such production or to recycle treated wastewater within the production process. Several industries have been successful at redesigning their manufacturing processes to reduce or eliminate the pollutants. Sources of industrial wastewater include battery manufacturing, chemical manufacturing, electric power plants, water treatment, food industry, iron and steel industry, metal working, mines and quarries, nuclear industry, oil and gas extraction, petroleum refining and petrochemicals, pharmaceutical manufacturing, pulp and paper industry, smelters, textile mills, industrial oil contamination, and wood preserving.

Treatment processes include brine treatment, solids removal (e.g. chemical precipitation, filtration), oils and grease removal, removal of biodegradable organics, removal of other organics, removal of acids and alkalis, and removal of toxic materials.

Agricultural Wastewater Treatment Plants

Agricultural Wastewater Treatment: This type of treatment is a farm management agenda for controlling pollution from confined animal operations and from surface runoff that may be contaminated by chemicals in fertilizer, pesticides, animal slurry, crop residues, or irrigation water. Agricultural wastewater treatment is required for continuous confined animal operations such as milk and egg production. It may be performed in plants using mechanized treatment units similar to those that are used for industrial wastewater.

In places where land is available for ponds, settling basins and facultative lagoons may have lower operational costs for seasonal use conditions from breeding or harvest cycles. Animal slurries are usually treated by containment in anaerobic lagoons before disposal by spray or trickle application to grassland. Constructed wetlands are used sometimes to facilitate the treatment of animal waste. Nonpoint source pollution includes sediment runoff, nutrient runoff, and pesticides. Point source pollution includes animal wastes, silage liquor, milking parlour (dairy farming) waste, slaughtering waste, vegetable washing water, and firewater. Several farms generate nonpoint source pollution from the surface runoff (rainfall water) which is not controlled through a treatment plant.

Leachate Treatment Plants

Leachate Treatment Plants: These types of plants are used to treat the leachate from landfills. The treatment options include: biological treatment, mechanical treatment by ultrafiltration, treatment with active carbon filters, electrochemical treatment including electrocoagulation by various proprietary technologies, and reverse osmosis membrane filtration using the disc tube module technology.

Wastewater Treatment Processes

The wastewater treatment process consists of cleaning influent wastewater as shown in Figure 1.

Figure 1: Wastewater

The process consists of eight stages as shown in Figure 2: bar screening, grit removal, primary clarifier, aeration, secondary clarifier, chlorination, water analysis and testing, and effluent disposal.

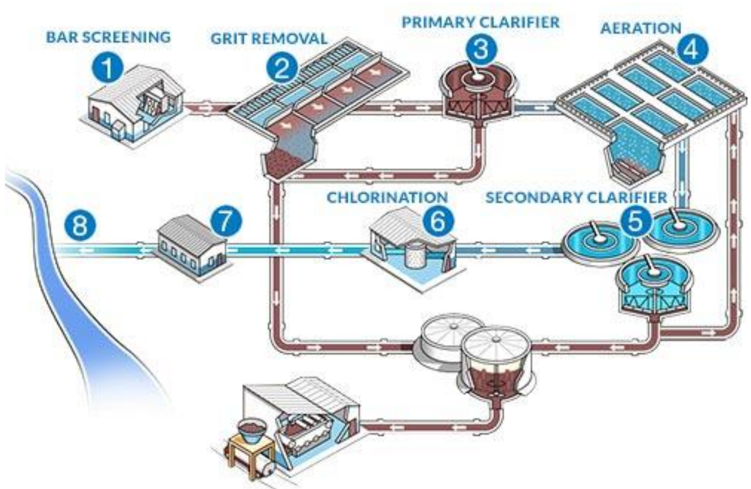

Figure 2: Process of wastewater treatment

Stage One: Bar Screening

Bar screening consists of the removal of large items from the influent to prevent damage to the facility's pumps, valves and other equipment.

The process of treating and reclaiming water from wastewater (any water that has been used in homes, such as flushing toilets, washing dishes, or bathing, and some water from industrial use and storm sewers) starts with the expectation that after it is treated it will be clean enough to reenter the environment.

The quality of the water is dictated by the Environmental Protection Agency (EPA) and the Clean Water Act, and wastewater facilities operate to specified permits by National Pollutant Discharge Elimination System (NPDES). According to the EPA, The Clean Water Act (CWA) establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters. Under CWA, EPA sets wastewater standards for industry. The EPA has also developed national water quality criteria recommendations for pollutants in surface waters. EPA's National Pollutant Discharge Elimination System (NPDES) permit program controls discharges.

As an example of expected standards, the Biochemical Oxygen Demand (BOD) of average wastewater effluent is 200 mg/L and the effluent after treatment is expected to be >30 mg/L. It is crucial a wastewater facility meets these expectations or risk stiff penalty.

The physical process of wastewater treatment begins with screening out large items that have found their way into the sewer system, and if not removed, can damage pumps and impede water flow. A bar screen is usually used to remove large items from the influent and ultimately taken to a landfill.

Stage Two: Grit Removal (Screening)

Screening consists of the removal of grit by flowing the influent over/through a grit chamber. Fine grit that finds its way into the influent needs to be removed to prevent the damage of pumps and equipment downstream (or impact water flow). Too small to be screened out, this grit needs to be removed from the grit chamber.

There are several types of grit chambers (horizontal, aerated or vortex) which control the flow of water, allowing the heavier grit to fall to the bottom of the chamber; the water and organic material continue to flow to the next stage in the process. The grit is physically removed from the bottom of the chamber and discarded.

Stage Three: Primary Clarifier

The initial separation of solid organic matter from wastewater is performed via the primary clarifier. Solids known as organics/sludge sink to the bottom of the tank and are pumped to a sludge digestor or sludge processing area, dried and hauled away. Proper settling rates are a key indicator for how well the clarifier operates. Adjusting flow rate into the clarifier can help the operator adjust the settling rates and efficiency.

After the grit removal, the influent enters large primary clarifiers that separate out between 25% and 50% of the solids in the influent. These large clarifiers (75 feet in diameter, 7½ inches at the edges, and 10½ feet in the center as an example) allow for the heavy solids to sink to the bottom and the cleaner influent to flow. The effectiveness of the primary clarification is a matter of appropriate water flow. If the water flow is too fast, the solids do not have time to sink to the bottom resulting in negative impact on water quality downstream. If the water flow is too slow, it impacts the process upstream.

The solids that fall to the bottom of the clarifier are known as sludge and pumped out regularly to ensure it doesn't impact the process of separation. The sludge is then discarded after any water is removed and commonly used as fertilizer.

Stage Four: Aeration

Aeration consists of pumping air into the aeration tank/basin to encourage conversion of NH_3 to NO_3 and provide oxygen for bacteria to continue to propagate and grow.
Once converted to NO_3, the bacteria remove/strip oxygen molecules from the nitrate molecules and the nitrogen (N) are given off as $N_2\uparrow$ (nitrogen gas).

At the heart of the wastewater treatment process is the encouragement and acceleration of the natural process of bacteria, breaking down organic material. This begins in the aeration tank. The primary function of the aeration tank is to pump oxygen into the tank to encourage the breakdown of any organic material (and the growth of the bacteria), as well as ensure there is enough time for the organic material to be broken down.

Aeration can be accomplished with pumping and defusing air into the tank or through aggressive agitation that adds air to the water. This process is managed to offer the best conditions for bacterial growth. Oxygen gas [O_2] levels below 2 ppm will kill off the bacteria, reducing efficiency of the plant. Dissolved oxygen monitoring at this stage of the plant is critical. Ammonia and nitrate measurements are common to measure how efficient the bacteria are in converting NH_3 to $N_2\uparrow$.

A key parameter to measure wastewater treatment is Biochemical Oxygen Demand (BOD). BOD is a surrogate indicator for organic material present and is used to determine the effectiveness of organic material breakdown. There are a number of other tests used to ensure optimal organic material breakdown (and BOD reduction) such as measuring pH, temperature, Dissolved Oxygen (DO), Total Suspended Solids (TSS), Hydraulic Retention Time (flow rate), Solids Retention Time (amount of time the bacteria is in the aeration chamber) and Mixed Liquor Suspended Solids. Ongoing and accurate monitoring is crucial to ensure the final required effluent BOD.

Stage Five: Secondary Clarifier

Treated wastewater is pumped into a secondary clarifier to allow any remaining organic sediment to settle out of treated water flow.

As the influent exits the aeration process, it flows into a secondary clarifier where, like the primary clarifier, any very small solids (or fines) sink to the bottom of the tank. These small solids are called activated sludges and consist mostly of active bacteria. Part of this activated sludge is returned to the aeration tank to increase the bacterial concentration, help in propagation, and accelerate the breakdown of organic material. The excess is discarded.

The water that flows from the secondary clarifier has substantially reduced organic material and should be approaching expected effluent specifications.

Stage Six: Chlorination (Disinfection)

This process consists of adding Chlorine to kill any remaining bacteria in the contact chamber. With the enhanced concentration of bacteria as part of the aeration stage, there is a need to test the outgoing effluent for bacteria presence or absence and to disinfect the water. This ensures that higher than specified concentrations of bacteria are not released into the environment.

Chlorination is the most common and inexpensive type of disinfection, but ozone and UV disinfection are also increasing in popularity. If chorine is used, it is important to test free-chlorine levels to ensure they are acceptable levels before being released into the environment.

Stage Seven: Water Analysis & Testing

This process consists of testing for proper pH level, ammonia, nitrates, phosphates, dissolved oxygen, and residual chlorine levels to conform to the plant's NPDES permit are critical to the plant's performance. Although testing is continuous throughout the wastewater treatment process to ensure optimal water flow, clarification, and aeration, final testing is performed to make sure that the effluent leaving the plant meets the permit specifications. Plants that do not meet the permit discharge levels are subject to fines and possible incarceration of the operator in charge.

Stage Eight: Effluent Disposal

After meeting all the permit specifications, clean water is reintroduced into the environment as shown in Figure 3.

Although testing is continuous throughout the wastewater treatment process to ensure optimal water flow, clarification, and aeration, final testing is performed to make sure that the effluent leaving the plant meets permit specifications. Plants that do not meet the permit discharge levels are subject to fines and possible incarceration of the operator in charge.

Figure 3: Clean water

Wastewater Treatment Levels & Disposal

Preliminary Treatment

Preliminary or pre-treatment, is the first stage of wastewater treatment and is used to prepare water for purification during the following phases. Thus, it consists of removing objects that could damage the plant or the equipment that will be used during the purification process. This is achieved by removing from the wastewater any constituents which can clog or damage the pumps or interfere with the subsequent treatment processes as illustrated in Figure 4.

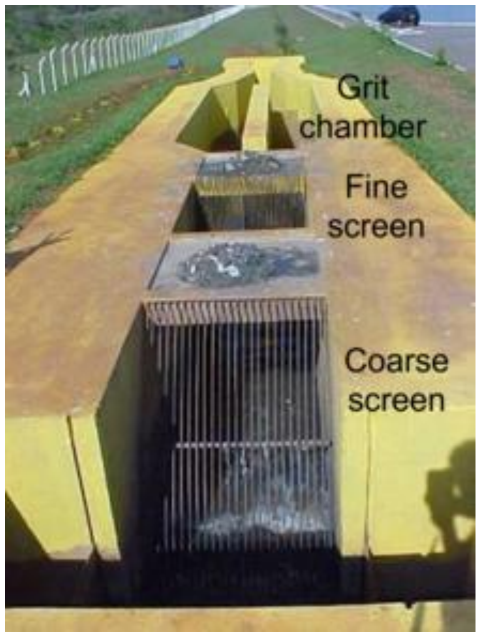

Figure 4: Preliminary Treatment

The preliminary treatment devices are, therefore, designed to:

- Remove or reduce in size the large, entrained, suspended, or floating solids. These solids consist of pieces of wood, cloth, paper, plastics, garbage, etc. together with some fecal matter.

- Remove heavy inorganic solids such as sand and gravel, as well as metal or glass. These objects are called grit.

- Remove excessive amounts of oil or greases. Several devices or types of equipment are used to obtain these objectives.

Screening: The influent in sewage water passes through a bar screen to remove all large objects like cans, rags, sticks, plastic packets, etc. carried in the sewage stream. This is most commonly achieved with an automated mechanically raked bar screen in modern plants serving large populations, while in smaller or less modern plants, a manually cleaned screen may be used. The raking action of a mechanical bar screen is typically paced according to the accumulation on the bar screens and/or flow rate. The solids are collected and later disposed in a landfill, or incinerated. Bar screens or mesh screens of varying sizes may be used to optimize solids removal. If gross solids are not removed, they become entrained in pipes and moving parts of the treatment plant, and can cause substantial damage and inefficiency in the process.

Grit Removal: Grit consists of sand, gravel, rocks, and other heavy materials. Preliminary treatment may include a sand or grit removal channel or chamber, where the velocity of the incoming sewage is reduced to allow the settlement of grit. Grit removal is necessary to:

- Reduce the formation of deposits in primary sedimentation tanks, aeration tanks, anaerobic digesters, pipes, channels, etc.

- Reduce the frequency of tank cleaning caused by excessive accumulation of grit.

- Protect moving mechanical equipment from abrasion and accompanying abnormal wear. The removal of grit is essential for equipment with closely machined metal surfaces such as comminutors, fine screens, centrifuges, heat exchangers, and high-pressure diaphragm pumps.

Grit chambers come in three types: horizontal grit chambers, aerated grit chambers, and vortex grit chambers. Vortex grit chambers include mechanically induced vortex, hydraulically induced vortex, and multi-tray vortex separators. Given that traditionally, grit removal systems have been designed to remove clean inorganic particles that are greater than 0.210 millimeters (0.0083 in), most of the finer grit passes through the grit removal flows under normal conditions. During periods of high flow deposited grit is resuspended and the quantity of grit reaching the treatment plant increases substantially.

Flow Equalization: Equalization basins can be used to achieve flow equalization. This is especially useful for combined sewer systems which produce peak dry-weather flows or peak wet-weather flows that are much higher than the average flows. Such basins can improve the performance of the biological treatment processes and the secondary clarifiers.

The disadvantages include the basins' capital cost and space requirements. Basins can also provide a place to temporarily hold, dilute, and distribute batch discharges of toxic or high-strength wastewater which might otherwise inhibit biological secondary treatment (such was wastewater from portable toilets or fecal sludge that is brought to the sewage treatment plant in vacuum trucks). Flow equalization basins require variable discharge control, typically include provisions for bypass and cleaning, and may also include aerators and odor control.

Fat and Grease Removal: In some larger plants, fat and grease are removed by passing the sewage through a small tank where skimmers collect the fat floating on the surface. Air blowers in the base of the tank may also be used to help recover the fat as a froth. Many plants, however, use primary clarifiers with mechanical surface skimmers for fat and grease removal.

