Wastewater Treatment Process

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Bachelor's thesis

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Fall Semester 2016
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ABSTRACT

Construction Engineering
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Author	Arash Jebrail	**Year** 2016
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The purpose of this thesis is mainly to explain the sources of producing wastewater and most common processes of wastewater treatment. In this thesis the characteristics and differences between domestic, industrial and municipal sewages and the causes of their contamination will be explained, also the processes which they should be treated is described. The most important wastewater contaminates will be introduced and explained.
There are also some natural methods of wastewater treatment that occur spontaneously in nature which shortly is explained.
Since our earth and its resources are not unlimited we should try to preserve them and saving and recycling its resources should be considered. Wastewater treatment is one of the methods or perhaps is the most important one for recycling water which is used by human. In this thesis the methods of wastewater treatment is tried to be explained in details.

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Keywords Wastewater, Contaminants, Treatment Process

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CONTENTS

1 INTRODUCTION

It may be surprising to know that the wastewater treatment is a modern function. Although sewers collection system for removing wastewater from city were used in ancient Rome, but real sewage system and wastewater treatment was not used until the 19th century when the large cities began to appear. As each person generate 200 to 500 liters of wastewater each day it is not difficult to imagine the huge amount of wastewater which a medium-sized city with population of 100000 to 900000 can generate. So authorities, decision makers and experts began to understand the necessity of reducing the amount of pollutants and recycling the used water.

The wastewater treatment occur naturally in oceans, surface waters, lake and rivers but populations and huge amount of generated wastewater had become so considerable and it was impossible to discharge this amount of wastewater to ocean or surface water. Beside that the pathogenic bacteria in the wastewater cause life threatening diseases which was commonplace in 19th century.

So it was necessary to cleanse the sewage water and speed up the wastewater treatment process. What happens in the wastewater plant is the same as happens in nature but safer and faster. Nowadays the sewage collection systems and wastewater treatment is almost perfect and quality of discharged water to the nature and public hygiene are way better than before.

2 OVERALL GOALS OF WASTEWATER TREATMENT:

The rapid growth of cities, increasing their populations and expansion of industries and factories have made the consideration of environmental pollution more important.

The industrial life style and neglecting in saving the natural resources make the environment polluted and threaten human life. One of the factors of environmental pollution is sewage and wastewater; therefore it should be collected and be brought out of the cities.

Sewage should be refined and then be returned to the water cycle in nature. It’s important to treat the wastewater to avoid diseases and odor and protect the clean water source from discharged sewage and to cleanse effluents that after discharging to the surface or ground water be suitable to be used as sources of potable supply. As wastewater may contain high levels of hydrocarbons and chemicals, without proper treatment, the wastewater will pollute the water body which the wastewater is being discharged into (http://www.allreadable.com/7ef0Ap6x).

Figure 2.1 Beijing Gaobeidian Wastewater Treatment Plant serving 2.4 million people
http://www.valmet.com/media/articles/all-articles/valmet-ts-in-beijing-gaobeidian-wastewater-treatment-plant-serving-2.4-million-people/

Collecting sewage and wastewater is necessary because of the following reasons:

- To improve health conditions
- To keep environment clean
- To recycle wastewater
- To produce natural fertilizers
- To produce energy

In everyday life a lot of water is being used for drinking, washing, cooking, going to the toilet and much more, by using these, water becomes polluted, wastewater which is produced is known as sewage. Everything that leaves the house through main drain pipe meets up at the sewer, in some places both wastewater and storm water are combined. It means everything from inside the house and everything from outside the house including rainwater and wastewater which is produced at the offices, shops, factories and other industries go to the single combine sewer. Together with the rain water that runs on the roofs and roads, sewage is washed, flushed and drained into the sewers. The underground network of sewer collects all these wastewater and storm water and takes them to the wastewater treatment plants. In some places sewers are separated, one for sewage water and one for storm water.

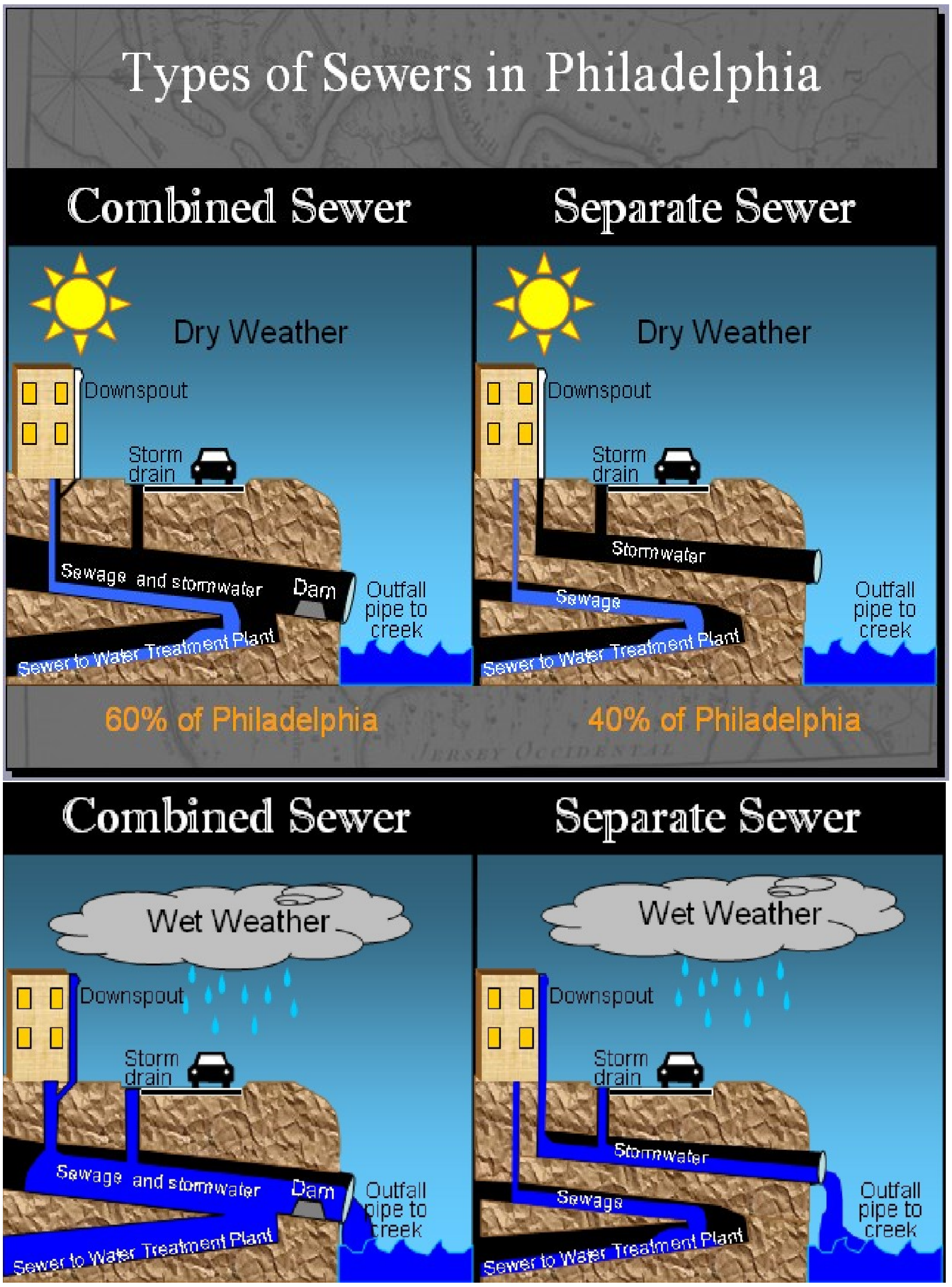


Figure 2.2 Types of Sewers in Philadelphia
https:// purocleanpers.us/solving-the-philadelphia-area-sewage-problem

European Union (EU) law seeks to ensure the proper treatment of wastewater so as to protect human health and the environment. Aimed at protecting the aquatic environment from the adverse effects of urban wastewater, it sets out EU-wide rules for collection, treatment and wastewater discharge. The law also covers wastewater generated by industries.

EU countries must:

• Collect and treat wastewater in urban settlements with a population of at least 2000 and apply secondary treatment on the collected wastewaters
• Apply more advanced treatment in urban settlements with populations over 10 000 located in designated sensitive areas
• Guarantee that treatment plants are properly maintained, so as to ensure sufficient performance, and can operate under all normal weather conditions
• Require authorization for discharges of urban wastewater from the agro-food industry and from industrial discharges into urban wastewater collecting systems
• Take measures to limit the pollution of receiving waters from storm water overflows under extreme situations, such as unusually heavy rain
• Monitor the performance of treatment plants and receiving waters;
• Monitor sewage sludge disposal and re-use.

As well as outlining methods for the monitoring and evaluation of results, Annex I lists general requirements for:

• Collecting systems;
• Discharges from urban wastewater treatment plants, including emission limit values for these;
• Industrial wastewater discharged into urban collecting systems. (http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=URISERV%3Al28008)

3 TYPES AND SOURCES OF WASTEWATER

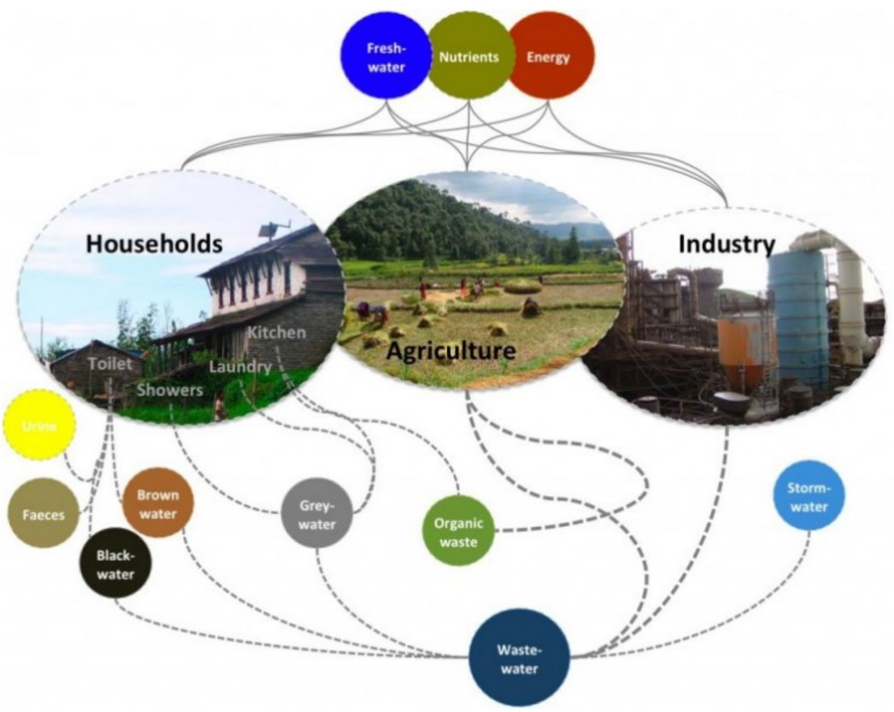


Figure 3.1 Sources of wastewater
http://www.sswm.info/ar/category/implementation-tools/reuse-and-recharge/hardware/introduction/sanitation-systems

Depending on source of wastewater and its characteristics, wastewater is divided into three groups: domestic, industrial, and agriculture.

