

Investigating the effective removal of fat, oil and grease (FOG) in water treatment plants of the Mangaung Metropolitan Municipality

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DECLARATION

I, Mpho Gladness Sello, hereby declare that the dissertation titled *Investigating the effective removal of fat, oil and grease (FOG) in water treatment plants of the Mangaung Metropolitan Municipality*, submitted to the Central University of Technology, Free State, for the degree Master of Engineering in Civil Engineering, is my own independent work, and complies with the Code of Academic Integrity, as well as other relevant policies, procedures, rules and regulations of the Central University of Technology, Free State. This dissertation has not been submitted before to any institution by myself or any other person in fulfilment of the requirements for attainment of any degree or qualification.

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ABSTRACT

The most common type of wastewater under low-strength waste streams is municipal wastewater. It is characterised by low organic strength and high particulate organic matter constituents. Common pollutants in municipal wastewater include viruses, bacteria, protozoa, helminths, suspended solids, total dissolved solids, a few chemicals, nitrates, phosphates and fats, oil and grease (FOG). The presence of high concentrations of nitrates and phosphates in wastewater effluent can cause eutrophication of receiving water bodies. On the other hand, FOG in the wastewater treatment plants leads to inefficiencies of the wastewater system, resulting in severe environmental degradation and contamination of water resources. As a result, optimal wastewater treatment technology is one of the most used criteria for the treatment of wastewater.

The activated sludge and trickling filter systems are both known to remove FOG; however, the degree of efficiency of each method against the other in the removal of FOG is not known. The effectiveness and degree of the activated sludge compared to the biological trickling filter system in the removal of FOG showed no difference, since both treatment plants release FOG in their effluents.

This study presented findings from investigating the effectiveness of the wastewater treatment technologies in two treatment plants in the Mangaung Metropolitan Municipality (MMM) in South Africa. The study was conducted to compare the efficiency of the trickling filter and activated sludge systems in the treatment of FOG, nitrogen and phosphorus and the possible correlation of nitrates and phosphates to FOG. The effects of other parameters such as pH, atmospheric pressure, temperature, dissolved oxygen, salinity, conductivity, resistivity and total dissolved solids were also investigated.

Twenty grab samples of both the influent and effluent of the NEWTP and the BWTP were collected in total for the months; June, July, August, September and October. Samples were analysed at the laboratory of the MMM situated at the BWTW. The sampling and laboratory analysis of FOG followed the description of the Environmental Protection Agency (EPA 1664B). The hexane extraction and

gravimetric method was used in the analysis. Nitrates were sampled and analysed using a SOP Chem 005 Spectroquant nitrate test, while phosphates were sampled and analysed using a Spectroquant Prove spectrophotometer in the laboratory. The Hanna HI98192 and Hanna HI98193 multimeters were used for field measurements of pH, dissolved oxygen, temperature, atmospheric pressure, conductivity, resistivity, salinity and total dissolved solids.

The results showed that the trickling filter system from BWTP removed FOG by 61.36%, while the activated sludge system from NEWTP removed FOG by 52.81%, which showed that the trickling filter is more effective than the activated sludge in the removal of FOG. Furthermore, the removal of nitrates and phosphates was found to be within the South African effluent discharge standards of ≤ 2.5 mg/l. 0.99 was found as the regression for BWTW and 1.00 for the NEWTW meaning there is a strong relationship between the presence of nitrates and FOG. Furthermore, In the NEWTW, it was noted that for the duration of the study, phosphate levels were lower in the effluent indicating that the plant is highly effective in eliminating phosphates. 0.00 was found to be the correlation coefficient of phosphates and FOG indicating no correlation. While, correlation was 0.999 for the NEWTW, showing a strong correlation.

In conclusion, the volume of FOG found in the effluents of these plants was influenced by the volume of nitrates and FOG. In addition, the comparison of the trickling filter and activated sludge systems indicated that the trickling filter system is an efficient treatment method for the treatment of FOG, compared to the activated sludge system.

Key terms: activated sludge, FOG, nitrates, phosphates, trickling filter, wastewater treatment

DEDICATION

This study is dedicated to God Almighty, my creator, for giving me the inspiration, wisdom, strength and endurance to complete this dissertation.

I also dedicate this work to my mother, Pauline Sello, and grandmother, Mamotsoari Sello, for their encouragement in my studies.

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LIST OF ABBREVIATIONS

ABR	Anaerobic baffled reactor
BOD	Biological oxygen demand
BWTW	Bloemspruit wastewater treatment works
COD	Chemical oxygen demand
DAF	Dissolved air flotation
DO	Dissolved oxygen
EGSB	Expanded granular sludge beds
EPA	Environmental Protection Agency
FOG	Fats, oil and grease
MMM	Mangaung Metropolitan Municipality
NEWTW	North eastern wastewater treatment works
PVC	Polyvinyl chloride
TDS	Total dissolved solids
UNESCO	United Nations Educational, Scientific and Cultural Organization
UASB	Up-flow Anaerobic Sludge Blanket
USEPA	United States Environmental Protection Agency

LIST OF UNITS

°C	degrees Celsius
°F	degrees Fahrenheit
%	percentage
ℓ	litre
g/ℓ	gram per litre
mℓ	millilitre
mg/ℓ	milligram per litre
m/h	metre per hour
mm	millimetre
mmHg	millimetres of mercury
mg	milligram
mm ³	Cubic metre
ML	Megalitres
mS/cm	milliSiemens per centimeter
N	Normality
Pa	Pascals
ppm	Parts per meter
ppt	Parts per trillion
S/cm	Conductivity Siemens per meter

ACADEMIC OUTPUT FROM THIS DISSERTATION

Conference paper

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CHAPTER 1

INTRODUCTION TO THE STUDY

1.1 Background to the problem

An adequate, clean and safe drinking water supply has to be available for various users (Bos et al., 2016). A great volume of wastewater is brought about by urbanisation advancement and human population increase, which results in an unsafe environment (Jonnalagadda & Mhere, 2001). As a result, poorly treated wastewater effluent creates an unfavorable environment for the surrounding habitat, therefore wastewater treatment technologies are frequently modified to address the current concerns. For this reason, it is of great importance to adequately treat wastewater prior to its disposal or reuse to avert pollutants from entering the receiving water bodies (Edokpayi et al., 2017).

Different types of wastewater are treated using different technologies. There are terrestrial wastewater treatment systems, municipal wastewater treatment plants, as well as domestic and industrial wastewater treatment systems. Municipal wastewater treatment deals with wastewater from household sewage, both run-off, domestic and institutional. It involves basic processes such as primary treatment which eliminates solid material, secondary treatment to break down dissolved and suspended organic material, and tertiary treatment to disinfect (Wells, 2016). Wastewater treatment is a combination of processes used in steps to remove, kill, or “inactivate” a large portion of the pollutants and disease-causing organisms in wastewater.

There are many technologies used for treating wastewater. Some of the technologies for treating municipal wastewater are the biological trickling filter system, which was used in the old days, and activated sludge which is a more recently introduced technology. The biological trickling filter technology is an aerobic treatment system that utilises microorganisms connected to a medium to eliminate organic matter from wastewater, while the activated sludge process is a part of the anaerobic process that falls under the biological treatment process (Gray, 2004).

Water quality and safety can be evaluated by assessing the concentration of dispersed fats, oil and grease (FOG) (Osibanjo et al., 2011; Westerhoff et al., 2018). FOG in discharged water can cause surface films and shoreline deposits contributory to environmental deterioration which poses health risks for humans when discharged in surface or groundwater (Pisal, 2010). Disposal of FOG in the wastewater treatment plants leads to inadequate wastewater treatment which leads to serious environmental deterioration and pollution of receiving water bodies (Edokpayi et al., 2017). In addition, FOG draws on an additional load of organic matter onto the secondary aerobic treatment stage, consequently increasing the total aeration requirement (Collin et al., 2020). FOG can also interfere with the co-digestion process because of its settling or floating characteristics. Settling is an important process in wastewater treatment plants that happens in primary sedimentation tanks and secondary sedimentation tanks, (Torfs et al., 2016). FOG is also implicated in causing sewer blockages leading to sewerage system overflows (Lasmin et al., 2014).

Apart from FOG, high concentrations of nitrogen and phosphorus in wastewater can cause eutrophication of receiving water bodies (Mujtaba et al., 2018). Nitrates and phosphates in wastewater emanate from wastes of animals and humans (De Girolamo & Lo Porto 2020; Li et al., 2018). In the aquatic environment, nitrates are contributory to several issues. For instance, the existence of nitrate in water causes algal revolution or eutrophication, which is the formation of algae mats, which obstruct sunlight and speed the use of dissolved oxygen (DO), resulting in the death of aquatic life (Guo et al., 2013). The rise in nitrate concentration has a serious effect on water ecosystems, leading to eutrophication and toxic algal blooms (Hoagland et al., 2019), while phosphate increase largely impairs the aquatic ecosystem, thus creating an environmental concern (Mavhungu et al., 2019).

1.2 Problem statement

The Bloemspruit wastewater treatment works (BWTW) of Mangaung, was constructed in 1902 and uses the biological trickling filter system. However, due to the rise in population, it became hydraulically overloaded hence the construction of the north eastern wastewater treatment works (NEWTW) in 2014, which uses an activated sludge system (Mail & Guardian, 2014). The rate of effectiveness of the

activated sludge technology in the removal of FOG, in comparison to the biological trickling filter system, is the same as the two treatment plants release FOG in their effluents as well as nutrients.

It has been noted that there are repetitive incidents of sewer blockages in Mangaung, which result from FOG accumulation in pipes. Furthermore, the two municipal treatment plants discharge FOG into the river catchment, which negatively affects the surrounding habitat. Stams and Elferink (1997) reported inadequate treatment of FOG in sewage treatment works has dangerous environmental impacts. On this basis, an investigation of the performance of the treatment works and their efficiency in the removal of FOG, nitrogen and phosphorus was carried out. No other studies have been conducted that established the correlation of nitrogen and phosphorus to FOG in municipal wastewater with activated sludge and biological trickling filter systems.

In response to this knowledge gap, this study evaluated the effectiveness of the two plant treatment technologies in the elimination of FOG and nutrients and explored the likely link between the amounts of FOG and nutrients released to the catchment post treatment. As reported by Rittman and McCarty (2010), the concentration of the contaminants treated, the presence or absence of oxygen, the efficiency and reliability of treatment, operating costs and construction times influence the pollutants treated and the effectiveness of the two treatment plants.

1.3 Research questions

- Is the activated sludge technology more efficient than the trickling filter technology in the elimination of FOG?
- Is the activated sludge technology more efficient than the trickling filter technology in the removal of nutrients?

1.4 Research hypotheses

Associated hypotheses with the above research questions include a null hypothesis that the activated sludge is more effective than the trickling filter technology in the removal of FOG and nutrients from wastewater in municipal wastewater treatment. Additionally, it is essential to conduct more scientific studies between the two

technologies to fully establish the difference between the two technologies. In this way, the discrepancy between the two technologies would be clearer.

1.5 Aim and objectives

The main aim of this research was to investigate the effectiveness of two treatment technologies used in wastewater treatment for the elimination of FOG and nutrients, by measuring the amount of FOG in the influent and effluent of the BWTW and NEWTW in the MMM.

1.5.1 Objectives

The objectives of this study were:

- To determine the effectiveness of the two wastewater treatment technologies in the elimination of FOG and nutrients.
- To investigate the need for extra pre-treatment measures to the plants for improvement in the elimination of FOG.
- To investigate the likely impact of FOG and nutrients released to the catchment after treatment.

1.6 Significance of the study

This study sought to investigate if there was a difference between the activated sludge and the trickling filter technologies in the removal of FOG in two wastewater treatment plants of the MMM. The NEWTW was built to relief the BWTW, which was hydraulically overloaded due to its capacity being unproportioned to the growing city of Mangaung. In addition, sewer blockages and overflows were frequently noted in Mangaung because of the accumulation of FOG in the pipes. Similarly, FOG was found in the effluent of the two plants, which is discharged in the river catchment, thus negatively impacting the ecosystem. FOG in effluents causes detrimental environmental impacts to aquatic life and health risks to humans, hence efficient treatment of wastewater containing FOG is critical.

1.7 Scope of the study

The study focused on the amount of FOG present in two municipal wastewater treatment plants of the MMM, namely the BWTW, which uses the trickling filter technology, and the NEWTW, which uses the activated sludge technology. The study further investigated the nitrogen and phosphate levels in the effluent. The BWTW discharges into a nearby stream, which can prove to be detrimental to the aquatic life if found in large quantities. The study also focused on other parameters such as salinity, conductivity, temperature, pH, atmospheric pressure, resistivity, total dissolved solids (TDS) and DO, which contributed to analysing the performance of the two technologies, the relationship between the parameters with regard to the performance of the two wastewater plants and the correlation of the parameters in the removal of FOG.

1.8 Limitations of the study

The study was limited to the investigation of the efficiency of the trickling filter and activated sludge systems in the removal of FOG, and its correlation with nitrates, phosphates pH, conductivity, resistivity, salinity, atmospheric pressure, DO and temperature. The study did not consider the following:

- Investigation of the two technologies in the removal of nitrogen and phosphorus.
- Efficiency of the two technologies in the removal of different pollutants.
- Removal of FOG in other wastewater plants in the MMM.

1.9 Structure of the dissertation

Chapter 1: Introduction

This chapter summarises the content of the study, starting with the background of the study, the problem statement, the research questions, the hypotheses and the research objectives. It also describes the significance and scope of the study as well as the limitations of the study.

Chapter 2: Literature Review

In this chapter, various studies, surveys, scientific articles and literature that provides a description, summary and critical evaluation of FOG in municipal wastewater treatment are reviewed.

Chapter 3: Study Area

This chapter describes the study area of the two wastewater treatment plants in detail. It surveys the significant demographic and environmental characteristics of the case study. It describes the relevant area directly related to the research and it defines FOG in municipal wastewater treatment by being location-specific.

Chapter 4: Research Methodology

In this chapter, specific procedures or techniques used to identify and analyse FOG in municipal wastewater systems are discussed. It outlines the research methodology, justification for using quantitative research, sampling, testing, data analysis, validation of data, control, challenges and implications of the project.

Chapter 5: Results and Analysis

This section presents the findings of the study derived from the methods applied to gather and analyse the information. It presents these findings in a logical sequence and breaks down the data into sentences that show its significance to the research questions.

Chapter 6: Conclusion

This chapter concludes the thesis. It includes a summary of the findings of the research, conclusions and recommendations based on the data analysed in the previous chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The result of an increase in human population and urbanisation growth is the production of a huge amount of wastewater that creates challenges for a safe environment (Jonnalagadda & Mhere, 2001). This causes a discharge of poorly treated wastewater that negatively affects the receiving water bodies (Edokpayi et al., 2017). As a result, proper wastewater treatment remains a critical issue globally, despite various technological advancements and breakthroughs (Chai et al., 2021). This necessitates the consideration of a more advanced technology in treating wastewater; hence, wastewater treatment technology is fast changing to meet the current daily challenges (Armah et al., 2020). Wastewater needs to be adequately treated prior to its disposal or reuse in order to protect receiving water bodies from contamination (Edokpayi et al., 2015).

Different technologies are used in wastewater treatment, namely terrestrial wastewater treatment systems, municipal wastewater treatment systems, and domestic and industrial wastewater treatment systems. Municipal wastewater treatment deals with wastewater from household sewage, both runoff, domestic and institutional. It mainly comprises of 99.9% water, together with relatively small concentrations of suspended and dissolved organic and inorganic solids. The organic substances present in municipal wastewater may include carbohydrates, lignin, fats, soaps, synthetic detergents, proteins and their decomposition products, as well as various natural and synthetic organic chemicals (Pereira et al., 2014). Furthermore, it involves basic processes such as preliminary treatment to separate easily removed particles such as bulky floating or suspended solids and grit (Enfrin et al., 2019; Pal, 2017a). Second is the primary treatment that removes up to 70% of solid material (Horan, 1990). Third is the secondary treatment to digest dissolved and suspended organic matter (Abdel-Raouf et al., 2012) and lastly the tertiary treatment to disinfect (Wells, 2016).

One of the common pollutants of municipal wastewater is FOG. The presence of FOG has proven to have adverse effects on the wastewater treatment plants and aquatic life in which it is sometimes discharged into; hence, the effective removal of FOG is essential (Alade et al., 2011).

2.2 What is FOG?

Fat, oil and grease are the end products of cooking (Husain et al., 2014). FOG may include matter such as food scraps, slaughterhouse meat fats, soaps, detergents and certain dyes (Arthur & Blanc, 2013; Husain 2014). FOG exists in different forms such as solid and liquid, based on the saturation of the carbon chain (Husain et al., 2014).

2.2.1 Chemical composition of FOG

Oil and grease are quite similar chemically compounds (esters) of alcohol or glycerol with fatty acids (Biermann et al., 2011). At room temperature, liquid fatty acids at room temperatures are called oils, while solids are called grease (Franklin et al, 2004). Fats and oils are complex mixtures of triacylglycerol, of which the fatty acid composition varies on the basis of the origin of the organism (Gunstone, 2004).

2.2.2 Physical properties of FOG

FOG may be in the form of a liquid or solid and is identified by a greasy texture. In its unblended state, FOG is colourless, odourless and tasteless. Moreover, FOG is insoluble in water but soluble in organic solvents such as hexane, ether, and chloroform (Sincero & Sincero, 2003). FOG has a density less than water (specific gravity <1); it thus floats on the water surface. In addition, FOG will form emulsions with aqueous media in the presence of soap or other emulsifying agents (Patrick, 2012).

FOG has a high viscosity that varies based on the fatty acid composition and presence of double bonds. The more double bonds present in the carbon chain, the lower the viscosity of FOG because of its more loosely packed structure (Firestone, 2006). The presence of a large amount of free fatty acids in FOG, which are generally formed by the hydrolysis and oxidation reactions of oils during deep frying of food, results in a characteristically low pH of FOG (Patrick, 2012).

2.2.3 Where does FOG come from?

FOG enters the sewerage system from restaurants and residences (Husain et al., 2014). Kitchen greywater is reported as the highest contributor of FOG in domestic greywater, although oil and grease are present in all greywater streams (Friedler, 2004). In addition, some food processing industries such as slaughterhouses, dairy and meat packing industries are well known for producing effluents containing FOG (Bustillo-Lecompte & Mehrvar, 2015). FOG containing wastewater is also sourced from non-vegetable manufacturing industries such as the steel, machine, petroleum refining, metal cutting and metal forming, and textile industries (Wake, 2005). Municipal wastewater may also contain FOG from small industries. Oily wastewater from the metalworking and finishing industries is generated from the application of coolants and lubricants used for cooling the work pieces and machine tools, reducing friction and wear of tools and dyes, as well as improving the surface quality of work pieces (Busca, 2004). Therefore, the concentration of FOG in raw domestic wastewater is invariably in the range between 50 mg/l and 100 mg/l (Franklin et al, 2004).

2.3 Problems caused by the presence of FOG

2.3.1 Sanitary sewer overflows

The reaction between FOG and calcium found in wastewater may cause sanitary overflows due to the built-up of insoluble calcium salts of fatty acids (Dominic et al., 2013). FOG deposits account for 40–50% of sewerage overflows nationwide and are an indirect cause of another 10–25% (Southerland, 2002; USEPA, 2003). Ultimately, this sewage may land in state water bodies as a pollutant (Husain et al., 2014). In the United Kingdom, over 15 million pounds is spent on dealing with sewer blockages, clearance, along with the additional cost of cleaning up after flooding incidents yearly (Arthur & Blanc, 2013).

2.3.2 Clogging of pipes

FOG causes clogging of sewers in treatment units that need cleaning and may cause replacement of pipes (Keener et al., 2008). As a result, wastewater treatment plants may lead to increased maintenance and running costs (Mueller et al., 2003).

Furthermore, a constant built-up of FOG lowers the sewerage system capacity as the FOG solidifies and deposits on the interior walls of the sewers, subsequently causing blockage of pipes and hence restricting the wastewater flow (Husain et al., 2014). As a result of blockage, FOG deposits may corrode the sewerage system, increase the frequency for cleaning and maintenance, and notably increase the volume of solid waste that reaches the wastewater treatment works. An overloaded wastewater treatment plant may result in a decrease in quality of the output from the treatment process (Aymong, 2007).

