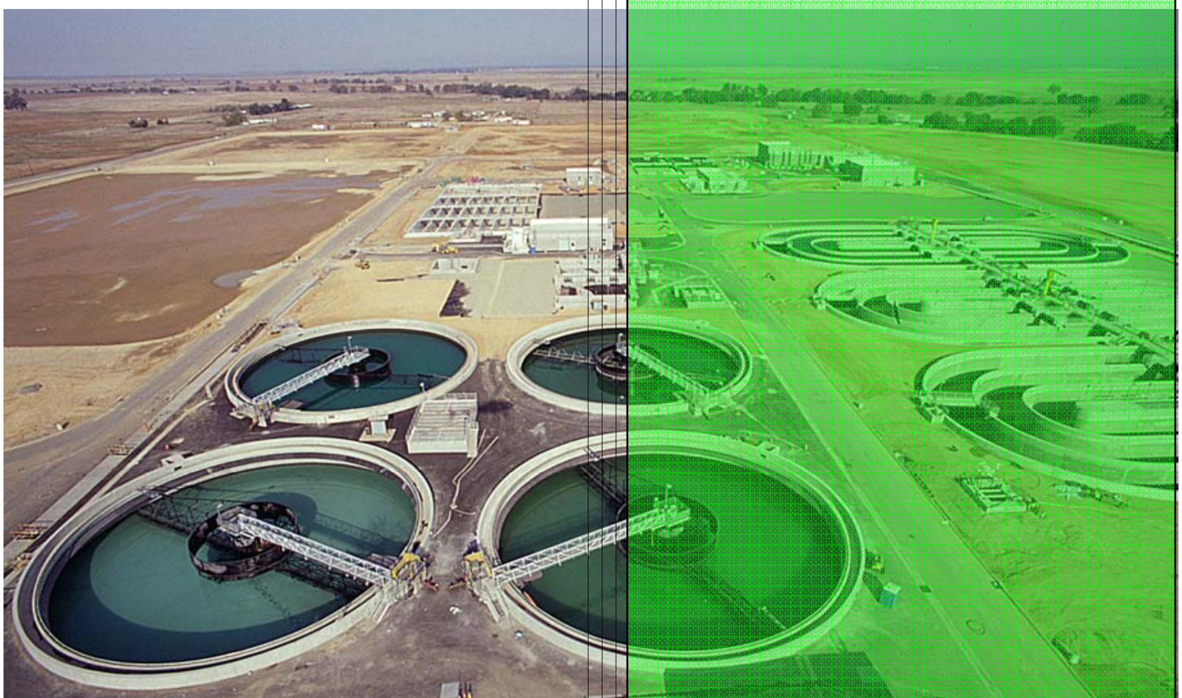
Wastewater Treatments



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WASTEWATER TREATMENT

1. Introduction

Water as molecule has two hydrogen atoms and one oxygen. Water is defined by being colourless, odourless and tasteless. Hover this pure water does not exist in nature even with rain water. In fact water bodies: rivers, oceans, seas and lakes contain water of different qualities depending on the various components in this water. Different salts are found in natural waters including sodium, chloride as the most abundant salt. Cations such as potassium, calcium, ferrous, magnesium, and zinc are found naturally as well as anions such as chlorides, carbonates, sulfate, and nitrate. Most of these salts are dissolved in the water. Other components of the natural waters are suspended such as organic matter from humic substances to microorganisms. Natural waters contain many living minute microorganisms like bacteria, diatoms, algae and several others.

Natural waters might be contaminated or polluted by human activities. The pollution load could be minimal and the water bodies with their natural cleaning process, with the activities of the living micro-flora and fauna could degrade these foreign material within a reasonable amount of time, however in many instances especially with the large population and indusial involvement, the self cleaning phenomena cannot cope with the loads reaching the water and hence can change its characteristics.

Composition of seawater is generally as follows:

ion	(mg/L)	ion	(mg/L)
Chloride (Cl-)	**21,200**	**Strontium (Sr2+)**	**13**
Sodium (Na+)	**11,800**	**Bromide (Br-)**	**155**
Sulfate (SO42-)	**2,950**	**Borate (BO33-)**	**72**
Magnesium (Mg2+)	**1,403**	**Fluoride (F-)**	**1**
Calcium (Ca2+)	**423**	**Silicate (SiO32-)**	**1**
Potassium (K+)	**463**	**Iodide (I-)**	**2**
Bicarbonate(HCO3-)	**140**	(TDS)	38,600

species	Concentration (mg/L)	species	Concentration (mg/L)
Cl- (chloride)	19,000	Br- (bromide)	67
Na^+ (sodium)	10,500	CO_3^{2-} (carbonate)	20
SO_4^{2-} (sulfate)	2700	Sr^{2+} (strontium)	7.9
Mg2+ (magnesium)	1280	$B(OH)_3 + B(OH)_4^-$ (borate)	5 (as Boron)
Ca2+ (calcium)	412	F- (fluoride)	1.3
K+ (potassium)	399	Organics	1 to 2
HCO3- (bicarbonate)	110	Everything else combined (except dissolved gasses)	Less than 1

Composition of River Nile water is generally as follows

Parameter	range	Parameter	range	Parameter	range
Turbidity (NTU)	**7-17**	**Alkalinity**	**130-180**	**Ammonia**	**0.2-2.5**
TDS	**200-600**	**Hardness**	**130-170**	**Nitrate**	**0.4-2.0**
Suspended Solids	**3-8**	**EC** *mohs/µcm*	**350-550**	**Phosphate**	**0.15-1.08**
Dissolved Oxygen	**5.4-7.2**	**Carbonate**		**Chlorides**	**23-65**
pH	**7.8-8.04**	**Bicarbonate**		**Silica**	**4.5-6.7**
Magnesium		**Sulfate**			

all in mg/L except Turbidity is in NTU and EC in mohs/µcm

2. Sources of water Pollution

Water can be polluted from manmade activities or natural sources. Natural sources could be volcanoes, dust storms or soil erosion. It is not the focus of this chapter to discuss these sources but to emphasize on manmade sources. The latter include domestic, agricultural and industrial activities.

2.1 Problems with Domestic Wastewater:

Sanitary drainage contains various components according to the network, piping and collection system. In totally residential areas wastewater would be composed of:

- Organic matter
- Nutrients (Nitrates, Phosphates are the two essential ones)
- Parasites and Pathogens

2.2 Problems with Industrial Wastewater:

Industrial wastewater is so versatile depending on the industry itself whether petrochemical, metallurgy, food processing and preservation, woodworks, or even power-plant generation. The wastewater characteristics depend on raw materials, processes and products. In fact thousands of chemicals (if not more) are used and produced by the industry. The general problems that arise from industrial wastewater can be:

- Organic matter
- Heavy metals
- Numerous chemicals according to the industry

Organic matter has a special consideration in the wastewater treatment processes because of its impact on the aquatic life. Heavy metals are another important aspect because of their toxicity at lower concentrations and because they tend to accumulate in certain tissues or organs. It is well documented that lead is accumulated in brains and causes mental retardation especially to children; aluminum has been correlated to the Alzheimer disease; other heavy metals are correlated to cancer, kidney failure, and other fatal disorders. A list of heavy metals and their use in industry is attached in Annex (2). Needless to say here that several other chemicals are used by the industry and can find their way to the water streams causing serious problems.

2.3. Problems with Agricultural Drainage Water

Agricultural drainage water is a major source for water pollution. Due to the intensive agricultural practices and the year-around cultivation the use of fertilizers and pesticides is causing drainage water to contain nutrients (nitrates, phosphates and sulfates) as well as the pesticides that are washed down to the drainage water. Agricultural drainage water in many instances is also contaminated with sewage from small communities and villages that don’t have a wastewater treatment facility.