3.1 Municipal Wastewater

Municipal wastewater is produced in bathrooms, kitchens, sanitary appliances such as toilets, sinks, washing machines, and through washing the different parts of houses. They all produce high volumes of wastewater. It also includes storm water which is wastewater caused by raining, snowing and ice melting in the cities. In some cases the contamination degree of this type of wastewater can be more than sewage. In addition to abovementioned domestic wastewater, what flows in urban wastewater collection systems contains some wastewater that inevitably enters wastewater collection channels from shops, stores, repair shops, workshops, and other similar establishments. Therefore, depending on the variety and kinds of these establishments, the type of urban wastewater may vary.

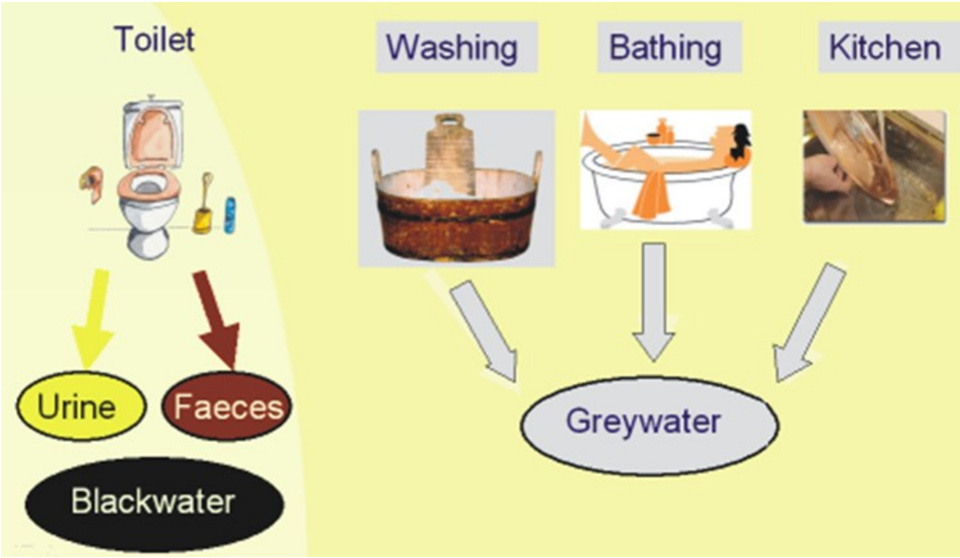


Figure 3.2 Sources of domestic wastewater
https://cgi.tu-harburg.de/~awwweb/wbt/emwater/lessons/lesson_a1/lm_pg_1066.html

3.2 Industrial Wastewater

Characteristics of industrial wastewater and factory effluents depend on the types of products that are manufactured. In effluents of some factories, including those related to mining, steel making and chemical factories, most of the foreign particles are mineral ones, while in some other factories, such as those produce food products and in starch manufacturing factories, organic matter constitutes most of the foreign materials.

The most important differences between factory effluents and domestic wastewater are:

(1). There are more chemical substances in factory effluents.
(2). Factory effluents are more corrosive.
(3). Factory effluents have higher alkalinity or acidity property.
(4). Living organisms are less likely to be in the factory effluents.

Figure 3.3 Sources of industrial wastewater
https://www.iswa.uni-stuttgart.de/lsww/arbeitsbereich/iwt/index.en.html

3.3 Agricultural Wastewater

Wastewater is generated from agricultural facilities, water used for cleaning in animal farms, washing harvested products and cleaning equipment. Chemical fertilizer and pesticides have become essential for present day agriculture. Consequently, they have become a potential source of water pollution. These fertilizers contain nutrients, mainly nitrogen, phosphorous and potassium.

4 SOME SPECIFICATIONS OF WASTEWATER

4.1 Color of wastewater

Color of wastewater indicates wastewater age. Fresh wastewater is grey but, after some time, it turns dark and black when the materials it carries get rotten.

4.2 Smell of wastewater

Smell of wastewater is result of gases which are released when the organic matter of wastewater is decomposed. Smell of fresh wastewater can be tolerated better than smell of stale wastewater because the smell of old wastewater is mainly from hydrogen sulfide generated by the activity of anaerobic bacteria. If wastewater receives sufficient air and oxygen, anaerobic bacteria stop their activity and aerobic bacteria take over decomposition of the organic matter in wastewater. The most important gas generated by the activity of aerobic bacteria is carbon dioxide. Therefore, if enough oxygen is blown into wastewater, which is what happens at the wastewater treatment plants, wastewater will become odorless.

4.3 Degree of acidity of wastewater

Pure and fresh domestic wastewater usually has a neutral pH, or slightly has an alkaline pH. Only after wastewater putrefaction starts the acidic gases are produced and the pH value of the wastewater declines then it becomes acidic. The higher the temperature of the environment is, the sooner the putrefaction process starts. Under relatively normal conditions, putrefaction begins 3-4 hours after wastewater is generated.

4.4 Temperature of wastewater

Because of the biological activities in wastewater, its temperature is usually higher than water in the same environment. On the coldest days in winter, wastewater temperature does not usually drop below 10˚C.

4.5 Foreign particles in the wastewater

There is always some dissolved or undissolved and suspended foreign particles in the wastewater. Foreign particles constitutes about 0.1 percent of wastewater and the rest is water. About half of the foreign particles in the wastewater is organic materials and the rest is mineral materials. The foreign particles in the wastewater is divided into settleable and non-settleable organic materials. Settleable suspended solids are settled at the bottom of container or tank after about two hours.

4.6 Living organisms in the wastewater

In addition to the mentioned foreign particles, there is always a large quantity of microscopic living organisms such as viruses and microbes (bacteria) in the wastewater. However, only some of these organisms may be pathogenic.

5 TYPES OF CONTAMINANTS

Depending on their source of generation, wastewaters contain different pollutants. Industrial wastewater has more diversity of pollutants in comparison with municipal wastewater. The type of industrial wastewater pollutants depend on the type of plant which produce those pollutants. In terms of pollutions types, some industrial wastewaters are comparable with municipal wastewater. Some Industrial wastewaters which containing toxic and corrosive gases and compounds can have devastating effects on sewage networks and biological treatment processes, therefore pre-treatment process is necessary before discharging them to the municipal wastewater network.

The purpose of pre-treatment is reducing the concentration of industrial wastewater pollution to the extent that after unloading the industrial wastewater into the municipal sewage it doesn't have the damaging effects on the drainage network and biological treatment.

Sewage is a complex mixture of suspended and dissolved solids. Sewage is 99.9% water and the wastewater process is designed to treat the 0.1% solids.

The most important wastewater contaminates are:

5.1 Biodegradable organic matter

Biodegradable organic matter includes proteins, sugars and fat. Proteins form most of these substances to the extent of 65 percent, and the lowest amount of these matters is fat which about 10 percent is. If organic substances enter water resources they cause consumption of dissolved oxygen and creates undesirable situation. To measure the concentration of biodegradable organic substances in the wastewater some parameters such as COD, BOD, and TOC are used.

Microorganisms consumes organic substances in the wastewater as a source of nutritious in order to growth, reproduction, and achieving energy. In terms of biological decomposition rate, first sugars then proteins and finally fats are decomposed.

5.2 Total suspended solids (TSS)

Water contains suspended and dissolved solids (mineral and organic). To measure them, the sewage pass through fiberglass filters with pores of

about one micron diameters at temperature of 105-130° C. To determine TSS weigh a piece of filter paper. Filter one litre sample of water through the filter paper. Dry the filter paper completely. Weigh the filter paper again. The change in weight is the weight of the total suspended solids. TSS values are shown in ppm (mg solids per litre of water).
Suspended solids can be divided into two categories: settleable suspended solids and non-settleable suspended solids.

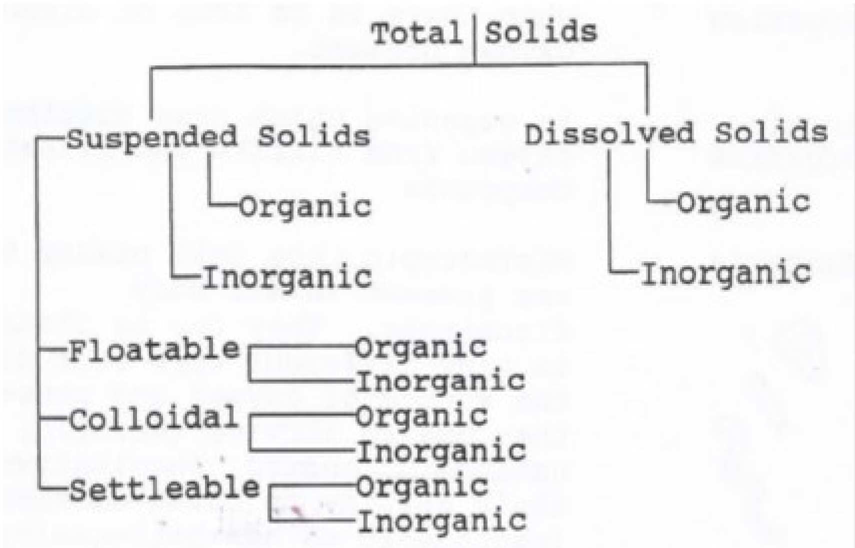


Figure 5.1 Total solids
https://water.me.vccs.edu/courses/ENV195WWBasics/lesson1_print.htm

5.3 **Pathogens**

Includes bacteria, viruses, protozoa and helminths which their existence in sewage cause communicable diseases. Due to the difference in health conditions of people living in industrialized and developing countries, the pathogen content is notably different and therefore the appropriate treatment options are also different. Removal of helminths eggs, bacteria and viruses is commonly achieved by wastewater stabilization ponds and other natural treatment processes. However, when more conventional or energy-intensive processes (e.g. activated sludge) are used, disinfection methods such as chlorination, ozonation and UV radiation are generally required for pathogen inactivation.
These disinfection methods remove bacteria and viruses, but not helminthes eggs as these are very resistant and behave quite differently from bacteria and viruses during treatment.

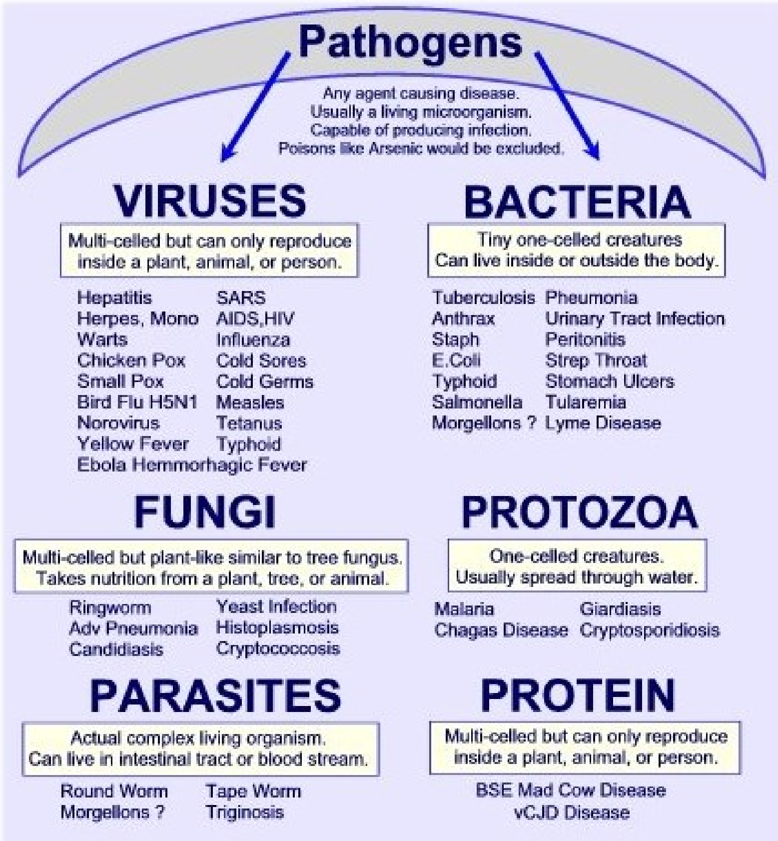


Figure 5.2 Pathogen is a specific microorganism that causes a specific disease

http://kmbiology.weebly.com/human-health-and-disease---notes.html

5.4 Nutrients

Wastewater contains nitrogen and phosphorus from human waste, food and detergents. High concentration of nitrogen and phosphorus in the aquatic environment causes eutrophication, which degrades water quality and kills the aquatic animals.

