Sewage Engineering

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Chapter 1

Sewage Treatment

The objective of sewage treatment is to produce a disposable effluent without causing harm to the surrounding environment and prevent pollution.

Sewage treatment, or **domestic wastewater treatment**, is the process of removing contaminants from wastewater and household sewage, both runoff (effluents) and domestic. It includes physical, chemical, and biological processes to remove physical, chemical and biological contaminants. Its objective is to produce an environmentally-safe fluid waste stream (or treated effluent) and a solid waste (or treated sludge) suitable for disposal or reuse (usually as farm fertilizer). Using advanced technology it is now possible to re-use sewage effluent for drinking water, although Singapore is the only country to implement such technology on a production scale in its production of NEWater.

Origins of sewage

Sewage is created by residential, institutional, and commercial and industrial establishments and includes household waste liquid from toilets, baths, showers, kitchens, sinks and so forth that is disposed of via sewers. In many areas, sewage also includes liquid waste from industry and commerce. The separation and draining of household waste into greywater and blackwater is becoming more common in the developed world, with greywater being permitted to be used for watering plants or recycled for flushing toilets.

Sewage may include stormwater runoff. Sewerage systems capable of handling stormwater are known as combined systems. Combined sewer systems are usually avoided now because precipitation causes widely varying flows reducing sewage treatment plant efficiency. Combined sewers require much larger, more expensive, treatment facilities than sanitary sewers. Heavy storm runoff may overwhelm the sewage treatment system, causing a spill or overflow. Sanitary sewers are typically much smaller than combined sewers, and they are not designed to transport stormwater. Backups of raw sewage can occur if excessive Infiltration/Inflow is allowed into a sanitary sewer system.

Modern sewered developments tend to be provided with separate storm drain systems for rainwater. As rainfall travels over roofs and the ground, it may pick up various contaminants including soil particles and other sediment, heavy metals, organic compounds, animal waste, and oil and grease. Some jurisdictions require stormwater to receive some level of treatment before being discharged directly into waterways. Examples of treatment processes used for stormwater include retention basins, wetlands, buried vaults with various kinds of media filters, and vortex separators (to remove coarse solids).

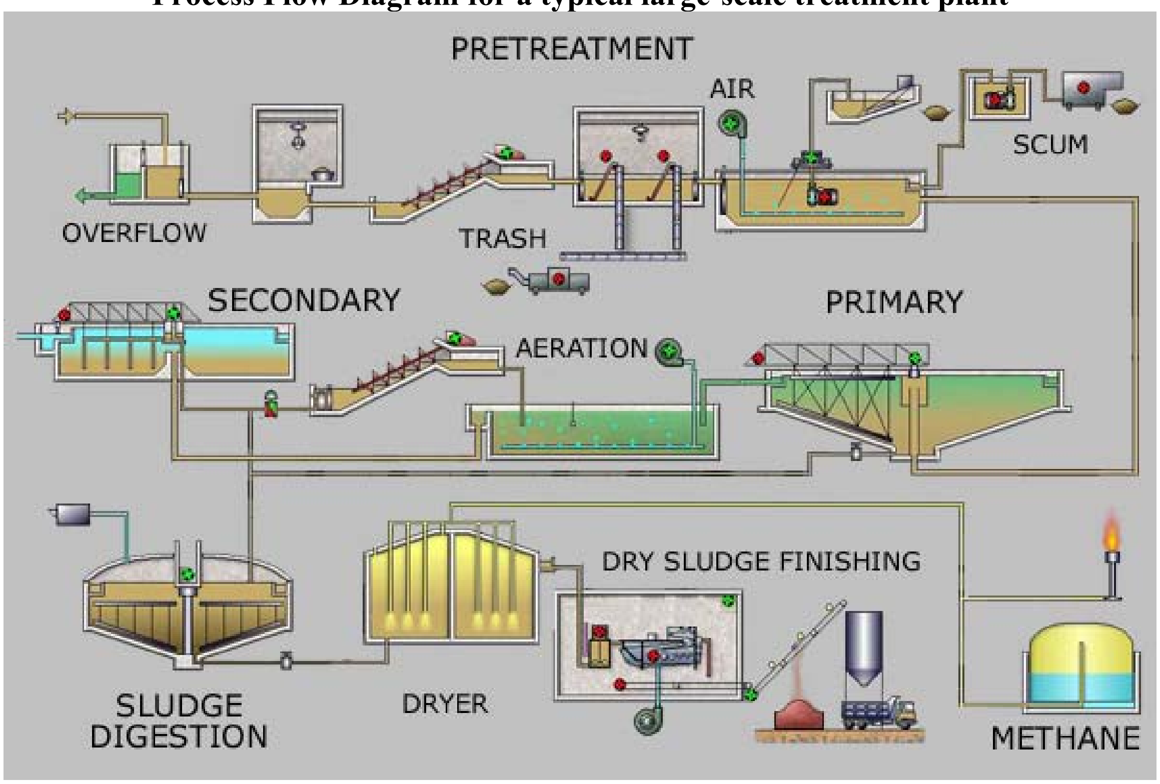
Process overview

Sewage can be treated close to where it is created, a decentralised system, (in septic tanks, biofilters or aerobic treatment systems), or be collected and transported via a network of pipes and pump stations to a municipal treatment plant, a centralised system. Sewage collection and treatment is typically subject to local, state and federal regulations and standards. Industrial sources of wastewater often require specialized treatment processes.

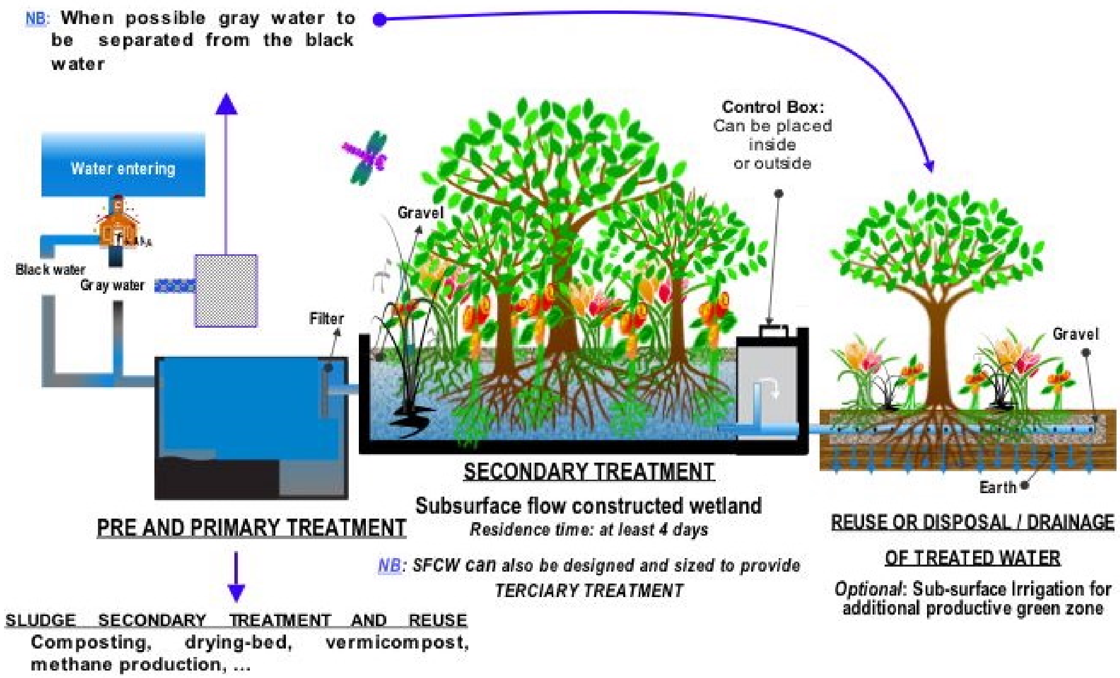
Sewage treatment generally involves three stages, called primary, secondary and tertiary treatment.

- *Primary treatment* consists of temporarily holding the sewage in a quiescent basin where heavy solids can settle to the bottom while oil, grease and lighter solids float to the surface. The settled and floating materials are removed and the remaining liquid may be discharged or subjected to secondary treatment.
- *Secondary treatment* removes dissolved and suspended biological matter. Secondary treatment is typically performed by indigenous, water-borne micro-organisms in a managed habitat. Secondary treatment may require a separation process to remove the micro-organisms from the treated water prior to discharge or tertiary treatment.
- *Tertiary treatment* is sometimes defined as anything more than primary and secondary treatment in order to allow rejection into a highly sensitive or fragile ecosystem (estuaries, low-flow rivers, coral reefs,...). Treated water is sometimes disinfected chemically or physically (for example, by lagoons and microfiltration) prior to discharge into a stream, river, bay, lagoon or wetland, or it can be used for the irrigation of a golf course, green way or park. If it is sufficiently clean, it can also be used for groundwater recharge or agricultural purposes.

Process Flow Diagram for a typical large-scale treatment plant



Process Flow Diagram for a typical treatment plant via Subsurface Flow Constructed Wetlands (SFCW)



Pre-treatment

Pre-treatment removes materials that can be easily collected from the raw waste water before they damage or clog the pumps and skimmers of primary treatment clarifiers (trash, tree limbs, leaves, etc.).

Screening

The influent sewage water is screened to remove all large objectslike cans,rags,sticks,plastic packets etc. carried in the sewage stream. This is most commonly done with an automated mechanically raked bar screen in modern plants serving large populations, whilst 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.[:9]

Grit removal

Pre-treatment may include a sand or grit channel or chamber where the velocity of the incoming wastewater is adjusted to allow the settlement of sand, grit, stones, and broken glass. These particles are removed because they may damage pumps and other equipment. For small sanitary sewer systems, the grit chambers may not be necessary, but grit removal is desirable at larger plants.

An empty sedimentation tank at the treatment plant in Merchtem, Belgium.

Fat and grease removal

In some larger plants, fat and grease is 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. In most plants however, fat and grease removal takes place in the primary settlement tank using mechanical surface skimmers.

Primary treatment

In the primary sedimentation stage, sewage flows through large tanks, commonly called "primary clarifiers" or "primary sedimentation tanks." The tanks are used to settle sludge while grease and oils rise to the surface and are skimmed off. 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.[:9-11] Grease and oil from the floating material can sometimes be recovered for saponification.

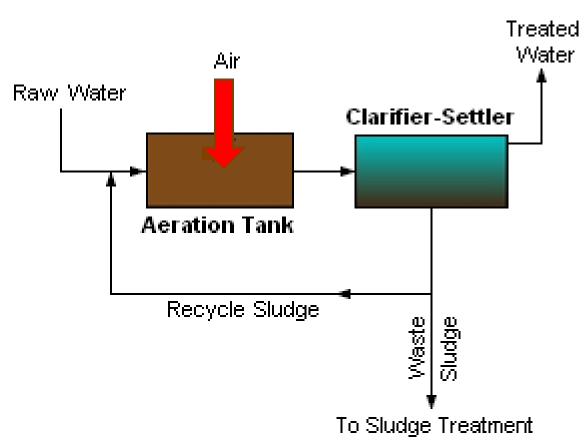
The dimensions of the tank should be designed to effect removal of a high percentage of the floatables and sludge. A typical sedimentation tank may remove from 60 to 65 percent of suspended solids, and from 30 to 35 percent of biochemical oxygen demand (BOD) from the sewage.

Secondary treatment

Secondary treatment is designed to substantially degrade the biological content of the sewage which are derived from human waste, food waste, soaps and detergent. The majority of municipal plants treat the settled sewage liquor using aerobic biological processes. To be effective, the biota require both oxygen and food to live. The bacteria and protozoa consume biodegradable soluble organic contaminants (e.g. sugars, fats, organic short-chain carbon molecules, etc.) and bind much of the less soluble fractions into floc. Secondary treatment systems are classified as *fixed-film* or *suspended-growth* systems.

- **Fixed-film** or **attached growth** systems include trickling filters and rotating biological contactors, where the biomass grows on media and the sewage passes over its surface.
- **Suspended-growth** systems include activated sludge, where the biomass is mixed with the sewage and can be operated in a smaller space than fixed-film systems that treat the same amount of water. However, fixed-film systems are more able to cope with drastic changes in the amount of biological material and can provide higher removal rates for organic material and suspended solids than suspended growth systems.

Roughing filters are intended to treat particularly strong or variable organic loads, typically industrial, to allow them to then be treated by conventional secondary treatment processes. Characteristics include filters filled with media to which wastewater is applied. They are designed to allow high hydraulic loading and a high level of aeration. On larger installations, air is forced through the media using blowers. The resultant wastewater is usually within the normal range for conventional treatment processes.



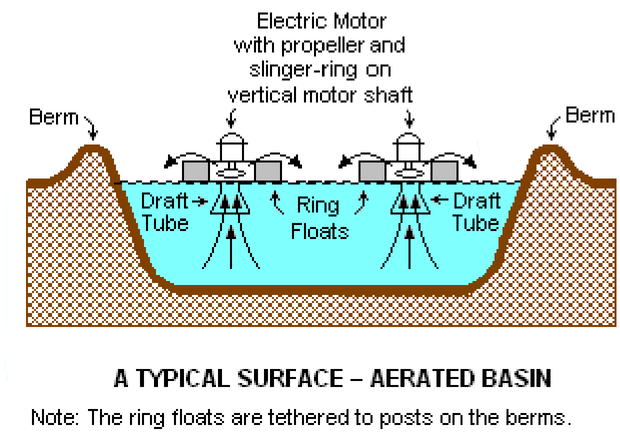
A generalized, schematic diagram of an activated sludge process.

A filter removes a small percentage of the suspended organic matter, while the majority of the organic matter undergoes a change of character, only due to the biological oxidation and nitrification taking place in the filter. With this aerobic oxidation and nitrification, the organic solids are converted into coagulated suspended mass, which is heavier and bulkier, and can settle to the bottom of a tank. The effluent of the filter is therefore passed through a sedimentation tank, called a secondary clarifier, secondary settling tank or humus tank.

Activated sludge

In general, activated sludge plants encompass a variety of mechanisms and processes that use dissolved oxygen to promote the growth of biological floc that substantially removes organic material.

The process traps particulate material and can, under ideal conditions, convert ammonia to nitrite and nitrate and ultimately to nitrogen gas.



A Typical Surface-Aerated Basin (using motor-driven floating aerators)

Surface-aerated basins (Lagoons)

Many small municipal sewage systems in the United States (1 million gal./day or less) use aerated lagoons.

Most biological oxidation processes for treating industrial wastewaters have in common the use of oxygen (or air) and microbial action. Surface-aerated basins achieve 80 to 90 percent removal of BOD with retention times of 1 to 10 days. The basins may range in depth from 1.5 to 5.0 metres and use motor-driven aerators floating on the surface of the wastewater.

In an aerated basin system, the aerators provide two functions: they transfer air into the basins required by the biological oxidation reactions, and they provide the mixing required for dispersing the air and for contacting the reactants (that is, oxygen, wastewater and microbes). Typically, the floating surface aerators are rated to deliver the amount of air equivalent to 1.8 to 2.7 kg O_2/kW·h. However, they do not provide as good mixing as is normally achieved in activated sludge systems and therefore aerated basins do not achieve the same performance level as activated sludge units.

Biological oxidation processes are sensitive to temperature and, between 0 °C and 40 °C, the rate of biological reactions increase with temperature. Most surface aerated vessels operate at between 4 °C and 32 °C.

Constructed wetlands

Constructed wetlands (can either be surface flow or subsurface flow, horizontal or vertical flow), include engineered reedbeds and belong to the family of phytorestoration and ecotechnologies; they provide a high degree of biological improvement and depending on design, act as a primary, secondary and sometimes tertiary treatment. One example is a small reedbed used to clean the drainage from the elephants' enclosure at Chester Zoo in England; numerous CWs are used to recycle the water of the city of Honfleur in France and numerous other towns in Europe, the US, Asia and Australia. They are known to be highly productive systems as they copy natural wetlands, called the "Kidneys of the earth" for their fundamental recycling capacity of the hydrological cycle in the biosphere. Robust and reliable, their treatment capacities improve as time go by, at the opposite of conventional treatment plants whose machinery age with time. They are being increasingly used, although adequate and experienced design are more fundamental than for other systems and space limitation may impede their use.

Filter beds (oxidizing beds)

In older plants and those receiving variable loadings, trickling filter beds are used where the settled sewage liquor is spread onto the surface of a bed made up of coke (carbonized coal), limestone chips or specially fabricated plastic media. Such media must have large surface areas to support the biofilms that form. The liquor is typically distributed through perforated spray arms. The distributed liquor trickles through the bed and is collected in drains at the base. These drains also provide a source of air which percolates up through the bed, keeping it aerobic. Biological films of bacteria, protozoa and fungi form on the media's surfaces and eat or otherwise reduce the organic content. This biofilm is often grazed by insect larvae, snails, and worms which help maintain an optimal thickness. Overloading of beds increases the thickness of the film leading to clogging of the filter media and ponding on the surface. Recent advances in media and process micro-biology design overcome many issues with Trickling filter designs.

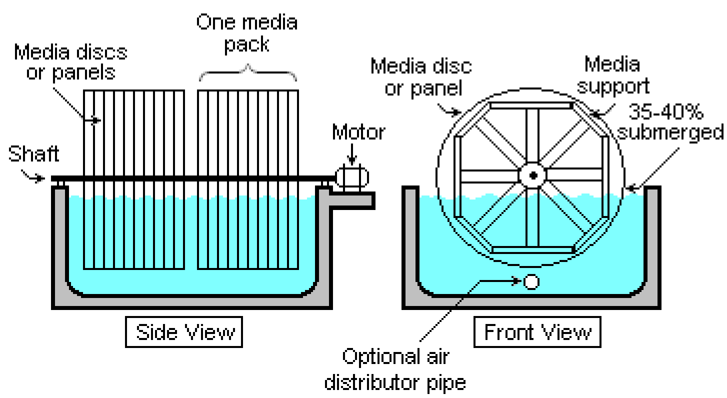
Soil Bio-Technology

A new process called Soil Bio-Technology (SBT) developed at IIT Bombay has shown tremendous improvements in process efficiency enabling total water reuse, due to extremely low operating power requirements of less than 50 joules per kg of treated water. Typically SBT systems can achieve chemical oxygen demand (COD) levels less than 10 mg/L from sewage input of COD 400 mg/L. SBT plants exhibit high reductions in COD values and bacterial counts as a result of the very high microbial densities available in the media. Unlike conventional treatment plants, SBT plants produce insignificant amounts of sludge, precluding the need for sludge disposal areas that are required by other technologies.

In the Indian context, conventional sewage treatment plants fall into systemic disrepair due to 1) high operating costs, 2) equipment corrosion due to methanogenesis and hydrogen sulphide, 3) non-reusability of treated water due to high COD (>30 mg/L) and high fecal coliform (>3000 NFU) counts, 4) lack of skilled operating personnel and 5) equipment replacement issues. Examples of such systemic failures has been documented by Sankat Mochan Foundation at the Ganges basin after a massive cleanup effort by the Indian government in 1986 by setting up sewage treatment plants under the Ganga Action Plan failed to improve river water quality.

Biological aerated filters

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.



Schematic diagram of a typical rotating biological contactor (RBC). The treated effluent clarifier/settler is not included in the diagram.

Rotating biological contactors

Rotating biological contactors (RBCs) are mechanical secondary treatment systems, which are robust and capable of withstanding surges in organic load. RBCs were first installed in Germany in 1960 and have since been developed and refined into a reliable operating unit. The rotating disks support the growth of bacteria and micro-organisms present in the sewage, which break down and stabilise organic pollutants. To be successful, 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. Effluent from the RBC is then passed through final clarifiers where the micro-organisms in suspension settle as a sludge. The sludge is withdrawn from the clarifier for further treatment.

A functionally similar biological filtering system has become popular as part of home aquarium filtration and purification. The aquarium water is drawn up out of the tank and then cascaded over a freely spinning corrugated fiber-mesh wheel before passing through a media filter and back into the aquarium. The spinning mesh wheel develops a biofilm coating of microorganisms that feed on the suspended wastes in the aquarium water and are also exposed to the atmosphere as the wheel rotates. This is especially good at removing waste urea and ammonia urinated into the aquarium water by the fish and other animals.