Primary Treatment

Primary treatment is the "removal of a portion of the suspended solids and organic matter from the sewage". It consists of allowing sewage to pass slowly through a basin where heavy solids can settle to the bottom while oil, grease and lighter solids float to the surface and are skimmed off as illustrated in Figure 5. These basins are called primary sedimentation tanks or primary clarifiers and typically have a hydraulic retention time (HRT) of 1.5 to 2.5 hours. The settled and floating materials are removed, and the remaining liquid may be discharged or subjected to secondary treatment. Primary settling tanks are usually equipped with mechanically driven scrapers that continually drive the collected sludge towards a hopper in the base of the tank where it is pumped to sludge treatment facilities.

Figure 5: Primary treatment

Sewage treatment plants that are connected to a combined sewer system sometimes have a bypass arrangement after the primary treatment unit. This means that during very heavy rainfall events, the secondary and tertiary treatment systems can be bypassed to protect them from hydraulic overloading, and the mixture of sewage and storm-water receives primary treatment only.

Primary sedimentation tanks remove about 50 – 70% of the suspended solids, and 25 – 40% of the biological oxygen demand (BOD).

The primary treatment of wastewater has been demonstrated by research to improve the quality and settling characteristics of wastewater that are otherwise difficult to treat.

The sewage primary treatment is beneficial for reducing the BOD (Biological Oxygen Demand) of wastewater. The removal of the settleable solids is the most crucial objective of this process.

Secondary Treatment

This process is designed to remove the organic matter from the water, as well as the nutrients such as nitrogen and phosphorus.

This secondary treatment, which is mainly biological, generally utilizes the bacteria and the microorganisms to degrade and eliminate the organic matter and the different nutrients contained in the water. The most widespread treatment is the activated sludge, where the water to be treated is left in a tank for several days under varying oxygen conditions (aerobic, anoxic, and anaerobic) depending on the required removal requirements, as shown in Figure 6. Here, the different types of bacteria that live in the tank or reactor feed on the organic matter and the nutrients contained in the water, removing them from the water and taking them into their organisms.

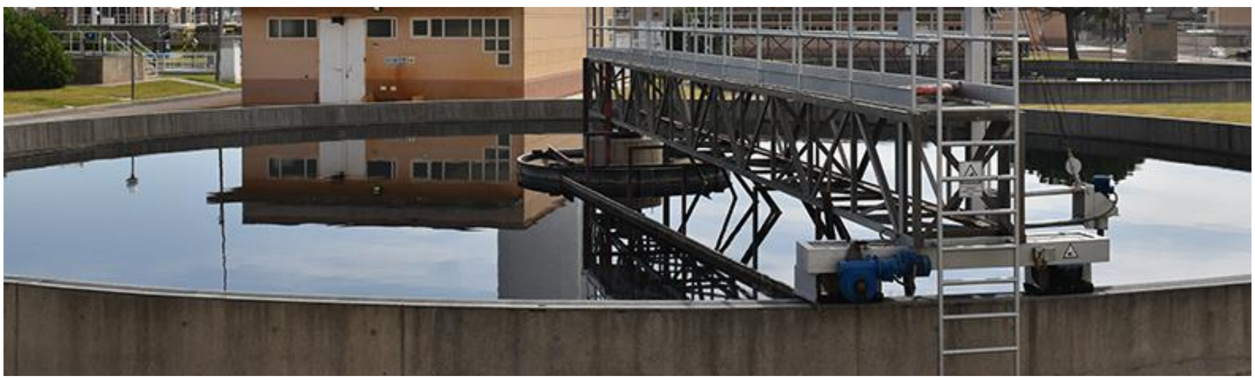

Figure 6: Activated Sludge

A second or secondary settling process is usual after the biological process. Here, the bacteria that have grown in the previous process precipitate to the lower part of the settling tank, generating a mixture of water and solids, which is called biological sludge. This mixture is extracted or flushed out through the lower part of the decanter and the purified water flows out through the upper part without most of the bacteria and solids, giving rise to clarified water.

It is common in wastewater treatment plants for water treatment to end at this point, when the treated water meets the defined discharge requirements and there are no additional water quality requirements for reuse or further use. Secondary treatment removes over 90% of the remaining suspended solids from wastewater.

Secondary treatment systems are classified as *fixed-film* versus *suspended-growth* systems, and as *aerobic* versus *anaerobic*.

Fixed Films

Fixed-film or attached growth systems include trickling filters, constructed wetlands, bio-towers, and rotating biological contactors, where the biomass grows on media and the sewage passes over its surface. The fixed-film principle has further developed into moving bed biofilm reactors (MBBR) and Integrated Fixed-Film Activated Sludge (IFAS) processes.

- **Trickling Filter Beds (Oxidizing Beds)**

This system consists of a fixed bed of rocks, coke, gravel, slag, polyurethane foam, sphagnum peat moss, ceramic, or plastic media over which sewage or other wastewater flows downward and causes a layer of microbial slime or biofilm to grow, covering the bed of media as shown in Figure 7.

Aerobic conditions are maintained by splashing, diffusion, and either by forced-air flowing through the bed or natural convection of air if the filter medium is porous. The treatment of sewage or other wastewater with trickling filters is among the oldest and most well characterized treatment technologies.

Figure 7: Microbial slime or biofilm growing

The fundamental components of a complete trickling filter system are:

- A bed of filter medium upon which a layer of microbial slime is promoted and developed.
- An enclosure or a container which houses the bed of filter medium.
- A system for distributing the flow of wastewater over the filter medium.
- A system for removing and disposing of any sludge from the treated effluent.

The terms trickle filter, trickling biofilter, biofilter, biological filter, and biological trickling filter are often used to refer to a trickling filter. These systems have also been described as roughing filters, intermittent filters, packed media bed filters, alternative septic systems, percolating filters, attached growth processes, and fixed film processes.

Typically, settled sewage flow enters at a high level and flows through the primary settlement tank. The supernatant from the tank flows into a dosing device, often a tipping bucket which delivers flow to the arms of the filter. The flush of water flows through the arms and exits through a series of holes pointing at an angle downwards. This propels the arms around distributing the liquid evenly over the surface of the filter media. Most are uncovered (unlike the accompanying diagram) and are freely ventilated to the atmosphere as illustrated in Figure 8.

The removal of pollutants from the waste water stream involves both absorption and adsorption of organic compounds and some inorganic species (such as nitrite and nitrate ions) by the layer of microbial biofilm. The filter media is typically chosen to provide a very high surface-to-volume ratio. Typical materials are often porous and have considerable internal surface area, in addition to the external surface of the medium. Passage of the wastewater over the media provides dissolved oxygen, which the biofilm layer requires for the biochemical oxidation of the organic compounds and releases carbon dioxide gas, water, and other oxidized end products. As the biofilm layer thickens, it eventually sloughs off into the liquid flow and subsequently forms part of the secondary sludge.

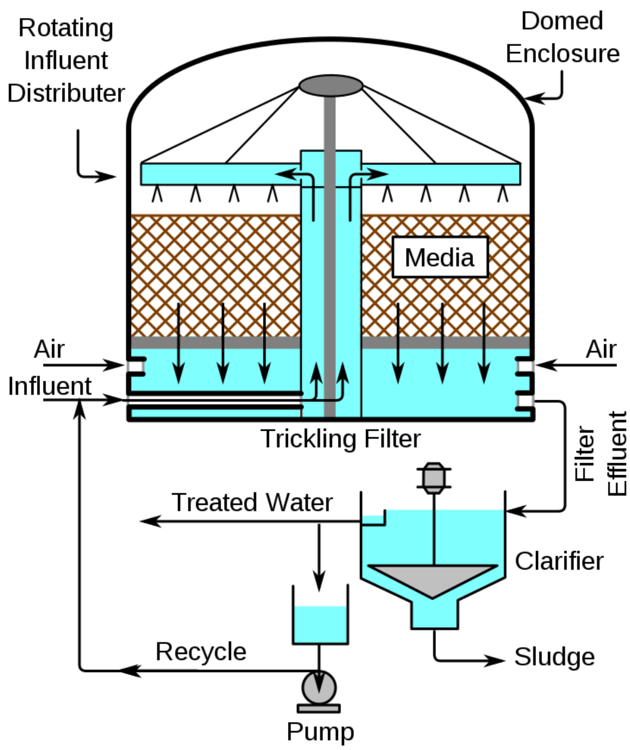

Figure 8: Trickle filter

Typically, a trickling filter is followed by a clarifier or sedimentation tank for the separation and removal of the sloughed film. Filters utilizing higher-density media, such as sand, foam and peat moss do not produce a sludge that must be removed, but may require forced air blowers, backwashing, and/or an enclosed anaerobic environment.

The biofilm that develops in a trickling filter may become several millimeters thick and is typically a gelatinous matrix that may contain many of bacteria species, ciliates and amoeboid protozoa, annelids, round worms, insect larvae, other microfauna. (If annelids are abundant, the filter may be considered a vermifilter.) This is very different from many other biofilms, which may be less than 1 mm thick.

Within the biofilm, both aerobic and anaerobic zones can exist supporting both oxidative and reductive biological processes as illustrated in Figure 9. At certain times of year, especially in the spring, rapid growth of organisms in the film may cause the film to be too thick and it may slough off in patches leading to the "spring slough".

A typical trickling filter is circular and between 10 meters and 20 meters across and between 2 meters to 3 meters deep. A circular wall, often of brick, contains a bed of filter media which in turn rests on a base of underdrains. These underdrains function both to remove liquid passing through the filter media but also to allow the free passage of air up through the filter media.

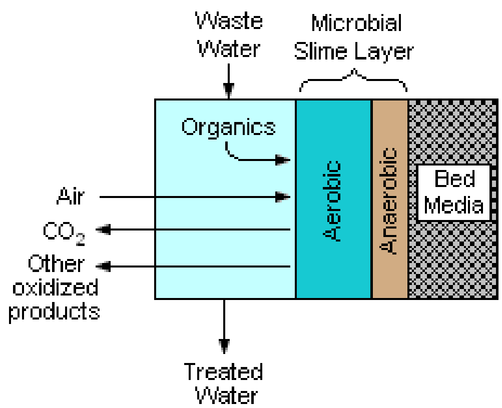

Figure 9: Biofilm

Mounted in the center over the top of the filter media is a spindle supporting two or more horizontal perforated pipes which extend to the edge of the media. The perforations on the pipes are designed to allow an even flow of liquid over the whole area of the media and are also angled so that when liquid flows from the pipes the whole assembly rotates around the central spindle. Settled sewage is delivered to a reservoir at the center of the spindle via some form of dosing mechanism, often tipping bucket device on small filters. Larger filters may be rectangular, and the distribution arms may be driven by hydraulic or electrical systems.

Single trickling filters may be used for the treatment of small residential septic tank discharges and very small rural sewage treatment systems. Larger centralized sewage treatment plants typically use many trickling filters in parallel.

Systems can be configured for single pass use where the treated water is applied to the trickling filter once before being disposed of, or for multi-pass use where a portion of the treated water is cycled back and re-treated via a closed loop. Multi-pass systems result in higher treatment quality and assist in removing Total Nitrogen (TN) levels by promoting nitrification in the aerobic media bed and denitrification in the anaerobic septic tank. Some systems use filters in two banks operated in series so that the wastewater has two passes through a filter with a sedimentation stage between the two passes. Every few days the filters are switched round to balance the load. This method of treatment can improve nitrification and de-nitrification since much of the carbonaceous oxidative material is removed on the first pass through the filters.

Trickling may have a variety of types of filter media used to support the biofilm. Types of media most commonly used include coke, pumice, plastic matrix material, open- cell polyurethane foam,

clinker, gravel, sand, and geotextiles. Ideal filter medium optimizes surface area for microbial attachment, wastewater retention time, allows air flow, resists plugging, is mechanically robust in all weathers allowing walking access across the filter, and does not degrade. Some residential systems require forced aeration units which will increase maintenance and operational costs.
The synthetic filter media may pose a significant risk of flammability as demonstrated in Christchurch, New Zealand in May 2022 when two large trickling filters filled with plastic filter bales caught fire. The resultant smell had a significant impact on many city residents and this event put out of action a significant proportion of the sewage treatment capacity.

The treatment of industrial wastewater may involve specialized trickling filters which use plastic media and high flow rates. Wastewaters from a variety of industrial processes have been treated in trickling filters. Such industrial wastewater trickling filters consist of two types:

- Large tanks or concrete enclosures filled with plastic packing or other media.
- Vertical towers filled with plastic packing or other media.

The availability of inexpensive plastic tower packings has led to their use as trickling filter beds in tall towers, some as high as 20 meters. As early as the 1960's, such towers were in use at: the Great Northern Oil's Pine Bend Refinery in Minnesota; the Cities Service Oil Company Trafalgar Refinery in Oakville, Ontario and at a kraft paper mill.

The treated water effluent from industrial wastewater trickling filters is typically processed in a clarifier to remove the sludge that sloughs off the microbial slime layer attached to the trickling filter media as for other trickling filter applications. Some of the latest trickle filter technology involves aerated biofilters of plastic media in vessels using blowers to inject air at the bottom of the vessels, with either downflow or up flow of the wastewater.

- **Constructed Wetlands**

A constructed wetland is an artificial wetland to treat sewage, greywater, stormwater runoff, or industrial wastewater. It may also be designed for land reclamation after mining, or as a mitigation step for natural areas lost to land development as illustrated in Figure 10.

Figure 10: Constructed Wetlands

Constructed wetlands are engineered systems that use the natural functions of vegetation, soil, and organisms to provide secondary treatment to wastewater. The design of the constructed wetland has to be adjusted according to the type of wastewater to be treated.

Constructed wetlands have been used in both centralized and decentralized wastewater systems. Primary treatment is recommended when there is a large number of suspended solids or soluble organic matter (measured as biochemical oxygen demand and chemical oxygen demand).

Similar to natural wetlands, constructed wetlands also act as a biofilter and/or can remove a range of pollutants (such as organic matter, nutrients, pathogens, heavy metals) from the water. Constructed wetlands are designed to remove water pollutants such as suspended solids, organic matter, and nutrients (nitrogen and phosphorus). All types of pathogens (i.e., bacteria, viruses, protozoans, and helminths) are expected to be removed to some extent in a constructed wetland. Subsurface wetlands provide greater pathogen removal than surface wetlands.

There are two main types of constructed wetlands: subsurface flow and surface flow. The planted vegetation plays an important role in contaminant removal. The filter bed, consisting usually of sand and gravel, has an equally important role to play. Several constructed wetlands may also serve as a habitat for native and migratory wildlife, although that is not their main purpose.

Subsurface flow constructed wetlands are designed to have either horizontal flow or vertical flow of water through the gravel and sand bed. Vertical flow systems have a smaller space requirement than horizontal flow systems.