2.3.3 Interference with wastewater treatment processes

When large amounts of FOG are discharged to receiving wastewater from community systems, they increase biological oxygen demand (BOD) and they may float to the surface and harden, causing aesthetically unpleasing conditions (Kasima, 2014). FOG reduces DO levels and elevates BOD in the water due to the formation of an oil layer on the water surface that inhibits oxygen transfer from the atmosphere (Sahu et al., 2007). Furthermore, FOG may partially block screens and trickling filter systems, clog sludge pumps, and in large volumes, decrease the activity of sludge-digesting microorganisms (Fulazzaky & Omar, 2012). This may lead to a reduction in the quality of outputs from the treatment process (Aymong, 2007). Furthermore, FOG creates floating scum that disrupts wastewater treatment processes (Klaucans & Sams, 2018). This poses a serious risk for the anaerobic biological process (Cammarota et al., 2001; Masse et al., 2001, Vidal et al., 2000). A high concentration of wastewater containing long-chain fatty acids has been observed to cause the inhibition in anaerobic treatment (Hwu et al., 1996). In addition, FOG creates problems such as the production of foul odours that interfere with the proper operation of sewage treatment works (Brooksbank et al., 2007).

2.3.4 Environmental impacts of FOG discharged into streams

The blockages and sewage flooding caused by FOG may result in environmental problems in the immediate and surrounding habitats (Chand and Kumar, 2017; Husain et al., 2014; Madanhire and Mbohwa et al., 2016). As a result, the concentration of FOG in wastewater streams increases adverse effects on the ecology (Alade et al., 2011). FOG in water bodies leads to the formation of an oil

layer that causes significant pollution problems, such as reducing light penetration and photosynthesis (Alade et al., 2011). Furthermore, it inhibits oxygen transfer from the atmosphere to the water medium and this leads to a reduced amount of DO at the bottom of the water, which adversely affects the survival of aquatic life in water (Mohammadi & Esmaelifar, 2005).

2.4 Removal of FOG

Different technologies are used in municipal wastewater treatment all over the world, namely aerobic technologies and anaerobic technologies. Aerobic wastewater treatment systems use oxygen-feeding bacteria, protozoa and other specialty microbes to clean water, whereas anaerobic treatment systems use a biological process where microorganisms degrade organic contaminants in the absence of oxygen (Englande et al., 2015). The activated sludge and the biological trickling filter are aerobic systems. Treatment in these two methods comprises the following stages: preliminary treatment, primary treatment, secondary treatment and tertiary treatment (Templeton & Butler, 2011). Other methods of removing FOG include physical and chemical methods, physicochemical, combined methods, treatment using biosurfactant and biological treatment using enzymatic activity (Azhdarpoor et al., 2014; Lafi et al., 2009). Some of the processing factors include concentration, size of droplets and the physical nature of FOG that are the main governing parameters for the extent of removal of oil (Coca et al., 2011).

2.4.1 Aerobic treatment of FOG

2.4.1.1 Preliminary treatment or primary treatment

Pre-treatment involves processes such as screening, catch basins, flotation, equalisation, and settlers for reclaiming of FOG (Mittal, 2006). Screens and filters are used to remove suspended solids in wastewater (Gibson et al., 2020). Solid particles may consist of FOG, paper, rags and hair. In addition, wastewater in this stage passes through strainers. Strainers are made of metal wire and can intercept particles of various sizes based on the mesh size of the strainer (Shengquan et al., 2008). The separation of coarser particles in most wastewater treatment plants is based on gravity and one of the by-products of this process is separated FOG (Gutu

et al., 2021). Catch basins can also be used to remove FOG and finely suspended solids by gravity. FOG and the fine solids will rise to the surface. While solids heavier than water, sink to the bottom (Kaya & Hung, 2021). Furthermore, FOG and scum are removed at the top by using a skimmer, while a scraper is used to remove sludge from the bottom (Mbulawa, 2017). Free floating FOG can also be removed using gravity separators in primary treatment (Pintor et al., 2016).

2.4.1.2 Secondary treatment

Biological treatments eliminate organic compounds and pathogens from the effluent using microorganisms (Roy & Saha, 2021). More than 90% of pollutants can be removed from wastewater using biological treatments (Mittal, 2006). Biological treatment happens in the secondary treatment, which includes secondary settling and the processes of aeration in an activated sludge system.

2.4.1.3 Tertiary treatment

In this stage, physical and biological processes are carried out and complete the removal of both organic microorganisms before the reuse of water, as well as nitrogen and phosphorus. The disinfection unit may also be used for bacterial removal (Abdel-Fatah et al., 2016).

2.4.1.4 Activated sludge

The activated sludge process is a suspended growth biological treatment process in which a mixture of wastewater and biological sludge, composed of microorganisms, is agitated and aerated (Rezai & Allahkarami, 2021). Air is provided through diffused or mechanical aeration (Niaounakis & Halvadakis, 2006). The microorganisms are thoroughly mixed with the organic compounds and utilise this organic matter as their food source (Hansen & Cheong, 2019). As the microorganisms grow and are mixed by agitation of the air, the individual organisms clump together (flocculation) to form a biological floc, an active mass of microbes called activated sludge (Yildiz, 2012).

The mixture of activated sludge and wastewater in the aeration tank, called mixed liquor, contains a variety of heterotrophic microorganisms such as bacteria, protozoa, fungi and larger microorganisms (Pike & Curds, 1971). This mixed liquor

flows from the aeration tank to the final clarifier where the activated sludge is settled out (Ahansazan et al., 2014). Following this, the activated sludge is separated from the wastewater and most of the settled sludge is returned to the aeration tank to maintain a high population of microbes (Singh et al., 2016).

Due to the excess production of activated sludge produced in the process, some of the return sludge is diverted or wasted to sludge systems (Sharma et al., 2021). If a lot of sludge is wasted, the concentration of microorganisms in the mixed liquor will become too low for efficient treatment. If a low volume of sludge is wasted, a large concentration of microorganisms will accumulate, causing the secondary tank to overflow into the receiving system (Theobald, 2014). The return sludge is an important feature of the activated sludge process as it ensures that the mean cell residence time or sludge age defined as the average amount of time that microorganisms are kept in systems is much greater than the hydraulic retention time (Deowan et al., 2015). This practice helps to maintain a large number of microorganisms able to effectively oxidise organic compounds in relatively a short time, which can then be recycled. The retention time in the aeration tank varies from four to eight hours (Pal, 2017b).

In Figure 2.1, which shows the activated sludge process, the preliminary treatment consists of screening, flow measurement, and grit removal (Pintor et al., 2016). The second component, the primary clarifier, is used to remove settleable suspended matter (Henneman et al., 2018). The underflow goes to sludge treatment and disposal and the overflow goes to an aeration tank (Kamizela & Kowalczyk, 2019). It is in this stage that biological oxidation of dissolved and fine suspended organic matter takes place.

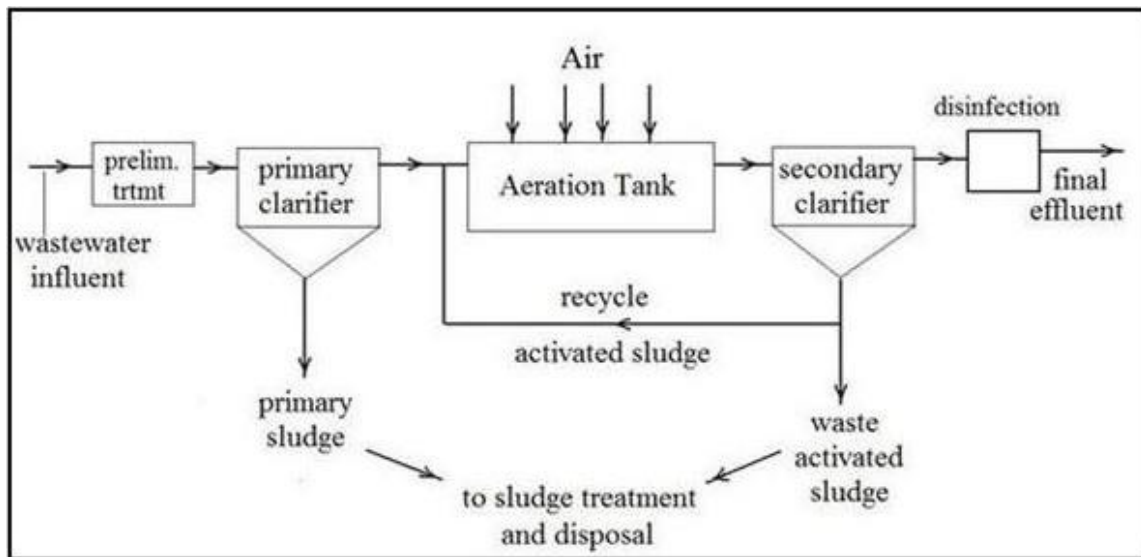


Figure 2.1 Activated sludge flow diagram (Sastry, Rao & Nahata 2013)

The biological oxidation takes place because aerobic microorganisms, organic matter and DO are all brought together in the aeration tank (Amin et al., 2020). Following this, the organic matter comes in with the primary effluent. The DO is then preserved by blowing air into the aeration tank through diffusers (Piotrowski, 2015). A satisfactory consolidation of microorganisms is kept in the aeration tank by settling out the “activated sludge” in the secondary clarifier and reclaiming them back into the aeration tank. FOG compounds are soaked up in wastewater through flocculation and then are metabolised slowly (He et al., 2013). Lipase is also an important enzyme for the removal of FOG (Mobarak-Qamsari et al., 2012; Rigo et al., 2008).

A study done from June to September 2011 in Iran at the Shiraz municipality wastewater treatment reported the average removal efficiency to be 70% (Dehghani et al., 2014) and the FOG removal efficiency met the effluent standards. The FOG removal efficiency range of wastewater treatment was 59–85% with an average of 70%. Furthermore, Dehghani et al. (2014) noted the average removal rate to be 70%. Nonetheless, it was discovered that the removal rate of FOG using activated sludge, was substantially built upon the volume of FOG in the wastewater treatment.

Another study investigated the build-up of a range of cultures using FOG from a fast-food restaurant grease-trap. The results indicated a more consistent removal from the activated sludge, which was greater than 90% (Wakelin & Forster, 1997).

Although other studies noted the successful removal of FOG, a study done by Reddy et al. (2003) reported that because to the short retention times, the microflora in activated sludge systems did not degrade FOG effectively. Furthermore, the study done by Chipasa and Mdrzycka (2008) reported that the volume of the retained FOG could not surpass 15% of the initial FOG. The results showed discrepancies in the build-up of single fatty acids in wastewater, which had also been used by microorganisms as feedstock.

2.4.1.5 Trickling filter

A trickling filter is a bed with a specific surface area material, such as shredded polyvinyl chloride (PVC) bottles, crushed rocks, gravel, or special pre-formed plastic filter media to form a biofilm (Rezai & Allahkarami, 2021). Trickling filters are used to eliminate organic matter from wastewater (Dhokpande et al., 2014). The trickling filter is aerobic and uses microorganisms attached to a medium to remove organic matter from wastewater (Jalowiecki et al., 2016). Figure 2.2 shows the trickling filter.

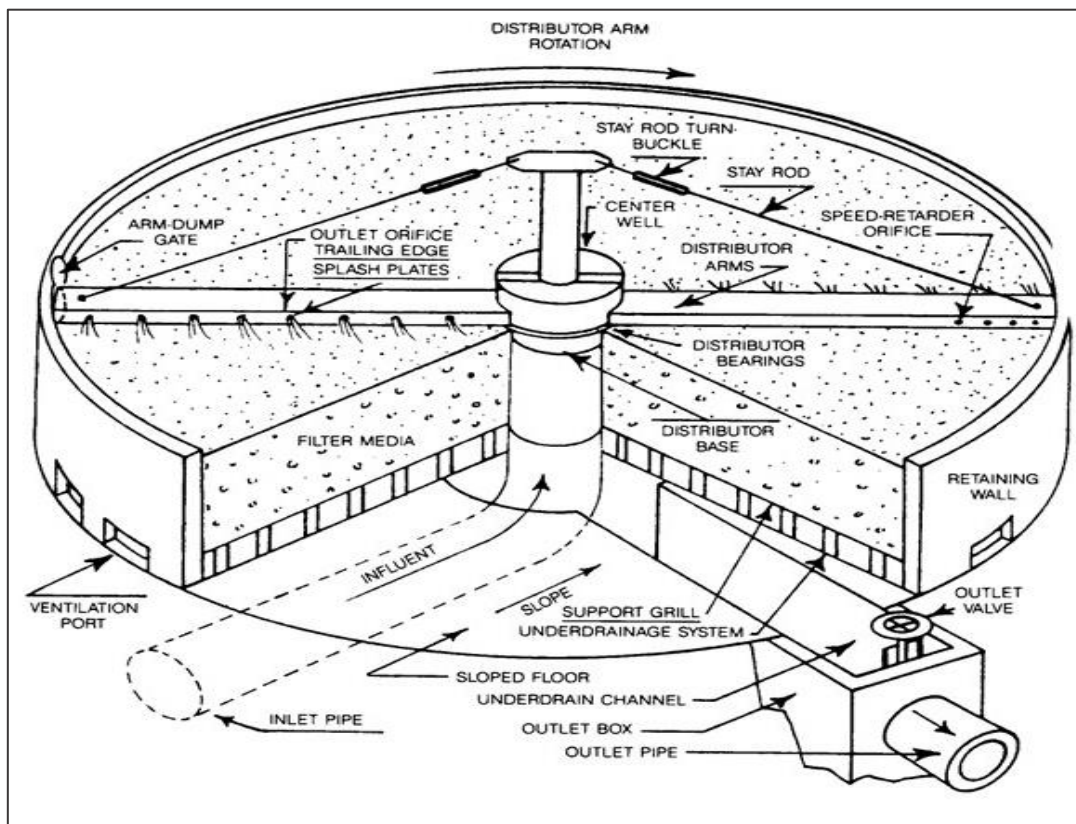


Figure 2.2 *Trickling filter* Tchnobonaglou et al. (1991)

The trickling filter system shown in Figure 2.2 includes a distribution system (Daigger & Boltz, 2011). A rotary hydraulic distribution is generally standard for this process; however, fixed nozzle distributors are also being used in square or rectangle reactors (Cabrera et al., 2019). Distributors can be set up to be mechanically driven at all times or during stalled conditions (Solum & Deming, 1992). In addition, a trickling filter has an underdrain system that collects the filtrate and solids, and also provides air for the microorganisms on the filter. The treated wastewater and solids are piped to a settling tank where the solids are segregated (Voutchkov, 2005).

Generally, a portion of the liquid from the settling chamber is recirculated to enhance wetting and flushing of the filter medium, advancing the process and elevating the removal rate (Daigger & Boltz, 2011). It is crucial that there is adequate air for the successful operation of the trickling filter. It has been found that to supply air to the system, natural draft and wind forces are normally proportionate if large enough ventilation ports are available at the bottom of the filter and the medium has a large enough void area (Butler & Boltz, 2014). Four basic categories of filter designs exist, which are based on the organic loading of the trickling filter: low-rate filters, intermediate-rate filters, high-rate filters and roughing filters (Muralikrishna & Manickam, 2017).

Pre-settled wastewater is continuously “trickled” over the filter. As the water moves through the pores of the filter, organics are aerobically degenerated by the biofilm covering the filter material. This filter material can be rocks, gravel, shredded PVC bottles, or special pre-formed plastic filter media. Organisms that grow in the thin biofilm formation over the surface of the media oxidise the organic load in the wastewater to carbon dioxide and water, while generating new biomass. The incoming pre-treated wastewater is “trickled” over the filter. In this way, the filter media goes through cycles of being dosed and exposed to air. Oxygen is consumed within the biomass and the inner layers may be anoxic or anaerobic (Rezai & Allahkarami, 2021).

The trickling filter is an extremely favored option of biological treatment because it is easy to maintain and control (Abou-Elela et al., 2017). Conversely, the biggest drawback of the trickling filter process is its poor dependability in the elimination of

nitrogen and phosphorus compared to the activated sludge (Franklin, 2004). For this reason, its limited ability for nutrient removal has led to the decrease in use of trickling filter though they are effective and power-saving treatment systems (Cramer et al., 2021). In addition, a study done by Kurian and Nakhla (2006), evaluated different methods in the removal of FOG. The results indicated that the membrane methods eliminated more than 90% of FOG. FOG removal efficiency by membrane methods was more than the conventional active sludge.

2.4.2 Anaerobic technologies of treating FOG in municipal wastewater

Anaerobic digestion is a biochemical process of degradation of complex insoluble organic matter with the help of a wide range of microbial communities in the absence of oxygen to form methane and carbon dioxide (Jiang et al., 2015). Similar to most of the biological processes, efficient operation of anaerobic digestion is built upon different environmental factors such as temperature, pH, availability of nutrients, carbon-to-nitrogen and carbon-to-phosphorus ratios, presence of inhibitory and toxic substances (Elalami et al., 2021). With so many related parameters, damage of digesters due to minor alterations is a common occurrence (Mata-Alvarez et al., 2000). In anaerobic processes, the microbes conduct respiration without oxygen, and in some cases oxygen is toxic to the microbes (Zia & Sreekrishnan 2016).

Although co-digestion has been claimed to have various benefits, studies investigating the anaerobic digestion of high-strength lipid wastes have also reported several operational challenges. These challenges include the deterioration of acetoclastic and methanogenic bacteria, substrate, and product transport limitation, sludge flotation, digester foaming, blockages of pipes and pumps, and clogging of gas collection and handling systems (Shea et al., 2010). Studies showed that wastewater containing a high volume of FOG is related to filamentous bulking during wastewater treatment and results in clogging and mechanical problems in anaerobic treatment units (Cammarota et al., 2001).

2.4.2.1 Anaerobic lagoons

Lagoons are one of the ancient and easy forms for domestic and industrial waste and are used broadly for agricultural industries such as piggeries, tanneries and

abattoirs (Woodard & Curran 2006). In Australia, lagoons have been adopted as a technology for treating agricultural wastewater as a result of their simplicity to construction and application (Laginestra & Van-Oorschot, 2009). As a result, anaerobic ponds are predominantly used in the meat industry as the first stage of secondary treatment of high-strength abattoir wastewater and are an effective means whereby the BOD and chemical oxygen demand (COD) can be reduced by close to 90% (McCabe et al., 2014). However, their downside is the production of odour emissions and the formation of methane (Selvakumar et al., 2022). Nonetheless, anaerobic lagoons are known to be highly adequate in the removal of FOG (Astals et al., 2014; Jensen et al., 2011; McCabe et al., 2014). Anaerobic lagoons in Australian slaughterhouses were found to be effective in the removal of FOG (McCabe et al., 2014).

2.4.2.2 Up-flow anaerobic sludge blanket

The functioning of an up-flow anaerobic sludge blanket (UASB) reactor is dominated by its granular sludge bed that gets extended as the wastewater is made to flow vertically upwards through it (Abbasi & Abbasi 2012). The UASB layout allows a notably accomplished blending between the biomass and the wastewater, resulting in an accelerated anaerobic decomposition (Tauseef et al., 2013). In this technology, wastewater enters at the bottom of the reactor and flows upwards through the commonly named “sludge blanket” comprising of a granular sludge bed (Tauseef et al., 2013). The microflora connected to the sludge particles removes the pollutants in wastewater, thus biofilm characteristics and the intensity of sludge–wastewater contact are some of the key elements controlling the UASB reactor performance. The standard layout and operational properties of a UASB reactor include a height-to-diameter ratio of 0.2–0.5 and an up-flow velocity of 0.5–1.0 m/h (Lim & Kim 2014). The UASB are very effective in the removal of FOG. A study done by Musa et al. (2019), assessing three UASBs, reported that the FOG removal rates using a UASB, were 89%, 81% and 74% in slaughterhouse effluent.

2.4.2.3 Expanded granular sludge beds

Expanded granular sludge beds (EGSBs) are much the same as the UASB technology, with the main difference being that the wastewater is recirculated

through the system to enhance substantial contact with the sludge (Cruz-Salomón et al., 2019). EGSBs are capable of treating streams with lots of organics (Gutierrez et al., 2022). Furthermore, the EGSB is an affordable, powerful and more favoured technology due to its ability to function using a fluidised bed that permits a rising organic load during cell retention times, increasing treatment efficiencies (up to 95%) and renewable energy (Cruz-Salomón et al., 2019). Nevertheless, the effectiveness of this bioreactor is mainly dependent on the functional conditions (Mahat et al., 2013). Furthermore, the drawback of the EGSB is that it needs a DAF system in the removal of FOG, as the performance of the entire process was noted to decline gradually as a result of the presence of a high quality of FOG (Basitere et al., 2015). However, in a research done by Meyo et al. (2021), the efficiency of the EGSB in removal of FOG was reported to be greater than 95%, following pre-treatment, and 83% FOG removal during pre-treatment.

2.4.2.4 Anaerobic baffled reactors

Anaerobic baffled reactors (ABRs) are built with semi-enclosed chambers holding a sizeable active microbial mass and positioned to drive the wastewater under and over (or through) the baffles, covering the whole surface of baffles and permitting contact between influent wastewater and biomass (Pal 2017a). ABRs are not effective in the removal of FOG. It was reported that the average removal efficiency for FOG was 41% in hog farming effluents, with ABR as the first stage in the biological treatment. This ABR composed of three chambers functioning as the first stage of a biological treatment system for swine wastewater for a duration of 116 days (Motteran et al., 2013). Similarly, only 50% of FOG was removed by the ABR in a study investigating the treatment of domestic wastewater using an ABR (Nasr et al., 2009).

