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Evaluating the Performance and Efficiency of CYCLATOR: A New Wastewater Treatment Technology based on Sequencing Batch Reactor

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The volume of wastewater generated is increasing with the rapid development giving the opportunity for new industries to expand. The rising population is one of the other important factors which directly proportionate with the quantity of discharge of wastewater. In the early 20th century, when environmental laws were slowly introduced, no laws existed to regulate the discharge of wastewater. However, with the economic development and the resulting negative impacts on the environment, laws on the environment were enforced and became important. The treatment of wastewater to achieve safe levels was difficult in older times. This is because the early technology allowed to treat one or two contaminants at a time and allowed other major contaminants to flow in the environment. Discharge of harmful and hazardous chemical and bacteriological contaminants present in the wastewater posed a big problem. Some of the effects of releasing the wastewater in the water bodies or rivers are degradation of the quality of water, decline in the population of aquatic plants and animals, eutrophication or algal bloom and waterborne diseases impacting the health of people. This thesis focuses on the newly developed technology called Cyclator (which is based on the sequencing batch reactor) to treat the wastewater efficiently and safely disposing of the wastewater in the environment. The samples were collected from the treated effluent of Cyclator and compared with the discharge standards to check the compliance. The results showed all the parameters were under the compliance of discharge standards and Cyclator is efficient in treating the wastewater.

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Keywords: Wastewater, Treatment, CYCLATOR, Nutrients, Biological oxygen demand, pH

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1 Introduction

The rapid development and industrialisation along with increasing population and urbanisation over the last 50 years have led to many environmental problems. Industries are producing the products continuously to meet the ever-growing demand of people. However, the high production rate from industries has resulted in the generation of many streams of waste including wastewater.

Improper management and inefficient treatment of wastewater cause problems for humans, animals and the environment. In many developing countries, the wastewater effluent is discharged into the rivers, lakes and coastal areas without any treatment resulting in the degradation of the quality of water and further impacting the aquatic life (Edokpavi *et al.* 2017). Some of the countries have adopted strict laws to meet the effluent criteria before discharging the wastewater on land or river. For example, India has established different discharge standards for land and river. However, the enforcement laws itself are not enough to improve the condition of the environment and the role of technology in treating the wastewater efficiently plays a pivotal role.

Water is being continuously exploited by humans considering it as the unlimited source. Many communities depend on raw water and freshwater. The raw water from the water bodies after treatment is used for drinking purpose and in some rural areas the raw water serves as the purpose of domestic water. Farmers either rely upon surface water or groundwater for the irrigation of their field. The livelihood of fishermen depends on the clear and good quality of surface water in which fish could survive and flourish. The clean surface water also attracts tourists for recreational activity. The pollution of surface water begins when the raw or partially treated sewage enters it. Therefore, protection of water bodies is necessary not to just preserve its beauty but to safeguard the livelihood of some people who are dependent on it.

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Disposal of wastewater on the land leads to percolation of contaminants present in the wastewater contaminating the groundwater (Yakubu 2017). The groundwater is extracted and further used for the drinking purpose, hence causing various diseases. Generally, the wastewater is composed of nitrates, ammonia, sulphates, phosphates, total dissolved solids, suspended solids, BOD (biological oxygen demand), COD (chemical oxygen demand) and heavy metals.

1.1 Research Objectives

Recently, a wastewater treatment technology was developed by the company UTB Envirotec which is called as Cyclator. The Cyclator uses the combined concept of sequencing batch reactor and activated sludge and simultaneously treat the wastewater continuously (without any intermittent process). The research investigates two questions:

- To determine how efficiently Cyclator treatment system works and how much is the removal efficiency of the contaminants?
- To check and compare the treated effluent from Cyclator with the discharge standard of wastewater. Is it in compliance with the discharge standards?

To achieve these aims and objectives, I collected the samples from the wastewater treatment plant, conducted laboratory experiments on various important parameters, analysed and interpreted the results. A more details about the method and research approach used is discussed in the methodology section.

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1.2 Global Water Situation

70% of the planet is covered with water however only 2.5% is the freshwater available (National Geographic). Every sector including industrial, commercial, agricultural and domestic is dependent on the freshwater leading to water stress. The availability of freshwater is one of the major problems the world is facing presently and approximately one-third of drinking water is acquired from the canal, lakes and river (Jonnalagada and Mhere 2001). The freshwater sources in South Africa have been contaminated through wastewater discharge (Tukura *et al.* 2009). Some areas of South Africa are dependent on the untreated water from the surface water bodies and are at risk of water-related diseases.

Water is a limited source which needs to be protected and preserved in terms of quantity and quality. The population is rising, however, the water sources are depleting. Less rainfall and depleting groundwater have worsened the situation in many parts of the world. "One of the Millenium Development Goals is to halve, by 2015, the proportion of people without sustainable access to safe drinking water and sanitation. Although food security has been significantly increased in the past thirty years, water withdrawals for irrigation represent 66 % of the total withdrawals and up to 90 % in arid regions, the other 34 % being used by domestic households (10 %), industry (20 %), or evaporated from reservoirs (4 %)" (Shiklomanov 1999).

Since the 1990s, the water pollution in the rivers of Asia, Africa and Latin America has worsened. The degradation of the quality of water in the river poses a threat to human, environment and sustainable development. The lower income and less developed countries have witnessed the absence of stringent laws regularising the wastewater discharge on river and land and have been observed to boldly release the contaminated effluent in the environment. Consumption of river water or groundwater which has been contaminated by wastewater directly or indirectly has caused many diseases to the poor people of developing countries.

The developed countries have adopted stringent environmental regulation and continuous monitoring of effluent has helped them to achieve clean and clear water bodies free from any contamination. Enforcement of environmental laws and implementation of clean

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technology in the field of wastewater will help to revive the surface water bodies (Gregory 2011). The advent of new technologies for waste management and awareness among people have further contributed to achieving their targets of protecting the water. Waterborne diseases have also reduced significantly in developed countries. Developing countries do have some enhanced wastewater treatment system however many areas are having the obsolete treatment technology which is not working properly or partially treating the wastewater. Some of the other problems associated with these plants are poor maintenance, high intake of energy and poor designs. In rural areas, no wastewater management system is present and the wastewater is simply dumped in surface water posing a high risk to the health of local people and danger to biodiversity.

Climate change is another factor playing an important role in disrupting the water cycle. The rainfall pattern has changed and the wet region is becoming wetter and dry areas are becoming dryer. At such a high demanding rate for quality water, we cannot afford to pollute the water sources. Many parts of the world rely on the untreated water for the drinking purpose and some do not even have access to water. This is attributed to the inadequate water supply system and authorities have been negligible and lenient towards the welfare of society, especially in rural areas. The ease of accessibility of surface water makes it convenient for the industries to discharge the wastewater.

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1.3 Surface Water Quality

Quality of water can be determined by checking its physical, chemical and biological characteristics which confirms that the water can be used for various purpose and is suitable for the aquatic life to survive (South African Water Quality Guidelines 1996). Each aquatic organism has the potential to adapt itself according to changes in water quality through the process of dilution (Dallas *et al.* 1998). Introduction of contaminants in the surface water through the discharge of wastewater or some other source decreases the buffering capacity of the river leading to the main problem of water pollution. Water quality is generally affected naturally and anthropogenically. The natural reason could be attributed to change in water quality with change in places, climate change, changes in season and erosion of rocks and soils through which water flows (Water Quality Management Series Guideline 2002).

Anthropogenic reasons are a discharge of untreated industrial effluent, mining activity, the connection of sewage lines to waterbodies, expansion of urban areas and construction work which degrades the quality of water and converting it into contaminated unusable water (South African Water Quality Guidelines 1996).

Advanced and efficient treatment technology is needed to treat high polluted water. The treatment cost increases with a decrease in water quality or highly contaminated wastewater. The utilisation of low-quality water in agriculture could affect the quality and productivity of crops (Ebrahimi *et al.* 2011). Low-quality surface water can be composed of various organic compounds and heavy metals which are detrimental to human health. The contaminated water also contains pathogens which can affect the aquatic life and the wildlife which uses it for drinking. Analysis of quality of water generally involves, physical parameters (temperature, colour, taste, total dissolved solids, turbidity, electrical conductivity), chemical parameters (BOD, COD, pH, organic pollutants) and biological parameters (faecal coliform and total coliform) (Rainwater Harvest.co.za. Water Quality & Water Quality Management in SA 2010).

1.4 Importance of Wastewater Treatment

Wastewater comprises of water which comes out from the home and industries including surface runoff which needs to be treated prior to its release in the environment in order to safeguard the health of public and prevent environmental pollution. The objective of wastewater treatment is to prevent any harm from contaminated water to public health, aquatic

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life, wildlife and simultaneously averting environmental degradation by treating the wastewater to safe levels and disposing of properly. One of the benefits of wastewater treatment is the reuse of the treated effluent in the irrigation field helping to conserve the water resource and solving the problem of water scarcity in the vulnerable area. In ancient times, there was no system of wastewater management (Sofroniou and Bishop 2014). The wastewater from the house was discharged through the pipes mixing along with gutters and finally ending in lakes and rivers. During that time, people were completely relying on the dilution process of wastewater and were using the river water. However, the population density during that time was low as compared to present times.

Sudden population growth and industrialisation led to high generation of wastewater channelling it to surface water bodies. Disposal of wastewater directly into rivers has led to the problems of eutrophication, fish kills and waterborne diseases. It becomes obvious to implement advanced treatment technology to conserve the environment and for sustainable development. Conventional wastewater treatment plants were initially designed to check common parameters such as total suspended solids, biological oxygen demand (BOD) and chemical oxygen demand (COD) (Ratola *et al.* 2012). However, later it was observed that wastewater contains many other hazardous organic contaminants and therefore additional new technology would be required.

Depending on the type of influent received in the wastewater treatment plant, the treatment process is decided. The quality of wastewater plays an important role in selecting the treatment method. The treatment process of influent received from domestic and agriculture are easy and achievable. However, the industrial wastewater contains various type of organic contaminants which are difficult to be treated. For example, it was observed that industrial influent containing persistent organic pollutant and pharmaceuticals have the same

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concentration of contaminants pre and post-treatment. Therefore, new technologies are being invented to face these challenges and to make the treatment system more efficient.

From the health point of view, bacteria and pathogens present in the wastewater pose danger to the health of pregnant women, babies and small children. It was discovered that many wastewater treatment plants in South Africa are not able to achieve the discharge standards and dispose of their wastewater in the streams nearby village where people are dependent only on this source (Ogola *et al.* 2009). Pindihama *et al.* (2011) found that the shortage of manpower, poor maintenance and the poor state of the plant could be the reasons for inefficient treatment. Waste stabilisation pond has been more effective than conventional treatment plant in the remote and rural areas as they are easy to design and operate and do not require much maintenance (Phuntsho *et al.* 2008). The storage capacity of wastewater treatment plants also limits the volume of wastewater treated and causes it to flow on surface soil and river, worsening the situation during monsoon and rain.

Weber *et al.* (2006) discovered the presence of a wide range of emerging contaminants even after the conventional treatment. The contaminants which were present included polyaromatic compounds, pharmaceutical and pesticides. Micro-organisms have been the focus of removing from the wastewater ignoring the other toxic pollutants and heavy metals which also impacts the health (Wastewater Management, a UN-Water Analytical Brief). Application of wastewater containing untreated pollutants such as heavy metals and persistent organic pollutants (POPs) for irrigation could lead to the bioavailability of pollutants for plants and animals and ultimately end up in the food chain (Stojić *et al.* 2018).

. The toxic heavy metals could leach into soil and can be uptake by plant roots leading to accumulation of these metals into edible and non-edible parts. The consumption of the plants (especially crops) can result in a potential hazard for the health of humans and animals. Since

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the heavy metals are non-biodegradable, it can easily accumulate into the plants (Van Assche and Clijsters 1990). The most identified way of heavy metal entering the human body is through the bioaccumulation of metals in the food chain. Crops which are grown on soil irrigated ill-treated wastewater have been the cause of several diseases.

1.5 Environmental Impact

Generally, the concentration of pollutants is high at the entrance of discharge of wastewater however it decreases with the distance. These pollutants once released into the environment are difficult to remediate as they persist over the long period of time. The effect of ill-treated wastewater on surface water bodies could have an acute and cumulative impact. The acute impacts depend on the presence of toxic elements like chlorine, heavy metals and oxygen-demanding organic compounds. The cumulative impact is a gradual increase in contaminants and is realised when the threshold is exceeded. Temperature range also plays an important role in the suitable habitat of aquatic organism (Weber *et al*. 2007). Deviation from the appropriate temperature range can impact their reproductivity, slow down their growth and can result in a short life span. The discharge effluent from the treatment plant also reduces the dissolved oxygen of surface water as the bacteria feed on organic pollutants by consuming oxygen. For the good quality of water in which aquatic life can survive and flourish, the dissolved oxygen is estimated to be 8-10 mg/L (Watson *et al.* 1985). The depletion of dissolved oxygen can have a drastic impact on aquatic life and thus oxygen balance in the water bodies plays a significant role in maintaining a suitable environment for the aquatic animals (Ozbay *et al.* 2014).

Biological oxygen demand (BOD) and chemical oxygen demand (COD) have been identified as key factors to determine the toxicity and quality of wastewater (Mamun and An 2018). Low BOD and COD values signify good quality and high values relates to bad quality

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of wastewater. Usually, the BOD/COD ratio is very less in the surface as compared to wastewater. The concentration of BOD and COD has an inverse relationship with the amount of oxygen dissolved (Wahyuningsih *et al.* 2010). The introduction of nutrients such as nitrates nitrogen and phosphorous in the water bodies could result in eutrophication. The wastewater which is rich in these nutrients is the potential threat for the receiving watershed. Excess amount of the nutrients leads to algae bloom and high biomass of plants. The new wastewater treatment plants are being developed which are capable of treating these nutrients before discharging it into rivers.

1.6 Health Impact

Wastewater has been observed to contain many types of pathogens which could adversely impact human health. In terms of number, 1400 species of pathogens exist and some of them are protozoa, bacteria, fungi and viruses (Woolhouse and Sequeria 2005). Diseases caused by these pathogens have been responsible for 25% of death worldwide (Trebi 2017). Health impacts from the use of water contaminated with wastewater occur very fast as compared to environmental impact. Some of the pathogens which exist in wastewater are described in Table 1.

Table 1: Pathogens generally found in wastewater and the diseases caused by them

Pathogen Class	**Examples**	**Disease**
Bacteria	Shigella sp.	Bacillary dysentery
	Salmonella sp.	Salmonellosis (gastroenteritis)
	Salmonella typhi	Typhoid fever

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	Vibrio cholerae	Cholera
	Escherichia coli	A variety of gastroenteric diseases
	Yersinia sp.	Yersiniosis (gastroenteritis)
	Campylobacter jejuni	Campylobacteriosis (gastroenteritis)
Viruses	Hepatitis A virus	Infectious hepatitis
	Norwalk viruses	Acute gastroenteritis
	Rotaviruses	Acute gastroenteritis
	Polioviruses	Poliomyelitis
	Coxsackie viruses	"flu-like" symptoms
	Echoviruses	"flu-like" symptoms
Protozoa	Entamoeba histolytica	Amebiasis (amoebic dysentery)
	Giardia lamblia	Giardiasis (gastroenteritis)
	Cryptosporidium sp.	Cryptosporidiosis (gastroenteritis)
	Balantidium coli	Balantidiasis (gastroenteritis)

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Helminths	Ascaris sp.	Ascariasis (roundworm infection)
	Taenia sp.	Taeniasis (tapeworm infection)
	Necator americanus	Ancylostomiasis (hookworm infection)
	Trichuris trichuria	Trichuriasis (whipworm infection)

Source: Use of Reclaimed Water and Sludge in Food Crop Production (1996)

Wastewater has been responsible for one of the major contributors to water pollution (Akpor *et al.* 2014). Treatment of wastewater becomes vital to prevent the degradation of the aquatic ecosystem and surface water quality. Wastewater treatment plants in the developing countries are in the poor state because of poor infrastructure, obsolete technology, enforcement laws are weak, no monitoring of effluent, overload capacity, corruption etc.