Membrane bioreactors

Membrane bioreactors (MBR) combine activated sludge treatment with a membrane liquid-solid separation process. The membrane component uses low pressure microfiltration or ultra filtration membranes and eliminates the need for clarification and tertiary 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 usually higher than conventional wastewater treatment. Membrane filters can be blinded with grease or abraded by suspended grit and lack a clarifier's flexibility to pass peak flows. The 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.

Secondary sedimentation

Secondary Sedimentation tank at a rural treatment plant.

The final step in the secondary treatment stage is to settle out the biological floc or filter material through a secondary clarifier and to produce sewage water containing low levels of organic material and suspended matter.

Tertiary treatment

The purpose of tertiary treatment is to provide a final treatment stage to raise the effluent quality before it is discharged to the receiving environment (sea, river, lake, ground, etc.). More than one tertiary treatment process may be used at any treatment plant. If disinfection is practiced, it is always the final process. It is also called "effluent polishing."

Filtration

Sand filtration removes much of the residual suspended matter. Filtration over activated carbon, also called *carbon adsorption,* removes residual toxins.

Lagooning

A sewage treatment plant and lagoon in Everett, Washington, United States.

Lagooning provides settlement and further biological improvement through storage in large man-made ponds or lagoons. These lagoons are highly aerobic and colonization by native macrophytes, especially reeds, is often encouraged. Small filter feeding invertebrates such as *Daphnia* and species of *Rotifera* greatly assist in treatment by removing fine particulates.

Nutrient removal

Wastewater may contain high levels of the nutrients nitrogen and phosphorus. Excessive release to the environment can lead to a build up of nutrients, called eutrophication, which can in turn encourage the overgrowth of weeds, algae, and cyanobacteria (blue-green algae). This may cause an algal bloom, a rapid growth in the population of algae. The algae numbers are unsustainable and eventually most of them die. The decomposition of the algae by bacteria uses up so much of oxygen in the water that most or all of the animals die, which creates more organic matter for the bacteria to decompose. In addition to causing deoxygenation, some algal species produce toxins that contaminate drinking water supplies. Different treatment processes are required to remove nitrogen and phosphorus.

Nitrogen removal

The removal of nitrogen is effected through the biological oxidation of nitrogen from ammonia to nitrate (nitrification), followed by denitrification, the reduction of nitrate to nitrogen gas. Nitrogen gas is released to the atmosphere and thus removed from the water.

Nitrification itself is a two-step aerobic process, each step facilitated by a different type of bacteria. The oxidation of ammonia (NH_3) to nitrite (NO_2^-) is most often facilitated by *Nitrosomonas* spp. (nitroso referring to the formation of a nitroso functional group). Nitrite oxidation to nitrate (NO_3^-), though traditionally believed to be facilitated by *Nitrobacter* spp. (nitro referring the formation of a nitro functional group), is now known to be facilitated in the environment almost exclusively by *Nitrospira* spp.

Denitrification requires anoxic conditions to encourage the appropriate biological communities to form. It is facilitated by a wide diversity of bacteria. Sand filters, lagooning and reed beds can all be used to reduce nitrogen, but the activated sludge process (if designed well) can do the job the most easily. Since denitrification is the reduction of nitrate to dinitrogen gas, an electron donor is needed. This can be, depending on the wastewater, organic matter (from faeces), sulfide, or an added donor like methanol.

Sometimes the conversion of toxic ammonia to nitrate alone is referred to as tertiary treatment.

Many sewage treatment plants use axial flow pumps to transfer the nitrified mixed liquor from the aeration zone to the anoxic zone for denitrification. These pumps are often referred to as *Internal Mixed Liquor Recycle* (IMLR) pumps. The sludge in the anoxic tanks must be mixed well (mixture of recirculated mixed liquor, return activated sludge [RAS], and raw influent) by using submersible mixers in order to achieve the desired denitrification.

Phosphorus removal

Phosphorus removal is important as it is a limiting nutrient for algae growth in many fresh water systems. It is also particularly important for water reuse systems where high phosphorus concentrations may lead to fouling of downstream equipment such as reverse osmosis.

Phosphorus can be removed biologically in a process called enhanced biological phosphorus removal. In this process, specific bacteria, called polyphosphate accumulating organisms (PAOs), are selectively enriched and accumulate large quantities of phosphorus within their cells (up to 20 percent of their mass). When the biomass enriched in these bacteria is separated from the treated water, these biosolids have a high fertilizer value.

Phosphorus removal can also be achieved by chemical precipitation, usually with salts of iron (e.g. ferric chloride), aluminum (e.g. alum), or lime. This may lead to excessive sludge production as hydroxides precipitates and the added chemicals can be expensive. Chemical phosphorus removal requires significantly smaller equipment footprint than biological removal, is easier to operate and is often more reliable than biological phosphorus removal. Another method for phosphorus removal is to use granular laterite.

Once removed, phosphorus, in the form of a phosphate-rich sludge, may be stored in a land fill or resold for use in fertilizer.

Disinfection

The purpose of disinfection in the treatment of waste water is to substantially reduce the number of microorganisms in the water to be discharged back into the environment. The effectiveness of disinfection depends on the quality of the water being treated (e.g., cloudiness, pH, etc.), the type of disinfection being used, the disinfectant dosage (concentration and time), and other environmental variables. Cloudy water will be treated less successfully, since solid matter can shield organisms, especially from ultraviolet light or if contact times are low. Generally, short contact times, low doses and high flows all militate against effective disinfection. Common methods of disinfection include ozone, chlorine, ultraviolet light, or sodium hypochlorite. Chloramine, which is used for drinking water, is not used in waste water treatment because of its persistence.

Chlorination remains the most common form of waste water disinfection in North America due to its low cost and long-term history of effectiveness. One disadvantage is that chlorination of residual organic material can generate chlorinated-organic compounds that may be carcinogenic or harmful to the environment. Residual chlorine or chloramines may also be capable of chlorinating organic material in the natural aquatic environment. Further, because residual chlorine is toxic to aquatic species, the treated effluent must also be chemically dechlorinated, adding to the complexity and cost of treatment.

Ultraviolet (UV) light can be used instead of chlorine, iodine, or other chemicals. Because no chemicals are used, the treated water has no adverse effect on organisms that later consume it, as may be the case with other methods. UV radiation causes damage to the genetic structure of bacteria, viruses, and other pathogens, making them incapable of reproduction. The key disadvantages of UV disinfection are the need for frequent lamp maintenance and replacement and the need for a highly treated effluent to ensure that the target microorganisms are not shielded from the UV radiation (i.e., any solids present in the treated effluent may protect microorganisms from the UV light). In the United Kingdom, UV light is becoming the most common means of disinfection because of the concerns about the impacts of chlorine in chlorinating residual organics in the wastewater and in chlorinating organics in the receiving water. Some sewage treatment systems in Canada and the US also use UV light for their effluent water disinfection.

Ozone (O_3) is generated by passing oxygen (O_2) through a high voltage potential resulting in a third oxygen atom becoming attached and forming O_3. Ozone is very unstable and reactive and oxidizes most organic material it comes in contact with, thereby destroying many pathogenic microorganisms. Ozone is considered to be safer than chlorine because, unlike chlorine which has to be stored on site (highly poisonous in the event of an accidental release), ozone is generated onsite as needed. Ozonation also produces fewer disinfection by-products than chlorination. A disadvantage of ozone disinfection is the high cost of the ozone generation equipment and the requirements for special operators.

Odour Control

Odours emitted by sewage treatment are typically an indication of an anaerobic or "septic" condition. Early stages of processing will tend to produce smelly gases, with hydrogen sulfide being most common in generating complaints. Large process plants in urban areas will often treat the odours with carbon reactors, a contact media with bio-slimes, small doses of chlorine, or circulating fluids to biologically capture and metabolize the obnoxious gases. Other methods of odour control exist, including addition of iron salts, hydrogen peroxide, calcium nitrate, etc. to manage hydrogen sulfide levels.

Package plants and batch reactors

To use less space, treat difficult waste and intermittent flows, a number of designs of hybrid treatment plants have been produced. Such plants often combine at least two stages of the three main treatment stages into one combined stage. In the UK, where a large number of wastewater treatment plants serve small populations, package plants are a viable alternative to building a large structure for each process stage. In the US, package plants are typically used in rural areas, highway rest stops and trailer parks.

One type of system that combines secondary treatment and settlement is the 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. SBR plants are now being deployed in many parts of the world.

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

Package plants may be referred to as *high charged* or *low charged*. This refers to the way the biological load is processed. In high charged systems, the biological stage is presented with a high organic load and the combined floc and organic material is then oxygenated for a few hours before being charged again with a new load. In the low charged system the biological stage contains a low organic load and is combined with flocculate for longer times.

Sludge treatment and disposal

The sludges accumulated in a wastewater treatment process must be treated and disposed of in a safe and effective manner. The purpose of digestion 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. Incineration is also used albeit to a much lesser degree.

Sludge treatment depends 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.

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.

Anaerobic digestion is the most common (mesophilic) treatment of domestic sewage in septic tanks, which normally retain the sewage from one day to two days, reducing the BOD by about 35 to 40 percent. This reduction can be increased with a combination of anaerobic and aerobic treatment by installing *Aerobic Treatment Units* (ATUs) in the septic tank.

One major feature of anaerobic digestion is the production of biogas (with the most useful component being methane), which can be used in generators for electricity production and/or in boilers for heating purposes.

Aerobic digestion

Aerobic digestion is a bacterial process occurring in the presence of oxygen. Under aerobic conditions, bacteria rapidly consume organic matter and convert it into carbon dioxide. The operating costs used to be characteristically much greater for aerobic digestion because of the energy used by the blowers, pumps and motors needed to add oxygen to the process.

Aerobic digestion can also be achieved by using diffuser systems or jet aerators to oxidize the sludge.

Composting

Composting is also an aerobic process that involves mixing the sludge with sources of carbon such as sawdust, straw or wood chips. In the presence of oxygen, bacteria digest both the wastewater solids and the added carbon source and, in doing so, produce a large amount of heat.

Incineration

Incineration of sludge is less common because of air emissions concerns and the supplemental fuel (typically natural gases or fuel oil) required to burn the low calorific value sludge and vaporize residual water. 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.

Sludge disposal

When a liquid sludge is produced, further treatment may be required to make it suitable for final disposal. Typically, sludges are thickened (dewatered) to reduce the volumes transported off-site for disposal. There is no process which completely eliminates the need to dispose of biosolids. There is, however, an additional step some cities are taking to superheat sludge and convert it into small pelletized granules that are high in nitrogen and other organic materials. In New York City, for example, several sewage treatment plants have dewatering facilities that use large centrifuges along with the addition of chemicals such as polymer to further remove liquid from the sludge. The removed fluid, called centrate, is typically reintroduced into the wastewater process. The product which is left is called "cake" and that is picked up by companies which turn it into fertilizer pellets. This product is then sold to local farmers and turf farms as a soil amendment or fertilizer, reducing the amount of space required to dispose of sludge in landfills. Much sludge originating from commercial or industrial areas is contaminated with toxic materials that are released into the sewers from the industrial processes. 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.

Treatment in the receiving environment

The outlet of a wastewater treating plant flows into a small river

Many processes in a wastewater treatment plant are designed to mimic the natural treatment processes that occur in the environment, whether that environment is a natural water body or the ground. If not overloaded, bacteria in the environment will consume organic contaminants, although this will reduce the levels of oxygen in the water and may significantly change the overall ecology of the receiving water. Native bacterial populations feed on the organic contaminants, and the numbers of disease-causing microorganisms are reduced by natural environmental conditions such as predation or exposure to ultraviolet radiation. Consequently, in cases where the receiving environment provides a high level of dilution, a high degree of wastewater treatment may not be required. However, recent evidence has demonstrated that very low levels of specific contaminants in wastewater, including hormones (from animal husbandry and residue from human hormonal contraception methods) and synthetic materials such as phthalates that mimic hormones in their action, can have an unpredictable adverse impact on the natural biota and potentially on humans if the water is re-used for drinking water. In the US and EU, uncontrolled discharges of wastewater to the environment are not permitted under law, and strict water quality requirements are to be met. A significant threat in the coming decades will be the increasing uncontrolled discharges of wastewater within rapidly developing countries.

Effects on Biology

Sewage treatment plants can have multiple effects on nutrient levels in the water that the treated sewage flows into. These effects on nutrients can have large effects on the biological life in the water in contact with the effluent. Stabilization ponds (or treatment ponds) can include any of the following:

- Oxidation ponds, which are aerobic bodies of water usually 1–2 meters in depth that receive effluent from sedimentation tanks or other forms of primary treatment.
    - Dominated by algae
- Polishing ponds are similar to oxidation ponds but receive effluent from an oxidation pond or from a plant with an extended mechanical treatment.
    - Dominated by zooplankton
- Facultative lagoons, raw sewage lagoons, or sewage lagoons are ponds where sewage is added with no primary treatment other than coarse screening. These ponds provide effective treatment when the surface remains aerobic; although anaerobic conditions may develop near the layer of settled sludge on the bottom of the pond.
- Anaerobic lagoons are heavily loaded ponds.
    - Dominated by bacteria
- Sludge lagoons are aerobic ponds, usually 2–5 meters in depth, that receive anaerobically digested primary sludge, or activated secondary sludge under water.
    - Upper layers are dominated by algae

Phosphorous limitation is a possible result from sewage treatment and results in flagellate-dominated plankton, particularly in summer and fall.

At the same time a different study found high nutrient concentrations linked to sewage effluents. High nutrient concentration leads to high chlorophyll a concentrations, which is a proxy for primary production in marine environments. High primary production means high phytoplankton populations and most likely high zooplankton populations because zooplankton feed on phytoplankton. However, effluent released into marine systems also leads to greater population instability.

A study done in Britain found that the quality of effluent effected the planktonic life in the water in direct contact with the wastewater effluent. Turbid, low-quality effluents either did not contain ciliated protozoa or contained only a few species in small numbers. On the other hand, high-quality effluents contained a wide variety of ciliated protozoa in large numbers. Due to these findings, it seems unlikely that any particular component of the industrial effluent has, by itself, any harmful effects on the protozoan populations of activated sludge plants.

The planktonic trends of high populations close to input of treated sewage is contrasted by the bacterial trend. In a study of *Aeromonas* spp. in increasing distance from a wastewater source, greater change in seasonal cycles was found the furthest from the effluent. This trend is so strong that the furthest location studied actually had an inversion of the *Aeromonas* spp. cycle in comparison to that of fecal coliforms. Since there is a main pattern in the cycles that occurred simultaneously at all stations it indicates seasonal factors (temperature, solar radiation, phytoplankton) control of the bacterial population. The effluent dominant species changes from *Aeromonas caviae* in winter to *Aeromonas sobria* in the spring and fall while the inflow dominant species is *Aeromonas caviae*, which is constant throughout the seasons.

Sewage treatment in developing countries

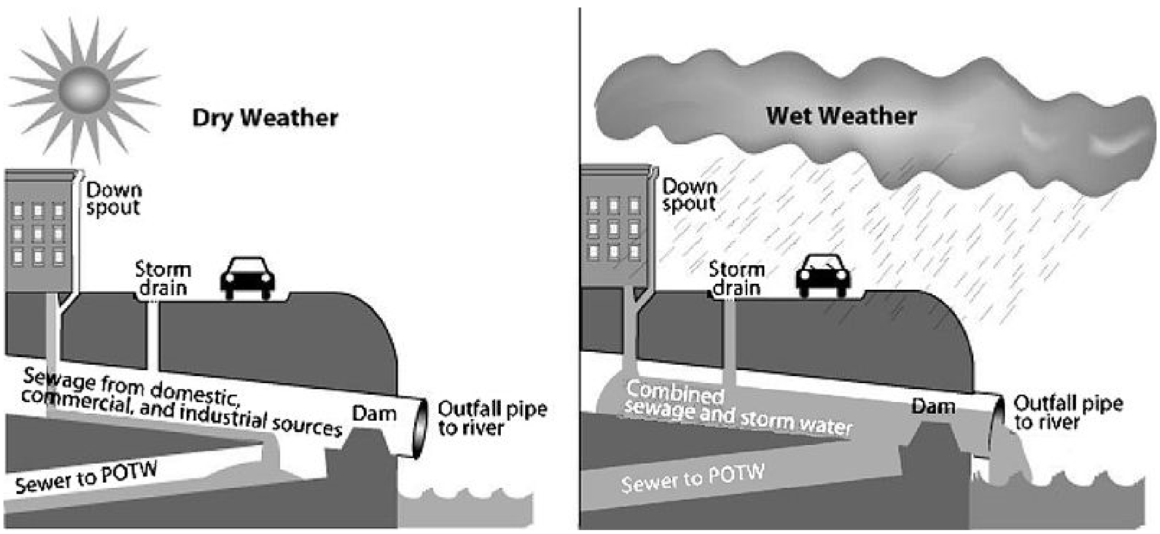
Few reliable figures on the share of the wastewater collected in sewers that is being treated in the world exist. In many developing countries the bulk of domestic and industrial wastewater is discharged without any treatment or after primary treatment only. In Latin America about 15% of collected wastewater passes through treatment plants (with varying levels of actual treatment). In Venezuela, a below average country in South America with respect to wastewater treatment, 97 percent of the country's sewage is discharged raw into the environment. In a relatively developed Middle Eastern country such as Iran, Tehran's majority of population has totally untreated sewage injected to the city's groundwater. However now the construction of major parts of the sewage system, collection and treatment, in Tehran is almost complete, and under development, due to be fully completed by the end of 2012.

In Israel, about 50 percent of agricultural water usage (total use was 1 billion cubic metres in 2008) is provided through reclaimed sewer water. Future plans call for increased use of treated sewer water as well as more desalination plants.

Most of sub-Saharan Africa is without wastewater treatment.

Chapter 2

Combined Sewer



Combined Sewer System. During dry weather (and small storms), all flows are handled by the publicly owned treatment works (POTW). During large storms, the relief structure allows some of the combined stormwater and sewage to be discharged untreated to an adjacent water body.

A **combined sewer** is a type of sewer system that collects sanitary sewage and stormwater runoff in a single pipe system. Combined sewers can cause serious water pollution problems due to combined sewer overflows, which are caused by large variations in flow between dry and wet weather. This type of sewer design is no longer used in building new communities, but many older cities continue to operate combined sewers.

Design history

The earliest covered sewers uncovered by archaeologists are in the regularly planned cities of the Indus Valley Civilization. In ancient Rome, the Cloaca Maxima, considered a marvel of engineering, disgorged into the Tiber. In ancient China, sewers existed in various cities such as Linzi. In medieval European cities, small natural waterways used for carrying off wastewater were eventually covered over and functioned as sewers. London's River Fleet is such a system. Open drains along the center of some streets were known as 'kennels' (= canals, channels). The nineteenth century brick-vaulted sewer system of Paris (The Paris sewers) offers tours for tourists.

Most of these early sewers received significant amounts of draft animal dung in street runoff; but handling of human waste varied with location. Public latrines were built over the Cloaca Maxima, but chamber pot contents were prohibited from Paris sewers as recently as 1880. People wealthy enough to enjoy 19th century flush toilets often had the political power to allow them to drain into public sewers; and the practice became the norm as indoor plumbing became more common.

Many cities that installed sewage collection systems in the early 20th century, or earlier, used single-pipe systems that collect both sewage and urban runoff from streets and roofs. This type of collection system is referred to as a **combined sewer system** or a CSS. The cities' rationale when these systems were built was that it would be cheaper to build just a single system.[:8] Most cities at that time did not have sewage treatment plants, so there was no perceived public health advantage in constructing a separate storm sewer system.[:p.2-3] Combined sewer systems are found throughout the United States, but are most heavily concentrated in the Northeast and Great Lakes regions. State and local authorities have generally not allowed the construction of new CSSs since the first half of the 20th century.

When constructed, combined sewer systems were typically sized to carry three to five times the average dry weather flows.[:p.2-4] As cities added sewage treatment plants, relief structures were installed in the collection system so that the flow could be discharged into a river or stream during large storm events when the capacity of the pipe exceeded the capacity of the wastewater treatment plant. By using these devices, called *regulators,* to discharge the excessive flow into a nearby water body, sewer backups in homes and streets are prevented.

In the UK, sewerage provision regulators (agencies) categorise all sewerage derived flooding as being one of two types: those due to hydraulic overloading and those due to all other causes. Although the media tends to focus on the former, 84% of sewerage derived flooding incidents (~26,000 per year) in England and Wales fall into the latter of these categories and ~90% of these are due to blockages. Considering the role of blockages is therefore a key research challenge; across the world they are probably the number one cause of losses in sewer serviceability (and hence flooding) in either dry or wet weather flow conditions.