2.4.2.5 Anaerobic filter reactors

An anaerobic filter is made of packed material produced using any non-degradable, shaped material or polymer that has a high surface-area-to-volume ratio (Chelliapan et al., 2020). The packed materials allow anaerobic microorganisms to connect and spread like a biofilm, creating an anaerobic channel mat (Heeg et al., 2014). Different matter such as plastics, sandstone, granular activated carbon,

granite quartz or reticulated foam polymers can be used for the packed materials (Selvakumar et al., 2022). Low or high quality water can be treated using this reactor (Kosseva 2011). However, because of its considerable advantages over aerobic processes such as lower nutrient requirement, less surplus sludge production, and energy recovery via methane production, the anaerobic filter process has recently been frequently used for the treatment of miscellaneous wastewaters (Lee et al., 2006).

Anaerobic filter reactor has overall adequate support and filter media function as a natural boundary against biomass decrease, particularly in the treatment of wastewater containing FOG (Alves et al., 2000, Martin et al., 2010). This is an evident dominance for anaerobic filters compared to other anaerobic processes (Chanakya & Khuntia, 2014). However, there are some drawbacks with this method, which are mostly physical difficulties to the degeneration of the composition of the bed by the growth of non-biodegradable solids; hence, the need for channelling and shortcutting the flow (Chelliapan et al., 2020). Additionally, the performance of the bioreactor fluctuates, based on the organic loading rate, hydraulic retention time, and wastewater type (Omil et al., 2003). Nearly full elimination of phenol was recorded from oil refinery wastewater at an eight hour hydraulic retention time (Jou & Huang 2003).

2.4.3 Chemical methods of removing FOG in wastewater

2.4.3.1 Dissolved air flotation

The DAF method has been commonly used as a substitute to sedimentation in the field of water treatment when water contains low-density particles that are inclined to sink slowly or to float (Kempeneers et al., 2001). Li et al. (2007) tested DAF and column flotation together to the tower separation system for oily wastewater treatment, to obtain a high oil–water separation rate. Additionally, Dassey and Theegala (2012) found a FOG removal efficiency of nearly 100% in a study assessing coagulation pre-treatment on poultry processing wastewater for DAF.

2.4.3.2 Induced air flotation

Induced air flotation is a flotation process with a backup bubble generation system (Fagkaew et al., 2022) which relies on gravity (Chalermssinsuwan et al., 2016e; Silva et al., 2018). Induced air flotation employs the centrifugal force of a high-speed backspin impeller through which gas is introduced at the top and liquid at the bottom (Zheng & Zhao, 1993). The gas and liquid become fully interlaced and, after traversing through a disperser outside the impeller, form an assemblage of gas bubbles, thus finishing the flotation separation operation of a solid or liquid–liquid heterogeneous system. Induced air flotation is one of the very efficient ways for eliminating FOG from wastewater (Zlokarnik, 1998). However, the efficacy of induced air flotation is built upon the introduction of chemical additives. Bennett and Shammass (2010) conducted a study that reported that FOG elimination ranged from 48% outside the use of chemical additives to 63% with them. A treatment of oily wastewater by an induced air flotation study was executed by Mohammed et al. (2013). The removal efficiency of FOG rose with the rising initial oil concentration and extended up to 76%.

2.4.3.3 Coagulation

A coagulant is a substance or chemical that is added to water to start and perform the coagulation–flocculation process (Zainol et al., 2011). There are different types of coagulants in the chemical market such as inorganic metal-based coagulants. Some examples of inorganic metal coagulants are aluminium sulphate (alum), ferric chloride and ferric sulphate (Bratby 2016). One of the very efficient techniques of eliminating FOG in wastewater is by coagulation. Daud et al. (2015), reported that coagulation is notably successful in the removal of FOG from wastewater in biodiesel wastewater after conducting a study in Malaysia. Furthermore, coagulation is one of the best ways to increase flotation performance. From a grease filter wash water, 80% reusable water was successfully retained together with 20% sludge (Irfan et al., 2017). The condition of the liquid portion was similar to that of drinking water. Due to its flexibility, chemical technology is capable of eliminating emulsified oil, dissolved oil and challenging biodegradable organic polymers in FOG treatment of wastewater (Ahmad et al., 2006).

2.4.3.4 Ultrafiltration

Ultrafiltration is filtration on a molecular level and its basis is a film of structured pore size, which segregates between large and small particles (Singh & Hankins, 2016). Ultrafiltration membrane separation is dependent on membrane pore size, pore size distribution, solution flow and degree of hydrophilicity (Vishali & Kavitha, 2021). The molecules held by the membrane may be dissolved in a solution or they may be detectable aggregates. The stream that passes through the membrane is called *permeate*. The larger molecular components are retained on the membrane and get dissolved in the water; this stream is termed the *concentrate* (Arvanitoyannis et al., 2008).

Treatment of the FOG-containing wastewater of the Tehran refinery using an ultrafiltration system was studied. Outcomes of various determining domains such as transmembrane pressure, cross-flow velocity, temperature and pH on permeate flux, fouling resistance and rejection were evaluated. A contrastive study revealed that ultrafiltration is highly more efficient than the traditional biological method in the removal of FOG (Salahi et al., 2009). Furthermore, in a study done by Sardari et al. (2018), it was reported that 95% of FOG was eliminated from poultry processing wastewater.

2.4.3.5 Electrocoagulation

Electrocoagulation (or electrofiltration) can be described as a process in which suspended, emulsified and dissolved pollutants in the aqueous phase are impaired by instituting an electric current (Emamjomeh & Sivakumar 2009). Aluminium or mild steel is commonly used as sacrificial electrode (Balasubramanian et al., 2009). It has been noted that electrocoagulation is capable of efficiently removing FOG in wastewater (Chen et al., 2000; Stephenson & Tennant 2003). The first time electrocoagulation was performed was in 1946 (Bonilla, 1947; Stuart, 1946). In a study conducted by Xu and Zhu (2004), electrocoagulation was used to remedy refractory wastewater with a high volume of oil and grease constituents. The removal efficiency of FOG, based on standard circumstances, surpassed 95%.

2.4.4 Physical methods of removing FOG in wastewater

2.4.4.1 Grease separator

The general immediate method for the degradation of FOG in wastewater is by using grease separators (Alves 2013). In this technique, FOG is eliminated from the wastewater in the preliminary stage. Wastewater is then channelled from the silt trap tank, kept in the settling tank for approximately 4–6 hours. Meanwhile, the floating FOG layer stays at the top in the tank. The bottom layer then exits the tank leaving the floating FOG behind. The activated sludge process is mostly suitable for this process as it prevents foaming in the secondary treatment (Pintor et al., 2016).

Ducoste et al. (2008) conducted a study to assess the elimination of FOG from food service establishments using a FOG flow-based grease interceptor. Assessment of the grease interceptor achievement was assumed on measurement of the influent and total oil and grease concentrations in effluent. The maximum FOG removal was 80%. However, Livingston et al. (2007) noted a slow rise in the oil and grease volumes in the effluent of grease separators with and without bioaugmentation.

2.4.4.2 Tilting plate separators

The installation of inclined plates into a wastewater treatment tank allows for several parallel gravity separators with low liquid depth, but a high surface area. These are termed tilting plate separators (Willey, 2001). The tilting plate separators conceivably take up below 10% of the space of a traditional fat trap. Furthermore, these components are package plants, which are movable to adjust to site developments. However, there are particular complications with edible oils and fats that demand attention, specifically: (1) The narrow gaps (20 mm) between the plates may be prone to fouling in the event that solid or semisolid fat is present in the effluent; (2) removal of the plate pack for cleaning is cumbersome and demands crane age; and (3) as a result, proper choice of pumps and flow control is essential to avert rising and unwanted changes in liquid depth. Plate separators are efficient and are a commonly used equipment for the segregation of droplets from FOG and water (Rommel et al., 1992).

2.5 Conclusion

The removal of FOG depends on physical and chemical characteristics of FOG, environmental conditions and the performance of the wastewater treatment plant. Different technologies have been widely investigated, as briefly reviewed. It is clear from the literature that there is still a lot of research in terms of the most optimal process in the removal of FOG. This includes process conditions, such as temperature, flow rate and the volume of FOG. The technology that is to be implemented is highly dependent on the desired product (i.e., effluent and biogas) and the quality of the feed (influent, i.e., municipal wastewater).

CHAPTER 3

BACKGROUND OF THE STUDY AREA

3.1 Introduction

This chapter describes the study area of the research. It also explains the different steps of the two technologies that were used in the treatment of the wastewater. The study area is situated in Bloemfontein, South Africa. Bloemfontein is in the Mangaung Metropolitan Municipality and is located in the Free State province in central South Africa. It is the sixth largest city in South Africa and currently has a population of approximately 567 000 (United Nations World Population Prospects 2021). The BWTW is located east of Bloemfontein, while the NEWTW is located north east of Bloemfontein.

3.2 Bloemfontein wastewater treatment works

The BWTW is located in McKenzie Street near the Schoeman Park Golf Club and was first constructed in 1904. It uses the biological trickling filter technology.

The BWTW receives 57 Ml per day of wastewater of which 17 Ml is diverted to the NEWTW as a means to relief its system. The influent at BWTW is mainly from the municipal offices, old suburbs of Bloemfontein, and neighbouring schools. The effluent of the BWTW is transported by pumps to the Schoeman Park golf course that is behind the BWTW, while another percentage of it flows into a nearby discharge stream and down to the Modder River. Figure 3.1 shows a map of the BWTW.

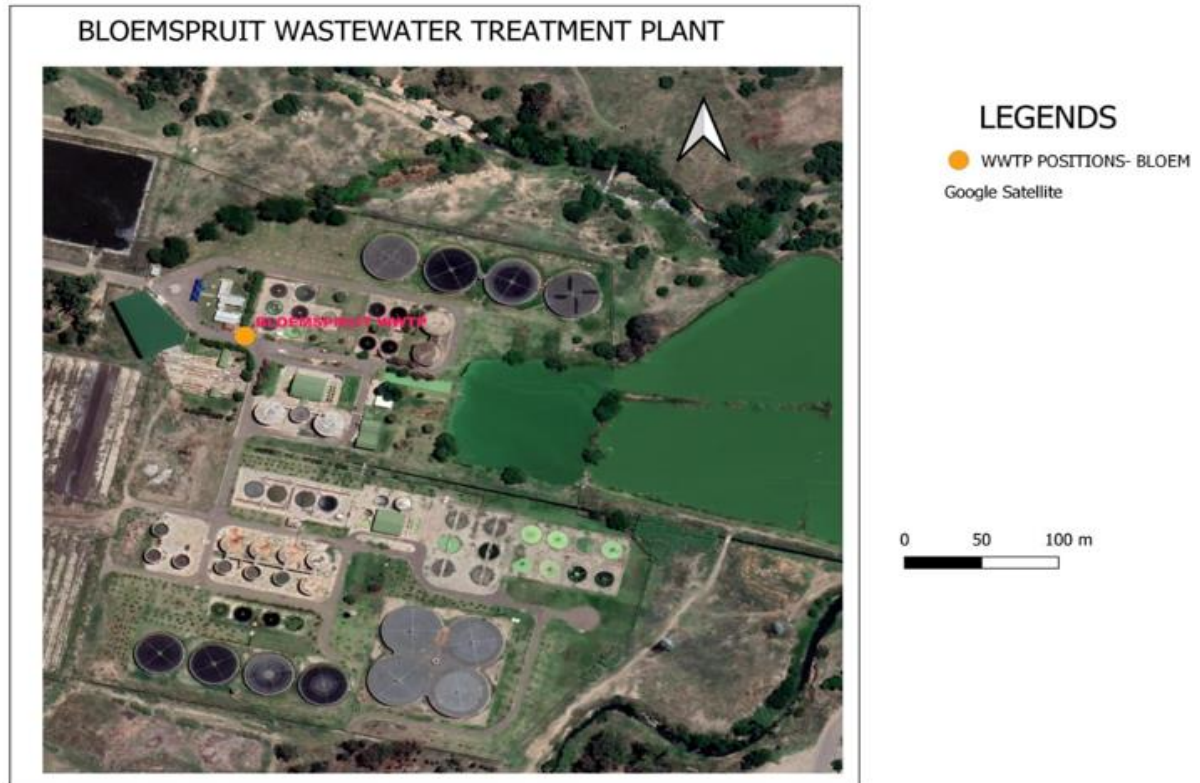


Figure 3.1 The location of the **BWTW** (VYMaps, 2020)

3.2.1 Preliminary treatment

The first stage in the wastewater treatment process is the preliminary treatment. Raw wastewater entering the treatment plant contains many kinds of impurities; therefore, the purpose of preliminary treatment is to protect plant equipment from damage that may be caused by these materials, such as clogging, jams, or excessive wear to the machinery (Guyer, 2011). Preliminary treatment at the BWTW includes pumping, screening and grit removal.

3.2.1.1 Screw pumps

The screw pumps transport wastewater from the bottom of the screw pump inlet to the exit of the pump (Jasim & Aziz, 2020). It is effective in pumping water filled with waste and debris with the least maintenance and highest effectiveness. Only one screw pump is currently working at the BWTW. Figure 3.2 shows pumping at the BWTW.



Figure 3.2 *Screw pumps at the BWTW* (Author's own, 2023)

3.2.1.2 Screening

The purpose of screening is to remove large solids, such as rags, cans, rocks, branches, leaves and roots, from the flow before the flow moves on to downstream processes (Ljunggren, 2006). A bar screen traps debris, as wastewater influent passes through. Typically, a bar screen consists of a series of parallel, evenly spaced bars or a perforated screen placed in a channel (Bhargava, 2016). The screen is cleaned once a week and the debris collected has been piled at the back of the plant for incineration at a later stage. Figure 3.2 shows screening at the BWTW.



Figure 3.3 *Bar Screen at the BWTW* (Author's own, 2023)

3.2.2 Primary treatment

Primary treatment (primary sedimentation or primary clarification) removes settleable organic and floatable solids (Sonune & Ghate, 2004). Normally, each primary clarification unit can be expected to remove 90–95% settleable solids, 40–60% TSS, and 25–35% BOD (Babu, 2007). Primary treatment reduces the organic loading on downstream treatment processes by removing a large amount of settleable, suspended, and floatable materials (Iyare et al., 2020). Heavier solids sink to the bottom while lighter solids float to the surface. Once settled, these materials are held back, while the remaining liquid is discharged or moved through to the rigorous secondary phase of wastewater treatment (Smarzewska & Morawska, 2021).

3.2.2.1 Primary settling tanks

These are large tanks equipped with mechanical scrapers that continually drive collected sludge in the base of the tank to a hopper that pumps it to the sludge treatment tank (Micek et al., 2020). Out of six primary settling tanks, only two are working well, the other four are clogged or working quite slowly compared to the other two. Figure 3.3 shows the primary settling tanks at the BWTW.



Figure 3.4 Primary settling tanks at the BWTW (Author's own, 2023)

3.2.2.2 Sludge drying beds

The sludge that is collected from the settling tanks at the BWTW is piled at the back of the plant. Local farmers frequently load it without a fee. Figure 3.5 shows sludge drying beds at the BWTW. Figure 3.5 shows the sludge drying beds at BWTW.



Figure 3.5 *Sludge drying beds at the BWTW* (Author's own, 2023)

3.2.3 Secondary treatment

The secondary treatment of wastewater removes biodegradable organic matter that is either suspended or dissolved in wastewater by allowing bacteria to feed on the organic parts of the wastes (Varjani et al., 2020).

3.2.3.1 Trickling filter

The trickling filter consists of a fixed bed of rocks that has microorganisms attached to it that aid in the removal of organic matter from wastewater (Buchanan, 2014). The trickling filters at the BWTW worked well. There was no routine maintenance. The trickling filter is fixed whenever there is a breakdown. Figure 3.6 shows the trickling filter at the BWTW.



Figure 3.6 *Trickling filter at the BWTW (Author's own, 2023)*

3.2.3.2 Secondary settling tanks

The secondary settling are circular tanks with a rotating mechanical sludge and scum collectors (Gao & Stenstrom, 2020). They remove microbes that are washed off the rocks by the flow of wastewater (Sonune & Ghate, 2004). In the BWTW, there are two secondary settling tanks as shown in Figure 3.7.



Figure 3.7 *Secondary settling tanks at the BWTW (Author's own, 2023)*

3.2.4 Tertiary treatment

The most commonly used method of disinfection is chlorination (Mazhar et al., 2020). Although it requires a relatively long contact time because of its high oxidation potential, chlorination is one of the best methods of chlorination (Lu et al., 2020). It is mostly used in treatment of wastewater with high organic compounds (Franklin et al., 2004). There was no chlorination at the BWTW.

3.3 North east wastewater treatment works

The NEWTW was constructed in 2014 and is located near Ribblesdale Road behind the Bram Fischer Airport. It is currently 85% complete and the sludge digesters are the missing operation. The plant receives 17 Ml of influent from the BWTW from two neighbouring abattoirs and some of the recently built suburbs of Bloemfontein. As a result of its low influent and being incomplete, the plant is not used to full capacity. Furthermore, the tertiary stage (chlorination) of the plant is not in use. The effluent of the plant goes to the Maselspoort wastewater treatment works that purifies the water into drinking water. The map in Figure 3.8 shows the NEWTW.

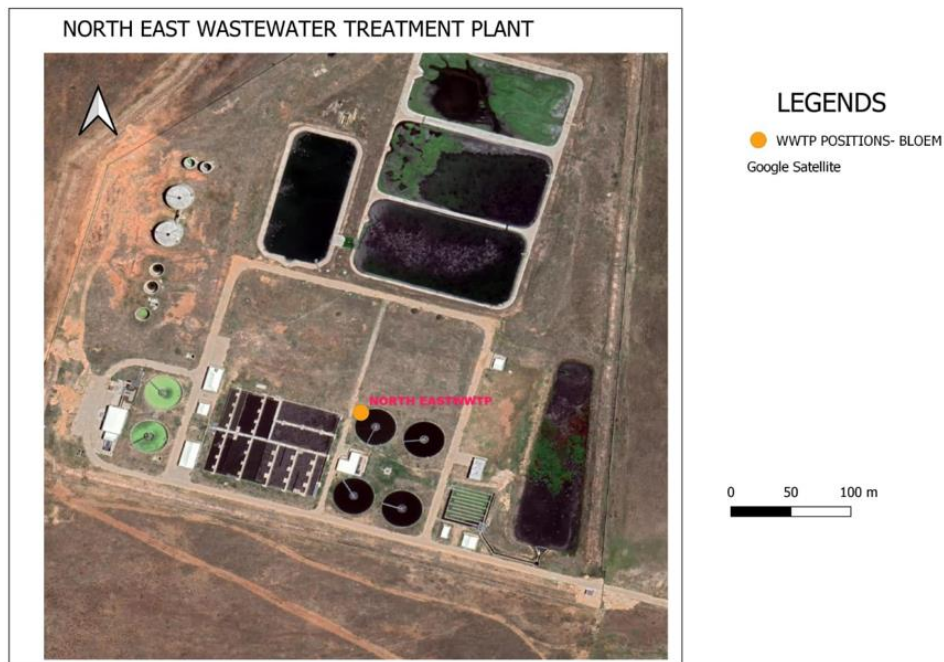


Figure 3.8 Location of the NEWTW AfriGIS (2022)

3.3.1 Preliminary treatment

One of the critical parts of preliminary treatment is pumping. Its purpose is to transport large amounts of organic solids, rags and other waste matter (Spellman & Drinan, 2001). At the NEWTW, the screw pumps work interchangeably. The screw pumps are programmed to alternate after a certain period of time. Figure 3.9 shows pumping at the NEWTW.



Figure 3.9 Screw pumps at the NEWTW (Author's own, 2023)

3.3.1.1 Screening

Screening removes large solids such as rags, paper, plastics and metals that can cause damage and clogging to the wastewater plant equipment (Pankratz, 2017). At the NEWTW there are two types of screens. First, the coarse screen that consists of parallel bars of rectangular shape with clear openings. It is used to remove coarse solids such as rags and large objects that may clog the machinery. Second, the drum screens that are rotating cylinders. They mainly remove fine solids. Figure 3.10 shows the bar screen, while Figure 3.11 shows the drum screen.



Figure 3.10 Bar screens at the NEWTW (Author's own, 2023)



Figure 3.11 Rotary drum screens at the NEWTW (Author's own, 2023)

3.3.2 Primary treatment

Primary treatment of wastewater is a sedimentation process that removes settleable solids; however, chemicals are sometimes used to remove small impurities that cannot settle (Rashed et al., 2013). There are two primary settling tanks at the NEWTW; however, both of them are not in use, therefore stagnant water with a layer of algae is visible in the tanks. Figure 3.12 shows one of the primary settling tanks at the NEWTW.