5.5 Heavy metals

The most commonly toxic heavy metals in wastewater are arsenic, lead, mercury, cadmium, chromium, copper, nickel and zinc. Industrial wastewater containing heavy metals which are produced from different industries such as electroplating, metal surface treatment processes, printed circuit board manufacturing, wood processing industry, inorganic pigment manufacturing, petroleum refining, and photographic operations. Because of high solubility of heavy metals in the aquatic environments, heavy metals can be absorbed by living organisms. When they enter the food chain, the heavy metals can accumulate in the human body. If the metals enter the human body beyond the permitted concentration, they can cause serious health problems such as learning disabilities, cancers and even death.

5.6 Non-Biodegradable Organics

Some organic materials are non-biodegradable or hardly biodegradable organic compounds with high toxicity. Tannic, lignic acids, cellulose and phenols biodegrade so slowly that they are considered as non-biodegradable materials. Some organics are non-biodegradable such as organic pesticides, some industrial chemicals and hydrocarbon compounds that have combined with chlorine.
The washing off the pesticides including herbicides and insecticides by rainfall can contaminate the surface streams. Pesticides are cumulative toxins and cause severe health problems at the higher end of the food chain.

5.7 Total dissolved solids (TDS)

Their biodegradation is difficult and take much time. They are toxic to micro-organism e.g. pesticide, industrial waste, cellulose, phenol, lignic acid. Primary sources for TDS are steel industry, pharmaceutical manufacturing, mining operations, oil and gas extraction, power plants, landfills and food processing facilities.

TDS:

- Are a secondary drinking water contaminant.
- Can cause operational problems for drinking water systems.
- Can cause toxicity to aquatic life through increases in salinity, changes in the ionic composition of the water, and the toxicity of individual ions.

6 THE METHODS OF MEASURING THE DEGREE OF WATER POLLUTION

6.1 Measuring the amount of Biochemical Oxygen Demand (BOD)

BOD is the amount of dissolved oxygen needed by aerobic biological organisms to break down organic material present in a given water sample at certain temperature over a specific time period (https://en.wikipedia.org/wiki/Biochemical_oxygen_demand). Among the living organisms in sewage there are two groups of bacteria which help in water treatment plants. The first group is aerobic bacteria which absorb dissolved oxygen in the waste water and oxidize organic materials and convert them into stable mineral compounds. In these interactions Co2 gas is produced and number of bacteria is increased. The second group is anaerobic bacteria which obtain required oxygen by decomposition of salts in wastewater. In these interactions sulfuric acid and methane is produced, therefore is accompanied by stench.

BOD curve: Oxygen absorption (oxidation), which starts from the moment that wastewater is exposed to the oxygen, takes place in the following two stages:

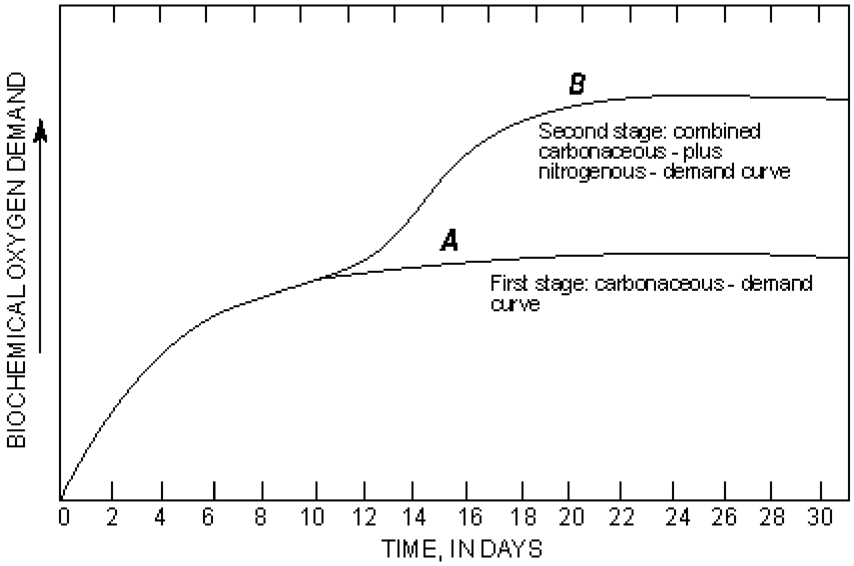


Figure 6.1 BOD Curve
http://water.usgs.gov/owq/FieldManual/Chapter7-Archive/chapter7.2/7.2.html

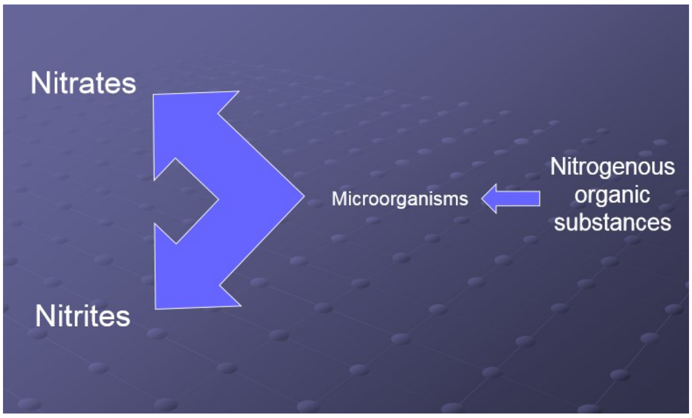
This figure (Figure 6.1) shows changes in BOD curve at three different temperatures (9, 20, and 30˚C) during a 70-day period from the beginning of bacterial activity. It can be concluded from the diagrams in this figure that most of the oxidation process in stage 1 takes place during the first five days, and it is almost completed after 20 days. Therefore, BOD5 is usually measured to show the degree of wastewater contamination. By definition, BOD5 is the amount of oxygen (in mg) required during the first five days for aerobic bacteria to oxidize the organic matter in one litre of wastewater at 20˚C.

Stage 1: Oxidation of carbonaceous organic materials

In this stage, oxidation of carbon containing compounds happens from the moment that bacterial activity starts, at 20˚C, and continues for 20 days. During this stage, the carbon in unstable organic compounds is turned into stable substances such as CO_2 that leave the wastewater.

Stage 2: Oxidation of organic nitrogen materials

In this stage, oxidation of nitrogen containing takes place from about the tenth day after the start of bacterial activity and continues for a long time. During this stage, nitrogen-containing materials are converted into nitrites and nitrates.



6.2 Measuring the Chemical oxygen demand (COD)

COD is the total amount of oxygen required to chemically oxidize the biodegradable and non-biodegradable organic matter. In this method a strong oxidizing chemical such as potassium permanganate or potassium dichromate is used to oxidize the organic matter to carbon dioxide and water under acidic conditions. COD is an important water quality parameter because, like BOD, it provides an index to show if discharged wastewater will have an effect on the receiving environment or not. Higher COD levels means a greater amount of organic material in the wastewater, which will reduce dissolved oxygen levels. A reduction in DO can lead to anaerobic conditions, which is dangerous to aquatic life forms. The COD test is often used as an alternate to BOD due to shorter length of testing time. But it should be considered that depending on the type of used oxidant, maybe all organic matters, especially detergents and soaps in the wastewater, not completely be oxidized with this method and thus the accuracy of this method is low.

Advantages of COD test to BOD:

i. COD result are available much sooner than BOD test results.
ii. The COD test requires fewer manipulations of the sample.
iii. The COD test oxidizes a wide range of chemical compounds.
iv. It can be standardize more easily.

6.3 Total organic carbon (TOC) analysis

In this method, carbon-containing organic compounds in the wastewater are measured and is often used as a non-specific indicator of water quality. This requires the conversion of carbonaceous material to CO2 using heat, ultraviolet irradiation or chemical oxidation, and then the produced CO2 is measured.

6.4 Measuring suspended solids in wastewater

Suspended solids are a part of total external materials in wastewater which measuring amount of them is important to predict the amount of sludge in wastewater treatment process. Suspended solids in the wastewater are either sediment or non- sediment. In terms of properties, suspended solids, are also either organic origin, and therefore are unstable or mineral origin and therefore are stable.

6.5 Measuring dissolved oxygen (DO)

There is a direct relationship between the amount of dissolved oxygen in the municipal wastewater and strength of natural treatment and its spontaneity. Dissolved oxygen in the wastewater causes aerobic bacteria activities and prevents the activities of anaerobic bacteria; therefore it prevents producing unpleasant smells. Thus the amount of dissolved oxygen in the wastewater shouldn’t drop below 1.5 mg per litre. This is very important in wastewater aeration ponds.

7 GENERAL PRINCIPLES OF WASTEWATER TREATMENT

Making Wastewater pollutants unstable and sedimentation is the foundation of wastewater purification. The main purpose of wastewater and sewage treatment is to eventually produce water which can be reused for various purposes. Some wastewater treatment methods produce water in very high purification level that can be used for agricultural purposes; other methods produce water that can be discharged to water sources with no bio-hazard. There are wastewater treatment methods that eliminate any remains of human waste by biological processes.

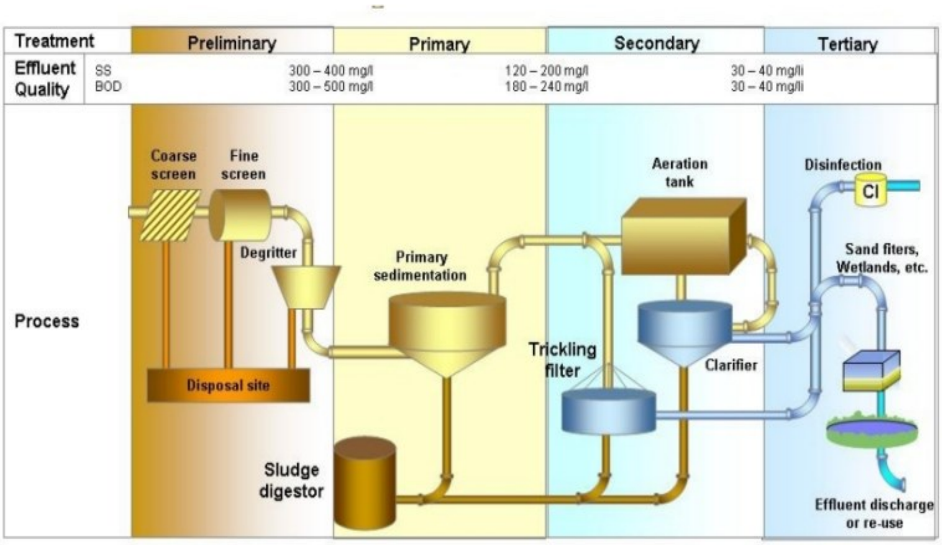


Figure 7.1 Principle of wastewater treatment
http://www.ewisa.co.za/frame.aspx?url=~/misc/WWTreatment/default.htm

The main difference between wastewater and clean water is the abundance of external materials, especially organic materials in wastewater. Therefore the following are the main purposes of wastewater treatment:

- Removing suspended and floating substances from wastewater
- Oxidation of unstable organic compounds in the wastewater and converting them to stable materials such as nitrates, sulphates and phosphates and then settling and separation of them.
- Separation of soluble and insoluble toxic substances like heavy metal
- Eliminating and disinfection of microbes in wastewater

All of the abovementioned processes take place spontaneously in nature but in relatively very long time. The purpose of constructing and developing treatment facilities (plants) is to speed up these processes to about a few hours on the one hand and to prevent contamination of natural water resources of the environment on the other hand.