Combined Sewer Overflows

A **combined sewer overflow,** or CSO, is the discharge of wastewater and stormwater from a combined sewer system directly into a river, stream, lake or ocean. Overflow frequency and duration varies both from system to system, and from outfall to outfall, within a single combined sewer system. Some CSO outfalls discharge infrequently, while others activate every time it rains.[:pp.2-3, 2-4.] During heavy rainfall when the stormwater exceeds the sanitary flow, the CSO is diluted.

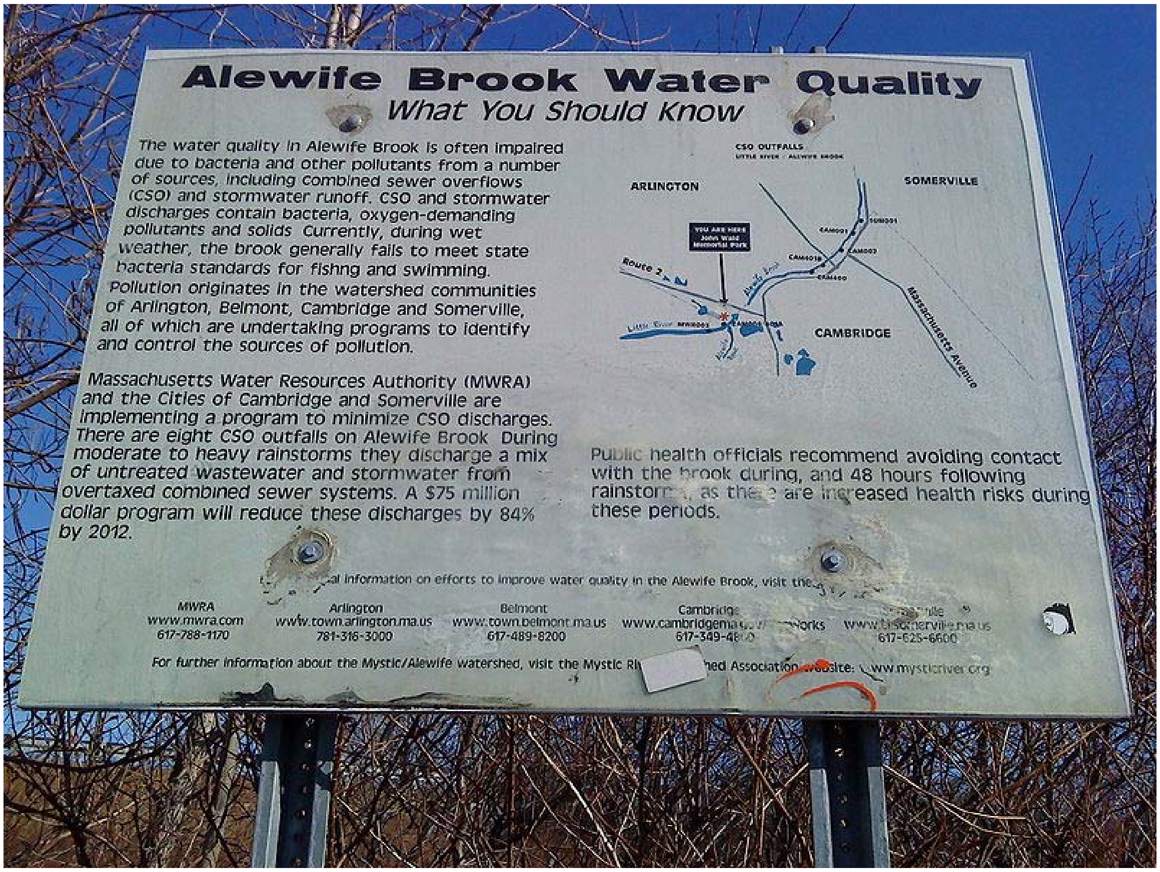
The storm water component contributes a significant amount of pollutants to CSO. Each storm is different in the quantity and type of pollutants it contributes. For example, storms that occur in late summer, when it has not rained for a while, have the most pollutants. Pollutants like oil, grease, fecal coliform from pet and wildlife waste, and pesticides get flushed into the sewer system. In cold weather areas, pollutants from cars, people and animals also accumulate on hard surfaces and grass during the winter and then are flushed into the sewer systems during heavy spring rains.

Extent and Effects of CSOs in United States

About 772 communities in the United States have combined sewer systems, serving about 40 million people. CSO discharges during heavy storms can cause serious water pollution problems in these communities. Pollutants from CSO discharges can include bacteria and other pathogens, toxic chemicals, and debris. The U.S. Environmental Protection Agency (EPA) issued a policy in 1994 requiring municipalities to make improvements to reduce or eliminate CSO-related pollution problems. In 2000 Congress amended the Clean Water Act to require the municipalities to comply with the EPA policy.

Mitigation of CSO Impacts in United States

Municipalities have been undertaking projects to mitigate CSO since the 1990s. For example, prior to 1990, the quantity of untreated combined sewage discharged annually to lakes, rivers and streams in southeast Michigan was estimated at more than 30 billion gallons per year. In 2005, with nearly US$1 billion of a planned $2.4 billion CSO investment put into operation, untreated discharges have been reduced by more than 20 billion gallons per year. This investment that has yielded a 67% reduction in CSO has included numerous sewer separation, CSO storage and treatment facilities and wastewater treatment plant improvements constructed by local and regional governments. Many other areas of the U.S. are undertaking similar projects to address CSO.



CSO signage at the Alewife Brook Reservation in Cambridge, MA.

Sewer separation

Some U.S. cities have undertaken sewer separation projects—building a second piping system for all or part of the community. In many of these projects, cities have been able to separate only portions of their combined systems. High costs or physical limitations may preclude building a completely separate system. Washington, D.C. is separating its sewers in four small neighborhoods at a cost of $11 million. (The project cost also includes improvements to the drinking water piping system.)

CSO storage

Another solution is to build a CSO storage facility, such as a tunnel that can store flow from many sewer connections. Because a tunnel can share capacity among several outfalls, it can reduce the total volume of storage that must be provided for a specific number of outfalls. Storage tunnels store combined sewage but do not treat it. When the storm is over, the flows are pumped out of the tunnel and sent to a wastewater treatment plant.

Expanding sewage treatment capacity

Some cities have expanded their basic sewage treatment capacity to handle some or all of the CSO volume. In 2002 the city of Toledo, Ohio, following litigation, agreed to double its treatment capacity, and build a storage basin, to eliminate most overflows. The city also agreed to study ways to reduce stormwater flows into the sewer system.

Retention basins

Retention treatment basins or large concrete tanks that store and treat combined sewage are another solution. These underground structures can range in storage and treatment capacity from 2 million to 120 million gallons of combined sewage. While each facility is unique, a typical facility operation is as follows. Flows from the overloaded sewers are pumped into a basin that is divided into compartments. The *first flush* compartment captures and stores flows with the highest level of pollutants from the first part of a storm. These pollutants include motor oil, sediment, road salt, and lawn chemicals (pesticides and fertilizers) that are picked up by the stormwater as it runs off roads and lawns. The flows from this compartment are stored and sent to the wastewater treatment plant when there is capacity in the interceptor sewer after the storm. The second compartment is a treatment or flow-through compartment. The flows are disinfected by injecting sodium hypochlorite, or bleach, as they enter this compartment. It then takes about 20 to 30 minutes for the flows to move to the end of the compartment. During this time, bacteria are killed and large solid materials settle out. At the end of the compartment, any remaining sanitary trash is skimmed off the top and the treated flows are discharged into the river or lake.

Screening and disinfection facilities

Screening and disinfection facilities treat CSO without ever storing it. Called flow-through facilities, they use fine screens to remove solids and sanitary trash from the combined sewage. Flows are injected with sodium hypochlorite for disinfection and mixed as they travel through a series of fine screens to remove debris. The fine screens have openings that range in size from 4 to 6 mm, or a little less than ¼ inch. The flow is sent through the facility at a rate that provides enough time for the sodium hypochlorite to kill bacteria. All of the materials removed by the screens are then sent to the wastewater treatment plant through the interceptor sewer.

Reducing stormwater flows

Communities may implement low impact development techniques to reduce flows of stormwater into the collection system. This includes:

- constructing new and renovated streets, parking lots and sidewalks with permeable paving and pervious concrete
- installing green roofs on buildings
- installing bioretention systems, also called rain gardens, in landscaped areas
- Rainwater harvesting equipment collects runoff from building roofs during wet weather for irrigating landscapes and gardens during dry weather
- Graywater collection and use on site reduces sewage discharges at all times

The 2004 EPA **Report to Congress** on CSO's provides a review of available technologies to mitigate CSO impacts.[:Ch. 8]

Chapter 3

Sanitary Sewer

PVC Sanitary Sewer Installation. Sanitary sewers are sized to carry the amount of sewage generated by the collection area. Sanitary sewers are much smaller than combined sewers designed to also carry surface runoff. The few sanitary sewers large enough for a man to stand erect typically carry flows that would sweep him off his feet.

A manhole cover for a sanitary sewer access point

Interior photo of a large sanitary sewer from an access manhole

A **sanitary sewer** (also called a **foul sewer**) is a separate underground carriage system specifically for transporting sewage from houses and commercial buildings to treatment or disposal. Sanitary sewers serving industrial areas also carry industrial wastewater. The 'system of sewers' is called sewerage.

Sanitary sewers are operated separately and independently of storm drains, which carry the runoff of rain and other water which wash into city streets.[:Ch.I] Sewers carrying both sewage and stormwater together are called combined sewers.

Nomenclature

In the developed world, sewers are usually pipelines that begin with connecting pipes from buildings to one or more levels of larger underground trunk mains, which transport the sewage to sewage treatment facilities. Vertical pipes, called manholes, connect the mains to the surface. The manholes are used for access to the sewer pipes for inspection and maintenance, and as a means to vent sewer gases. They also facilitate vertical and horizontal angles in otherwise straight pipelines. Sewers are generally gravity powered, though pumps may be used if necessary. The most commonly used sanitary pipe is SDR-35 (standard dimension ratio), with smaller sized laterals interconnected within a larger sized main.

Pipes conveying sewage from an individual building to a common gravity sewer line are called laterals. Branch sewers typically run under streets receiving laterals from buildings along that street and discharge by gravity into trunk sewers at manholes. Larger cities may have sewers called interceptors receiving flow from multiple trunk sewers. A lift station is a gravity sewer sump with a pump to lift accumulated sewage to a higher elevation. The pump may discharge to another gravity sewer at that location or may discharge through a pressurized force main to some distant location.

History

As an outgrowth of the Industrial Revolution, many cities in Europe and North America grew in the 19th century, frequently leading to crowding and increasing concerns about public health. As part of a trend of municipal sanitation programs in the late 19th and 20th centuries, many cities constructed extensive sewer systems to help control outbreaks of disease such as typhoid and cholera. Initially these systems discharged sewage directly to surface waters without treatment. As pollution of water bodies became a concern, cities added sewage treatment plants to their systems.

Maintenance

All sewers deteriorate with age; but Infiltration/Inflow is a problem unique to sanitary sewers; since both combined sewers and storm drains are sized to carry these contributions. Holding infiltration to acceptable levels requires a higher standard of maintenance than necessary for structural integrity considerations of combined sewers. A comprehensive construction inspection program is required to prevent inappropriate connection of cellar, yard, and roof drains to sanitary sewers. The probability of inappropriate connections is higher where combined sewers and sanitary sewers are found in close proximity; because construction personnel may not recognize the difference. Many older cities still use combined sewers while adjacent suburbs were built with separate sanitary sewers.

Simplified sewers

Simplified sanitary sewers consist of small-diameter pipes (typically 100 mm or about 4 inches), often laid at fairly flat gradients (1 in 200). The investment cost for sanitary sewers can be about half the costs of conventional sewers. However, the requirements for operation and maintenance are usually higher. Simplified sewers are most common in Brazil and are also used in a number of other developing countries.

Chapter 4

Sludge

Sludge

Sludge refers to the residual, semi-solid material left from industrial wastewater, or sewage treatment processes. It can also refer to the settled suspension obtained from conventional drinking water treatment, and numerous other industrial processes. The term is also sometimes used as a generic term for solids separated from suspension in a liquid; this 'soupy' material usually contains significant quantities of 'interstitial' water (between the solid particles).

When fresh sewage or wastewater is added to a settling tank, approximately 50% of the suspended solid matter will settle out in an hour and a half. This collection of solids is known as raw sludge or primary solids and is said to be "fresh" before anaerobic processes become active. The sludge will become putrescent in a short time once anaerobic bacteria take over, and must be removed from the sedimentation tank before this happens.

This is accomplished in one of two ways. In an Imhoff tank, fresh sludge is passed through a slot to the lower story or digestion chamber where it is decomposed by anaerobic bacteria, resulting in liquefaction and reduced volume of the sludge. After digesting for an extended period, the result is called "digested" sludge and may be disposed of by drying and then landfilling. More commonly with domestic sewage, the fresh sludge is continuously extracted from the tank mechanically and passed to separate sludge digestion tanks that operate at higher temperatures than the lower story of the Imhoff tank and, as a result, digest much more rapidly and efficiently.

Excess solids from biological processes such as activated sludge may still be referred to as sludge, but the term biosolids, is more commonly used to refer to the material, particularly after further processing such as aerobic composting. Industrial wastewater solids are also referred to as sludge, whether generated from biological or physical-chemical processes. Surface water plants also generate sludge made up of solids removed from the raw water.

Background and history

Biosolids, the treated form of sewage sludge, have been in use in UK and European agriculture for more than 80 years, though there is increasing pressure to stop the practice of land application. In the 1990s there was pressure in some European countries to ban the use of sewage sludge as a fertilizer. Switzerland, Sweden, Austria, and others introduced a ban. Since the 1960s there has been cooperative activity with industry to reduce the inputs of persistent substances from factories. This has been very successful and, for example, the content of cadmium in sewage sludge in major European cities is now only 1% of what it was in 1970.

European legislation on dangerous substances has eliminated the production and marketing of some substances that have been of historic concern such as persistent organic micropollutants. The European Commission has said repeatedly that the "Directive on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture" (86/278/EEC) has been very successful in that there have been no cases of adverse effect where it has been applied. The EC encourages the use of sewage sludge in agriculture because it conserves organic matter and completes nutrient cycles. Recycling of phosphate is regarded as especially important because the phosphate industry predicts that at the current rate of extraction the economic reserves will be exhausted in 100 or at most 250 years.

Of general interest on this topic is the Swanson et al. (2004) brief history of sewage management in New York City [Swanson, R.L., M.L. Bortman, T.P. O'Connor, and H M. Stanford. 2004. Science, policy and the management of sewage materials; The New York City experience. Mar. Poll. Bull. 49: 679-687]. Since 1884 when sewage was first treated the amount of sludge has increased along with population and treatment technology. At first the sludge was discharged directly along the banks of rivers surrounding the city, a bit later piped further into the rivers, and then further still out into the harbor. In 1924, to relieve a dismal condition in New York Harbor which actually putrefied in places as a result of decay of sewage, New York City began dumping sludge at sea at a location in the New York Bight called the 12-Mile Site. This was deemed a successful public health measure and not until the late 1960s was there any examination of its consequences to marine life or to humans. There was accumulation of sludge particles on the seafloor and consequent changes in the numbers and types of benthic organisms. In 1970 a large area around the site was closed to shellfishing From then until to 1986, the practice of dumping at the 12-Mile Site came under increasing pressure stemming from a series of untoward environmental crises in the New York Bight that were attributed partly to sludge dumping. In 1986, sludge dumping was moved still further seaward to a site over the deep ocean called the 106-Mile Site. Then, again in response to political pressure arising from events unrelated to ocean dumping, the practice ended entirely in 1992. Since 1992, New York City sludge has been applied to land (outside of New York state). That practice, now employed by two/thirds of the sewage treatment plants in the US, has been under continued scrutiny. The wider question is whether or not changes on the sea floor caused by the portion of sludge that settles are severe enough to justify the added operational cost and human health concerns of applying sludge to land. The cost versus benefit question is moot in the U.S. because ocean dumping of sludge is banned, but international treaty (London Dumping Convention) allows the practice so, on a global basis, as more and more sewage is treated, every sludge management option deserves practical consideration.

The term biosolids was formally created in 1991 by the Name Change Task Force of the Water Environment Federation (WEF), formerly known as the "Federation of Sewage Works Associations" to differentiate raw, untreated sewage sludge from treated and tested sewage sludge that can legally be utilized as soil amendment and fertilizer. The Federation newsletter published a request for alternative names. Members sent in over 250 suggestions, including "all growth," "purenutri," "biolife," "bioslurp," "black gold," "geoslime," "sca-doo," "the end product," "humanure," "hu-doo," "organic residuals," "bioresidue," "urban biomass," "powergro," "organite," "recyclite," "nutri-cake" and "ROSE," short for "recycling of solids environmentally." In June 1991, the Name Change Task Force finally settled on "biosolids," which it defined as the "nutrient-rich, organic byproduct of the nation's wastewater treatment process."

The legal term for biosolids by law is sludge. Treatment processes do not remove cancer causing agents. According to the 1995 *Plain English Guide to the Part 503 Risk*

Assessment, There was never a risk assessment for the cancer causing agents or heavy metals found in sludge.

Treatment process

Sewage sludge is produced from the treatment of wastewater and consists of two basic forms — raw primary sludge (basically faecal material) and secondary sludge (a living 'culture' of organisms that help remove contaminants from wastewater before it is returned to rivers or the sea). The sludge is transformed into biosolids using a number of complex treatments such as digestion, thickening, dewatering, drying, and lime/alkaline stabilisation. Some treatment processes such as composting and alkaline stabilization involve significant amendments may dilute contaminant concentrations; depending on the process and the contaminant in question, treatment may decrease or in some cases increase the bioavailability and/or solubility of contaminants. In general, the more effectively a wastewater stream is treated, the greater the resulting concentration of contaminants into the product sludge.

Biosolids

Biosolids, also referred to as treated sludge, is a term used by the waste water industry to denote the byproduct of domestic and commercial sewage and wastewater treatment. These residuals are further treated to reduce pathogens and vector attraction by any of a number of approved methods. Toxic chemicals such as PCBs, dioxin, and brominated flame retardants, may remain in treated sludge. One of the main concerns in the treated sludge is the concentrated metals content; certain metals are regulated while others are not. Leaching methods can be used to reduce the metal content and meet the regulatory limit. The U.S. divides biosolids into two grades: Class B sewage sludge, and Class A treated sewage sludge. Class A sludge has been treated to reduce bacteria prior to application to land; Class B sludge has not.

Depending on their level of treatment and resultant pollutant content, biosolids can be used in regulated applications for non-food agriculture, food agriculture, or distribution for unlimited use. Treated biosolids can be produced in cake, granular, pellet or liquid form and are spread over land before being incorporated into the soil or injected directly into the soil by specialist contractors. It used to be common practice to dump sewage sludge into the ocean, however, this practice has stopped in many nations due environmental concerns as well to domestic and international laws and treaties. In particular, after the 1991 Congressional ban on ocean dumping, the U.S. Environmental Protection Agency (EPA) instituted a policy of digested sludge reuse on agricultural land. The EPA promoted this policy by presenting it as recycling and rechristening sewage sludge as "biosolids", as they are solids produced by biological activities.

A 2004 survey of 48 individuals near affected sites found that most reported irritation symptoms, about half reported an infection within a month of the application, and about a fourth were affected by *Staphylococcus aureus*, including two deaths. The number of reported S. aureus infections was 25 times as high as in hospitalized patients, a high-risk group. The authors point out that regulations call for protective gear when handling Class

B biosolids and that similar protections could be considered for residents in nearby areas given the wind conditions.

Khuder, Milz, Bisesi, Vincent, McNulty, and Czajkowski (as cited by Harrison and McBride of the Cornell Waste Management Institute in *Case for Caution Revisited: Health and Environmental Impacts of Application of Sewage Sludges to Agricultural Land*) conducted a health survey of persons living in close proximity to sludged land. A sample of 437 people exposed to sludge (living within 1-mile (1.6 km) of sludged land) - and using a control group of 176 people not exposed to sludge (not living within 1-mile (1.6 km) of sludged land) reported the following:

"Results revealed that some reported health-related symptoms were statistically significantly elevated among the exposed residents, including excessive secretion of tears, abdominal bloating, jaundice, skin ulcer, dehydration, weight loss, and general weakness. The frequency of reported occurrence of bronchitis, upper respiratory infection, and giardiasis were also statistically significantly elevated. The findings suggest an increased risk for certain respiratory, gastrointestinal, and other diseases among residents living near farm fields on which the use of biosolids was permitted."