Figure 3.12 *Primary settling tank at the NEWTW* (Author's own, 2023)

3.3.3 Secondary treatment

Secondary tanks are used to separate the biomass generated during the secondary treatment process from the treated plant effluent (Voutchkov, 2005). There are two secondary settling tanks at the NEWTW and both of them are functioning well. Figure 3.13 shows one of the secondary settling tanks at the NEWTW.



Figure 3.13 *Secondary settling tank at the NEWTW* (Author's own, 2023)

3.3.3.1Aerated grit chamber

This is a system that removes particles by forcing water that has passed through bar screens into a grit chamber which has air pumped into it (Ghawi, 2018). The heavier particles settle to the bottom of the tank, while the lighter organic particles are suspended and eventually passed through the tank. It removes sand, silt and grit from wastewater (Plana et al., 2018). Figure 3.14 shows one of the aerated grit chamber tanks at the NEWTW.



Figure 3.14 Grit settling tank at the NEWTW (Author's own, 2023)

3.3.3.2Aeration

In the aeration process, air is directly added directly to wastewater (Mareddy, 2017). This allows for aerobic biodegradation of any remaining pollutants contained in the wastewater (Skouteris et al., 2020). The aeration process uses microorganisms that are already present within the wastewater to degrade the contaminants (Ahammad & Sreekrishnan, 2016). Figure 3.15 shows one of the aeration tanks at the NEWTW.



Figure 3.15 Aeration tank at the NEWTW (Author's own, 2023)

3.3.3.3 Sludge treatment

Following the settling tanks (primary and secondary), the wastewater is directed to the sludge treatment tanks (Muralikrishna & Manickam, 2017). The sludge treatment tanks at the NEWTW are not in use, therefore, the water collected from the humus tanks is led to the sludge drying tanks and out to Maselspoort for purifying it as drinking water. Figure 3.16 shows the digester tanks at the NEWTW.



Figure 3.16 Digester tanks at the NEWTW (Author's own, 2023)

The produced and collected sludge at primary and secondary levels requires a high concentration and thickening process. This is achieved by putting them into the thickening tanks, then let it to settle down and later separated from the water. The process of sludge treatment may take up to 24 hours. After treating the sludge, some of the remaining water is collected and reversed back to the large aeration tank to enable further treatment. This is called sludge dewatering (Kamizela & Kowalczyk, 2019). The water above the sludge is led out to Maselspoort, where it is purified into drinking water. Once the sludge has been dewatered, it is stored near the dams or used as fertiliser by neighbouring farmers who occasionally collect it. Figure 3.17 shows the sludge at a settling tank at the NEWTW.



Figure 3.17 Sludge settling tank at the NEWTW (Author's own, 2023)

3.3.4 Tertiary treatment

The tertiary treatment is where chlorination takes place. Chlorination is the most prevalent practice of disinfection. It is mostly used in treatment of wastewater with high organic compounds (Franklin et al., 2004). There is no chlorination at the NEWTW since the water is not discharged into the environment. Figure 3.18 shows the chlorination room at the NEWTW.



Figure 3.18 Chlorination room at the NEWTW (Author's own, 2023)

3.4 FOG in the Bloemspuit wastewater treatment works

The FOG at the BWTW comes from soaps, detergents, and the mostly the abattoir in Estoire, which dumps a minimum of 4 000 l per day, and on maximum, two loads (8 000 l). The abattoir dumps in mornings and late afternoons and the wastewater dumped is blood coloured, and occasionally with traces of visible fats. The abattoir and some trucks carrying domestic wastewater dump directly into the plant, whereas some of the domestic wastewater from homes and nearby shops, offices and schools flows into the treatment plant through sewerage channels. The wastewater from domestic homes in septic tanks also contains a high fat content from soaps, detergents and plant and animal fats. Visually, the raw wastewater looks creamy white, except just after it has been dumped by the abattoir.

Because of the high content of fats from the abattoir, the wastewater at the BWTW daily contains a high amount of fat. There are no definite boundaries as to exactly which institutions and domestic homes discharge their wastewater to the BWTW. Most old suburbs and institutions that date as far back as the beginning or the middle of the twentieth century discharge their wastewater into the BWTW.

3.5 FOG in north east wastewater treatment works

At the NEWTW, FOG is mostly from recent suburbs of Bloemfontein located to the north and north-west of the central business district, a nearby abattoir located opposite the Schoeman golf course and a greater part of FOG being from the 17 Mℓ it receives daily from the BWTW. The abattoir does not directly discharge the blood-coloured wastewater, but it is rather discharged from their drainage into a nearby manhole and is then directed to the NEWTW. There are no definite intervals as to when the abattoir discharges the wastewater; however, it was noted that it is mainly on either Tuesdays or Thursdays at least each week. Apart from the times when the abattoir just released wastewater into the plant, the raw wastewater at the NEWTW is visually creamy white but a little less than that of the BWTW.

The following chapter discusses the methodology used in this study.

CHAPTER 4

RESEARCH METHODOLOGY

4.1 Introduction

This chapter presents the description of the research process. It provides information concerning the method that was used in undertaking this research as well as justification for the use of this method. This chapter also describes the stages of the research, which includes sampling, and the process of data analysis.

This research investigated the effective removal of FOG in water treatment plants of the Mangaung Metropolitan Municipality and the effect of different wastewater parameters on the effective removal of FOG.

This study was based on the following objectives:

- To determine the effectiveness of the two wastewater treatment technologies in the removal of FOG and nutrients.
- To investigate and recommend extra pre-treatment measures to the plants for improvement in the removal of FOG.
- To investigate the likely impact of FOG and nutrient released to the catchment after treatment.

4.2 Research methodology

A research methodology or strategy is determined by the nature of the research question and the subject being investigated (Denzin & Lincoln, 2005). Subsequently, the research format used in an investigation should be seen as a tool to answer the research question.

The BWTW, which uses an older technology, namely the biological trickling filter, was servicing the greater Bloemfontein and was hydraulically overloaded due to many reasons, among which were plant capacity, increase in the population of Mangaung, new and emerging contaminants present in wastewater and wear and tear of plant equipment; hence, the construction of the new NEWTW in Mangaung

that uses a newer treatment technology: the activated sludge system (Mail & Guardian, 2014). In addition, Mangaung scored 38% in the Green Drop Assessment in 2013 (South Africa, Department of Water and Forestry, 2014) due to the poor wastewater discharge to the catchment.

These two technologies both remove FOG as an impurity in the wastewater; however, there is no difference in the effectiveness and degree of the new technology, activated sludge, compared to the older technology, biological trickling filter system, in the removal of FOG as both treatment plants release FOG to the catchment. The discharged water from the NEWTW still contains FOG; hence, this study determined the amount of FOG present and the effectiveness of the new technology compared to the older technology was analysed in terms of the FOG present.

4.3 Justification for using quantitative research

Burns and Grove (2005) described quantitative research as a formal, objective and systematic process to illustrate and test relationships, and investigate cause and effect interactions among variables. Furthermore, as outlined by Creswell (2009), a quantitative approach is appropriate when a researcher seeks to understand relationships between variables. A quantitative research approach was chosen as methodology to evaluate the effect that different parameters exert over each other and the impact on the removal of FOG.

4.4 Sampling

Twenty samples of the influent and effluent of the NEWTW and the BWTW were collected once a week from June to November 2021 and evaluated for the following parameters: COD, oxygen absorbed and FOG. pH, TDS, temperature and conductivity which were measured on site using a Hanna HI 98195 meter. Dissolved oxygen was also measured using a Hanna HI 98193 DO meter. These parameters were selected from the South African water quality guidelines for the protection of the freshwater aquatic ecosystems (SA Department of Water Affairs and Forestry, 1996). For FOG grab samples were collected weekly every Tuesday, while grab samples for COD and oxygen absorbed were collected once after every two weeks.

Sampling was taken at midday when temperatures reached 17 °C in June, July and August, while for September and October sampling was done around 10:30 at the same temperature. The next paragraphs outline a detailed justification for selecting the specific approaches and methods.

There are many methods of measuring FOG; however, these methods differ according to the composition of FOG. The method of the Environmental Protection Agency (EPA 1664B) is one of the approved methods of FOG and uses n-hexane as a solvent. For the purpose of this test, anything that is soluble in hexane is counted as FOG. This includes some organic dyes, sulphur compounds, non-volatile petroleum hydrocarbons, waxes, animal fats, mineral and vegetable oils, soaps, chlorophyll and substituted hydrocarbons but does not include heavier petroleum residuals. For this reason, the EPA 1664B was the chosen method for this study.

4.5 Testing

4.5.1 FOG

For FOG testing, the Oil and Grease in Water by Hexane Extraction and Gravimetric method was used. This method is applicable to the quantitative determination of oil and grease (hexane extractable material) in water. Oil and grease provides a measure of hexane extractable non-volatile oils and greases (USEPA, 2010).

Samples were collected in 2ℓ glass bottles which were not pre-rinsed with the sample before collection. All samples collected for this analysis were grab samples. Oil and grease are hydrophobic and prefer to associate with the glass container rather than the water of the collected sample. The samples were then refrigerated if the analysis could not be done on the same day. Upon analysis, if the pH was not less than 2, hydrochloric acid was added to adjust it to 2. The sample was transferred to a separatory funnel, received 30 mL of n-hexane, mixed vigorously for two minutes and allowed to settle to let the organic and aqueous phases to separate (USEPA, 2010).

The separatory funnel was then rinsed with acetone to ensure that all the oil has been retrieved from the separatory funnel. Sample volumes were measured

gravimetrically to at least the nearest 10 mL. Residual water, solvent, and other volatiles were removed by heating in an oven at 60 °C for 30 minutes prior to gravimetric determination of the residue using a four-place balance. The original sample went through the process two more times to remove oil and grease compounds for the analysis. Once the three extract portions were collected, the solvent was evaporated and the preweighed container was weighed to constant weight. The extract was then evaporated to dryness at ambient temperature (25 °C). Following evaporation, residual water, solvent, and other volatiles are removed by heating in an oven at 60 °C for 30 minutes (USEPA, 2010).

4.5.2 Chemical oxygen demand

Chemical oxygen demand (COD) is a critical analytical parameter for water quality assessment. COD was determined using the potassium dichromate method. COD represents the degree of organic pollution in water bodies (Li et al., 2018). The COD Method 410: Chemical oxygen demand (titrimetric, mid-level) was used to determine the COD in the wastewater.

Equipment

- Erlenmeyer flask
- Small beaker
- Titration apparatus
- 50 mL burette, graduated in 0.1 mL
- Burette support
- 100 mL graduated cylinder

Reagents

- Standard potassium dichromate solution, 0.250 N or 0.025 N
- Sulfuric acid reagent containing silver sulphate catalyst
- Standard ferrous ammonium sulphate titrant
- Ferroin indicator solution
- Ammonium ferrous sulphate hexahydrate
- Concentrated sulphuric acid
- Distilled water

Procedure

1. The sample (2.5 ml) was placed in a culture tube and $K_2Cr_2O_7$ digestion solution (1.5 ml) was added.
2. Sulphuric acid reagent (3.5 ml) was carefully run down inside of the vessel so an acid layer was formed under the sample digestion solution layer. The cap tubes were tightly closed.
3. The tubes were placed in a block digester preheated to 150 °C and refluxed for two hours.
4. The tubes were then placed in a test tube rack and cooled to room temperature.
5. Three drops of Ferroin indicator were added and the mixture was shaken.
6. The mixture was then titrated with standardised 0.10 M Ferrous Ammonium Suphate (Method: 5220 C. Closed Reflux Titrimetric Method).

Preparation of the blank sample

1. A volume of distilled water equal to that of the sample was pipetted into a 500 ml refluxing flask.
2. 1 g of ammonium ferrous sulphate hexahydrate was added to the distilled water.
3. 5 ml of sulphuric acid reagent was added very slowly and 0.250 N potassium dichromate solution was added and mixed.
4. The samples and the blank flask were then refluxed for two hours.

4.5.3 Oxygen absorbed

Oxygen absorbed in four hours is calculated by evaluating the amount of standard potassium permanganate solution consumed by the sample while kept under specific conditions for four hours (Bureau of Indian Standards, 1989).

Apparatus

- Incubator
- Air oven

Reagents

- Stock potassium permanganate solution –
3.951 g of potassium permanganate (dried at 105 °C) was mixed with distilled water and made up to 1 000 ml. The solution was kept in the dark and its strength checked periodically.
- Standard potassium permanganate solution
This solution was prepared just before use by using a suitable dilution of stock potassium permanganate solution.
- Dilute sulphuric acid
50 ml of concentrated sulphuric acid was added to 130 ml of distilled water, cooled and diluted to 200 ml with distilled water. Standard permanganate solution was added until a very faint pink colour showed after four hours.
- Potassium iodide crystals
- Stock sodium thiosulphate solution

Procedure

1. 259 ml of the well-mixed sample was placed into a clean, glass-stoppered bottle of 400 ml capacity.
2. 10 ml of dilute sulphuric acid was added, followed by an accurately measured volume of standard potassium permanganate solution.
3. The contents were then mixed by gentle rotations and placed in a water-bath at 37 ± 1 °C for four hours.
4. At the end of four hours, the mixture was cooled to about 15 °C and a few crystals of potassium iodide were added. The mixture was then titrated with a standard sodium thiosulphate solution using a few drops of starch indicator solution.

5. The blank sample for oxygen absorbed was also titrated.
6. A 10-fold dilution was carried out for mixtures that fell out of range after titration.

Procedure

- The correction was to take 10 mm³ of the sample and dilute it to 90 mm³ of distilled water.

4.5.4 Nitrates

The SOP Chem 005 Spectroquant nitrate test was used to analyse nitrates. The test tubes for analysis were prerinsed with distilled water and dried in the oven prior to analysis (Sigmaaldrich, 2017).

The following steps were followed in the testing of nitrates in wastewater:

1. 4.0 ml of NO₃⁻¹ was pipetted into a dry empty round cell.
2. 0.50 ml of the sample was pipetted into the cell.
3. 0.50 ml of NO₃⁻² was pipetted and the cell was closed, while shaking it vigorously.
4. The solution was then transferred into a corresponding rectangular cell and read.

4.5.5 Phosphates

The phosphate results were analysed using the Spectroquant Prove spectrophotometer in the laboratory. The test tubes for analysis were prerinsed with distilled water and dried in the oven.

The following steps were carried out in the testing of phosphates in wastewater:

1. The pH was checked if between specified ranges 0–10. If required, sulphuric acid was added drop-by-drop to adjust the pH.
2. 5.0 ml of the sample was added to the test tube.
3. Five drops of PO₄⁻¹ were added to the test tube.
4. One level of micro-spoon PO₄⁻² was added.
5. The mixture was then shaken vigorously to dissolve the solid substance.

6. The solution was then transferred into a corresponding cell.
7. The reading was then taken.

4.5.6 Testing of parameters using multimeters

4.5.7 Dissolved oxygen

The specifications for the DO meter were as follows:

Table 4.1 Specifications of dissolved oxygen on the Hanna HI98193 multimeter

Range	0.00 to 50.00 mg/l (ppm); 0.0 to 600.0% saturation
Resolution	0.01 mg/l (ppm); 0.1% saturation
Accuracy	±1.5% of reading ±1 digit
Calibration	Automatic one or two points at 100% (8.26 mg/l) and 0% (0 mg/l) manual one point using a value entered by the user in % saturation or mg/l

Source: Hanna (2021)

4.5.8 Temperature

The specifications for the temperature were as follows:

Table 4.2 Specifications of temperature on the Hanna HI98193 multimeter

Range	−20.0 to 120.0 °C; −4.0 to 248.0 °F
Resolution	0.1 °C; 0.1 °F
Accuracy (@ 25 °C / 77 °F)	±0.2 °C; ±0.4 °F (excluding probe error)
Calibration	One or two points at any in range temperature value

Source: Hanna (2021)

4.5.9 Atmospheric pressure

The specifications for the atmospheric pressure were as follows:

Table 4.3 Specifications of atmospheric pressure on the Hanna HI98193 multimeter

Range	450 to 850 mmHg
Resolution	1 mmHg
Accuracy	±3 mmHg within ±15% from the calibration point
Calibration	One point at any in range pressure value

Source: Hanna (2021)

4.6. Parameters measured using the HI98192 meter.

4.6.1 Salinity

The specifications for salinity were as follows:

Table 4.4 Specifications of temperature on the Hanna HI98192 multimeter

Range	Percentage NaCl: 0.0–400.0%; Practical salinity scale: 0.00–42.00 (PSU); Natural seawater scale (UNESCO, 1966): 0.00–80.00 (ppt)
Resolution	0.1%; 0.01
Accuracy	±1% of reading
Calibration	Maximum one point only in percentage range (with HI7037 standard); use conductivity calibration for all other ranges

Source: Hanna (2021)

4.6.2 Conductivity

The specifications for conductivity were as follows:

Table 4.5 Specifications of conductivity on the Hanna HI98192

Range	0.000–9.999 S/cm; 10.00–99.99 S/cm; 100.0–999.9 S/cm; 1.000–9.999 mS/cm; 10.00–99.99 mS/cm; 100.0–1000.0 mS/cm (actual conductivity; temperature compensated to 400 mS/cm)
Resolution	0.001 S/cm; 0.01 S/cm; 0.1 S/cm; 0.001 mS/cm; 0.01 mS/cm; 0.1 mS/cm
Accuracy	±1% of reading (±0.01 S/cm or 1 digit, whichever is greater)
Calibration	Automatic up to five points with seven memorised standards (0.00 S/cm, 84.0 S/cm, 1.413 mS/cm, 5.00 mS/cm, 12.88 mS/cm, 80.0 mS/cm, 111.8 mS/cm)

Source: Hanna (2021)

4.6.3 Resistivity

The specifications for resistivity were as follows:

Table 4.6 Specifications for resistivity on the Hanna HI98192 multimeter

Range	1.0–99.9 $\Omega\cdot\text{cm}$; 100–999 $\Omega\cdot\text{cm}$; 1.00–9.99 $\text{K}\Omega\cdot\text{cm}$; 10.0–99.9 $\text{K}\Omega\cdot\text{cm}$; 100–999 $\text{K}\Omega\cdot\text{cm}$; 1.00–9.99 $\text{M}\Omega\cdot\text{cm}$; 10.0–100.0 $\text{M}\Omega\cdot\text{cm}$
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Resolution	0.1 $\Omega\cdot\text{cm}$; 1 $\Omega\cdot\text{cm}$; 0.01 $\text{K}\Omega\cdot\text{cm}$; 0.1 $\text{K}\Omega\cdot\text{cm}$; 1 $\text{K}\Omega\cdot\text{cm}$; 0.01 $\text{M}\Omega\cdot\text{cm}$; 0.1 $\text{M}\Omega\cdot\text{cm}$
Accuracy	$\pm 1\%$ of reading (± 10 or 1 digit)

Source: Hanna (2021)

4.6.4 Total dissolved solids

The specifications for TDS were as follows:

Table 4.7 Specifications of total dissolved solids on the Hanna HI98192 multimeter

Range	0.00–99.99 ppm; 100.0–999.9 ppm; 1.000–9.999 ppt (g/l); 10.00–99.99 ppt (g/l); 100.0–400.0 ppt (g/l)
Resolution	0.01 ppm; 0.1 ppm; 0.001 ppt (g/l); 0.01 ppt (g/l); 0.1 ppt (g/l)
Accuracy	$\pm 1\%$ of reading (± 0.05 mg/l [ppm] or one digit, whichever is greater)

Source: Hanna (2021)

The specifications for pH were as follows:

Table 4.8 Specifications of pH on the Hanna HI98192 multimeter

Range	0.00–14.00 pH
pH resolution	0.01 pH
pH accuracy	± 0.02
pH calibration	Automatic one, two, or three points with automatic recognition of five standard buffers (pH 4.01, 6.86, 7.01, 9.18, 10.01) or one custom buffer

Source: Hanna (2021)

4.7 Data analysis

Data analysis is the process whereby a phenomenon is broken down into its constituent parts in order for it to be understood better (Mouton & Marais, 1991).