Many terms are used to denote constructed wetlands, such as reed beds, soil infiltration beds, treatment wetlands, engineered wetlands, man-made, or artificial wetlands. A biofilter has some similarities with a constructed wetland but is usually without plants.

The term of constructed wetlands can also be used to describe restored and recultivated land that was destroyed in the past through draining and converting into farmland, or mining.

A constructed wetland is an engineered sequence of water bodies designed to treat wastewater or storm water runoff as illustrated in Figure 11.

Vegetation in a wetland provides a substrate (roots, stems, and leaves) upon which microorganisms can grow as they break down organic materials. This community of microorganisms is known as periphyton. The periphyton and natural chemical processes are responsible for approximately 90 percent of pollutant removal and waste breakdown. The plants remove about seven to ten percent of pollutants, and act as a carbon source for the microbes when they decay. Different species of aquatic plants have different rates of heavy metal uptake, a consideration for plant selection in a constructed wetland used for water treatment.

Constructed wetlands are of two basic types: subsurface flow and surface flow wetlands.

Constructed wetlands are one example of nature-based solutions and of phytoremediation. Nature-based solutions (NBS or NbS) is sustainable management and use of natural features and processes to tackle socio-environmental issues. These issues include for example climate change (mitigation and adaptation), water security, food security, preservation of biodiversity, and disaster risk reduction. Through the use of NBS healthy, resilient, and diverse ecosystems (whether natural, managed, or newly created) can provide solutions for the benefit of both societies and overall biodiversity.

Figure 11: Water from constructed wetlands

The 2019 UN Climate Action Summit highlighted nature-based solutions as an effective method to combat climate change. For example, NBS in the context of climate action can include natural flood management, restoring natural coastal defenses, providing local cooling, and restoring natural fire regimes as illustrated in Figure 12.

Figure 12: NBS

Phytoremediation technologies use living plants to clean up soil, air and water contaminated with hazardous contaminants. It is defined as "the use of green plants and the associated microorganisms, along with proper soil amendments and agronomic techniques to either contain, remove, or render toxic environmental contaminants harmless". The term is an amalgam of the Greek phyto (plant) and Latin remedium (restoring balance). Although attractive for its cost, phytoremediation has not been demonstrated to redress any significant environmental challenge to the extent that contaminated space has been reclaimed.

Constructed wetland systems are highly controlled environments that intend to mimic the occurrences of soil, flora, and microorganisms in natural wetlands to aid in treating wastewater. They are constructed with flow regimes, micro-biotic composition, and suitable plants in order to produce the most efficient treatment process.

Uses: Constructed wetlands can be used to treat raw sewage, storm water, agricultural and industrial effluent. Constructed wetlands mimic the functions of natural wetlands to capture stormwater, reduce nutrient loads, and create diverse wildlife habitat. Constructed wetlands are used for wastewater treatment or for greywater treatment. Many regulatory agencies list treatment wetlands as one of their recommended "best management practices" for controlling urban runoff.

Removal of Contaminants: Physical, chemical, and biological processes combine in wetlands to remove contaminants from wastewater. An understanding of these processes is fundamental not only to designing wetland systems but to understanding the fate of chemicals once they enter the wetland. Theoretically, wastewater treatment within a constructed wetland occurs as it passes through the wetland medium and the plant rhizosphere. A thin film around each root hair is aerobic due to the leakage of oxygen from the rhizomes, roots, and rootlets. Aerobic and anaerobic micro-organisms facilitate the decomposition of organic matter. Microbial nitrification and subsequent denitrification releases nitrogen as gas to the atmosphere. Phosphorus is coprecipitated with iron, aluminum, and calcium compounds located in the root-bed medium. Suspended solids filter out as they settle in the water column in surface flow wetlands or are physically filtered out by the medium within subsurface flow wetlands. Harmful bacteria, fungi, and viruses are reduced by filtration and adsorption by biofilms on the gravel or sand media in subsurface flow and vertical flow systems.

Nitrogen Removal: The dominant forms of nitrogen in wetlands that are of importance to wastewater treatment include organic nitrogen, ammonia, ammonium, nitrate, and nitrite. Total nitrogen refers to all nitrogen species. Wastewater nitrogen removal is important because of ammonia's toxicity to fish if discharged into watercourses. Excessive nitrates in drinking water are thought to cause methemoglobinemia in infants, which decreases the blood's oxygen transport ability. Moreover, excess input of N from point and non-point sources to surface water promotes eutrophication in rivers, lakes, estuaries, and coastal oceans which causes several problems in aquatic ecosystems e.g. toxic algal blooms, oxygen depletion in water, fish mortality, loss of aquatic biodiversity.

Ammonia removal occurs in constructed wetlands (if they are designed to achieve biological nutrient removal) in a similar way as in sewage treatment plants, except that no external, energy-intensive addition of air (oxygen) is needed. It is a two-step process, consisting of nitrification followed by denitrification. The nitrogen cycle is completed as follows: ammonia in the wastewater is converted to ammonium ions; the aerobic Nitrosomonas sp. oxidizes ammonium to nitrite; the bacterium Nitrobacter sp. then converts nitrite to nitrate. Under anaerobic conditions, nitrate is reduced to relatively harmless nitrogen gas that enters the atmosphere.

Nitrification: Nitrification is the biological conversion of organic and inorganic nitrogenous compounds from a reduced state to a more oxidized state, based on the action of two different bacteria types. Nitrification is strictly an aerobic process in which the end product is nitrate (NO_3^-). The process of nitrification oxidizes ammonium (from the wastewater) to nitrite (NO_2^-), and then nitrite is oxidized to nitrate (NO_3^-).

Denitrification: Denitrification is the biochemical reduction of oxidized nitrogen anions, nitrate and nitrite to produce the gaseous products nitric oxide (NO), nitrous oxide (N_2O) and nitrogen gas (N_2), with concomitant oxidation of organic matter. The end product, N_2, and to a lesser extent the intermediary by product, N_2O, are gases that re-enter the atmosphere.

Ammonia removal from mine water: Constructed wetlands have been used to remove ammonia and other nitrogenous compounds from contaminated mine water, including cyanide and nitrate.

Phosphorus Removal: Phosphorus occurs naturally in both organic and inorganic forms. The analytical measure of biologically available orthophosphates is referred to as soluble reactive phosphorus (SR-P). Dissolved organic phosphorus and insoluble forms of organic and inorganic phosphorus are generally not biologically available until transformed into soluble inorganic forms.

In freshwater aquatic ecosystems, phosphorus is typically the major limiting nutrient. Under undisturbed natural conditions, phosphorus is in short supply. The natural scarcity of phosphorus is demonstrated by the explosive growth of algae in water receiving heavy discharges of phosphorus-rich wastes. Because phosphorus does not have an atmospheric component, unlike nitrogen, the phosphorus cycle can be characterized as closed. The removal and storage of phosphorus from wastewater can only occur within the constructed wetland itself. Phosphorus may be sequestered within a wetland system by:

- The binding of phosphorus in organic matter as a result of incorporation into living biomass.
- The precipitation of insoluble phosphates with ferric iron, calcium, and aluminum found in wetland soils.

Biomass Plants Incorporation: Aquatic vegetation may play an important role in phosphorus removal and, if harvested, extend the life of a system by postponing phosphorus saturation of the sediments. Plants create a unique environment at the biofilm's attachment surface. Certain plants transport oxygen which is released at the biofilm/root interface, adding oxygen to the wetland system. Plants also increase soil or other root-bed medium hydraulic conductivity. As roots and rhizomes grow, they are thought to disturb and loosen the medium, increasing its porosity, which may allow more effective fluid movement in the rhizosphere. When roots decay, they leave behind ports and channels known as macropores which are effective in channeling water through the soil.

Metals Removal: Constructed wetlands have been used extensively for the removal of dissolved metals and metalloids. Although these contaminants are prevalent in mine drainage, they are also found in stormwater, landfill leachate, and other sources (e.g., leachate or flue-gas desulfurization (FDG) wash water at coal-fired power plants), for which treatment wetlands have been constructed for mines.

Mine Water/Acid Drainage Removal: Constructed wetlands can also be used for the treatment of acid mine drainage from coal mines.

Pathogen Removal: Constructed wetlands are not designed for pathogen removal, but have been designed to remove other water quality constituents such as suspended solids, organic matter (biochemical oxygen demand and chemical oxygen demand), and nutrients (nitrogen and phosphorus).

All types of pathogens are expected to be removed in a constructed wetland; however, greater pathogen removal is expected to occur in a subsurface wetland. In a free water surface flow wetland, one can expect 1 to 2 log10 reduction of pathogens; however, bacteria and virus removal may be less than 1 log10 reduction in systems that are heavily planted with vegetation. This is because constructed wetlands typically include vegetation which assists in removing other pollutants such as nitrogen and phosphorus. Therefore, the importance of sunlight exposure in removing viruses and bacteria is minimized in these systems.

Removal in a properly designed and operated free water surface flow wetland is reported to be less than 1 to 2 log10 for bacteria, less than 1 to 2 log10 for viruses, 1 to 2 log10 for protozoa, and 1 to 2 log10 for helminths. In subsurface flow wetlands, the expected removal of pathogens is reported to be 1 to 3 log10 for bacteria, 1 to 2 log10 for viruses, 2 log10 for protozoa, and 2 log10 for helminths.

The log10 removal efficiencies reported here can also be understood in terms of the common way of reporting removal efficiencies as percentages: 1 log10 removal is equivalent to a removal efficiency of 90%; 2 log10 = 99%; 3 log10 = 99.9%; 4 log10 = 99.99%, and so on.

Types and Design Considerations: The main three broad types of constructed wetlands include:

- *Subsurface Flow Constructed Wetland:* In subsurface flow constructed wetlands, the flow of wastewater occurs between the roots of the plants and there is no water surfacing (it is kept below gravel). As a result, the system is more efficient, does not attract mosquitoes, is less odorous and less sensitive to winter conditions. Additionally, less area is needed to purify water. A downside to the system are the intakes, which can clog or bioclog easily, although some larger sized gravel will often solve this problem. Subsurface flow wetlands can be further classified as horizontal flow or vertical flow constructed wetlands. In the vertical flow constructed wetland, the effluent moves vertically from the planted layer down through the substrate and out (requiring air pumps to aerate the bed) as illustrated in Figure 13.

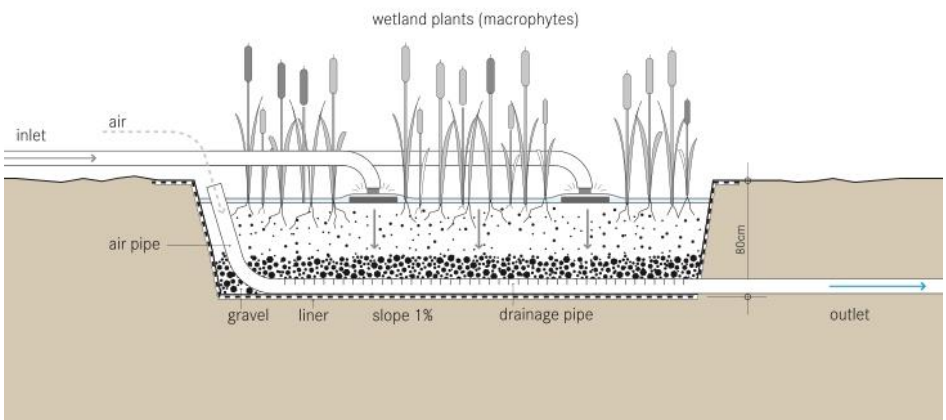

Figure 13: Vertical flow

In the horizontal flow constructed wetland, the effluent moves horizontally via gravity, parallel to the surface, with no surface water thus avoiding mosquito breeding as illustrated in Figure 14. Vertical flow constructed wetlands are considered to be more efficient with less area required compared to horizontal flow constructed wetlands. However, they need to be interval-loaded, and their design requires more know-how while horizontal flow constructed wetlands can receive wastewater continuously and are easier to build.

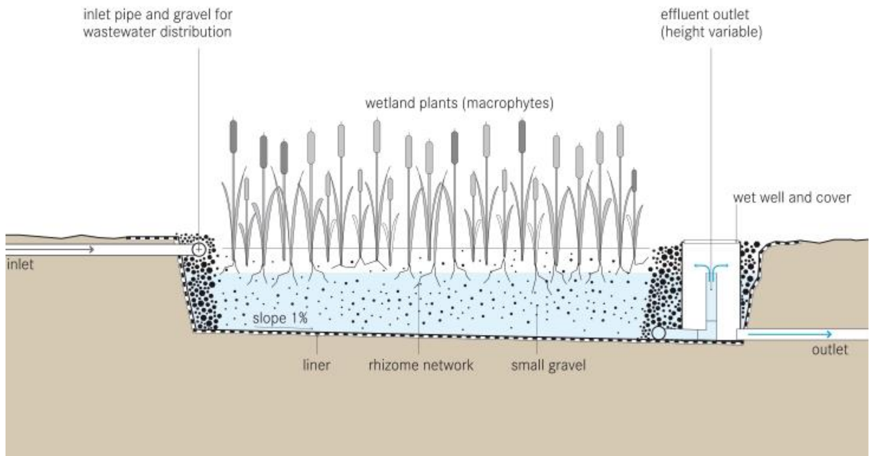

Figure 14: Horizontal flow

Due to the increased efficiency, a vertical flow subsurface constructed wetland requires only about 3 square meters (32 sq ft) of space per person equivalent, down to 1.5 square meters in hot climates.

- *Surface Flow Constructed Wetland:* (this wetland has horizontal flow): surface flow wetlands, also known as free water surface constructed wetlands, can be used for tertiary treatment or polishing of effluent from wastewater treatment plants. They are also suitable to treat stormwater drainage.

  Surface flow constructed wetlands always have horizontal flow of wastewater across the roots of the plants, rather than vertical flow as illustrated in Figure 15. They require a relatively large area to purify water compared to subsurface flow constructed wetlands and may have increased smell and lower performance in winter.

  Surface flow wetlands have a similar appearance to ponds for wastewater treatment (such as "waste stabilization ponds") but are in the technical literature not classified as ponds. Pathogens are destroyed by natural decay, predation from higher organisms, sedimentation, and UV irradiation since the water is exposed to direct sunlight. The soil layer below the water is anaerobic but the roots of the plants release oxygen around them, this allows complex biological and chemical reactions.