2 Literature Review

2.1 Wastewater Treatment

Wastewater treatment is the removal process of contaminants (such as nutrients which leads to the uncontrolled growth rate of aquatic plant and other pathogens) from the wastewater up to the levels of its safe discharge in the receiving body that will not impact the human health (Metcalf & Eddy 2003). “Wastewater contains reusable water, carbon (energy) and nutrients (nitrogen, phosphorus, and sulfur) that could be recovered or reused (Crawford 2010)”.

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Many treatment methods exist and each treatment technique has its pros and cons. Working principles of some of the treatment methods and general information about wastewater are discussed in the following section.

2.2 Characteristics of Wastewater

The wastewater has basically been categorised into two components: domestic and industrial. The domestic wastewater is also known as sewage and is generally composed of human urine, human faeces, water used in the kitchen, toilet, laundry, wash basin etc. The composition of industrial wastewater is dependent upon the type of industries (Naidoo and Olaniran 2013). As the different industry produces different products, the waste generated is also different. However, the chemical composition of a few industries such as pharmaceutical, chemical and textile could be similar. The composition of wastewater can be physical, chemical and biological. The physical component includes inorganics and solids. Chemical components are nutrients, dissolved compounds and heavy metals. The biological component of wastewater has bacteria, protozoa, pathogens and viruses. Some of the components present in the wastewater and the reasons to remove them are summarised in the Table 2.

Table 2: Components present in wastewater and reasons for their treatment

Components	**Reasons**
Heavy Metals	Industrial wastewater contains heavy metals because of different chemical processes. These can accumulate in plant roots and can get into the food chain. It has also been one of the causes of groundwater contamination.
Pathogens	These can impact human health negatively by transmitting various diseases.

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Nutrients	The main components of nutrients are nitrogen and phosphorous which cause eutrophication in lakes and rivers.
Suspended Solids	Suspended solids have to be removed in the preliminary stage during the settling process and is the reason for formation of sludge.
Biodegradable Organics	Depletion of dissolved oxygen occurs due to the presence of organics.

The quality and characteristic of wastewater can be determined by collecting the samples and conducting its analysis on physical, chemical and biological parameters.

2.2.1 Physical Characteristics

The physical characteristics include turbidity, colour, temperature and odour. These have been summarised below.

2.2.1.1 Turbidity

It measures the transparency of water and the amount of light which could pass through the water. Higher the suspended solids in wastewater more it will be turbid. The wastewater is usually turbid as it contains water from toilets and kitchen waste. The cause of turbidity is the presence of suspended solids, faecal matter, different chemicals, grease etc. Turbidity is a good parameter to check the quality of wastewater by observing it with naked eyes. It can be measured by analysing the sample in turbidity meter or rods. The suspended matter not only responsible for turbidity but absorbs the sunlight and warms the water. Some of the organisms are heat sensitive and cannot survive in it.

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2.2.1.2 Colour

The colour of wastewater can be observed from naked eyes. Wastewater is usually called fresh when its colour is yellow or grey. However, if the colour is black or brown it is most probably stale (Water and Air Effluents Treatment Handbook 2009). Due to other industrial and chemical wastes, there could be another colour also.

2.2.1.3 Odour

The wastewater starts omitting offensive odours with the time as it becomes stale. The fresh wastewater does not emit odours however, within 3-4 hours the oxygen present in it gets depleted and obnoxious smell of hydrogen sulphide can be observed.

2.2.1.4 Temperature

Temperature plays an important role in the treatment process of wastewater (Brehara *et al.* 2019). The biological activity or rate of micro-organism decomposing organic compounds can be controlled by temperature. It also determines the solubility of gases and viscosity of wastewater which is an important factor for the sedimentation of suspended solids. The optimum temperature for the efficient performance of biological activity is 20 ^{0}C. Usually, the temperature of wastewater is higher than the normal water due to the chemical reactivity. The concentration of dissolved oxygen decreases with the rise of temperature (Dissolved Oxygen and Water, USGS).

2.2.2 Chemical Characteristics

Chemical characteristics provide the details about the decomposition rate of wastewater, the strength of wastewater and the type of treatment required for its proper safe disposal.

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2.2.2.1 Solids

Wastewater is composed of 99.9% by water and has solids about 0.005 to 0.1%. This means the solids content is about 500 to 1000 mg/L. Solids can be present in the four forms: suspended solids, dissolved solids, settleable solids and colloidal solids.

Suspended solids are those particles which remain suspended in the wastewater. Dissolved solid gets dissolved like sugar in water. Settleable solids are formed at the bottom of the tank if the wastewater is left undisturbed. Colloidal particles either remain in the solution phase or in suspended form. The size of different types of solids present in the wastewater is shown in Table 3.

Table 3: Size of solids present in the wastewater

Solids	**Size of solids**
Dissolved solids	10^{-3} μm
Colloidal solids	10^{-3} μm to 1 μm
Suspended solids	>1 μm

Source: USEPA, Constructed Wetlands Treatment of Municipal Wastewater (Sept 2010)

Solids are further categorised in organic and inorganic matter (Chan and Wang 2016). Organic matter comes from different sources and can be carbohydrates like starch and sugar, or oil and fats from laundry and kitchen wastes, or nitrogenous compounds like proteins and including hydrocarbons and animal wastes. Example of inorganic matter can be chlorides, sulphates, sand, gravel etc. The presence of inorganic particles in the wastewater does not pose much problem as it is easy to filter them out using physical techniques of separation. However, it is organic compounds which cause a nuisance to the environment if ill-treated and therefore biological treatment is applied.

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2.2.2.2 pH

pH is a measure of the concentration of hydrogen ions in substance (Insel *et al.* 2004). The acidity and alkalinity of wastewater can be determined by the pH value of wastewater. If the value of pH is greater than 7, it is alkaline and pH less than 7 signify it is acidic. The solution is said to be neutral if the pH equals 7. Generally, the fresh wastewater is alkaline however with time it changes to acidic because the bacteria starts its mechanism of decomposing the organic matter and releasing acids. Before deciding the treatment technique, pH is important to measure to implement the technique. pH can be measured by a potentiometer which measures the electrical signal of hydrogen ions.

2.2.2.3 Chloride

Chlorides are generally found in domestic wastewater as they are present in human faeces, urine and kitchen wastes. Ice-cream industries and meat salt industries generate the effluent which has high chloride content as compared to domestic wastewater. High chloride content indicates the presence of industrial effluent or the presence of sea water.

2.2.2.4 Nitrogen

Nitrogen content of wastewater can indicate the presence and the decomposition rate of organic matter. Nitrogen is present in three forms:

a) Ammonia (NH_3)

b) Nitrites (NO_2^-)

c) Nitrates (NO_3^-)

Ammonia indicates the initial stage before the decomposition of organic matter. If the ammonia content is high that means the wastewater is stale. Nitrites are formed during the decomposition and its concentration can indicate the percentage of organic matter left. This is

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also used to observe the progress of treatment as the nitrites are intermediate compound during the conversion of ammonia to nitrates. Presence of nitrates shows that the wastewater has been treated with no organic matter remaining and all the organic compounds have been stabilised and oxidised in the treated effluent.

However, the concentration of nitrates in the final effluent is controlled before its disposal because it can be harmful to the health of a human baby and can lead to nitrate poisoning. The intestine of infants is capable of reducing the nitrates to nitrites. Nitrites have a high affinity with the blood and replace the oxygen. This causes the suffocation in the body because of an inadequate supply of oxygen and the body starts to turn blue. Therefore, it is also known as blue baby disease or methemoglobinemia (Alpha Water Systems Inc.). Once the child is above 6 months, the capability of nitrate-reducing bacteria significantly decreases and thereafter no such diseases occur.

2.2.2.5 Phosphorous

Phosphorous is present in the wastewater either in the form of organic or inorganic (Staukewich 1973). The concentration of inorganic phosphorous is higher than organic phosphorous due to the usage of synthetic detergent. Presence of phosphorous in the wastewater is one of the main cause for eutrophication of lakes and river bodies (Lenntech). Controlling the concentration level of phosphorous in wastewater is an expensive and difficult process.

2.2.2.6 Fats, Oil and Greases

These are formed in wastewater due to the disposal of vegetable or animal products, hotel kitchens and garage. They are light in weight and therefore float on the surface of wastewater and can be problematic as they clog the voids of the filter. It can also reduce the working efficiency of pumps and blowers thus affecting the treatment process.

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2.2.2.7 Sulphides, Sulphates and Hydrogen Sulphide Gas

The decomposition of various sulphur containing matter leads to the formation of sulphides, sulphates and hydrogen sulphide (H_2S) (Metcalf & Eddy 2003). H_2S is an obnoxious gas with a strong odour like rotten eggs and can cause corrosion of sewer pipes. Aerobic decomposition of sulphur containing compounds initially forms sulphides which later convert to sulphates after its oxidation. In the process, H_2S is also released however it is also oxidised and the ultimate product formed is sulphates. Anaerobic decomposition leads to the formation of sulphides along with the release of H_2S, carbon dioxide and methane. If the concentration of H_2S is below 1 part per million (ppm), then the foul smell is not emitted.

2.2.2.8 Dissolved Oxygen (DO)

DO is one of the most important parameters which is measured and can define the quality of wastewater. The minimum DO require for the fish to survive is 4 ppm. Therefore, prior to discharging wastewater in the rivers or streams, it is necessary to ensure that the concentration of DO in wastewater is at least 4 ppm. Fresh wastewater contains some DO. However, with time and aerobic decomposition, the DO gets depleted. The DO also depends on the temperature of the wastewater. Higher the temperature, lesser is the solubility, hence DO present will be less.

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2.2.2.9 Chemical Oxygen Demand (COD)

Organic matter present in the wastewater can be computed by knowing the amount of oxygen required to decompose it completely to water (H_2O), carbon dioxide (CO_2) and other oxidised compounds. If the concentration of organic matter is known then the oxygen required to decompose it can be calculated. Using chemical formulas and balanced chemical reactions, the oxygen content for the decomposition of organic waste can be calculated and is known as theoretical oxygen demand. The organic matter can be biodegradable or non-biodegradable and COD indicates the decomposition of organic matter as a whole. COD tests are done in the laboratory by using strong oxidants like potassium dichromate or potassium permanganate on the sample wastewater. The concentration of oxygen used in decomposition helps to compute the concentration of organic matter present in wastewater.

2.2.2.10 Biological Oxygen Demand (BOD)

As described above, there are two types of organic matter: biodegradable (which can be biologically decomposed by biological bacteria) and non-biodegradable (which are biologically inactive matter and cannot be decomposed simply by bacteria). The amount of oxygen required to decompose the biological active matter or biodegradable organic matter in the wastewater is called as BOD. The COD test (discussed above) was used for total organic matter decomposition.

The aerobic bacteria available in the wastewater will decompose the biodegradable organic matter until all the oxygen are used up. Since the surface wastewater absorbs the atmospheric oxygen, the bacteria can use that oxygen till the organic matter is completely decomposed and this could take months. Therefore, BOD for 5 days at a temperature of 20 ^{0}C is calculated for the standard measurement.

2.2.3 Bacteriological Characteristics

Several types of micro-organisms such as bacteria, fungi, virus, protozoa etc. are found in the wastewater and occur in large numbers. Micro-organism in the wastewater originates from human faeces and urine. They can adapt and survive in any environment from very high to very low temperature and pH. Their minimum requirement facilitates them to grow in extreme conditions.

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Bacteria are single cell organism and exist in various shapes like a straight rod, curved shape, spiral, or spherical. They don't have chlorophyll like plants with which they can manufacture their food themselves. Through binary fission their reproduction process takes place. They are very small in size (1μm to 4μm) and are not visible to naked eyes. Micro-organisms are studied under a microscope. Some micro-organisms like virus are not even observable under a microscope.

Most of the bacteria are harmless to humans and does not affect health. Some of the bacteria are even beneficial to human and animal health and are known as non-pathogens. The bacteria which causes disease or put human health at risk are called pathogens. Similarly, viruses can be pathogenic and non-pathogenic.

Those bacteria which require oxygen for their survival and to decompose the organic matter is called aerobic bacteria. Some bacteria can perform the same activity in the absence of oxygen and are known as anaerobic bacteria. There are bacteria which can survive and flourish with or without oxygen and these are called facultative bacteria.

2.3 Wastewater Treatment System

Wastewater treatment goes through mainly 4 stages: preliminary treatment, primary treatment, secondary treatment and tertiary treatment. In preliminary treatment, the large and medium-sized objects are removed to increase the efficiency of operation and maintenance of the treatment plant. The primary treatment includes the settling tank where the suspended solids and inorganics are removed. The role of secondary treatment is to remove the dissolved or soluble biological organic compounds. In some plants, the tertiary treatment is optional however it is important as it helps to eliminate the nutrients such as nitrogen and phosphorous and also heavy metals. Figure 1 shows the treatment steps in the wastewater treatment plant.

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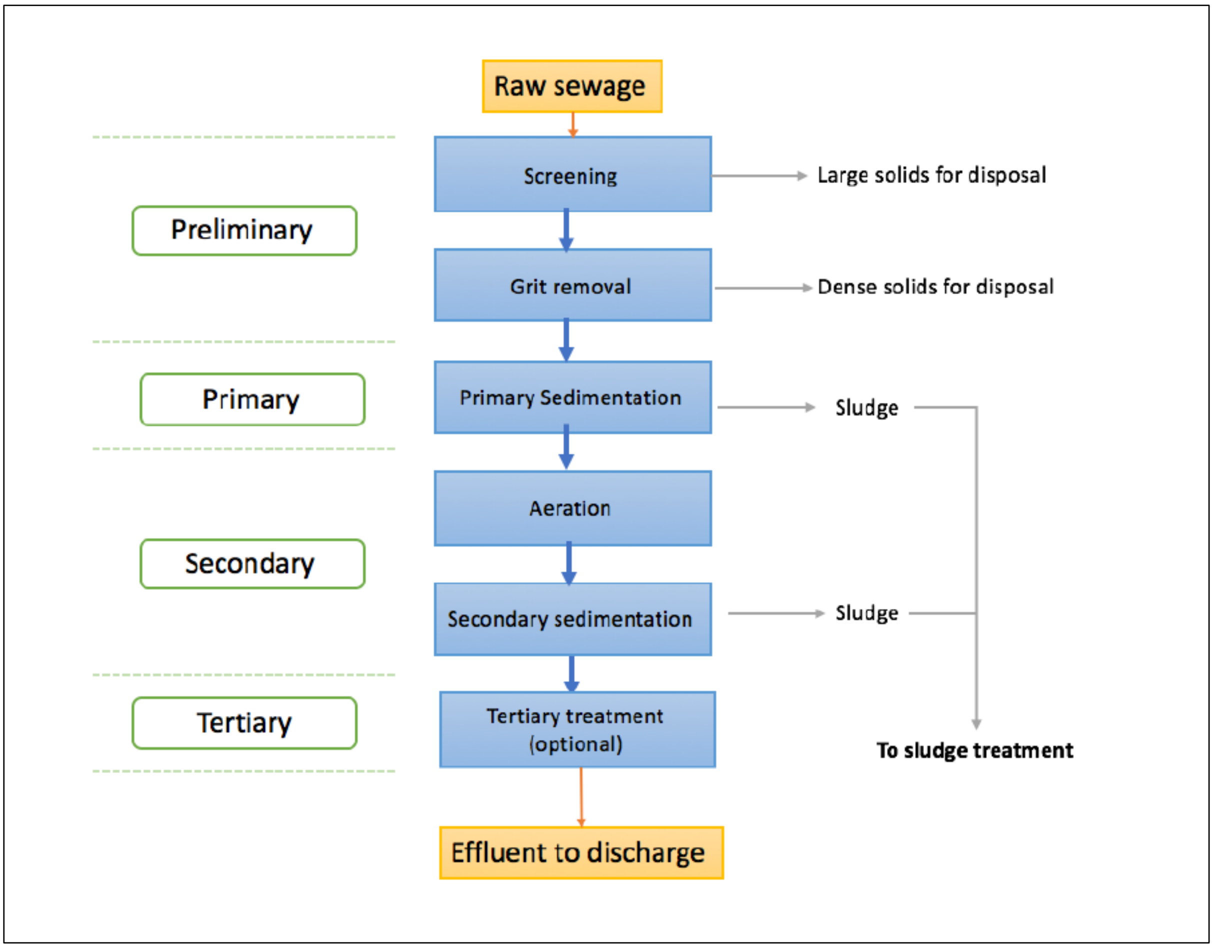

Figure 1: Typical stages in the conventional wastewater treatment (Parr 2002)

2.3.1 Preliminary Treatment

The preliminary treatment is important to protect the equipment and mechanical parts of treatment plant by removing the large object and inorganics which can damage and clog the machine parts resulting into inefficiency and fouling (Davis 2008). The wastes which are removed in this stage are papers, clothes, wood branches, plastics, metals and glass. Screens of three types fine screens, medium screens and coarse screens are used and can be manually or mechanically operated. The inorganics such as gravel and sand are filtered through a grit chamber. These inorganics can easily enter the pump inlet and cause operational problems. Usually, the screens are installed before the grit chambers. Skimmers are used for the removal of fat, oil and grease which are floating on the wastewater. The final waste collected from the

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preliminary treatment has to be cleaned periodically and is disposed of by incineration, landfill or sometimes used as fertilisers in agriculture field.