4.7.1 FOG

To analyse FOG with the EPA gravimetric method 1664B, the following equation was used to demonstrate initial precision and recovery to establish the ability to generate acceptable precision and accuracy.

$$s = \frac{\sum x^2 - \frac{(\sum x)^2}{n}}{n - 1} \quad (1)$$

(USEPA, 2010)

Where:

s = Standard deviation of the percent recovery

n = Number of samples

x = recovery in each sample

The equation below was used to show the percentage recovery of FOG in each aliquot:

$$P = \frac{100(A - B)}{T} \quad (2)$$

(USEPA, 2010)

Where:

P = Percent recovery of hexane extractable material

A = Measured concentration of the sample after spiking

B = Measured background concentration of FOG

T = True concentration of the spiked sample

The following equation was used to calculate the extract volume that contains 1 000 mg extractable material:

$$V_a = \frac{1\,000\,V_t}{W_h} \quad (3)$$

(USEPA, 2010)

Where:

V_a = Volume of the aliquot to be withdrawn (mℓ)

V_t = Total volume of solvent used

W_h = Weight of extractable material from FOG measurement (mg)

4.7.2 Chemical oxygen demand

The following formula was used to calculate COD:

$$COD = \frac{(v_1 - v_2) \times C \times 8\,000}{v_0} \quad (4)$$

(Indian Institute of Technology, 2013)

Where:

v_0 = the volume of the sample aliquot, in millimetres

v_1 = the volume of ammonium iron (ii) sulphate used in blank titration, in millimetres

v_2 = the volume of ammonium iron (ii) sulphate used in sample titration, in millimetres

C = the exact concentration after standardisation of the ammonium iron (ii) sulphate, in moles per litre

4.7.3 Oxygen absorbed

The formula below was used to calculate the oxygen absorbed:

$$\text{Oxygen absorbed} = \frac{(A - B) \times 200}{\text{volume of sample}} \quad (5)$$

(Bureau of Indian Standards, 1989)

Where:

A = the titration value of the blank sample

B = the titration value of the sample

4.7.4 Nitrates

The SOP Chem 005 Spectroquant nitrate test was used to analyse nitrates. The samples were analysed on the day of sampling. A spectrophotometer was used to read the test tubes containing nitrates. The Person Correlation Coefficient was used to calculate the correlation between FOG and nitrates.

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{(\sum(x_i - \bar{x})^2) \sum(y_i - \bar{y})^2}} \quad (6)$$

(Benesty et al., 2009a)

Where:

x_1 = values of the x variable in a sample

$\bar{x}$ = mean of the values of the $\bar{x}$ variable

y = values of the y variable in a sample

$\bar{y}$ = mean of the values of the $\bar{y}$ variable

4.7.5 Phosphates

A Spectroquant Prove spectrophotometer was used to read the test tubes containing phosphates. Samples were analysed on the day of sampling. The Person Correlation Coefficient was used to calculate the correlation between FOG and phosphates.

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}} \quad (7)$$

(Benesty et al., 2009a)

Where:

x_1 = values of the x variable in a sample

$\bar{x}$ = mean of the values of the $\bar{x}$ variable

y = values of the y variable in a sample

$\bar{y}$ = mean of the values of the $\bar{y}$ variable

4.7.6 pH, conductivity, resistivity, salinity, atmospheric pressure, dissolved oxygen and temperature

A mean of the readings was taken for analysis, while the ranges of the different parameters measured are given in the tables mentioned above.

4.6 Validation of data

The validity of an instrument is the degree to which an instrument measures what it is intended to measure (Polit & Hungler, 1993). For all parameters measured by the multimeter, the readings were taken at an average temperature of 17 °C, which was achieved around midday for the months of June, July, August and September and around the morning hours for the summer month, October.

The experiments conducted in the laboratory – COD, oxygen absorbed and FOG – were repeated three times to ensure validation of the data, whereas the data collected using multimeters was verified by checking the range of the multimeters and recalibrating for the different parameters each time. For the nitrates and phosphates, the spectrophotometer was reset every time before taking a new reading.

Reliability of measuring tools and the experiments was ensured. For all the parameters investigated in the laboratory and parameters measured using a multimeter, the experiments were carried out three times to ensure accuracy. Polit and Hungler (1993) referred to reliability as the degree of consistency with which an instrument measures the attribute it is designed to measure.

4.7 Control

4.7.7 FOG

FOG samples were extracted within 28 days of collection. If they were not analysed on the same day, they were refrigerated at $\leq 6^{\circ}\text{C}$ prior to analysis to inhibit microbial degradation. Furthermore, samples were kept at $\leq 10^{\circ}\text{C}$ during transport to the laboratory. Before analysis, the pH was adjusted to 2 for all samples. All equipment used to analyse FOG was washed in hot soapy water and dried thoroughly in an oven before the next experiment to ensure all FOG has left the container. All data collection bottles were labelled appropriately and accordingly used for collection of data.

4.7.8 Nitrates and phosphates

The samples were analysed immediately and the test tubes for analysis were prerinsed with distilled water to exclude all other contaminants. The test tubes were washed in distilled water and dried in the oven to ensure that all moisture has evaporated. To ensure that the correct parameter was being read on the spectrophotometer, the spectrophotometer first read the parameter to be checked as soon as the representative cell was inserted into the parameter slot.

4.7.9 Chemical oxygen demand and oxygen absorbed

Blank samples were formulated for COD and oxygen absorbed. Moreover, the samples were collected in glass bottles that were not prerinsed and the samples were analysed immediately or refrigerated at $\leq 6^{\circ}\text{C}$ to minimise microbial degradation. The containers for analysing the samples were always washed and rinsed with distilled water to ensure accurate results. All the water used in the experiment for the reactions and the experiment itself was distilled water.

4.7.10 pH, resistivity, conductivity, salinity, dissolved oxygen, atmospheric pressure, and temperature

The samples were all taken when the temperature was 17°C . The equipment was calibrated every Tuesday prior to sampling using the Hanna calibration liquid, which was fit for the equipment in the experiment. Furthermore, the readings were taken at the very time that the samples were collected to ensure accuracy.

4.8 Challenges and implications

- There was a shortage of laboratory glassware, hence the analysis had to be postponed on some days to first give preference to the staff of the laboratory. As a result, data was collected on Tuesdays and analysed on Wednesdays. This resulted in a fewer analysis than had been planned initially, which in turn, had adverse effects on the analysis of the research.
- It was challenging to sample and analyse parameters consistently in terms of time due to delays in transport. The research sampling and analysis relied on hired transport, hence the parameters affected by temperatures were negatively impacted.
- The constituents of the wastewater were inconsistent due to the nearby abattoirs dumping at different time intervals. This meant that the samples varied each time and contributed to the inaccurate results.
- There were frequent power outages, hence the validity of the results was compromised due to sampling being done at different times.

The following chapter discusses the results obtained from the study and analyses the findings.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Introduction

This chapter contains a detailed presentation and discussion of the data analysis and the results of this study. The findings are presented under the following headings: FOG, nitrates, phosphates, pH, resistivity, temperature, dissolved oxygen, TDS, salinity, conductivity, atmospheric pressure and COD.

The aim of the study was to investigate the effective removal of FOG of two technologies by two wastewater treatment plants of the Mangaung Metropolitan Municipality, thus the following results show the different parameters and their relationship with the removal of FOG in the two wastewater treatment plants.

5.2 Analysis of results

5.2.1 FOG

FOG has a very low biodegradability. It is for this reason that its release into the environment can affect the biosphere, causing lethal effects such as drowning of waterfowls, fish asphyxiation or adverse aesthetic effects of fouled shorelines and beaches; even the thinnest layer of FOG will affect aquatic life (Pintor et al., 2016). FOG from discharge streams is one of the most common types of water pollutants, which can cause damage to the aquatic environment and mainly comes from wastewater effluents, where the concentrations of FOG have been increasing over the last years because of the use of FOG in high-demanded oil-processed foods and growth of municipalities, as well as indiscriminate discharge of FOG into the water drains within municipalities.

Previous investigations concerning FOG levels and their treatment have indicated that predicted FOG removal does not match the measured FOG removal (Ducoste et al. 2008; Lopez-Vazquez & Fall, 2004). Investigation into FOG recovery efficiency has demonstrated measurement interference when protein and/or detergent surfactants are present. The surfactant molecules form micelles around the FOG

droplets that inhibit hexane solvation; and proteins can be carried into the solvent increasing the total mass transferred.

The average FOG removed in each technology was calculated and the mean was used to determine the efficiency of each technology. Figures 5.1 and 5.2 show the influents and effluents of the two wastewater treatment plants.

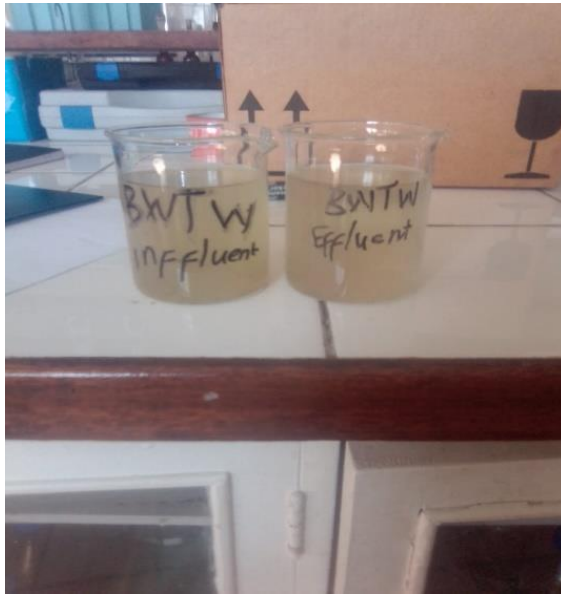


Figure 5.1 The BWTW influent and effluent
(Author's own, 2023)



Figure 5.2 The NEWTW influent and effluent
(Author's own, 2023)

The above figures visually show that there is a little difference in the influent and effluent in the BWTW, whereas there is a significant difference in the NEWTW. The BWTW receives more volume of wastewater than the NEWTW, which explains why it is more concentrated than the wastewater at the NEWTW.

FOG was also calculated using the EPA 1664B method. Table 5.1 shows the FOG that was calculated over a period of 20 consecutive weeks at the two plants.

Table 5.1 FOG values in the BWTW and NEWTW

Period	BWTW influent FOG in mg/ℓ	BWTW effluent FOG in mg/ℓ	NEWTW influent FOG in mg/ℓ	NEWTW effluent FOG in mg/ℓ
Week 1	21.12	19.76	14.62	7.90
Week 2	21.18	19.98	14.62	9.76
Week 3	10.66	3.26	17.42	3.02
Week 4	8.06	6.14	3.32	1.98
Week 5	1.72	0.70	6.62	2.66
Week 6	7.08	6.00	16.96	5.22
Week 7	13.6	10.86	18.88	13.12
Week 8	12.60	10.42	6.02	3.98
Week 9	23.52	6.40	14.40	3.98
Week 10	23.4	5.04	10.20	4.64
Week 11	24.06	6.34	14.24	6.02
Week 12	21.26	5.44	8.56	5.66
Week 13	6.22	5.38	11.48	5.80
Week 14	7.62	6.82	8.54	6.96
Week 15	13.28	7.84	1.32	0.42
Week 16	6.96	1.37	3.18	2.84
Week 17	11.54	10.82	9.52	7.28
Week 18	14.96	13.82	7.98	6.84
Week 19	9.04	8.54	9.02	3.34
Week 20	13.34	11.56	6.18	5.86
Average FOG	13.56	8.32	10.15	5.36
Percentage removal	61.36%		52.81%	

The results in Table 5.1 indicate that the elimination of FOG in the two wastewater treatment plants was below the average removal efficiency. The FOG removal efficiency range of wastewater treatment was 59% to 85%, with an average of 70% (Dehghani et al., 2014). The BWTW removal efficiency was 61.36%, resulting in an average of 8.32 mg/ℓ in the effluent. The NEWTW showed an average of 5.36 mg/ℓ and a removal efficiency of 52.81%. According to the permissible South African wastewater standards for the discharge of FOG into a water source, the volume of FOG permissible to be discharged into a water is ≤ 2.5 mg/ℓ (SA Department of Forestry, Fisheries and the Environment, 2014), meaning neither of the two wastewater plants complied. In Iran, a similar study done at the Shiraz wastewater treatment plant removed 70% of the FOG, and 90% of the FOG was removed in

the trickling filter (Dehghani et al., 2014). Moreover, removal efficiencies were over 90% in a study done by Porwal et al. (2015) using a mixed culture of dairy sludge in the activated sludge. Likewise, the trickling filter is also a very effective technology in the removal of FOG from wastewater. FOG removal was reported to be substantial in a study done by Pontes and Chernicharo (2011) while evaluating lipids in raw sewage. In addition, El-Masry et al. (2004) noted the FOG elimination rate to be 100% using the trickling filter technology in wastewater containing vegetable oil and grease.

In the current study, the trickling filter was more efficient than the activated sludge in the removal of FOG. However, the South African wastewater effluent standards (SA Department of Forestry, Fisheries and the Environment, 2014) limit applicable to the discharge into a water source as $\leq 2.5 \text{ mg/l}$, meaning that neither of the wastewater effluents complied. In the United States, a similar study reported that the removal rate of FOG in domestic water using the activated sludge system was 15.2% in Waipio and 97.8% in Pohakapu, which used the trickling filter (Young & Chan, 1970). Additionally, based on their findings, the current study compared agreeably with the results found by Young and Chan (1970).

This results indicated that FOG removal using the trickling filter system is higher than FOG removal using the activated sludge system. More scientific studies done under the same conditions for the two wastewater treatment plants are vital to further investigate the difference between the two technologies. In this way, the discrepancy between the two technologies can be established.

5.2.2 Nitrates

The Pearson Correlation Coefficient was used to calculate the correlation between FOG and nitrates.

The following equation shows the Pearson formula which was used to measure the dependence of FOG to nitrates.

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{(\sum(x_i - \bar{x})^2) \sum(y_i - \bar{y})^2}}$$

Nitrate levels in the BWTW and NEWTW were measured in the effluents for a period of nine alternating weeks from June 2021 to October 2021.

Figure 5.3 shows correlation of FOG and nitrates in the BWTW.

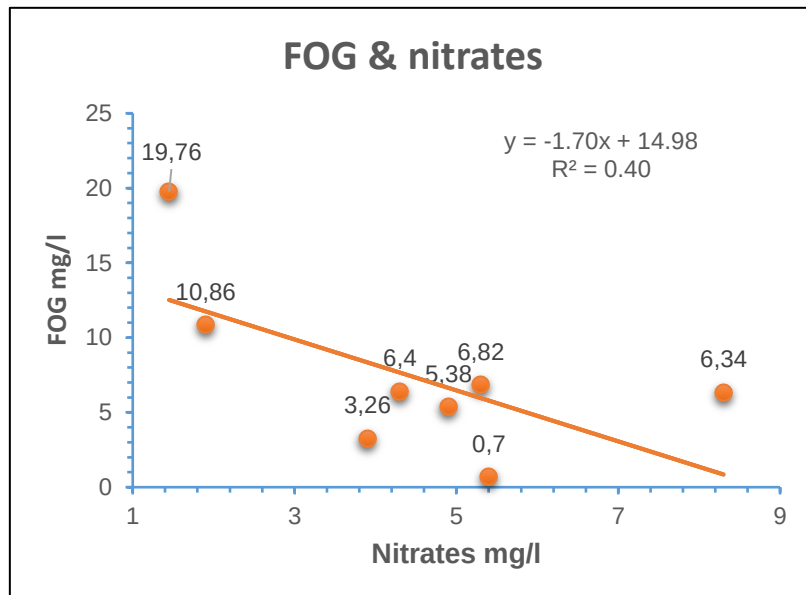


Figure 5.3 Correlation of FOG and nitrates in the BWTW

Figure 5.4 shows correlation of FOG and nitrates in the NEWTW.

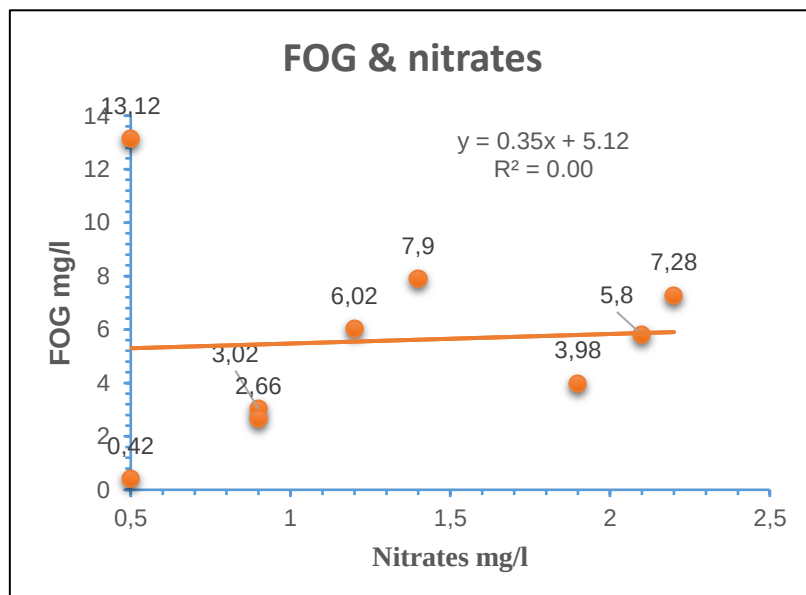


Figure 5.4 Correlation of FOG and nitrates in the NEWTW

The average nitrates in the BWTW effluent were reported to be 4.43 mg/l and 1.29 mg/l for the NEWTW, which met the South African discharge standards of ≤ 15 mg/l (SA Department of Forestry, Fisheries and the Environment, 2014). A study done by Kim et al. (2014) indicated good results of the trickling filter in nitrification. Similarly, Almstrand et al. (2011) and Persson et al. (2002) also agreed that the trickling filter is highly effective in the elimination of nitrates.

In addition, the regression figure was 1.0 for both the BWTW and the NEWTW, hence showing a strong correlation between nitrates and FOG. The coefficient of determination between nitrates and FOG was 0.0, indicating no low variance and 0.4 in the BWTW indicating a nearly medium variance. The regression figure was 1.0 for both the BWTW and the NEWTW, which indicated a strong correlation between nitrates and FOG.

5.2.3 Phosphates

Phosphate enrichment largely impairs aquatic ecosystem functions and services, thus comprising an emerging problem of environmental concern (Mavhungu et al., 2019). Figures 5.5 and 5.6 shows the relationship between phosphate levels and FOG levels in the BWTW and NEWTW, respectively.

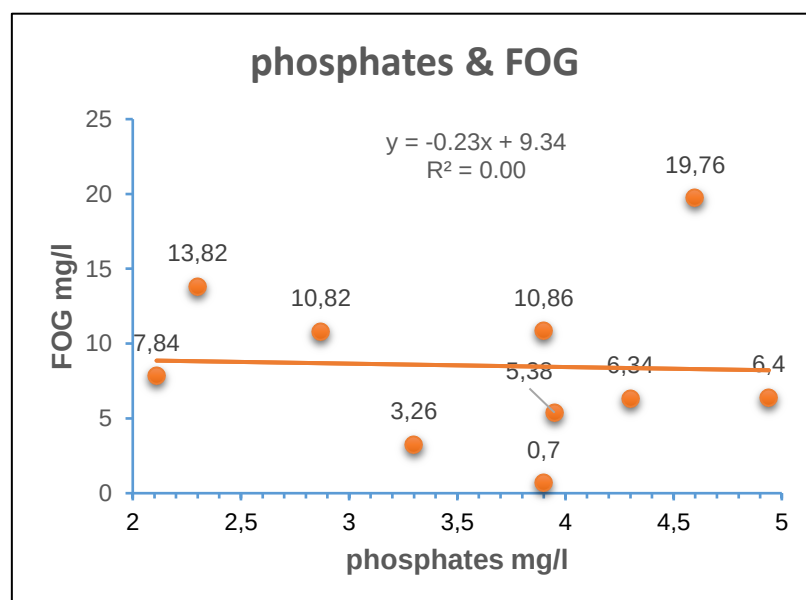


Figure 5.5 Correlation between FOG and phosphates in the BWTW

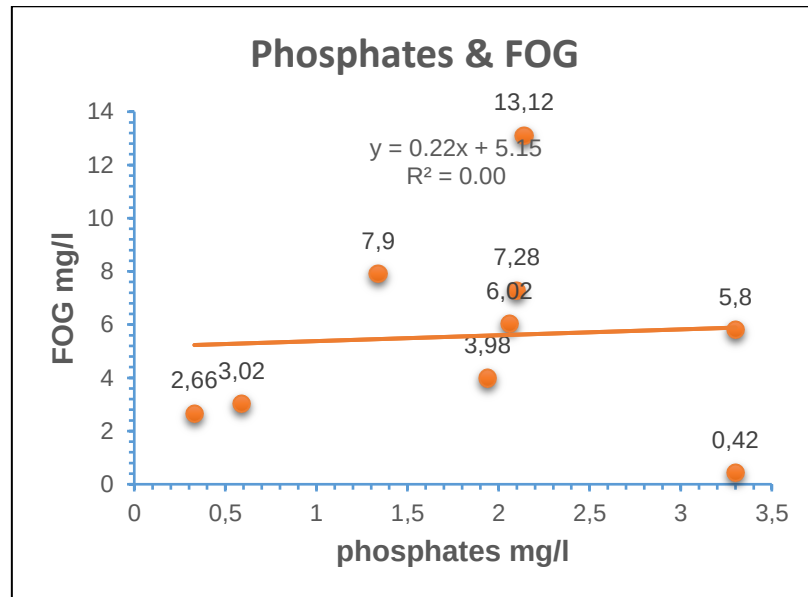


Figure 5.6 Correlation between FOG and phosphates in the NEWTW

Phosphate volumes in the effluents of the two plants were reported to be 3.6 mg/l for the BWTW and 1.9 mg/l for the NEWTW, which met the effluent standards of ≤ 10 mg/l. In a study exploring phosphorus removal in the activated sludge, the removal rate was reported to be 97% (Gebremariam et al., 2012). The results of this study compare agreeably to a study done by İrdemez et al. (2006), which reported the highest level of phosphorus removal of 90.1%.