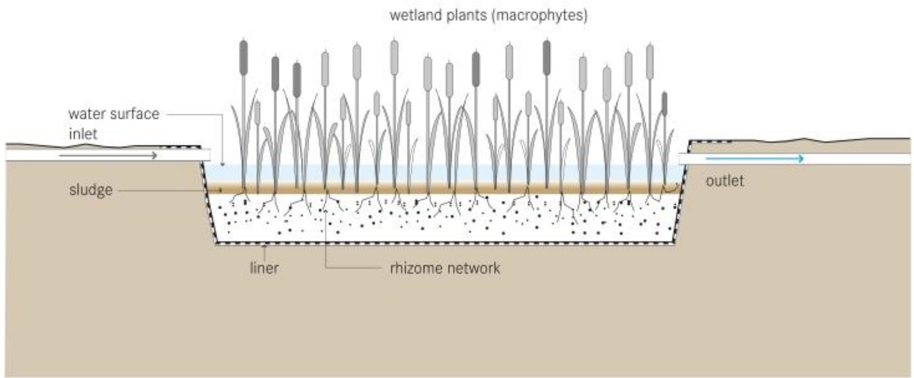

Figure 15: Surface flow

Surface flow wetlands can be supported by a wide variety of soil types including bay mud and other silty clays.

Plants such as water hyacinth (Eichhornia crassipes) and Pontederia spp. are used worldwide (although Typha and Phragmites are highly invasive). However, surface flow constructed wetlands may encourage mosquito breeding. They may also have high algae production that lowers the effluent quality and due to open water surface mosquitos and odors, it is more difficult to integrate them in an urban neighborhood.

- *Floating Treatment Wetland:* Floating treatment wetlands (FTWs) or islands as illustrated in Figure 16, are small artificial platforms that allow these aquatic emergent plants to grow in water that is typically too deep for them. Their roots spread through the floating islands and down into the water creating dense columns of roots with lots of surface area.

Figure 16: Floating treatment wetland

- **Bio Towers**

A bio tower in wastewater treatment is a type of biological treatment system used to remove contaminants from wastewater. It consists of a tall, vertical tower filled with a medium, such as plastic or wood, where microorganisms grow and break down organic matter in the wastewater as illustrated in Figure 17. As the wastewater flows through the tower, the microorganisms remove pollutants, making the water cleaner before it is discharged. Bio towers are a common and effective method for treating wastewater in various industries and municipal wastewater treatment plants.

Figure 17: Bio tower

A bio tower is a unit that uses oxidation of organic wastes by aerobic bacteria in liquid effluents, mostly industrial effluents. It is used to reduce the BOD (Biological Oxygen Demand) value of a liquid effluent. A bio tower is an above-ground cylindrical or rectangular structure that contains plastic media with a high surface area, such as randomly filled polypropylene shapes or modular blocks of corrugated PVC. The effluent is pumped to the top of the tower and distributed over the surface of the media using rotating distributors, troughs, or nozzles, and splash plates. The effluent trickles down over the media, which become coated with microbial films (aerobic bacteria) that consume the organic material.

The outer surfaces of the microbial films are highly aerobic, being continuously aerated by the air that passes upwards through the media. Below this the conditions become progressively less aerobic as the film builds up. Eventually the film sloughs off but the plastic medium has a large void volume that ensures unimpeded passage of sloughed biomass, air and liquor.

The treated liquid may be recycled over the bio tower before the biological solids are settled out. Bio towers can be arranged in series with inter-stage settlement. Fan ventilation may be incorporated where the biomass must be highly aerobic, for example where nitrification is required.

Bio towers are used in the food and drink and other industries. They can accommodate high hydraulic and BOD loadings and may be employed as a roughing stage for the treatment of high strength industrial wastewaters prior to discharge to sewer or as the secondary or tertiary part of a complete treatment system. Some effluents, such as sugary solutions, may require nutrients such as nitrogen or phosphorus to be added to maintain the oxidation process.

Problems such as fly nuisance or odor can be avoided through fan ventilation or treated by roofing over and scrubbing where high loadings produce large quantities of sludge and solids contact, re-aeration system may be advantageous.

With an average effluent and loading rates of about 0.5 kg BOD/m^3/day, over 90% of the BOD may be removed. With a loading rate of 2.5 kg BOD/m^3/day, about 60% of the BOD may be removed. Combined with solids-contacting and re-aeration, about 95% of the BOD can be removed.

Media used for BOD removal has surface area ratios of 100-240 m^2/m^3. Nitrification requires the higher surface area media and low loading.

A bio tower may be up to 10 m high and requires energy to pump and recirculate wastewater over the medium. A typical industrial bio tower with a volume of 1000 m^3, and an effluent flow of 25 m^3/hour recycled 6 times would use an 11kW pump.

- **Rotating Biological Contactors**

A rotating biological contactor or RBC is a biological fixed-film treatment process used in the secondary treatment of wastewater following primary treatment. The primary treatment process involves removal of grit, sand, and coarse suspended material through a screening process, followed by settling of suspended solids. The RBC process allows the wastewater to come in contact with a biological film in order to remove the pollutants in the wastewater before discharge of the treated wastewater to the environment, usually a body of water (river, lake, or ocean).

A rotating biological contactor is a type of secondary (biological) treatment process. It consists of a series of closely spaced, parallel discs mounted on a rotating shaft which is supported just above the surface of the wastewater as illustrated in Figure 18. Microorganisms grow on the surface of the discs where biological degradation of the wastewater pollutants takes place.

Rotating biological contactors (RBCs) are capable of withstanding surges in organic load.

Figure 18: A rotating biological contactor

To be successful, the micro-organisms need both oxygen to live and food to grow. Oxygen is obtained from the atmosphere as the disks rotate. As the micro-organisms grow, they build up on the media until they are sloughed off due to shear forces provided by the rotating discs in the sewage as illustrated in Figure 19. Effluent from the RBC is then passed through a clarifier where the sloughed biological solids in suspension settle as a sludge.

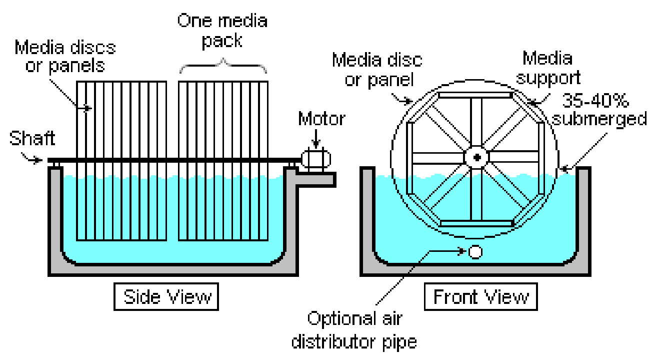

Figure 19: Rotating discs

Operation: The rotating packs of disks (known as the media) are contained in a tank or trough and rotate at between 2 and 5 revolutions per minute. Commonly used plastics for the media are polyethylene, PVC, and expanded polystyrene. The shaft is aligned with the flow of wastewater so that the discs rotate at right angles to the flow, with several packs usually combined to make up a treatment train. About 40% of the disc area is immersed in wastewater.

Biological growth is attached to the surface of the disc and forms a slime layer. The discs contact the wastewater with the atmospheric air for oxidation as it rotates. The rotation helps to slough off excess solids. The disc system can be staged in series to obtain nearly any detention time or degree of removal required. Since the systems are staged, the culture of the later stages can be acclimated to the slowly degraded materials.

The discs consist of plastic sheets ranging from 2 to 4 m in diameter and are up to 10 mm thick. Several modules may be arranged in parallel and/or in series to meet the flow and treatment requirements. The discs are submerged in waste water to about 40% of their diameter. Approximately 95% of the surface area is thus alternately submerged in waste water and then exposed to the atmosphere above the liquid. Carbonaceous substrate is removed in the initial stage of RBC. Carbon conversion may be completed in the first stage of a series of modules, with nitrification being completed after the 5^{th} stage. Most design of RBC systems will include a minimum of 4 or 5 modules in series to obtain nitrification of waste water. As the biofilm biomass changes from Carbon metabolizing to nitrifying, a visual color change from grey/beige to brown can be seen which is illustrated in Figure 20.

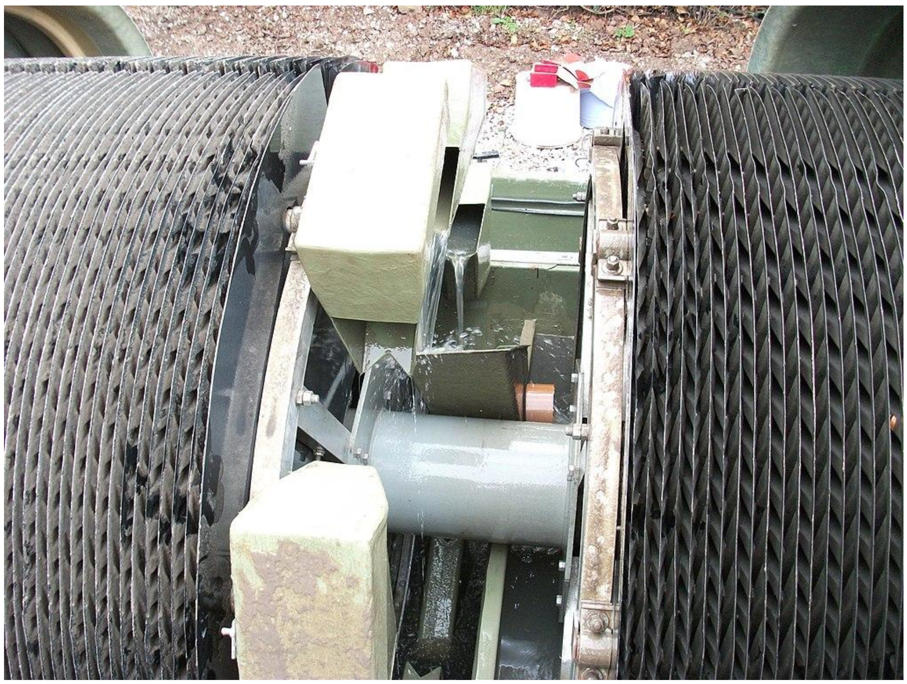

Figure 20: Illustration for water color

Biofilm color transition from grey/beige to brown, left to right, indicates slow transition from Carbon metabolizing bacteria to Nitrogen metabolizing bacteria.

Biofilms, which are biological growths that become attached to the discs, assimilate the organic materials (measured as BOD_5) in the wastewater. Aeration is provided by the rotating action, which exposes the media to the air after contacting them with the wastewater, facilitating the degradation of the pollutants being removed. The degree of wastewater treatment is related to the amount of media surface area and the quality and volume of the inflowing wastewater.

RBC's regularly achieve the following effluent parameters for treated waste water: BOD_5: 20 mg/L, Suspended Solids: 30 mg/L, and Ammonia N: 20 mg/L. They consume very low power and make little noise due to the slow rotation of the rotor (2-5 RPM). They are generally considered very robust and low maintenance systems. Better discharge effluent parameters can be achieved by adding a tertiary polishing filter after the RBC to lower BOD_5, SS, and Ammonia Nitrogen. An additional UV or Chlorination step can achieve effluent parameters that make the water suitable for irrigation or toilet flushing.

Suspended Growth Systems

Suspended-growth systems include activated sludge and surface aerated lagoons or ponds.

- *Activated Sludge:* which is an aerobic treatment system, based on the maintenance and recirculation of a complex biomass composed of micro-organisms (bacteria and protozoa) able to absorb and adsorb the organic matter carried in the wastewater.

  Activated sludge is a common suspended-growth method of secondary treatment. Activated sludge plants encompass a variety of mechanisms and processes using dissolved oxygen to promote growth of biological floc that substantially removes organic material.

  Biological floc is an ecosystem of living biota subsisting on nutrients from the inflowing primary clarifier effluent. These mostly carbonaceous dissolved solids undergo aeration to be broken down and either biologically oxidized to carbon dioxide or converted to additional biological floc of reproducing micro-organisms. Nitrogenous dissolved solids (amino acids, ammonia, etc.) are similarly converted to biological floc or oxidized by the floc to nitrites, nitrates, and, in some processes, to nitrogen gas through denitrification.

  While denitrification is encouraged in some treatment processes, denitrification often impairs the settling of the floc causing poor quality effluent in many suspended aeration plants. Overflow from the activated sludge mixing chamber is sent to a clarifier where the suspended biological floc settles out while the treated water moves into tertiary treatment or disinfection. Settled floc is returned to the mixing basin to continue growing in primary effluent.

  A generalized schematic of an activated sludge process is illustrated in Figure 20.

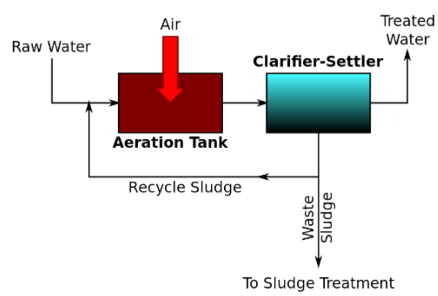

Figure 20: A generalized schematic of an activated sludge process

  Like most ecosystems, population changes among activated sludge biota can reduce treatment efficiency. Nocardia, a floating brown foam sometimes misidentified as sewage fungus, is the best known of many different fungi and protists that can overpopulate the floc and cause process upsets. Elevated concentrations of toxic wastes including pesticides, industrial metal plating waste, or extreme pH, can kill the biota of an activated sludge reactor ecosystem.

The *Oxidation Ditch* is a modified activated sludge biological treatment process that uses long solids retention times (SRTs) to remove biodegradable organics. The typical oxidation ditch is equipped with aeration rotors or brushes that provide aeration and circulation as illustrated in Figure 21.

Figure 21: Typical oxidation ditch

The wastewater moves through the ditch at 1 to 2 ft/s. The ditch may be designed for continuous or intermittent operation. Because of this feature, this process may be adaptable to the fluctuations in flows and loadings associated with recreation area wastewater production. Several manufacturers have developed modifications to the oxidation ditch design to remove nutrients in conditions cycled or phased between the anoxic and aerobic states.

One type of system that combines secondary treatment and settlement is the cyclic activated sludge (CASSBR), or sequencing batch reactor (SBR). Typically, activated sludge is mixed with raw incoming sewage, and then mixed and aerated. The settled sludge is run off and re-aerated before a proportion is returned to the headworks.

The disadvantage of the CASSBR process is that it requires a precise control of timing, mixing and aeration. This precision is typically achieved with computer controls linked to sensors. Such a complex, fragile system is unsuited to places where controls may be unreliable, poorly maintained, or where the power supply may be intermittent.

There are a wide range of types of *Package Plants*, often serving small communities or industrial plants that may use hybrid treatment processes often involving the use of aerobic sludge to treat the incoming sewage. In such plants the primary settlement stage of treatment may be omitted. In these plants, a biotic floc is created which provides the required substrate.

Package plants are designed and fabricated by specialty engineering firms in dimensions that allow for their transportation to the job site in public highways, typically width and height of 3.7 by 3.7 meters (12 ft × 12 ft). The length varies with capacity with larger plants being fabricated in pieces and welded on site. Steel is preferred over synthetic materials (e.g., plastic) for its durability. Package plants are commonly variants of extended aeration, to promote the "fit and forget" approach required for small communities without dedicated operational staff.