Wastewater treatment, whether artificially in treatment plants or naturally and spontaneously, may take place in three different ways:

Wastewater treatment mainly carried out in three ways:

(1). Mechanical or physical treatment
(2). Biological treatment
(3). Chemical treatment

7.1 Physical or Mechanical method

Physical treatment processes generally refer to processes which are designed to separate and concentrate various components of a waste stream without chemically changing the form of these components. Physical properties will be used for the separation of suspended materials. Filtration and sedimentation are two examples of physical treatment processes.

1- Wastewater is screened to remove larger objects
2- Then grit is removed
3- Rests of the solids are finally extracted by using gravity in large sedimentation tanks.

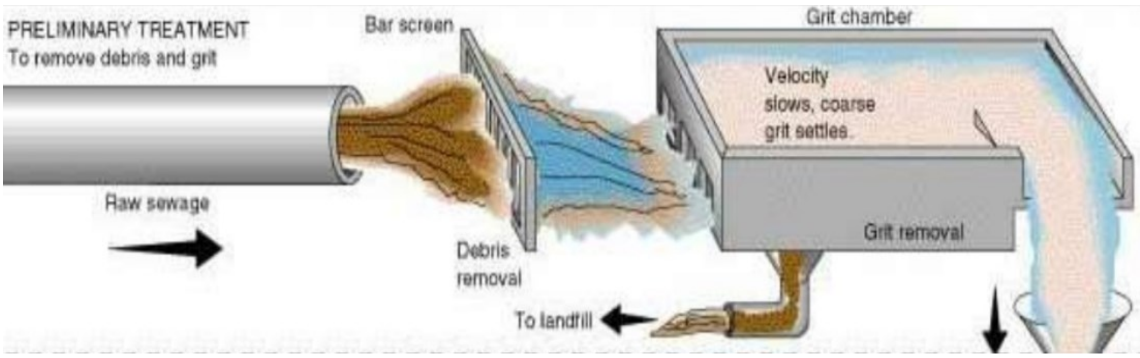


Figure 7.2 Raw sewage moves from the grit chamber to primary treatment, where sludge is removed and the clarified water then proceeds to secondary treatment
http://www.slideshare.net/ghildiyal8811/ag-wastewater-treatment-by-agpdf-2

7.2 Biological method

Biological wastewater treatment is often a secondary treatment process, used to remove any material remaining after primary treatment. In biological treatment plants the intensified process is used which naturally is done in nature but slowly. Biological treatment is to reduce the level of organic materials in the wastewater. About 90% of the Biological Oxygen Demand is removed during Biological treatment.

7.3 Chemical method

Chemical treatment is based on using chemicals for oxidation of "wastewater's organic materials ". This method is mostly used in water purification and industrial wastewater treatment.

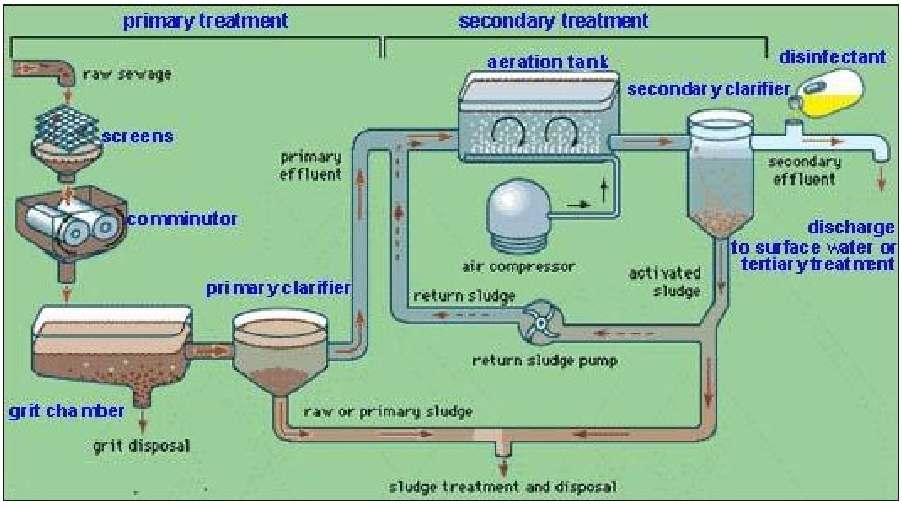


Figure 7.3 Tertiary Treatment and Disinfection occur only at some facilities where a very high quality effluent is required

http://wastematerials.blogspot.co.uk/2010/04/secondary-treatment.html

8 MOST IMPORTANT PHYSICAL TREATMENT METHODS

8.1 Physical barriers

Many separation methods are used so that the pollutants cannot pass, simply because of their size. Bar racks, screens, and sieves are considered to be part of primary treatment, and filters, micro-screens, dialysis processes and reverse osmosis are normally considered as secondary treatment. In this method particles are often caught on the barrier bridge cross the openings and form a filter themselves.

8.1.1 Bar rack

1-Wastewater first passes through bar racks.

2. It removes coarse solids like sticks, stones and other large objects.
3-Screens of various size and shape are used depending on the nature of solids to be removed.
4-Bar screens should be manually cleaned regularly to avoid clogging problems.

Figure 8.1 Bar Screening
http://www.clearcovesystems.com/primary-treatment-basics/

8.1.2 Grit chamber

Grit means small and dense materials like sand, dirt or broken glass which is usually removed in grit chamber. In grit chamber the speed of wastewater flow is reduced to a point where dense grit is settle out but organic solids are remained in the suspension. The speed of flow is usually 0.15-0.3m/s

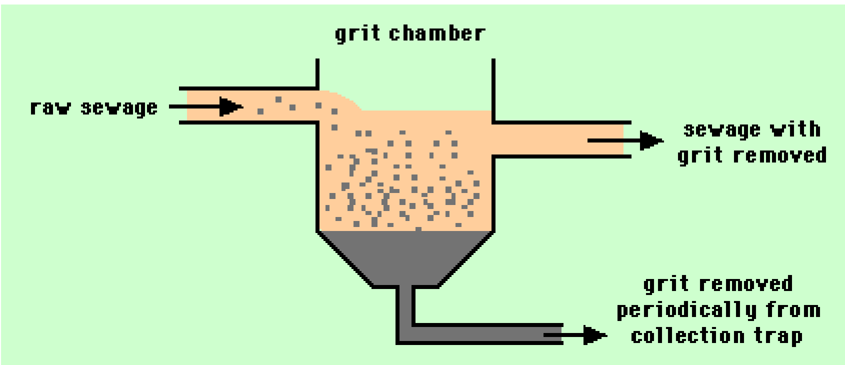


Figure 8.2 Grit Chamber
http://legacy.chemgym.net/environmental_chemistry/topic_5b/page_4_diag.html

8.2 Sedimentation tanks

The settling tanks are used for gravity separation of settleable solids in the wastewater. The main purpose of the primary settling tanks is to remove suspended solids from the wastewater. Secondary settling tanks are located downstream of the plant's biological treatment facilities, such as aeration basins or tricking filters, and are used to separate the biogases generated during the secondary treatment process. A layer of accumulated solids, called sludge, forms at the bottom of the tank and is periodically removed.

-The effluent is passed from grit chamber into a primary sedimentation tank.
-In sedimentation tank suspended solids are removed by gravitation under motionless condition.
-Flocculants are added to water to promote sedimentation.
-Purpose of using flocculants is to accelerate sedimentation process.
-The settled solids is called primary sludge or raw sludge.

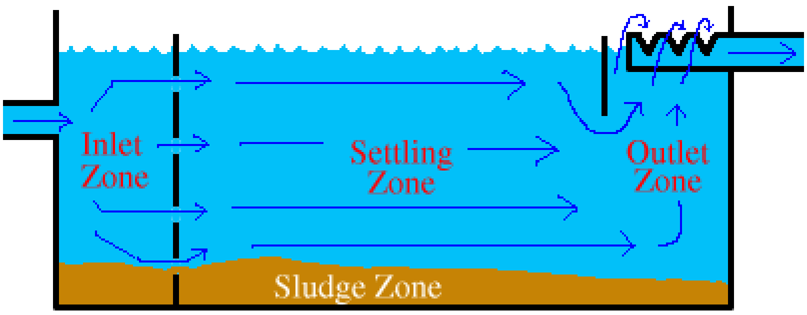


Figure 8.3 Primary sedimentation tank
http://www.thewatertreatments.com/wastewater-sewage-treatment/zones-sedimentation-basin/

8.3 Flotation Systems

Air flotation is one of methods for the removal of solids, oil, grease and fibrous materials from wastewater. Suspended solids and oil and grease removals as high as 99% can be achieved by this process. Air flotation simplify the production of microscopic air bubbles which carry wastewater contaminants to the surface of the tank to remove by mechanical skimming.