2.3.1.1 Screens

Coarse screens have the opening size of 50 mm and mostly collect wastes such as paper, rags and woods. These wastes do not putrefy and can be disposed of by burning, burial or dumping.

Medium screens are usually rectangular in shape with the opening size of 6-40 mm. The screens can collect organic wastes which can putrefy and cause a bad smell. Therefore, dumping of these wastes is not recommended and incineration or burial is preferred. The screens are installed at an angle of 30^0 to 60^0 as it slows down the speed of wastewater stream and provides more opening area for the separation. The screens can be fixed or movable. The fixed screens are set in a permanent position. In movable screens, the screen is kept fixed during the treatment process and later it can be lifted for the cleaning process.

Fine screens are provided with the size of 1.5 mm to 3 mm and thus remain effective in filtering small particles. They remove about 20% of suspended solids from the wastewater. The screens collect a large amount of wastes and therefore need regular cleaning to prevent clogging. The screens are effective and are used in the treatment of industrial wastewater. The screen material is made of brass as it has to be resistant to corrosion and rust. Figure 2, 3, and 4 shows a different type of screens generally installed in the wastewater treatment plant.

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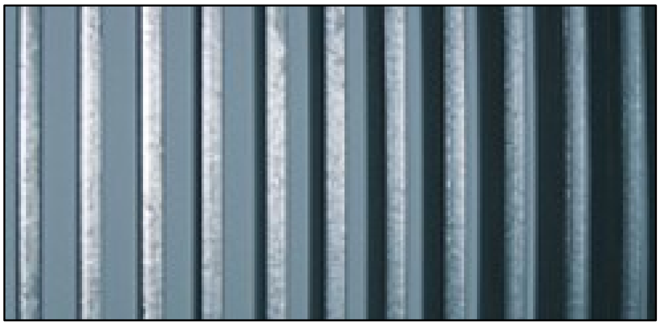
Figure 2: Coarse screen (Source: Huber Technology)


Figure 3: Fine screen (Source: Huber Technology)

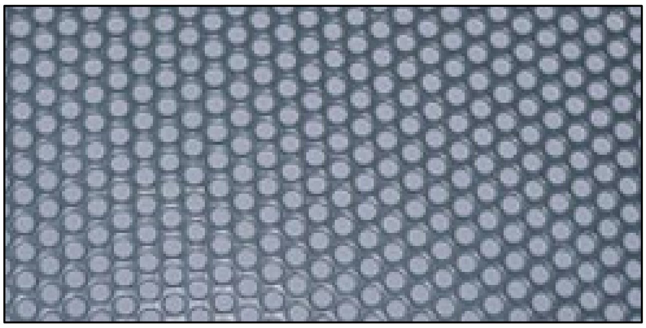
Figure 4: Perforated plate screen (Source: Huber Technology)


Figure 5: Mesh screen (Source: Huber Technology)

The materials collected on screens are called screenings. The composition of screenings is about 85% water and others are floating material. The screenings can be disposed of by incineration, burying or dumping (Gautam, Waste Management). The screenings collected

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from the medium and fine screens are not dumped as stated earlier because these have an organic matter which can decompose and cause a bad smell. Incineration of screenings is done in a similar way as incineration of wastes. However, prior to incineration, screenings have to be dried under the sun and the moisture is reduced up to 60% by using a hydraulic press. The temperature of incineration of screenings is approximately 760 ^{0}C to avoid the smell.

Burial of screenings is also adopted in which screenings are buried in the depth of approximately 1 m and are covered with the permeable soil. After some months, the buried screenings get converted to manure due to redox reaction.

Dumping of screenings (only for coarse screenings) is another method usually adopted for raising the low-lying areas away from the residential colony. Dumping in the sea is done only when the force of the sea current is high and keeps the waste far away from the shoreline.

2.3.1.2 Grit Basins

The grit removal basins or detritus tank (Figure 5) are used to remove heavy inorganic material such as sand, silt, gravel and other non-putrescible materials which can cause abrasion to pump or clog the treatment system or sludge digester. They are generally placed after the fine screens. Grit chambers use the same principal of sedimentation tank and filters out the heavier inorganic particle using the gravitational force.

Figure 6: Overview of the grit chamber (Source: Huber Technology)

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2.3.1.3 Skimming Tank

Skimming tank (Figure 6) is used to remove oil and grease from the wastewater and are employed before the sedimentation tank. Oil and grease can derive from oil refineries, soap and wax industry, candle industries, automobile garages and kitchens of hotels and restaurants. Industrial wastewater has a high amount of oil and grease and therefore skimming tanks are installed mostly in industries. It is important to remove these oily matters because they can defunct some of the machinery of the treatment system. It can also reduce the biological activity of micro-organisms.

The grease and oil in the skimming tank are removed by aerating the tank from the bottom. This leads to coagulation and solidification of greasy matter and the aerated air cause the solidified matter to rise on the surface of wastewater from where it can be easily removed.

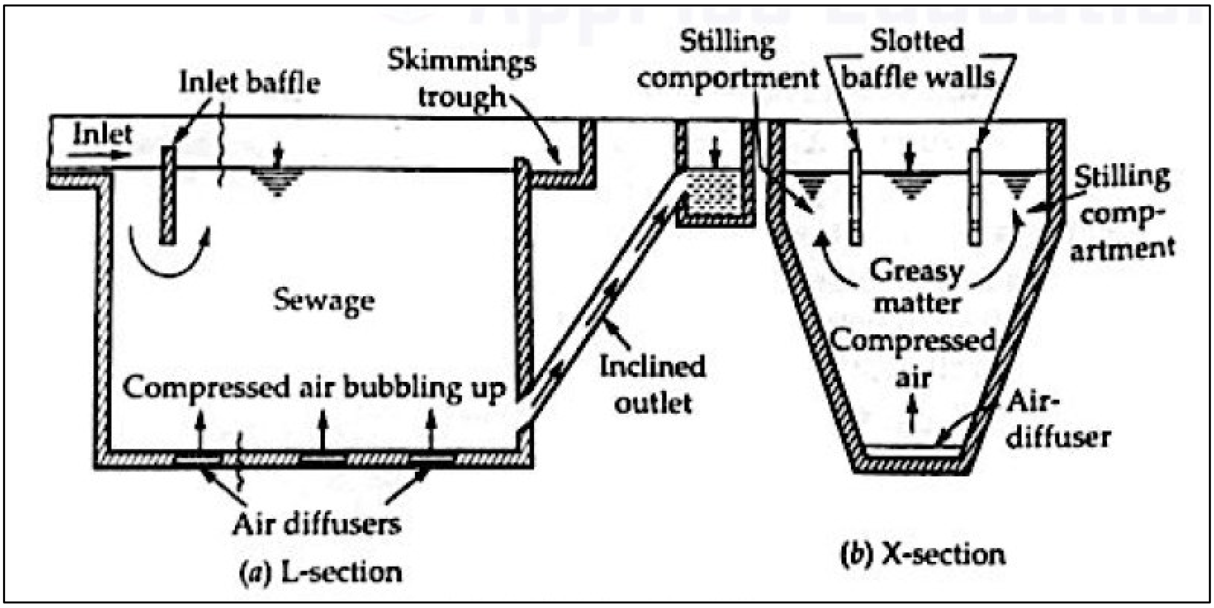

Figure 7: Schematic of the skimming tank (Garg 2012)

Skimmings (oil and grease matter) removed in the skimming tank are disposed of by incineration or by its burial. However, sometimes these wastes can be a raw material for the industries such as soap, candle and non-edible industries. When the skimming contains more vegetable or organic matter and less of mineral oil, it generates fuel of high calorific value.

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2.3.2 Primary Treatment

After the preliminary treatment of wastewater, some of the solids and inorganics are still present in the suspended form. In the primary treatment, wastewater is contained in the large circular or rectangular tank in still/immobilise condition. This helps in the sedimentation of suspended particles to settle down under the force of gravity at the bottom of the tank. The sediments formed are also called as sludge and are removed by scrapers. In this process, 30 to 40 percent of BOD and 50 to 70 percent of settleable solids can be removed (Qasim 1994).

2.3.2.1 Sedimentation or Settling in Wastewater

Sedimentation is a process of settling down of particles under the action of gravity. This is the basic process in any wastewater treatment plant. The wastewater contains inorganic particles which have specific gravity more than water. The inorganic particles in the flowing wastewater cannot settle as the particles are in turbulent motion. The turbulence is reduced by slowing down the speed of wastewater by keeping it in the storage tank.

The sedimentation of particles depends on the following factors:

i) The velocity of wastewater: higher the velocity more will be the turbulence and lesser is the settlement of particles. Increasing the travel length of suspended particles or detaining the wastewater in the basin reduces the velocity and helps in the sedimentation process.

ii) Area of flow: larger area reduces the velocity of wastewater and increases the sedimentation process.

iii) Specific gravity and size of particles: the particles which are more dense or heavy or have specific gravity more than water settles down easily. Adding certain chemical (also known as coagulants) increases the size of suspended particles by attaching it to coagulants and accelerates the settling process.

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iv) Viscosity: viscous wastewater resists the particles to settle. The viscosity can be controlled by the temperature. Warm water has less viscosity and allows the particles to sediment.

Another type of sedimentation is by addition of chemicals such as ferric chloride and ferric sulphate in wastewater which forms gelatinous material. The fine suspended particles get attached to the gelatinous material to form flocs which are larger in size and have specific gravity more than water. The solution is then passed through the sedimentation tank where the flocs settle down. This whole process is called coagulation.

2.3.3 Secondary Treatment

The objective of secondary treatment is to remove soluble organic matter using the biological process. This process requires the use of micro-organism which can feed on organic matter and decompose it to simpler compounds which can be removed as sludge. “The principal objectives of biological treatment are to stabilize the organic matter and to coagulate and remove non-settleable colloidal solids found in wastewater (Crites 1998)”. However, the secondary treatment requires expertise as the conditions such as temperature, type of micro-organism, the surface area of organic matter for the bacteria to feed on, pH, oxygen supplied have to be constantly maintained (Davis 2008). Some of the examples of secondary treatment are activated sludge, sequencing batch reactor, moving bed biofilm reactor, membrane bioreactor and many others. A brief description of these processes has been given below.

2.3.3.1 Activated sludge

Activated sludge process (Figure 7) has two tanks, primary and secondary. In the primary tank, the wastewater is aerated and the bacteria feed on the organic matter. This result in the formation of lumps called flocculation. In the secondary tank, the wastewater is kept in steady condition to allow the flocculated material to settle down. This is called sludge which

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is formed at the bottom of the tank. Some of the sludge formed (activated sludge) is transferred to the primary tank for the same process and therefore this cycle is repeated.

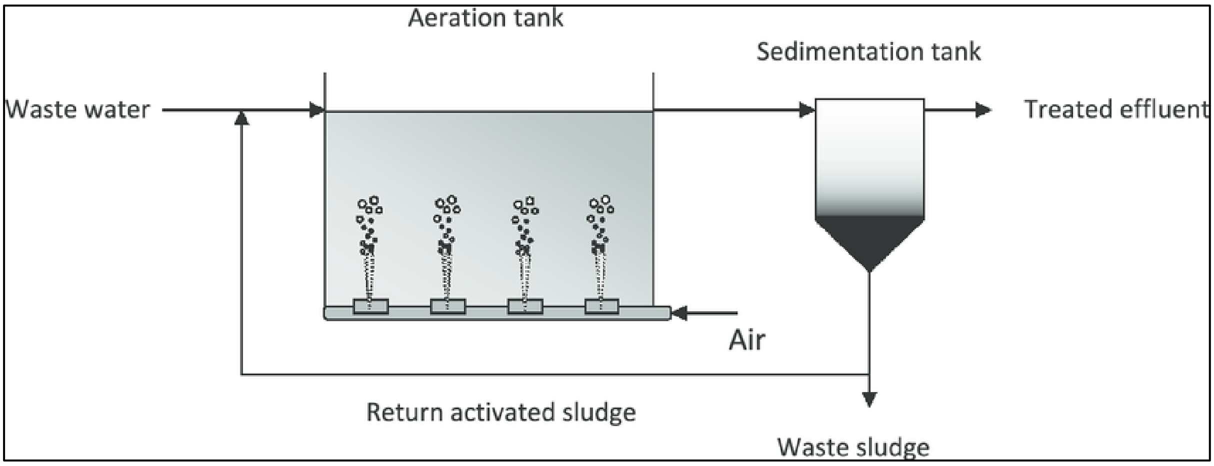

Figure 8: Flow diagram of the activated sludge process (Taylor & Francis 2013)

2.3.3.2 Sequencing Batch Reactor (SBR)

SBR (Figure 8) is a type of activated sludge process and undergoes through five main steps: fill, aeration, settle, decant and idle. In the first step, the wastewater influent is filled in the tank. The second step involves aerating the wastewater in the tank. This is usually carried out by air blowers which are installed in the bottom of the tank. The aerobic bacteria in the presence of oxygen consume the organic matter. In the third step, the decomposed organic matter is allowed to settle/sediment at the bottom. A portion of the sludge formed in the third step is removed and is transferred to the first stage to help increase the population of micro-organisms (as discussed in the activated sludge process). The fourth step decanting helps in the removal of clean and clear effluent from the tank. The excess sludge is drawn in the idle stage and is transferred for sludge treatment.

SBR has been a proven technology in the treatment of organic compounds efficiently. Nutrients such as nitrogen and phosphorous are also removed in SBR. It is costlier to install and operate in comparison to other treatment technologies, however, the maintenance cost is low over its lifetime.

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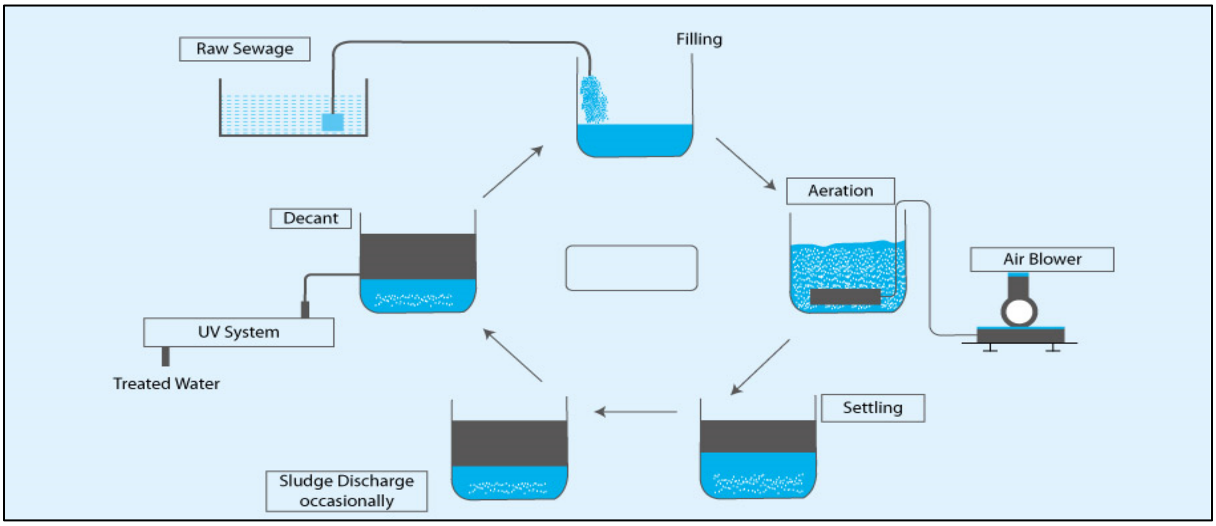

Figure 9: Treatment stages in a sequencing batch reactor (Source: Optimus Enviropro)

2.3.3.3 Moving Bed Biofilm Reactor (MBBR)

MBBR (Figure 9) is a process in which plastic chips are used as floating material having the unique property of attaching the micro-organisms on its surface. These plastic chips remain suspended in wastewater tank as the aeration is continued and provides a large surface area for micro-organisms to decompose organic matter. It takes advantage of biofilm and activated sludge principles. MBBR is simple to operate, has long durability and resistance from abrasion and has a life year of about 20 years. It is efficient in the removal of BOD, COD and can be used for nitrification/ denitrification.