3. Water Quality Requirements

Water bodies, water streams, rivers and seas have to be kept clean from pollution sources. Thus the associated problems that are previously mentioned should be eliminated before their discharge. All countries of the world have set regulations to the maximum levels of contaminates allowed to enter these resources. In Egypt there are three regulatory mandates for wastewater; law 48/1984 cited the limits for discharge to River Nile, its branches and the lakes (brackish water bodies); law 4/1994 for discharge to seawater; Ministerial Decree 44/2000 for discharging to general sewers. A summary of these laws and regulations is listed in Annex (3).

The parameters monitored to judge the water quality and their relevance are mentioned next.

a. Physical parameters:

- *Temperature*: the regulations observe that no thermal pollution should occur. This type of pollution is associated to industrial activities using hot water. Good examples of those are power-plants that use water for cooling as well as the textile industry that uses hot water for dying. If hot water was released to the treatment plant it would certainly affect its performance.
- *pH*: various industries use acids or alkalis in their manufacturing process. Examples of that are metallurgic industries, paper making, and soap and detergents manufacturing. Wastewater has to be neutralized before treatment.
- *Solids content*: Total solids, suspended solids, dissolved solids, settleable solids are all indicative of water quality from different angles that are important to the treatment facility. <u>Suspended solids</u> include particulate matter found in water which could be organic matter, colloidal clay particles, microorganisms, algae, plant debris, and all un-dissolved particulates. <u>Dissolved solids</u> are mainly the salts found in water either naturally or from a certain activity. The latter two

combined are called Total Solids. Settleable solids are important to in order for the wastewater treatment plant to know the required sedimentation time and if a coagulation is needed to speed the separation of particulates.

- *Turbidity*: water should be clear; if any discharge makes the water turbid that would imply the presence of undissolved matter.

b. Chemical and Biochemical Parameters

- *Biochemical {Biological} Oxygen Demand (BOD):* is a measure of the amount of oxygen used up by biological and chemical processes in a sample of stream water over a 5-day. Oxygen in the water is consumed by process such as: the break down of organic material; oxygen use by bacterial activity; and chemical reactions as chemicals are converted to more stable forms (e.g. the conversion of ammonia to nitrate).

  BOD is calculated by measuring the oxygen level of the water on collection and then 5 days later after storage in the dark (to stop photosynthetic activity) at a constant temperature (usually 20°C). The difference between the two values is the demand or consumption of oxygen by chemical and biological processes.

- *Chemical Oxygen Demand (COD):* COD is defined as the amount of a specified oxidant that reacts with the sample under controlled conditions. The quantity of oxidant consumed is expressed in terms of its oxygen equivalence. COD often is used as a measurement of pollutants in wastewater and natural waters. Oxidation of most organic compounds is 95 to 100% of the theoretical value. Straight-chain aliphatic compounds are oxidized more effectively in the presence of a silver sulfate catalyst. Chloride reacts with silver ion to precipitate silver chloride, and thus inhibits the catalytic activity of silver. Bromide, iodide, and any other reagent that inactivates the silver ion can interfere similarly. The difficulties caused by the presence of the chloride can be overcome largely by complexing with mercuric sulfate ($HgSO_4$) before the refluxing procedure.

- Other parameters like nutrients, metals, are demonstrated in the slides of this subject which are complementary to this part.

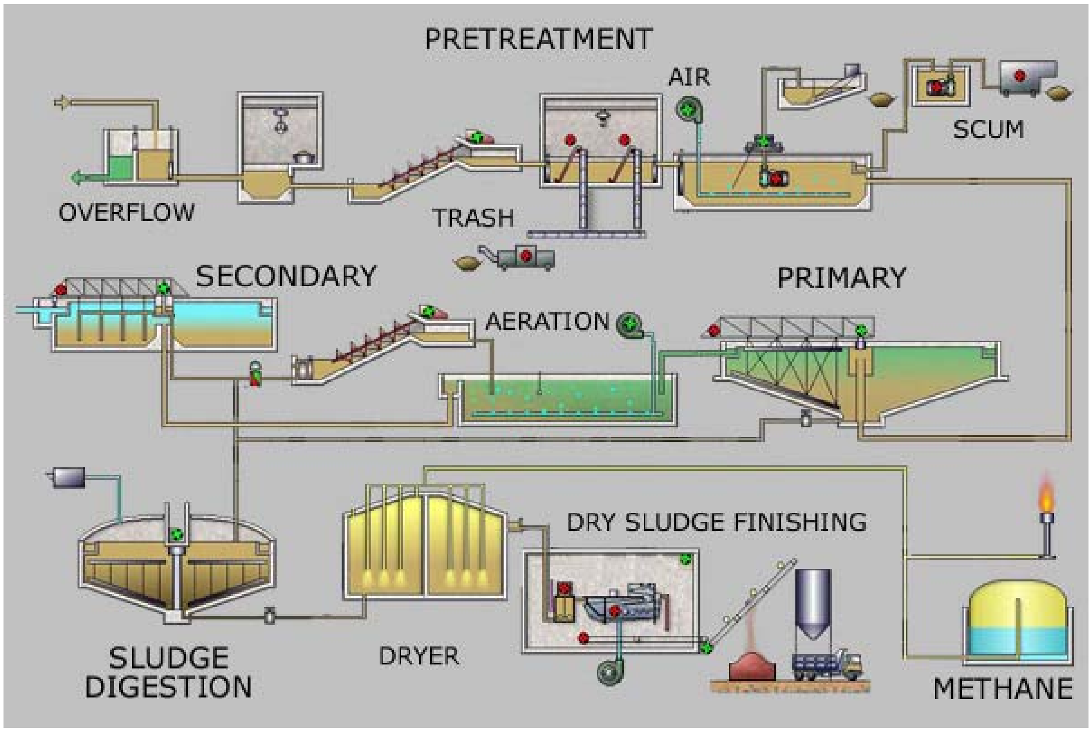
Conventional wastewater treatment processes

Conventional wastewater treatment consists of a combination of physical, chemical, and biological processes and operations to remove solids, organic matter and, sometimes, nutrients from wastewater. General terms used to describe different degrees of treatment, in order of increasing treatment level, are preliminary, primary, secondary, and tertiary and/or advanced wastewater treatment. In some countries, disinfection to remove pathogens sometimes follows the last treatment step.

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 a waste stream (or treated effluent) and a solid waste or sludge suitable for discharge or reuse back into the environment. This material is often inadvertently contaminated with many toxic organic and inorganic compounds.

Sewage can be treated close to where it is created or collected and transported via a network of pipes and pump stations to a municipal treatment plant (see sewerage and pipes and infrastructure). Sewage collection and treatment is typically subject to local, state and federal regulations and standards.

Conventional sewage treatment involves three stages, called primary, secondary and tertiary treatment. First, the solids are separated from the wastewater stream. Then dissolved biological matter is progressively converted into a solid mass by using indigenous, water-borne micro-organisms. Finally, the biological solids are neutralized then disposed of or re-used, and the treated water may be disinfected chemically or physically (for example by lagoons and microfiltration). The final effluent can be discharged 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.



Pre-treatment

Pre-treatment removes the materials that can be easily collected from the raw wastewater and disposed of. The typical materials that are removed during pre treatment include fats, oils, and greases (also referred to as FOG), sand, gravels and rocks (also referred to as grit), larger settleable solids and floating materials (such as rags and flushed feminine hygiene products). In developed countries, sophisticated equipment with remote operation and control are employed. The developing countries still rely on low cost equipment like manually cleaned screen etc.

