Treatment of Abattoir wastewater using a downflow Expanded Granular Bed Reactor coupled with a hybrid membrane bioreactor system.

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DECLARATION

I, **Larryngeal Gutu** declare that the contents of this thesis represent my own unaided work, and that the thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

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ABSTRACT

Biological wastewater treatment processes such as activated sludge and anaerobic digestion remain the most favorable when compared to processes such as chemical precipitation and ion exchange due to their cost-effectiveness, eco-friendliness, ease of operation, and low maintenance. Since Abattoir Wastewater (AWW) is characterized as having high organic content, anaerobic digestion is slow and inadequate for complete removal of all nutrients and organic matter when required to produce a high-quality effluent that satisfies discharge standards. Multi-integrated systems can be designed in which additional stages are added before the anaerobic digester (pre-treatment), as well as after the digester (post-treatment) for nutrient recovery and pathogen removal. This can aid the water treatment plant effluent to meet the discharge regulations imposed by the legislator and allow the possibility for reuse on-site. This study aims to provide information on the principles of anaerobic digestion, aeration pre-treatment technology using enzymes and a hybrid membrane bioreactor, describing their various roles in AWW treatment. Simultaneous nitrification and denitrification are essential to add after anaerobic digestion for nutrient recovery utilizing a single step process. Nutrient recovery has become more favorable than nutrient removal in wastewater treatment because it consumes less energy, making the process cost-effective. In addition, recovered nutrients can be used to make nutrient-based fertilizers, reducing the effects of eutrophication and land degradation. The downflow expanded granular bed reactor is also compared to other high-rate anaerobic reactors, such as the up-flow anaerobic sludge blanket (UASB) and the expanded granular sludge bed reactor (EGSB).

Another objective of this study was to evaluate the operating costs of treating abattoir wastewater using combined biological processes. The processes were evaluated based on removal efficiency and cost of treating wastewater/KL. The process with the most removal efficiencies was the raw-AD-MBR and the effluent met the municipal discharge standards. A potential for reuse onsite for irrigation can be explored if a UV system is added and an anaerobic stage for phosphorus removal could be added before the MBR. The removal efficiencies for FOGs, TSS, COD, ammonia and E.coli were >98%, 98%, >90%, 80-90%, >97% respectively. The lab scale plant achieved that at a price of R801,40/KL.

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DEDICATION*;*

To my adoptive parents;

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I am here because of you. Thank you

And to

My late mother,

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You will forever be missed

RESEARCH OUTPUTS

Published Review Paper

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OUTLINE OF THE THESIS

Chapter1	•This chapter briefly descpribes the background of the study, research questions, aims, objectives, hypothesis and any highlights presented for the study.
Chapter 2	•This is a literature review of the thesis. It gives an indepth knowledge of the difficulties faced in the wastewater, the varoius technologies available and their limitations, what could be improved and what this study is suggesting to take part in the improvement. This chapter was published in the MDPI water journal for 2021.
Chapter 3	•This chapter presents the methodology and experimental results of the study. The chapter also discusses the obtained results, problems faced in the course of the laboratory work and any observations made that could have impacted the outcome of the results
Chapter 4	•This chapter gives the recommendations and conclusions based on Chapter 3. It puts emphasis on what can be improved from our experimental work to achieve better results
Chapter 5	• References and Additional information

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GLOSSARY

Abbreviation	Meaning
COD	Chemical oxygen demand
BOD	Biological oxygen demand
TSS	Total suspended solids
VSS	Volatile suspended solids
DEGBR	Downflow expanded granular bed reactor
EGSB	Expanded granular sludge bed reactor
AnMBR	Anaerobic membrane bioreactor
VFA	Volatile fatty acids
FOG	Fats oils and grease
WQI	Water quality index
TDS	Total dissolved solids
UASB	Up-flow anaerobic sludge bed
PSW	Poultry slaughterhouse wastewater
HRABS	High rate anaerobic bioreactors
AGS	Anaerobic granular sludge

HRT	Hydraulic retention time
OLR	Organic loading rate
UV	Ultraviolet
SRT	Solids retention time
MLSS	Mixed liquor suspended solids
ANOs	Ammonia oxidising organisms
NNOs	Nitrite oxidising organisms
MLE	Modified Ludzack Ettinger
PAO	Phosphorus accumulating organisms
LPRO	Low pressure reverse osmosis
RO	Reverse osmosis
UF	Ultrafiltration
MF	Microfiltration
FO	Forward osmosis
OMBR	Osmosis membrane bioreactor
EDBM	Electrodialysis bipolar membrane
NF	Nanofiltration

CLARIFICATION OF BASIC TERMS AND CONCEPTS

a) **Biological oxygen demand (BOD)**: The amount of oxygen required by aerobic micro-organisms for the biodegradation of organic matter (Rinquest.,2017).

b) **Chemical oxygen demand (COD):** The amount of oxygen used for the oxidation of organic matter (Judd, 2011).

c) **Total suspended solids (TSS)**: The number of solutes in moles multiplied by valence of solute in one liter solution. This is the measure for concentration margin used in chemistry and biological sciences.

d) **Abattoir waste water (AWW):** The polluted water collected from the slaughterhouse for treatment which contains a high amount of BOD, COD, VFAs and TSS

e) **Expanded Granular Bed Reactor (EGBR) :** A high-rate down-flow anaerobic digester which utilizes a bed of active anaerobic granules for the treatment of wastewater (Rinquest.,2017)

f) **Eco-flush:** Mixture of microorganisms naturally occurring in the environment which include aerobic, anaerobic, nitrifying and sulphur-oxidising bacteria combined with fungi and enzymes all sustained in a polymeric vehicle of natural origin.

g) **Anaerobic digestion**: An environment in which bacteria do not use free molecular oxygen for digestion process (Gerardi.,2003)

h) **Aerobic digestion:** Conditions where oxygen acts as electron donor for biochemical digestion reactions (judd.,2011)

i) **Membrane bioreactor (MBR):** A biological treatment process integrating a perm-selective membrane with a biological process (Judd.,2011)

j) **Nitrification:** The oxidation of ammonium ions to nitrite ions or the oxidation of nitrite ions to nitrate ions (Gerardi.,2003)

k) **Denitrification:** Biochemical reduction of nitrate to nitrogen gas (Judd.,2011)

l) **FOGs:** Fats, oils and grease

CHAPTER 1:

INTRODUCTION

CHAPTER 1: INTRODUCTION

1.1 Background of research problem

Environmental awareness has become a global issue in our present time. More and more people are partaking in raising awareness on the various impacts either positive or negative, humans have done to the environment. With only less than 3% of the world water accessible for consumption and agricultural use, whilst the rest is stored in oceans as salty water, water security has become a major cause of concern. Most of the available water is highly contaminated by effluent from agricultural and industrial activity and cannot be consumed. Therefore, water quality and quantity are the main problems that need to be solved especially in developing countries such as South Africa (Nqombolo et al.,2018).

The laws and importance of treating highly polluted wastewater has tightened over time. Different industries produce wastewater with different levels of contaminants. Discharge policies by the government are required to control waste and mitigate the harmful causes of wastewater to the environment. Amongst these industries, slaughterhouses/abattoirs have a considerable amount of fresh water consumption and in turn generate high quantities of used polluted water (Musa et al.,2019). Wastewater produced during slaughtering and cleaning processes usually consists of the animal fats, blood, urine, faeces, soil from hides, soft tissue removed during trimming, and cleaning as well as sanitizing compounds (Musa et al.,2019). Discharging untreated abattoir wastewater (AWW), especially in developing countries, poses severe threats to public health and the environment as most people live in undeveloped towns with poor sanitary conditions (Musa et al.,2019) .

1.2 Motivation of research study

Due to the various impacts of discharging untreated wastewater into the water bodies, such as eutrophication, different bodies both international and local have drawn up legislations for discharging polluted water. South Africa is no exception. The abattoir wastewater has to be treated of the COD,BOD, TSS, FOGs, orthophosphates, ammonia and nitrates first before being discharged either into the water bodies or the council sewer systems.