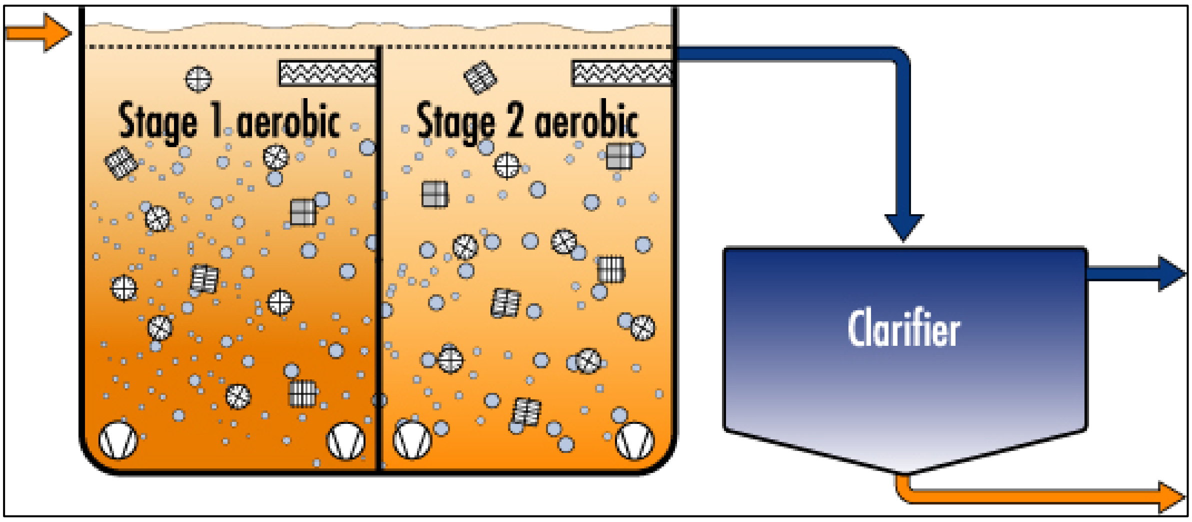

Figure 10: Schematic of Moving Bed Biofilm Reactor (Source: Lenntech)

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2.3.3.4 Membrane Bioreactor (MBR)

MBR uses the combined principle of conventional activated sludge process and membrane filtration process. In MBR, the wastewater influent is aerated in the bioreactor to decompose the organic matter. Once the complex organic compounds are broken down to simpler compounds, the influent is passed through a semi-permeable membrane and separates the decomposed pollutants resulting in high-quality effluent. The membrane filtration can either be separately provided in another tank after the biological activity or it can be submerged in the same bioreactor tank. The filtration pores are very small in size (approximately less than 0.4 microns) and thus clear effluent is drawn from the MBR. As the membrane filtration replaces the sedimentation tank in the MBR process, the footprint (area) is significantly reduced (Gutiérrez-Bouzán *et al.* 2013).

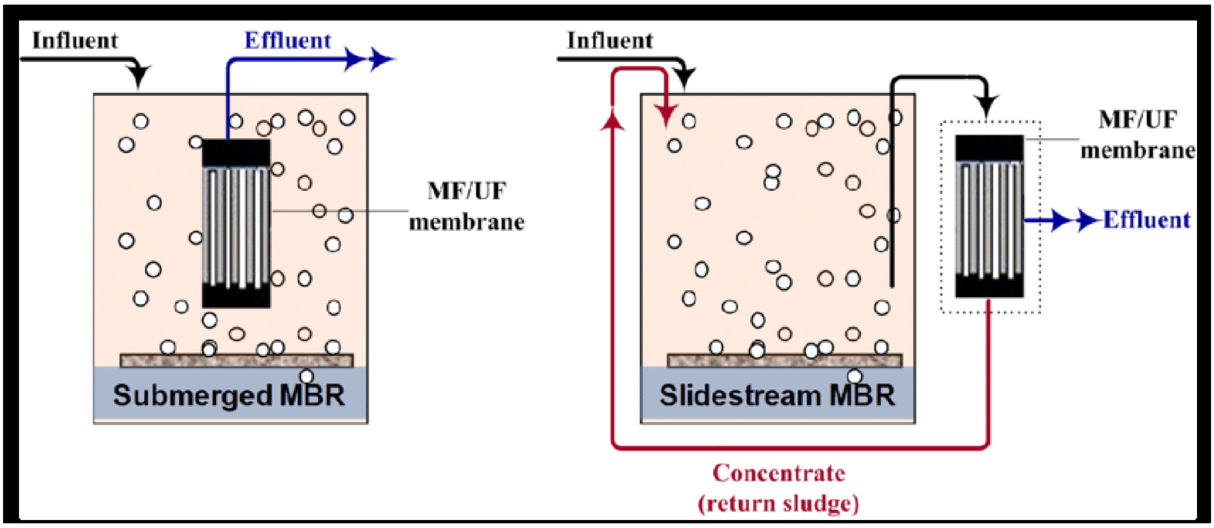

Figure 11: Configuration of Membrane Biofilm Reactor: Submerged and Separated membrane filtration (Alturki 2013)

2.3.4 Tertiary Treatment

Tertiary treatment is important to remove pathogens like bacteria and pollutants such as phosphorous, nitrogen and heavy metals. These pollutants create a nuisance, especially for aquatic plants and animals. Ammonia and nitrates are the nutrients and excess of it have to be

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removed. Ammonia can be oxidised to nitrates by nitrifying bacteria and nitrates can be denitrified to nitrogen gas. Phosphorous is also one of the nutrients which cause eutrophication leading to an algal bloom. Polyphosphates organisms are able to absorb and accumulate the phosphates in their cell from the wastewater and later these organisms settle down at the bottom as solids which can be used for fertilisers.

2.3.4.1 Disinfection

This is the process to kill the bacteria and pathogens which could be harmful to human health. There are several ways of disinfection such as ultra-violet (UV) treatment, ozonation and chlorination. Mostly, treatment plants use chlorination process as it is easy and cheap. Dosage of chlorine in wastewater can be achieved in the form of hypochlorite solution or chlorine gas. However, concerns are raised over the residual chlorine in the treated wastewater which eliminates good micro-organism and affects the human health and aquatic life. The DNA or nucleic acid of micro-organisms and bacteria under the UV rays is damaged which neutralises its function of reproduction and toxicity. No chemicals are added in the UV disinfection and the chemical composition of wastewater remains the same. Ozonation is the process of infusion of ozone gas in the wastewater. Ozone is a powerful oxidant and attacks the micro-organism destroying its cell wall and significantly reducing bacteria, viruses and protozoa. However, ozonation is a very expensive treatment method and require engineers for maintenance.

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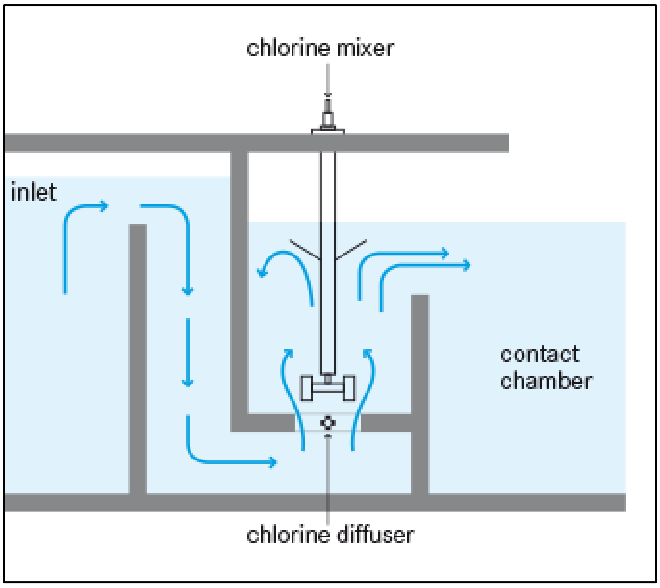

Figure 12: Schematic of chlorination in wastewater treatment plant (Tilley et al. 2014)

2.3.5 Sludge Treatment

In all the treatment process, finally, sludge is produced which has to be disposed of safely (Bonito 2008). The sludge which is produced in the primary sedimentation tank is called raw sludge and has a high content of organic matter and are therefore putrescible (Demirbas *et al.* 2017). The sludge which is formed in the secondary tank or clarifier is known as secondary sludge and is less putrescible as compared to raw sludge.

Sludge can be treated using stabilisation, dewatering and thickening. Stabilisation can be done in three ways: aerobic, anaerobic and chemical. Generally, anaerobic stabilisation is preferred as it has an advantage of energy recovery and electricity generation. Stabilisation process includes removal of pathogens, odour elimination and volume reduction (Qasim 1994). Dewatering and thickening of sludge reduce the cost of transportation. Land disposal is the cheapest method for disposing of the sludge however the most sustainable way is by landfilling or incineration. Some of the processes which are used to treat the sludge have been discussed below.

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2.3.5.1 Upflow Anaerobic Sludge Blanket (UASB)

In UASB, the wastewater flows from bottom to top (upflow) passing through the blanket of granular sludge (Rajasingh and Balasundaram 2016). The sludge contains micro-organism which degrades the organic compounds present in the wastewater in the absence of oxygen or air and therefore biogas (methane and carbon dioxide) are also formed as the by-product (Francisca 2011). UASB is less used in rural areas because it needs a constant supply of energy and electricity. The preparation of granular sludge can take about a month. The efficiency and effluent quality of UASB are better than a septic tank. However, the operation and maintenance is not easy and therefore require professionals.

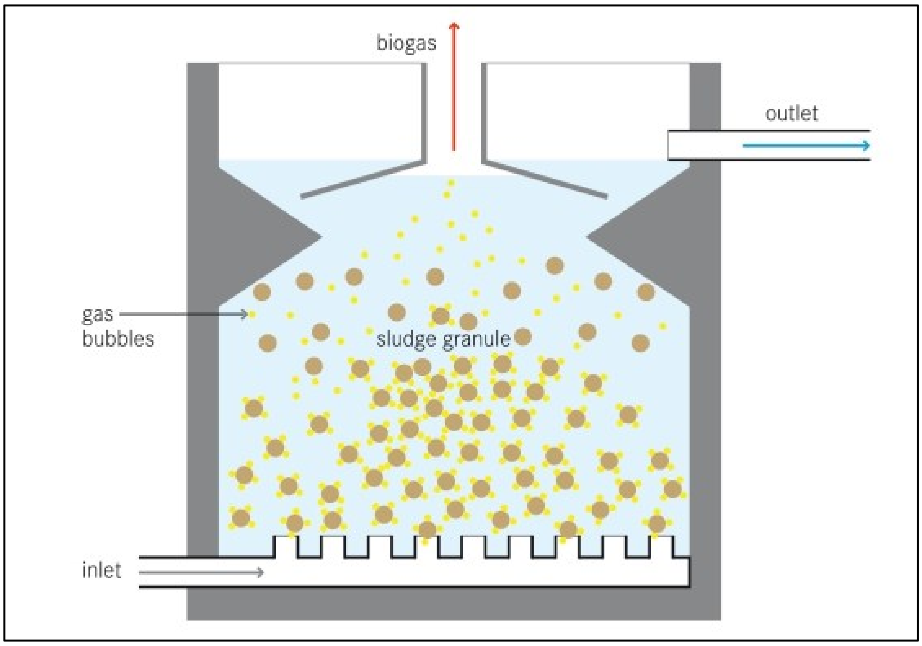

Figure 13: Schematic of upflow anaerobic sludge blanket (Tilley et al. 2014)

2.3.5.2 Trickling Filter

In the trickling filter, wastewater passes vertically through the bed made of gravel and rocks. The micro-organism present in the wastewater forms a biofilm where it degrades the organic matter of wastewater. Initially, the condition is aerobic but gradually with the formation of thick biofilm the condition changes to anaerobic. As the biofilm thickens and grows in

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weight, it detaches itself from the medium (gravel) and falls at the bottom. It is further removed from the wastewater through underlain system.

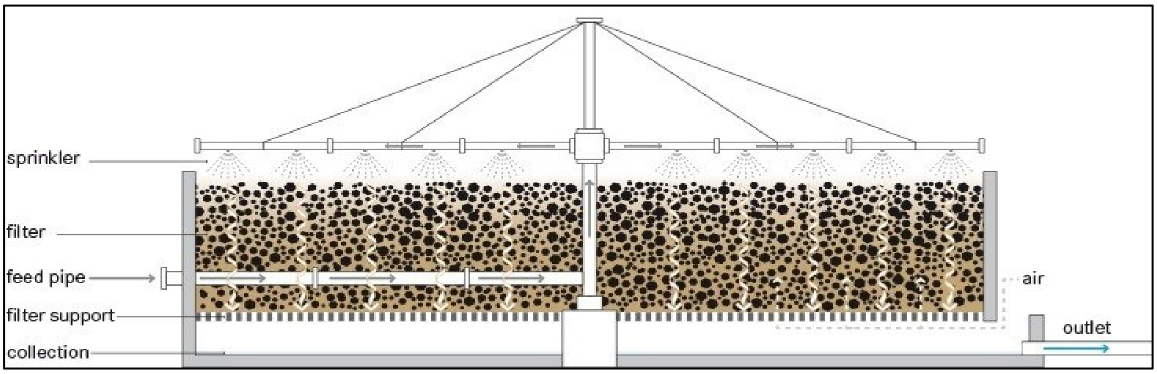

Figure 14: Schematic of the trickling filter (Tilley et al. 2013)

2.3.5.3 <u>Constructed wetland</u>

In the constructed wetland, the plants and medium (gravel and sand) are used for the treatment of organic waste, nutrients and pathogens from the wastewater. These are of two types: horizontal subsurface flow and vertical subsurface flow. In both, the wastewater flows through the plant roots and the medium. However, the difference is that the vertical subsurface is supplied with air from the vented pipes to make the aerobic conditions and horizontal subsurface has the anaerobic condition. The constructed wetlands are applied in the rural areas and for treating high suspended solids and organic matter and therefore usually wastewater goes through primary treatment to reduce the load on the constructed wetland.