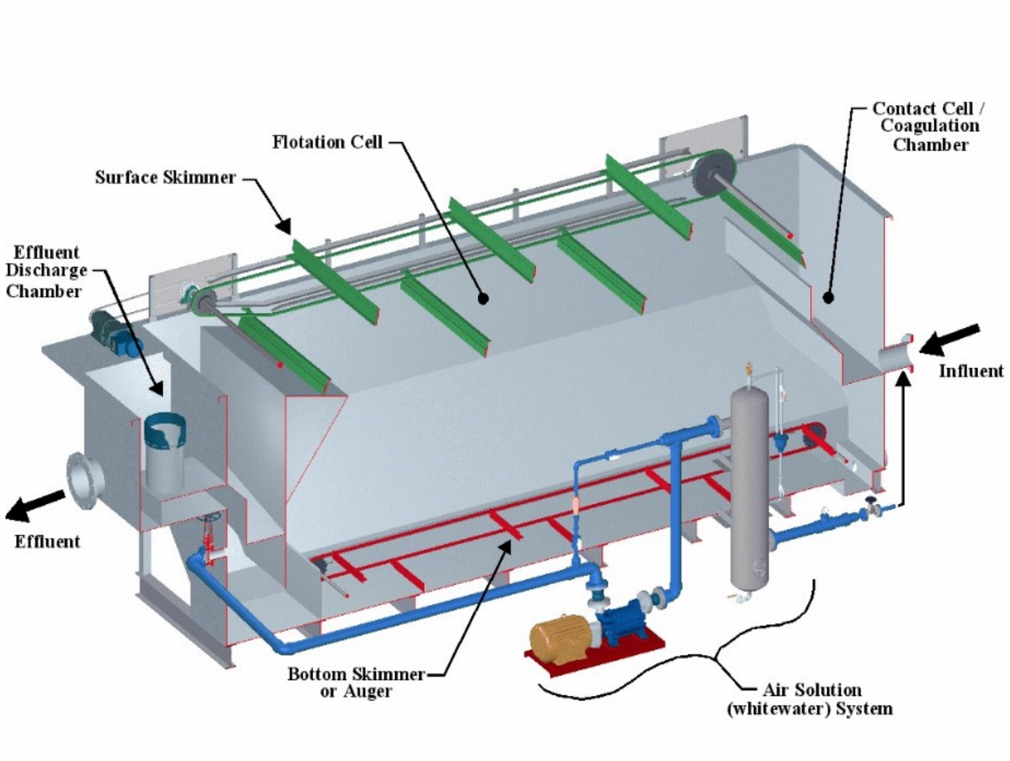


Figure 8.4 Air flotation unit
http://www.etsenvironmental.com/white-papers/rethinking-dissolved-air-flotation

9 BIOLOGICAL TREATMENT METHODS

After primary treatment the effluent undergoes a secondary treatment which degrades the biological content of the sewage. In the secondary treatment usually biological processes are used. Microorganisms are added to the wastewater to consume the organic matters. Oxygen is delivered to the system ensuring microorganism survival. These biological processes occur naturally in the nature but it is accelerated in biological treatment systems. Secondary treatment is mainly done by activated sludge process, trickling filters, aerated lagoons and oxidation ponds.

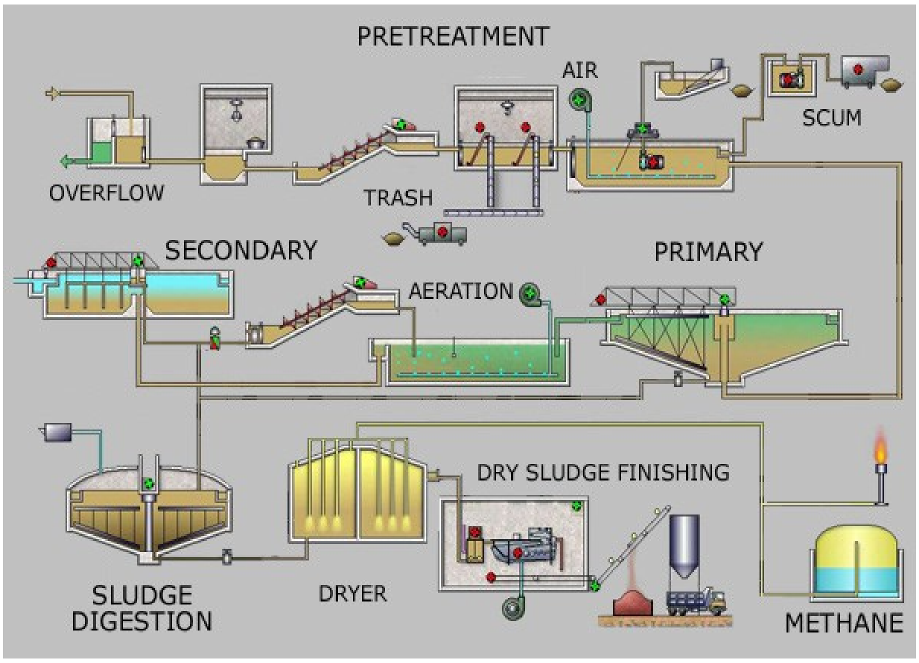


Figure 9.1 Simplified process flow diagram for a typical large-scale treatment plant

https://en.wikipedia.org/wiki/Sewage_treatment

9.1 Activated sludge process

In activated sludge process microorganism (usually bacteria) are used to aerobically treat the wastewater. Organic matters in the wastewater provide the carbon and energy which is required for bacteria growth and reproduction. To promote their growth nitrogen and phosphorus are sometimes added. The wastewater is mixed with microorganisms which are in the aeration tank and the organic contaminants are converted into microbial cell tissues and carbon dioxide. When microorganisms grow they form particles that clump together. These particles are settled on the bottom of the tank and relatively clear liquid free of organic and suspended solids is left above those particles. The settled organic matter that consists of several microorganisms is called activated sludge. Any organic nitrogen or phosphorus in the mixture is converted into nitrate (NO_3^-) and phosphate ions (PO_4^{3-}).

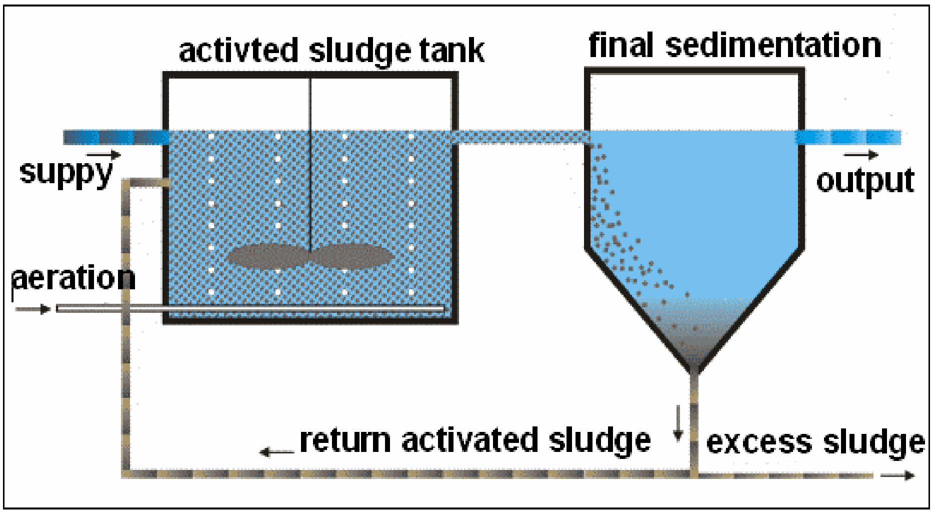


Figure 9.2 Example for an activated sludge process

https://cgi.tu-harburg.de/~awwweb/wbt/emwater/lessons/lesson_c1/lm_pg_1425.html

9.2 Trickling Filters

Trickling Filter is an aerobic treatment system that utilizes microorganisms attached to a medium to remove organic matter from wastewater. It consists of a bed of packing material to which microbes are attached. This microbial growth on the filtering medium consists of bacteria, fungi, algae etc. and is called biological slime. Wastewater is sprayed into the air, and then allowed to trickle through the media. Microorganisms attached to the media break down organic material in the wastewater. When more and more wastewater is passed, the slime layer thickens and eventually gets detached from the surface. This is called Sloughing. A settling thank after the trickling filter removes the detached bacterial film and some suspended matters.

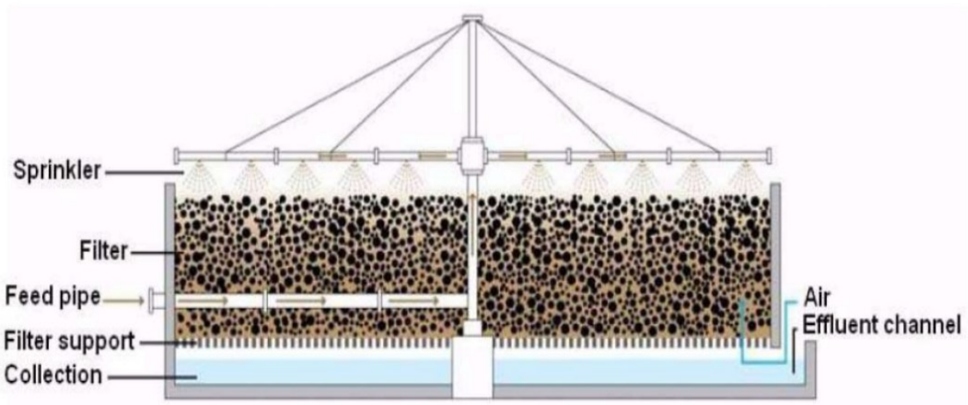


Figure 9.3 Trickling Filters

http://filtrospc.blogspot.co.uk/2012/03/tipos-de-filtros-percoladores.html

9.3 Sludge Digestion

The sludge which settles in the sedimentation basin is pumped to the sludge digesters where a temperature of 30-35C is maintained. It is designed to encourage the growth of anaerobic bacteria that decreases organic solids by reducing them to soluble substances and gases (CO_2&CH_4).

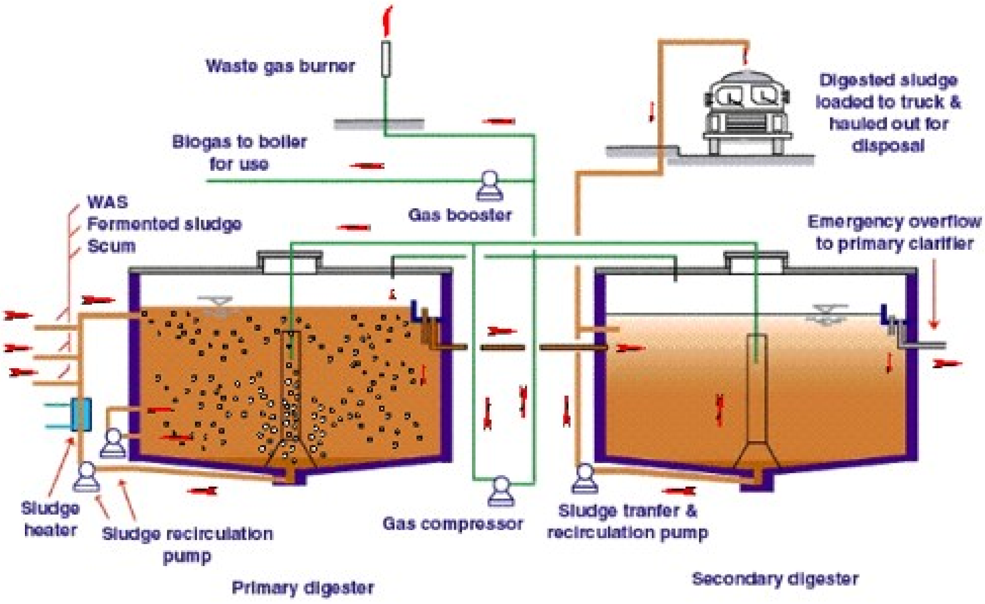


Figure 9.4 Schematic of sludge digesters

http://www.acrwc.ab.ca/treatment/anaerobic-sludge-digesters/

9.4 Oxidation Ponds

Oxidation ponds are large and shallow ponds designed to treat waste water through the interaction of sunlight, bacteria and algae. Algae grow within the pond and utilize sunlight to produce oxygen by photosynthesis. O_2 is used by the aerobic bacteria in the oxidation pond to breakdown the organic waste in the wastewater. The broken down solids settle down in the ponds, resulting in effluent that is relatively well treated.