Various methods have been implemented in treating AWW. Conventionally, the treatment methods are similar to recent technologies used in municipal wastewater treatment. These include lagoon and ponds systems, sedimentation, floatation, coagulation/flocculation, adsorption, membrane technology, dissolve air, and other advanced oxidation processes (Bustillo-Lecompte and Mehrvar, 2015). However, several researchers have also published various methods of treating AWW. Such work includes aerobic/anaerobic (Musa et al.,2019) fixed-bed reactor (Saddoud et al.,2007) and fixed-bed granular sludge with/without static activated sludge (Musa et al.,2019). But most of the studies have consistently shown the numerous drawbacks, ranging from i) a large area of space requirement, ii) the massive volume of sludge generation, iii) intensive use of energy for aeration, and iv) the high overall cost of maintenance (Musa et al.,2019).

1.3 Statement of the research problem

Abattoir wastewater contains a high concentration of organic matter i.e. BOD, COD and colloidal particles or suspended solids. This means the AWW cannot be released directly into the environment's fresh water bodies or the municipal sewer systems without prior treatment as regulated by the law. The treatment steps are required to avoid the environmental, human health problems and to some extent mitigate the socio-economic problems caused by water scarcity as recently been witnessed in the Cape town 2015-day zero crisis. The abattoirs are required by law to produce and implement solutions that reduce their water consumption and how they are complying with the municipal discharge standards

The treatment of wastewater has evolved over the past few decades. Many industries such as textiles, food processing and to a greater extent, the sewerage treatment plants have taken measures to preserve the available water resources by reuse and recycling of wastewater. There are various methods that can be used to treat the wastewater such as, chemical treatment, biological treatment and physical treatment. In this study, an eco-flush reagent will be used as a pre-treatment stage (Primary treatment) to bioremediate the fats, oils and grease prior the anaerobic reactor. Active anaerobic micro-organisms present in the downflow expanded granular bed reactor (DEGBR) are used for the further biodegradation of organic matter in the secondary stage. The tertiary stage is also a biological process which consists of a hybrid membrane bioreactor (MBR) where further purification and screening occurs. The abattoir wastewater (AWW) contains a high concentration of organic contaminants such as Fats, oils and greases (FOGs) as well as proteins (Jensen et al.,2016)]. Therefore, their high biodegradability makes them a good candidate for anaerobic digestion with the great benefit of energy recovery and waste reduction (Affes et al.,2017). Due to the nature of the treatment process, and the use of living organisms in various stages in the plant, this project/study qualifies under biological engineering. Overall studies show there is a need in more effective ways to recycle and reuse water.

This study is therefore aligned with the same visions of providing sustainability without exhausting the available fresh water resources. This provides an alternative way for industries not only limited to abattoirs, to be able to:

i) reuse the wastewater and therefore reducing the cost charged per m^3 of fresh water,

ii) reducing their massive water consumption volumes and

iii)help in curbing global warming and environmental degradation.

1.4 Research questions

1) What are the characteristics of the abattoir waste water?
2) How effective is a pre-treatment stage in removing the total suspended solids, FOGs, BOD and COD?
3) What are the optimum operation conditions of the Pre-treatment and nature of the micro-organisms are in the Eco flush?
4) How effective is the pre-treatment, DEGBR coupled with a hybrid MBR in reducing the COD, BOD, TN and TSS, orthophosphates, ammonia and nitrates in the wastewater
5) How does varying Hydraulic Retention Time and Organic Loading Rate affect the performance of the DEGBR?
6) Does the final obtained effluent comply with the discharge water regulations imposed by the law
7) Is the process/pilot plant economically feasible to be adopted into industries

1.5 Hypothesis

The Pre-treatment prior the DEGBR coupled with a hybrid MBR can effectively treat the abattoir waste water to meet the Municipal discharge standards.

1.6 Research aims and objectives

- To characterizes the abattoir wastewater
- To optimize the pre-treatment stage using the Eco-flush reagent
- To identify the conditions the micro-organisms in the Eco-flush perform best at (whether they are anaerobes or aerobes or facultative microorganisms)
- To assess the effectiveness of the DEGBR and the whole system on the removal of the BOD, COD, TSS, TN, ammonia, orthophosphates and smells
- To assess any problems or drawbacks on the system performance and recommend ideas on improvement
- To determine whether the final effluent complies with the water municipal discharge regulations

- To perform an economic analysis on the system.

1.7 Significance of research

The development of sustainable, reliable and low-cost technologies is necessary for the treatment of wastewater. Due to this problem, the downflow anaerobic digestors such as the SGBR and DEGBR has attracted some researchers, because it has several advantages like design simplicity, usage of unsophisticated equipment, low anaerobic granular sludge (AGS) production, high treatment efficiency, low operating costs and its potential to generate renewable energy (like biogas, biomethane or biohydrogen). All these advantages have turned this bioreactor into a sustainable alternative to mitigate the crisis of water pollution (Cruz-salomon.,2019). Therefore this research plays a huge part into contributing to the cyclic economy as well as providing an insight of the economic impact of this new technology as compared to conventional methods.

1.8 Delineation of study

- This study will not look at:
- The composition and quantities of the biogas produced
- The composition/characteristics of the anaerobic reactor micro-organisms
- The reaction kinetics of the Anaerobic digestion process

1.9 References

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CHAPTER 2

MULTI-INTEGRATED SYSTEMS FOR TREATMENT OF ABATTOIR WASTEWATER

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CHAPTER 2: MULTI-INTEGRATED SYSTEMS FOR TREATMENT OF ABATTOIR WASTEWATER: A REVIEW

2.1 Introduction

The continuous influx and increase in urbanization and industrialization have led to an increase in the consumption of goods and services. Relative to other commodities such as winery and car manufacturing, the abattoir industries have also increased and doubled in production in the past decade, increasing water consumption. This increase in water consumption inevitably poses a threat to the environment due to added pollution and increasing water scarcity such that by 2050 global water demand is projected to be 20-30% higher than current levels given both population growth and socio-economic development (Beck et al., 2021).This is caused by the presence of organic matter such as COD, which poses a threat to the environment by accelerating the deoxygenation of rivers and contamination of ground water (Abdelhay et al., 2020). Abattoir industries consume about 26L of portable water per bird to clean the blood off of slaughtered animals, clean off the slaughtering surfaces, cleaning of by-products, steam generation and for chilling (Barbut, 2015) The slaughtering process and the periodic washing of residue particles in the slaughterhouse result in large quantities of water containing high amounts of biodegradable organic matter (Aziz et al., 2018, Marchesi et al., 2021). The contribution of organic load to these effluents usually comes from different materials such as undigested food, blood, fats, oil and grease (FOG) and lard, loose meat, paunch, colloidal particles, soluble proteins, manure, grit and suspended materials (Aziz et al., 2018). Farzadkia et al. (2016) stated that the characterization of abattoir wastewater contaminants is influenced by the type of treated water, the kind of animals that have been slaughtered for the particular time frame leading up to water collection, the sampling techniques of the individuals involved, as well as the cleaning and sanitizing procedures of a specific abattoir. These wastewater contaminants can be further characterized into three categories, as shown in Figure 2:1. Biological oxygen demand (BOD), chemical oxygen demand (COD) and total organic carbon (TOC) are the most widely used parameters for testing effluent quality before discharge according to discharge standards, as shown in Table 2:1.