Screening

The influent sewage water is strained to remove all large objects carried in the sewage stream, such as rags, sticks, tampons, cans, fruit, etc. This is most commonly done with a manual or automated mechanically raked bar screen. The raking action of a mechanical bar screen is typically paced according to the accumulation on the bar screens and/or flow rate. The bar screen is used because large solids can damage or clog the equipment used later in the sewage treatment plant. The large solids can also hinder the biological process. The solids are collected and later disposed in a landfill or incineration.

Pre treatment also typically includes a sand or grit channel or chamber where the velocity of the incoming wastewater is carefully controlled to allow sand grit and stones to settle, while keeping the majority of the suspended organic material in the water column. This equipment is called a de-gritter or sand catcher. Sand, grit, and stones need to be removed early in the process to avoid damage to pumps and other equipment in the remaining treatment stages. Sometimes there is a sand washer (grit classifier) followed by a conveyor that transports the sand to a container for disposal. The contents from the sand catcher may be fed into the incinerator in a sludge processing plant, but in many cases, the sand and grit is sent to a landfill.

Primary treatment (Sedimentation)

In the primary sedimentation stage, sewage flows through large tanks, commonly called "primary clarifiers" or "primary sedimentation tanks". The tanks are large enough that sludge can settle and floating material such as grease and oils can rise to the surface and be skimmed off. The main purpose of the primary sedimentation stage is to produce both a generally homogeneous liquid capable of being treated biologically and a sludge that can be separately treated or processed. 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 from where it can be pumped to further sludge treatment stages.

Secondary treatment

Secondary treatment is designed to substantially degrade the biological content of the sewage such as are derived from human waste, food waste, soaps and detergent. The majority of municipal plants treat the settled sewage liquor using aerobic biological processes. For this to be effective, the biota require both oxygen and a substrate on which to live. There are a number of ways in which this is done. In all these methods, 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. Fixed-film treatment process including trickling filter and rotating biological contactors where the biomass grows on media and the sewage passes over its surface. In suspended growth systems, such as activated sludge, the biomass is well 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 typically tall, circular filters filled with open synthetic filter media to which wastewater is applied at a relatively high rate. They are designed to allow high hydraulic loading and a high flow-through of air. On larger installations, air is forced through the media using blowers. The resultant wastewater is usually within the normal range for conventional treatment processes.

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, (see also denitrification).

Secondary sedimentation

The final step in the secondary treatment stage is to settle out the biological floc or filter material and produce sewage water containing very 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".

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 (nitrification) to nitrate, 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.

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% 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 productions as hydroxides precipitates and the added chemicals can be expensive. Despite this, chemical phosphorus removal requires significantly smaller equipment footprint than biological removal, is easier to operate and is often more reliable than biological phosphorus removal.

Once removed, phosphorus, in the form of a phosphate rich sludge, may be land filled or, if in suitable condition, resold for use in fertilizer.

Disinfection

The purpose of disinfection in the treatment of wastewater 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, or ultraviolet light. Chloramine, which is used for drinking water, is not used in wastewater treatment because of its persistence.

Chlorination remains the most common form of wastewater 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, 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. Edmonton and Calgary, Alberta, Canada 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.

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.

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.

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.

One major feature of anaerobic digestion is the production of biogas, which can be used in generators for electricity production and/or in boilers for heating purposes.

Aerobic treatments

Aerobic treatments are 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 are characteristically much greater for aerobic digestion because of the energy costs needed to add oxygen to the process.

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.

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 the wastewater 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 landfill.

References

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4. Israel uses both desalinated sea water and recycled sewer water for agriculture

Industrial wastewater treatment

Industrial wastewater treatment covers the mechanisms and processes used to treat waters that have been contaminated in some way by anthropogenic industrial or commercial activities prior to its release into the environment or its re-use.

Most industries produce some wet waste although recent trends in the developed world have been to minimise such production or recycle such waste within the production process. However, many industries remain dependent on processes that produce wastewaters.

Iron and steel industry

The production of iron from its ores involves powerful reduction reactions in blast furnaces. Cooling waters are inevitably contaminated with products especially ammonia and cyanide. Production of coke from coal in coking plants also requires water cooling and the use of water in by-products separation. Contamination of waste streams includes gasification products such as benzene, naphthalene, anthracene, cyanide, ammonia, phenols, cresols together with a range of more complex organic compounds known collectively as polycyclic aromatic hydrocarbons (PAH).

The conversion of iron or steel into sheet, wire or rods requires hot and cold mechanical transformation stages frequently employing water as a lubricant and coolant. Contaminants include hydraulic oils, tallow and particulate solids. Final treatment of iron and steel products before onward sale into manufacturing includes *pickling* in strong mineral acid to remove rust and prepare the surface for tin or chromium plating or for other surface treatments such as galvanisation or painting. The two acids commonly used are hydrochloric acid and sulfuric acid. Wastewaters include acidic rinse waters together with waste acid. Although many plants operate acid recovery plants, (particularly those using Hydrochloric acid), where the mineral acid is boiled away from the iron salts, there remains a large volume of highly acid ferrous sulfate or ferrous chloride to be disposed of. Many steel industry wastewaters are contaminated by hydraulic oil also known as *soluble oil.*

Mines and quarries

The principal waste-waters associated with mines and quarries are slurries of rock particles in water. These arise from rainfall washing exposed surfaces and haul roads and also from rock washing and grading processes. Volumes of water can be very high, especially rainfall related arisings on large sites. Some specialized separation operations, such as coal washing to separate coal from native rock using density gradients, can produce wastewater contaminated by fine particulate haematite and surfactants. Oils and hydraulic oils are also common contaminants. Wastewater from metal mines and ore recovery plants are inevitably contaminated by the minerals present in the native rock formations. Following crushing and extraction of the desirable materials, undesirable materials may become contaminated in the wastewater. For metal mines, this can include unwanted metals such as zinc and other materials such as arsenic. Extraction of high value metals such as gold and silver may generate slimes containing very fine particles in where physical removal of contaminants becomes particularly difficult.

Food industry

Wastewater generated from agricultural and food operations has distinctive characteristics that set it apart from common municipal wastewater managed by public or private wastewater treatment plants throughout the world: it is biodegradable and nontoxic, but that has high concentrations of biochemical oxygen demand (BOD) and suspended solids (SS).[1] The constituents of food and agriculture wastewater are often complex to predict due to the differences in BOD and pH in effluents from vegetable, fruit, and meat products and due to the seasonal nature of food processing and postharvesting.

Processing of food from raw materials requires large volumes of high grade water. Vegetable washing generates waters with high loads of particulate matter and some dissolved organics. It may also contain surfactants.

Animal slaughter and processing produces very strong organic waste from body fluids, such as blood, and gut contents. This wastewater is frequently contaminated by significant levels of antibiotics and growth hormones from the animals and by a variety of pesticides used to control external parasites. Insecticide residues in fleeces is a particular problem in treating waters generated in wool processing.

Processing food for sale produces wastes generated from cooking which are often rich in plant organic material and may also contain salt, flavourings, colouring material and acids or alkali. Very significant quantities of oil or fats may also be present.

Complex organic chemicals industry

A range of industries manufacture or use complex organic chemicals. These include pesticides, pharmaceuticals, paints and dyes, petro-chemicals, detergents, plastics, paper pollution, etc. Waste waters can be contaminated by feed-stock materials, by-products, product material in soluble or particulate form, washing and cleaning agents, solvents and added value products such as plasticisers.