—Khuder, et al., *Health Survey of Residents Living near Farm Fields Permitted to Receive Biosolids*

Although correlation does not imply causation, such extensive correlations may lead reasonable people to conclude that precaution is necessary in dealing with sludge and sludged farmlands.

Harrison and Oakes suggest that, in particular, "until investigations are carried out that answer these questions (...about the safety of Class B sludge...), land application of Class B sludges should be viewed as a practice that subjects neighbors and workers to substantial risk of disease." They further suggest that even Class A treated sludge may have chemical contaminants (including heavy metals, such as lead) or endotoxins present, and a precautionary approach may be justified on this basis, though the vast majority of incidents reported by Lewis, et al. have been correlated with exposure to Class B untreated sludge and not Class A treated sludge.

The EPA has recently (as of 2009) released the Targeted National Sewage Sludge Study, which reports on the level of metals, chemicals, hormones, and other materials present in a statistical sample of sewage sludges. Some highlights include:

- Silver is present to the degree of 20 mg/kg of sludge, on average, a near economically recoverable level, while some sludges of *exceptionally high quality* have up to 200 milligrams of silver per kilogram of sludge; one outlier demonstrated a silver lode of 800–900 mg per kg of sludge. It is unknown whether mineral speculators have yet invested in the sludge stocks of the United States.
- Barium is present at the rate of 500 mg/kg, while manganese is present at the rate of 1 g/kg sludge.

- High levels of sterols and other hormones have been detected, with averages in the range of up to 1,000,000 μg/kg sludge.
- Lead, arsenic, chromium, and cadmium are estimated by the EPA to be present in detectable quantities in 100% of national sewage sludges in the US, while thallium is only estimated to be present in 94.1% of sludges.

Recent studies (2010) have indicated that pharmaceuticals and personal care products, which often adsorb to sludge during wastewater treatment, can persist in agricultural soils following biosolid application. Some of these chemicals, including potential endocrine disruptor Triclosan, can also travel through the soil column and leach into agricultural tile drainage at detectable levels. Other studies, however, have shown that these chemicals remain adsorbed to surface soil particles, making them more susceptible to surface erosion than infiltration. These studies are also mixed in their findings regarding the persistence of chemicals such as triclosan, triclocarban, and other pharmaceuticals. The impact of this persistence in soils is unknown, but the link to human and land animal health is likely tied to the capacity for plants to absorb and accumulate these chemicals in their consumed tissues. Studies of this kind are in early stages, but evidence of root uptake and translocation to leaves did occur for both triclosan and triclocarban in soybeans. This effect was not present in corn when tested in a different study.

For produce to be USDA-certified organic, sludge (biosolids) cannot be used.

A PhD thesis studying the addition of sludge to neutralize soil acidity concluded that the practice was not recommended if large amounts are used because the sludge produces acids when it oxidizes.

United States

According to the United States Environmental Protection Agency (EPA), biosolids that meet treatment and pollutant content criteria of Part 503.13 "can be safely recycled and applied as fertilizer to sustainably improve and maintain productive soils and stimulate plant growth." However, they can not be disposed of in a sludge only landfill under Part 503.23 because of high chromium levels and boundary restrictions. After the 1991 Congressional ban on ocean dumping, the US EPA promulgated regulations - 40 CFR Part 503 - that continued to allow the use of biosolids on land as fertilizers and soil amendments which had been previously allowed under Part 257. The EPA promoted biosolids recycling throughout the 1990s. The EPA's Part 503 regulations were developed with input from university, EPA, and USDA researchers from around the country and involved an extensive review of the scientific literature and the largest risk assessment the agency had conducted to that time. However, there was no risk assess for pathogens or chemicals and heavy metals were not considered to be cancer causing agents. The Part 503 regulations became effective in 1993.

United States municipal wastewater treatment plants in 1997 produced about 7.7 million dry tons of biosolids, and about 6.8 million dry tons in 1998 according to sources relying on EPA estimates. As of 2002, about 60% of all biosolids were applied to land as a soil amendment and fertilizer for growing crops. Biosolids that meet the Class B pathogen treatment and pollutant criteria, in accordance with the EPA "Standards for the use or disposal of sewage sludge" (40 CFR Part 503), can be land applied with formal site restrictions and strict record keeping. Biosolids that meet Class A pathogen reduction requirements or equivalent treatment by a "Process to Further Reduce Pathogens" (PFRP) have the least restrictions on use. PFRPs include pasteurization, heat drying, thermophilic composting (aerobic digestion, most common method), and beta or gamma ray irradiation. Processes to reduce pathogens have no effect on heavy metals and may or may not have effects on the levels of other trace pollutants in biosolids. Treatment processes that involve significant amendments such as composting and alkaline stabilization may dilute total trace metals concentrations, but, depending on the process and the element in question, may decrease or in some cases increase the bioavailability and/or solubility of trace elements.

Often thought to consist of only "human waste", treated sewage sludge or "biosolids" contain any contaminants from sewage that are not broken down in the treatment process, or which do not remain with the water effluent leaving the treatment plant. The most commonly detected trace contaminants of concern are heavy metals (arsenic, cadmium, copper, etc., some of which are also critical plant micronutrients), and toxic chemicals (e.g. plasticizers, PDBEs, and others generated by human activities, including personal care products and medicines). Synthetic fibers from fabrics persist in biosolids as well as in biosolids-treated soils and may thus serve as an indicator of past biosolids application. Pathogens are not a significant health issue if biosolids are properly treated and site-sepcific management practices are followed; there is generally a greater concern for products that have been fertilized with un-treated animal wastes and which may be eaten raw.

The National Research Council published "Biosolids Applied to Land: Advancing Standards and Practices" in July 2002. The NRC concluded that while there is no documented scientific evidence that sewage sludge regulations have failed to protect public health, there is persistent uncertainty on possible adverse health effects. The NRC noted that further research is needed and made about 60 recommendations for addressing public health concerns, scientific uncertainties, and data gaps in the science underlying the sewage sludge standards. EPA responded with a commitment to conduct research addressing the NRC recommendations.

The EPA Office of the Inspector General (OIG) completed two assessments in 2000 and 2002 of the EPA sewage sludge program. The follow-up report in 2002 documented that "the EPA cannot assure the public that current land application practices are protective of human health and the environment." The report also documented that there had been an almost 100% reduction in EPA enforcement resources since the earlier assessment. This is probably the greatest issue with the practice: under both the federal program operated by the EPA and those of the several states, there is limited inspection and oversight by agencies charged with regulating these practices. To some degree, this lack of oversight is a function of the perceived (by the regulatory agencies) benign nature of the practice. However, a greater underlying issue is funding. Few states and the US EPA have the discretionary funds necessary to establish and implement a full enforcement program for biosolids. To do so would require substantial spending that most legislatures are unwilling to support. Some states and companies involved in biosolids management have willingly agreed to use a "fee" per unit of biosolids managed to help fund such programs, and generally, where such programs are in place, biosolids land application proceeds without incident, however these fees are seldom sufficient to fully fund a rigorous inspection program.

A cautionary approach to land application of biosolids has been advocated by some for regions where soils have lower capacities for toxics sorption or due to the presence of unknowns in sewage biosolids. In 2007 the Northeast Regional Multi-State Research Committee (NEC 1001) issued conservative guidelines tailored to the soils and conditions typical of the northeastern US.

Alternative pathways for sludge reuse

Feridun of the United Sludge Free Alliance suggests that sludge can be recycled in a variety of ways that are both environmentally beneficial and sustainable, and which do not involve application of biologically active materials to croplands that humans live close to. These include using anaerobic digestion to produce biogas, pyrolysis of the sludge to create syngas and potentially biochar, or incineration in a waste-to-energy facility for direct production of electricity and steam for district heating or industrial uses. Synergies from these processes include a far lower, controlled level of methane release (an extremely potent greenhouse gas) to the atmosphere from the pyrolyzed/digested/combusted sludge rather than the uncontrolled release of methane from untreated sludge. If methane is captured rather than allowed to outgas, it can be used for fuel, closing the carbon cycle. Thermal or anaerobic processes greatly reduce the volume of the sludge, as well as achieve remediation the biological concerns. Direct waste-to-energy incineration systems require multi-step cleaning of the exhaust gas, to ensure no hazardous substances are released. In addition, the ash produced by incineration is difficult to use without subsequent treatment due to its high heavy metal content; solutions to this include leaching of the ashes to remove heavy metals followed by reuse of the ash as aggregate for concrete, or if biochar is used, the heavy metals may be fixed in place by the char structure. An other way to use dried sewage sludge as a energy resource is to burn it together with coal in coal-fired power stations. This is considered as biomass co-firing, which allows to produce the same amount of electricity with less carbon-dioxide emissions.

Chapter 5

Wastewater

Wastewater is any water that has been adversely affected in quality by anthropogenic influence. It comprises liquid waste discharged by domestic residences, commercial properties, industry, and/or agriculture and can encompass a wide range of potential contaminants and concentrations. In the most common usage, it refers to the municipal wastewater that contains a broad spectrum of contaminants resulting from the mixing of wastewaters from different sources.

Sewage is correctly the subset of wastewater that is contaminated with feces or urine, but is often used to mean any waste water. "Sewage" includes domestic, municipal, or industrial liquid waste products disposed of, usually via a pipe or sewer or similar structure, sometimes in a cesspool emptier.

The physical infrastructure, including pipes, pumps, screens, channels etc. used to convey sewage from its origin to the point of eventual treatment or disposal is termed sewerage.

Origin

Wastewater or sewage can come from (text in brackets indicates likely inclusions or contaminants):

- Human waste (fæces, used toilet paper or wipes, urine, or other bodily fluids), also known as blackwater, usually from lavatories;
- Cesspit leakage;
- Septic tank discharge;
- Sewage treatment plant discharge;
- Washing water (personal, clothes, floors, dishes, etc.), also known as greywater or sullage;
- Rainfall collected on roofs, yards, hard-standings, etc. (generally clean with traces of oils and fuel);
- Groundwater infiltrated into sewage;
- Surplus manufactured liquids from domestic sources (drinks, cooking oil, pesticides, lubricating oil, paint, cleaning liquids, etc.);

- Urban rainfall runoff from roads, carparks, roofs, sidewalks, or pavements (contains oils, animal fæces, litter, fuel or rubber residues, metals from vehicle exhausts, etc.);
- Seawater ingress (high volumes of salt and micro-biota);
- Direct ingress of river water (high volumes of micro-biota);
- Direct ingress of manmade liquids (illegal disposal of pesticides, used oils, etc.);
- Highway drainage (oil, de-icing agents, rubber residues);
- Storm drains (almost anything, including cars, shopping trolleys, trees, cattle, etc.);
- Blackwater (surface water contaminated by sewage);
- Industrial waste
- industrial site drainage (silt, sand, alkali, oil, chemical residues);
    - Industrial cooling waters (biocides, heat, slimes, silt);
    - Industrial process waters;
    - Organic or bio-degradable waste, including waste from abattoirs, creameries, and ice cream manufacture;
    - Organic or non bio-degradable/difficult-to-treat waste (pharmaceutical or pesticide manufacturing);
    - extreme pH waste (from acid/alkali manufacturing, metal plating);
    - Toxic waste (metal plating, cyanide production, pesticide manufacturing, etc.);
    - Solids and Emulsions (paper manufacturing, foodstuffs, lubricating and hydraulic oil manufacturing, etc.);
    - agricultural drainage, direct and diffuse.

Wastewater constituents

The composition of wastewater varies widely. This is a partial list of what it may contain:

- Water (> 95%) which is often added during flushing to carry waste down a drain;
- Pathogens such as bacteria, viruses, prions and parasitic worms;
- Non-pathogenic bacteria;
- Organic particles such as feces, hairs, food, vomit, paper fibers, plant material, humus, etc.;
- Soluble organic material such as urea, fruit sugars, soluble proteins, drugs, pharmaceuticals, etc.;
- Inorganic particles such as sand, grit, metal particles, ceramics, etc.;
- Soluble inorganic material such as ammonia, road-salt, sea-salt, cyanide, hydrogen sulfide, thiocyanates, thiosulfates, etc.;
- Animals such as protozoa, insects, arthropods, small fish, etc.;
- Macro-solids such as sanitary napkins, nappies/diapers, condoms, needles, children's toys, dead animals or plants, etc.;
- Gases such as hydrogen sulfide, carbon dioxide, methane, etc.;
- Emulsions such as paints, adhesives, mayonnaise, hair colorants, emulsified oils, etc.;
- Toxins such as pesticides, poisons, herbicides, etc.
- Pharmaceuticals and other hormones.

Wastewater quality indicators

Any oxidizable material present in a natural waterway or in an industrial wastewater will be oxidized both by biochemical (bacterial) or chemical processes. The result is that the oxygen content of the water will be decreased. Basically, the reaction for biochemical oxidation may be written as:

Oxidizable material + bacteria + nutrient + O_2 → CO_2 + H_2O + oxidized inorganics such as NO_3 or SO_4

Oxygen consumption by reducing chemicals such as sulfides and nitrites is typified as follows:

$$S^{--} + 2\ O_2 \rightarrow SO_4^{--}$$
$$NO_2^{-} + \tfrac{1}{2}\ O_2 \rightarrow NO_3^{-}$$

Since all natural waterways contain bacteria and nutrients, almost any waste compounds introduced into such waterways will initiate biochemical reactions (such as shown above). Those biochemical reactions create what is measured in the laboratory as the Biochemical oxygen demand (BOD). Such chemicals are also liable to be broken down using strong oxidizing agents and these chemical reactions create what is measured in the laboratory as the Chemical oxygen demand (COD). Both the BOD and COD tests are a measure of the relative oxygen-depletion effect of a waste contaminant. Both have been widely adopted as a measure of pollution effect. The BOD test measures the oxygen demand of biodegradable pollutants whereas the COD test measures the oxygen demand of oxidizable pollutants.

The so-called 5-day BOD measures the amount of oxygen consumed by biochemical oxidation of waste contaminants in a 5-day period. The total amount of oxygen consumed when the biochemical reaction is allowed to proceed to completion is called the Ultimate BOD. Because the Ultimate BOD is so time consuming, the 5-day BOD has been almost universally adopted as a measure of relative pollution effect.

There are also many different COD tests of which the 4-hour COD is probably the most common.

There is no generalized correlation between the 5-day BOD and the ultimate BOD. Similarly there is no generalized correlation between BOD and COD. It is possible to develop such correlations for a specific waste contaminants in a specific waste water stream but such correlations cannot be generalized for use with any other waste contaminants or waste water streams. This is because the composition of any waste water stream is different. As an example and effluent consisting of a solution of simple sugars that might discharge from a confectionery factory is likely to have organic components that degrade very quickly. In such a case the 5 day BOD and the ultimate BOD would be very similar . I.e there would be very little organic material left after 5 days. . However a final effluent of a sewage treatment works serving a large industrialised area might have a discharge where the ultimate BOD was much greater than the 5 day BOD because much of the easily degraded material would have been removed in the sewage treatment process and many industrial processes discharge difficult to degrade organic molecules.

The laboratory test procedures for the determining the above oxygen demands are detailed in many standard texts. American versions include the "Standard Methods For the Examination Of Water and Wastewater"

Sewage disposal

Industrial wastewater effluent with neutralized pH from tailing runoff. Taken in Peru.

In some urban areas, sewage is carried separately in sanitary sewers and runoff from streets is carried in storm drains. Access to either of these is typically through a manhole. During high precipitation periods a sanitary sewer overflow can occur, forcing untreated sewage to flow back into the environment. This can pose a serious threat to public health and the surrounding environment.

Sewage may drain directly into major watersheds with minimal or no treatment. When untreated, sewage can have serious impacts on the quality of an environment and on the health of people. Pathogens can cause a variety of illnesses. Some chemicals pose risks even at very low concentrations and can remain a threat for long periods of time because of bioaccumulation in animal or human tissue.

Treatment

There are numerous processes that can be used to clean up waste waters depending on the type and extent of contamination. Most wastewater is treated in industrial-scale wastewater treatment plants (WWTPs) which may include physical, chemical and biological treatment processes. However, the use of septic tanks and other On-Site Sewage Facilities (OSSF) is widespread in rural areas, serving up to one quarter of the homes in the U.S . The most important aerobic treatment system is the activated sludge process, based on the maintenance and recirculation of a complex biomass composed by micro-organisms able to absorb and adsorb the organic matter carried in the wastewater. Anaerobic processes are widely applied in the treatment of industrial wastewaters and biological sludge. Some wastewater may be highly treated and reused as reclaimed water. For some waste waters ecological approaches using reed bed systems such as constructed wetlands may be appropriate. Modern systems include tertiary treatment by micro filtration or synthetic membranes. After membrane filtration, the treated wastewater is indistinguishable from waters of natural origin of drinking quality. Nitrates can be removed from wastewater by microbial denitrification, for which a small amount of methanol is typically added to provide the bacteria with a source of carbon. Ozone Waste Water Treatment is also growing in popularity, and requires the use of an ozone generator, which decontaminates the water as Ozone bubbles percolate through the tank.

Disposal of wastewaters from an industrial plant is a difficult and costly problem. Most petroleum refineries, chemical and petrochemical plants have onsite facilities to treat their wastewaters so that the pollutant concentrations in the treated wastewater comply with the local and/or national regulations regarding disposal of wastewaters into community treatment plants or into rivers, lakes or oceans. Other Industrial processes that produce a lot of waste-waters such as paper and pulp production has created environmental concern leading to development of processes to recycle water use within plants before they have to be cleaned and disposed of.

Reuse

Treated wastewater can be reused as drinking water, in industry (cooling towers), in artificial recharge of aquifers, in agriculture (70% of Israel's irrigated agriculture is based on highly purified wastewater) and in the rehabilitation of natural ecosystems (Florida's Everglades).

Algal fuel

Woods Hole Oceanographic Institution and Harbor Branch Oceanographic Institution, following the conclusions of the USDOE´s Aquatic Species Program, use wastewater for breeding algae. The wastewater from domestic and industrial sources contain rich organic compounds, which accelerate the growth of algae. This algae can be used to produce algal fuels

Algaewheel, based in Indianapolis, Indiana, presented a proposal to build a new wastewater treatment facility in Cedar Lake, Indiana that uses algae to treat municipal wastewater and uses the sludge byproduct to produce biofuel.

Etymology

The words "sewage" and "sewer" came from Old French *essouier* = "to drain", which came from Latin *exaquāre*. Their formal Latin antecedents are *exaquāticum* and *exaquārium*.