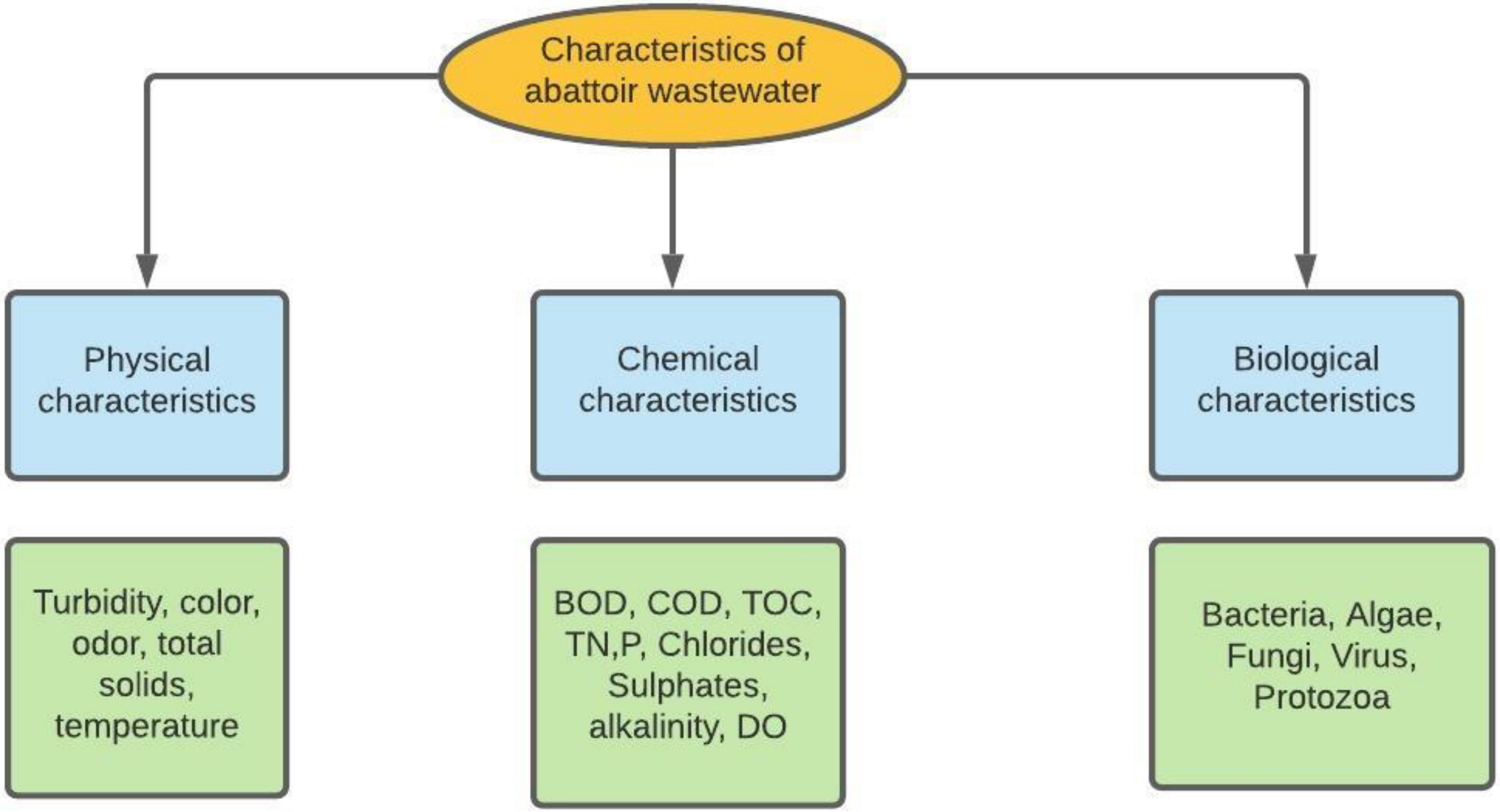

Figure 2:1: Characteristics of Abattoir wastewater

Table 2:1:Maximum limits permitted by the City of Cape Town: Wastewater and Industrial Effluent By-law 2013 and the characteristics of different abattoir wastewater

		CCT industrial effluent by-law (2013)	**SANS 214:2011 (portable water quality)**	**AWW (Basitere, 2017)**	**AWW (Aziz et al., 2019)**	**AWW (Brennan et al., 2021a)**
Parameter	Unit	Maximum limits		Range	Range	Range
General limits						
Temperature	ºC	40	-	-	-	-
Conductivity at 25ºC	mS/m	500	170	-	-	-
pH at 25^0C	n/a	12	9.7	6.5-8.0	5-7.8	6.5
Chemical oxygen demand (COD)	Mg/L	5000	-	2 133-10 655	1100 - 15 000	8575
Turbidity	NTU	-	1/5	-	-	-

Chemical substance limits						
Total dissolved solids(TDS)	mg/L	4000	1200	-		-
Total suspended solids (TSS)	mg/L	1000	-	315-1273	220-6400	1550
Fats, oils and greases (FOGs)	mg/L	400	-	131-684	40-1385	121.5
Ammonium as (N)	mg/L	-	1.5	29-51	20-300	-
Nitrates as (N)	mg/L	-	11	-	50-840	455
Nitrites as (N)	mg/L	-	0.9	-	40-700	455
Total phosphates as (P)	mg/L	25	-	8-30	15-200	112.5

The discharge of untreated water not only poses a severe threat to public health but also causes the death of aquatic species and eutrophication, leading to the depletion of dissolved oxygen (DO) and possible emanation of harmful gases (Aziz et al., 2019, Musa et al., 2019) . Blood and fat are a major problem in contaminated AWW. Blood has a COD of 375 000 mg/L which is considered very high and on the other hand, fats cause physical problems in treatment plants such as blockages, clogging, scum formation and possible shut downs (Abdelhay et al., 2020). Governments have imposed strict regulations on the discharge of water to mitigate the expenses of pollution, for which non-compliance results in heavy penalties. Each municipality in South Africa has regulation standards for water discharge, whether it is into the sewers, land application or for onsite reuse.

Due to the high costs associated with the efforts to reduce and handle waste, abattoirs are aiming to treat the wastewater onsite with the possibility of reusing and recycling to reduce plant running costs, have a smaller foot print, as well as upgrading to newer cost effective technologies. The increase in onsite treatment and waste eradication requires advanced refuse-handling equipment and methods to produce organic-rich and less bio-toxic waste (Chen et al., 2008). The wastewater can be treated using biological and chemical treatment. Recently, chemical treatment has become less popular as the use of chemicals increases the cost of treatment, leaves the difficult task of disposing of the chemical sludge and is environmentally unfriendly, making this option uneconomical and unfavorable (Aziz et al., 2019). As a result, aerobic and anaerobic treatment systems have become dominant and favorable options (Aziz et al., 2019, Bustillo-Lecompte et al., 2013).AWW contains high concentrations of organic contaminants and is rich in proteins and lipids, making it ideal for biogas production (Aziz et al., 2018), as well as being a good candidate for the highly attractive anaerobic digestion(Marchesi et al., 2021).According to Ozdemir and Yetilmezsoy (2020), analysis confirmed that the bio-diesel produced from the waste fats, oils and grease (FOG) obtained from slaughterhouse waste showed excellent fuel properties when compared to biodiesel produced from other common crop-based feedstocks. This is because AWW is protein and lipid rich and has great potential to produce high methane yields at different concentrations of volatile solids.

Anaerobic treatment is advantageous as it has excellent eco-friendly organic matter removal, less sludge production, lower energy consumption, execution of higher organic loading rates (OLR), fewer nutrients and chemical requirements, high COD and BOD removal efficiency, requires a smaller footprint as well as the considerable production of renewable energy in the form of biogas (Damasceno et al., 2018, Basitere et al., 2020). However, anaerobic digestion poses some limitations, such as having longer start-up and running periods, sensitivity to higher temperature conditions and the inability to effectively remove nutrients such as nitrogen and phosphates, which results in low to moderate effluent quality (Liew et al., 2020). Additionally, the process often faces operational challenges due to the difficulties related to the treatment of suspended solids, fats, oils and grease (FOGs) accumulating in the reactors, leading to reduced methanogenic activity, as well as sludge and biomass washout (Aziz et al., 2018, Meiramkulova et al., 2020, Zhang et al., 2020). These challenges result in process failure, hence the need to incorporate pre-treatment for FOG removal, initiate hydrolysis as well as remove solid particles and feathers.

Mondal et al. (2017) stated that aerobic treatment is superior to anaerobic treatment for treating water with a high organic content because it is quicker and more effective for degrading contaminants. However, aerobic digestion also has its flaws, such as high energy requirements for aeration compared to anaerobic, which adds to running costs. Hence a combination of both anaerobic and aerobic processes must be employed to tackle this predicament and effectively remove the nutrients and organic matter (Aziz et al., 2018, Aziz et al., 2019). The fraction of lipids presents in AWW poses a threat due to their slow hydrolysis rate (Affes et al., 2017). Typically, induced and dissolved air flotation is used to remove the oils and grease before aerobic-anaerobic digestion. However, the costs of the air and reagents used, if chemically assisted, tend to make this process uneconomical and expensive. Additionally, the removal efficiency is low and sometimes produces difficult sludges to treat (Damasceno et al., 2018). Other methods tested include alkaline, thermal (Carrère et al., 2010, Pilli et al., 2015) and ultrasonic (Doosti et al., 2012) pre-treatment; however, these all fall short in one way or another. Enzymatic pre-treatment is a good option to satisfy the concerns of improving methane production, reducing the number of suspended solids before anaerobic digestion and is environmentally friendly (Zhang et al., 2020). Enzymes hydrolyse the triglycerides to fatty acids and glycerol, which improves the efficiency of biodegradation by microorganisms and eases operation during biological treatment (Damasceno et al., 2018). A study done by Zhang et al. (2020) compared the stability of anaerobic digestion by feeding enzyme pre-treated water vs non-pre-treated water. The reactor containing the enzyme pre-treated feed showed higher stability during operation, even at higher organic loading rates (OLR).