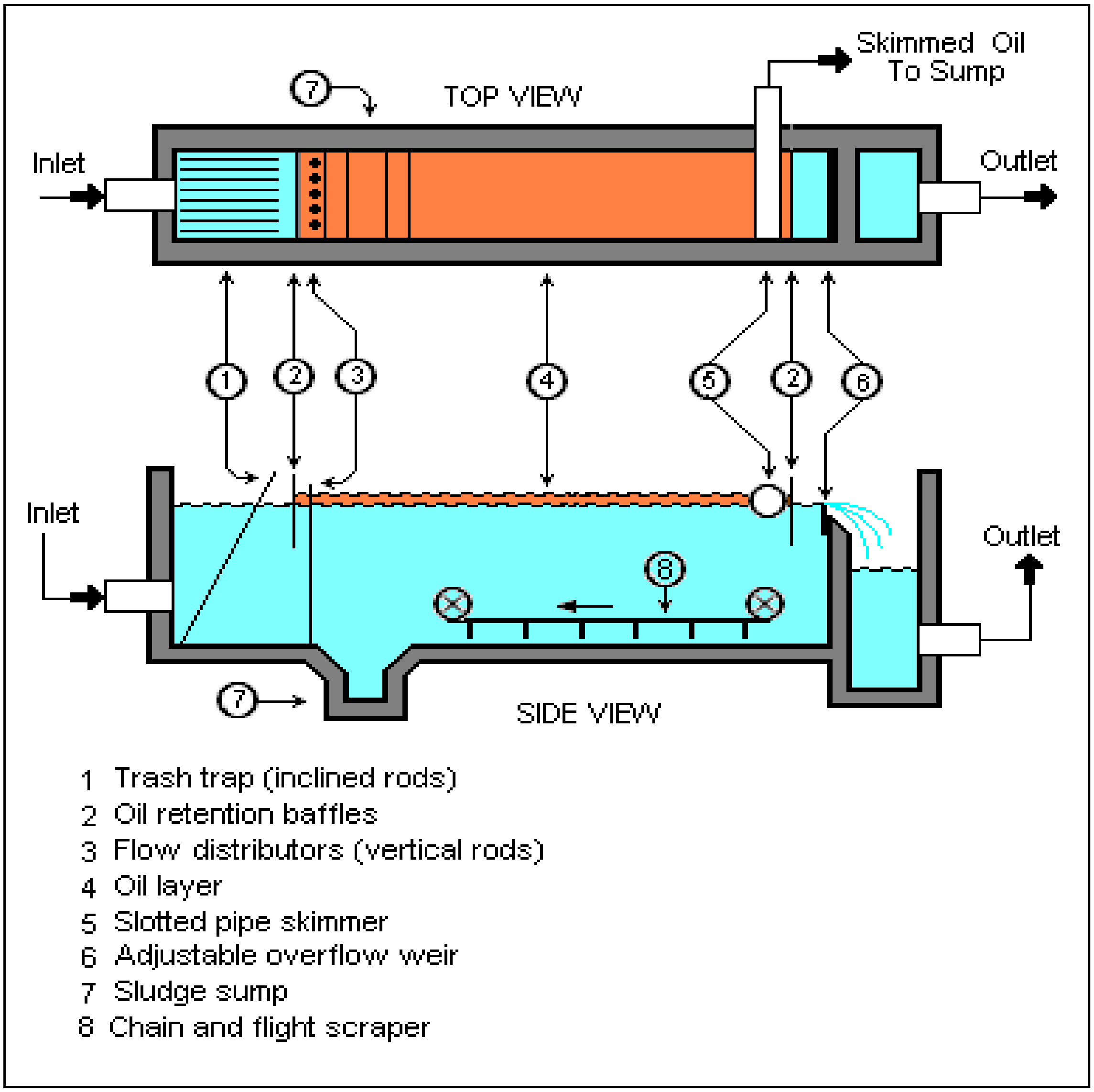
Treatment of industrial wastewater

The different types of contamination of wastewater require a variety of strategies to remove the contamination.[2][3]

Solids removal

Most solids can be removed using simple sedimentation techniques with the solids recovered as slurry or sludge. Very fine solids and solids with densities close to the density of water pose special problems. In such case filtration or ultrafiltration may be required. Alternatively, flocculation may be used, using alum salts or the addition of polyelectrolytes.

Oils and grease removal



A typical API oil-water separator used in many industries

Many oils can be recovered from open water surfaces by skimming devices. However, hydraulic oils and the majority of oils that have degraded to any extent will also have a soluble or emulsified component that will require further treatment to eliminate. Dissolving or emulsifying oil using surfactants or solvents usually exacerbates the problem rather than solving it, producing wastewater that is more difficult to treat.

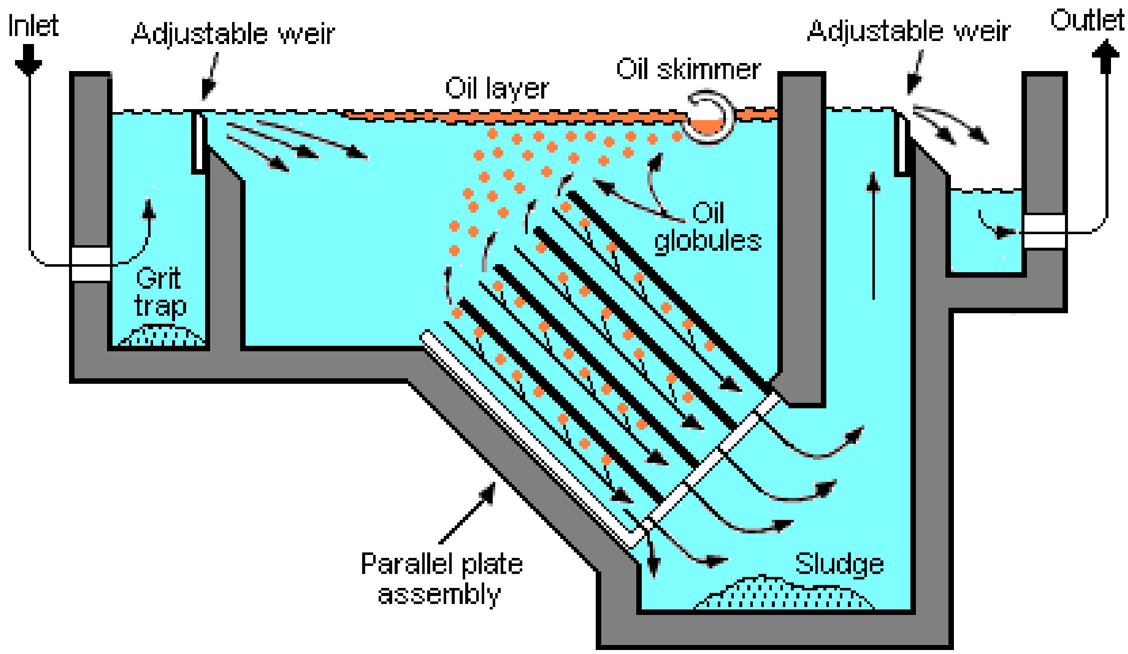
The wastewaters from large-scale industries such as oil refineries, petrochemical plants, chemical plants, and natural gas processing plants commonly contain gross amounts of oil and suspended solids. Those industries use a device known as an API oil-water separator which is designed to separate the oil and suspended solids from their wastewater effluents. The name is derived from the fact that such separators are designed according to standards published by the American Petroleum Institute (API).[4][3]

The API separator is a gravity separation device designed by using Stokes Law to define the rise velocity of oil droplets based on their density and size. The design is based on the specific gravity difference between the oil and the wastewater because that difference is much smaller than the specific gravity difference between the suspended solids and water. The suspended solids settles to the bottom of the separator as a sediment layer, the oil rises to top of the separator and the cleansed wastewater is the middle layer between the oil layer and the solids.[3]

Typically, the oil layer is skimmed off and subsequently re-processed or disposed of, and the bottom sediment layer is removed by a chain and flight scraper (or similar device) and a sludge pump. The water layer is sent to further treatment consisting usually of a dissolved air flotation (DAF) unit for additional removal of any residual oil and then to some type of biological treatment unit for removal of undesirable dissolved chemical compounds.