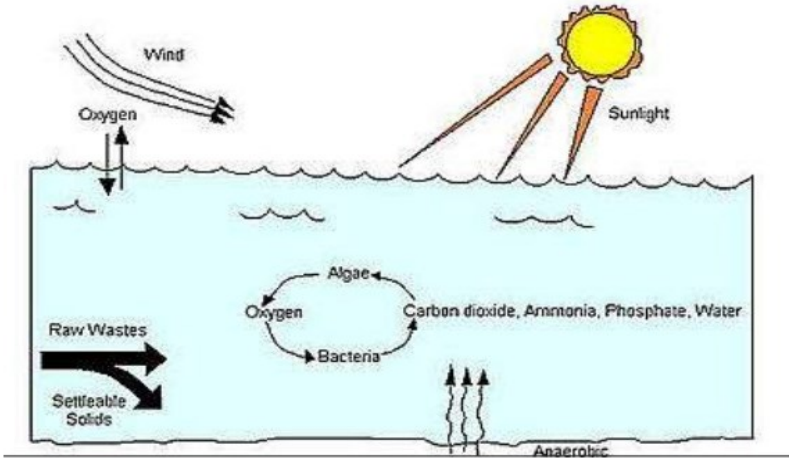


Figure 9.5 Oxidation Pond

https://water.me.vccs.edu/courses/ENV149/lesson5_print.htm

9.5 **Aerated Lagoons**

Aerated lagoon is a treatment pond with artificial aeration to promote the biological oxidation of wastewater (https://en.wikipedia.org/wiki/Aerated_lagoon). In nature lagoons are made up of three layers an aerobic (layer with oxygen), an anaerobic layer with no oxygen and a facultative (mixed layer). In a constructed aerated lagoon air is pumped into the lagoon to turn the whole pond into an aerobic zone. Adding air to the water speeds up the natural processes that break down organic waste. Mechanical aeration device is present which supply the oxygen needed by bacteria for stabilization. Water from trickling Filters and Activated Sludge Tanks frequently are pumped into concrete tanks or man-made ponds and lagoons.

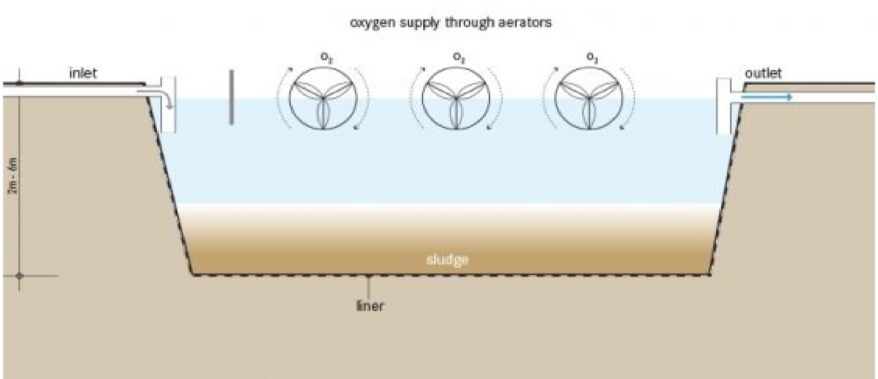


Figure 9.6 Schematic view of an artificially aerated facultative lagoon

http://www.sswm.info/content/aerated-pond-0

10 CHEMICAL TREATMENT

Chemical treatment or Tertiary Treatment is the final treatment the wastewater undergoes before it is discharged into the environment. It's also referred to as effluent polishing. Chemical treatment involves advanced treatment processes that generate a higher quality effluent than secondary treatment can produce. These processes are vital for wastewater reuse. In chemical treatment, the base is using chemicals for oxidation of wastewater's organic materials. The purpose of chemical treatment is to improve the secondary treated wastewater by removing the nutrients and dissolved solids. The major processes are, Filtration, Nutrient removal and Disinfection.

10.1 Filtration

Either sand or activated charcoal is used to filter treated effluent. In Filtration all remaining suspended solids which are not removed in secondary treatment will be removed.

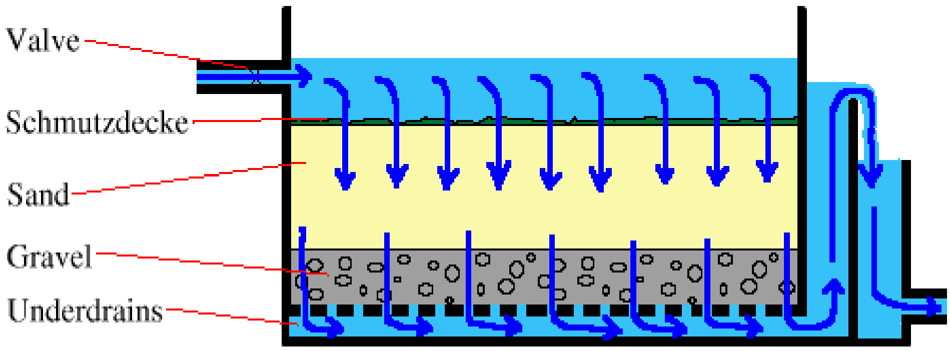


Figure 10.1 Sand Filter

http://water.me.vccs.edu/concepts/filters.html

10.2 Nutrient removal

High levels of nutrients such N2 and P must be removed otherwise eutrophication is happened.

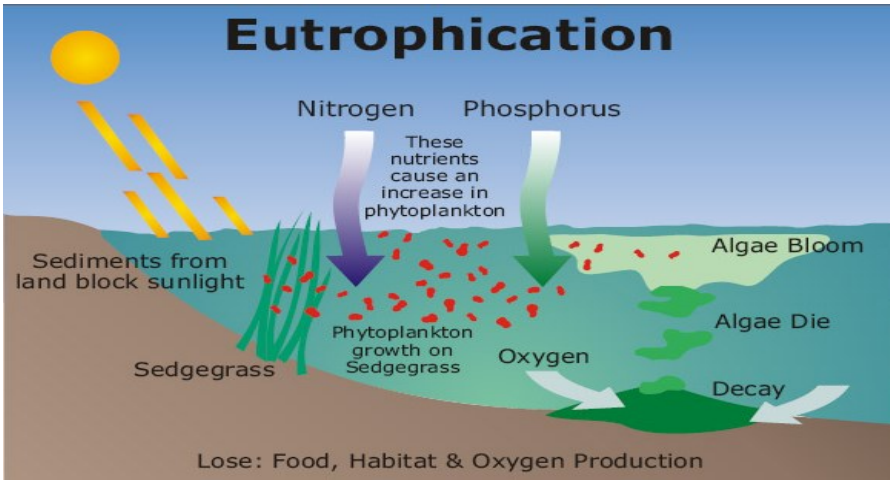


Figure 10.2 Eutrophication

http://05lovesgeography.blogspot.co.uk/2011/02/eutrophication.html

Nutrient removal is done through biological treatment by passing wastewater through five different chambers:

a. Anaerobic fermentation zone with very low dissolved oxygen levels and the absence of nitrates

b. Anoxic zone with low dissolved oxygen levels but nitrates present

c. Aerobic zone

d. Secondary anoxic zone

e. Final aeration zone

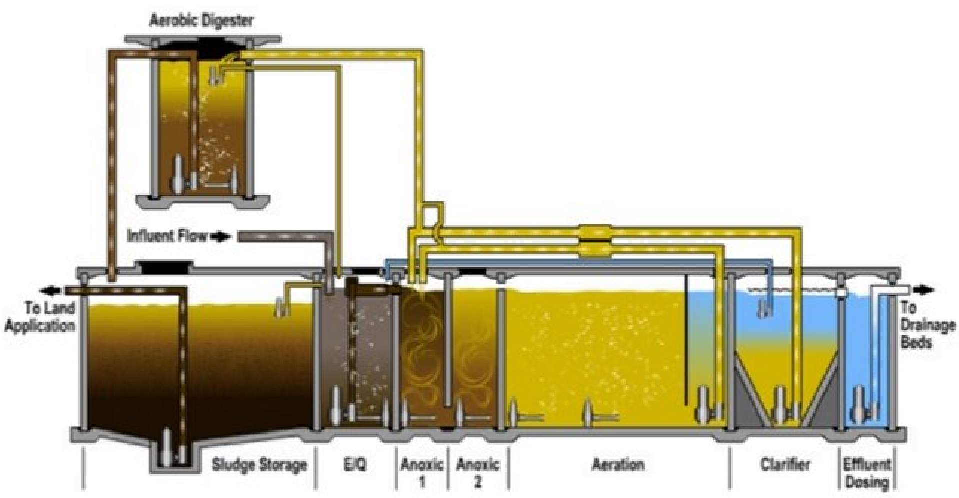


Figure 10.3 Biological Nutrient Removal Zones

http://www.wedotanks.com/anaerobic-aerobic-wastewater-treatment-plant.asp

10.2.1 Phosphorous removal

Phosphorous can be removed by Polyphosphate accumulating organisms (PAOs). It can also be removed by chemical precipitation, usually with salts of Fe, Al or lime.

10.2.2 Nitrogen removal

In the wastewater much of the nitrogen is found in the form of ammonia. When secondary treatment is used a great deal of this ammonia is discharged in the effluent. Bacteria can utilize this ammonia as an energy source and convert ammonia to nitrite and nitrate.

$$NH_3 \xrightarrow{\text{Nitrosomonas}} NO_2 \xrightarrow{\text{Nitrobacter}} NO_3$$

10.3 **Disinfection**

Disinfection is to kill microorganisms present in water. Chlorination is the most common method of disinfection. Chlorine, chlorine dioxide, chloramines calcium hypochlorite, sodium, UV light and ozone can be used for disinfection. UV is a disinfection method that uses 254 nanometer ultraviolet to kill microorganisms. UV disinfection plant is much more economical compared to Chlorination or Ozonation.

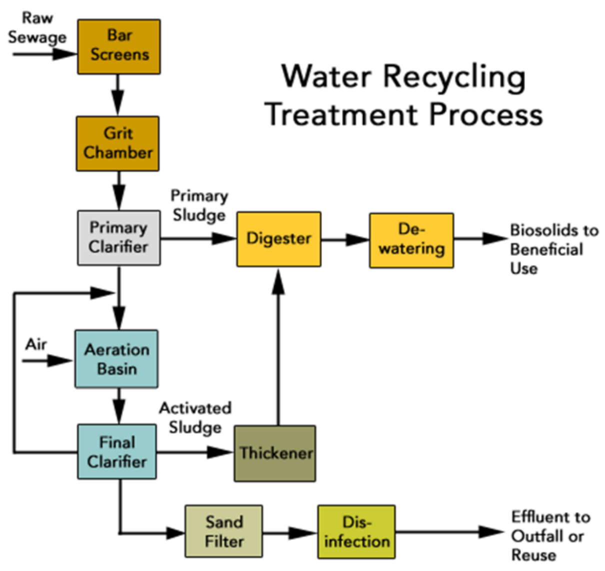


Figure 10.3 Wastewater Treatment system

http://alfa-img.com/show/tertiary-wastewater-system.html

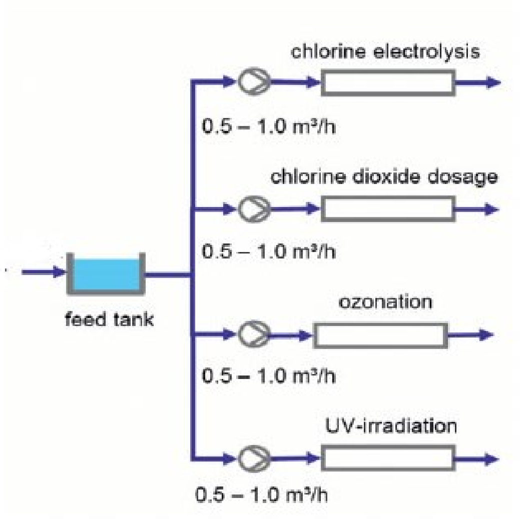
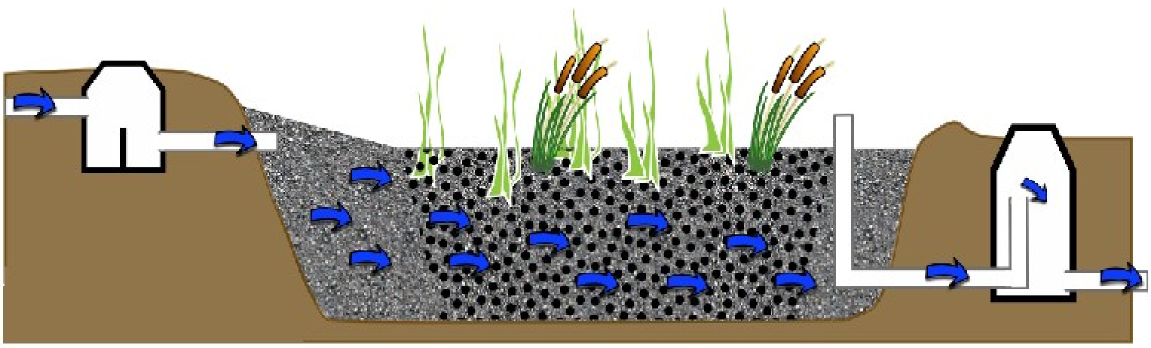