Although it may be a great option, it is not economically feasible to use commercial enzymes practically in engineering practice, as most enzymes have to be significantly monitored as they are sensitive to temperature, pH and some cannot digest all the organic matter present (Zhang et al., 2020). An economic and feasibility study done by (Damasceno et al., 2018), without considering the ability of methane production to offset costs, revealed that using enzymes to pre-treat wastewater with high fat content has lower installation and operational costs than the traditional technologies. Therefore, it is still a better and cheaper alternative with great potential, despite its complex operation if methane generation is considered as an income generating byproduct. Alternatively, the application of biosurfactants produced by micro-organisms has recently been reported in studies as a cheaper alternative to commercial enzymes (Sanghamitra et al., 2021). The biosurfactants enhance biodegradation by dissolving FOGs and can be incorporated simultaneously into the biological aeration process, reducing the number of stages for pre-treatment. Other advantages include lower capital and operation costs, reduction in operational problems, as well as an increase in methane production through anaerobic digestion (Damasceno et al., 2018, Nakhla and Farooq, 2003).

This review highlights the importance of using biological processes in wastewater treatment. The use of a bioremediation agent known as the eco-flush, a product developed by Mavu Biotechnologies (Pty) limited during aerobic treatment, is a novel method that has not been extensively researched. Still, it can pose as an economical and better approach when compared to pure commercial enzymes. Since biological processes are generally slow and not adequate, a multi-integrated system approach can be used, where each stage focuses solely on removing a particular nutrient or pathogen.

2.2 Analytical methods for testing water quality

Measurements need to be performed to check if the treated water complies with municipal discharge regulations. The analytical methods are all outlined in the Environmental protection agency (EPA) handbook, and each analysis is specifically coded. Analysis can be tested on: pH (EPA 9040C), temperature, total dissolved solids (TDS) (EPA 160.1), salinity (EPA 320), turbidity (EPA 180.1), Total suspended solids (TSS) (EPA 160.2), Volatile suspended solids (VSS) (EPA 1684), COD (EPA 410.4), ammonium (EPA 350.1), nitrates concentration (EPA 353.4), biological oxygen demand (BOD) (EPA 405.1), volatile fatty acids (VFAs) (EPA 8260D) and fats, oils and grease(FOGs) (EPA 1664A). Monitoring the efficiency of a wastewater treatment plant is essential. One of the widely used methods for presenting water quality data is the water quality index (WQI) approach. A summary of different water quality parameters is calculated to a single number, which helps define the general quality status of water and its suitability for various purposes like drinking, irrigation, fishing etc. (Bora and Goswami, 2017).

2.3 Aerobic treatment

Aerobic treatments involve the treatment of sludge with air in the presence of aerobic or facultative anaerobic microbes before anaerobic digestion (Aziz et al., 2019). Oxygen is injected into the treatment system, which accelerates the hydrolysis rate of the organics by enhancing the activity of the micro-organisms (Nguyen et al., 2021). Aerobic treatment prior to anaerobic digestion improves the hydrolysis stage, the sludge solubilization, accelerates hydrolytic activities, increases the methane yield by 20–50%, and decreases VS by 21–64% (Nguyen et al., 2021). This suggests that aerobic pre-treatment does not decrease the methanogenic activity of methanogens within the anaerobic digester and can be a great addition to a multi-stage system (Nguyen et al., 2021). Besides being used in the pre-treatment stages, aerobic processes can be employed after anaerobic digestion to enhance nutrient removal. The required oxygen and treatment time correlate with the strength of the AWW being treated (Yuan et al., 2019). Due to the expenses incurred during the pumping of artificial oxygen and maintenance, using aerobic treatment for extended periods becomes uneconomical and produces large volumes of biomass. Furthermore, due to the benefits of aerobic treatment, it can be incorporated for shorter processes such as before anaerobic digestion and for nutrient removal after the digester. This will ensure maximum organic matter removal and lower costs, as the processes are relatively short. Despite the higher running costs compared to anaerobic digestion, aerobic treatment has some advantages, such as low odor production and a fast-biological growth rate (Bustillo-Lecompte and Mehrvar, 2017).

2.4 Aeration pretreatment using enzymes

Enzymes are used to accelerate the hydrolysis of macromolecules to enhance anaerobic digestion (Affes et al., 2017). Pre-treatment is included to ensure complete degradation during anaerobic digestion at shorter hydraulic retention times (HRT). Enzymes breakdown the bonds between the triglycerides and hydrolyse them to basic components of fatty acids and glycerol, thereby giving the aerobic micro-organisms a higher chance to biodegrade the FOGs (Damasceno et al., 2018). An eco-flush is an Ergofito's commercially manufactured bioremediation agent supplied in South Africa by Mavu Biotechnologies. An eco-flush is a mixture of natural ingredients and bacteria with the ability to remain dormant until a rich organic source, which acts as a substrate (such as AWW), is applied to activate them, primarily producing enzymes for hydrolysing FOGs (Ergofito, 2021, Meyo et al., 2021). Its natural ingredients are derived from glaucids and essential amino acids, which form powerful decomposing agents that stimulate the natural predisposition of certain bacteria to produce enzymes. These enzymes are capable of breaking down the hydrocarbon chains in FOGs and also compete with the bacteria that are responsible for producing Ammonia (NH_3) and

Hydrogen Sulphide (H_2S), which results in no to less odour during pre-treatment (Ergofito, 2021). The eco-flush can be added to raw AWW at the desired ratio as shown in Figure 2:2, a systematic diagram representing the pretreatment stage before anaerobic digestion. Artificial aeration is required to facilitate the bacteria to produce enzymes to degrade the FOGs by providing oxygen as an electron acceptor. For successful enzymatic pre-treatment, several parameters such as temperature, pH, substrate quantity and enzymes stability have to be assessed and optimized (Nguyen et al., 2021).

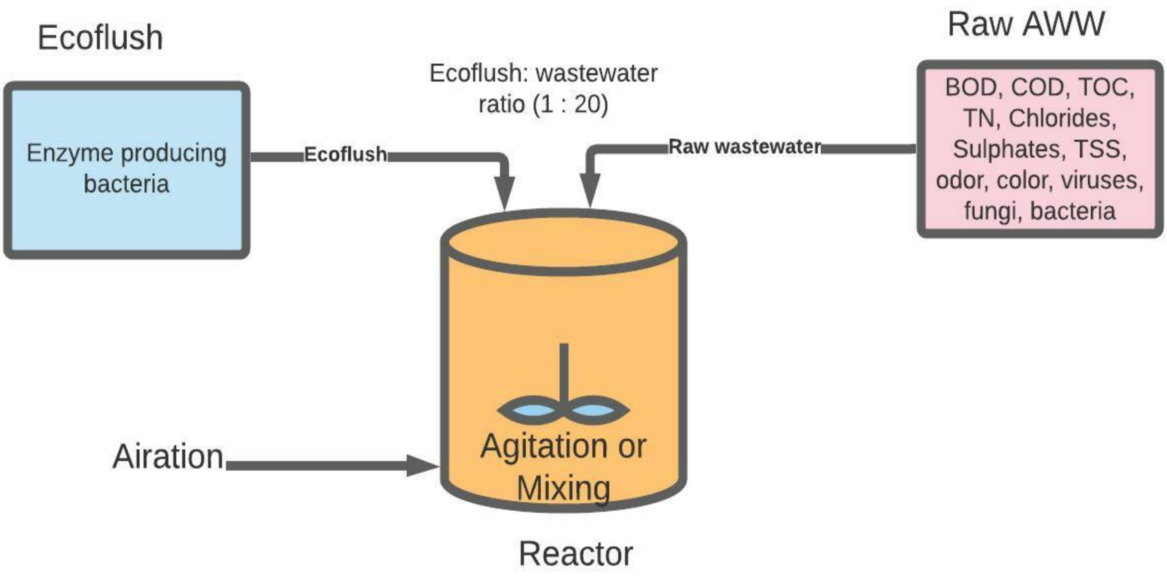

Figure 2:2:AWW pre-treatment stage using an eco-flush

Generally, the oxidation of 1 kgCOD requires 1kWh of aeration energy when the aerobic treatment is selected for wastewater treatment (Henze et al., 2008). Oxygen is slightly soluble in water and has to be transferred from the gas phase to the liquid phase, which is called absorption, driven by the concentration gradient between the atmosphere and the bulk liquid (Henze et al., 2008, Njoya et al., 2019a). The aeration requirements results in the need for a large surface for efficient oxidation of the organic matter which increases the running costs (Henze et al., 2008).