Extended aeration package plants use separate basins for aeration and settling, and are somewhat larger than SBR plants with reduced timing sensitivity.

Membrane Bio Reactors (MBR) are activated sludge systems using a membrane liquid-solid phase separation process. The membrane component uses low pressure microfiltration or ultrafiltration membranes and eliminates the need for a secondary clarifier or filtration. The membranes are typically immersed in the aeration tank; however, some applications utilize a separate membrane tank.

One of the key benefits of an MBR system is that it effectively overcomes the limitations associated with poor settling of sludge in conventional activated sludge (CAS) processes. The technology permits bioreactor operation with considerably higher mixed liquor suspended solids (MLSS) concentration than CAS systems, which are limited by sludge settling. The process is typically operated at MLSS in the range of 8,000 – 12,000 mg/L, while CAS are operated in the range of 2,000 – 3,000 mg/L. The elevated biomass concentration in the MBR process allows for very effective removal of both soluble and particulate biodegradable materials at higher loading rates. Thus, increased sludge retention times, usually exceeding 15 days, ensure complete nitrification even in extremely cold weather.

The cost of building and operating an MBR is often higher than conventional methods of sewage treatment. Membrane filters can be blinded with grease or abraded by suspended grit and lack a clarifier's flexibility to pass peak flows. Technology has become increasingly popular for reliably pretreated waste streams and has gained wider acceptance where infiltration and inflow have been controlled, however, and the life-cycle costs have been steadily decreasing. The small footprint of MBR systems, and the high-quality effluent produced, make them particularly useful for water reuse applications.

Aerobic Granular Sludge as illustrated in Figure 22, can be formed by applying specific process conditions that favor slow growing organisms such as PAOs (polyphosphate accumulating organisms) and GAOs (glycogen accumulating organisms). Another key part of granulation is selective wasting whereby slow settling floc-like sludge is discharged as waste sludge and faster settling biomass is retained. This process has been commercialized as Nereda process.

Figure 22: Aerobic granular sludge

- *Surface Aerated Lagoons:* Aerated lagoons are a low technology suspended-growth method of secondary treatment using motor-driven aerators floating on the water surface to increase atmospheric oxygen transfer to the lagoon and to mix the lagoon contents. The floating surface aerators are typically rated to deliver the amount of air equivalent to 1.8 to 2.7 kg O_2/kW·h.

  Aerated lagoons provide less effective mixing than conventional activated sludge systems and do not achieve the same performance level. The basins may range in depth from 1.5 to 5.0 meters. Surface-aerated basins achieve 80 to 90 percent removal of BOD with retention times of 1 to 10 days. Many small municipal sewage systems in the United States (1 million gal./day or less) use aerated lagoons. A typical surface-aerated basin (using motor-driven floating aerators) is illustrated in Figure 23.

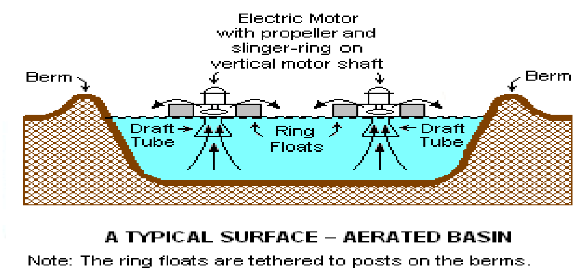

Figure 23: Surface-aerated basin

- *Emerging Technologies:* Biological Aerated (or Anoxic) Filter (BAF) or Biofilters combine filtration with biological carbon reduction, nitrification, or denitrification. BAF usually includes a reactor filled with a filter media. The media is either in suspension or supported by a gravel layer at the foot of the filter. The dual purpose of this media is to support highly active biomass that is attached to it and to filter suspended solids. Carbon reduction and ammonia conversion occurs in aerobic mode and sometime achieved in a single reactor while nitrate conversion occurs in anoxic mode. BAF is operated either in upflow or downflow configuration depending on design specified by manufacturer.

Aerobic and Activated Sludge Treatment

An aerobic treatment system (ATS), often called an aerobic septic system, is a small-scale sewage treatment system similar to a septic tank system, but which uses an aerobic process for digestion rather than just the anaerobic process used in septic systems. These systems are commonly found in rural areas where public sewers are not available, and may be used for a single residence or for a small group of homes.

Unlike the traditional septic system, the aerobic treatment system produces a high-quality secondary effluent, which can be sterilized and used for surface irrigation. This allows much greater flexibility in the placement of the leach field, as well as cutting the required size of the leach field by as much as half.

Aerobic treatment systems convert organic contaminants to end products such as water, carbon dioxide, and additional microorganisms. This treatment method uses microorganisms with metabolic processes that require oxygen. Aerobic treatment systems use aeration to supply wastewater with oxygen, which feeds microorganisms that then consume waste from the wastewater.

Process:

The ATS process generally consists of the following phases:

- Pre-treatment stage to remove large solids and other undesirable substances.
- Aeration stage, where aerobic bacteria digest biological wastes.
- Settling stage allows undigested solids to settle. This forms a sludge that must be periodically removed from the system.
- Disinfecting stage, where chlorine or similar disinfectant is mixed with the water, to produce an antiseptic output. Another option is UV disinfection, where the water is exposed to UV light inside of a UV disinfection unit.

The disinfecting stage is optional, and is used where a sterile effluent is required, such as cases where the effluent is distributed above ground. The disinfectant typically used is tablets of calcium hypochlorite, which are specially made for waste treatment systems. The tablets are intended to break down quickly in sunlight. Stabilized forms of chlorine persist after the effluent is dispersed, and can kill plants in the leach field.

Since the ATS contains a living ecosystem of microbes to digest the waste products in the water, excessive amounts of items such as bleach or antibiotics can damage the ATS environment and reduce treatment effectiveness. Non-digestible items should also be avoided, as they will build up in the system and require more frequent sludge removal.

Activated sludge treatment is a common aerobic process. Using both aeration and flocculation, this process uses a sludge blanket made up of clumped biosolids known as flocs. These flocs form during the aeration process and settle at the bottom of the water tank.

During the activated sludge treatment process, water treatment plants use secondary clarifiers to mix settled sewage with raw or primary sludge. They then use air compressors to add compressed air to the mixture and pump the flocs back into the water inside the aeration tank, allowing the microorganisms in the return sludge to break down more waste. Treatment plants use different processes and equipment for this treatment option:

- *Surface Aerators or Diffusers:* Several treatment plants mix air into the water using surface aerators in lagoons. Other plants use ceramic diffusers or rubber membrane diffusers in aeration tanks.

  An aeration tank pumps air through a tube or disc-shaped diffusers containing several small perforations. Air flows through the perforations and enters the aeration tank as tiny bubbles. These bubbles rise through the water tank to transfer oxygen and facilitate aerobic digestion.

- *Media Filters:* Several treatment plants facilitate aerobic digestion using media filters. The moving bed biofilm reactor (MBBR) system is a common media filter system. This type of system uses thousands of small plastic media pieces inside a basin. A biofilm forms on the media pieces when bacteria attach to them.

  The media pieces comprise approximately 50% to 70% of the basin's volume and provide surface areas for bacterial growth. The pieces maximize space by suspending throughout the water, which is possible due to their density. Each intricate media piece resembles a wheel with several small spokes, providing maximum surface area for bacterial growth. The optimal shape and density of media pieces allow them to reach as much waste as possible and efficiently digest it to reduce hydraulic retention time.

Anaerobic Treatment

Anaerobic processes work without oxygen to convert organic contaminants to biofuel gas. This process works without any form of oxygen and often occurs in covered digestion lagoons. Inside the lagoons, anaerobic bacteria break down organic waste. The anaerobic process uses less energy than the aerobic process because it does not require equipment to pump oxygen into the wastewater.

Anaerobic water treatment typically produces biogas byproducts such as water vapor, carbon dioxide, and methane. Wastewater treatment plants often reuse the resulting methane to fuel their plants. Anaerobic treatment is ideal for plants that treat water containing concentrated amounts of biodegradable materials such as food waste, animal excrement, or municipal waste.

Anoxic Treatment

Anoxic treatment treats water using microbes with metabolic processes that do not require oxygen. This process occurs without free molecular oxygen, but it can happen in the presence of some oxygen in the form of sulfates, nitrates, or nitrites. Plants often use this process to denitrify wastewater containing high nitrogen content.

Anoxic denitrification uses a suspended growth system or a trickling filter to convert nitrogen to nitrate. The wastewater plant then introduces certain microbes to consume the nitrogen content in the nitrate and leave only oxygen molecules behind. Treatment plants usually tightly seal reactors to prevent molecular oxygen interference.

Key Differences between Aerobic and Anaerobic Wastewater Treatment

Aerobic Wastewater Treatment

The aerobic wastewater systems have the following characteristics:

- Aerobic systems use oxygen.
- Aerobic systems can be a stand-alone system, or combined with an anaerobic system.
- Aerobic systems tend to be more expensive than anaerobic.
- Aerobic systems require electricity and mechanical air pumps to treat the waste.
- A qualified professional is required to inspect and maintain the electrical and mechanical components regularly to ensure they are working correctly.
- Aerobic treatment of wastewater is more often used in rural areas or small communities where a central facility is not practical to implement.

Anaerobic Wastewater Treatment

The anaerobic wastewater systems have the following characteristics:

- Anaerobic systems dos not use oxygen.
- Anaerobic systems generate less sludge than aerobic.
- Anaerobic systems have lower sludge-handling costs than aerobic systems.
- Anaerobic systems require no electricity.
- Anaerobic components require lower level of maintenance than aerobic.
- Anaerobic treatment systems may be used in areas where a central treatment plant is not possible. They can also be used in individual households or in small shared facilities.

Tertiary Treatment

Tertiary treatment is a method of wastewater treatment that consists of eliminating non-biodegradable pollutants. It follows primary and secondary treatment. This technique allows the removal of phosphorus and nitrogen contained in the water to refine it. It is based on the use of chemical and physical processes.

During tertiary or chemical treatment, the aim is to increase the final quality of the water so that it can be returned to the environment (sea, rivers, lakes and other hydrographic basins) and, in some cases, used for human activity as shown in Figure 24. To achieve this, a series of processes are carried out to eliminate pathogenic agents, such as fecal bacteria.

Figure 24: water treatment

The techniques used include filtration with sand beds or other materials, and disinfection, either using chlorine (usually sodium hypochlorite) or UV light, to reduce the amount of microscopic living organisms that have been generated in the previous stages.

The final stage of the tertiary wastewater treatment process involves removing the chlorine that was used to disinfect the water. This step is very important because chlorine is harmful to aquatic life. Chlorine also reduces biological water quality when it is present in high concentrations.

To remove the chlorine, a compound called sodium bisulfite is added to the water. Chlorine ions in the water react with this chemical and are removed. Once the chlorine concentration has been reduced to a safe level, the treated water is now considered clean enough to be safely released into the environment.

Treated Effluent and Sludge Disposal

Sewage sludge treatment describes the processes used to manage and dispose of sewage sludge produced during sewage treatment. Sludge treatment is focused on reducing sludge weight and volume to reduce transportation and disposal costs, and on reducing potential health risks of disposal options. Water removal is the primary means of weight and volume reduction, while pathogen destruction is frequently accomplished through heating during thermophilic digestion, composting, or incineration.

The choice of a sludge treatment method depends on the volume of sludge generated, and comparison of treatment costs required for available disposal options. Air-drying and composting may be attractive to rural communities, while limited land availability may make aerobic digestion and mechanical dewatering preferable for cities, and economies of scale may encourage energy recovery alternatives in metropolitan areas.

Sludge is mostly water with some amounts of solid material removed from liquid sewage. Primary sludge includes settleable solids removed during primary treatment in primary clarifiers, while secondary sludge is sludge separated in secondary clarifiers that are used in secondary treatment bioreactors or processes using inorganic oxidizing agents as illustrated in Figure 25.

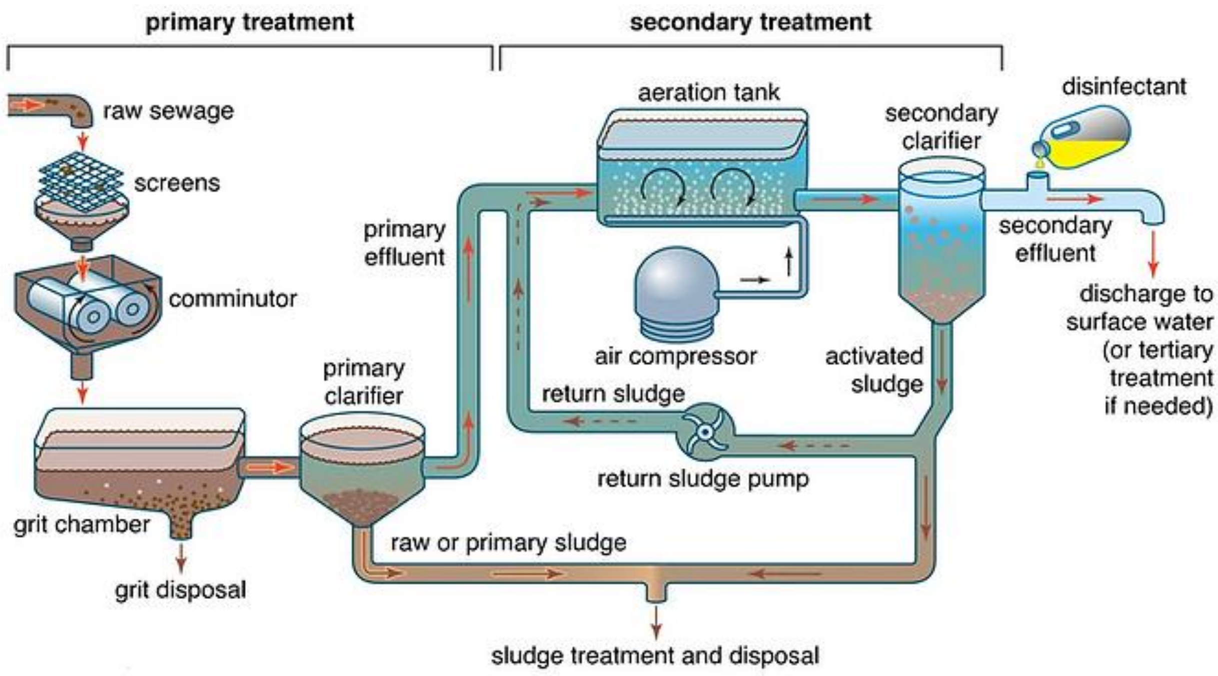

Figure 25: Sludge treatment

In intensive sewage treatment processes, the sludge produced needs to be removed from the liquid line on a continuous basis because the volumes of the tanks in the liquid line have insufficient volume to store sludge. This is achieved in order to keep the treatment processes compact and in balance (production of sludge approximately equal to the removal of sludge). The sludge removed from the liquid line goes to the sludge treatment line. Aerobic processes (such as the activated sludge process) tend to produce more sludge compared with anaerobic processes. On the other hand, in extensive (natural) treatment processes, such as ponds and constructed wetlands, the produced sludge remains accumulated in the treatment units (liquid line) and is only removed after several years of operation.