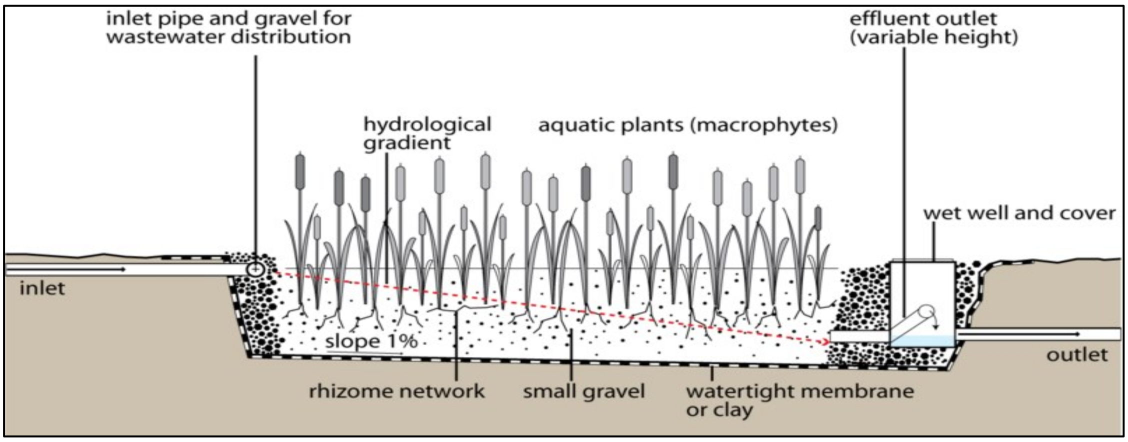

Figure 15: Schematic of horizontal subsurface flow constructed wetland (Eawag)

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2.3.5.4 Waste stabilisation pond (WSP)

This is basically a pond which is divided into three compartments: anaerobic, facultative and maturation (USEPA 1973). The wastewater enters through an inlet in the anaerobic pond, passes through facultative pond and exits from the maturation pond as treated effluent. Facultative and maturation ponds are much shallower than the anaerobic ponds because the oxygen from the atmosphere can dissolve in these ponds efficiently. The treatment process can take several days. WSP is more suitable in the region of warm climate because many of the micro-organism in the open pond do not survive in the cold climate.

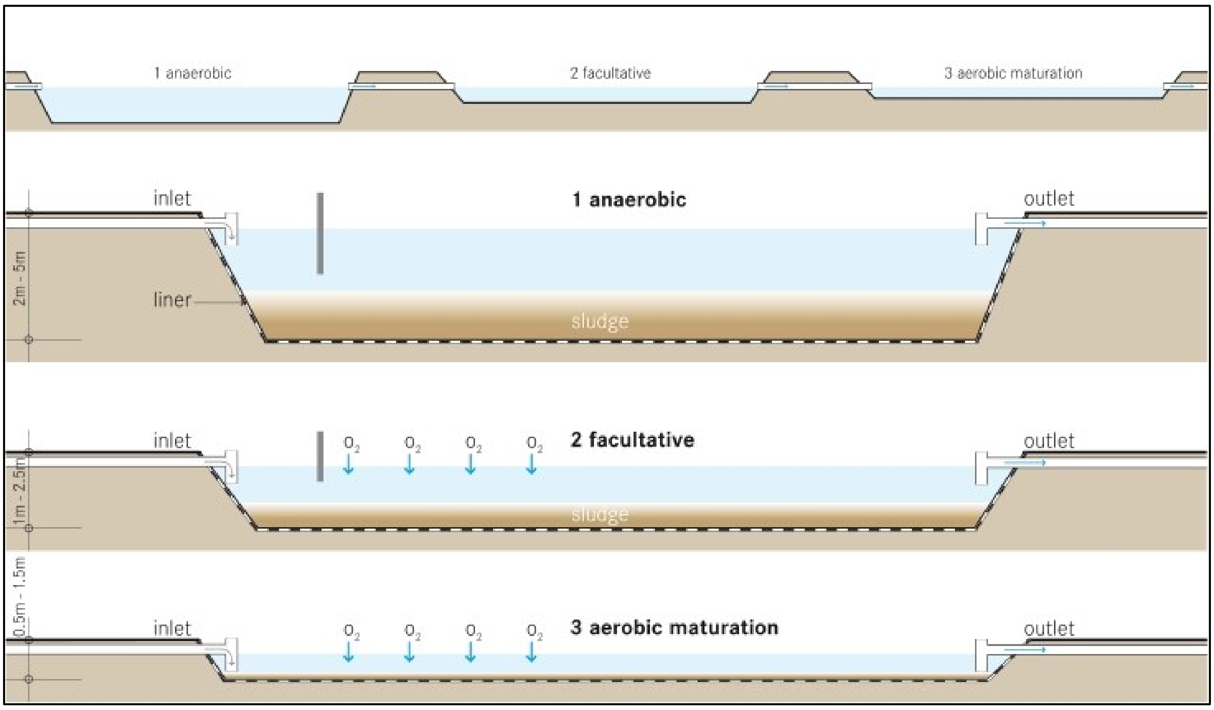

Figure 16: Schematic of waste stabilisation pond with three compartments (Tilley et al. 2014)

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3 Methodology

3.1 Site Location

The wastewater treatment plant is located in Vácszentlászló. The plant is approximately 38 kms (aerial distance) and in the east of Budapest, Hungary.

Figure 17: Satellite view of Vácszentlászló Wastewater Treatment Plant (Google Earth)

3.2 Description of Treatment Plant

The wastewater treatment plant treats the wastewater coming from the domestic houses from many nearby villages of Vácszentlászló, Valkó and Zsámbok. Three (3) lines containing the wastewater meet and discharge the wastewater in the storage tank (installed with lifting pumps). The flow meter installed at these three lines provides the information on the flow rate. The lifting pumps are also provided with a variable frequency drive to control the flow rates of incoming wastewater. The raw wastewater from the tank is pumped for the preliminary treatment where the gravel, fats, grease and sand particles are separated on the screw press and the screen. The wastewater is then distributed to the treatment unit installed with Cyclator.

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Figure 18: Overview of the Vácszentlászló Wastewater Treatment Plant

Figure 19: Domestic wastewater coming from the three (3) lines of the nearby counties

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Figure 20: Domestic wastewater coming from the three (3) lines of the nearby counties

3.3 Cyclator

The Cyclator process with a feed-forward (FF) cycle runs automatically, has an easy function, treats the wastewater biologically with time-based and generates high-quality effluent. The main advantage of Cyclator is most of the processes such as nitrification, denitrification, oxidation, biological phosphorous removal and liquids/solids separation are achieved in one tank.

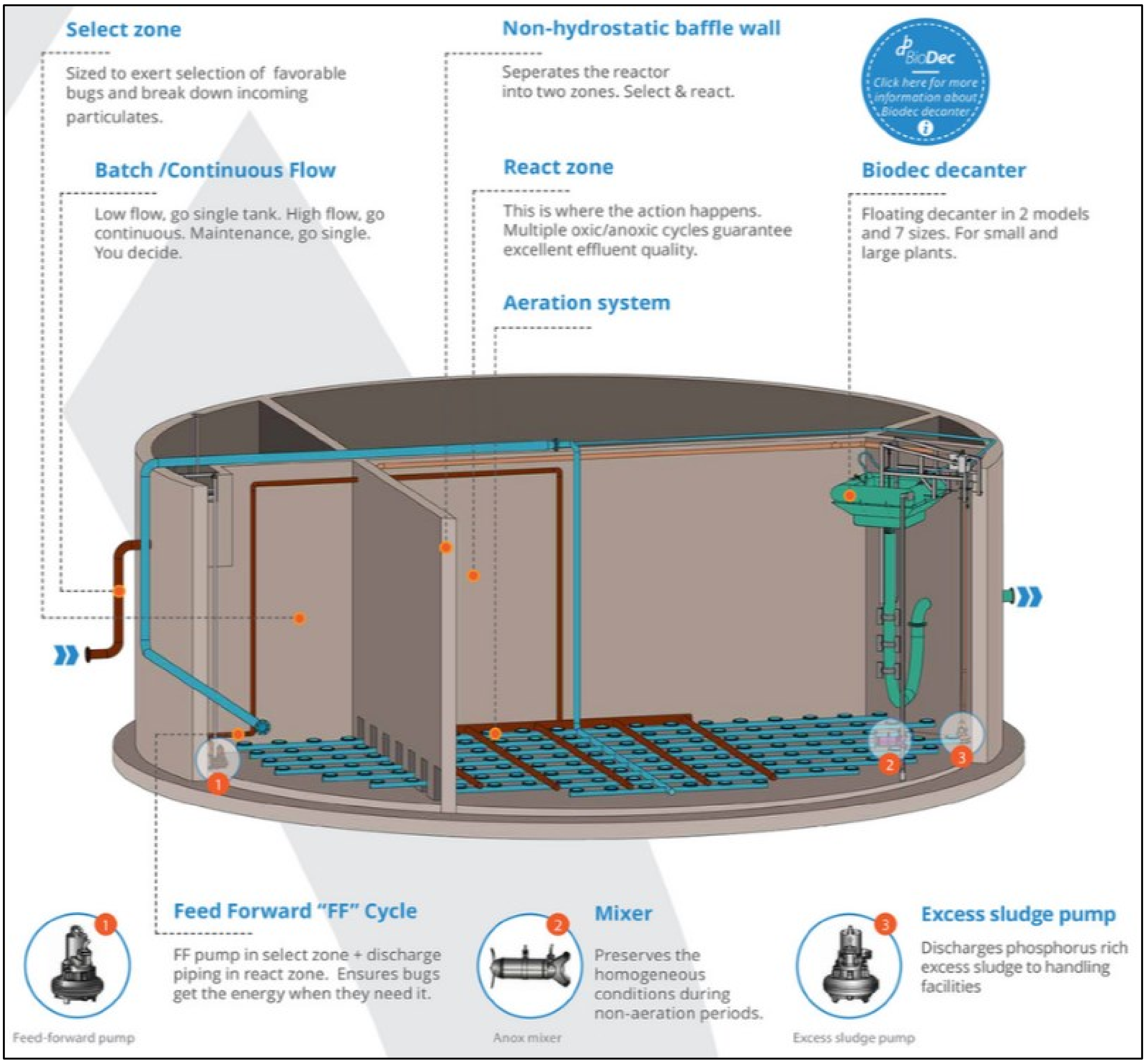

Figure 21: Schematic of Cyclator and its functioning process (Source: UTB Envirotec)

The Cyclator is equipped with Biodec decanter which helps to separate the sludge from clear effluent and is very useful in the Sequencing Batch Reactor (SBR)/Cyclic process. The speciality of the decanter is that it floats on the wastewater surface in the "park" position and slowly submerges in the "operate" position when the pressure or air is released to collect the clear effluent.

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Figure 22: Biodec decanter installed in the Cyclator to decant treated water

One of the unique features of Cyclator is the highly efficient removal of nutrients such as phosphorous and nitrogen. Cyclator uses the principle of enhanced biological phosphorous removal (EPBR). During the anaerobic environment in the Cyclator, the polyphosphates accumulating organisms (PAOs) present in the activated sludge stores the phosphorous in the cell walls for their development. Because PAOs have high affinity for storing the large quantities of phosphorous, their concentration in the intracellular increases. PAOs biomass can contain upto 5-7 % of phosphorous and therefore it is removed as excess sludge after the treatment process is complete (Biological Phosphorus Removal - Manual for Design and Operation 2002).

The Cyclator has two zones: select zone and react zone. The select zone is installed with the aeration system and the react zone is installed with aeration and mixing system. As

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the Cyclator is a continuous flow process the wastewater enters the select zone prior to react zone. Cyclator is a cyclic process and has four main step process: aeration, mixing, settling and decanting. These processes are run for a specific time to achieve higher quality effluent.

The influent first enters the select zone and then it flows to the react zone. During active phases two processes of aeration and mixing is done alternatively and repeatedly. Once the Cyclator treats the wastewater the settling process is initiated with the continuous feed flow of influent for 60 minutes to the settled sludge bed to enhance biological phosphorous removal. The sludge settles at the bottom of both zones and the excess sludge is pumped out. The clean water which floats at the top is separated by the Biodec decanter for 60 minutes.

Table 4: Continuous cyclic process in Cyclator

Aeration	Mixing	Aeration	Mixing	Aeration	Mixing	Aeration	Settling	Decanting
24 mins	24 mins	24 mins	24 mins	24 mins	24 mins	24 mins	60 mins	60 mins

3.4 Sample Collection

One of the difficulties of collecting the sample is the true representative sample. The characteristics of wastewater changes with depth (i.e. from top to bottom) and with time (i.e. from morning to evening). The sample is generally collected from the bottom because turbulence at the bottom is high and mixes the solution. This is called a grab sample. Many such samples are collected in regular interval and are finally mixed. Care is taken while mixing as the quantity mixed from each specimen is proportionate to flow rate of that specimen at that time. This ensures the best possible way of collecting a true representative sample.

Before the samples were collected, the ambient hydrogen sulphide (H_2S) concentration was checked in the primary tank using the digital meter. The value in digital meter greater than 5 indicates that the concentration of H_2S in the influent is high and leads to the foul smell in

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the nearby areas. Presence of high level of H_2S also indicates the high strength of wastewater and corrodes the machinery part which is made of iron.

Figure 23: Measuring the ambient concentration of H2S in the primary tank

The samples were collected from the influent and the treated effluent of Cyclator. The samples were collected approximately twice a week in the plastic bottles. The sludge sample was also collected to measure the sludge settling and its quality.

The bucket was attached to the rod which was used to dip into the clarifier of treated effluent and the sample of effluent was collected in the bucket. The sample was collected from the bottom of the clarifier to get the true representative of effluent. The sample from the bucket was transferred to the sampling bottle.

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Figure 24: Sample collected from the effluent of Cyclator

In order to prevent the biological activity in the sample, it is important to keep the temperature of the sample very low. The samples, immediately after its collection, are kept in the cooler box which contains ice-bricks. The sample bottles have preservatives such as sulphuric acid, chloroform and formaldehyde to keep the samples fresh till its holding time. However, the preservatives for different parameters in sample bottle are different to ensure that no chemical reaction of preservative with sample occurs. For example, the BOD sample bottle is free from any preservatives.

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Figure 25: Sludge collected in measuring flask to measure the sludge settling property

Sludge settling is an important characteristic in every wastewater treatment plant. The wastewater treatment plant neither wants slow settling nor fast settling. Settling test is conducted by filling a graduated cylinder of 1000 ml and noting down the value of sludge settlement every 5 minutes for a total length of 30 minutes. The settlement basically happens either in two ways. The formation of large particles which are less dense than water taking a long time to settle. Smaller particles flocculating and having a density higher than water allowing it to settle faster.

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Figure 26: Measuring the sludge concentration using the digital meter

Figure 27: Samples are kept in the cooler box to prevent biological activity

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3.5 Instruments Used

Sophisticated instruments were used in conducting the experiment and analysing the samples. There were mainly two (2) instruments which were used in the analysis of all the sample tests.

3.5.1 Thermostat

HACH LT200 Thermostat was used in the experiment for digesting the cuvette samples. The thermostat is equipped with a controllable heat system (i.e. temperature) and time settings. The digital timer shows the time period of heating and the transparent lid is closed while digestion takes place.

Figure 28: HACH LT200 Thermostat used for the experiment in the laboratory

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3.5.2 Spectrophotometer

HACH DR6000 Spectrophotometer was used for the analysis of cuvette samples. The basic principle of spectrophotometer is the intensity of light absorbed in the sample and measuring the output intensity of light. Spectrometer produces light and photometer measure the light. The sample is kept between spectrometer and photometer. The light produced by the source is focused on monochromator (prism) using the collimator lens. The prism splits the light into different wavelengths. The selector helps to transmit only the wavelength which is relevant and the detector measures the intensity of light. Depending upon the concentration of contaminants in the sample, the intensity of light correlates with the concentration. The digital display meter shows the concentration of desired parameters.