Legislation

European Union

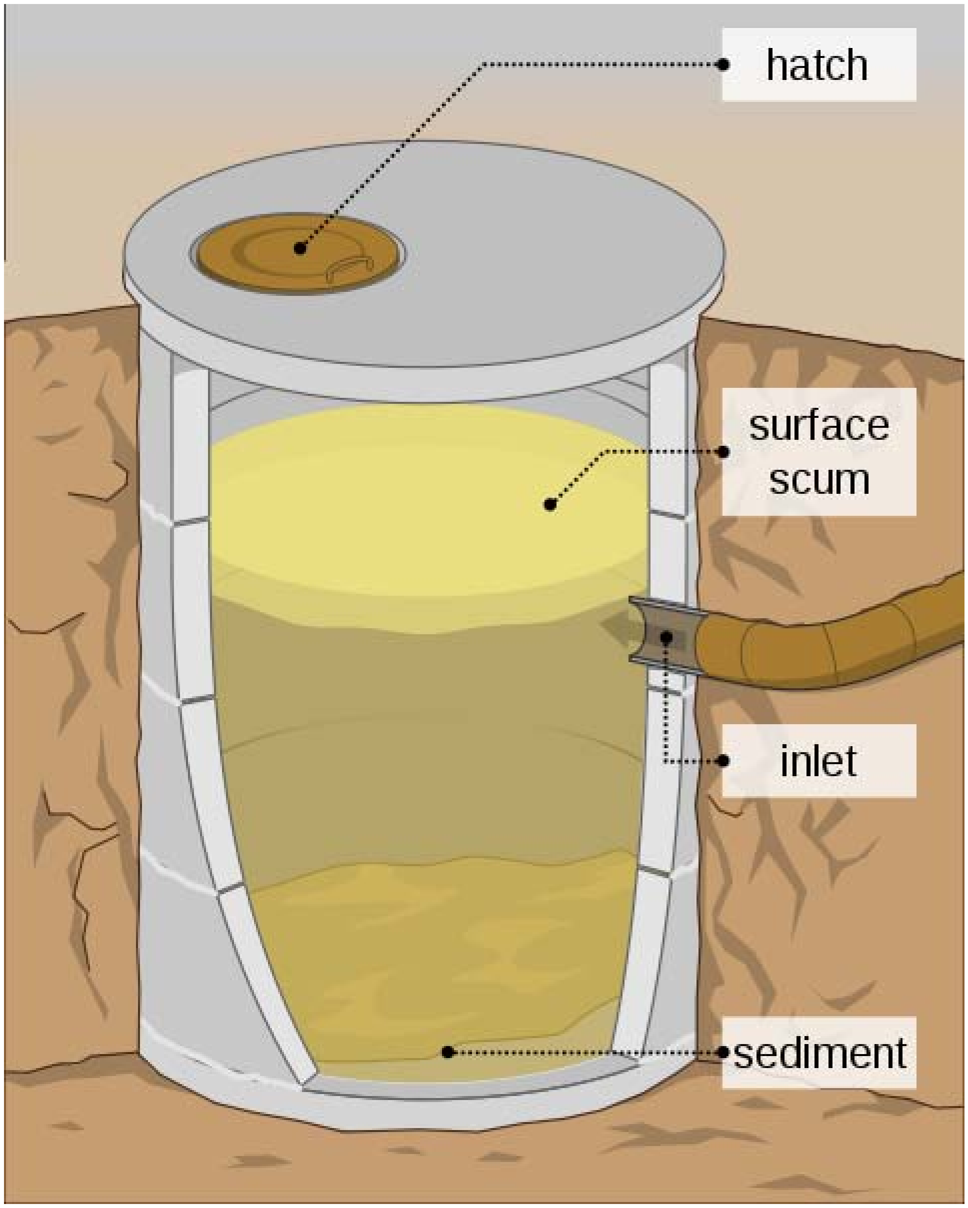
Council Directive 91/271/EEC on Urban Waste Water Treatment was adopted on 21 May 1991 , amended by the Commission Directive 98/15/EC . Commission Decision 93/481/EEC defines the information that Member States should provide the Commission on the state of implementation of the Directive.

Chapter 6

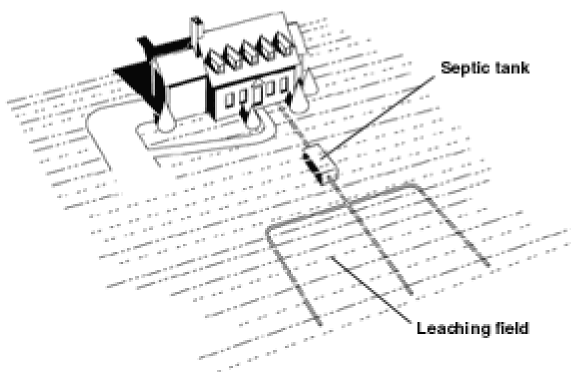
Septic Tank

A septic tank before installation

The same tank partially installed in the ground



Septic tank scheme



Septic tank and septic drain field

A **septic tank** is a key component of the **septic system**, a small scale sewage treatment system common in areas with no connection to main sewage pipes provided by local governments or private corporations. (Other components, typically mandated and/or restricted by local governments, optionally include pumps, alarms, sand filters, and clarified liquid effluent disposal means such as a septic drain field, ponds, natural stone fibre filter plants or peat moss beds.) Septic systems are a type of On-Site Sewage Facility (OSSF). In North America approximately 25% of the population relies on septic tanks; this can include suburbs and small towns as well as rural areas (Indianapolis is an example of a large city where many of the city's neighborhoods are still on separate septic systems). In Europe they are generally limited to rural areas only.

The term "septic" refers to the anaerobic bacterial environment that develops in the tank and which decomposes or mineralizes the waste discharged into the tank. Septic tanks can be coupled with other on-site wastewater treatment units such as biofilters or aerobic systems involving artificial forced aeration.

Periodic preventive maintenance is required to remove the irreducible solids which settle and gradually fill the tank, reducing its efficiency. In most jurisdictions this maintenance is required by law, yet often not enforced. Those who ignore the requirement will eventually be faced with extremely costly repairs when solids escape the tank and destroy the clarified liquid effluent disposal means. A properly maintained system, on the other hand, can last for decades and possibly a lifetime.

Description

A septic tank generally consists of a tank (or sometimes more than one tank) of between 4000 - 7500 litres (1,000 and 2,000 gallons) in size connected to an inlet wastewater pipe at one end and a septic drain field at the other. These pipe connections are generally made via a T pipe which allows liquid entry and exit without disturbing any crust on the surface. Today the design of the tank usually incorporates two chambers (each of which is equipped with a manhole cover) which are separated by means of a dividing wall which has openings located about midway between the floor and roof of the tank.

Wastewater enters the first chamber of the tank, allowing solids to settle and scum to float. The settled solids are anaerobically digested, reducing the volume of solids. The liquid component flows through the dividing wall into the second chamber where further settlement takes place, with the excess liquid then draining in a relatively clear condition from the outlet into the leach field, also referred to as a drain field or seepage field, depending upon locality.

The remaining impurities are trapped and eliminated in the soil, with the excess water eliminated through percolation into the soil (eventually returning to the groundwater), through evaporation, and by uptake through the root system of plants and eventual transpiration. A piping network, often laid in a stone filled trench, distributes the wastewater throughout the field with multiple drainage holes in the network. The size of the leach field is proportional to the volume of wastewater and inversely proportional to the porosity of the drainage field. The entire septic system can operate by gravity alone, or where topographic considerations require, with inclusion of a lift pump. Certain septic tank designs include siphons or other methods of increasing the volume and velocity of outflow to the drainage field. This helps to load all portions of the drainage pipe more evenly and extends the drainage field life by preventing premature clogging.

An Imhoff tank is a two-stage septic system where the sludge is digested in a separate tank. This avoids mixing digested sludge with incoming sewage. Also, some septic tank designs have a second stage where the effluent from the anaerobic first stage is aerated before it drains into the seepage field.

Waste that is not decomposed by the anaerobic digestion eventually has to be removed from the septic tank, or else the septic tank fills up and undecomposed wastewater discharges directly to the drainage field. Not only is this bad for the environment, but if the sludge overflows the septic tank into the leach field, it may clog the leach field piping or decrease the soil porosity itself, requiring expensive repairs.

How often the septic tank has to be emptied depends on the volume of the tank relative to the input of solids, the amount of indigestible solids and the ambient temperature (as anaerobic digestion occurs more efficiently at higher temperatures). The required frequency varies greatly depending on jurisdiction, usage, and system characteristics. Some health authorities require tanks to be emptied at prescribed intervals, while others leave it up to the determination of the inspector. Some systems require pumping every few years or sooner, while others may be able to go 10–20 years between pumpings. Contrary to what many believe, there is no "rule of thumb" for how often tanks should be emptied. An older system with an undersized tank that is being used by a large family will require much more frequent pumping than a new system used by only a few people. Anaerobic decomposition is rapidly re-started when the tank re-fills.

A properly designed and normally operating septic system is odour free and, besides periodic inspection and pumping of the septic tank, should last for decades with no maintenance.

A well designed and maintained concrete, fibreglass or plastic tank should last about 50 years.

Potential problems

- Excessive dumping of cooking oils and grease can cause the inlet drains to block. Oils and grease are often difficult to degrade and can cause odour problems and difficulties with the periodic emptying.
- Flushing non-biodegradable items such as cigarette butts and hygiene products such as sanitary towels and cotton buds will rapidly fill or clog a septic tank; these materials should not be disposed of in this way.
- The use of garbage disposers for disposal of waste food can cause a rapid overload of the system and early failure.
- Certain chemicals may damage the working of a septic tank, especially pesticides, herbicides, materials with high concentrations of bleach or caustic soda (lye) or any other inorganic materials such as paints or solvents.

- Roots from trees and shrubbery growing above the tank or the drainfield may clog and/or rupture them.
- Playgrounds and storage buildings may cause damage to a tank and the drainage field. In addition, covering the drainage field with an impervious surface, such as a driveway or parking area, will seriously affect its efficiency and possibly damage the tank and absorption system.
- Unsupervised septic tanks may cause serious injury or death to children playing nearby.
- Excessive water entering the system will overload it and cause it to fail. Checking for plumbing leaks and practicing water conservation will help the system's operation.
- Very high rainfall, rapid snow-melt, and flooding from rivers or the sea can all prevent a drain field from operating and can cause flow to backup and stop normal operation of the tank
- Over time biofilms develop on the pipes of the drainage field which can lead to blockage. Such a failure can be referred to as "Biomat failure".
- Septic tanks by themselves are ineffective at removing nitrogen compounds that can potentially cause algal blooms in receiving waters; this can be remedied by using a nitrogen-reducing technology, or by simply ensuring that the leach field is properly sited to prevent direct entry of effluent into bodies of water.
- Historically at least, not all varieties of toilet paper were suitable for disposal in a septic tank as they did not deteriorate sufficiently (or, at least at some points in history, some toilet paper was specifically marked as suitable for use in septic systems and some was not).

Environmental issues

Some pollutants, especially sulfates, under the anaerobic conditions of septic tanks, are reduced to hydrogen sulfide, a pungent and toxic gas. Likewise, methane, a potent greenhouse gas is another by-product. Nitrates and organic nitrogen compounds are reduced to ammonia. Because of the anaerobic conditions, fermentation processes take place, which ultimately generate carbon dioxide and methane.

The fermentation processes cause the contents of a septic tank to be anaerobic with a low redox potential, which keeps phosphate in a soluble and thus mobilized form. Because phosphate can be the limiting nutrient for plant growth in many ecosystems, the discharge from a septic tank into the environment can trigger prolific plant growth including algal blooms which can also include blooms of potentially toxic cyanobacteria.

Soil capacity to retain phosphorus is large compared with the load through a normal residential septic tank. An exception occurs when septic drain fields are located in sandy or coarser soils on property adjoining a water body. Because of limited particle surface area, these soils can become saturated with phosphate. Phosphate will progress beyond the treatment area, posing a threat of eutrophication to surface waters.

In areas with high population density, groundwater pollution levels often exceed acceptable limits. Some small towns are facing the costs of building very expensive centralized wastewater treatment systems because of this problem, owing to the high cost of extended collection systems.

To slow development, building moratoriums and limits on the subdivision of property are often imposed. Ensuring existing septic tanks are functioning properly can also be helpful for a limited time, but becomes less effective as a primary remediation strategy as population density increases.

Trees in the vicinity of a concrete septic tank have the potential to penetrate the tank as the system ages and the concrete begins to develop cracks and small leaks. Tree roots can cause serious flow problems due to plugging and blockage of drain pipes, but the trees themselves tend to grow extremely vigorously due to the continuous influx of nutrients into the septic system.

Chapter 7

Activated Sludge

Activated sludge is a process for treating sewage and industrial wastewaters using air and a biological floc composed of bacteria and protozoans.

Purpose

In a sewage (or industrial wastewater) treatment plant, the activated sludge process can be used for one or several of the following purposes:

- oxidizing carbonaceous matter: biological matter.
- oxidizing nitrogeneous matter: mainly ammonium and nitrogen in biological materials.
- removing phosphate.
- driving off entrained gases carbon dioxide, ammonia, nitrogen, etc.
- generating a biological floc that is easy to settle.
- generating a liquor that is low in dissolved or suspended material.

The process

The process involves air or oxygen being introduced into a mixture of primary treated or screened sewage or industrial wastewater (called wastewater from now on) combined with organisms to develop a biological floc which reduces the organic content of the sewage. This material, which in healthy sludge is a brown floc, is largely composed of saprotrophic bacteria but also has an important protozoan flora mainly composed of amoebae, Spirotrichs, Peritrichs including Vorticellids and a range of other filter feeding species. Other important constituents include motile and sedentary Rotifers. In poorly managed activated sludge, a range of mucilaginous filamentous bacteria can develop including *Sphaerotilus natans* which produces a sludge that is difficult to settle and can result in the sludge blanket decanting over the weirs in the settlement tank to severely contaminate the final effluent quality. This material is often described as sewage fungus but true fungal communities are relatively uncommon.

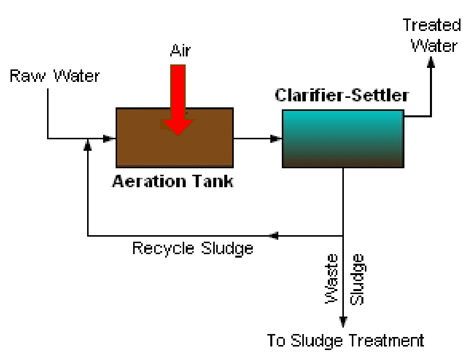
The combination of wastewater and biological mass is commonly known as **mixed liquor**. In all activated sludge plants, once the wastewater has received sufficient treatment, excess mixed liquor is discharged into settling tanks and the treated supernatant is run off to undergo further treatment before discharge. Part of the settled material, the sludge, is returned to the head of the aeration system to re-seed the new wastewater entering the tank. This fraction of the floc is called **return activated sludge** (R.A.S.). Excess sludge is called **surplus activated sludge**(S.A.S.) or **waste activated sludge**(W.A.S). S.A.S is removed from the treatment process to keep the ratio of biomass to food supplied in the wastewater in balance. S.A.S is stored in sludge tanks and is further treated by digestion, either under anaerobic or aerobic conditions prior to disposal.

Many sewage treatment plants use axial flow pumps to transfer nitrified mixed liquor from the aeration zone to the anoxic zone for denitrification. These pumps are often referred to as **internal mixed Liquor recycle pumps** (IMLR pumps). The raw sewage, the RAS, and the nitrified mixed liquor are mixed by submersible mixers in the anoxic zones in order to achieve denitrification.

Activated sludge is also the name given to the active biological material produced by activated sludge plants.

History

The activated sludge process was discovered in 1913 in the UK by two engineers, Edward Ardern and W.T. Lockett, conducting research for the Manchester Corporation Rivers Department at Davyhulme Sewage Works. Experiments on treating sewage in a draw-and-fill reactor (the precursor to today's sequencing batch reactor) produced a highly treated effluent. Believing that the sludge had been activated (in a similar manner to activated carbon) the process was named *activated sludge*. Not until much later was it realized that what had actually occurred was a means to concentrate biological organisms, decoupling the liquid retention time (ideally, low, for a compact treatment system) from the solids retention time (ideally, fairly high, for an effluent low in BOD_5 and ammonia.)



A generalized, schematic diagram of an activated sludge process.

Arrangement

The general arrangement of an activated sludge process for removing carbonaceous pollution includes the following items:

- Aeration tank where air (or oxygen) is injected in the mixed liquor.
- Settling tank (usually referred to as "final clarifier" or "secondary settling tank") to allow the biological flocs to settle, thus separating the biological sludge from the clear treated water.

Treatment of nitrogenous matter or phosphate involves additional steps where the mixed liquor is left in anoxic condition (meaning that there is no residual dissolved oxygen).

Types of plants

Activated sludge system in China

There are a variety of types of activated sludge plants. These include:

Package plants

There are a wide range of other types of 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 commonly variants of extended aeration, to promote the 'fit & forget' approach required for small communities without dedicated operational staff. There are various standards to assist with their design.

Oxidation ditch

In some areas, where more land is available, sewage is treated in large round or oval ditches with one or more horizontal aerators typically called brush or disc aerators which drive the mixed liquor around the ditch and provide aeration. These are oxidation ditches, often referred to by manufacturer's trade names such as Pasveer, Orbal, or Carrousel. They have the advantage that they are relatively easy to maintain and are resilient to shock loads that often occur in smaller communities (i.e. at breakfast time and in the evening).

Oxidation ditches are installed commonly as 'fit & forget' technology, with typical design parameters of a hydraulic retention time of 24 - 48 hours, and a sludge age of 12 - 20 days. This compares with nitrifying activated sludge plants having a retention time of 8 hours, and a sludge age of 8 - 12 days.

Deep Shaft

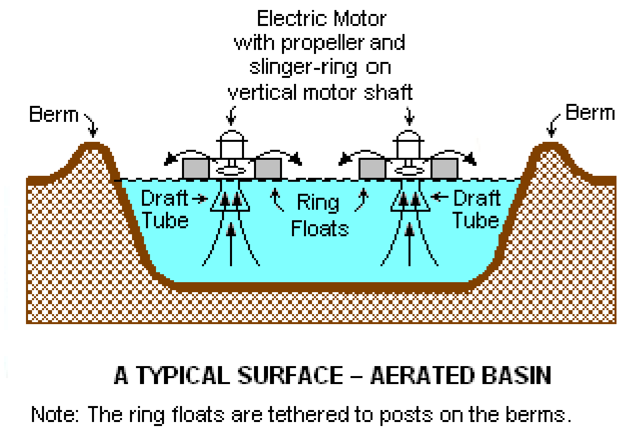
Where land is in short supply sewage may be treated by injection of oxygen into a pressured return sludge stream which is injected into the base of a deep columnar tank buried in the ground. Such shafts may be up to 100 metres deep and are filled with sewage liquor. As the sewage rises the oxygen forced into solution by the pressure at the base of the shaft breaks out as molecular oxygen providing a highly efficient source of oxygen for the activated sludge biota. The rising oxygen and injected return sludge provide the physical mechanism for mixing of the sewage and sludge. Mixed sludge and sewage is decanted at the surface and separated into supernatant and sludge components. The efficiency of deep shaft treatment can be high.

Surface aerators are commonly quoted as having an aeration efficiency of 0.5 - 1.5 kg O_2/kWh, diffused aeration as 1.5 - 2.5 kg O_2/KWh. Deep Shaft claims 5 - 8 kg O_2/kWh.

However, the costs of construction are high. Deep Shaft has seen greatest uptake in Japan, because of the land area issues. Deep Shaft was developed by ICI, as a spin-off from their Pruteen process. In the UK it is found at three sites: Tilbury, Anglian water, treating a wastewater with a high industrial contribution; Southport, United Utilities, because of land space issues; and Billingham, ICI, again treating industrial effluent, and built (after the Tilbury shafts) by ICI to help the agent sell more.

DeepShaft is a patented, licensed, process. The licensee has changed several times and, currently (2007), it is Aker Kvaerner Engineering Services.