Although an aerated pre-treatment stage improves the anaerobic digestion as mentioned previously, the presence of dissolved oxygen in the treated wastewater can also inhibit the methanogenic activity in the anaerobic digestion stage. One critical parameter for a good performance of anaerobic treatment is the lack of oxygen. This is usually determined through the redox potential that should remain <-50 mV for anaerobic digestion and <-300 mV for a good methanogenic activity (Gerardi, 2003). For a digester hermetically closed, there is usually no need to attempt to remove the oxygen present, as the BOD in the wastewater consumes the oxygen present rapidly since aerobes and facultative aerobes normally use 100 mg/L of dissolved oxygen to degrade 100 mg/L of BOD (Henze et al., 2008). Furthermore, for lab studies and industrial scales, oxygen removal must be implemented through nitrogen purging, which includes three main methods (Gerardi, 2003), namely: Displacement purging, Pressurizing purging, and Dilution purging. Purging consists of the replacement of one gas by another in an enclosed chamber or space eg removal of oxygen and replacing it with nitrogen gas in anaerobic digestion (Njoya et al., 2019a). Therefore, before the pre-treated water is fed into the anaerobic digester, the Dissolved Oxygen must be monitored.

A study done by (Dyosile et al., 2021) a pre-treatment using an Ecoflush bioremediation agent was implemented and resulted in FOG removal of 80% and the TSS and COD removal reached 38% and 56%, respectively before feeding the slaughter wastewater into the anaerobic digester. Meyo et al. (2021) also did a similar study on the pre-treatment of the Poultry Slaughter Wastewater (PSW), and the removal percentages varied between 20% -50% for total suspended solids (TSS), 20%-70% for chemical oxygen demand (COD), and 50% -83% for fats, oil, and grease (FOG) before anaerobic treatment using an EGSB reactor. These studies are amongst the few that reported the use of an Ecoflush reagent. The removal efficiencies do suggest there is potential in bioremediation technology as a pre-treatment stage for high fat content wastewater.

2.5 Anaerobic digestion

Anaerobic digestion is a degradation process that occurs in the absence of oxygen to produce methane and carbon dioxide. It consists of four stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis, as shown in Figure 2:3. The hydrolysis stage reduces insoluble organic matter and high molecular weight compounds such as polysaccharides, proteins, and lipids into monosaccharides and amino and fatty acids (Appels et al., 2008). During acidogenesis, acidogenic bacteria produce volatile fatty acids, carbon dioxide, hydrogen sulphide, ammonia and other by-products, using the components formed during hydrolysis (Yuan et al., 2019). Acetogenesis is the third stage in which acetic acid, carbon dioxide and hydrogen are produced from the digestion of higher alcohols and organic acids. Methanogenesis is the last and final step in which methane gas is produced by methanogenic bacteria (Appels et al., 2008). The production and accumulation of volatile fatty acids (VFAs) can cause a drop in pH, which can affect methane production. Consequently, the VFA: alkalinity ratio is a critical factor in determining reactor performance and should in no case exceed 0.3 (Aziz et al., 2019, Del Nery et al., 2007). Besides a pH range of 6.8–7.2, the organic matter loading/ substrate ratio largely affects biogas production, where either too little or too much can cause a slow digestion process and should in no case be >0.3 (Aziz et al., 2019)

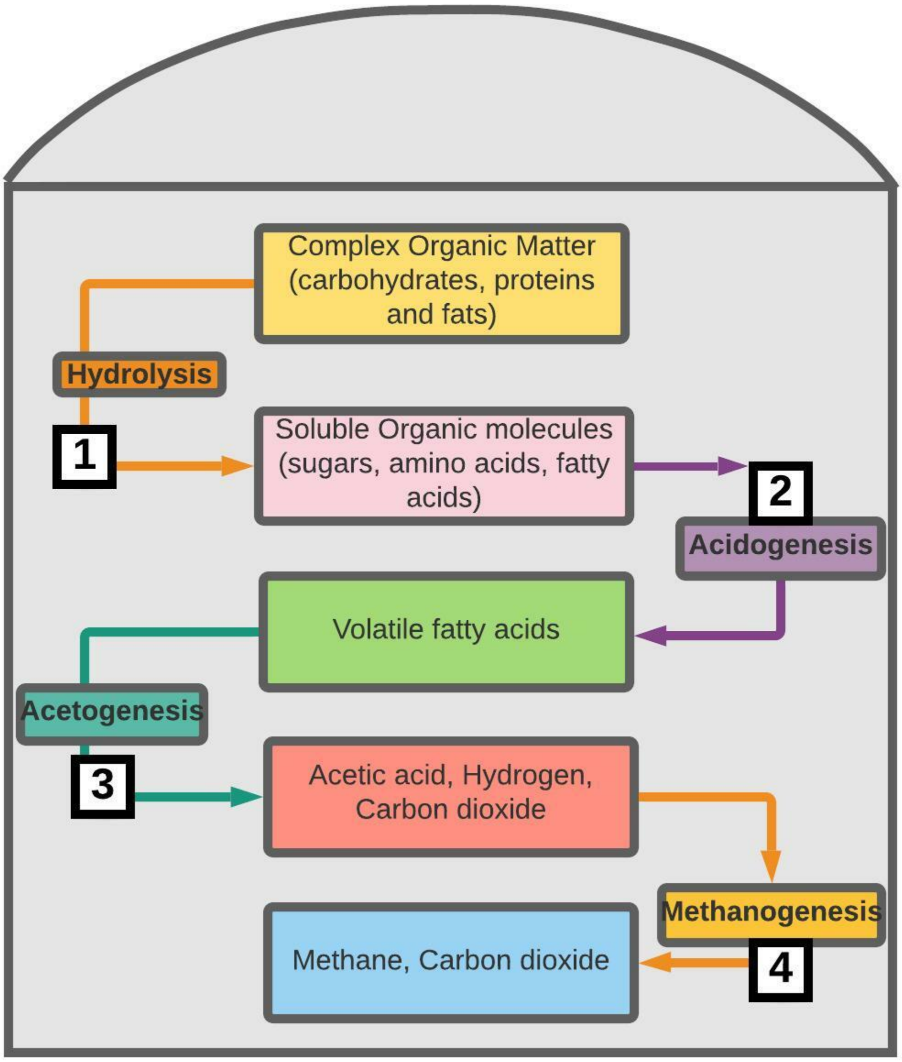

Figure 2:3:Anaerobic digestion stages in an anaerobic Reactor

2.6 High-rate anaerobic reactors (HRABS)

High-rate anaerobic digesters have received an increasing interest, due to their high loading capacity and low sludge production. The commonly used high-rate anaerobic digesters include: anaerobic filters, up flow anaerobic sludge blanket (UASB) reactors, anaerobic baffled, fluidized beds, expanded granular sludge beds (EGSB), sequencing batch reactors, anaerobic hybrid/hybrid upflow anaerobic sludge blanket reactors and the downflow expanded granular bed reactors (DEGBR) which is a hybrid of the EGSB and static granular bed reactor (SGBR) which is shown in Figure 2:4 (Rajagopal et al., 2013).

Biological processes heavily rely on the growth and bio-preservation of the required microorganisms through controlling essential operational parameters such as the temperature, pH, organic loading rate, carbon to nitrogen ratio, inoculation and start-up of the biodigester, mixing, and inhibition factors (Njoya et al., 2019a). The stability of the HRABS is usually reliant on the maintenance of the mentioned operational parameters within a specific prescribed range for growth of microorganisms(Gerardi, 2003, Henze et al., 2008). Table 2:2 below describes some of the inhibition parameters for anaerobic digestion and how they affect methanogenic activity.