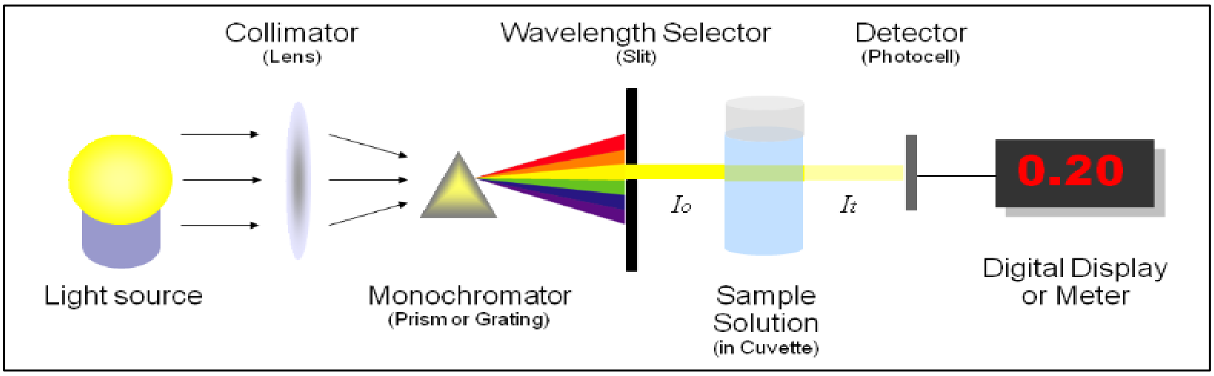

Figure 29: Working principle of spectrophotometer (illustrated by Heesung Shim)

Figure 30: HACH DR6000 Spectrophotometer used for the experiment in laboratory

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3.5.3 pH meter

HQ11D Portable pH Meter was used for determining the pH of the influent and effluent samples. The pH Meter has a probe which contains two electrodes: glass sensing electrode and reference electrode. Both electrode contains the solution of potassium chloride and silver chloride. However, the bulbs of both electrodes are different. The bulb of reference electrode is made of plastic. The glass sensing electrode has the bulb made of metal salts and silica. When the pH Meter is dipped into the sample, the potential difference is created and electricity flows. The glass sensing electrode measures the concentration of hydrogen ion in the solution and the volts seen on the digital pH Meter is automatically converted to the pH value.

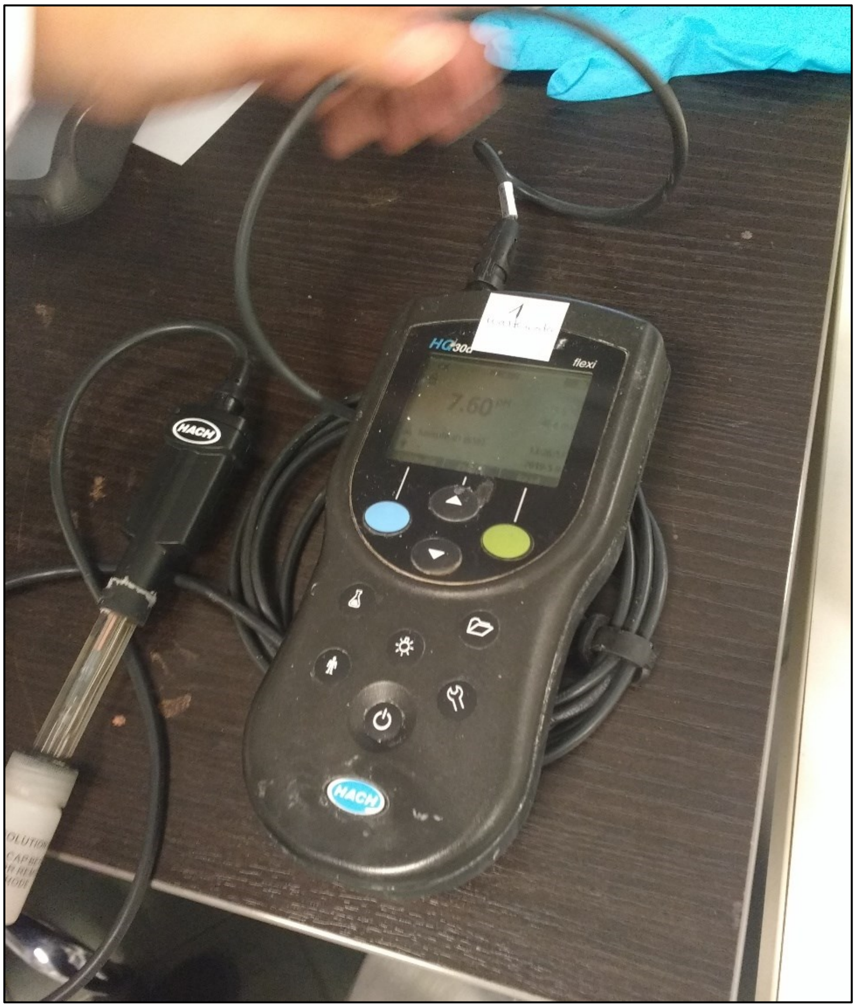

Figure 31: HQ11D Portable pH Meter used for the experiment in laboratory

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3.6 Experimental Procedure to Measure the Parameters

After the samples were collected, it was transferred to the laboratory for conducting the various test and analysing the various parameters (quantitative analysis). The experiments tests which were performed are given below.

3.6.1 Chemical Oxygen Demand (COD)

1. The thermostat is pre-heated at the temperature of 148^0C.
2. The sample collected in the cuvette is disturbed to bring the sediments into suspension.
3. The sample is pipetted to form 2.0 mL of sample cuvette. A reagent blank of 2.0 mL water free from COD is also formed.
4. The cuvette is closed tightly and the outside is cleaned properly.
5. The cuvettes are inverted and shaken to bring the particles in the suspension mode.
6. The cuvettes are put again in the pre-heated thermostat and are again heated at 148^0C for 2 hours.
7. Once the cuvettes are heated, it is removed from the thermostat and is allowed to cool down at 60^0C with a bit of shake.
8. The cuvettes are then cooled at the room temperature (25^0C).
9. The outside of cuvettes is cleaned thoroughly and is analysed in the photometer.

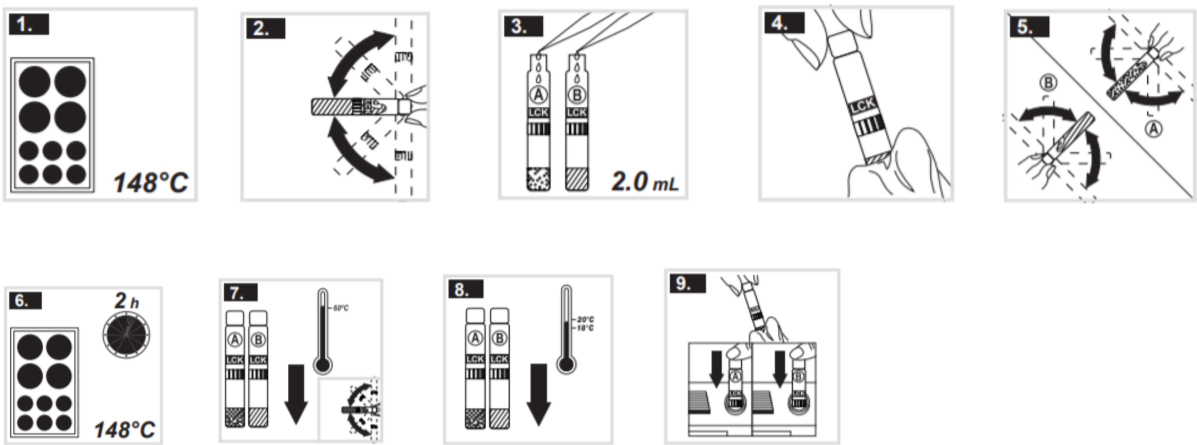

Figure 32: Illustration of experimental procedure for COD Testing (Source: Hach)

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Figure 33: Sample brought in the laboratory and to be analysed

3.6.2 Biological Oxygen Demand (BOD)

A. The sample is filled in the two (2) cuvettes. The BOD test on Cuvette 1 is carried out instantly and the BOD of Cuvette 2 is measured after 5 days.
B. The cap (DosiCapZip) of the cuvette is opened and the funnel is placed on the inlet of the cuvette.
C. The aluminium foil attached to Cuvette 1 is removed and the contents are poured into the sample of Cuvette 1 through the funnel.
D. The funnel is removed and immediately the Cuvette 1 is closed with the DosiCap Zip carefully to avoid the formation of air bubbles.
E. The cuvette is then inverted and shaken gently to dissolve and mix the tablets into the sample properly.
F. The solution is left to settle for 3 minutes.

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G. The outside of cuvettes is cleaned thoroughly and is analysed in the photometer.

H. The Cuvette 2 is left undisturbed for 5 days and same process is repeated as in Cuvette 1.

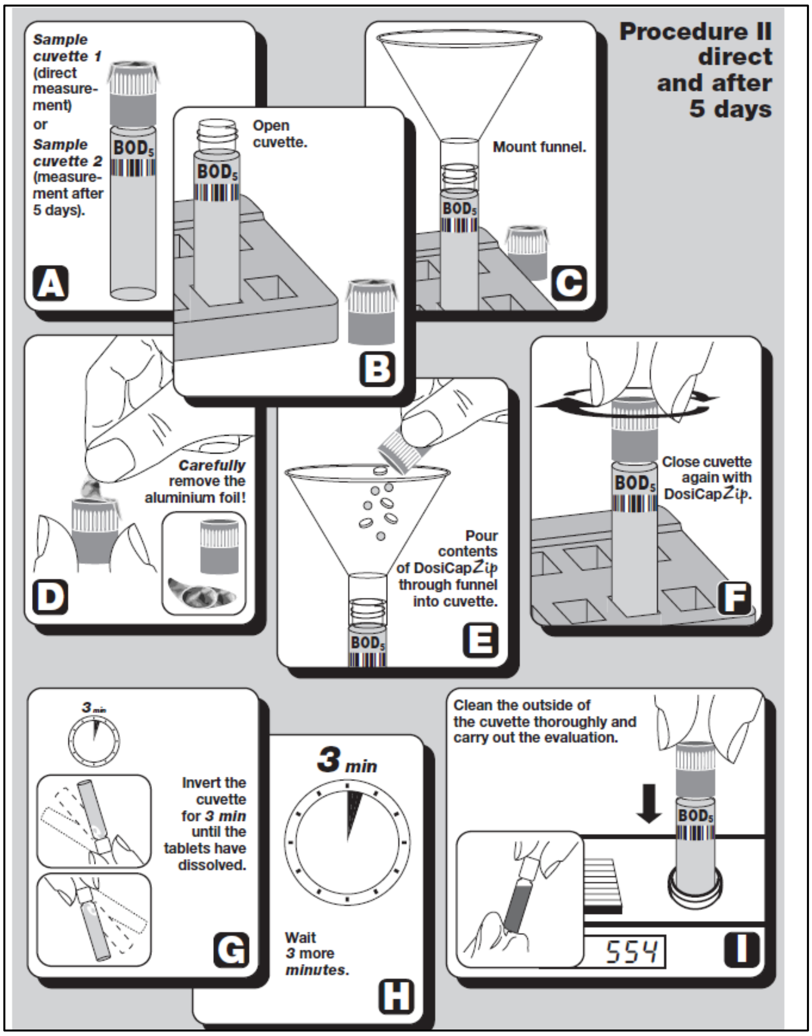

Figure 34: Illustration of the experimental procedure for BOD Testing (Source: Hach)

3.6.3 Ammonium Nitrogen (NH_4-N)

1. The aluminium foil attached to the cap of the cuvette is removed.
2. The cap of the cuvette is unscrewed and opened.
3. The sample is pipetted to form 0.2 mL of sample cuvette.
4. The cuvette is closed with its cap immediately.
5. The sample is shaken firmly.

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6. The outside of cuvette is cleaned thoroughly and is analysed after 15 mins in the photometer.

Figure 35: Pipetting 0.2mL of sample cuvette for the testing of NH4-N

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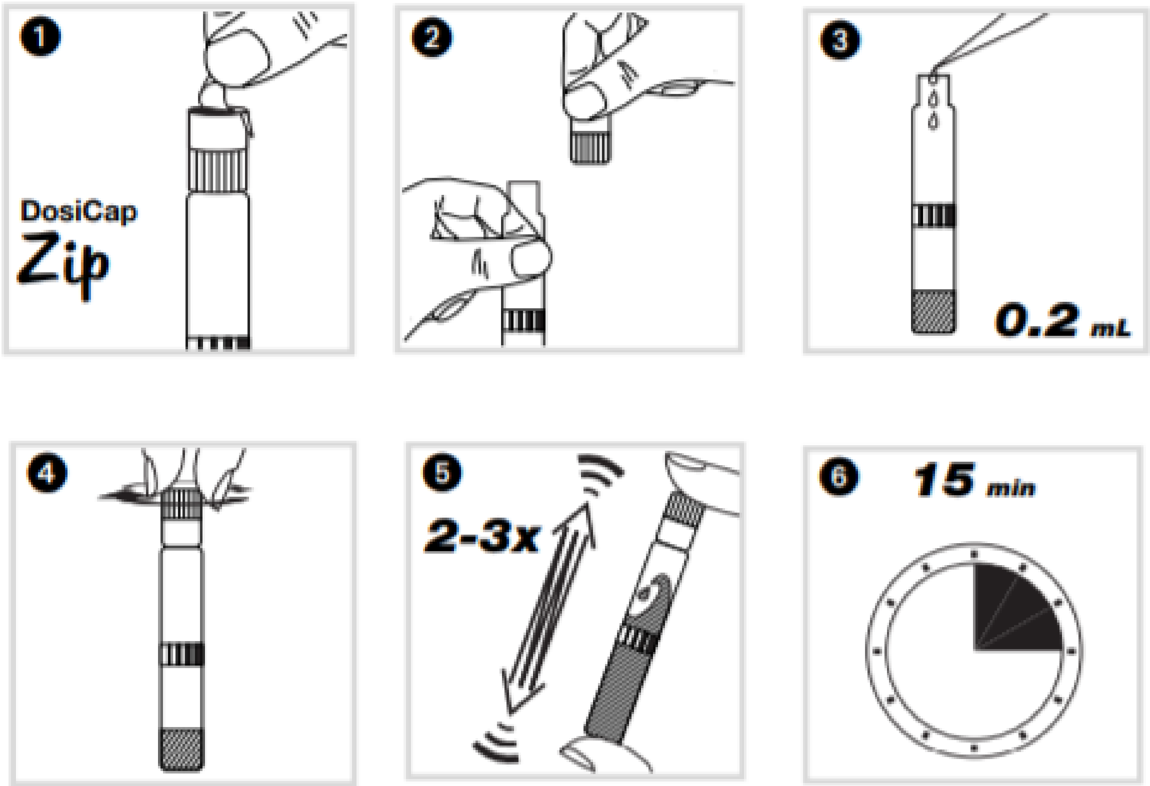

Figure 36: Illustration of experimental procedure for BOD Testing (Source: Hach)

3.6.4 Total Phosphorous

1. The aluminium foil attached to the cap of cuvette is removed.
2. The cap of the cuvette is unscrewed and opened.
3. The sample is pipetted to form 2.0 mL of sample cuvette.
4. The cuvette is closed with its cap immediately.
5. The cuvette containing the sample is shaken vigorously.
6. The cuvette is then placed inside the thermostat and is heated at 148^0C for 15 minutes.
7. The cuvette is left to cool down at room temperature.
8. The sample is shaken vigorously.
9. The outside of cuvette is cleaned thoroughly and is analysed in the photometer.