Surface-aerated Basins/Lagoons



A Typical Surface-Aerated Basing (using motor-driven floating aerators)

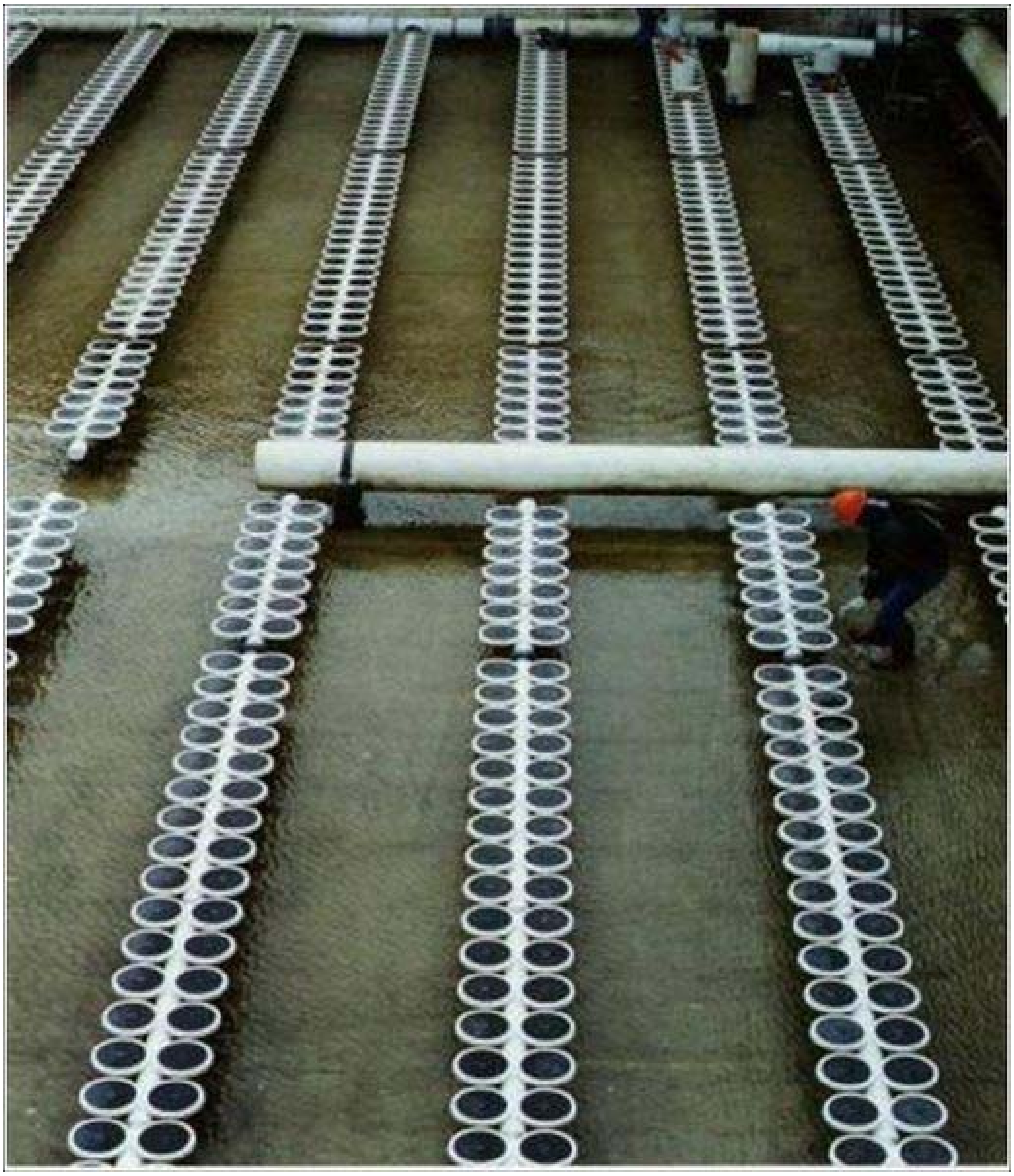
Most biological oxidation processes for treating industrial wastewaters have in common the use of oxygen (or air) and microbial action. Surface-aerated basins achieve 80 to 90% removal of BOD with retention times of 1 to 10 days. The basins may range in depth from 1.5 to 5.0 metres and utilize motor-driven aerators floating on the surface of the wastewater.

In an aerated basin system, the aerators provide two functions: they transfer air into the basins required by the biological oxidation reactions, and they provide the mixing required for dispersing the air and for contacting the reactants (that is, oxygen, wastewater and microbes). Typically, the floating surface aerators are rated to deliver the amount of air equivalent to 1.8 to 2.7 kg O_2/kWh. However, they do not provide as good mixing as is normally achieved in activated sludge systems and therefore aerated basins do not achieve the same performance level as activated sludge units.

Biological oxidation processes are sensitive to temperature and, between 0 °C and 40 °C, the rate of biological reactions increase with temperature. Most surface aerated vessels operate at between 4 °C and 32 °C.

Aeration methods

Diffused Aeration



Fine bubble membrane diffusers in an aeration tank

Sewage liquor is run into deep tanks with diffuser grid aeration systems that are attached to the floor. These are like the diffused airstone used in tropical fish tanks but on a much larger scale. Air is pumped through the blocks and the curtain of bubbles formed both oxygenates the liquor and also provide the necessary mixing action. Where capacity is limited or the sewage is unusually strong or difficult to treat, oxygen may be used instead of air. Typically, the air is generated by some type of blower or compressor.

Jet Aerators

A jet aerator works through aspirating technology and thus does not require any external air source (i.e. compressor), except for the surrounding atmosphere. Jet aerators can be installed either as submersible units or piped through the tank wall using an external dry-installed chopper pump to feed the aspirating ejector(s).

Surface aerators (cones)

Vertically mounted tubes of up to 1 metre diameter extending from just above the base of a deep concrete tank to just below the surface of the sewage liquor. A typical shaft might be 10 metres high. At the surface end the tube is formed into a cone with helical vanes attached to the inner surface. When the tube is rotated, the vanes spin liquor up and out of the cones drawing new sewage liquor from the base of the tank. In many works each cone is located in a separate cell that can be isolated from the remaining cells if required for maintenance. Some works may have two cones to a cell and some large works may have 4 cones per cell.

Chapter 8

Sewage

A preserved medieval waste pipe in Stockholm Old Town used to guide sewage onto the street where rain eventually would carry it away.

Sewage is water-carried wastes, in either solution or suspension, that is intended to flow away from a community. Also known as wastewater flows, sewage is the used water supply of the community. It is more than 99.9% pure water and is characterized by its volume or rate of flow, its physical condition, its chemical constituents, and the bacteriological organisms that it contains. Depending on their origin, wastewater can be classed as sanitary, commercial, industrial, agricultural or surface runoff.

The spent water from residences and institutions, carrying body wastes, washing water, food preparation wastes, laundry wastes, and other waste products of normal living, are classed as domestic or sanitary sewage. Liquid-carried wastes from stores and service establishments serving the immediate community, termed commercial wastes, are included in the sanitary or domestic sewage category if their characteristics are similar to household flows. Wastes that result from an industrial process or the production or manufacture of goods are classed as industrial wastes. Their flows and strengths are usually more varied, intense, and concentrated than those of sanitary sewage. Surface runoff, also known as storm flow or overland flow, is that portion of precipitation that runs rapidly over the ground surface to a defined channel. Precipitation absorbs gases and particulates from the atmosphere, dissolves and leaches materials from vegetation and soil, suspends matter from the land, washes spills and debris from urban streets and highways, and carries all these pollutants as wastes in its flow to a collection point.

Wastewater from all of these sources may carry pathogenic organisms that can transmit disease to humans and other animals; contain organic matter that can cause odor and nuisance problems; hold nutrients that may cause eutrophication of receiving water bodies; and can lead to ecotoxicity. Proper collection and safe, nuisance-free disposal of the liquid wastes of a community are legally recognized as a necessity in an urbanized, industrialized society

"Sewage" and "Sewerage" may be used interchangeably in the USA but elsewhere they retain separate and different meanings - sewage being the liquid material and sewerage being the pipes, pumps and infrastructure through which sewage flows.

Etymology

- The words 'sewage' and 'sewer' come from Old French *seuwiere* or from Anglo-Norman *sewere* or from Anglo-French *assewer*, *essiver* meaning "(channel) to drain the overflow from a fish pond" or "to drain" and ultimately from Vulgar Latin *exaquaticum and *exaquarium, from the verb *exaquare = "to drain", from Latin ex- ‘out of’ + aqua ‘water’.

Sewage services

Collection and disposal

A system of sewer pipes (sewers) collects sewage and takes it for treatment or disposal. The system of sewers is called *sewerage* or *sewerage system* in British English and *sewage system* in American English. Where a main sewerage system has not been provided, sewage may be collected from homes by pipes into septic tanks or cesspits, where it may be treated or collected in vehicles and taken for treatment or disposal. Properly functioning septic tanks require emptying every 2–5 years depending on the load of the system.

Sewage and waste water is also disposed of to rivers, streams and the sea in many parts of the world. Doing so can lead to serious pollution of the receiving water. This is common in third world countries and may still occur in some developed countries, where septic tank systems are too expensive.

Treatment

Sewage treatment is the process of removing the contaminants from sewage to produce liquid and solid (sludge) suitable for discharge to the environment or for reuse. It is a form of waste management. A septic tank or other on-site wastewater treatment system such as biofilters can be used to treat sewage close to where it is created.

Sewage water is a complex matrix, with many distinctive chemical characteristics. These include high concentrations of ammonium, nitrate, phosphorus, high conductivity (due to high dissolved solids), high alkalinity, with pH typically ranging between 7 and 8. Trihalomethanes are also likely to be present as a result of past disinfection.

In developed countries sewage collection and treatment is typically subject to local, state and federal regulations and standards.

Conversion to fertiliser

Sewage sludge can be collected through a sludge processing plant that automatically heats the matter and conveys it into fertiliser pellets (hereby removing possible contamination by chemical detergents, ...) This approach allows to eliminate seawater pollution by conveying the water directly to the sea without treatment (a practice which is still common in developing countries, despite environmental regulation). Sludge plants are useful in areas that have already set-up a sewage-system, but not in areas without such a system, as composting toilets are more efficient and do not require sewage pipes (which break over time).

Electricity

Power can also be obtained from sewage water. The technique uses Microbial fuel cells.

Chapter 9

Vacuum Sewerage

A vacuum sewer system uses the differential pressure between atmospheric pressure and a partial vacuum maintained in the piping network and vacuum station collection vessel. This differential pressure allows a central vacuum station to collect the wastewater of several thousand individual homes, depending on terrain and the local situation. Vacuum sewers take advantage of available natural slope in the terrain and are most economical in flat sandy soils with high ground water.

Vacuum sewers were first installed in Europe in 1882 but until the last 30 years it had been relegated to a niche market. The first who has applied the negative pressure drainage (so called vacuum sewerage) was the Dutch engineer Liernur in the second half of the 19th century. It was only used on ships, trains and airplanes for a long time. Technical implementations of **vacuum sewerage** systems were started after 1959 in Sweden by Joel Liljendahl and afterwards brought onto the market by Electrolux. Nowadays several system suppliers offer a wide range of products for many applications.

Introduction

1.Collection chambers and vacuum valve units 2.Vacuum sewer lines 3.Central vacuum station Vacuum technology is based on differential air pressure. Rotary vane vacuum pumps generate an operation pressure of -0.4 to -0.6 bar at the vacuum station, which is also the only element of the vacuum sewerage system that must be supplied with electricity. Interface valves that are installed inside the collection chambers work pneumatically. Any sewage flows by means of gravity into each house's collection sump. After a certain fill level inside this sump is reached, the interface valve will open. The impulse to open the valve is usually transferred by a pneumatically (pneumatic pressure created by fill level) controlled controller unit. No electricity is needed to open or close the valve. The according energy is provided by the vacuum itself. While the valve is open, the resulting differential pressure between atmosphere and vacuum becomes the driving force and transports the wastewater towards the vacuum station. Besides these collection chambers, no other manholes, neither for changes in direction, nor for inspection or connection of branch lines, are necessary. High flow rates keep the system free of any blockages or sedimentation.

Vacuum sewer systems are considered to be free of ex- and infiltration which allows the usage even in water protection areas. For this reason, vacuum sewer lines may even be laid in the same trench as potable water lines (depending on local guidelines). The system supplier should certify his product to be used in that way. To achieve the condition of an infiltration-free system and therefore allowing to reduce the waste water amounts that need to be treated, water tight (PE material or similar) collection chambers should be used. Valve and collection sump (waste water) preferably should be physically separated (different chambers) in order to protect service personal against direct contact with waste water and to ensure longer life cycles (waste water is considered to be corrosive).

In order to ensure reliable transport, the vacuum sewer line is laid in a saw-tooth (length-) profile, which will be referred to more precisely afterwards. The whole vacuum sewers are filled with air at a pressure of -0.4 to -0.6 bar. The most important aspect for a reliable operation is the air-to-liquid ratio. When a system is well designed, the sewers contain only very small amounts of sewage. The air-to-liquid ratio is usually maintained by "intelligent" controller units or valves that adjust their opening times according to the pressure in the system.

Considering that the vacuum idea relies on external energy for the transport of fluids, sewers can be laid in flat terrain and up to certain limits may also be counter-sloped. The saw-tooth profile keeps sewer lines shallow, lifts minimise trench depth (approx. 1.0 – 1.2 m). In this depth, expensive trenching, as it is the case for gravity sewers with the necessity to install continuously falling slopes of at least 0.5 - 1.0%, is avoided. Lifting stations are not required.

Once arrived in the vacuum collection tank at the vacuum station, the wastewater is pumped to the discharge point, which could be a gravity sewer or the treatment station directly. As the dwell time of the watewater inside the system is very short and the wastewater is continuously mixed with air, the sewage is kept fresh and any fouling inside the system is avoided (less H_2S).

Advantages

Closed, pneumatically controlled system with a central vacuum station. Electrical energy is only needed at this central station No sedimentation due to self-cleansing high velocities spooling and maintenance of the sewer lines is not necessary Manholes are not required Usually only a single vacuum pump station is required rather than multiple stations found in gravity and low pressure networks. This frees up land , reduces energy costs and reduces operational costs. Capital costs can be reduced by up to 50% due to simple trenching at shallow depths, close to surface Flexibility of piping, obstacles (as open channels) can be over- or underpassed reduced installation time Small diameter sewer pipes of HDPE, PVC materials; savings of material costs Aeration of sewage, less development of H_2S, with its dangers for workers, inhabitants, as well as corrosion of the pipes may be avoided; No infiltration, less hydraulic load at treatment station and discharge sewers absolutely no leakages (vacuum avoids exfiltration) Sewers may be laid in the same trench with other mains, also with potable water or storm-water, as well as in water protection areas Lower cost to maintain in the long term due to shallow trenching and easy identification of problems In combination of vacuum toilets it creates concentrated waste streams, which makes it feasible to use different waste water treatment techniques, like anaerobic treatment

Application Fields

Vacuum sewer systems becomes more and more the preferred system in the case of particular circumstances:

Especially difficult situations as ribbon, peripheral settlements on flat terrain with high specific conduit lengths of longer than 4 metres per inhabitant are predestined for the application of vacuum sewerage systems. In the case of sparse population density the influence of the costs for the collection chambers and vacuum stations are less important in comparison to the costs of long and deep sewers on gravity. Missing incline of the ground, unfavourable soil (rocky or swampy grounds) and high groundwater table (with the necessity of dewatering trenches) lead to enormous investment costs in regards to gravity sewerage systems. On the contrary vacuum sewers that are small in diameter can be laid close to the surface in small trenches. Vacuum sewers can pass through water protection areas and areas with sensitive high ground water tables, because there is no danger of spoiling groundwater resources (vacuum sewers have a high leak tightness due to their material; moreover the vacuum itself does not allow exfiltration). Vacuum systems has also been applied to collect toxic wastewater. Vacuum systems are seen as a priority in many environmentally sensitive areas such as the Couran Cove Eco Resort close to the Barrier Reef in Australia. In seasonal settlements (recreation areas, camping sites etc.) with conventional gravity sewer systems, sedimentation problems can easily occur as automatic spooling from the daily waste water does not take place. High flow velocities within vacuum sewers prevent such sedimentation problems. The Formula 1 race tracks in Shanghai and Abu Dhabi are using a vacuum sewer system for that reason. Even in old narrow and historical villages, the use of vacuum sewer systems becomes more and more important due to a fast (traffic, tourism), cost-effective and flexible installation. Good examples and references can be found in France, such as the village of Flavigny, in Oman at the township of Khasab and Al Seeb. Lack of water in many countries and drastic water savings measures have led to difficulties with aging gravity networks with solids blocking in the pipes. Neither the lack of water nor solids affect resp. occur in vacuum sewer systems. That's why this technology becomes interesting for such kind of applications. As PE or PVC pipes are used, no solids from ageing pipes will enter the system. All other solid are kept out at the collection chambers. vacuum sewer systems don't have any manholes to dump big solids into the system.

Collection chambers / vacuum valves

Raw sewage flows by gravity from one or more lots into a sealed collection sump. A vacuum interface valve is installed, which is controlled and operated pneumatically without electricity. When a certain amount of sewage has accumulated the controller opens the valve. It is important to understand that the valve shall open only, if the low pressure inside the vacuum sewer line is strong enough to ensure reliable transport. A minimum value of 0.15 bar for the existing low pressure in the adjacent vacuum line.

When the valve opens, between 20 and 40 l (depending on adjustment and valve) portions of effluent are sucked into the sewer line. Air entering via the incoming gravity line or air vent will be sucked into the sewer line due to the pressure difference to push the sewage. The interface valve will close again after a few seconds. The exact time should have an option to be adjusted and must be long enough to make sure that enough air can enter in order to push the sewage efficiently. This depends on the negative pressure conditions: Generally, the volume of air-stream should be lessened as far as possible, so that the pumps do not have to work unnecessarily. On the other hand minimum ratios of air-to-liquid should be guaranteed to have reliable transporting conditions. Usually the systems work with air-liquid ratios of about 4:1 to 15:1. Vacuum Technology is very reliable and tested technology when the right equipment is used. The restricting minimum diameter of the system should prevent the interface valves and the vacuum sewers from clogging. So, the connection from the sump to the interface valve should have a diameter of 75mm so that no blockage point is created. Usually, larger particles do not arrive in the sump, even though it still can occur. Large particles can be easily removed from the sump by an operator if required. But generally anything that can fit down a house service line should be able to enter the vacuum system and then the vacuum pump station without blockage.

Vacuum Lines / Description of Hydropneumatic Transport

Flow situations in vacuum sewers cannot be simply described with hydraulic laws. Instead of it a two-phases-flow transport has to be considered (e.g. hydropneumatical). Conveyance takes place by means of a two-phase regime, air (compressible) and effluent. Because of this the continuity equation becomes very complicated.

As it was mentioned before, the main characteristic of vacuum sewerage is the necessity to lay the sewers in the form of a distinct saw-tooth or stepped profile. An effective transport of sewage can only be guaranteed, if the hydraulic losses are agreed to by an approved supplier.

Doses of sewage enter the vacuum line from the collection chambers. As sewage arrive at a low point of the sewer line, sewage is collected there, - until valves upstream open and arriving air will increase the pressure gradient again. Air moving at high velocity into the direction of the vacuum station will exert a strong impulse on the developing sewage.

In this way sewage will be shifted with almost the same velocity over the next peak down the line. The transport of sewage will continue along the sewer line as far as the pressure gradient remains. In a horizontally laid pipe air would stream over water without moving it further.

High flow velocities in the low points of up to 5 m/s avoid any kind of sedimentation, since during the starting movement this kind of flushing effect would take away all hypothetical deposits. Sedimentation problems have never been reported for vacuum sewerage systems.

Prevailing diameters in vacuum sewers are in range of DN 80 and DN 315 (inner diameter). Usually PEHD or PVC pipes are applied in vacuum systems due to their low costs of installation and flexibility. Vacuum sewers have to be absolutely tight. Therefore, DIN EN 1091 requires a thickness of at least PN 10. Leakages do not appear in vacuum systems due to an absolute tightness of installations (each construction company is easily able to install vacuum pipes).

Vacuum Station

The vacuum collection station is the only place of the complete system, where energy is required! The vacuum station consists of rotary vane vacuum pumps (generate vacuum in the sewer lines), a collection tank, and duplicated sewage pumps (duty/standby) that discharge sewage away from the collection tanks to a wastewater treatment facility. The vacuum pumps maintain a negative pressure inside the collection tank in a range of -0.4 to -0.6 bar (adjustable). When the negative pressure inside the system falls under a certain limit the vacuum pumps will start working. Vacuum pumps run only for a few hours a day and do not need to run continuously since the vacuum interface valves at collection pits are normally closed.

Collection tanks are mostly made of steel and not of stainless steel (risk of local chemical element corrosion). In choosing tank materials, water tightness has a high priority, subsequently all joints should be sealed. Vacuum tanks are sized according to flow rates and vacuum suction capacity with typical volumes ranging from 5 to 12 m3. About 75% of the tank's volume will be required as a vacuum reservoir. With this vacuum reserve the vacuum pumps shall be prevented from too high a starting rate, which is normally limited to 10-15 starts per hour (worst case).

Design

Planning a vacuum sewerage system seems to be initially a question of design. There is never only one solution at sewer networks in general, but vacuum systems can be designed in many different ways (e.g. connected area, location of the vacuum station, choice of the length profile etc.). A good design needs a perfect overall picture on all the system's parameters! Some suppliers of vacuum system components help seriously during the design with their assistance. The use of such experienced help is recommendable and preferable.

In the guidelines mentioned above the control of the following parameters is demanded:

- air-liquid ratio (depending from distances and population density
- energetic loss (derived from the maximum trunk length in between the vacuum station and the furthest interface valve as well as from geodetic steps due to topography)
- network-length (sum of all trunks leading together)
- flow-rate
- vacuum reserve volume (considering also the sewer network)
- maximum tolerable distances in between air inlets (interface valves).

The most significant step in designing a vacuum sewerage system is the choice of a good pipe-routing. System boundaries such as maximum trunk length and additional elevations of the pipe length-profile do not have to be surpassed. As this kind of work requires iterations, design-diagrams have been developed. The maximum trunk length is restricted to 4000 m in absolutely flat terrain. A longer distance can be handled must be done in consultation with a system supplier.