Additionally, the coefficient of determination for phosphates and FOG in the NEWTW was found to be 0.00, indicating no weak correlation, and 0.00 for the BWTW, also showing no correlation, while the correlation coefficient was 1.0 in both the BWTW and the NEWTW, showing a strong fit for regression in both plants. Furthermore, a study done by Vialkova et al. (2019) revealed that wastewater mixture was characterised by an elevated concentration of nitrates, ammonium and phosphates, which indicated the curd and cheese in the effluent that contained fats. Hence, the FOG seen in the effluents of the two plants was of a large proportion from domestic homes.

5.2.4 pH

It is known that pH is a measure of acidity and alkalinity (Hailu & Ayenew, 2015). The optimum pH range for biological treatment is between 6.5 and 8.5 (Eckenfelder, 1989). The pH can be affected by the concentration of DO and determines which

organisms can live and thrive. Figure 5.7 shows the correlation between FOG and pH in the BWTW.

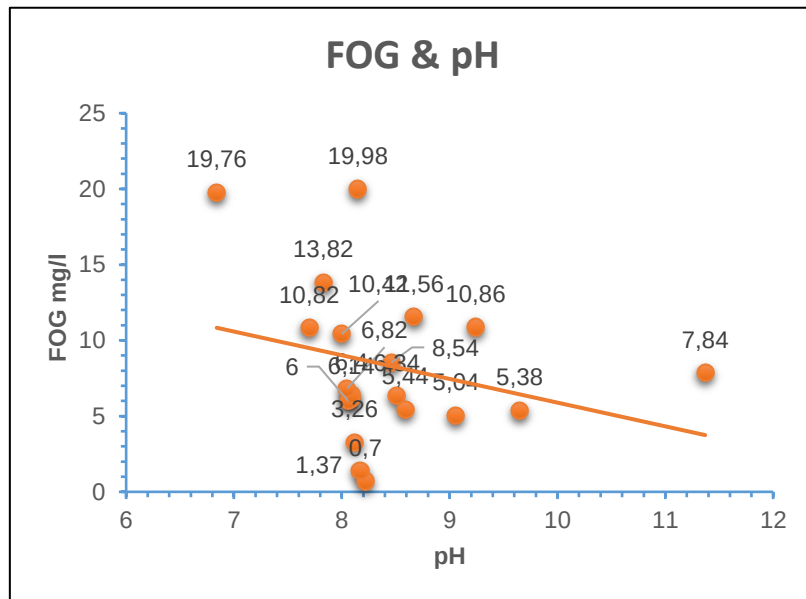


Figure 5.7 Correlation between FOG and pH in the BWTW

Figure 5.8 shows the correlation between FOG and pH in the NEWTW.

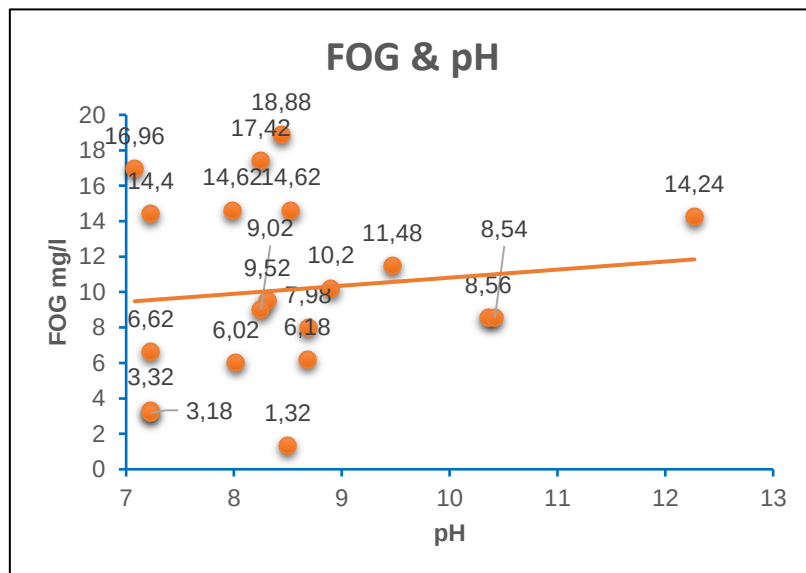


Figure 5.8 Correlation between FOG and pH in the NEWTW

The results indicated that FOG in both wastewater treatment plants had an alkaline pH due to the presence of fatty acids. In a study done by Sawain et al. (2009), the results of the experiments showed that the change of emulsion and coalesce of oil was observed when the pH value decreased to about 5. Furthermore, Eckenfelder

and Wesley (2000), Fujiia et al. (2007) and Reynolds and Richards (1996) reported that the separation of FOG could be noted when pH was lower than 3.

The results indicated that FOG in both wastewater treatment plants had an alkaline pH due to the presence of fatty acids. The mean pH in the BWTW influent was 8.83 and 8.44 in the effluent, which indicated a basis for both readings. The mean pH in the NEWTW influent was 8.55 and 8.14. As a result, FOG removal in the two wastewater treatment plants was low.

5.2.5 Resistivity

The resistivity of water is directly determined by the concentration of dissolved salts found in the water (Sensorex, 2020). An ample amount of dissolved salts in the water results in low resistivity. Subsequently, a high resistivity equates to cleaner and purer water. The average resistivity in the NEWTW influent was 0.00143 and 0.0015 in the NEWTW effluent. The average resistivity was 0.0011 in the BWTW and 0.0014 in the BWTW effluent. Comparing the influent and effluent in both plants, this results imply that there was a little volume of oxygen dissolved in the wastewater of the two plants.

5.2.6 Temperature

The presence of oxygen in wastewater is affected by solubility (Akan et al., 2008). In addition, the toxicity of particular chemicals in wastewater is affected by temperature (Dojlido & Best, 1993; Mayer & Ellersieck, 1988). As a result, secondary wastewater treatment processes heavily rely on the use of bacteria to eliminate organic matter from sewage. Bacteria used in water treatment plants function optimally at temperatures between 20 °C and 35 °C. Lower temperatures are still functional for bacteria; however, the rate of microbial action decreases with a decrease in temperature. On the other hand, very high temperatures have proven to be detrimental to these microorganisms and resulted in ineffective microbial processes (Marrone et al., 2020). Figure 5.9 shows the effect of temperature on FOG removal efficiency.

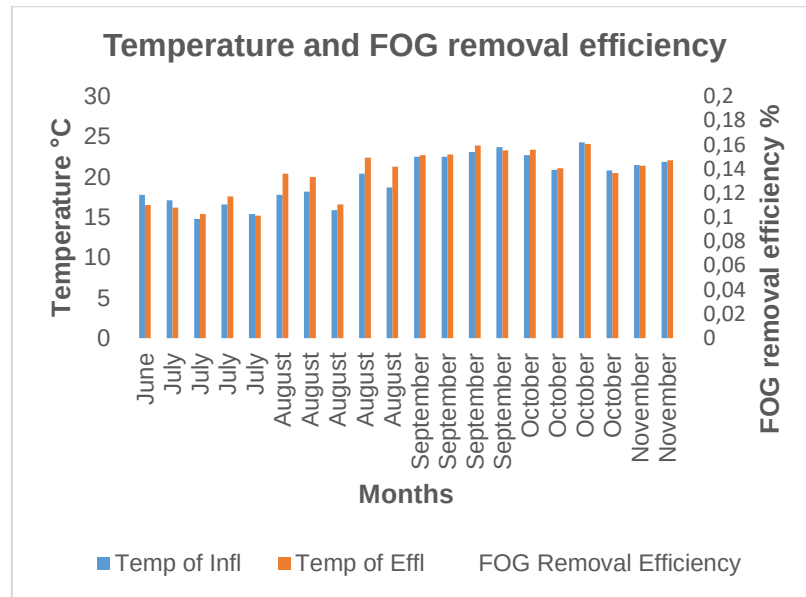


Figure 5.9 Relationship between FOG removal efficiency and temperature in the BWTW

Figure 5.10 shows the relationship between temperature and FOG removal efficiency in the NEWTW.

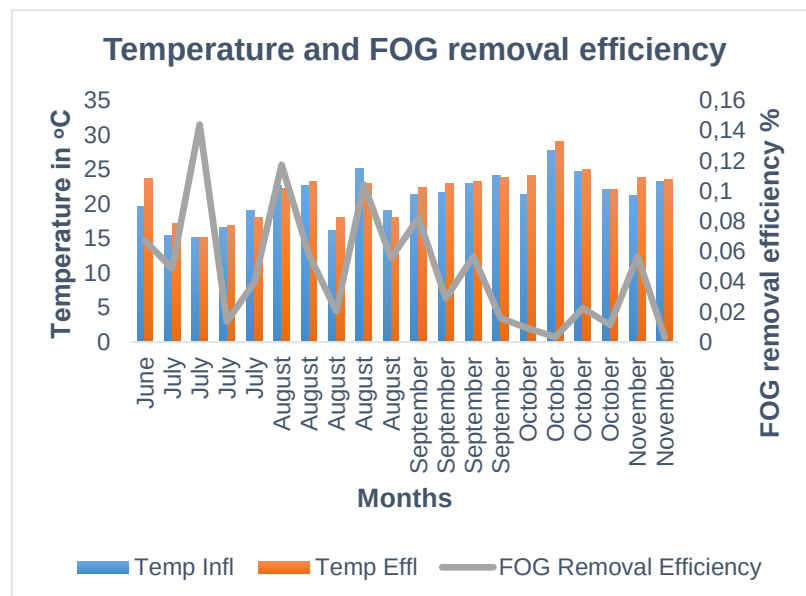


Figure 5.10 Relationship between FOG removal efficiency and temperature in the NEWTW

The results indicated that FOG removal efficiency varied considerably with regard to temperature. The results showed that FOG removal efficiency was lower in the warmer months of September, October and November. Furthermore, the results indicated that in the colder months of June, July and August, FOG removal

efficiency was higher, which mean that FOG removal efficiency is indirectly proportional to temperature.

5.2.7 Dissolved oxygen

The amount of oxygen in wastewater is called DO (Zareie et al., 2021). The level of contamination in wastewater is determined by the DO levels that are significantly reduced by the presence of organic waste, domestic and animal waste, together with waste from commercial activities. In addition, DO solubility is directly proportional to atmospheric pressure and inversely proportional to water temperature and salinity (Trick et al., 2018). Because the system may lack oxygen or nutrients, some processes may not work properly. This may also be because of an increase in fibrous microorganisms in the sludge that causes deteriorated sedimentation properties in the sedimentation tank. Figure 5.11 shows the DO levels of the BWTW.



Figure 5.11 Dissolved oxygen levels in the BWTW

Figure 5.12 shows the DO levels in the NEWTW.

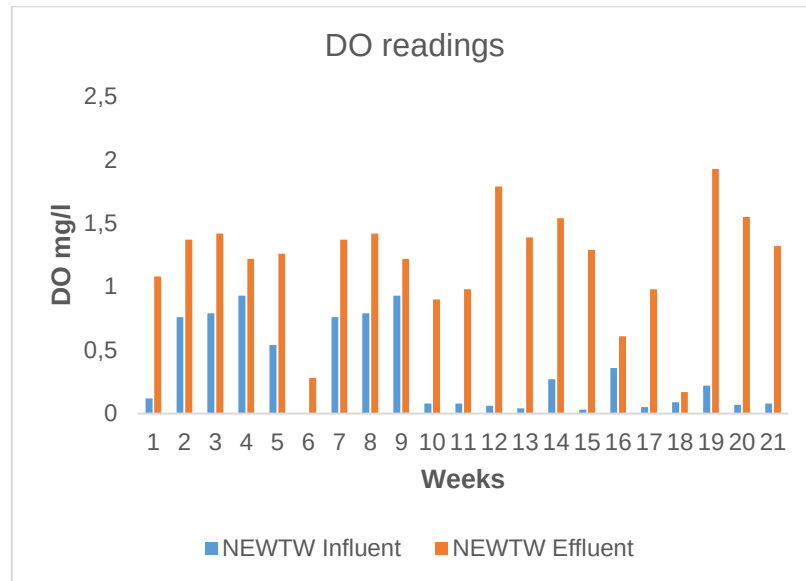


Figure 5.12 Dissolved oxygen levels in the NEWTW

According to Torres-Bejarano et al. (2018), DO is one of the most affected parameters by oil and greases. Levels of DO vary in each stage in the wastewater treatment. However, by keeping the critical bacteria alive, the presence of dead zones in the biological floc can be avoided by having at least 2 mg/l of DO (Online, 2021). At both influents, the readings were very low, but rose at the effluents, which is a result of aeration in the activated sludge. However, neither plants reached a DO of 2 mg/l. The average DO in the BWTW influent was between 0.35 mg/l and 1.39 mg/l, which was below the recommended DO level. On the other hand, the average DO in the NEWTW influent was found to be 0.33 mg/l, and 1.17 mg/l in the effluent. Furthermore, during the warmer weeks, the rate of biological oxidation was highly increased and this resulted in a low DO concentration compared to the colder weeks; hence, the DO levels fluctuated throughout the study.

5.2.8 Total dissolved solids

TDS is the measure of the amount of solid materials that can pass through a filter. This material can include carbonate, bicarbonate, chloride, sulphate, phosphate, nitrate, calcium, magnesium, sodium, organic ions, as well as other ions. Figure 5.13 shows TDS in the BWTW.

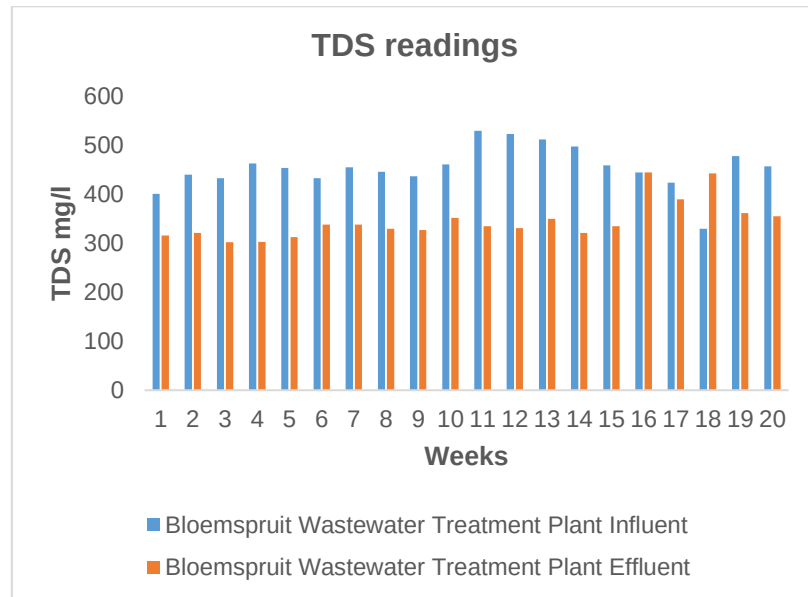


Figure 5.13 Total dissolved solids volume in the BWTW

Figure 5.14 shows TDS readings in the NEWTW.

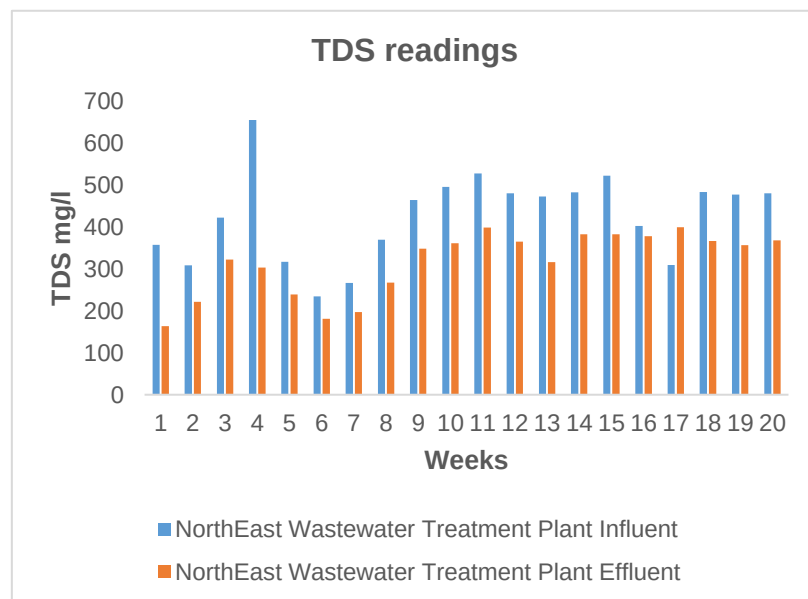


Figure 5.14 Total dissolved solids volume in the NEWTW

The results showed that the BWTW had higher readings of TDS than the NEWTW. The BWTW received a higher volume of wastewater, which correlates with a high level of TDS. Additionally, most of the wastewater entering the BWTW comes from homes and nearby small manufacturers; hence, a high volume of TDS.

5.2.9 Salinity

The efficacy of the activated sludge wastewater treatment process was impeded by a high level of salinity (Ahanger and Agarwal et al., 2017). The solubility of oxygen was reduced by a high volume of salinity. Urine contained fractions of nitrogen, phosphorus and potassium and as a result had a pH of 6.2 (Rose et al., 2015). Canfield et al., 1963, Guyton and Hall, 2000, Kien et al., 1981, Rivero-Marcotegui et al., 1998 and Wierdsma et al., 2011 reported that fats found in the wet weight of faeces was between 2.4% and 8%. Similarly, Calloway & Kretsch, 1978, Stephen et al., 1986 and Tarpila et al., 1978 indicated that the fats found in the dry weight of faeces was 8.7–16.0%. Furthermore, daily loadings of fat in faecal fraction were evaluated in eight studies and a median value of 4.1 g/cap/day as well as a span of 1.9-6.4 g/cap/day were noted.

Figure 5.15 shows the salinity levels in the BWTW.

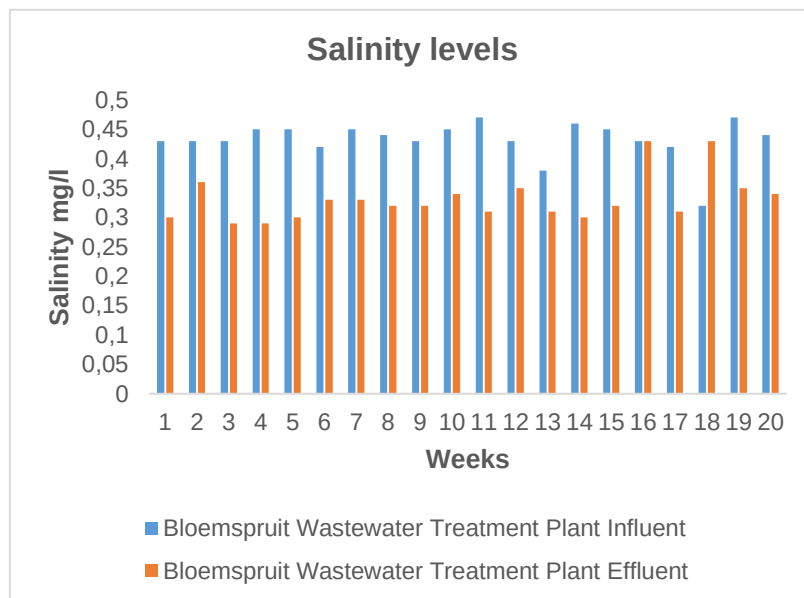


Figure 5.15 Salinity levels for the BWTW

Figure 5.16 shows the salinity levels in the NEWTW.