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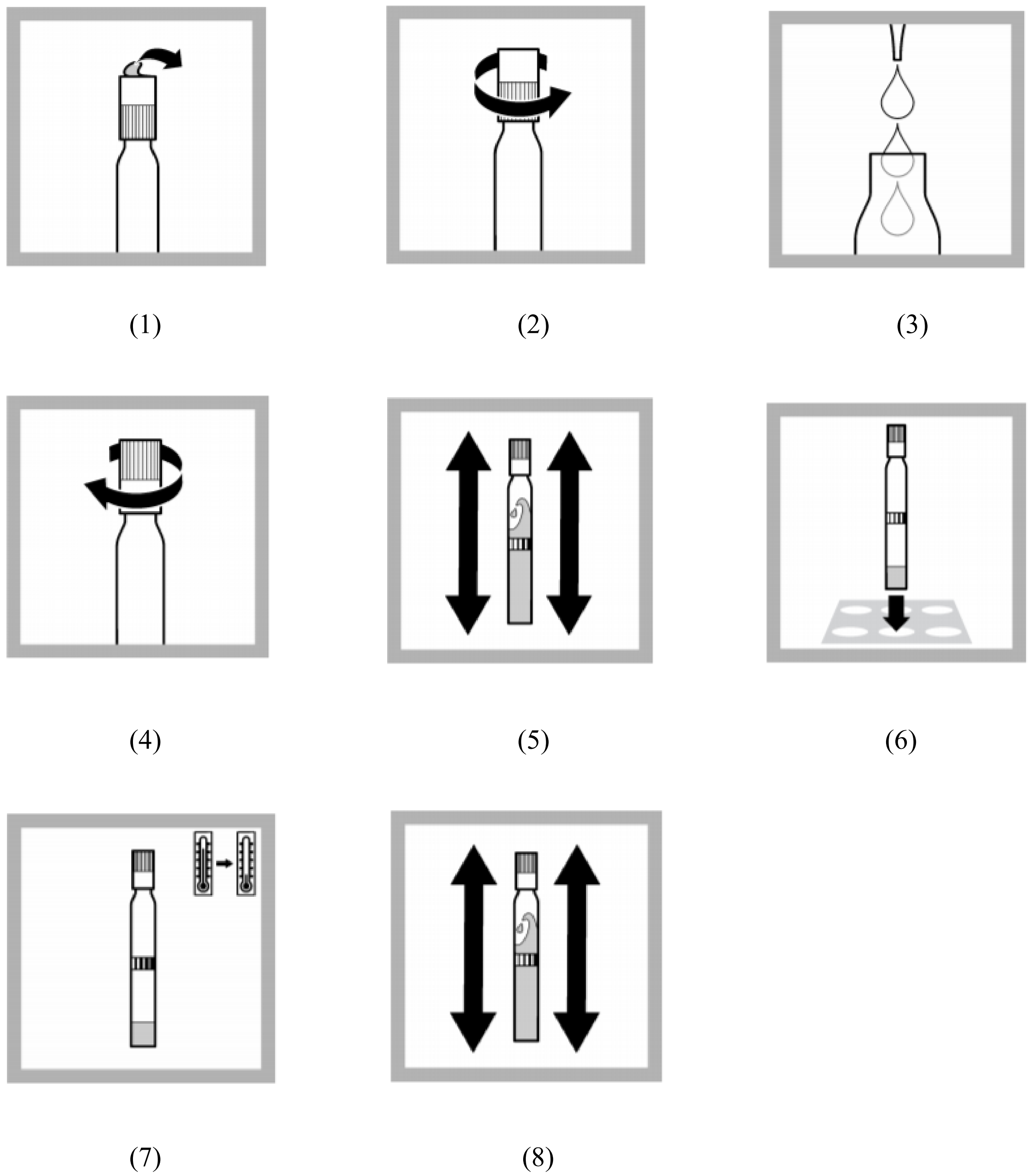

Figure 37: Illustration of experimental procedure for measuring Total Phosphorous (Source: Hach)

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Figure 38: Color change observed after the sample preparation in the cuvette

Figure 39: Placing the cuvettes inside the thermostat for heating

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Figure 40: Placing the cuvettes in the photometer and noting down the result

3.6.5 pH

The pH was simply measured by dipping the probe of pH meter into the sample and pressing the Read button on the meter. The pH values obtained on the meter was noted.

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4 Results

A total of sixteen (16) samples were collected and analysed for different parameters over a period of 2 months. The parameters which were considered in the analysis test were: pH, chemical oxygen demand (COD), biological oxygen demand (BOD), ammonium nitrogen (NH_4-N), inorganic nitrogen, total nitrogen and total phosphorous. The discharge standards of these parameters have been given below in Table 5.

Table 6 shows the values obtained of various parameters in the influent and effluent. The results after the laboratory analysis were compared and checked if they meet the discharge standards of wastewater. The results show that the influent after the treatment from Cyclator are in full compliance with the discharge standards. The removal efficiency for each parameter was also calculated by the formula: [(Influent Conc. – Effluent Conc.)/Influent Conc.]x100

Table 5: The discharge standards of various parameters

Parameter	**Discharge Standards**
pH	6.5-9.0
COD	120 mg/L
BOD_5	40 mg/L
Ammonium nitrogen (NH_4-N)	1 mg/L
Inorganic Nitrogen	-
Total nitrogen	25 mg/L
Total phosphorous	1 mg/L

Source: Third Schedule, Regulation 6, General Notice No. 44 of 2003, Environmental Protection Act 2002.

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Table 6: Results obtained for various parameters in the influent and effluent

pH		COD (mg/L)		BOD_5 (mg/L)		NH_4-N (mg/L)		Inorganic Nitrogen (mg/L)		Total Nitrogen (mg/L)		Total Phosphorous (mg/L)	
Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
7.6	7.8	783	30	530	7	43	0.3	43.26	0.86	72.1	5	9.9	2.2
7.6	7.6	565	30	361	7	42.5	0.2	42.76	3.86	45.6	5.5	5.7	1.6
7.4	7.6	906	38	524	7	56.7	0.2	56.96	4.76	87.5	5.5	8.3	5.1
7.3	7.5	621	30	459	7	50.5	0.2	50.76	2.23	112	5	7.7	0.5
7.8	7.6	1110	30	563	7	42	0.37	42.26	1.72	92.7	5	10.8	2.3
7.3	7.4	707	30	468	7	45.9	1	46.16	1.66	69.1	5	5.29	0.9
7.4	7.7	724	32.6	506	7.6	37.2	0.3	37.46	3.58	50	5	6.7	1.57
7.8	7.7	440	30	318	7	54.5	1	54.76	1.71	105	5	8.69	0.63
8.2	7.9	276	30	167	7	38	0.2	38.26	0.86	50	5	2.9	0.15
7.3	7.6	572	218	254	49.4	28.2	0.33	28.46	0.71	75	9.1	6	1.9
7.8	7.7	674	30	411	7	38.2	0.2	38.46	0.46	66.8	5	5.84	0.54
7.8	7.8	674	84.6	484	23.9	36.6	1.84	36.86	2.14	85	5	6.2	4.9
7.8	7.4	459	30	310	7.3	24.3	1.96	24.56	2.25	41.5	5	4	2.82
7.8	7.7	537	30	383	7.3	34.2	1.86	34.46	3.07	73.7	5.99	5.22	1.24
7.6	7.7	602	46.2	372	8.1	42.7	1.75	42.96	2.06	74.2	5	5.81	1.76
7.9	7.7	569	32	179	8.5	26	0.96	26.59	2.08	40.9	5	4.79	0.21

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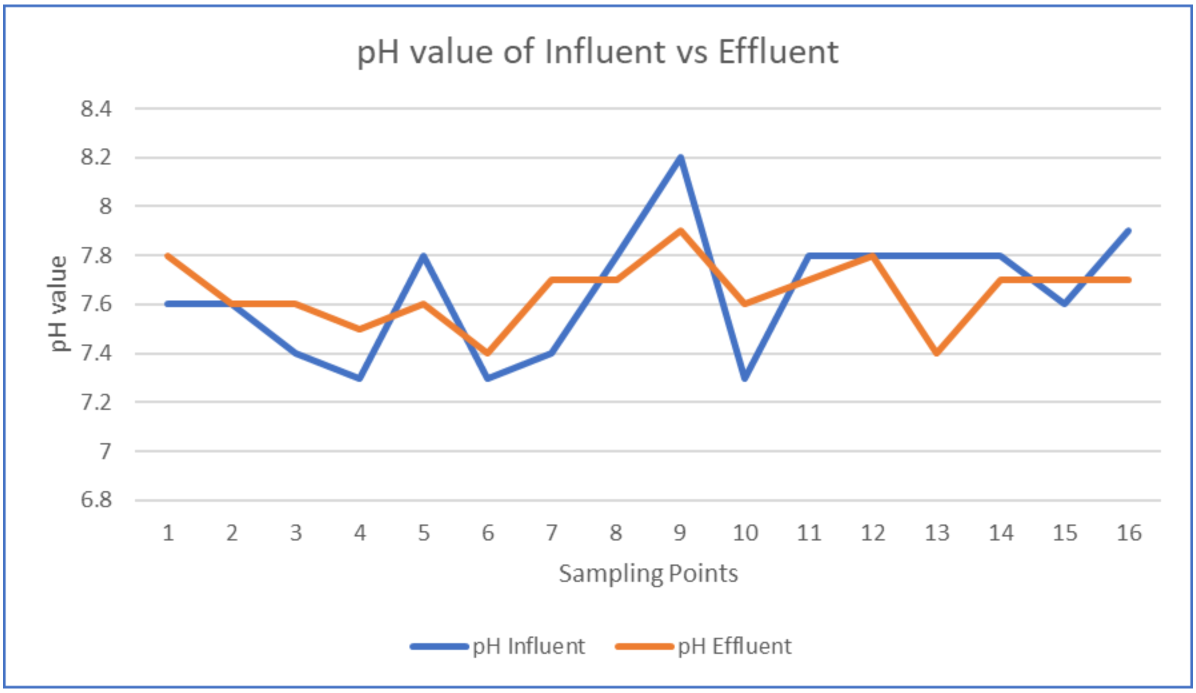
4.1 Effect on pH

The pH of influent in all the samples was observed to be more than 7 which signifies the influent was alkaline from the initial condition and therefore under the discharge standard. The treated effluent coming out from the Cyclator was also observed to be alkaline with no significant change from its initial value.



Graph 1: pH measurement values of influent and effluent at different times

4.2 Effect on COD

The concentration of COD was observed to be very high in the influent sample (>500 mg/L) indicating the high strength of wastewater. The Cyclator was able to achieve the efficient removal of COD from the raw wastewater and bring its contamination level to an average of 30 mg/L. The average removal efficiency was calculated to be 92% (Table 7).

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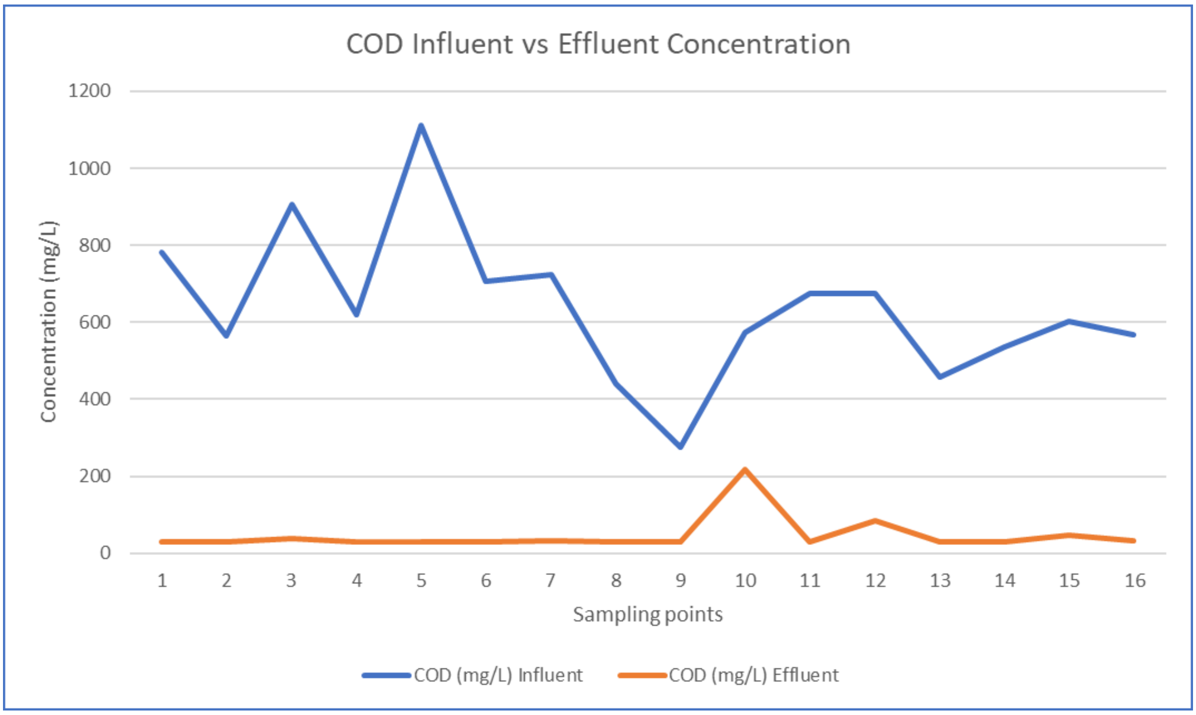

Graph 2: COD measurement values of influent and effluent at different times

Table 7: Removal efficiency for COD for each sampling point

Influent (mg/l)	783	565	906	621	1110	707	724	440	276	572	674	674	459	537	602	569
Effluent (mg/l)	30	30	38	30	30	30	32.6	30	30	218	30	84.6	30	30	46.2	32
Removal Efficiency (%)	96.2	94.7	95.8	95.2	97.3	95.8	95.5	93.2	89.1	61.9	95.5	87.4	93.5	94.4	92.3	94.4

4.3 Effect on BOD

The discharge standard for BOD_5 is 40 mg/L which is not easy to achieve. The influent was observed to have BOD_5 more than 300 mg/L. The treated effluent from the Cyclator was observed to have a BOD_5 level below the discharge standard. The average removal efficiency was calculated to be 96.6% (Table 8).

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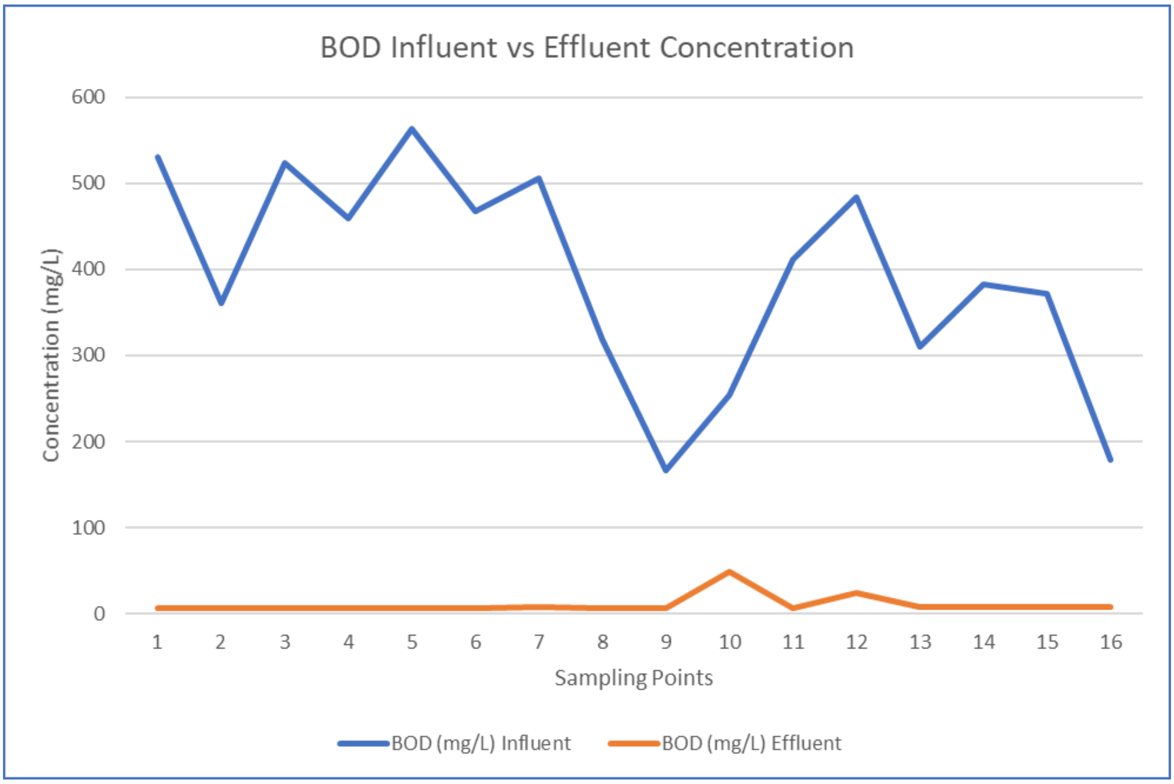

Graph 3: BOD measurement values of influent and effluent at different times

Table 8: Removal efficiency for BOD for each sampling point

Influent (mg/l)	530	361	524	459	563	468	506	318	167	254	411	484	310	383	372	179
Effluent (mg/l)	7	7	7	7	7	7	7.6	7	7	49.4	7	23.9	7.3	7.3	8.1	8.5
Removal Efficiency (%)	98.7	98.1	98.7	98.5	98.8	98.5	98.5	97.8	95.8	80.6	98.3	95.1	97.6	98.1	97.8	95.3

4.4 Effect on Ammonium Nitrogen (NH_4-N)

The Cyclator had a positive effect on treating ammonium nitrogen from the wastewater. The concentration of (NH_4-N) was observed to be above 25 mg/L and the concentration decreased to less than 2 mg/L after its treatment. The average removal efficiency was calculated to be 97.7% (Table 9).