Table 2:2:Inhibition factors in anaerobic digestion

Inhibition parameter	**Operational range**	**References**
Oxygen concentration	Oxygen concentration is measured as ORP which serves as a relative quantity of oxidised materials i.e. NO_3^-, NH_4^+, SO_4^{2-} ORP between -200mV and -400mV is ideal for anaerobic conditions. An ORP of +50mV suggests a high presence of molecular oxygen and affects the anaerobic microorganisms.	(Gerardi, 2003, Njoya et al., 2019a)

Temperature	Psychrophilic (0ºC - 15ºC), mesophilic (20ºC - 40ºC), Thermophilic (45ºC - 60ºC) and hyper thermophilic >65ºC. Mesophilic and thermophilic temperatures offer better organic biodegradation and biogas production. Mesophilic is most stable, requires less energy and there is less dominant ammonium inhibition as compared to thermophilic	(Metcalf et al., 2003, Henze et al., 2008, Njoya et al., 2019a)
pH	Prescribed range for anaerobic digestion is 6.5-8 Hydrolysis and acetogenesis favours pH range of 5.5-6.5 A pH range of 6.5-8.2 favours methanogenic activity and promotes methane producing bacteria i.e. methanogenium, methanolobus	(Njoya et al., 2019a) (Gerardi, 2003)

Nutrients concentration	Nutrients are required to promote growth of microorganisms and results in efficiency of treatment process Some nutrients required are N (65g/kg TSS), P (16g/kg TSS), and Mg (3g/kgTSS) and these quantities correlate to the chemical composition of the methanogenic microorganisms	(Njoya et al., 2019a)

Good methanogenic activity in HRABS results in the production of biogas and biogas production can be used as a direct measure of biodegradability efficiency. However, there were instances where a good removal of the substrate from the influent, which usually translates to a good COD or BOD5 removal percentage, didn't align with consequent production of biogas (Basitere et al., 2016, Basitere, 2017). This may have been due to biogas entrapment within the anaerobic granular bed as a result of loss in kinetic energy due to frictions losses, a weak connected porosity of the anaerobic granular bed or high surface tensions weakening the emergence of biogas bubbles(Basitere, 2017, Njoya et al., 2019b).

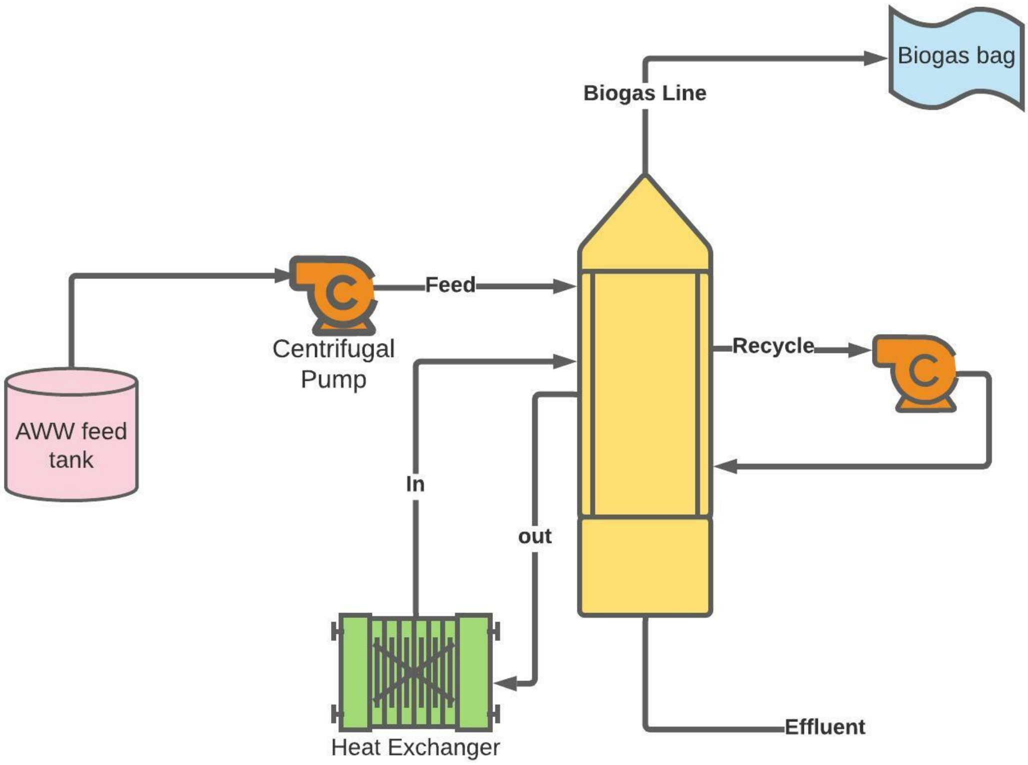

Figure 2:4:Schematic diagram of a downflow expanded granular bed reactor

2.6.1 High Rate Anaerobic Downflow Expanded Granular Bed Reactor

Numerous studies have been carried out to develop high-rate bioreactors; however, most studies show various drawbacks, ranging from large space requirements, a massive volume of sludge generation, intensive use of energy, and the high overall cost of maintenance (Musa et al., 2019). For instance, in the expanded granular sludge bed reactor (EGSB) and the up-flow anaerobic sludge blanket (UASB), the liquid up-flow velocity causes low and inadequate removal of nutrients, pathogens and suspended solids, which results in the requirement of post-treatment for compliance with environmental regulations (Cruz-Salomón et al., 2019). Unlike the EGSB and UASB, the downflow expanded granular bed reactor (DEGBR) as shown in Figure 2:4, takes advantage of gravity as a supplementary force through the granular bed, hence using less energy, as there are no gravitational forces or upward frictional forces to compensate for (Njoya et al., 2019b). The DEGBR consists of a recycle stream, which aids in wastewater distribution of the influent to the anaerobic biomass, and also develops a counter-current flow inside the bioreactor for enhanced mixing of its content (Cruz-Salomón et al., 2019, Njoya et al., 2019b). Furthermore, the downflow configuration results in the effluent being collected at the bottom and the gas naturally rises to the top, which eliminates the need for a three-phase separator to separate the gas and biomass compared to the UASB and EGSB (Njoya et al., 2019b). Moreover, the DEGBR also has several advantages like design simplicity, low anaerobic granular sludge (AGS) production, high treatment efficiency, low operating costs, all of which have turned this bioreactor into a sustainable alternative to mitigate the crisis of water pollution (Basitere et al., 2020)

2.7 Multi-integrated systems

Anaerobic treatment does not produce discharge compliant effluent on its own. The complete degradation of the organic matter is difficult due to the high organic content levels in AWW, the long hydraulic retention times (HRTs) required to remove all the organics as well as the anaerobic process being slow as compared to aerobic processes. An additional treatment stage(s) is/are recommended to remove the organic matter, nutrients, and pathogens that remain after anaerobic treatment (Bustillo-Lecompte and Mehrvar, 2017).The integration of multi-stage systems can be used to remove pollutants such as heavy metals, grease and oils, color, BOD, TSS, COD and can be handled within one system with multiple stages (Meiramkulova et al., 2020). Several studies have been done to incorporate additional stages after anaerobic digestion, as shown in Table 2:3. Comparing single systems and multi-stage systems shows that the latter provides higher removal efficiencies. The data from Table 2:3 was used to plot a graph, as shown in Figure 2:5.

Treatment technologies such as i) membrane separation using reverse osmosis, ii) anaerobic, iii) aerobic, iv) anaerobic-aerobic-UV, v) anaerobic-aerobic-advanced oxidation vi) anaerobic-aerobic-chemical coagulation were compared graphically to show the effect of introducing multiple stages. Figure 2:5 shows that all single-stage processes have a BOD removal efficiency below 50%, whilst in multi-integrated systems, the values are above 90%. The TN removal follows the same trend, with reverse osmosis having the highest efficiency despite being a single-stage process. This further supports why membranes are necessary for nutrient recovery after anaerobic digestion as a separation process. Although multi-integrated systems offer many benefits, the type of water, cost and effluent quality will determine the number of stages and processes to be used.