While the norms do not give sufficient information about checking and dimensioning of design parameters, it shall be emphasised, that vacuum sewerage systems could become remarkably larger than the norms show it!

Hints about Operation

Unjustified prejudices against “new” technologies still prevail. Highly assumed maintenance/operational costs are the main obstacle against further expansion of vacuum sewerage systems on the market. Problems, especially at collection chambers, and frequent system break-downs (drowning) were the birth labour of first vacuum sewerage systems. Nowadays, vacuum systems are reliable when their design is based on special knowledge of professional companies.

Vacuum stations should be visited at least once a week to carry out a visual inspection. Experiences have shown that a well-designed vacuum station will not need more than one visible control and short check once a week (similar to a pumping system). Operating hours and power consumption of the pumps should be checked regularly. Mechanical and electrical maintenance, cleaning of the vacuum tank, briefly a total check of the vacuum station, should at least be done once a year (oil-change and filter change of the vacuum pumps).

Conclusion

Highly estimated operation costs and fear of malfunction have been the main prejudices and obstacles in the past against an expanded use of vacuum sewers. For an unprejudiced choice of a sewerage concept, it is necessary not to overestimate operational costs of alternative wastewater collection systems. Further, more difficult conditions during construction have to be considered for conventional gravity sewerage! When a vacuum sewerage system is well designed, operational reliability will be guaranteed.

Vacuum sewerage seems to become more and more important as capital costs could be reduced remarkably. Good references from communities seem to show satisfaction. Especially in cases of sparse population density, flat terrain, and high specific costs of pipe-laying, alternative sewerage systems could become much more economic, also in the long run.

It is significant not to over-estimate the operation costs of alternative wastewater collection systems, in comparison with the costs of a conventional gravity system (which constitutes work under more difficult conditions). When a vacuum sewerage system is duly designed and built, its operational reliability is guaranteed.

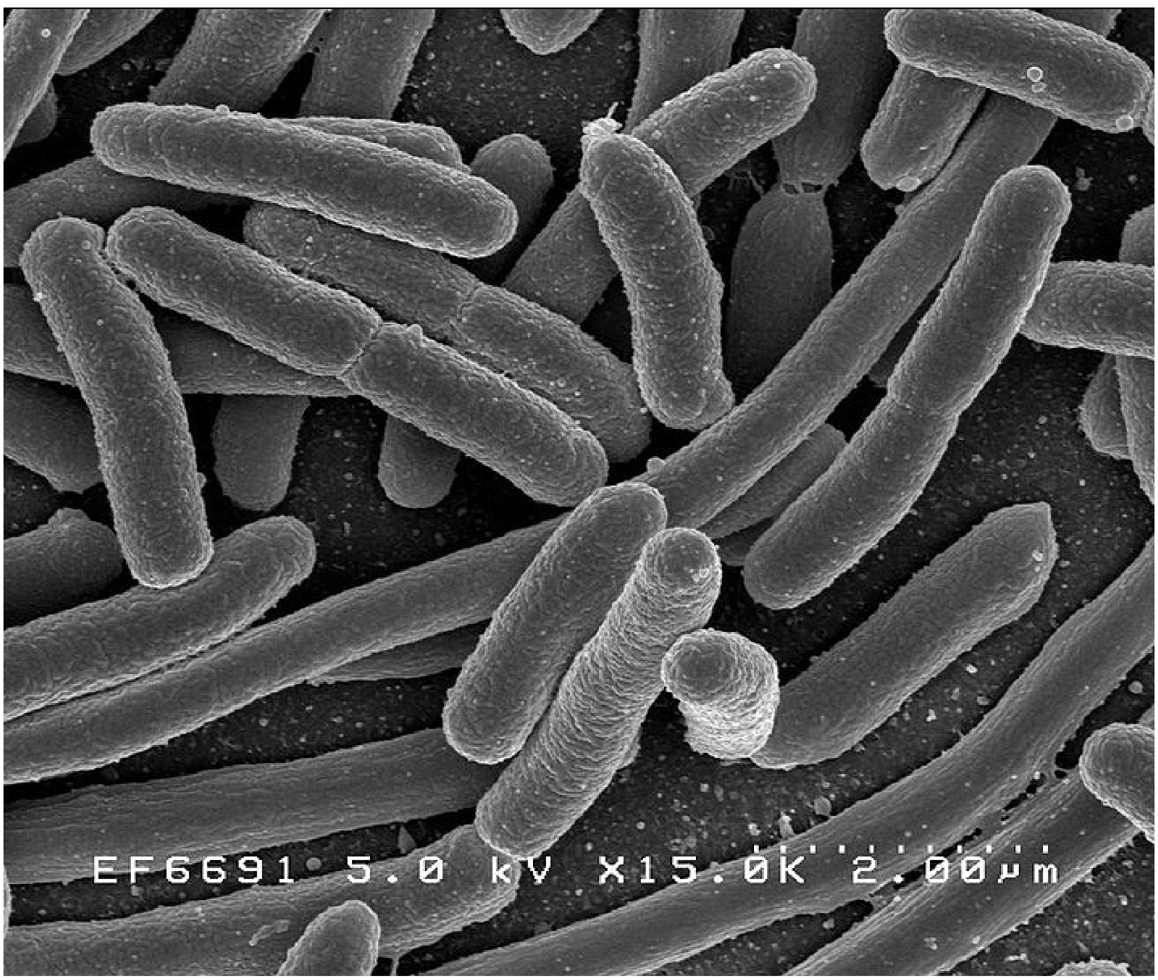
As engineers and municipal officials become acquainted with the advantages of vacuum sewers, the use of this technology will probably expand more and more worldwide.

It is hoped that the use of alternative sewerage concepts will allow designers and regulators to find ways of keeping project costs at a minimum.

Frequently, a combination of different alternative systems together as well as conventional sections will become the most feasible and the most reliable solution for the collection of wastewater.

Chapter 10

Sanitation



E. coli bacteria under magnification

Sanitation is the hygienic means of promoting health through prevention of human contact with the hazards of wastes. Hazards can be either physical, microbiological, biological or chemical agents of disease. Wastes that can cause health problems are human and animal feces, solid wastes, domestic wastewater (sewage, sullage, greywater), industrial wastes, and agricultural wastes. Hygienic means of prevention can be by using engineering solutions (e.g. sewerage and wastewater treatment), simple technologies (e.g. latrines, septic tanks), or even by personal hygiene practices (e.g. simple handwashing with soap).

The World Health Organization states that:

"Sanitation generally refers to the provision of facilities and services for the safe disposal of human urine and faeces. Inadequate sanitation is a major cause of disease world-wide and improving sanitation is known to have a significant beneficial impact on health both in households and across communities. The word 'sanitation' also refers to the maintenance of hygienic conditions, through services such as garbage collection and wastewater disposal.

The term "**sanitation**" can be applied to a specific aspect, concept, location, or strategy, such as:

- **Basic sanitation** - refers to the management of human feces at the household level. This terminology is the indicator used to describe the target of the Millennium Development Goal on sanitation.
- **On-site sanitation** - the collection and treatment of waste is done where it is deposited. Examples are the use of pit latrines, septic tanks, and imhoff tanks.
- **Food sanitation** - refers to the hygienic measures for ensuring food safety.
- **Environmental sanitation** - the control of environmental factors that form links in disease transmission. Subsets of this category are solid waste management, water and wastewater treatment, industrial waste treatment and noise and pollution control.
- **Ecological sanitation** - a concept and an approach of recycling to nature the nutrients from human and animal wastes.

History

The earliest evidence of urban sanitation was seen in Harappa, Mohenjo-daro and the recently discovered Rakhigarhi of Indus Valley civilization. This urban plan included the world's first urban sanitation systems. Within the city, individual homes or groups of homes obtained water from wells. From a room that appears to have been set aside for bathing, waste water was directed to covered drains, which lined the major streets. Houses opened only to inner courtyards and smaller pole.

Roman cities and Roman villas had elements of sanitation systems, delivering water in the streets of towns such as Pompeii, and building stone and wooden drains to collect and remove wastewater from populated areas - see for instance the Cloaca Maxima into the River Tiber in Rome. But there is little record of other sanitation in most of Europe until the High Middle Ages. Unsanitary conditions and overcrowding were widespread throughout Europe and Asia during the Middle Ages, resulting periodically in cataclysmic pandemics such as the Plague of Justinian (541-42) and the Black Death (1347–1351), which killed tens of millions of people and radically altered societies.

Very high infant and child mortality prevailed in Europe throughout medieval times, due not only to deficiencies in sanitation but to insufficient food for a population which had expanded faster than agriculture. This was further complicated by frequent warfare and exploitation of civilians by brutal rulers. Life for the average person at this time was indeed 'nasty, brutish and short.

The word Sanitation is also now used in pop culture. It is used as a substitution of "yo" and means a smelly person.

Wastewater sanitation

Wastewater collection

The standard sanitation technology in urban areas is the collection of wastewater in sewers, its treatment in wastewater treatment plants for reuse or disposal in rivers, lakes or the sea. Sewers are either combined with storm drains or separated from them as sanitary sewers. Combined sewers are usually found in the central, older parts or urban areas. Heavy rainfall and inadequate maintenance can lead to combined sewer overflows or sanitary sewer overflows, i.e. more or less diluted raw sewage being discharged into the environment. Industries often discharge wastewater into municipal sewers, which can complicate wastewater treatment unless industries pre-treat their discharges.

The high investment cost of conventional wastewater collection systems are difficult to afford for many developing countries. Some countries have therefore promoted alternative wastewater collection systems such as condominial sewerage, which uses smaller diameter pipes at lower depth with different network layouts from conventional sewerage.

Wastewater treatment

Sewage treatment plant, Australia.

In developed countries treatment of municipal wastewater is now widespread, but not yet universal. In developing countries most wastewater is still discharged untreated into the environment. For example, in Latin America only about 15% of collected sewerage is being treated.

Reuse of wastewater

The reuse of untreated wastewater in irrigated agriculture is common in developing countries. The reuse of treated wastewater in landscaping (esp. on golf courses), irrigated agriculture and for industrial use is becoming increasingly widespread.

In many peri-urban and rural areas households are not connected to sewers. They discharge their wastewater into septic tanks or other types of on-site sanitation.

Ecological sanitation

Ecological sanitation is sometimes presented as a radical alternative to conventional sanitation systems. Ecological sanitation is based on composting or vermicomposting toilets where an extra separation of urine and feces at the source for sanitization and recycling has been done. It thus eliminates the creation of blackwater and eliminates fecal pathogens from any still present wastewater (urine). If ecological sanitation is practiced municipal wastewater consists only of greywater, which can be recycled for gardening. However, in most cases greywater continues to be discharged to sewers.

Sanitation and public health

The importance of waste isolation lies in an effort to prevent water and sanitation related diseases, which afflicts both developed countries as well as developing countries to differing degrees. It is estimated that up to 5 million people die each year from preventable water-borne disease, as a result of inadequate sanitation and hygiene practices. The affects of sanitation have also had a large impact on society. Published in *Griffins Public Sanitation* proven studies show that higher sanitation produces more attractiveness.

Global access to improved sanitation

The Joint Monitoring Program for water and sanitation of WHO and UNICEF has defined improved sanitation as

- connection to a public sewer
- connection to a septic system
- pour-flush latrine
- simple pit latrine
- ventilated improved pit latrine

According to that definition, 62% of the world's population has access to improved sanitation in 2008, up 8% since 1990. Only slightly more than half of them or 31% of the world population lived in houses connected to a sewer. Overall, 2.5 billion people lack access to improved sanitation and thus must resort to open defecation or other unsanitary forms of defecation, such as public latrines or open pit latrines. This includes 1.2 billion people who have access to no facilities at all. This outcome presents substantial public health risks as the waste could contaminate drinking water and cause life threatening forms of diarrhea to infants. Improved sanitation, including hand washing and water purification, could save the lives of 1.5 million children who suffer from diarrheal diseases each year.

In developed countries, where less than 20% of the world population lives, 99% of the population has access to improved sanitation and 81% were connected to sewers.

Solid waste disposal

Hiriya Landfill, Israel.

Disposal of solid waste is most commonly conducted in landfills, but incineration, recycling, composting and conversion to biofuels are also avenues. In the case of landfills, advanced countries typically have rigid protocols for daily cover with topsoil, where underdeveloped countries customarily rely upon less stringent protocols. The importance of daily cover lies in the reduction of vector contact and spreading of pathogens. Daily cover also minimises odor emissions and reduces windblown litter. Likewise, developed countries typically have requirements for perimeter sealing of the landfill with clay-type soils to minimize migration of leachate that could contaminate groundwater (and hence jeopardize some drinking water supplies).

For incineration options, the release of air pollutants, including certain toxic components is an attendant adverse outcome. Recycling and biofuel conversion are the sustainable options that generally have superior life cycle costs, particularly when total ecological consequences are considered. Composting value will ultimately be limited by the market demand for compost product.

Sanitation in the developing world

The United Nations Millennium Development Goals (MDGs) include a target to reduce by half the proportion of people without access to basic sanitation by 2015. In December 2006, the United Nations General Assembly declared 2008 'The International Year of Sanitation', in recognition of the slow progress being made towards the MDGs sanitation target. The year aims to develop awareness and action to meet the target. Particular concerns are:

- Removing the stigma around sanitation, so that the importance of sanitation can be more easily and publicly discussed.
- Highlighting the poverty reduction, health and other benefits that flow from better hygiene, household sanitation arrangements and wastewater treatment.

Research from the Overseas Development Institute suggests that sanitation and hygiene promotion needs to be better 'mainstreamed' in development, if the MDG on sanitation is to be met. At present, promotion of sanitation and hygiene is mainly carried out through water institutions. The research argues that there are, in fact, many institutions that should carry out activities to develop better sanitation and hygiene in developing countries. For example, educational institutions can teach on hygiene, and health institutions can dedicate resources to preventative works (to avoid, for example, outbreaks of cholera).

The Institute of Development Studies (IDS) coordinated research programme on Community-led Total Sanitation (CLTS) is a radically different approach to rural sanitation in developing countries and has shown promising successes where traditional rural sanitation programmes have failed. CLTS is an unsubsidized approach to rural sanitation that facilitates communities to recognize the problem of open defecation and take collective action to clean up and become 'open defecation free'. It uses community-led methods such as participatory mapping and analysing pathways between feces and mouth as a means of galvanizing communities into action. An IDS 'In Focus' Policy Brief suggests that in many countries the Millennium development goal for sanitation is off track and asks how CLTS can be adopted and spread on a large scale in the many countries and regions where open defecation still prevails.

Sanitation in the food industry

Modern restaurant food preparation area.

Sanitation within the food industry means to the adequate treatment of food-contact surfaces by a process that is effective in destroying vegetative cells of microorganisms of public health significance, and in substantially reducing numbers of other undesirable microorganisms, but without adversely affecting the product or its safety for the consumer (U.S. Food and Drug Administration, Code of Federal Regulations, 21CFR110, USA). Sanitation Standard Operating Procedures are indispensable for food industries in US, which are regulated by 9 CFR part 416 in conjunction with 21 CFR part 178.1010. Similaly in Japan, food hygiene has to be reached through the compliance of Food Sanitation Law.

Additionally, in the food and Biopharmaceutical industries, the term sanitary equipment means equipment that is fully cleanable using Clean-in-place (CIP), and Sterilization in place (SIP) procedures: that is fully drainable from cleaning solutions and other liquids. The design should have a minimum amount of deadleg or areas where the turbulence during cleaning is not enough to remove product deposits. In general, to improve cleanability, this equipment is made from Stainless Steel 316L, (an alloy containing small amounts of molybdenum). The surface is usually electropolished to an effective surface roughness of less than 0.5 micrometre, to reduce the possibility of bacterial adhesion to the surface.

Chapter 11

Sewage Sludge Treatment

Sewage sludge treatment described the processes used to manage and dispose of the sludges produced during sewage treatment.

Sources of sludge

Coarse primary solids and secondary biosolids accumulated in a wastewater treatment process must be treated and disposed of in a safe and effective manner. This material may be inadvertently contaminated with toxic organic and inorganic compounds (e.g. heavy metals).

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.

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, thus smaller tanks, thermophilic digestion is more expensive in terms of energy consumption for heating the sludge.

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. In large treatment plants sufficient energy can be generated in this way to produce more electricity than the machines require. The 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.

Under laboratory conditions it is possible to directly generate useful amounts of electricity from organic sludge using naturally occurring electrochemically active bacteria. Potentially, this technique could lead to an ecologically positive form of power generation, but in order to be effective such a microbial fuel cell must maximize the contact area between the effluent and the bacteria-coated anode surface, which could severely hamper throughput.

Aerobic digestion

Aerobic digestion is a bacterial process occurring in the presence of oxygen. 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 costs for aeration needed to add oxygen to the process.

Composting

Composting is also an aerobic process that involves mixing the wastewater solids with sources of carbon such as sawdust, straw or wood chips. In the presence of oxygen, bacteria digest both the wastewater solids and the added carbon source and, in doing so, produce a large amount of heat.

Both anaerobic and aerobic digestion processes can result in the destruction of disease-causing microorganisms and parasites to a sufficient level to allow the resulting digested solids to be safely applied to land used as a soil amendment material (with similar benefits to peat) or used for agriculture as a fertilizer provided that levels of toxic constituents are sufficiently low.

The largest composting site in the world that also processes sewage is the Edmonton Composting Facility, in Edmonton, Canada.

Thermal depolymerization

Thermal depolymerization uses hydrous pyrolysis to convert reduced complex organics to oil. The premacerated, grit-reduced sludge is heated to 250C and compressed to 40 MPa. The hydrogen in the water inserts itself between chemical bonds in natural polymers such as fats, proteins and cellulose. The oxygen of the water combines with carbon, hydrogen and metals. The result is oil, light combustible gases such as methane, propane and butane, water with soluble salts, carbon dioxide, and a small residue of inert insoluble material that resembles powdered rock and char. All organisms and many organic toxins are destroyed. Inorganic salts such as nitrates and phosphates remain in the water after treatment at sufficiently high levels that further treatment is required.

The energy from decompressing the material is recovered, and the process heat and pressure is usually powered from the light combustible gases. The oil is usually treated further to make a refined useful light grade of oil, such as no. 2 diesel and no. 4 heating oil, and then sold.

The choice of a wastewater solid treatment method depends on the amount of solids generated and other site-specific conditions. However, in general, composting is most often applied to smaller-scale applications followed by aerobic digestion and then lastly anaerobic digestion for the larger-scale municipal applications.

Sludge disposal

When a liquid sludge is produced, further treatment may be required to make it suitable for final disposal. Typically, sludges are thickened (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 are concerns about sludge incineration because of air pollutants in the emissions, along with the high cost of supplemental fuel, making this a less attractive and less commonly constructed means of sludge treatment and disposal. There is no process which completely eliminates the requirements for disposal of biosolids.

In South Australia, after centrifugation, the sludge is then completely dried by sunlight. The nutrient rich biosolids are then provided to farmers free-of-charge to use as a natural fertiliser. This method has reduced the amount of landfill generated by the process each year.

In the very large metropolitan areas of southern California inland communities return sewage sludge to the sewer system of communities at lower elevations to be reprocessed at a few very large treatment plants on the Pacific coast. This reduces the required size of interceptor sewers and allows local recycling of treated waste-water while retaining the economy of a single sludge processing facility.

Chapter 12

Trickling Filter

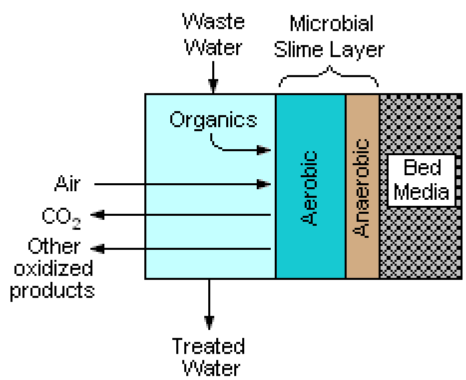


Image 1: A schematic cross-section of the contact face of the bed of media in a trickling filter

A **trickling filter** consists of a fixed bed of rocks, lava, 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 (biofilm) to grow, covering the bed of media. 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 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.