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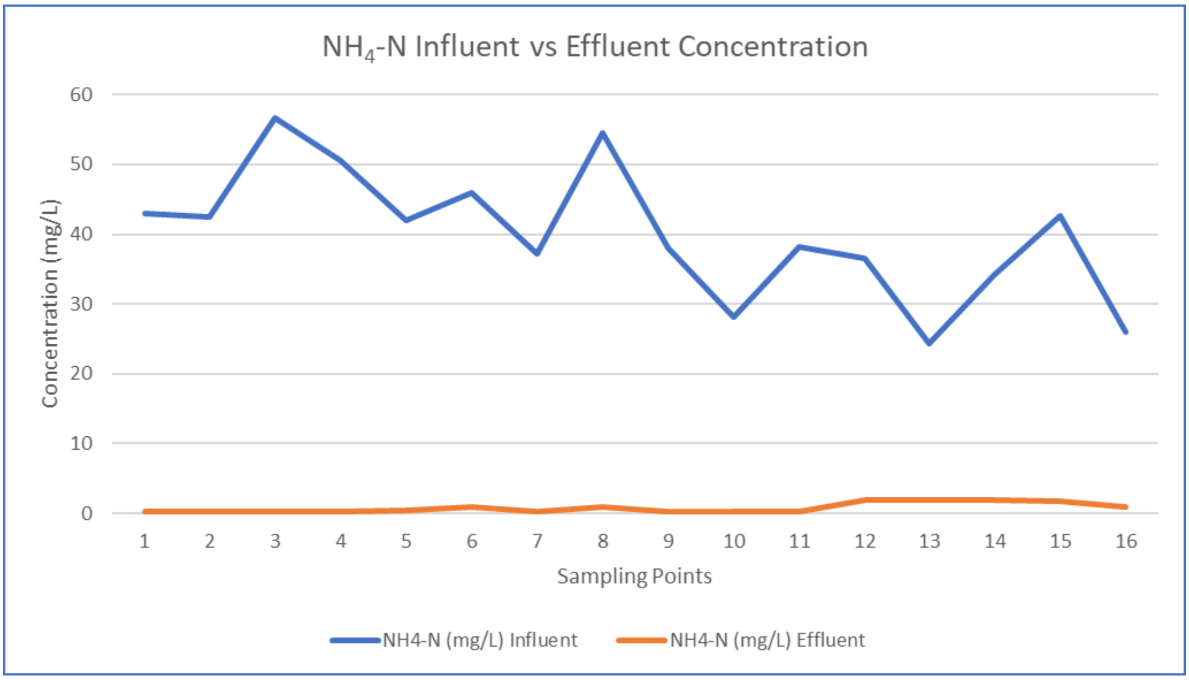

Graph 4: NH_4-N measurement values of influent and effluent at different times

Table 9: Removal efficiency for NH4-N for each sampling point

Influent (mg/l)	43	42.5	56.7	50.5	42	45.9	37.2	54.5	38	28.2	38.2	36.6	24.3	34.2	42.7	26
Effluent (mg/l)	0.3	0.2	0.2	0.2	0.37	1	0.3	1	0.2	0.33	0.2	1.84	1.96	1.86	1.75	0.96
Removal Efficiency (%)	99.3	99.5	99.6	99.6	99.1	97.8	99.2	98.2	99.5	98.8	99.5	95.0	91.9	94.6	95.9	96.3

4.5 Effect on Inorganic Nitrogen

The influent was analysed and observed to have the concentration of inorganic nitrogen from 25 mg/L up to 60 mg/L. After the treatment in Cyclator, the effluent was observed to have concentration below 5 mg/L. The average removal efficiency was calculated to be 94.6% (Table 10).

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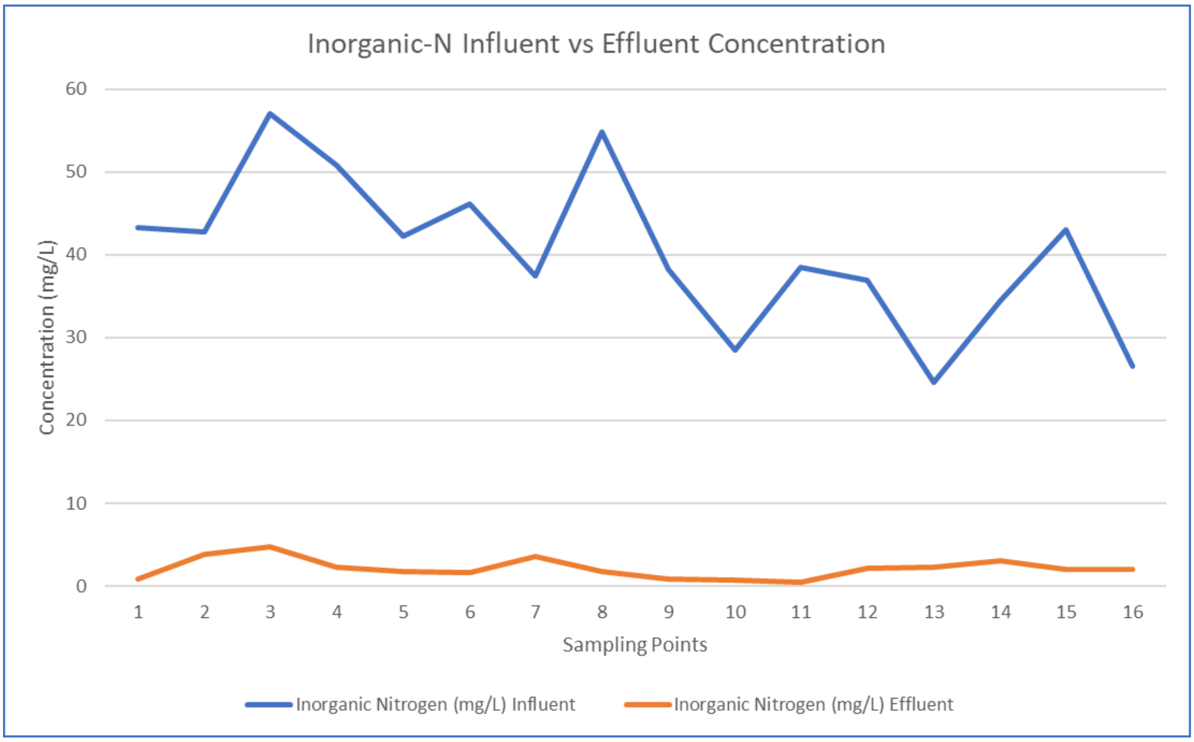

Graph 5: Inorganic nitrogen measurement values of influent and effluent at different times

Table 10: Removal efficiency for Inorganic N for each sampling point

Influent (mg/l)	43.26	42.76	56.96	50.76	42.26	46.16	37.46	54.76	38.3	28.5	38.5	36.9	24.6	34.5	43	26.6
Effluent (mg/l)	0.86	3.86	4.76	2.23	1.72	1.66	3.58	1.71	0.86	0.71	0.46	2.14	2.25	3.07	2.06	2.08
Removal Efficiency (%)	98.0	91.0	91.6	95.6	95.9	96.4	90.4	96.9	97.8	97.5	98.8	94.2	90.8	91.1	95.2	92.2

4.6 Effect on Total Nitrogen

The concentration of total nitrogen in the influent varied from 40 mg/L to 105 mg/L. However, after its treatment, the level decreased less than 10 mg/L which is in compliance with the discharge standard of total nitrogen i.e. 25 mg/L. The average removal efficiency was calculated to be 91.8% (Table 11).

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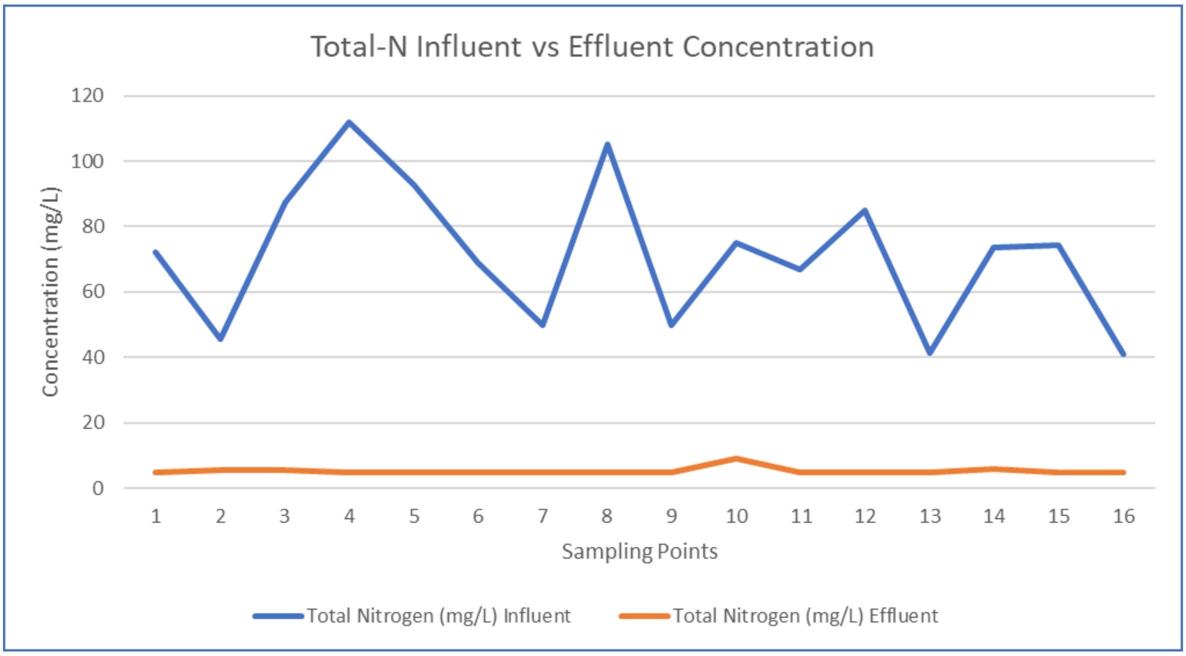

Graph 6: Total nitrogen measurement values of influent and effluent at different times

Table 11: Removal efficiency for Total N for each sampling point

Influent (mg/l)	72.1	45.6	87.5	112	92.7	69.1	50	105	50	75	66.8	85	41.5	73.7	74.2	40.9
Effluent (mg/l)	5	5.5	5.5	5	5	5	5	5	5	9.1	5	5	5	5.99	5	5
Removal Efficiency (%)	93.1	87.9	93.7	95.5	94.6	92.8	90.0	95.2	90.0	87.9	92.5	94.1	88.0	91.9	93.3	87.8

4.7 Effect on Total Phosphorous

Phosphorous in wastewater influent was observed to be present in a low concentration varying from 2 mg/L to 10 mg/L. The Cyclator removed the phosphorous efficiently in most cases and decreased the concentration level below its discharge standards (i.e. 1 mg/L). However, in some cases, the treated effluent had concentration more than the discharge standard. The average removal efficiency was calculated to be 72.4% (Table 12).

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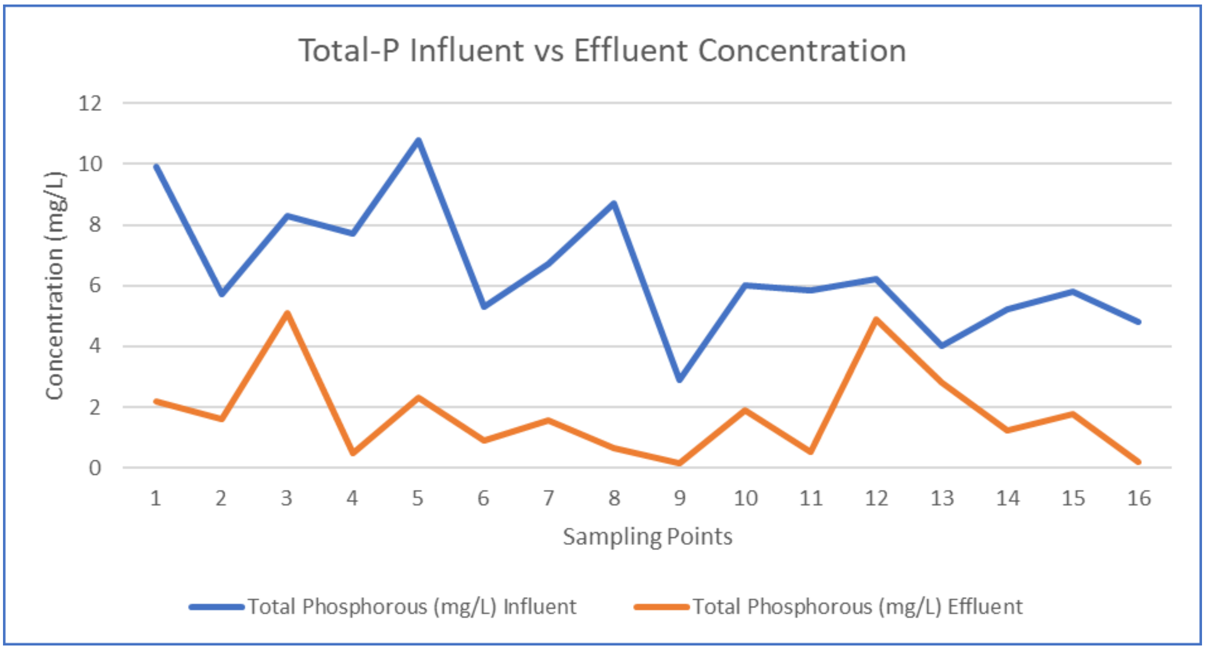

Graph 7: Total phosphorous measurement values of influent and effluent at different times

Table 12: Removal efficiency for Total P for each sampling point

Influent (mg/l)	9.9	5.7	8.3	7.7	10.8	5.29	6.7	8.69	2.9	6	5.84	6.2	4	5.22	5.81	4.79
Effluent (mg/l)	2.2	1.6	5.1	0.5	2.3	0.9	1.57	0.63	0.15	1.9	0.54	4.9	2.82	1.24	1.76	0.21
Removal Efficiency (%)	77.8	71.9	38.6	93.5	78.7	83.0	76.6	92.8	94.8	68.3	90.8	21.0	29.5	76.2	69.7	95.6

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5 Conclusions and Recommendations

The wastewater was treated using the CYCLATOR system which is a sequencing batch reactor process. The raw wastewater (influent) and the treated wastewater (effluent) were collected and analysed over the period of two (2) months in the laboratory. Parameters such as pH, biological oxygen demand (BOD), chemical oxygen demand (COD), ammonium nitrogen (NH_4-N), organic nitrogen, inorganic nitrogen and total phosphorous were studied. The values of such parameters were noted in the influent and effluent and the graph was prepared to interpret the results. The graph clearly shows that the Cyclator has been efficient in treating the wastewater. A significant reduction in the concentration of contaminants was observed in the wastewater after its treatment in the Cyclator. All the parameters were under the discharge standards and it can be concluded that the effluent can be disposed of in the river bodies without causing any harm and danger to aquatic environment.

Our recommendation will be to develop technologies like Cyclator which can treat the wastewater efficiently. Not only in terms of efficient treatment, Cyclator has a less footprint (area needed for the building the wastewater), has a continuous feed forward system (allowing the continuous wastewater treatment without halt) and low investment. Such treatment technologies will encourage the industries and government municipals to install efficient and low-cost wastewater treatment system. The developed countries have the enough financial resources to treat their wastewater. However, poor countries which cannot afford to invest huge sum of money can avail treatment technologies like Cyclator.

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