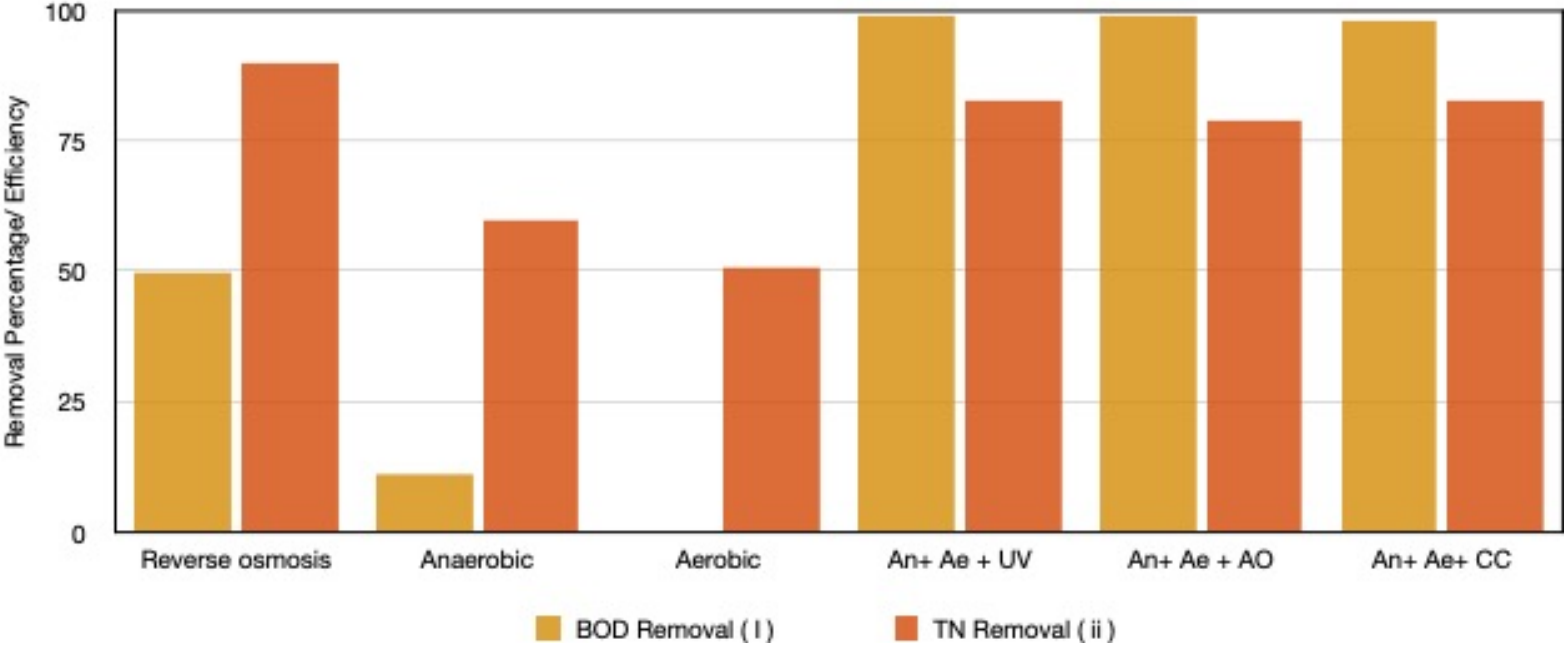

Figure 2:5:Comparison between single systems and MIS in removing BOD & TN [Abbreviations: An-anaerobic process ; Ae- aerobic process; AO- advanced oxidation process, CC- chemical coagulation]

Table 2:3:Comparison between effluent qualities of single systems vs multi integrated systems

	INFLUENT CHARACTERISTICS					**EFFLUENT CHARACTERISTICS (removal efficiency)**				
Process	HRT (h)	TOC (mg/L)	BOD (mg/L)	TN (mg/L)	COD (mg/L)	TOC (%)	BOD (%)	TN (%)	COD (%)	REFERENCES
Anaerobic + Aerobic + UV	96	1,0	640,0	200,0	-	99,98	99,69	82,84	-	(Bustillo-Lecompte et al., 2013)
Anaerobic + Aerobic + Advanced oxidation	75-168	941-1009	630-650	254-428	-	89,5-99,90	99,70	76,40-81,60	-	(Bustillo-Lecompte et al., 2013)
Aerobic	3-96	-	-	1 950-3 400	6185 - 6840	-	-	8,81-93,22	9,42 - 80,11	(Kundu et al., 2014)
Reverse osmosis	-	-	10,0	13,0	76,0	-	50,0	90,0	85,8	(Bohdziewicz and Sroka, 2005)
Anaerobic	24	-	30-76	6,1-27	49-137	-	11,30	42,30-77,20	13,90	(Luu et al., 2014)
Anaerobic + Aerobic + Chemical coagulation	16-72	-	5143-8360	46,6-138	6363-11000	-	97,76-98,92	73,48-92,72	50,10-97,42	(López-López et al., 2010)

The use of multi integrated systems provide a significant impact on the effluent quality. Dyosile et al. (2021) had a higher overall removal efficiency when an integrated system of using enzymatic pretreatment-DEGBR-MBR was analysed as compared to anaerobically digesting the poultry slaughterhouse wastewater (PSW) with the DEGBR with no prior or post treatment. The pre-treatment had FOG removal of 80% and the TSS and COD removal reached 38% and 56%, respectively. The removal results on the DEGBR, at an OLR of 18–45 g COD/L.d, was 87%, 93%, and 90% for COD, TSS, and FOG, respectively. The total removal efficiency across the pre-treatment-DEGBR-MBR units was 99% for COD, TSS, and FOG which is much higher than the single stages. Their effluent quality also met requirements for effluent discharge after post treatment using a MBR.

A similar setup of incorporating pretreatment–EGSB digester–MBR system was used by (Meyo et al., 2021) to reduce the concentration of organic matter in PSW. The pretreatment stage resulted in a 50% for TSS removal, 80% for COD removal, and 82% for FOG removal. The EGSB effluent had removal percentages of 90% for TSS, >70% for COD, and >90% for FOG. Further removal was also observed using the MBR with the removal performance being >95% for both TSS and COD and 80% for FOG. Their effluent after the MBR process met the discharge standards. These studies add to the fact that single stages alone do not possess the ability to treat AWW to the required discharge standards. Pre and post treatment is required with any anaerobic processes.

Figure 2:6 shows a proposed process flow diagram of a multi-integrated system to treat AWW. The raw wastewater is first aerobically pre-treated to remove suspended solids and FOGs and enhance anaerobic digestion. Oxygen is artificially added using an adjustable pump. A stainless-steel sieve is used to filter out any suspended solids remaining from pre-treatment. The pre-treated wastewater is added to a holding tank, which feeds into the DEGBR at the desired organic loading rate. The DEGBR operates anaerobically to biodegrade the nutrients, and biogas is produced as a by-product. The effluent from the DEGBR does not meet the required discharge standards as mentioned previously. The effluent becomes the feed to the membrane bioreactor (MBR) where nitrification and denitrification takes place. The micropollutants that pass through membranes can be disinfected using the ultraviolet system (UV). Bustillo-Lecompte et al. (2013), Bustillo-Lecompte and Mehrvar (2017)did an evaluation on treating AWW using combined advanced oxidation processes. The evaluation factored in treatment capability and overall costs for treatments technologies, including ABR, AS and UV. It was proven that the combined process of the ABR-AS-UV system was the most cost-effective solution compared to single processes for TOC removal under optimal conditions. However, as this may be a guide, different wastewaters have different characteristics, and analysis must be done to find the best method possible.