Operation

The removal of pollutants from the wastewater stream involves both absorption and adsorption of organic compounds by the layer of microbial biofilm. The filter media is typically chosen to provide a very high surface area to volume. 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 furnishes dissolved air, the oxygen which the slime 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 treated effluent and subsequently forms part of the secondary sludge. Typically, a trickling filter is followed by a clarifier or sedimentation tank for the separation and removal of the sloughing. Other filters utilizing higher-density media such as sand, foam and peat moss do not produce a sludge that must be removed, but require forced air blowers and backwashing or an enclosed anaerobic environment.

The treatment of sewage or other wastewater with trickling filters is among the oldest and most well characterized treatment technologies.

Types

The three basic types of trickle filters are used for:

- the treatment of small individual residential or rural sewage
- large centralized systems for treatment of municipal sewage
- systems applied to the treatment of industrial wastewater.

Septic system leach field

This is the simplest form of waste liquid disposal system, typically using pipes buried in loose sand or gravel to dissipate the liquid outflow from a septic tank. Liquid purification is performed by a biofilm which naturally forms as a coating on the sand and gravel in the absorption field and feeds on the dissolved nutrients in the waste stream.

Due to the system being completely buried and generally isolated from the surface environment, the process of waste breakdown is slow and requires a relatively large surface area to absorb and process liquid wastes. If too much liquid wastes enter the field too quickly, the wastes may pass out of the biofilm before waste consumption can occur, leading to pollution of groundwater.

In order to prolong the life of a leaching field, one method of construction is to build two fields of piping side-by-side, and use a rotating flow valve to direct waste into one field at a time, switching between fields every year or two. This allows a period of rest to let the microorganisms have time to break down the wastes built up in the gravel bed.

In areas where the ground is insufficiently absorptive (fails the percolation test) a homeowner may be required to construct a mound system which is a special engineered waste disposal bed of sand and gravel mounded on the surface of the ground with poor liquids absorption.

Leach field dosing

Generally it is better if the biofilm is permitted a period of time to rest between liquid influxes and for the liquids to be evenly distributed through the leaching bed to promote biofilm growth throughout the pipe network. Typically flows from septic systems are either small surges (handwashing) or very large surges (clothes washer emptying), resulting in highly erratic liquid outflow into the field and uneven biofilm growth concentrating primarily around the field inlet and dropping off in the outer reaches of the piping system.

For this reason it is common for engineered mound systems to include an electrically powered *dosing system* which consists of a large capacity underground storage tank and lift pump after the septic tank. When the tank fills to a predetermined level, it is emptied into the leaching field.

The storage tank collects small outflows such as from handwashing and saves them for dosing when the tank fills from other sources. During this fill period the field is able to rest continuously. When full, the discharge dose fills out the entire field completely to the same degree of flow, every time, promoting an even biofilm growth throughout the system.

Dosing systems have maintenance requirements over traditional non-powered surge systems. The pump and float system can break down and require replacement, and the dosing system also needs electricity. However, the system can be designed so that in the event of power failure the storage tank overflows to the field operating in the traditional surge-flow manner until power is restored or repairs can be done.

Soil Compaction issues

The biofilm is most productive if the absorption field is loosely packed, to permit easy air infiltration down into the biofilm bed. Consequently the land over the leaching field is often a restricted area where large vehicles cannot be allowed to drive, because the heavy weight will compact the bed, and potentially cause system failure due to hindering of biofilm growth.

One method to help prevent compaction of the field is to place a U-shaped cover over gravel trenches in the bed, with a dosing pipe suspended above the bed by the cover. Any weight from above is passed to the sides of the trench keeping the bed directly under the cover free from compaction.

Sewage treatment trickle filters

Onsite sewage facilities (OSSF) are recognized as viable, low-cost, long-term, decentralized approaches to sewage treatment if they are planned, designed, installed, operated and maintained properly (USEPA, 1997).

Sewage trickling filters are used in areas not serviced by municipal wastewater treatment plants (WWTP). They are typically installed in areas where the traditional septic tank system are failing, cannot be installed due to site limitations, or where improved levels of treatment are required for environmental benefits such as preventing contamination of ground water or surface water.

Sites with a high water table, high bedrock, heavy clay, small land area, or which require minimal site destruction (for example, tree removal) are ideally suited for trickling filters.

All varieties of sewage trickling filters have a low and sometimes intermittent power consumption. They can be somewhat more expensive than traditional septic tank-leach field systems, however their use allows for better treatment, a reduction in size of disposal area, less excavation, and higher density land development.

Configurations and components

All sewage trickling filter systems share the same fundamental components:

- a septic tank for fermentation and primary settling of solids
- a filter medium upon which beneficial microbes (biomass, biofilm) are promoted and developed
- a container which houses the filter medium
- a distribution system for applying wastewater to be treated to the filter medium
- a distribution system for disposal of the treated effluent or percolation ponds.

By treating septic tank effluent before it is distributed into the ground, higher treatment levels are obtained and smaller disposal means such as leach field, shallow pressure trench or area beds are required.

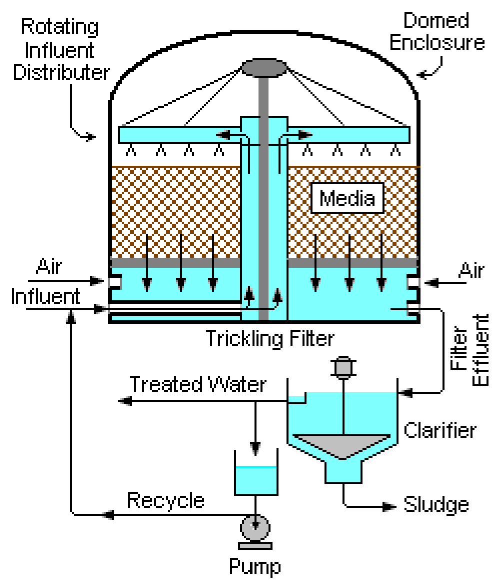
Systems can be configured for single-pass use where the treated water is applied to the trickling filter once before being disposed of, or for multi-pass use where a portion of the treated water is cycled back to the septic tank and re-treated via a closed-loop. Multi-pass systems result in higher treatment quality and assist in removing Total Nitrogen (TN) levels by promoting nitrification in the aerobic media bed and denitrification in the anaerobic septic tank.

Trickling filters differ primarily in the type of filter media used to house the microbial colonies. Types of media most commonly used include plastic matrix material, open-cell polyurethane foam, sphagnum peat moss, recycled tires, clinker, gravel, sand and geotextiles. Ideal filter medium optimizes surface area for microbial attachment, wastewater retention time, allows air flow, resists plugging and does not degrade. Some residential systems require forced aeration units which will increase maintenance and operational costs.

Regulatory approvals

Third-party verification of trickling filters has proven them to be a reliable alternative to septic systems with increased levels of treatment performance and nitrogen removal. Typical effluent quality parameters are Biochemical Oxygen Demand (BOD), Total suspended solids (TSS), Total Kjeldahl Nitrogen (TKN), and fecal coliforms.

The leading testing facility in the United States is the Massachusetts Alternative Septic System Test Center, a program of the Buzzards Bay National Estuary Program. Testing conducted here includes the stringent Environmental Technology Initiative (ETI) where systems are tested in triplicate over two years, and the Environmental Technology Verification (ETV) program which is funded by the U.S. Environmental Protection Agency (EPA) and includes stress testing as well as evaluation of nitrogen removal over 14 months. Systems are approved for installation by local, state and federal regulations and controls.



A typical complete trickling filter system

Industrial wastewater treatment trickle filters

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 1960s, 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 very often subsequently processed in a clarifier-settler to remove the sludge that sloughs off the microbial slime layer attached to the trickling filter media.

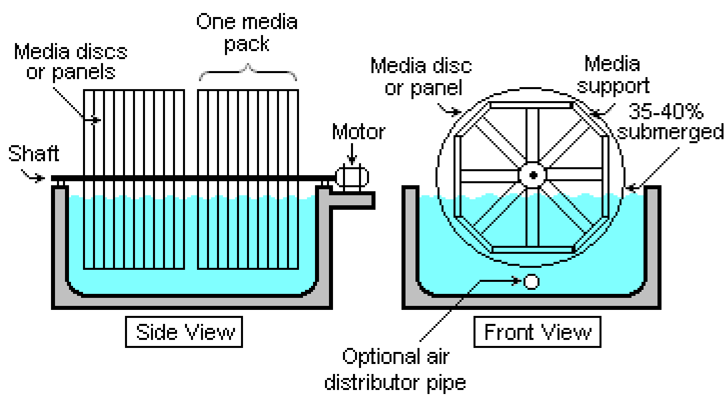
Currently, some of the latest trickle filter technology involves aerated biofilters which are essentially trickle filters consisting of plastic media in vessels using blowers to inject air at the bottom of the vessels, with either downflow or upflow of the wastewater.

Regulatory requirements

Many countries regulate the composition of treated water effluents from industrial facilities. For example, in the United States, the Clean Water Act mandates a National Pollutant Discharge Elimination System (NPDES), which regulates industrial point sources that discharge pollutants into rivers, lakes, and oceans. All U.S. industrial facilities that discharge liquid effluents must obtain effluent discharge permits under that system.

Chapter 13

Rotating Biological Contactor



Schematic diagram of a typical rotating biological contactor (RBC). The treated effluent clarifier/settler is not included in the diagram.

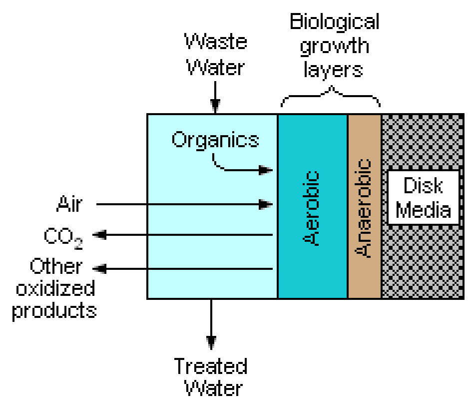
A **rotating biological contactor** or **RBC** is a biological treatment process used in the treatment of wastewater following primary treatment. The primary treatment process removes the grit and other solids through a screening process followed by a period of settlement. The RBC process involves allowing the wastewater to come in contact with a biological medium in order to remove 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 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 waste water. Microorganisms grow on the surface of the discs where biological degradation of the wastewater pollutants takes place.

Biotechnology for wastewater

Environmental consciousness and concern sustainable society have driven the society to the direction of re-organization of the infrastructures and the urban systems. To build an environmental management system that satisfies various social needs simultaneously in the water environment, it is essential to optimize environmental control technologies by comprehensive and systematic approaches. In this course, we critically discuss several key issues that are important in achieving desirable environmental technology systems. Biochemistry to understand the technology of wastewater treatment technologies using microorganisms is the main topic. The characteristics of complex microbial community and mathematical design modeling for Rotating Biological Contactors are discussed in this project. Biotechnology for wastewater treatment is needed so that we can use our rivers and stream for fishing, swimming and drinking water. For the first half of the 20th century, population in the Nation's urban waterways resulted in frequent occurrences of low dissolved oxygen, fish kills, algal blooms and bacterial contamination. Early efforts in water pollution control prevented human waste from reaching water supplies or reduced floating debris that obstructed shipping. Pollution problems and their control were primarily local, not national, concerns. Since then, population and industrial growth have increased demand on our natural resources, altering the situation dramatically. Progress in abating pollution has barely kept ahead of population growth, changes in industrial processes, technological developments, and changes in land use, business innovations, and many other factors. Increases in both the quantity and variety of goods produced can greatly alter the amount and complexity of industrial wastes and challenge traditional treatment technology. The application of commercial fertilizers and pesticides, combined with sediment from growing development activities, continue to be source of significant pollution as runoff washes off the land. Water pollution issues now dominate public concerns about national water quality and maintaining healthy ecosystems. Although a large investment in water pollution control has helped to reduce the problems, many miles of streams are still impacted by variety of different pollutants. This, in turn, affects the ability of people to use the water for beneficial purpose. Past approaches used to control must be modified to accommodate current and emerging issues. Hence the appropriate biotechnology should be used for wastewater treatment plant.

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 polythene, 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 the wastewater. RBC's are closely packed circular discs submerged in wastewater and rotated slowly. Biological growth is attached to the surface of the disc and forms a slime layer. The disc contact wastewater and air for oxidation as it rotates. Helps to slough off excess solids. About one third of the disc is submerged. 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. RBC media in the form of large, flat disc mounted on common shaft are rotated through specially contoured tanks in which waste water flow on a continuous basis. The medium consists of plastic sheets ranging from 2 to 4 m in dia and 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 there diameter and are rotated by power supplied to the shaft. Approximately 95% of the surface area is thus alternately immerged in waste water in then exposed to the atmosphere above the liquid under normal operating conditions; 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 5th stage. Most design of RBC systems will include a minimum of 4 or 5 modules in series to obtain nitrification of waste water.



A schematic cross-section of the contact face of the bed media in a rotating biological contactor (RBC)

Biofilms, which are biological growths that become attached to the discs, assimilate the organic materials 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 were first installed in West Germany in 1960 and were later introduce in U.S and Canada, 70% of the RBC systems installed are used for carbonaceous. BOD removal only,25 % for combine carbonaceous BOD removal and nitrification, and 5% for the nitrification of secondary effluent.

Construction

Rotating Biological contactor is the attached growth process. Rotating biological consist of 3-4m diameter plastic sheet of thickness 10mm attached to a shaft which is connected to a motor power 40kW, rotate at 1-2 rpm. 1 module contains 4-6 discs. And 5-6 module in series to assure complete nitrification Process-in this process the disc rotate in the tank at 1-2 rpm to assure proper growth of bio logical film on the disc. The disc is submerged in the waste water about 45% to 90% of it dia according to the characteristic of waste water. When the disc rotates outside the tank the air enters the voids of the disc and water inside the disc trickles out the surface of the disc on the biological growth. During the submergence period the microbes present in the waste water get attached to the disc and from a bio-logical film. The film is around 3-4mm thick. This film when enter in to the waste water it consumes the organic waste by breaking the complex organic matter into the compound organic matter. Again when the disc surface faces the open atmosphere to receive enough oxygen to sustain and carry out their metabolic activities. Since the bio film is oxygenated externally from the wastewater, aerobic condition may develop in the liquid. Under normal operating condition the carbonaceous sustain in the initial stage of RBC. The carbon conversion may be completed in the first stage of a series of modules with nitrification being completed after the fifth stage. Nitrification proceeds only after carbon concentration is substantially reduced. Most design of RBC system will include minimum of four to five module in series to obtain nitrification of wastewater. The sloughed bio mass is relatively dense and settles well in secondary clarifier. Since it is continuous process it has no detention time.

Details

History

RBC was first installed in Germany in 1960 later it was introduced in U.S.A. In U.S,A RBC is used for industries producing high B.O.D. i.e. for industries producing high B.O.D i.e. for petroleum industry dairy industries etc.

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Detail:- size of disc- 3 to 3.7m
              Length of shaft- 8 to 8.5m
              Length of module- 7.6 to 8m
PVC or plastic media is used for disc.
Thickness of plastic media is 10mm.
Submergence of disc in wastewater 45 - 95% as pre design.
Speed of disc -: 1-2rpm (revolution per minute)
NO. Of disc in module -: 4 – 6 as per design.
Hydraulic loading -: 40 – 60 lit/day/m²
Organic loading -: 0.05to0.06 lit/day/m²
Film of micro organism on disc -: 3-4mm as per characteristic of waste
water.
Power of motor -: 40 kW.
Detention time -: it is a continuous process.
```

The rotating biological contactor reactor is a unique adaptation of the attached-growth process. Media in the form of large, flat disks mounted on a common shaft are rotated through specially contoured tanks in which waste water flows on a continuous basis. The medium consist of plastic sheets ranging from 2 to 4 m in diameter and upto 10mm thick. Spacing between flat disks is approximately 30 to 40 mm. the disk are mounted through the center on a sheet shaft in width up to 8 m. Each shaftul of medium, along with its tanks and rotating device, become a reactor module.

The disk are submerged in waste water to about 40 percent of their diameter and are rotated by power supplied to the shaft. Approximately 95% of the surface area is thus alternately immersed in the waste water and then exposed to atmosphere above the liquid. Rotational speed of the unit ranges from 1 to 2 r/min. Micro-organism growing on the medium surface remove food from the waste water and oxygen from the air to sustain their metabolic process. Growth and sloughing of the bio-film reach 2 to 4 mm. since the bio-film is oxygenated externally from the wastewater, an anaerobic condition may develop in the liquid. Provision for air injection near the bottom of the tank is usually provided when multiple modules in series are used. Under normal operating conditions,carbonaceous substrate is removed in the initial stages of the R.B.C. carbon conversion may be completed in the first stage of a series of modules with nitrification being completed after fifth stage.

Most designs of R.B.C include minimum of 4 to 5 module in series to obtain nitrification of the wastewater. One module of 3.7 m in diameter by 7.6 m long contains approximately 10,000 m² of surface area for bio-film growth. A 40-kw motor is sufficient to turn the 3.7 by 7.6 m unit.

Secondary clarification

The unit of secondary clarifier are quite similar in appearance to those used in primary clarification I wastewater treatment. Difference in different sludge-removel mechanisms. Sludge should be removed as rapidly as possible to ensure that the aeration unit. A rapid sludge return also prevent anaerobic condition from developing, with subsequent sludge floatation due to the release of gases. The sludge-return system must be capable of handling a wide range of flow. Underflow rates may exceed 100% of wastewater flowof wastewater flow under upset conditions, wt conditions, while normal underflow rates range from 20 to 40 % of the wastewater flow.

Disinfection of effluents

Disinfection of effluent includes:

1. Disinfection of wastewater.
2. Sludge treatment.

Disinfection of wastewater

The wastewater after from secondary clarifier is allow to pass through chlorine contact tank for reducing harmful bacteria. The dosage are comparatively much higher than which was require for chlorination of potable water since wastewater contain ammonium and other substance and free residual. The use of chlorine for disinfection of water effluent has come under close scrutiny due to formation of halo-form by contact of chlorine in wastewater with certain constituent.

Wastewater type	Chlorine dosage
(mg/l)to yield 0.2 mg/l	
After 15-min contact time	free residual
Raw:	
Fresh to stale	6 – 12
Septic	12 – 25
Seetled:	
Fresh to stale	5 – 10
Septic	12 – 40
Effluent chemical precipitation	3 – 6
Trickling filter:	
Normal	3 – 5
Poor	5 – 10
Activated sludge:	
Normal	2 – 4
Poor	3 – 8

Intermittent sand filter:
Normal 1 - 3
Poor 3 - 5

After chlorination then the water is disposed off.

Sludge treatment

After the secondary clarifier the sludge which is removed from clarifier some part of sludge is again re circulate to biological process and some part is treated. The sludge first thickened with gravity thickner and then sludge digestion is done. In sludge digestion organic-matter of sewage is aerobically decomposed under condition of adequate operational control. The sludge is broken in three different from. 1. Digested sludge which is stable humus like solid matter with reduced moisture content. 2. Supernatant liquor which include liquefied and finely divided solid matter. 3. Gases of decomosition Methane, Carbon dioxide, Nitrogen etc. Digested sludge is dewatered, dried and used as fertilizer. Gases produced is used as fuel. And the supernatant liquor is retreated by treatment plant along with raw sludge.

Typical design information for rotating biological contactors

Treatment level
Item Secondary Combined
nitrification Separate
nitrification
Hydraulic loading, m3/m2 .d 0.08 - 0.16 0.03 - 0.08 0.04 -
0.10
Organic loading
kg SBOD5/m2 .da,b

kg TBOD5/m2 .da,c
3.68x10-3 - 9.8x10-3
9.8x10-3 -
0.017
2.45x10-3 -
7.35x10-3
7.35x10-3 -
0.015

4.9x10-4 -
1.47x10-3
9.8x10-4 -
2.94x10-3
Maximum loading on first stage
kg SBOD5 /m2 .da,b
kg TBOD5/m2 .da,c

0.02 - 0.03
0.04 - 0.06

0.02 - 0.03

0.04 – 0.06
NH3 loading, kg/m2 .d 7.35x10-4 – 1.47x10-3 9.8x10-4 –
1.96x10-3
Hydraulic retention time , θ, h 0.7 – 1.5 1.5 - 4 1.2 – 2.9
Effluent BOD5, mg/l 15 - 30 7 - 15 7 – 15
Effluent NH3, mg/l <2 1 - 2

Note:
a Wastewater temperature above 13°C
b SBOD = Soluble BOD.
c TBOD = Total BOD.