Parallel plate separators[5] are similar to API separators but they include tilted parallel plate assemblies (also known as parallel packs). The parallel plates provide

A typical parallel plate separator [5]



more surface for suspended oil droplets to coalesce into larger globules. Such separators still depend upon the specific gravity between the suspended oil and the water. However, the parallel plates enhance the degree of oil-water separation. The result is that a parallel plate separator requires significantly less space than a conventional API separator to achieve the same degree of separation.

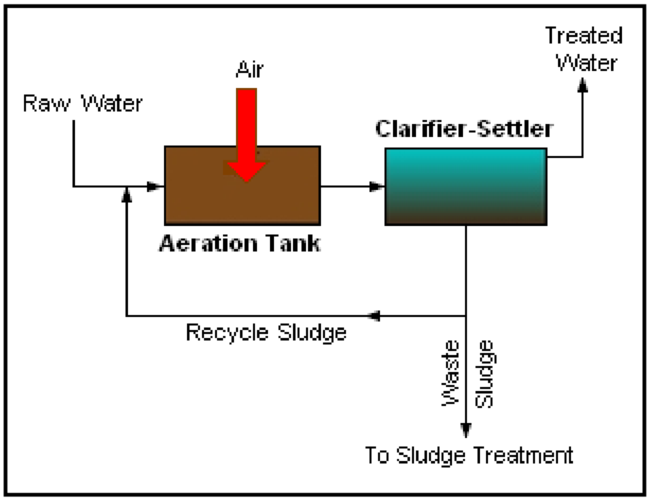
Removal of biodegradable organics

Biodegradable organic material of plant or animal origin is usually possible to treat using extended conventional wastewater treatment processes such as activated sludge or trickling filter.[2][3] Problems can arise if the wastewater is excessively diluted with washing water or is highly concentrated such as neat blood or milk. The presence of cleaning agents, disinfectants, pesticides, or antibiotics can have detrimental impacts on treatment processes.

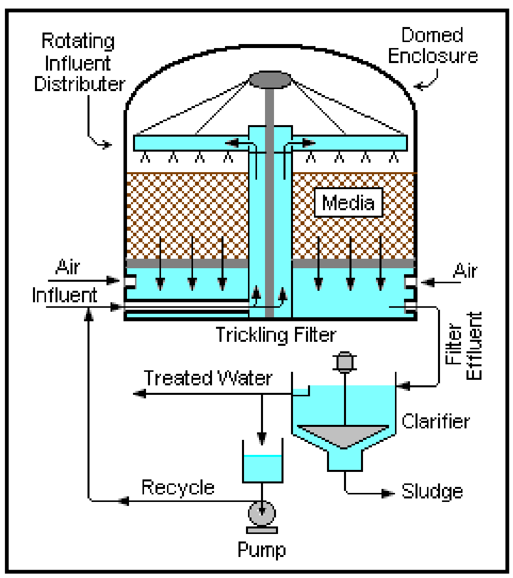
Activated sludge process

Activated sludge is a biochemical process for treating sewage and industrial wastewater that uses air (or oxygen) and microorganisms to biologically oxidize organic pollutants, producing a waste sludge (or floc) containing the oxidized material. In general, an activated sludge process includes:

A generalized, schematic diagram of an activated sludge process.



- An aeration tank where air (or oxygen) is injected and thoroughly mixed into the wastewater.
- A settling tank (usually referred to as a "clarifier" or "settler") to allow the waste sludge to settle. Part of the waste sludge is recycled to the aeration tank and the remaining waste sludge is removed for further treatment and ultimate disposal.



Trickling filter process

A trickling filter consists of a bed of rocks, gravel, slag, peat moss, or plastic media over which wastewater flows downward and contacts a layer (or film) of microbial slime covering the bed media. Aerobic conditions are maintained by forced air flowing through the bed or by natural convection of air. The process involves adsorption of organic compounds in the wastewater by the microbial slime layer, diffusion of air into the slime layer to provide the oxygen required for the biochemical oxidation of the organic compounds. The end products include carbon dioxide gas, water and other products of the oxidation. As the slime layer thickens, it becomes difficult for the air to penetrate the layer and an inner anaerobic layer is formed.

The components of a complete trickling filter system are:

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

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

A trickling filter is also often called a *trickle filter*, *trickling biofilter*, *biofilter*, *biological filter* or *biological trickling filter*.

Treatment of other organics

Synthetic organic materials including solvents, paints, pharmaceuticals, pesticides, coking products and so forth can be very difficult to treat. Treatment methods are often specific to the material being treated. Methods include Advanced Oxidation Processing, distillation, adsorption, vitrification, incineration, chemical immobilisation or landfill disposal. Some materials such as some detergents may be capable of biological degradation and in such cases, a modified form of wastewater treatment can be used.

Treatment of acids and alkalis

Acids and alkalis can usually be neutralised under controlled conditions.

Neutralisation frequently produces a precipitate that will require treatment as a solid residue that may also be toxic. In some cases, gasses may be evolved requiring treatment for the gas stream. Some other forms of treatment are usually required following neutralisation.

Waste streams rich in hardness ions as from de-ionisation processes can readily lose the hardness ions in a buildup of precipitated calcium and magnesium salts. This precipitation process can cause severe *furring* of pipes and can, in extreme cases, cause the blockage of disposal pipes. A 1 metre diameter industrial marine discharge pipe serving a major chemicals complex was blocked by such salts in the 1970s. Treatment is by concentration of de-ionisation waste waters and disposal to landfill or by careful pH management of the released wastewater.

Treatment of toxic materials

Toxic materials including many organic materials, metals (such as zinc, silver, cadmium, thallium, etc.) acids, alkalis, non-metallic elements (such as arsenic or selenium) are generally resistant to biological processes unless very dilute. Metals can often be precipitated out by changing the pH or by treatment with other chemicals. Many, however, are resistant to treatment or mitigation and may require concentration followed by landfilling or recycling. Disolved organics can be *incinerated* within the wastewater by Advanced Oxidation Processes.

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Constructed Wetlands

A constructed wetland or wetpark is an artificial marsh or swamp, created for anthropogenic discharge such as wastewater, stormwater runoff or sewage treatment, and as habitat for wildlife, or for land reclamation after mining or other disturbance. Natural wetlands act as biofilters, removing sediments and pollutants such as heavy metals from the water, and constructed wetlands can be designed to emulate these features.

Operation

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

Constructed wetlands are of two basic types: subsurface-flow and surface-flow wetlands. Subsurface-flow wetlands can be further classified as horizontal flow and vertical flow constructed wetlands. Subsurface-flow wetlands move effluent (agricultural or mining runoff, tannery or meat processing wastes, wastewater from sewage or storm drains, or other water to be cleansed) through a gravel lavastone or sand medium on which plants are rooted; surface-flow wetlands move effluent above the soil in a planted marsh or swamp, and thus can be supported by a wider variety of soil types including bay mud and other silty clays.