Sludge treatment options depend on the amount of solids generated and other site-specific conditions. Composting is most often applied to small-scale plants with aerobic digestion for mid-sized operations, and anaerobic digestion for the larger-scale operations. The sludge is sometimes passed through a so-called pre-thickener which de-waters the sludge. Types of pre-thickeners include centrifugal sludge thickeners, rotary drum sludge thickeners, and belt filter presses. Dewatered sludge may be incinerated or transported offsite for disposal in a landfill or use as an agricultural soil amendment.

Energy may be recovered from sludge through methane gas production during anaerobic digestion or through incineration of dried sludge, but energy yield is often insufficient to evaporate sludge water content or to power blowers, pumps, or centrifuges required for dewatering.
Coarse primary solids and secondary sewage sludge may include toxic chemicals removed from liquid sewage by sorption onto solid particles in clarifier sludge. Reducing sludge volume may increase the concentration of some of these toxic chemicals in the sludge.

Biosolids: is a term often used in wastewater engineering publications and public relations efforts by local water authorities when they want to put the focus on reuse of sewage sludge, after the sludge has undergone suitable treatment processes. In fact, biosolids are defined as organic wastewater solids that can be reused after stabilization processes such as anaerobic digestion and composting as illustrated in Figure 26.

Figure 26: Anaerobic digestion

The term "biosolids" was introduced by the Water Environment Federation in the U.S. in 1998. However, some people argue that the term is a euphemism to hide the fact that sewage sludge may also contain substances that could be harmful to the environment when the treated sludge is applied to land, for example environmental persistent pharmaceutical pollutants and heavy metal compounds.

Sludge Treatment Processes

The sludges accumulated in a wastewater treatment process must be treated and disposed of in a safe and effective manner. In many large plants the raw sludges are reduced in volume by a process of digestion.

Thickening: Thickening is often the first step in a sludge treatment process. Sludge from primary or secondary clarifiers may be stirred (often after addition of clarifying agents) to form larger, more rapidly settling aggregates. Primary sludge may be thickened to about 8 or 10 percent solids, while secondary sludge may be thickened to about 4 percent solids. Thickeners often resemble a clarifier with the addition of a stirring mechanism as illustrated in Figure 27.

Figure 27: Thickeners

Thickened sludge with less than ten percent solids may receive additional sludge treatment while liquid thickener overflow is returned to the sewage treatment process.

Dewatering: The water content of sludge may be reduced by centrifugation, filtration, and/or evaporation to reduce transportation costs of disposal, or to improve suitability for composting. Centrifugation may be a preliminary step to reduce the sludge volume for subsequent filtration or evaporation. Filtration may occur through underdrains in a sand drying bed or as a separate mechanical process in a belt filter press. Filtrate and centrate are typically returned to the sewage treatment process as illustrated in Figure 28. After dewatering, the sludge may be handled as a solid containing 50 to 75 percent water. Dewatered sludges with higher moisture content are usually handled as liquids.

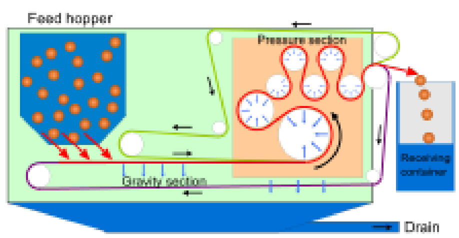

Figure 28: Filtrate and centrate

Digestion: Many sludges are treated using a variety of digestion techniques, the purpose of which is to reduce the amount of organic matter and the number of disease- causing microorganisms present in the solids. The most common treatment options include anaerobic digestion, aerobic digestion, and composting. Sludge digestion offers significant cost advantages by reducing sludge quantity by nearly 50% and providing biogas as a valuable energy source.

The purpose of digestion is to reduce the amount of organic matter and the number of disease-causing microorganisms present in the solids. The process is often optimized to generate methane gas which can be used as a fuel to provide energy to power the plant or for sale.

Anaerobic Digestion: Anaerobic digestion is a bacterial process that is carried out in the absence of oxygen. The process can either be thermophilic digestion, in which sludge is fermented in tanks at a temperature of 55 °C, or mesophilic, at a temperature of around 36 °C. Though allowing shorter retention time (and thus smaller tanks), thermophilic digestion is more expensive in terms of energy consumption for heating the sludge.

Mesophilic anaerobic digestion (MAD) is also a common method for treating sludge produced at sewage treatment plants. The sludge is fed into large tanks and held for a minimum of 12 days to allow the digestion process to perform the four stages necessary to digest the sludge. These are hydrolysis, acidogenesis, acetogenesis, and methanogenesis. In this process the complex proteins and sugars are broken down to form more simple compounds such as water, carbon dioxide, and methane.

Anaerobic digestion generates biogas with a high proportion of methane that may be used to both heat the tank and run engines or microturbines for other on-site processes. Methane generation is a key advantage of the anaerobic process. Its key disadvantage is the long time required for the process (up to 30 days) and the high capital cost. Many larger sites utilize the biogas for combined heat and power, using the cooling water from the generators to maintain the temperature of the digestion plant at the required 35 ± 3 °C. Sufficient energy can be generated in this way to produce more electricity than the machines require. Anaerobic digesters for sewage sludge treatment are illustrated in Figure 29.

Figure 29: Anaerobic digesters for sewage sludge treatment

Aerobic Digestion: Aerobic digestion is a bacterial process occurring in the presence of oxygen resembling a continuation of the activated sludge process. Under aerobic conditions, bacteria rapidly consume organic matter and convert it into carbon dioxide. Once there is a lack of organic matter, bacteria die and are used as food by other bacteria. This stage of the process is known as endogenous respiration. Solids reduction occurs in this phase. Because the aerobic digestion occurs much faster than anaerobic digestion, the capital costs of aerobic digestion are lower.

However, the operating costs are characteristically much greater for aerobic digestion because of energy used by the blowers, pumps, and motors needed to add oxygen to the process. However, recent technological advances include non-electric aerated filter systems that use natural air currents for the aeration instead of electrically operated machinery.

Aerobic digestion can also be achieved by using diffuser systems or jet aerators to oxidize the sludge. Fine bubble diffusers are typically the more cost-efficient diffusion method, however, plugging is typically a problem due to sediment settling into the smaller air holes. Coarse bubble diffusers are more commonly used in activated sludge tanks or in the flocculation stages. A key component for selecting diffuser type is to ensure it will produce the required oxygen transfer rate.

Sidestream Treatment Technologies

Sludge treatment technologies that are used for thickening or dewatering of sludge have two products: the thickened or dewatered sludge, and a liquid fraction which is called sludge treatment liquids, sludge dewatering streams, liquors, centrate (if it stems from a centrifuge), filtrate (if it stems from a belt filter press), or similar. This liquid requires further treatment as it is high in nitrogen and phosphorus, particularly if the sludge has been anaerobically digested. The treatment can take place in the sewage treatment plant itself (by recycling the liquid to the start of the treatment process) or as a separate process.

Phosphorus Recovery: One method for treating sludge dewatering streams is by using a process that is also used for phosphorus recovery. Another benefit for sewage treatment plant operators of treating sludge dewatering streams for phosphorus recovery is that it reduces the formation of obstructive struvite scale in pipes, pumps, and valves. Such obstructions can be a maintenance headache particularly for biological nutrient removal plants where the phosphorus content in the sewage sludge is elevated. For example, a well-known company is marketing a process based on controlled chemical precipitation of phosphorus in a fluidized bed reactor that recovers struvite in the form of crystalline pellets from sludge dewatering streams. The resulting crystalline product is sold to the agriculture, turf, and ornamental plants sectors as fertilizer under the registered trade name "Crystal Green".

Composting: Composting is an aerobic process of mixing sewage sludge with agricultural byproduct sources of carbon such as sawdust, straw, or wood chips. In the presence of oxygen, bacteria digesting both the sewage sludge and the plant material generate heat to kill disease-causing microorganisms and parasites. Maintenance of aerobic conditions with 10 to 15 percent oxygen requires bulking agents allowing air to circulate through the fine sludge solids. Stiff materials like corn cobs, nut shells, shredded tree-pruning waste, or bark from lumber or paper mills better separate sludge for ventilation than softer leaves and lawn clippings. Light, biologically inert bulking agents like shredded tires may be used to provide structure where small, soft plant materials are the major source of carbon.

The uniform distribution of pathogen-killing temperatures may be aided by placing an insulating blanket of previously composted sludge over aerated composting piles. The initial moisture content of the composting mixture should be about 50 percent; but temperatures may be inadequate for pathogen reduction where wet sludge or precipitation raises compost moisture content above 60 percent. Composting mixtures may be piled on concrete pads with built-in air ducts to be covered by a layer of unmixed bulking agents. Odors may be minimized by using an aerating blower drawing vacuum through the composting pile via the underlying ducts and exhausting through a filtering pile of previously composted sludge to be replaced when moisture content reaches 70 percent. The liquid accumulating in the underdrain ducting may be returned to the sewage treatment plant; and composting pads may be roofed to provide better moisture content control.

After a composting interval sufficient for pathogen reduction, composted piles may be screened to recover undigested bulking agents for re-use, and composted solids passing through the screen may be used as a soil amendment material with similar benefits to peat. The optimum initial carbon-to-nitrogen ratio of a composting mixture is between 26-30:1; but the composting ratio of agricultural byproducts may be determined by the amount required to dilute concentrations of toxic chemicals in the sludge to acceptable levels for the intended compost use. Although toxicity is low in most agricultural byproducts, suburban grass clippings may have residual herbicide levels detrimental to some agricultural uses; and freshly composted wood byproducts may contain phytotoxins inhibiting germination of seedlings until detoxified by soil fungi.

Incineration: Incineration is also used, albeit to a much lesser degree. The incineration of sludge is less common because of air emissions concerns and the supplemental fuel (typically natural gas or fuel oil) required to burn the low calorific value sludge and vaporize residual water. On a dry solids basis, the fuel value of sludge varies from about 9,500 British thermal units per pound (5,300 cal/g) of undigested sewage sludge to 2,500 British thermal units per pound (1,400 cal/g) of digested primary sludge. Stepped multiple hearth incinerators with high residence time and fluidized bed incinerators are the most common systems used to combust wastewater sludge. Co-firing in municipal waste-to-energy plants is occasionally done, this option being less expensive assuming the facilities already exist for solid waste and there is no need for auxiliary fuel. Incineration tends to maximize heavy metal concentrations in the remaining solid ash requiring disposal; but the option of returning wet scrubber effluent to the sewage treatment process may reduce air emissions by increasing concentrations of dissolved salts in sewage treatment plant effluent. A sludge incineration process schematic is illustrated in Figure 30.

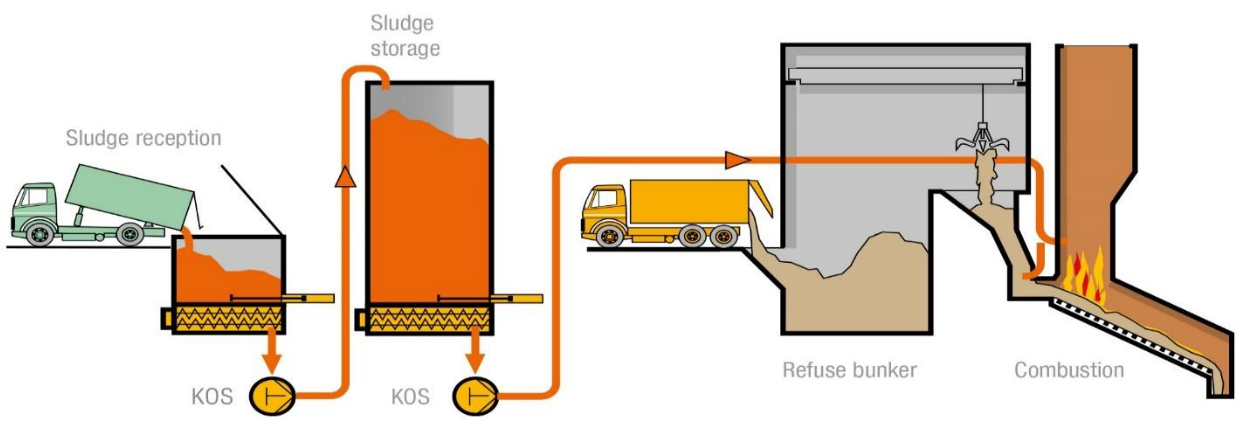

Figure 30: A sludge incineration process schematic

Drying Beds: Simple sludge drying beds are used in many countries, particularly in developing countries, as they are a cheap and simple method to dry sewage sludge. Drainage water must be captured; drying beds are sometimes covered but usually left uncovered. Mechanical devices to turn over the sludge in the initial stages of the drying process are also available on the market.

Drying beds are typically composed of four layers consisting of gravel and sand. The first layer is coarse gravel that is 15 to 20 centimeters thick. Followed by fine gravel that is 10 centimeters thick. The third layer is sand that can be between 10 and 15 centimeters and serves as the filter between the sludge and gravel. Sludge dries up and water percolates to the first layer that is collected at the drainage pipe that is beneath all layers. Sewage sludge after drying in a sludge drying bed is illustrated in Figure 31. A simple evaporative sludge drying bed as illustrated in

Figure 32 illustrates the initial consistency of primary sludge being discharged from the primary settling tank via the pipe in the foreground.

Figure 31: Sewage sludge after drying in a sludge drying bed

Figure 32: The initial consistency of primary sludge

Emerging Technologies:

- Phosphorus recovery from sewage sludge or from sludge dewatering streams is receiving increased attention particularly in Sweden, Germany, and Canada, as phosphorus is a limited resource (a concept also known as "peak phosphorus") and is needed as fertilizer to feed a growing world population.

  Phosphorus recovery methods from wastewater or sludge can be categorized by the origin of the used matter (wastewater, sludge liquor, digested or non-digested sludge, ash) or by the type of recovery processes (precipitation, wet-chemical extraction and precipitation, thermal treatment).

  Research on phosphorus recovery methods from sewage sludge has been carried out in Sweden and Germany since around 2003, but the technologies currently under development are not yet cost effective, given the current price of phosphorus on the world market.

- The Omni Processor is a process that was under development in 2015 and treats sewage sludge. It can generate a surplus of electrical energy if the input materials have the right level of dryness.

- Thermal depolymerization produces light hydrocarbons from sludge heated to 250 °C and compressed to 40 MPa.