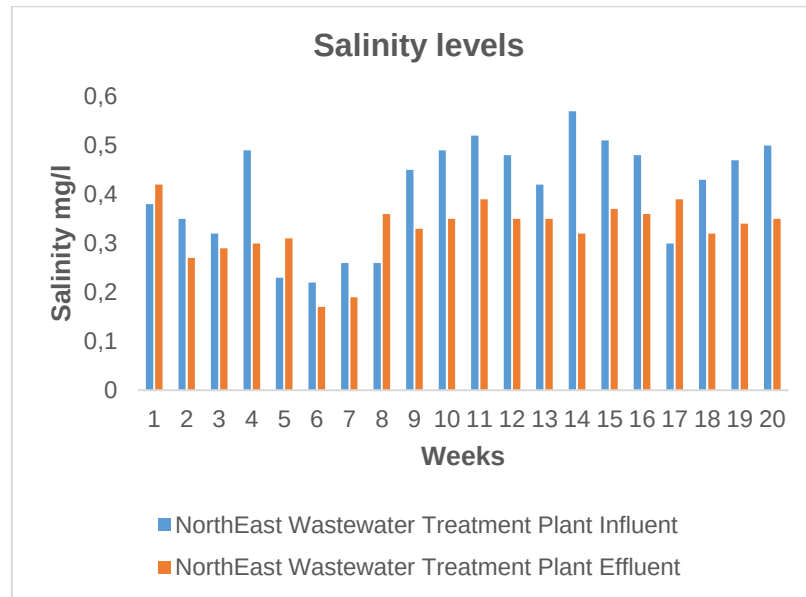


Figure 5.16 Salinity levels in the NEWTW

Both plants showed a significant difference in salinity levels in the influent and in the effluent. However, the salinity levels in the BWTW were high because it received a greater volume of influent, and a large percentage of its influent was from gray water from homes and institutions.

4.8.1 Conductivity

The conductivity of water is an expression of its ability to conduct an electric current (Mulu et al., 2015). Conductivity also indicates the amount of dissolved salt and can be used to assess processes on which the change in total salt concentration relies and subsequent changes in conductivity (Levlin, 2010). The presence of inorganic dissolved solids such as chloride, nitrate, sulphate and phosphate anions or sodium, magnesium, calcium, iron and aluminium cations affect conductivity (Rice et al., 2012). Many municipalities require that discharge effluents measure conductivity that is not higher than 500 mS/m (Levlin, 2010).

In a study done on two wastewater treatment plants in Stockholm, no reduction of conductivity was noted in the pre-sedimentation, while 28% reduction in the activated sludge was observed (Levlin, 2010). In addition, conductivity in the inflowing wastewater to the Lotsbroverket wastewater treatment plant in Mariehamn, Åland, during 2006 varied from 58 mS to 137 mS/m, with roughly 23%

reduction of conductivity in the activated sludge process (Levlin, 2010). Figures 5.16 and 5.17 shows the conductivity levels in the BWTW and NEWTW, respectively.

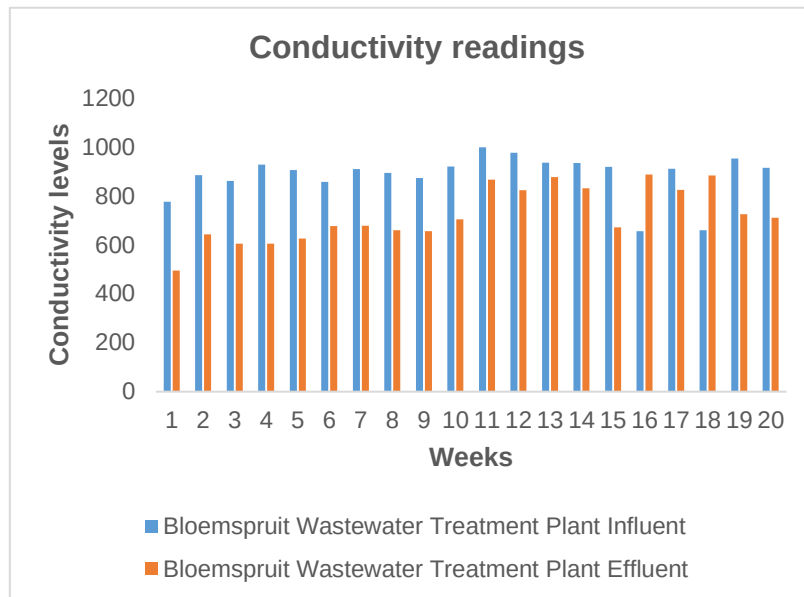


Figure 5.17 Conductivity levels in the BWTW

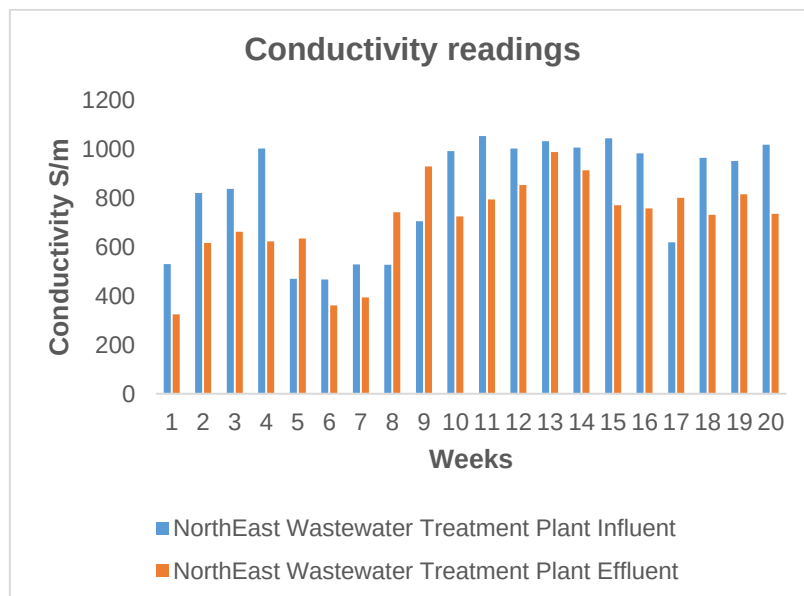


Figure 5.18 Conductivity levels in the NEWTW

The results indicated that in the BWTW, conductivity increased by an average of over 50% after wastewater treatment, which is not normal. This could result from the plant not functioning well. In addition, the conductivity in the influent was still found to be above 500 mS/m. On the other hand, the NEWTW had a satisfactory

conductivity increase rate of about 200%, although the effluent had conductivity levels of close to 1 000 mS/m, which is detrimental to the environment.

5.2.10 Chemical oxygen demand

The COD is defined as the amount of oxygen equivalents consumed in the chemical oxidation of organic matter by strong oxidants (e.g., potassium dichromate) (Jain & Singh, 2003). The importance of COD is to provide an index that assists in assessing the potential effect of wastewater discharge on the environment. The COD test also gives the value of the total quantity of oxygen required for the oxidation of the organic matter present in the wastewater to carbon dioxide and water (Kang et al. 1999).

In a study done by Yapicioğlu and Yeşilnacar (2020), the COD removal efficiency was found to be 70% and a FOG removal efficiency of 97%, while assessing wastewater containing dairy wastes. There were higher levels of COD at the NEWTW than at the BWTW. This is because the BWTW receives a higher volume of wastewater than the NEWTW, with mostly wastewater from domestic homes that contains organic matter. Figure 5.19 shows the COD levels for the BWTW.

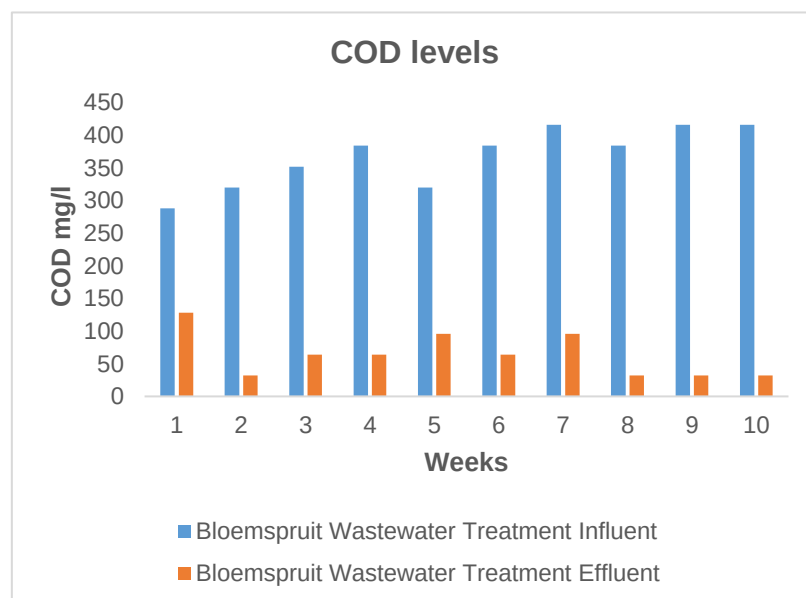


Figure 5.19 Chemical oxygen demand levels in the BWTW

Figure 5.20 shows the COD levels for the NEWTW.

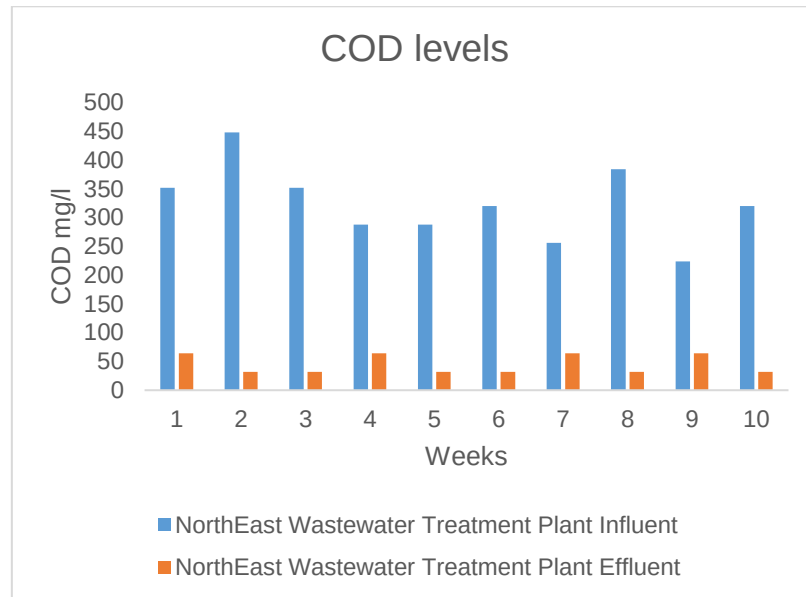


Figure 5.20 Chemical oxygen demand levels in the NEWTW

The average COD was found to be 368 mg/l in the BWTW influent and 64 mg/l in the effluent, while the NEWTW influent had 323.55 mg/l and 46.22 mg/l in the effluent. These results indicated that both wastewater treatment plants were functioning well in the removal of pollutants.

5.3 Summary of the study

The study investigated the efficiency of the activated sludge and the trickling filter technologies in the removal of FOG and the possible correlation of nitrates and phosphates to FOG in the effluent of two wastewater treatment plants of the Mangaung Metropolitan Municipality. The NEWTW was built to relief the hydraulically overloaded BWTW; however, these two wastewater treatment plants both release FOG into the catchment using the trickling filter system, despite activated sludge being the latest technology of the two.

The study began in June 2021 and ended in November 2021. Sampling were taken at 12:00 when temperatures were 17 °C in June, July and August, and for September and October sampling were collected around 10:30. Twenty samples of the influent and 20 samples of the effluent of the BWTW and NEWTW were taken once a week and tested for the presence of FOG, nitrates and phosphates, COD, oxygen absorbed, salinity, conductivity, temperature, atmospheric pressure, DO, pH and TDS. FOG was analysed using the EPA 1664B method in the laboratory, while

nitrate test, and phosphates analysed using the phosphate Spectroquant test in the laboratory. Furthermore, the regression formula was used to analyse the correlation between nitrates, phosphates and FOG. COD was analysed in the laboratory using the variation of the potassium dichromate method. Oxygen absorbed was analysed in the laboratory using the Part 63 oxygen absorbed in four hours method. The parameters salinity, conductivity, temperature, atmospheric pressure, and TDS were analysed using the Hanna HI98193 multimeter, while DO and pH were analysed using the Hanna 98192 multimeter.

In addition, the trickling filter technology had a higher removal rate than the activated sludge technology. The percentage removal of FOG at the BWTW was 61.36% and 52.81% for the NEWTW. When compared to the South African wastewater effluent standards limit applicable to the discharge into a water source of $\leq 2.5 \text{ mg/l}$, it means that neither of the wastewater effluents standards.

Moreover, the regression figure was 0.99 for the BWTW and 1.00 for the NEWTW, meaning a strong relationship between nitrates and FOG was evident. In the NEWTW, the coefficient of determination was 0.00. This showed little variance of FOG in nitrates, while in the BWTW the coefficient of determination was found to be 0.4039, which shows an almost equal chance of the variance of FOG to nitrates. This concludes that the volume of FOG found in the effluents of both plants was influenced by the volume of nitrates and FOG.

For the NEWTW, the results showed that the phosphate levels were lower in the effluent throughout the study, meaning that the plant is performing well in the removal of phosphate. Many number of soaps and detergents contain phosphates, hence a significant volume of phosphates in the wastewater influent of the two plants. However, the BWTW contained the most phosphates as it receives a higher volume of influent. Furthermore, the correlation coefficient of phosphates and FOG in the BWTW was found to be 0.00, showing a weak to moderate correlation and 0.999 for the NEWTW, showing a strong correlation, while the coefficient of determination was 0.07 for FOG in the BWTW, indicating a weak fit for regression and 0.00 for phosphates, also indicating a weak fit for regression. In the NEWTW,

phosphates showed a greater dependency on FOG by 0.67, while FOG showed a low 0.02 dependency on phosphates.

On the other hand, the volume of oxygen absorbed in the two wastewater treatment plants was found to be low as a result of a large number of organic compounds present in the water. The average oxygen absorbed in the BWTW influent was found to be 47.50 mg/l and 60.80 mg/l in the effluent. Additionally, the oxygen absorbed measured 41.33 mg/l in the influent of the NEWTW and 11.88 mg/l in the effluent. This resulted from power outages which led to malfunction of the plant, which accounted for dropping oxygen absorbed levels in the effluent.

Furthermore, there were higher levels of COD at the NEWTW than at the BWTW despite the BWTW receiving a higher volume of wastewater than the NEWTW. The average COD was found to be 368 mg/l in the BWTW influent and 64 mg/l in the effluent, while the NEWTW influent showed 323.55 mg/l and 46.22 mg/l in the effluent. These results indicated that both wastewater treatment plants are functioning well in terms of removal of pollutants.

At both influents, the DO readings were very low, but rose at the effluents, which is a result of aeration in the activated sludge. However, neither plant reached the recommended 2 mg/l. The average DO in the BWTW influent was 0.35 mg/l and 1.39 mg/l, which was below the recommended DO. On the other hand, the average DO in the NEWTW influent was found to be 0.33 mg/l and 1.17 mg/l in the effluent.

As can be seen, the results indicated that FOG in both wastewater treatment plants had an alkaline pH due to the presence of fatty acids. The mean pH in the BWTW influent was 8.83 and 8.44 in the effluent, which indicate alkalinity for both readings. The mean pH in the NEWTW influent was 8.55 and 8.14. Similarly, both readings indicated alkalinity.

Moreover, both plants showed a significant difference in salinity levels in the influent and in the effluent. The mean salinity in the BWTW influent was 0.41 ppt and 0.33 ppt in the effluent. On the other hand, salinity in the NEWTW influent was found to be 0.41 ppt and 0.33 ppt in the effluent. However, the salinity levels in the BWTW were high due to the greater volume of influent it receives and most of it being from grey water from homes and institutions.

Typically, the presence of chloride, nitrate, sulphate, phosphate, sodium, magnesium, calcium, iron and aluminium increases conductivity of water. Conductivity in the BWTW was higher in the effluent by over 50%, which is not common. These results implies that the plant is not functioning well. Similarly, in the NEWTW, conductivity results were close to 1 000 mS/m, indicating that the plant was also not functioning well and posing a threat to the discharge environment. As a result, the average conductivity in the BWTW influent was 882.95 mS/m and 722.1 mS/m in the effluent, while 827.05 mS/m in the NEWTW influent and 707.85 mS/m in the effluent.

The results indicated that FOG removal efficiency varied considerably with regard to temperature. The results showed that FOG removal efficiency was lower in the warmer months of September, October and November. Furthermore, the results indicated that in the colder months of June, July and August, FOG removal efficiency was higher, which means that FOG removal efficiency is indirectly proportional to temperature.

Furthermore, the average atmospheric pressure for each treatment plant taken over a period of 20 weeks were as follows: the BWTW influent was 642.14 Pa, the BWTW effluent was 642.48 Pa, while the NEWTW influent was 646.69 Pa and the NEWTW effluent was 646.43 Pa.

On the other hand, the results showed that the BWTW had higher readings of TDS than the NEWTW. The mean TDS in the BWTW influent was 453.95 mg/l and the effluent 345.35 mg/l. Likewise, TDS in the NEWTW influent was 412.67 mg/l and 314.32 mg/l in the effluent. The BWTW receives a higher volume of wastewater, which correlates with a high level of TDS. Also, most of the wastewater entering the BWTW comes from homes and nearby small manufacturers, hence a high volume of TDS.

CHAPTER 6 .

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The study was carried out to measure the efficiency of the trickling filter and the activated sludge in the treatment of FOG, nitrogen and phosphorus and the likely correlation of nitrates and phosphates to FOG. The effluent discharged by the two treatment plants did not comply with the South African wastewater discharge standards, in addition, the results indicated a strong correlation between FOG and nitrates and FOG and phosphates in the two treatment plants. This infers that the volume of FOG found in the effluents of these plants is dependent on the volume of nitrates and FOG. Furthermore, from the observation of the performance of the trickling filter and the activated sludge, it can be drawn that the trickling filter is an efficient treatment method in the treatment of FOG in contrast to the activated sludge. However, additional empirical research for the two wastewater treatment technologies is necessary to institute the degree of discrepancy between the two technologies in the elimination of FOG, nitrogen and phosphorus in municipal wastewater. Nevertheless, this study has shown the distinction between the two wastewater treatment technologies in the elimination of FOG and its interrelationship to nitrates and phosphates.

In determining the effectiveness of the two wastewater treatment technologies in the elimination of FOG and nutrients, it was found that the effluent discharged by the two treatment plants did not comply with the South African wastewater discharge standards which state that the FOG in effluents should be $\leq 2.5 \text{ mg/l}$. Furthermore, nitrates and phosphates present in the effluent should be $\leq 2.5 \text{ mg/l}$. However, for FOG, the volume of discharged FOG in effluents was found to be 8.32 mg/L and 5.36 mg/L for BWTW and NEWTW respectively. This poses a great risk to aquatic life in the receiving water bodies which prompts for remedial action to stop FOG from entering the wastewater treatment plant or ensure it is efficiently removed in the wastewater treatment.

The effluent of the two wastewater treatment plants was found to contain FOG hence there is a need for extra pre-treatment measures to the plants for improvement in the elimination of FOG.

After investigation of the likely impact of FOG and nutrients released to the catchment after treatment, it was noted that the presence of FOG in the effluent discharged into the catchment is likely to have adverse effects to the aquatic life in and around the catchment. Furthermore, the presence of nutrients in the effluent discharged into the catchment is likely to cause eutrophication and ultimately the death of organisms in the catchment.

This concludes that the volume of FOG found in the effluents of these plants is effected by the volume of nitrates and FOG. Furthermore, in comparing the trickling filter and the activated sludge technologies, the results indicated that the trickling filter is a more efficient treatment method for the treatment of FOG compared to the activated sludge technology.

6.2 Recommendations

The current findings will serve as a useful information concerning FOG found in effluents. FOG was found in the effluent of the two-treatment plant, therefore the following pre-treatment measures are recommended:

- Reinforcement of laws that prohibit the discharge of food industry FOG into the wastewater treatment plants.
- Introducing pre-treatment methods such as tilting plates in the preliminary stage of the two wastewater treatment plants.
- Recycling FOG found in the effluent into biodiesel.
- Ensuring that the wastewater treatment plants are functioning efficiently can not only properly reduce FOG, but it can promote the need for commercialising by-products such as sludge for biogas.