Newly Planted Constructed Wetland

In subsurface-flow systems, the effluent may move either horizontally, parallel to the surface, or vertically, from the planted layer down through the substrate and out. Subsurface horizontal-flow wetlands are less hospitable to mosquitoes, whose populations can be a problem in constructed wetlands (carnivorous plants have been used to address this problem). Subsurface-flow systems have the advantage of requiring less land area for water treatment, but are not generally as suitable for wildlife habitat as are surface-flow constructed wetlands.

The same constructed wetland two years later

Plantings of reedbeds are popular in European constructed wetlands, and plants such as cattails or bulrushes (*Typha* spp.), sedges, water hyacinth and *Pontederia* spp. are used worldwide. Recent research in use of constructed wetlands for subarctic regions has shown that buckbeans (*Menyanthes trifoliata*) and pendant grass (*Arctophila fulva*) are also useful for metals uptake.

General contaminant removal

Physical, chemical, and biological processes combine in wetlands to remove contaminants from wastewater. An understanding of these processes is fundamental not only to designing wetland systems but to understanding the fate of chemicals once they have entered the wetland. Theoretically, treatment of wastewater within a constructed wetland occurs as it passes through the wetland medium and the plant rhizosphere. A thin aerobic film around each root hair is aerobic due to the leakage of oxygen from the rhizomes, roots, and rootlets.[1] Decomposition of organic matter is facilitated by aerobic and anaerobic micro-organisms present. Microbial nitrification and subsequent denitrification releases nitrogen as gas to the atmosphere. Phosphorus is coprecipitated with iron, aluminum, and calcium compounds located in the root-bed medium.[2][3] Suspended solids are filtered out as they settle in the water column in surface flow wetlands or are physically filtered out by the medium within subsurface flow wetland cells. Harmful bacteria and viruses are reduced by filtration and adsorption by biofilms on the rock media in subsurface flow and vertical flow systems.

Removal of nitrogen

The dominant forms of nitrogen in wetlands that are of importance to wastewater treatment include organic nitrogen, ammonia, ammonium, nitrate, nitrite, and nitrogen gases. Inorganic forms are essential to plant growth in aquatic systems but if scarce can limit or control plant productivity.[4] The nitrogen entering wetland systems can be measured as organic nitrogen, ammonia, nitrate and nitrite. Total Nitrogen refers to all nitrogen species. The removal of nitrogen from wastewater is important because of ammonia’s toxicity to fish if discharged into water courses. Excessive levels of nitrates in drinking water is thought to cause methemoglobinemia in infants, which decreases the oxygen transport ability of the blood. The UK has experienced a significant increase in nitrate concentration in groundwater and rivers.[5]

Organic nitrogen

Mitsch & Gosselink define nitrogen mineralisation as "the biological transformation of organically combined nitrogen to ammonium nitrogen during organic matter degradation".[6] This can be both an aerobic and anaerobic process and is often referred to as ammonification. Mineralisation of organically combined nitrogen releases inorganic nitrogen as nitrates, nitrites, ammonia and ammonium, making it available for plants, fungi and bacteria.[6] Mineralisation rates may be affected by oxygen levels in a wetland.[3]

Ammonia (NH_3) and ammonium (NH_4^+)

The formation of ammonia (NH_3) occurs via the mineralisation or ammonification of organic matter under either anaerobic or aerobic conditions (Keeney, 1973). The ammonium ion (NH_4^+) is the primary form of mineralized nitrogen in most flooded wetland soils. The formation of this ion occurs when ammonia combines with water as follows:

$NH_3 + H_2O \leftarrow\text{---}> NH_4^+ + OH^-$[6]

Upon formation, several pathways are available to the ammonium ion. It can be absorbed by the plants and algae and converted back into organic matter, or the ammonium ion can be electrostatically held on negatively charged surfaces of soil particles.[6] At this point, the ammonium ion can be prevented from further oxidation because of the anaerobic nature of wetland soils. Under these conditions the ammonium ion is stable and it is in this form that nitrogen predominates in anaerobic sediments typical of wetlands (Brock & Madigan, 1991;).[3]

Most wetland soils have a thin aerobic layer at the surface. As an ammonium ion from the anaerobic sediments diffuses upward into this layer it is converted to nitrite or nitrified (Klopatek, 1978). An increase in the thickness of this aerobic layer results in an increase in nitrification.[3] This diffusion of the ammonium ion sets up a concentration gradient across the aerobic-anaerobic soil layers resulting in further nitrification reactions (Klopatek, 1978).[3]

Nitrification is the biological conversion of organic and inorganic nitrogenous compounds from a reduced state to a more oxidized state.[7] Nitrification is strictly an aerobic process in which the end product is nitrate (NO_3^-); this process is limited when anaerobic conditions prevail.[3] Nitrification will occur readily down to 0.3 ppm dissolved oxygen (Keeney, 1973). The process of nitrification (1) oxidizes ammonium (from the sediment) to nitrite (NO_2^-), and then (2) nitrite is oxidized to nitrate (NO_3^-). The overall nitrification reactions are as follows:

(1) $2\ NH_4^+ + 3\ O_2 \leftarrow\!\!-\!\!-\!\!> 4\ H^+ + 2\ H_2O + 2\ NO_2^-$
(2) $2\ NO_2^- + O_2 \leftarrow\!\!-\!\!-\!\!> 2\ NO_3^-$ (Davies & Hart, 1990)

Two different bacteria are required to complete this oxidation of ammonium to nitrate. Nitrosomonas sp. oxidizes ammonium to nitrite via reaction (1) , and Nitrobacter sp. oxidizes nitrite to nitrate via reaction (2) (Keeney, 1973).

Denitrification is the biochemical reduction of oxidized nitrogen anions, nitrate (NO_3^-) and nitrite (NO_2^-) to produce the gaseous products nitric oxide (NO), nitrous oxide (N_2O) and nitrogen gas (N_2), with concomitant oxidation of organic matter.[7] The general sequence is as follows:

NO_3^- ---> NO_2^- ---> NO ---> N_2O ---> N_2

The end products, N_2O and N_2 are gases that re-enter the atmosphere.

Denitrification occurs intensely in anaerobic environments but will also occur in aerobic conditions (Bandurski, 1965). A deficiency of oxygen causes certain bacteria to use nitrate in place of oxygen as an electron acceptor for the reduction of organic matter.[3] The process of denitrification is restricted to a narrow zone in the sediment immediately below the aerobic-anaerobic soil interface (Nielson *et al.*, 1990).[6] Denitrification is considered by Richardson *et al.* (1978) to be the predominant microbial process that modifies the chemical composition of nitrogen in a wetland system and the major process whereby elemental nitrogen is returned to the atmosphere.[3] To summarize, the nitrogen cycle is completed as follows: ammonia in water, at or near neutral pH is converted to ammonium ions; the aerobic bacterium Nitrosomonas sp. oxidizes ammonium to nitrite; Nitrobacter sp. then converts nitrite to nitrate. Under anaerobic conditions, nitrate is reduced to relatively harmless nitrogen gas, that is given off to the atmosphere.

Nitrogen removal in constructed wetlands used to treat domestic sewage

In a review of 19 surface flow wetlands (US EPA, 1988) it was found that nearly all reduced total nitrogen. In a review of both surface flow and subsurface flow wetlands Reed (1995) concluded that effluent nitrate concentration is dependent on maintaining anoxic conditions within the wetland so that denitrification can occur. He found that subsurface flow wetlands were superior to surface flow wetlands for nitrate removal. The 20 surface flow wetlands reviewed reported effluent nitrate levels below 5 mg/L; the 12 subsurface flow wetlands reviewed reported effluent nitrate ranging from <1 to < 10 mg/L. Results obtained from the Niagara-On-The-Lake vertical flow systems show a significant reduction in both total nitrogen and ammonia (> 97%) when primary treated effluent was applied at a rate of $60L/m^2/day$.