- Thermal hydrolysis is a two-stage process combining high-pressure boiling of sludge, followed by a rapid decompression. This combined action sterilizes the sludge and makes it more biodegradable, which improves digestion performance. Sterilization destroys pathogens in the sludge resulting in it exceeding the stringent requirements for land application (agriculture). Thermal hydrolysis systems are operating at sewage treatment plants in Europe, China, and North America, and can generate electricity as well as high quality sludge. The thermal hydrolysis system at the Blue Plains treatment plant in Washington, D.C. is the largest in the world as of 2016 and is shown in Figure 33.

Figure 33: The thermal hydrolysis system at the Blue Plains treatment plant in Washington, D.C.

- The use of a green approach, such as phytoremediation, has been recently proposed as a valuable tool to improve sewage sludge contaminated by trace elements and persistent organic pollutants.

Disposal or Use as Fertilizer: When a liquid sludge is produced, further treatment may be required to make it suitable for final disposal. Sludges are typically thickened and/or dewatered to reduce the volumes transported off-site for disposal. Processes for reducing water content include lagooning in drying beds to produce a cake that can be applied to land or incinerated; pressing, where sludge is mechanically filtered, often through cloth screens to produce a firm cake; and centrifugation where the sludge is thickened by centrifugally separating the solid and liquid. Sludges can be disposed of by liquid injection to land or by disposal in a landfill.

There is no process which eliminates the need to dispose of treated sewage sludge.
Much sludge originating from commercial or industrial areas is contaminated with toxic materials that are released into the sewers from industrial or commercial processes or from domestic sources. Elevated concentrations of such materials may make the sludge unsuitable for agricultural use and it may then have to be incinerated or disposed of to landfill.

Despite the apparent unsuitability of at least some sewage sludge, application to farm-land remains a commonly used option.

Sludge treatment and disposal generally include several unit processes and operations, which fall under the following classifications: thickening, stabilization, disinfection, conditioning, dewatering, drying, thermal reduction, miscellaneous processes, ultimate disposal, or reuse .

The proper treatment and disposal of sludge require knowledge of the origin of the solids to be handled, as well as their characteristics and quantities. The type of treatment employed and the method of operation determine the origin of sludge. In sewage treatment plants, sludge is produced by primary settling, which is used to remove readily settleable solids from raw wastewater.

Biological sludges are produced by treatment processes such as activated sludge, trickling filter, and rotating biological contractors. Chemical sludges result from the use of chemicals to remove constituents through precipitation; examples of precipitates that are produced by this process include phosphate precipitates, carbonate precipitates, hydroxide precipitates, and polymer solids. Sludge is characterized by the presence or absence of organic matter, nutrients, pathogens, metals, and toxic organics. These characteristics are an important consideration for determining both the type of treatment to be used and the method of disposal after processing. According to the Environmental Protection Agency (EPA), the typical chemical compositions of untreated and digested primary sludge include solids, grease and fats, protein, nitrogen, phosphorus, potash, iron, silica, and pH.

Municipal sludge is a high-volume waste. Typical volumes for raw primary sludge range from 2,950 to 3,530 gallons per million gallons of wastewater treated. Volumes for trickling filter humus range from 530 to 750 gallons per million, while the volumes for activated sludge are much higher, from 14,600 to 19,400 gallons per million. It is possible to calculate the quantities of sludge theoretically, but the EPA recommends that treatment operations use pilot plant equipment to make these calculations whenever possible. In developing a treatment and disposal system, the EPA also recommends that large wastewater treatment plants adopt a methodical approach "to prevent cursory dismissal of options." For small plants, with a capacity of less than a million gallons a day, the task of determining an operating procedure is often shorter and less complex.

Thickening is a volume-reducing process in which the sludge solids are concentrated to increase the efficiency of further treatment. It has recently been reported that sludge with 0.8% solids thickened to a content of 4% solids yields a five-fold decrease in sludge volume. Thickening methods commonly employed are gravity thickening, flotation thickening, and centrifuge.

Sludges are stabilized to eliminate offensive odors and reduce toxicity. A stable sludge has been defined as "one that can be disposed of without damage to the environment, and without creating nuisance conditions." In sludges, toxicity is characterized by high concentrations of metals and toxic organics, as well as by high oxygen demand, abnormally high or low pH levels, and unsafe levels of pathogenic microorganisms. There are a variety of technologies available for stabilizing toxic sludge; these include lime stabilization, heat treatment, and biological stabilization, which consists of aerobic or anaerobic digestion and composting.

Sludge that has been stabilized may also be disinfected in order to further reduce the level of pathogens. There are several methods of sludge disinfection: thermal treatment such as pasteurization, chemical treatment, and irradiation. This process is important for the reuse and application of sludge on land.

Dewatering is used to achieve further reductions in moisture content. It is a process designed to reduce moisture to the point where the sludge behaves like a solid; at the end of this process, the concentration of solids in sludge is often greater than 15%. Dewatering can include a number of unit operations: Sludge can be dried in drying beds or lagoons, filtered through a vacuum filter, a filter press, or a strainer, and separated in machines such as a solid-bowl centrifuge. It can be determined whether a sludge will settle in a centrifuge by testing it in a test-tube centrifuge, where the concentration of cake solids is determined as a function of centrifugal acceleration. The Capillary Suction Time (CST) and the specific resistance to filtration are important parameters for the filterability of sludge.

Sludge is conditioned to prepare it for other treatment processes; the purpose of sludge conditioning is to improve the effectiveness of dewater and thickening. The methods most commonly employed are the addition of organic materials such as polymers, or the addition of inorganic materials such as aluminum compounds. Heat treatment is also used; in this treatment, temperatures range from 356 – 392°F (180 – 200°C) for a period of 20 – 30 minutes.

After thickening and dewatering, further reduction of moisture is necessary if the sludge is going to be incinerated or processed into, starved air combustion, co-disposal, and wet oxidation. These processes have a number of advantages. They can achieve maximum volume reduction; they can destroy toxic organic compounds, and they also produce heat energy which can be utilized. But sludge combustion cannot be considered an ultimate or long-term disposal option because of the residuals it produces, such ash and air emissions, which may have detrimental effects on the environment.

Landfills are another disposal option, but limitations on space as well as regulatory constraints restrict their long-term feasibility. Reuse is probably the best solution for the long-term management of sludge; the most feasible beneficial use option will probably be either land application, land reclamation, or raw material recovery. Examples include the conversion of sludge into commercial fertilizer, fuel, and building products.

Whatever the selected array of sludge treatment and disposal measures are, the main factors that influence the choice will always be cost-effectiveness, public health, and environmental protection.

Different Strategic Treatment Plants and their Usage

A2O Process

Anaerobic-anoxic-aerobic method (A2O method) is a wastewater treatment method whose main purpose is to remove nitrogen and phosphorus from wastewater, and reaction tank is configured by three tanks which are called anaerobic tank, anoxic tank, and aerobic tank.

Since no air is sent into anaerobic tanks and there is no oxygen, microorganism and activated sludge become less active and release phosphorus. Sewage in anaerobic tanks is sent to anoxic tank after releasing phosphorus, then sent to aerobic tank. Agitators are settled in anaerobic tanks and activated sludge in the tanks are kept being agitated.

Similar to anaerobic tank, anoxic tank is tank with no air sent into and no oxygen melt in water in the tank. Since microorganism (denitrifier) which prefer anaerobic state consume oxygen, nitrate ion in nitrate containing liquid pumped from aerobic tank is decomposed in the anoxic tank.

During this decomposed process, nitrogen is released to air as nitrogen gas by being removed its oxygen with nitrate ion. Inside of aerobic tank is in the state that aeration is done and oxygen are added into water. Activated sludge and microorganisms (Nitrifying bacteria: Nitrosomonas bacteria, Nitrobacter bacteria) which is active in aerobic tank decompose ammoniacal nitrogen sent from anoxic tank and change into nitrate ion. The nitrate containing liquid with the nitrate ion is circulated to anoxic tank with pumps.

Also, in aerobic tank, activated sludge and microorganisms which have taken in phosphorus are sent to final settling tank and sedimented. Clarified water in the final settling tank is discharged after passing through disinfection apparatus and some of settled activated sludge is returned to reaction tank as returned sludge, then remained stuffs are sent to sludge thickening tank as waste sludge. Sludge thickened in thickening tank are dehydrated and treated as dehydrated sludge such as being dried.

This method of removing nitrogen is also called recirculating denitrification system since nitrification and denitrification took place while nitrate containing liquid is circulated. In case that only nitrogen is aimed to be removed, the reaction tank is configured with only anoxic tank and aerobic tank and anaerobic tank is not used.

- Anaerobic Zone: Facilitates phosphorus release by phosphorus-accumulating organisms in the absence of oxygen.
- Anoxic Zone: Enables denitrification, converting nitrate to nitrogen gas without oxygen.
- Oxic Zone: Conducts nitrification, turning ammonia into nitrate, and helps in phosphorus uptake with the presence of oxygen.
- Sludge Recycle: Recycles activated sludge back to the anaerobic and anoxic zones, maintaining effective microorganism populations.
- Key Microorganisms: Different bacteria in each zone break down organic matter, nitrify ammonia, denitrify nitrate, and accumulate phosphorus.

- Advantages: Effective in removing nitrogen and phosphorus, adjustable for different treatment needs, and cost-efficient as it reduces the need for chemical additives.
- Applications: Used in both municipal and industrial wastewater treatment, especially where nutrient discharge regulations are stringent.

The A2O process is illustrated in Figures 34 and 35.

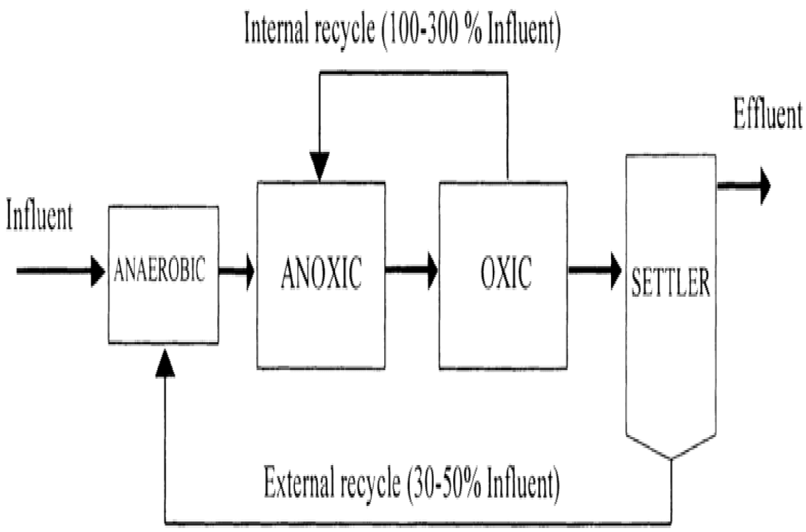

Figure 34: The A2O process

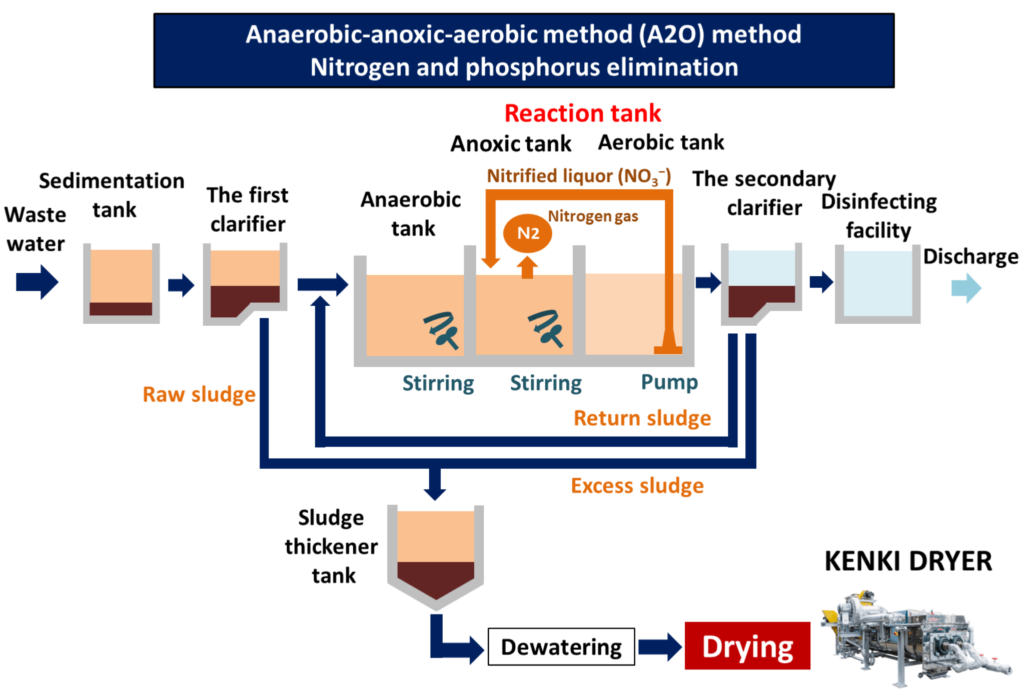

Figure 35: The A2O process

5-Stage Bardenpho

The 5-Stage Bardenpho Process offers advantages such as high removal efficiencies for various contaminants like total chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP), and ammonium. Additionally, this process enhances biological nutrient removal due to the biofilm's contribution, resulting in improved conversion rates. However, challenges exist, including the need for optimization of parameters like hydraulic retention time (HRT) and nitrate recycle ratio (R) to achieve optimal nitrogen and phosphorus removal. Furthermore, the complexity of the process may require advanced monitoring and control systems to ensure efficient operation and maintenance. Overall, the 5-Stage Bardenpho Process shows promise in wastewater treatment but necessitates careful management and fine-tuning for optimal performance.

The 5-stage Bardenpho process consists of five distinct reactors which are respectively: anaerobic reactor, first anoxic reactor, first aerobic reactor, second anoxic reactor, and second aerobic reactor as illustrated in Figure 36.