Figure 10.4 Disinfection systems

http://ressourcewasser.fona.de/

11 NATURAL WASTEWATER TREATMENT



Natural treatment is the process that happens spontaneously in the nature and without human intervention or use of mechanical equipment or chemical compounds. Wastewater treatment may happen when wastewater enters to the surface water such as rivers and seas or when it penetrates into the groundwater.

In natural treatment, all types of treatment are usually used including aerobic biological treatment in rivers and seas, anaerobic treatment in wastewater disposal wells, and chemical treatment through oxidation or disinfection.

The most important type of natural treatment is biological treatment with help of aerobic and anaerobic bacteria. In addition to these bacteria, some small unicellular bacteria and multicellular organisms including algae and fungi help natural treatment.

Wastewater treatment with the help of aerobic bacteria takes place in two stages: oxidation of carbon-containing compounds that is followed by oxidation of nitrogen-containing compounds. In both stages, the amount of oxygen dissolved in wastewater decrease.

The less the amount of dissolved oxygen in wastewater is, the lower the ability of wastewater will be in absorbing oxygen through its contact with air to compensate for the deficiency of oxygen and to reach the saturation state. The rate of oxygen absorption, and the time required to correct oxygen shortage, vary depending on the type of water stream and on its surface area that is in contact with air. Moreover, recovery of oxygen dissolved in water is influenced by the presence of aquatic plants such as algae (and the consequent photosynthesis) and by sunlight.

The minimum amount of dissolved oxygen in water that is required for aquatic animals, especially fish, is 3-4mg/l.

Since surface water resources usually contain more oxygen than the amount required by aquatic animals and fish, these water resources can cause rapid reproduction of aerobic bacteria in wastewater. These bacteria will then treat the wastewater.

Of course, considering what was said above, and in order to maintain a healthy environment for fish and keep human environment clean, this natural and spontaneous wastewater treatment must be used cautiously and on a limited scale.

The mentioned natural treatment includes oxidation of unstable organic matter to nitrates and sedimentation of suspended solids in the natural bed. In addition, presence of dissolved oxygen in water and ultraviolet rays which is in sunlight cause disinfection of wastewater.

Natural treatment reduces the amount of oxygen dissolved in water. This oxygen deficiency will be corrected through contact of water with air. Depending on natural factors, several days may be needed for the lost oxygen to be replaced. Wind currents that generate waves on water surface, land slope that causes water flow in rivers, riverbed topography that causes turbulent flow and, finally, water temperature and depth in the natural resource, all influence the rate of oxygen recovery. Presence of oils and petroleum products on water surface and/or frozen water surface greatly reduce oxygen absorption.

11.1 Discharging wastewater into the rivers

Depending on their volumes, flow rates, degrees of turbulence, and water temperatures, rivers have a limited treatment capacity.

If wastewater is discharged into rivers without considering and calculating their treatment capacities, environmental pollution may occur. Uncontrolled reduction of dissolved oxygen in water may happen and hence fish living in them may be endangered.

11.2 Discharging wastewater into the seas

At first glance, it seems that seas and oceans, because of their vast sizes, are able to absorb any quantity of wastewater and treat wastewater by their power of natural treatment. But dumping wastewater into seas may pollute seashores, coastal cities, swimming locations, and fishing grounds. Moreover, this will reduce the amount of oxygen dissolved in water of seas, which results in the death of aquatic animals, especially fish, generation of unpleasant odors, and even the spread of various diseases.

Following points, must be considered if wastewater is discharged into the lakes and seas:

(1). Increases in water salinity will reduce the amount of oxygen dissolved in water, which will reduce the capacity of seas and lakes for natural treatment.

(2). Specific gravity of water in free seas is close to 1.03, while the specific gravity of wastewater is about 0.99g/cm^3. This difference keeps the wastewater on sea surface and prevent it from mixing easily with seawater. Therefore, wastewater must be injected into the seas at depths of at least 3-4 meters.

(3). Wind direction and intensity on different days of the year and, hence, direction of wave movement and seawater movement must be considered accurately based on data of several years.

(4). Intensity and direction of marine currents, which are the characteristics of any sea and cause movement of wastewater, must be accurately studied and determined.

(5). In relation to lakes, in addition to the above-mentioned points, water balance and probable changes in water quality must be examined.

11.3 Discharging wastewater into the natural lagoons.

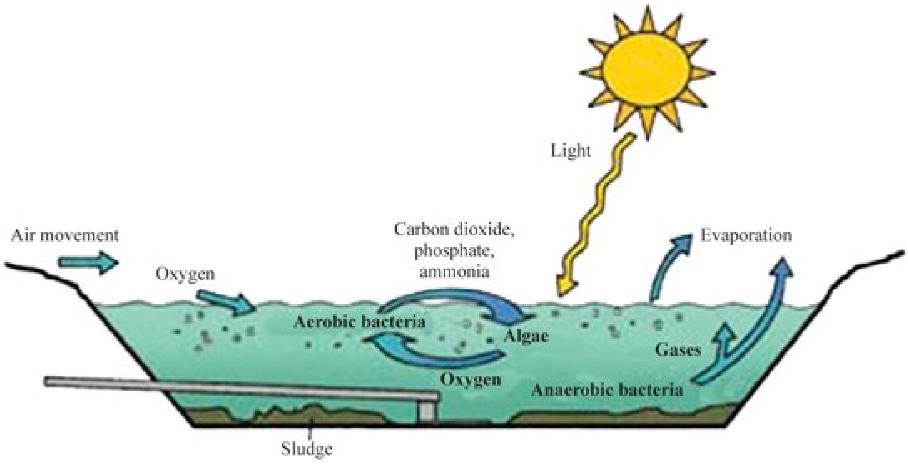


Figure 11.1 Processes occurring within a wastewater lagoon

http://extensionpublications.unl.edu/assets/html/g1423/build/g1423.htm

Shallow lakes where aquatic plants grow are usually called lagoons. Growth of plants such as water hyacinth, duckweed, and various types of rush and moss cause aerobic bacteria to gather on stems and bodies of these plants and decompose the organic matter in wastewater. Considering natural lagoons are often used to protect habitats of birds and aquatic animals, their capacity for natural treatment is very limited.

11.4 Discharging wastewater to the ground

Wastewater may be dumped to the ground for two purposes: natural treatment and irrigation in agriculture. Here, the first purpose is studied. In this method of natural treatment, thin layers of wastewater are spread on the surface of non-arable land, aerobic bacteria carry out the necessary treatment because of the exposure of the wastewater to air and sunlight, and the water remaining after evaporation following this treatment infiltrates into the ground and joins groundwater.

The necessary requirements for this method to be practical are loose and unfilterable soil, deep water table (minimum depth of 3 meters), low rainfall in the region, and abundance of non-arable land near cities. Far locations increase the costs of wastewater transfer.

The most important risks of this natural treatment are environmental pollution, such as groundwater contamination, and the spread of various diseases. The mentioned hazards will be increased if these lands are near cities to reduce costs of wastewater transfer.

11.5 **Discharging wastewater into wastewater disposal wells**

This is a traditional method of natural treatment that has been used up to the present time in most parts of some countries. In this method, domestic wastewater, and in some cases together with stormwater is collected by wastewater pipeline networks inside buildings and guided, without being treated, into one or more relatively deep wells. After entering into these wells, anaerobic bacteria digest the wastewater and the volume of suspended solids in it is substantially reduced. The excess wastewater then infiltrates into the soil and joins the groundwater. These bacteria release foul smelling gases on the one hand and deposit mineral materials at the bottom of the wells on the other hand.

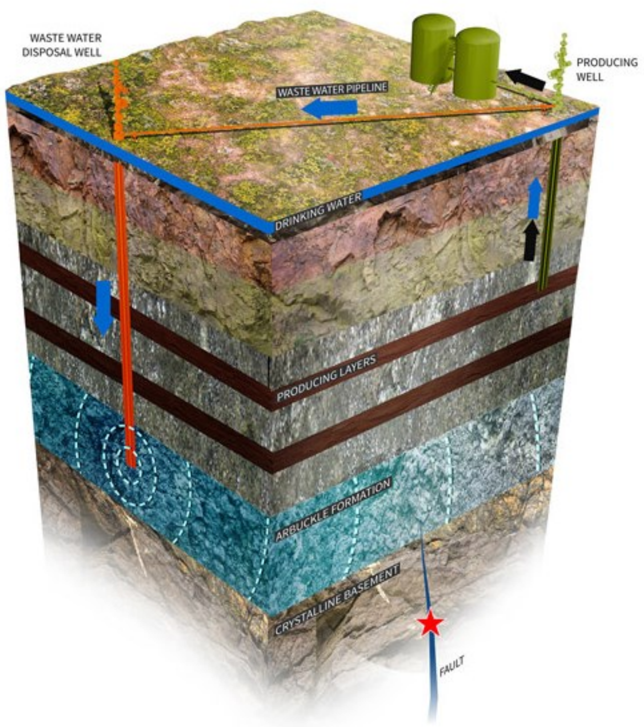


Figure 11.2 Wastewater disposal well

http://news.stanford.edu/2015/06/18/okla-quake-drilling-061815/

Advantages and disadvantages of the wastewater disposal wells:

This method is the simplest, cheapest, and most harmless method of natural treatment if wastewater has a small volume and be limited to a few households, the soil reaches an unfilterable alluvial layer at relatively low depths (maximum of 20 meters), the water table is at least 3-4 meters below this layer, and the groundwater is not for daily uses.

11.6 Stabilization ponds

Stabilization ponds (also called lagoons and waste stabilization ponds) consist of natural or artificial trenches which the wastewater is dumped to be treated naturally by air and sunlight over a relatively long time. Wastewater Stabilization Ponds are large, man-made which wastewater or faecal sludge are treated by natural processes and influence of solar light, wind, microorganisms and algae.