Calculations made showed that over 50% of the total nitrogen going into the system was converted to relatively harmless nitrogen gas. Effective removal of nitrate from the sewage lagoon influent was dependent on medium type used within the vertical cell as well as water table level within the cell (Lemon *et al.*, 1997).

Removal of phosphorus

Phosphorus occurs naturally in both organic and inorganic forms. The analytical measure of biologically available orthophosphates is referred to as soluble reactive phosphorus (SR-P). Dissolved organic phosphorus and insoluble forms of organic and inorganic phosphorus are generally not biologically available until transformed into soluble inorganic forms.[6]

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

1. The binding of phosphorus in organic matter as a result of incorporation into living biomass,
2. Precipitation of insoluble phosphates with ferric iron, calcium, and aluminum found in wetland soils.[6]

Incorporation into biomass

Higher plants in wetland systems may be viewed as transient nutrient storage compartments absorbing nutrients during the growing season and releasing large amounts at senescence (Guntensbergen, 1989).[8] Generally, plants from nutrient-rich habitats accumulate more nutrients than plants found in nutrient-poor habitats, a phenomenon referred to as luxury uptake of nutrients (Guntensbergen, 1989; Kadlec, 1989). Aquatic vegetation may play an important role in phosphorus removal and, if harvested, extend the life of a system by postponing phosphorus saturation of the sediments (Breen, 1990; Guntensbergen, 1989; Rogers *et al.*, 1991). According to Sloey *et al.* (1978) vascular plants may account for only a small amount of phosphorus uptake with only 5 to 20% of the nutrients detained in a natural wetland being stored in harvestable plant material. Bernard and Solsky also reported relatively low phosphorus retention, estimating that a sedge (*Carex* sp.) wetland retained 1.9 g of phosphorus per square metre of wetland.[8] Bulrushes (Scirpus sp.) in a constructed wetland system receiving secondarily treated domestic wastes contained 40.5% of the total phosphorus influent. The remaining 59.0% was found to be stored in the gravel substratum (Sloey *et al.*, 1978). Phosphorus removal in a surface flow wetland treatment system planted with one of *Scirpus* sp., *Phragmites* sp. or *Typha* sp. was investigated by Finlayson and Chick (1983).

Phosphorus removal of 60%, 28%, and 46% were found for *Scirpus sp*., *Phragmites sp*. and *Typha sp*. respectively. More recent work by Breen (1990) may prove this to be a low estimate. His work on an artificial wetland indicated that vascular plants are a major phosphorus storage compartment accounting for 67.3% of the influent phosphorus. Thut (1989) attributed plant adsorption with 80% phosphorus removal.

Only a small proportion (<20%) of phosphate removal by constructed wetlands can be attributed to nutritional uptake by bacteria, fungi and algae (Moss, 1988). Swindell *et al.*, (1990) found that the lack of seasonal fluctuation in phosphorus removal rates suggests that the primary mechanism is bacterial and alga fixation. However, Richardson (1985) dismisses this mechanism as temporary saying that although the initial removal of dissolved inorganic phosphorus from the water under natural loading levels is due largely to microbial uptake and adsorption, the microbial pool is small and quickly becomes saturated at which point the soil medium takes over as the major contributor to phosphate removal.

There are more indirect ways in which plants contribute to wastewater purification. Plants create a unique environment at the attachment surface of the biofilm. Certain plants transport oxygen which is released at the biofilm/root interface perhaps adding oxygen to the wetland system (Pride *et al.*, 1990). Plants also increase soil or other root-bed medium hydraulic conductivity. As roots and rhizomes grow they are thought to disturb and loosen the medium increasing its porosity which may allow more effective fluid movement in the rhizosphere. When roots decay they leave behind ports and channels known as macropores which are effective in channeling water through the soil (Conley *et al.*, 1991).

Whether or not wetland systems act as a phosphorus sink or source seems to depend on system characteristics such as sediment and hydrology. Kramer *et al.*, (1972) indicated that there seems to be a net movement of phosphorus into the sediment in many lakes. In Lake Erie as much as 80% of the total phosphorus is removed from the waters by natural processes and is presumably stored in the sediment. According to Klopatek (1978) marsh sediments high in organic matter act as sinks. He has also shown that phosphorus release from a marsh exhibits a cyclical pattern. Much of the spring phosphorus release comes from high phosphorus concentrations locked up in the winter ice covering the marsh; in summer the marsh acts as a phosphorus sponge. Simpson (1978) found that phosphorus was exported from the system following dieback of vascular plants. It has been demonstrated by Klopatek (1978) that phosphorus concentrations in water are reduced during the growing season due to plant uptake but decomposition and subsequent mineralisation of organic matter releases phosphorus over the winter and accounts for the higher winter phosphorus concentrations in the marsh (Klopatek, 1978;).[6]

Phosphorus retention by soils or root-bed media

Two types of phosphate retention mechanisms may occur in soils or root-bed media: chemical adsorption onto the medium (Hsu, 1964) and physical precipitation of the phosphate ion (Faulkner and Richardson, 1989). Both result from the attraction between phosphate ion and ions of Al, Fe or Ca (Hsu, 1964; Cole *et al.*, 1953) and terminate with formation of various iron phosphates (Fe-P), aluminum phosphates (Al-P) or calcium phosphates (Ca-P) (Fried and Dean, 1955).

Redox potential (E_h) of soil or water is a measure of its ability to reduce or oxidize chemical substances and may range between -300 and +300 millivolts (mV) (Hammer, 1992). Though the oxidation state of phosphorus is unaffected by redox reactions, the redox potential is important because of Fe reduction. Severely reduced conditions in the sediments may result in phosphorus release (Mann, 1990). Typical wetland soils may have an E_h of -200 mV

(Hammer, 1992). Under these reduced conditions Fe^{3+} (Ferric iron) may be reduced to Fe^{2+} (Ferrous iron) and may release the bound phosphate ion back into solution (Faulkner and Richardson, 1989; Sah and Mikkelson, 1986). The introduction of oxygen causes the Fe^{2+} to be oxidized to Fe^{3+} producing a simultaneous reduction of phosphate.[7] The solubility of phosphorus may be affected by the amount of oxygen present in the sediment because saturation by water and subsequent loss of oxygen generally cause wetland soils to have negative redox potentials (Hammer, 1992). A well documented occurrence in the hypolimnion of lakes is the release of soluble phosphorus when conditions become anaerobic (Burns & Ross, 1972; Williams & Mayer, 1972). This phenomenon also occurs in natural wetlands (Gosselink & Turner, 1978) and Kramer *et al.*, (1972) report that oxygen concentrations of less than 2.0 mg/l result in the release of phosphorus from sediments.

Phosphorus removal in constructed wetlands used to treat domestic sewage

Adsorption to binding sites within the sediments was identified as the major phosphorus removal mechanism in the surface flow constructed wetland system at Port Perry, Ontario (Snell, unpublished data). Release of phosphorus from the sediments occurred when anaerobic conditions prevailed. The lowest wetland effluent phosphorus levels occurred when oxygen levels of the overlying water column were above 1.0 mg / L. Removal efficiencies for total phosphorus were 54-59% with mean effluent levels of 0.38 mg P/L. Wetland effluent phosphorus concentration was higher than influent levels during the winter months.

Lantzke *et al.*, (1999) investigated phosphorus removal in a VF wetland in Australia and found that the quantity of phosphorus removed over a short term was stored in the following wetland components in order of decreasing importance: substratum> macrophyte >biofilm but over the long term phosphorus storage was located in macrophyte> substratum>biofilm components. They also found that medium iron-oxide adsorption provides additional removal for some years.