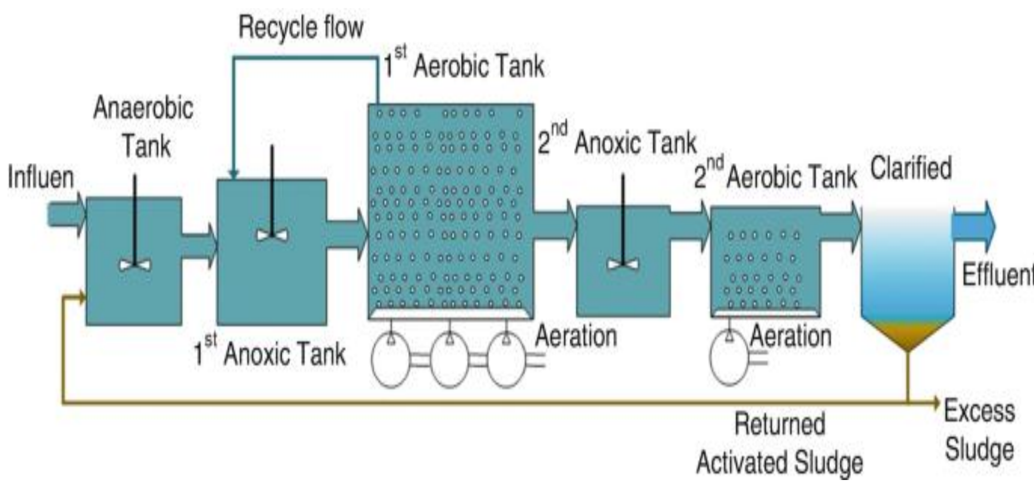

Figure 36: The 5-stage Bardenpho process

- **Anaerobic Zone**
    1. **Purpose**: Phosphorus Release.
    2. **Process**: Promotes the release of phosphorus from the biomass into the water in the absence of oxygen.

- **First Anoxic Zone**
    1. **Purpose**: Denitrification.
    2. **Process**: Converts nitrate (NO_3) to nitrogen gas (N_2) in the absence of oxygen, using the nitrate as an electron acceptor.

- **First Aerobic Zone**
    1. **Purpose**: Nitrification and Phosphorus Uptake.
    2. **Process**: Ammonia (NH_4) is converted to nitrate (NO_3), and phosphorus is taken up by the biomass.

- **Second Anoxic Zone**
  1. **Purpose**: Enhanced Denitrification.
  2. **Process**: Further reduces nitrate to nitrogen gas, using the remaining nitrate recycled from the second aerobic zone.

- **Second Aerobic Zone**
  1. **Purpose**: Final Nitrification.
  2. **Process**: Completes the conversion of any remaining ammonia to nitrate.

- **Sludge Recycle**: Recycles activated sludge through the system to maintain adequate microorganism levels for treatment.

- **Advantages**: Efficient removal of nitrogen and phosphorus, improved effluent quality, and flexibility in handling variable loads.

- **Applications**: Suitable for advanced municipal and industrial wastewater treatment facilities, especially in areas with strict nutrient discharge limits.

Oxidation Ditch

Treatment of wastewater using an oxidation ditch is relatively similar to wastewater treatment in a packaged plant. But the oxidation ditch replaces the aeration basin and provides better sludge treatment.

The only pretreatment typically used in an oxidation ditch system is the bar screen. After passing through the bar screen, wastewater flows directly into the oxidation ditch.

The oxidation ditch is a circular basin through which the wastewater flows. Activated sludge is added to the oxidation ditch so that the microorganisms will digest the BOD. in the water. This mixture of raw wastewater and returned sludge is known as mixed liquor.

Oxygen is added to the mixed liquor in the oxidation ditch using rotating biological contactors (RBC's.) RBC's are more efficient than the aerators used in packaged plants. In addition to increasing the water's dissolved oxygen, RBC's also increase surface area and create waves and movement within the ditches.

Once the BOD. has been removed from the wastewater, the mixed liquor flows out of the oxidation ditch. Sludge is removed in the clarifier. This sludge is pumped to an aerobic digester where the sludge is thickened with the help of aerator pumps. This method greatly reduces the amount of sludge produced. Some of the sludge is returned to the oxidation ditch while the rest of the sludge is sent to waste. The oxidation ditch treatment process is illustrated in Figure 37.

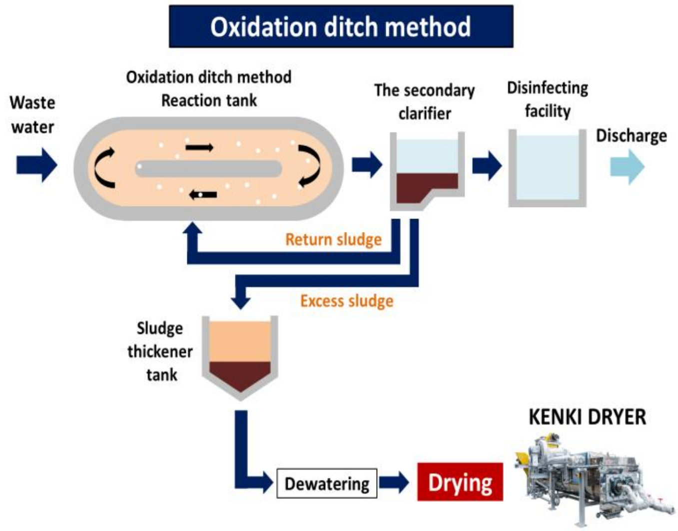

Figure 37: The oxidation ditch treatment process

The treatment of wastewater in an oxidation ditch is similar to treatment in a packaged plant. The two main differences between the processes are the retention time and the type of organisms which digest the wastewater.

Retention time is much longer in an oxidation ditch. A packaged plant usually has a retention time of two to four hours while an oxidation ditch retains the wastewater for two days.
Since the DO is higher in the oxidation ditch than in a packaged plant, a greater variety of microorganisms live in the oxidation ditch. In contrast, packaged plants usually depend upon only a few types of microorganisms to eat the sewage.

Oxidation ditches can be set up to remove ammonia very effectively. Wastewater can be sent through two sets of ditches, each of which has a different pH. The different pH in the two ditches creates a niche for certain microorganisms. These microorganisms are very efficient at removing BOD and converting ammonia to nitrates. Oxidation ditches are much more efficient at ammonia removal than packaged plants are. As a result, most new treatment facilities are designed as oxidation ditches.

Some oxidation ditches have a *diversion basin* to hold the influent when flows increase because of excessive rainfall. The diversion basin holds the excess influent and allows more time for treatment.

Without a diversion basin, heavy rains could cause a *washout* to occur. A washout occurs when a large influx of influent rushes into the oxidation ditches. The ditches are unable to contain the extra water, so microorganisms, sludge, and wastewater are pushed through the plant and out into a river or stream before being properly treated.

Without diversion basins, total washouts can be prevented by shutting off the inner ditches and allowing the outside ditch to circulate the influent, providing primary treatment to the water before it is released. In periods of excessive rainfall, oxidation plants can be operated on high flow settings for a month at a time.

The greatest advantage of an oxidation ditch is the efficiency of sludge removal. In an oxidation ditch, only about 15% of the original BOD ends up as sludge, compared to a packaged plant where about 60% of the BOD becomes sludge.

However, oxidation ditches are expensive to maintain. The monetary cost is very high per ton of BOD removed. In some cases, the cost may reach nearly 350 dollars per ton.
Oxidation ditches have an additional environmental drawback. The water is moved through the ditches using rotors, and these rotors in turn use electricity. The electricity used to operate the plant causes Sulphur dioxide and other contaminants to be released into the atmosphere from coal-burning electrical plants.

Oxidation ditches provide the most thorough process for treating sewage, but oxidation ditches are also one of the costliest forms of treatment.

Advanced Treatment Technologies:

Reverse Osmosis

Reverse osmosis (RO) is a water purification process that uses a semi-permeable membrane to separate water molecules from other substances as illustrated in Figure 38. RO applies pressure to overcome osmotic pressure that favors even distributions.

RO can remove dissolved or suspended chemical species as well as biological substances (principally bacteria), and is used in industrial processes and the production of potable water. RO retains the solute on the pressurized side of the membrane and the purified solvent passes to the other side. It relies on the relative sizes of the various molecules to decide what passes through. "Selective" membranes reject large molecules, while accepting smaller molecules (such as solvent molecules, e.g., water).

RO is most commonly known for its use in drinking water purification from seawater, removing the salt and other effluent materials from the water molecules.

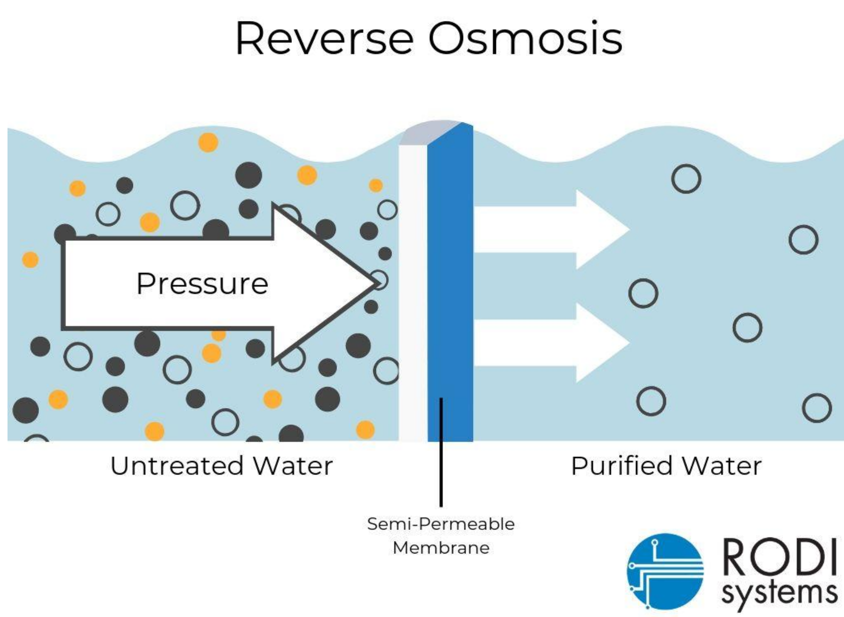

Figure 38: Reverse Osmosis

Ultra-Violet Disinfection

Ultra-Violet (UV) light is a form of light that is invisible to the human eye. It occupies the portion of the electromagnetic spectrum between X-rays and visible light and is uniquely able to inactivate microorganisms such as *E.Coli* and Fecal Coliforms. This capability has led to widespread adoption of UV light as a highly effective way to treat wastewater and drinking water.

Microorganisms are inactivated by UV light when nucleic acids are damaged. When nucleic acids are exposed to certain wavelengths of UV light via UV lamps, they are instantly unable to reproduce. If a microorganism cannot reproduce, it is unable to cause infection. UV light has proven efficient in inactivating a variety of different microorganisms, including the ones responsible for cholera, polio, typhoid, hepatitis, along with other diseases.

UV light is also effective at inactivating *Cryptosporidium* and *Giardia*, two microbes that chlorine is unable treat. Treating these two chlorine-resistant microbes is extremely important as they are often found in bodies of water that communities use as a source of drinking water and for recreational use. The UV disinfection process is illustrated in Figure 39.

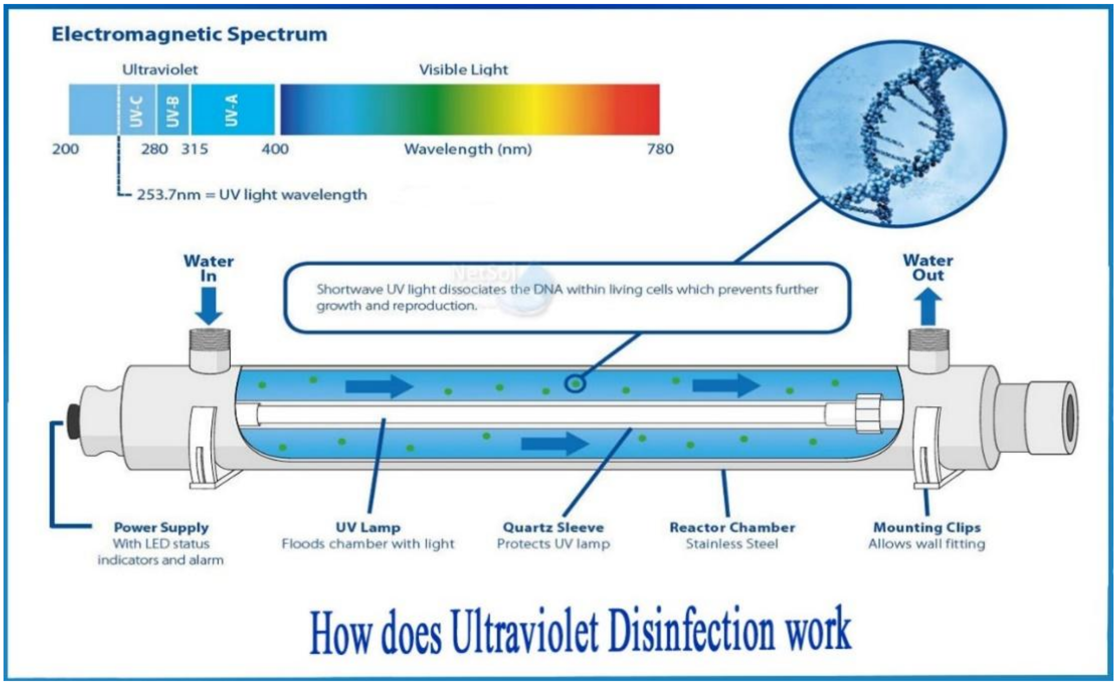

Figure 39: The UV disinfection process

MBR Tanks

Moving bed biofilm reactor (MBBR) is a type of wastewater treatment process that takes place in an aeration tank with plastic carriers that a biofilm can grow on as illustrated in Figure 40. The compact size and cheap wastewater treatment costs offers many advantages for the system. The main objective of using MBBR being water reuse and nutrient removal or recovery. In theory, wastewater will be no longer considered waste, it can be considered a resource.

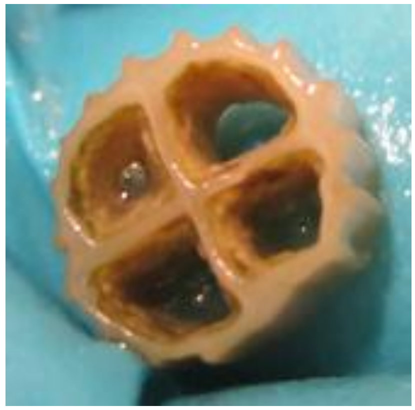

Figure 40: Moving bed biofilm reactor

There are many design components of MBBR that come together to make the technology highly efficient. First, the process occurs in a basin (or aeration tank). The overall size of this tank is dependent on both the type and volume of wastewater being processed. The influent enters the basin at the beginning of treatment.

The second component being the media. The media consists of the free-floating biocarriers mentioned earlier and can occupy as much as 70 percent of the tank.

Third, an aeration grid is responsible for helping the media move through the basin and ensure the carriers come into contact with as much waste as possible, in addition to introducing more oxygen into the basin. Lastly, a sieve keeps all the carriers in the tank to prevent the plastic carriers from escaping the aeration.

Though there are a few different methods, they all use the same design components. The continuous flow method involves continuous flow of wastewater into the basin, with an equal flow of treated water exiting through the sieve. Intermittent aeration method operating in cycles of aeration and non-aeration, allowing for both aerobic conditions and anoxic conditions.

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