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APPENDIX A

SUPPLEMENTARY INFORMATION TO CHAPTER 5

Fats, oil and grease (FOG)

Parameters	BWTW		NEWTW	
	Influent	Effluent	Influent	Effluent
Week 1 23/06/2021				
pH before analysis	2.00	2.00	2.00	2.00
Mass of container (g)	45.44	44.80	47.42	47.83
Mass before drying (g)	83.55	78.5	77.77	75.23
After drying (g)	56.0	54.68	54.73	55.73
FOG	21.12	19.76	14.62	7.90
Week 2 30/06/2021				
pH before analysis	2.00	2.00	2.00	2.00
Mass of container (g)	45.41	44.69	47.42	47.85
Mass before drying (g)	83.55	77.5	77.76	54.73
Mass after drying (g)	56.00	54.68	54.73	52.73
FOG	21.18	19.98	14.62	9.76
Week 3 07/07/2021				
pH before analysis	2.00	2.00	2.00	2.00
Mass of container (g)	47.42	49.42	45.41	47.90
Mass before drying (g)	53.34	52.89	69.42	51.55
Mass after drying (g)	52.75	51.05	54.12	49.41
FOG	10.66	3.26	17.42	3.02
Week 4 14/07/2021				
pH before analysis	2.00	2.00	2.00	2.00
Mass of container (g)	45.44	44.80	47.80	47.90
Mass before drying (g)	53.20	56.70	50.45	57.79
Mass after drying (g)	49.47	47.87	49.46	48.89
FOG	8.06	6.14	3.32	1.98
Week 5 21/07/2021				
pH before analysis	2.00	2.00	2.00	2.00
Mass of container (g)	45.44	44.80	47.48	47.90
Mass before drying (g)	57.25	55.96	57.45	56.76
Mass after drying (g)	46.30	45.15	50.79	49.23
FOG	1.72	0.70	6.62	2.66

Parameters	BWTW		NEWTW	
	Influent	Effluent	Influent	Effluent
Week 6 28/07/2021				
pH before analysis	2.00	2.00	2.00	2.00
Mass of container (g)	45.41	44.69	47.42	47.83
Mass before drying (g)	57.90	53.55	57.70	52.50
Mass after drying (g)	48.95	47.69	55.90	50.44
FOG	7.08	6.00	16.96	5.22
Week 7 04/08/2021				
pH before analysis	2.00	2.00	2.00	2.00
Mass of container (g)	45.41	44.69	47.42	47.83
Mass before drying (g)	53.26	50.31	57.70	52.50
Mass after drying (g)	52.21	50.12	56.86	54.39
FOG	13.6	10.86	18.88	13.12
Week 8 11/08/2021				
pH before analysis	2.00	2.00	2.00	2.00
Mass of container (g)	45.40	44.69	47.42	47.83
Mass before drying (g)	57.64	53.37	57.15	57.52
Mass after drying (g)	51.70	49.90	50.43	49.82
FOG	12.60	10.42	6.02	3.98
Week 9 18/08/2021				
pH before analysis	2.00	2.00	2.00	2.00
Mass of container (g)	45.40	54.39	45.37	47.83
Mass before drying (g)	61.10	66.81	57.61	55.34
Mass after drying (g)	57.16	57.59	52.57	49.82
FOG	23.52	6.40	14.40	3.98
Week 10 25/08/2021				
pH before analysis	2.01	2.01	2.01	2.01
Mass of container (g)	51.84	59.77	45.42	47.85
Mass before drying (g)	66.41	72.93	57.70	60.29
Mass after drying (g)	63.54	62.29	55.62	52.49
FOG	23.4	5.04	10.20	4.64
Week 11 01/09/2021				
pH before analysis	2.01	2.01	2.01	2.01
Mass of container(g)	51.83	59.77	45.37	47.86
Mass before drying (g)	65.15	69.45	58.42	59.52
Mass after drying (g)	63.86	62.94	52.49	50.87
FOG	24.06	6.34	14.24	6.02

Parameters	BWTW		NEWTW	
	Influent	Effluent	Influent	Effluent
Week 12 08/09/2021				
pH before analysis	2.01	2.01	2.01	2.01
Mass of container (g)	47.83	52.51	59.77	50.66
Mass before drying (g)	62.60	61.35	69.01	59.23
Mass after drying (g)	58.46	55.23	64.05	53.49
FOG	21.26	5.44	8.56	5.66
Week 13 15/09/2021				
pH before analysis	2.01	2.01	2.01	2.01
Mass of container (g)	53.27	51.45	54.40	47.96
Mass before drying (g)	58.36	53.31	63.91	58.86
Mass after drying (g)	56.38	54.14	60.14	50.86
FOG	6.22	5.38	11.48	5.80
Week 14 22/09/2021				
pH before analysis	2.01	2.01	2.01	2.01
Mass of container (g)	51.94	56.42	59.95	45.50
Mass before drying (g)	61.26	63.05	66.89	51.59
Mass after drying (g)	55.75	59.83	64.22	48.98
FOG	7.62	6.82	8.54	6.96
Week 15 29/09/2021				
pH before analysis	2.01	2.01	2.01	2.01
Mass of container (g)	53.25	52.48	54.39	50.65
Mass before drying (g)	63.33	61.89	64.08	60.69
Mass after drying (g)	59.89	56.40	55.05	50.86
FOG	13.28	7.84	1.32	0.42
Week 16 06/10/2021				
pH before analysis	2.01	2.01	2.01	2.01
Mass of container (g)	53.20	49.66	47.43	45.41
Mass before drying (g)	62.91	57.73	58.09	57.13
Mass after drying (g)	56.68	56.51	49.42	46.83
FOG	6.96	1.37	3.18	2.84
Week 17 13/10/2021				
pH before analysis	2.01	2.01	2.01	2.01
Mass of container (g)	47.83	44.69	59.77	47.83
Mass before drying (g)	57.89	54.30	66.26	55.30
Mass after drying (g)	53.60	50.10	64.53	51.47
FOG	11.54	10.82	9.52	7.28

Parameters	BWTW		NEWTW	
	Influent	Effluent	Influent	Effluent
Week 18 20/10/2021				
pH before analysis	2.01	2.01	2.01	2.01
Mass of container (g)	53.20	49.66	47.43	45.41
Mass before drying (g)	62.91	57.73	58.09	57.13
Mass after drying (g)	60.68	56.57	51.42	48.83
FOG	14.96	13.82	7.98	6.84
Week 19 27/10/2021				
pH before analysis	2.01	2.01	2.01	2.01
Mass of container (g)	51.83	49.67	45.32	45.41
Mass before drying (g)	65.04	58.85	57.86	55.22
Mass after drying (g)	56.35	53.94	49.83	47.08
FOG	9.04	8.54	9.02	3.34
Week 20 03/11/2021				
pH before analysis	2.01	2.01	2.01	2.01
Mass of container (g)	53.20	49.66	47.43	45.41
Mass before drying (g)	62.58	59.63	59.18	55.22
Mass after drying (g)	59.87	55.44	50.52	48.34
FOG	13.34	11.56	6.18	5.86

Multimeter readings

Parameters	NEWTW		BWTW	
	Influent	Effluent	Influent	Effluent
Week 1 30/06/2021				
pH	8.53	8.61	7.25	6.84
Conductivity	530	324	776	495
Atmospheric pressure	644	643	642	642
Resistivity	0.0017	0.0013	0.0014	0.0012
TDS	357	163	401	316
Salinity	0.38	0.42	0.43	0.30
Temperature	19.6	23.7	17.8	16.5
DO	0.12	1.08	0.08	0.16
Week 2 06/07/2021				
pH	7.99	7.85	8.81	8.15
Conductivity	820	616	884	643
Atmosphere pressure	647	647	642	642
Resistivity	0.0018	0.0015	0.0016	0.0014
TDS	221	308	440	321
Salinity	0.35	0.27	0.43	0.36
Temperature	15.5	17.1	17.1	16.2
DO	0.76	1.37	0.80	1.36
Week 3 13/07/2021				
pH	8.25	7.23	8.14	8.12
Conductivity	837	661	861	604
Atmosphere pressure	644	644	649.8	649.6
Resistivity	0.0015	0.0012	0.0012	0.0017
TDS	422	332	433	302
Salinity	0.32	0.42	0.43	0.29
Temperature	15.1	15.1	14.8	15.4
DO	0.93	1.22	1.05	1.98
Week 4 20/07/2021				
pH	7.23	7.23	8.05	8.09
Conductivity	1001	622	927	605
Atmospheric pressure	647	645	643	643
Resistivity	0.0010	0.0016	0.0011	0.0017
TDS	654.4	303	463	303
Salinity	0.49	0.30	0.45	0.29
Temperature	16.6	16.9	16.6	17.6
DO	0.54	1.26	0.68	1.99

Parameters	NEWTW		BWTW	
	Influent	Effluent	Influent	Effluent
Week 5 27/07/2021				
pH	7.23	8.20	8.12	8.22
Conductivity	469	634	905	626
Atmospheric pressure	657.3	657.5	643	643
Resistivity	0.0021	0.0016	0.0011	0.0016
TDS	239	317	454	313
Salinity	0.23	0.31	0.45	0.30
Temperature	19.1	18.1	15.4	15.2
DO	0.00	0.28	0.10	1.75
Week 6 03/08/2021				
pH	7.08	8.90	8.11	8.06
Conductivity	467	361	857	676
Atmospheric pressure	650	649	645	645
Resistivity	0.0021	0.0017	0.0012	0.0015
TDS	234	181	433	338
Salinity	0.22	0.17	0.42	0.33
Temperature	22.7	22.3	17.8	20.4
DO	0.76	1.37	0.61	1.22
Week 7 10/08/2021				
pH	8.44	8.70	8.37	9.24
Conductivity	528	393	909	678
Atmospheric pressure	658.2	656.6	646	646
Resistivity	0.0019	0.0025	0.0011	0.0015
TDS	266	197	455	338
Salinity	0.26	0.19	0.45	0.33
Temperature	22.7	23.2	18.2	20.0
DO	0.79	1.42	0.80	1.36
Week 8 17/08/2021				
pH	8.02	8.13	8.07	8.00
Conductivity	527	741	893	659
Atmospheric pressure	652.4	652.5	640	640
Resistivity	0.0019	0.0014	0.0011	0.0015
TDS	267	369	446	330
Salinity	0.26	0.36	0.44	0.32
Temperature	16.1	18.1	15.9	16.6
DO	0.93	1.22	0.98	1.05

Parameters	NEWTW		BWTW	
	Influent	Effluent	Influent	Effluent
Week 9 24/08/2021				
pH	7.23	8.28	8.19	8.09
Conductivity	705	928	873	655
Atmospheric pressure	644	644	642	642
Resistivity	0.0011	0.0014	0.0011	0.0015
TDS	464	348	437	327
Salinity	0.45	0.33	0.43	0.32
Temperature	25.2	23.0	20.4	22.4
DO	0.08	0.90	0.08	1.10
Week 10 31/08/2021				
pH	8.90	8.30	8.37	9.06
Conductivity	991	724	920	704
Atmospheric pressure	644	643	642	643
Resistivity	0.0010	0.0014	0.0011	0.0014
TDS	495	361	461	352
Salinity	0.49	0.35	0.45	0.34
Temperature	19	18.0	18.7	21.3
DO	0.08	0.98	0.09	1.54
Week 11 07/09/2021				
pH	12.27	7.60	10.42	8.51
Conductivity	1052	794	998	866
Atmospheric pressure	643	643	640	641
Resistivity	0.0010	0.0013	0.0002	0.0005
TDS	527	398	530	335
Salinity	0.52	0.39	0.47	0.31
Temperature	21.3	22.31	22.5	22.7
DO	0.06	1.79	0.71	1.92
Week 12 14/09/2021				
pH	10.36	8.25	12.22	8.59
Conductivity	1002	852	976	823
Atmospheric pressure	643	643	640	640
Resistivity	0.0021	0.0023	0.0011	0.0016
TDS	480	365	523	331
Salinity	0.48	0.32	0.43	0.35
Temperature	21.7	22.9	22.5	22.8
DO	0.04	1.39	0.03	1.68

Parameters	NEWTW		BWTW	
	Influent	Effluent	Influent	Effluent
Week 13 21/09/2021				
pH	9.47	8.30	11.05	9.65
Conductivity	1032	987	935	876
Atmospheric pressure	643	643	640	640
Resistivity	0.0012	0.0015	0.0011	0.0015
TDS	472	316	512	350
Salinity	0.42	0.35	0.38	0.31
Temperature	23.0	23.2	23.1	23.9
DO	0.27	1.54	0.07	1.23
Week 14 28/09/2021				
pH	10.42	8.26	9.24	8.05
Conductivity	1005	913	934	831
Atmospheric pressure	643	643	640	640
Resistivity	0.0015	0.0017	0.0010	0.0013
TDS	482	382	498	321
Salinity	0.57	0.32	0.46	0.30
Temperature	24.1	23.9	23.7	23.3
DO	0.03	1.29	0.21	1.65
Week 15 05/10/2021				
pH	8.50	8.45	10.17	11.37
Conductivity	1044	770	919	671
Atmospheric pressure	644	644	640	640
Resistivity	0.0010	0.0013	0.0011	0.0015
TDS	522	382	459	335
Salinity	0.51	0.37	0.45	0.32
Temperature	21.4	24.1	22.7	23.4
DO	0.61	0.36	0.09	1.78
Week 16 12/10/2021				
pH	7.23	7.88	8.18	8.17
Conductivity	982	757	656	887
Atmospheric pressure	643	643	640	641
Resistivity	0.0010	0.0013	0.0011	0.0015
TDS	402	378	445	445
Salinity	0.48	0.36	0.43	0.43
Temperature	27.8	29.0	20.9	21.1
DO	0.05	0.98	0.01	0.76

Parameters	NEWTW		BWTW	
	Influent	Effluent	Influent	Effluent
Week 17 19/10/2021				
pH	8.31	7.98	8.98	7.70
Conductivity	618	800	911	824
Atmospheric pressure	642	643	640	640
Resistivity	0.0016	0.0017	0.0015	0.0018
TDS	309	399	424	390
Salinity	0.30	0.39	0.42	0.31
Temperature	24.7	25.0	24.3	24.1
DO	0.09	0.17	0.04	0.09
Week 18 26/10/2021				
pH	8.69	7.50	7.68	7.83
Conductivity	964	731	659	883
Atmospheric pressure	648	646	644	644
Resistivity	0.0010	0.0014	0.0015	0.0011
TDS	483	366	330	443
Salinity	0.47	0.35	0.32	0.43
Temperature	22.1	22.1	20.8	20.5
DO	0.22	1.93	0.42	1.99
Week 19 2/11/2021				
pH	8.25	8.55	8.47	8.46
Conductivity	950	814	952	725
Atmospheric pressure	648	648	643	643
Resistivity	0.0011	0.0014	0.0010	0.0014
TDS	477	356	478	362
Salinity	0.47	0.34	0.47	0.35
Temperature	21.2	23.9	21.5	21.4
DO	0.07	1.55	0.05	1.66
Week 20 9/11/2021				
pH	8.68	8.65	8.68	8.67
Conductivity	1017	735	914	711
Atmospheric pressure	646	646	645	645
Resistivity	0.0010	0.0014	0.0011	0.0014
TDS	480	368	457	355
Salinity	0.50	0.35	0.44	0.34
Temperature	23.2	23.5	21.9	22.1
DO	0.08	1.32	0.06	1.53

Chemical Oxygen Demand, Oxygen Absorbed, Ammonia, Phosphate

Parameters	BWTW						NWTW					
	Blank	Titrated value	Influent	Blank	Titrated value	Effluent	Blank	Titrated value	Influent	Blank	Titrated value	Effluent
Week 1 23/06/2021												
COD	1.6	0.7	288	1.6	1.2	128	1.6	0.5	352	1.6	1.4	64
OA	9.8	5.6	42	9.8	9.2	6	9.8	6.0	38	9.8	8.9	9
NH ₃						1.45						1.4
PO ₄			5.3			4.6			3.7			1.34
Week 2 07/07/2021												
COD	1.6	0.6	320	1.6	1.5	32	DATA UNAVAILABLE DUE TO MALFUNCTIONING OF THE NEWTW PLANT					
OA	9.8	6.2	36	9.8	8.0	18						
NH ₃						3.9						
PO ₄			4.83			3.3						
Week 3 21/07/2021												
COD	1.6	0.5	352	1.6	1.4	64	1.6	0.2	448	1.6	1.5	32
OA	9.8	4.8	50	9.8	8.9	9	9.8	6.5	33	9.8	9.1	7
NH ₃						5.4						0.9
PO ₄			8.7			3.9			3.25			0.59
Week 4 28/07/2021												
COD	ELECTRICITY CABLE STOLEN AT BWTW. NO DATA ANALYSED DUE TO ABSENCE OF POWER.											
OA												
NH ₃												
PO ₄												

Parameters	BWTW						NWTW					
	Blank	Titrated value	Influent	Blank	Titrated value	Effluent	Blank	Titrated value	Influent	Blank	Titrated value	Effluent
Week 5 04/08/2021												
COD	1.6	0.4	384	1.6	1.4	64	1.6	0.8	352	1.6	1.5	32
OA	9.8	2.8	70	7.5	6.5	10	9.8	6.1	37	9.8	8.5	13
NH ₃						1.9						0.9
PO ₄			6.06			3.90			4.61			0.33
Week 6 18/08/2021												
COD	1.6	0.6	320	1.6	1.3	96	1.6	0.7	288	1.6	1.4	64
OA	9.8	5.2	46	9.8	8.7	11	9.8	6.0	38	9.8	8.4	14
NH ₃						4.3						0.5
PO ₄			5.85			4.94			4.14			2.14
Week 7 01/09/2021												
COD	1.6	0.4	384	1.6	1.4	64	1.6	0.7	288	1.6	1.5	32
OA	9.8	3.4	64	9.8	6.7	31	9.8	1.9	60	9.8	8.0	28
NH ₃						8.3						1.9
PO ₄			3.18			4.30			4.69			1.94
Week 8 15/09/2021												
COD	1.6	0.3	416	1.6	1.3	96	1.6	0.6	320	1.6	1.5	32
OA	9.8	4.5	53	9.8	7.9	19	9.8	5.0	48	9.8	9.2	6
NH ₃						4.90						1.2
PO ₄			3.34			3.95			4.23			2.06

Parameters	BWTW						NWTW					
	Blank	Titrated value	Influent	Blank	Titrated value	Effluent	Blank	Titrated value	Influent	Blank	Titrated value	Effluent
Week 9 29/09/2021												
COD	1.6	0.4	384	1.6	1.5	32	1.6	0.8	256	1.6	1.4	64
OA	9.8	6.6	32	9.8	8.8	10	9.8	5.6	42	9.8	8.5	13
NH ₃						5.30						2.1
PO ₄			4.5			2.11			4.5			3.3
Week 10 13/10/2021												
COD	1.6	0.3	416	1.6	1.5	32	1.6	0.4	384	1.6	1.5	32
OA	9.8	5.9	39	9.8	7.8	20	9.8	6.0	38	9.8	9.1	7
NH ₃			15.1			8.90						0.5
PO ₄			4.09			2.87			3.9			3.3
Week 11 27/10/2021												
COD	1.6	0.3	416	1.6	1.5	32	1.6	0.9	224	1.6	1.4	64
OA	9.8	5.5	43	9.8	8.9	9	9.8	6.0	38	9.8	8.8	10
NH ₃						6.50						2.2
PO ₄			5.2			2.30			4.3			2.1

APPENDIX B

TURNITIN REPORT

APPENDIX C

LANGUAGE EDITOR REPORT



Letter of Confirmation

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23 January 2023

CONFIRMATION OF EDITING AND PROOFREADING

I hereby confirm that I have done the proofreading and technical editing for the following master's dissertation:

Student: Mpho Gladness Sello
Student number: 219011460
Title: Investigating the effective removal of fat, oil and grease (FOG) in water treatment plants of the Mangaung Metropolitan Municipality
Degree: Master of Engineering in Civil Engineering
University: Faculty of Engineering, Built Environment & Information Technology, Central University of Technology, Free State

Language editing included consistency and accuracy in grammar, punctuation, spelling and sentence structure. I tried to keep as much as possible of the student's own writing style, while making sure that the student's intended meaning was not altered in the editing process. All amendments were marked with the Microsoft Word track changes feature. I also left comments for issues that the student had to double-check or revise. The student thus had the option to accept or reject the changes.

Technical editing included the layout done on a Microsoft Word template that I created specifically for this dissertation. I checked all acronyms and abbreviations for consistent use in the text. I also cross-checked the list of references making sure that dates, spelling, and author names used in the text matched those in the list of references. The student was notified of sources in the reference list that were not cited, or cited but not included in the list.

I have more than 40 years of experience in typing, editing, and proofreading for postgraduate students from universities all over South Africa and also abroad. I gained my experience during the years I was typing student dissertations and theses and while working at different departments at the UFS. I also assisted in compiling a document on technical layout and referencing methods and have presented guest lectures on referencing methods and technical layout issues to postgraduate students at the UFS. In the past couple of years, I have also proofread six books for publication, plus a number of journal articles.

Disclaimer: The ultimate responsibility for accepting or rejecting the amendments and recommendations made by means of track changes rests with the student. The editor cannot be held responsible for any changes in terms of the format and style due to subsequent additions or deletions to the document, or any language issues that may have emerged as a result of subsequent amendments to the text.

Yours sincerely



Dorathea (Dora) du Plessis
Technical & Language Editor