Mann (1990) investigated the phosphorus removal efficiency of two large-scale, surface flow wetland systems in Australia which had a gravel substratum. He then compared these results to laboratory phosphorus adsorption experiments. For the first two months of wetland operation the mean phosphorus removal efficiency of system 1 and 2 was 38% and 22%, respectively. Over the first year a decline in removal efficiencies occurred. During the second year of operation release of phosphorus from the system was often recorded such that more phosphorus came out than was put in. This release was attributed to the saturation of phosphorus binding sites. Close agreement was found between the phosphorus adsorption capacity of the gravel as determined in the laboratory and the adsorption capacity recorded in the field.

The phosphorus adsorption capacity of a subsurface flow constructed wetland system containing a predominantly quartz gravel was investigated by Breen (1990). The adsorption characteristics of this gravel as determined by laboratory adsorption experiments and using the Langmuir adsorption isotherm was 25 mg P / g gravel. Close agreement between calculated and realized phosphorus adsorption was found. Because of the poor adsorption capacity of the quartz gravel, plant uptake and subsequent harvesting were identified as the major phosphorus removal mechanism.[9]

Set-up of commercial treatment ponds/combined treatment ponds construction in urban areas

As previously mentioned, 3 types of reedbed-set ups are used. All these systems are used in commercial systems (usually together with septic tanks).[10] The system again are:

- Surface flow (SF) reedbeds
- Sub Surface Flow (SSF) reedbeds
- Vertical Flow (VF) reedbeds

All three types of reed beds are placed in a closed basin with a substrate. Also, for most commercial undertakings (eg agricultural enterprises), the bottom is covered with a rubber foil (to ensure that the whole is completely waterproof, which is essential in urban areas). The substrate can be either gravel, sand or lavastone.

Design characteristics of the commercial systems

Surface flow reed beds are characterised by the horizontal flow of wastewater between the roots of the plants. They are no longer used as much due to the land-area requirements to purify water for a single person (20 m^2), and the increased smell and poor purification in winter.[10]

With subsurface flow reedbeds, the flow of wastewater occurs between the roots of the plants itself (and not at the water surface). As a result the system is more efficient, less odorous and less sensitive to winter conditions. Also, less area is needed to purify water for a single person (5-10 m^2). A downside to the system are the intakes, which can clog easily.[10]

A water-purifying pond, planted with Iris pseudacorus

Vertical flow reed beds are very similar to subsurface flow reed beds (subsurface wastewater flow is present here as well), according comparable advantages in efficiency and winter hardiness. The wastewater is divided at the bottom with the assistance of a pump. Other than the 2 previous systems, this system makes almost exclusive use of fine sand to increase bacteria counts. Intake of oxygen into the water is also better, and pumping is pulsed to reduce obstructions within the intakes. Through the increased efficiency, only 3 m^2 of space is needed to purify the water for one person.[10]

Plants/organisms used in treatment ponds in commercial undertakings

Usually, Common reed or Phragmites australis are used in treatment ponds (eg in greywater treatment systems to purify wastewater). In self-purifying water reservoirs(used to purify rainwater) however, certain other plants are used as well. These reservoirs firstly need to be dimensioned to be filled with 1/4th of lavastone and water-purifying plants to purify a certain water quantity.[11]

The water-purifying plants used include a wide variety of plants, depending on the local climate and geographical location. Plants are usually chosen which are indigenous in that location for ecological reasons and optimum workings of the system. In addition to water-purifying (de-nutrifying) plants, plants that supply oxygen, and shade are also added in to allow a complete ecosystem to form. Finally, in addition to plants, locally grown bacteria and non-predatory fish are also added to eliminate pests. The bacteria are usually grown locally by submerging straw in water and allowing it to form bacteria (arriving from the surrounding atmosphere). The plants used (placed on an area 1/4th of the water mass) are divided in 4 separate water depth-zones; knowingly:

1. A water-depth zone from 0-20cm; *Iris pseudacorus*, *Sparganium erectum*.
2. A water-depth zone from 40-60cm; *Stratiotes aloides*, *Hydrocharis morsus-ranae*.
3. A water-depth zone from 60-120cm; *Nymphea alba*.
4. A submerged water-depth zone; *Myriophyllum spicatum*.

Finally, 3 types of (non-predatory) fish (surface; bottom and ground-swimmers) are chosen. This is to ensure that the fish may 'get along'. Examples of the 3 types of fish (for temperate climates) are:

- Surface swimming fish: *Leuciscus leuciscus*, *Leuciscus idus*, *Scardinius erythrophthalmus*, ...
- Middle-swimmers: *Rutilus rutilus*, ...
- Bottom-swimming fish: *Tinca tinca*, ...

The plants are usually grown on coconut fibre growing medium.[12] At the time of implantation to water-purifying ponds, de-nutrified soil is used to prevent the possible growth of algae and unwanted organisms.

Flowforms in treatment pond in Norway

Finishing

Finally, also worth mentioning are the hybrid systems. These are systems that for example aerate the water after the final reedbed using cascades such as [Flowforms]flowformsamerica.com before holding the water in a shallow pond.[13] Also, primary treatments as septic tanks, and different types of pumps as grinder pumps may also be added.[14]

Reed Beds

Reed beds are a natural habitat found in floodplains, waterlogged depressions and estuaries. Reed beds are part of a succession from young reed colonising open water or wet ground through a gradation of increasingly dry ground. As reed beds age, they build up a considerable litter layer which eventually rises above the water level, and ultimately provides opportunities for scrub or woodland invasion. Artificial reed beds are used as a method of removing pollutants from grey water.

Types of reed bed

Reed beds vary in the species they can support, depending on water levels within the wetland system, climate, seasonal variations, and the nutrient status and salinity of the water. Those that normally have 20 cm or more of surface water during the summer are referred to as reed swamp. These often have high invertebrate and bird species use. Reed beds with water levels at or below the surface during the summer are often more complex botanically and are known as reed fen. Reeds and similar plants do not generally grow in very acidic water, and so in these situations reed beds are replaced by other vegetation such as poor-fen and bog.

Although common reed is characteristic of reed beds, not all vegetation dominated by this species is reed bed. It also occurs commonly in unmanaged damp grassland and as an understorey in certain types of damp woodland.

Wildlife:

Most European reed beds are composed mainly of the large wetland grass common reed (*Phragmites australis*), but also include many other tall monocotyledons adapted to growing in wet conditions – other grasses such as reed sweet-grass (*Glyceria maxima*), Canary reed-grass (*Phalaris arundinacea*) and small-reed (*Calamagrostis species*), large sedges (species of *Carex*, *Scirpus*, *Schoenoplectus*, *Cladium* and related genera), yellow flag iris (*Iris pseudacorus*), reed-mace ("bulrush" – *Typha* species), water-plantains (*Alisma* species), and flowering rush (*Butomus umbellatus*). Many dicotyledons also occur, such as water mint (*Mentha aquatica*), gipsywort (*Lycopus europaeus*), skull-cap (*Scutellaria species*), touch-me-not balsam (*Impatiens noli-tangere*), brooklime (*Veronica beccabunga*) and water forget-me-nots (*Myotis species*).

Many animals are adapted to living in and around reed-beds. These include mammals such as Eurasian otter, European beaver, water vole, harvest mouse and water shrew, and birds such as Great Bittern, Purple Heron, European Spoonbill, Water Rail (and other rails), Purple Gallinule, Marsh Harrier, various warblers (Reed Warbler, Sedge Warbler etc), Bearded Reedling and Reed Bunting.

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