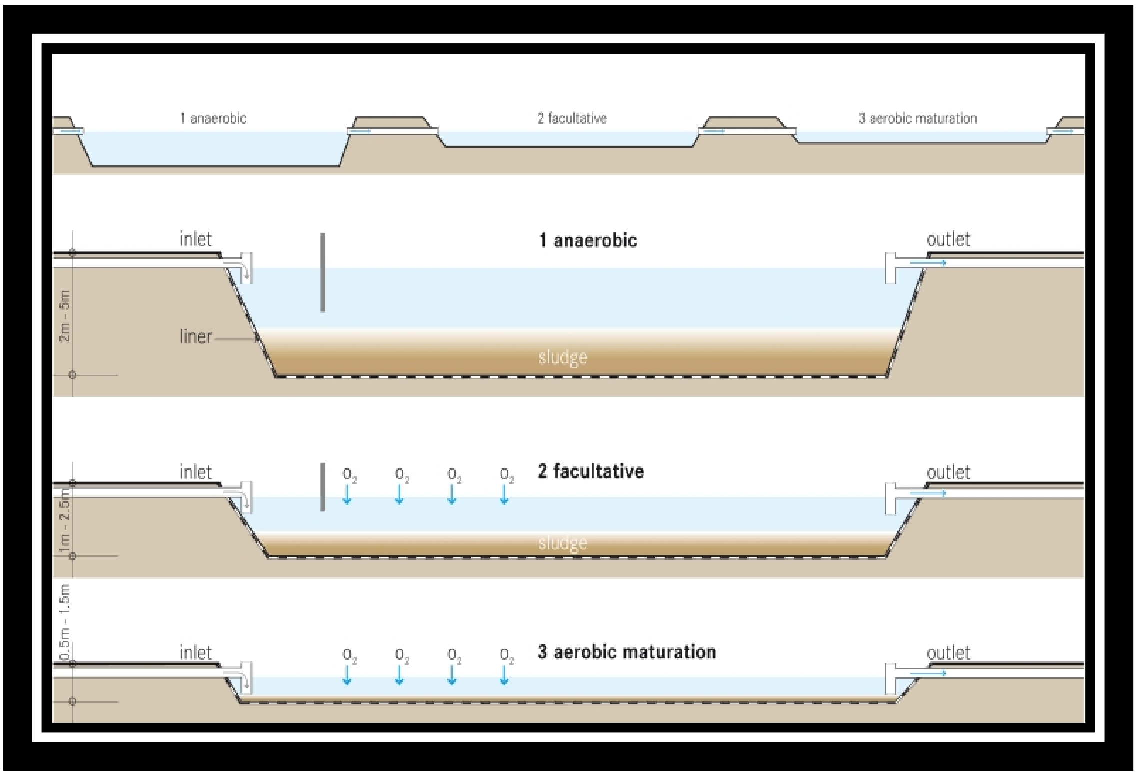


Figure 11.3 Schematic of Waste Stabilization Ponds

http://ecompendium.sswm.info/sanitation-technologies/waste-stabilization-ponds-wsp

The oxygen required by bacteria is provided from four sources:

1. Oxygen dissolved in wastewater
2. Oxygen in the air
3. Oxygen in organic compounds
4. Oxygen produced in photosynthesis by aquatic plants using sunlight

Advantages of stabilization ponds over other artificial methods:

1. Mechanical equipment and specialist personnel are not required
2. Electrical energy and fuels are not used and most of the needed energy is provided by sunlight
3. Establishment of the required facilities is less expensive

Disadvantages of stabilization ponds compared to other methods:

1. There is risk of environmental pollution such as spread of malaria
2. Large land areas are required
3. Wastewater must be transferred for a distance of at least one to 1.5 kilometers from cities, which caused high costs.

Types of stabilization ponds

1. Aerobic stabilization ponds
2. Aerobic-anaerobic (facultative) stabilization ponds
3. Anaerobic stabilization ponds
4. Complementary stabilization ponds
5. Primary stabilization ponds
6. Aerating ponds

11.6.1 Aerobic stabilization ponds

These shallow ponds (0.3-1.5 meters deep) are constructed for aerobic bacteria to grow and for sufficient sunlight to reach the bottom of the ponds so that aquatic plants can grow and generate oxygen to help aerobic bacteria. Anaerobic bacteria can grow only in a thin layer of sludge that settle at the bottom of these ponds. The aquatic plants must be regularly cut out so that the surface of the ponds be in sufficient contact with air and sunlight. If these plants are not cut, they will gradually die and the ponds will be polluted again with unstable organic matter of the dead plants. The amount of dissolved oxygen in the water of these ponds should be enough for aquatic animals to live in them.

Depending on the wastewater load per hectare of the surface of these ponds, they are divided into the three groups of low load, normal, and productive stabilization ponds.

The suitable temperature for these ponds is 20˚C, so they produce carbon dioxide, aquatic plants, and bacteria. Nitrification takes place in low-load stabilization ponds, and nitrates are added to the list of products of these ponds.

11.6.2 **Aerobic-anaerobic (facultative) stabilization ponds**

These ponds are 1 to 1.5 meters deep. Aerobic bacteria grow in the upper layer of these lakes and use water oxygen which is generated by photosynthesis activity of aquatic plants and dissolved in water.

Anaerobic bacteria are active in the lower part of these ponds close to the bottom where sludge is formed.

In the middle part of these lakes, facultative bacteria carry out wastewater treatment. They can survive by using oxygen dissolved in water and, if there is no oxygen, are able to absorb oxygen present in organic compounds through decomposing and reducing them.

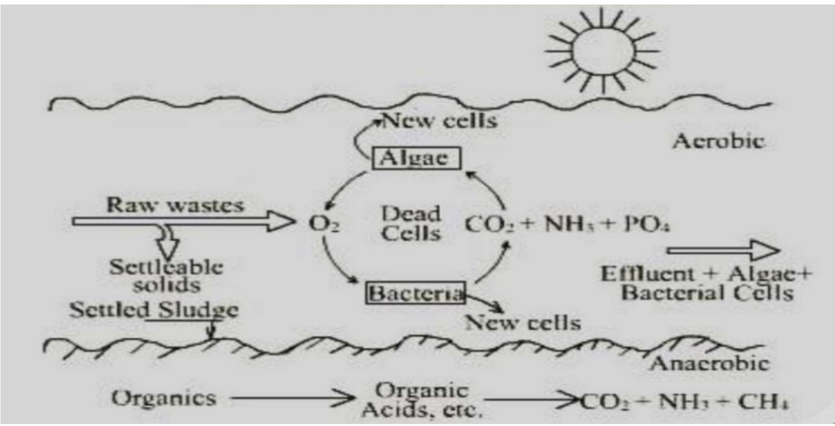


Figure 11.4 Facultative stabilization ponds

http://stabilizationponds.sdsu.edu/

11.6.3 Anaerobic stabilization ponds

Because of the greater depths of these ponds (2.5 to 5 meters), anaerobic bacteria are more active in them. These ponds are deep so that oxygen in the air cannot penetrate into wastewater and growth of plants is prevented to allow anaerobic bacteria to do their job well.

The main shortcoming of these ponds is their strong odor, and this odor will only decrease if the water in these ponds is alkaline and methane fermentation takes place in them.

Sudden changes in temperature or in amounts of salts in wastewater, and presence of toxic materials in wastewater can return the alkaline state to the acidic one and generate strong and unpleasant odors. These ponds are mostly used to treat sludge. If they are used to treat wastewater, it is better that wastewater enters to facultative stabilization ponds so that the final treatment of wastewater can take place with the help of low-load aerobic stabilization ponds. Most of the suspended solids present in wastewater in anaerobic stabilization ponds are deposited and the obtained sludge is treated and stabilized after several months.

11.6.4 Complementary stabilization ponds

These ponds are used for complementary treatment and clarification of wastewater when its primary and secondary treatment has already been carried out. Complementary stabilization ponds are 1.5 meters deep and wastewater retention time in them is 5-20 days.

11.6.5 Primary stabilization ponds

These ponds are only used for preliminary treatment that usually ends with a simple deposition. Therefore, the wastewater that leaves these ponds must be treated again in subsequent ponds.

Figure 11.5 Carlton city sewage is treated in a sanitary lagoon treatment facility located approximately 1.6 km west of the city limits. After being treated water is released into the North Yamhill River.

http://www.ci.carlton.or.us/public-works-sewer

11.6.6 **Aerated ponds**

Using mechanical aerators or blowing air into wastewater intensifies the treatment process. The depth of these ponds can be 2-4 meters and, as in aerated tanks, about 15-30 watts are required for complete mixing of every cubic meter of wastewater in these ponds. Most of this energy is used for mixing the wastewater and only a small part of it for biological actions.

11.6.7 **Artificial wetlands**

These shallow ponds (10-60 centimeters deep) can be used for complementary treatment of wastewater. Artificial wetlands are constructed to improve the environment and create a balance in the living conditions of animals and humans.

Artificial wetlands have the same treatment characteristics that were described for natural lagoons with the difference that it is easier to control the quality of wastewater leaving artificial wetlands. Wastewater that has already gone through at least thorough secondary treatment permanently enters a number of ponds or parallel shallow channels (artificial wetlands). The bottom of artificial wetlands must made of impenetrable or very slightly penetrable material, and usually an impenetrable layer of gravel is laid at their bottom to support roots of aquatic plants and help their sustainability. The layer of gravel that supports plant roots is thicker in some artificial wetlands so that wastewater flows in it and on the surface of the ground. Treatment takes place when wastewater moves slowly and gets in contact with stems and roots of aquatic plants and aerobic bacteria become active. After some time, the surface of artificial wetlands is covered with aquatic plants, free water surface and, finally, turns into green islands.

Figure 11.6 Artificial wetlands near Augusta's Bush Regional Airport

http://srel.uga.edu/outreach/snapshots/wetlands_birds_airports.html

Advantages

1. Low maintenance cost

2. Good efficiency in reducing concentrations of organic pollutants and suspended solids

3. Creation and improvement of natural habitats for aquatic animals and plants

Disadvantages

Large area of required land (about 4 hectares for every liter per second of incoming wastewater)

12 CONCLUSION

After studying all different wastewater treatment methods and solutions, it is still not easy to choose only one method for the whole global, because each country and each region depending on their geographical, political and financial situation have different preferences about the choosing of treatment methods, or even about the choosing between plants or individual systems. For example for some small European country with high density of population it is not easy to have very large treatment plants or to have large stabilization ponds. Or for a country like Finland that has a long winter and price of energy is high maybe it is difficult to have any kind of outdoor treatment facilities.

But by looking at the future problems that may arise in the future like increasing the price of energy, increasing the population or increasing the immigration from developing countries to developed countries it seems using very large wastewater treatment plants because of using more energy and occupying vast space are not very economically affordable. In some countries with high population and small area it is not possible to build huge wastewater treatments between people’s houses.

So in this situations and in these countries maybe having smaller treatment plants or using individual systems or small size plants for each high raised building or each residential complex can be good solution. For sure there will be still wastewater treatment plants in future but by using induvial systems and small size plants we can decrease the entering load to the large plants.

In some countries like my country, Iran, or USA where the price of energy is not as high as Europe and there is not very harsh winter in all their parts maybe using large treatment plants or outdoor ponds are still reasonable.

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