Ultraviolet (UV) light is frequently used for pathogen inactivation in wastewater treatment (Song et al., 2016, Hijnen et al., 2006, Gibson et al., 2017, Chevremont et al., 2012). UV light effectively inactivates viruses, bacteria, and cysts by penetrating cell walls and damaging DNA or RNA without chemical addition. Traditional UV lamps are low-cost and accessible in developing economies, but contain toxic mercury vapor. UV LEDs on the other hand are more expensive, but mercury-free. (Azaizeh et al., 2013, Beck et al., 2021)

The study by Beck et al. (2021) evaluated a cost-effective, user-friendly, and relatively fast treatment process involving a woven-fiber microfiltration (WFMF) membrane to filter domestic wastewater followed by UV disinfection to disinfect the permeate. With an effective pore size of 1–3 µm (Vongsayalath, 2015) the membrane was capable of removing *Ascaris lumbricoides* eggs (50 mm) and *Giardia* cysts (10 µm), whereas bacteria (1–2 µm), viruses, and *Cryptosporidum* oocysts (3 µm), which are small enough to pass through the filter pores, were inactivated by exposure to UV light. The bacteria (total coliform and *Escherichia coli*) and viruses (MS2 bacteriophage) passing through the membrane were disinfected by flow-through UV reactors containing either a low-pressure mercury lamp or light-emitting diodes (LEDs) emitting an average peak wavelength of 276 nm. For domestic wastewater from a university campus that they used in their study, the membrane reduced TSS (by 79.8%), turbidity by 76.5%, COD by 38.5%, BOD by 47.8%, and NO_3 by 41.4%. UVT at 254 nm improved by 19.4%, and UVT at 280 nm by 12.4%. (Beck et al., 2021). Following UV disinfection, wastewater quality met the WHO standards for unrestricted irrigation. UV lambs can succumb to fouling and scaling after extensive use and it is reversible through citric acid circulation(Nguyen et al., 2019).

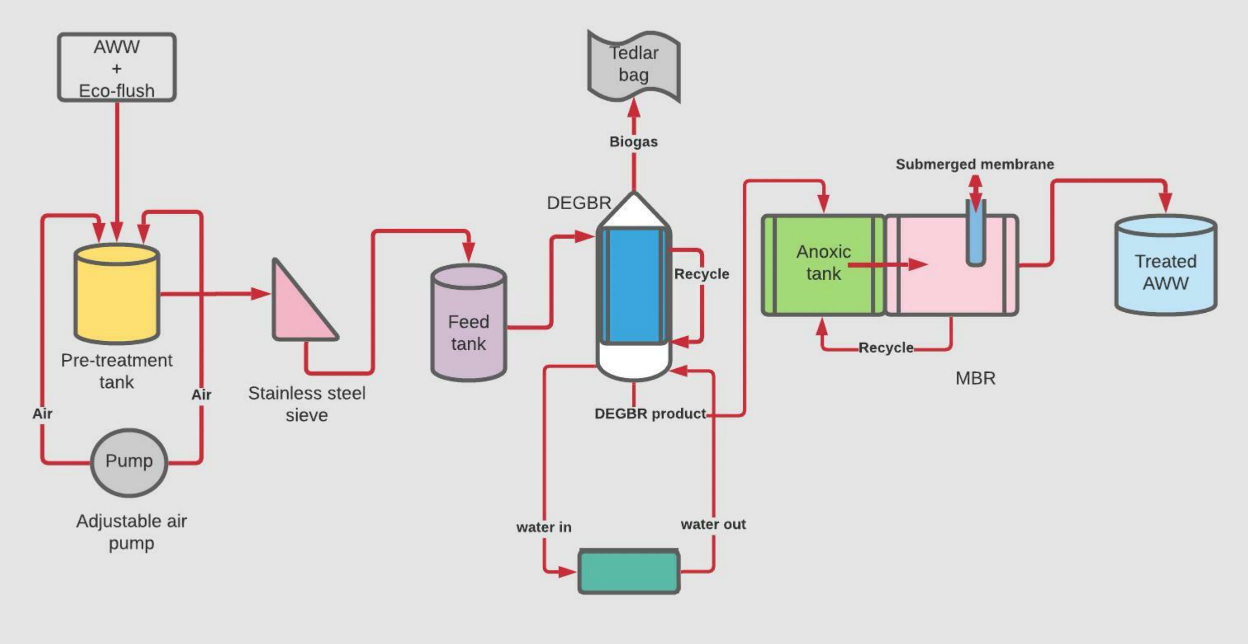

Figure 2:6: Process flow diagram of a proposed multi-stage integrated system to treat AWW

2.8 Hybrid membrane bioreactor

A membrane bioreactor (MBR) is an integrated system with membrane filtration for the biological degradation of waste present in wastewater. Generally, it is composed of a biological unit and a membrane module, which separates water from the aerobically digested water and returns activated sludge to the biological unit. (Fatima et al., 2021).

Anaerobic membrane bioreactors (AnMBRs) retain solids selectively through microfiltration membranes which offer an alternative to lagoons and granule based high-rate anaerobic treatments (Yan et al., 2018). They produce an excellent effluent quality, have a high tolerance to OLR variations, as well as the ability to produce a solid free effluent for the purposes of reuse (Jensen et al., 2015). The hybrid membrane bioreactor consists of i) an anoxic stage and ii) an aerobic membrane filtration stage. Since the DEGBR operates anaerobically, it has two significant drawbacks, i) it is ineffective in removing nitrates and phosphorous, and ii) it reduces the organic nitrogen and sulphur to ammonia and hydrogen sulphide, which are toxic hence the need for incorporating a membrane bioreactor stage as post-treatment. The advantages of MBR compared with conventional activated sludge process include high effluent quality, decreased reactor volume, elevated solid retention time (SRT) and high mixed liquor suspended solids (MLSS), low sludge yield, and easier operation (Yadav et al., 2020, Skoczko et al., 2020). However there are still some drawbacks associated with MBRs such as; membrane fouling, high energy consumption and low removal efficiency of poorly biodegradable micropollutants like diclofenac, atrazine, and carbamazepine (Yadav et al., 2020).

MBR technology has been widely used recently for nutrient recovery. Coagulation or flocculation can be used to recover valuable nutrients in the conventional process. Unfortunately, the protein concentrate obtained by the traditional methods cannot be used as animal food because coagulants and flocculants can introduce some harmful compounds and change protein properties. Pressure-driven membrane processes are good at protein recovery while keeping protein unchanged since membrane separation is a physical process (Fatima et al., 2021).

Recovering nutrients from wastewater reduce the environmental effects of wastewater treatment, and subsequently, the recovered nutrients can be used to produce fertilizers. Phosphorus and Nitrogen are essential for organism growth and result in eutrophication in surface water sources, leading to the death of aquatic life (Yan et al., 2018). If ammonium and phosphate ions were to be removed from wastewater using processes such as chemical precipitation, it would consume a large amount of electricity and cost about 4% extra compared to nutrient recovery (Svardal and Kroiss, 2011). Besides the extra costs involved, nutrient recovery is better than complete removal because i) nutrient-based fertilizers can be produced for agricultural purposes, ii) the environmental impact from wastewater discharged is reduced hence less eutrophication, and iii) N recovery can reduce the consumption of natural resources and save costs on Nitrogen fixation (Yan et al., 2018).

The hybrid membrane bioreactor is required to provide an anoxic-aerobic stage where oxygen is utilized by bacteria to oxidize the ammonia and hydrogen sulphide to less harmful substances. Nitrification occurs due to two specific autotrophic bacteria, the ammonia oxidising organisms (ANOs) and the nitrite oxidising organisms (NNOs), and occurs in two steps. The ANOs convert free and saline ammonia to nitrite. In the second step, the NNOs convert nitrite to nitrate. Ammonia and nitrite are used for catabolism (Henze et al., 2008). Nitrification is a prerequisite for denitrification, and without it, biological N removal is not possible. Denitrification becomes possible once nitrification takes place by incorporating anoxic zones in the reactor. The denitrification occurs anoxically via facultative heterotrophic biomass (Henze et al., 2008). During nitrification, the N remains in the liquid phase because it is transformed from ammonia to nitrate. In the denitrification step, the N is transferred from the liquid to the gas phase and escapes to the atmosphere.

The proposed study referred to in Figure 2:7 employs the modified Ludzack-Ettinger system (MLE), which separates the anoxic and aerobic reactors by putting them in series, as shown in Figure 7 below. It also consists of a recycle for the underflow feeding back to the first anoxic reactor as well as a mixed liquor recycle from the aerobic to the primary anoxic reactor. The influent is discharged to the first or primary anoxic reactor, which is maintained in an anoxic state by mixing without aeration and provides conducive conditions for denitrification. The second reactor is aerated and is where nitrification takes place. However, the MLE system has one major drawback: complete nitrate removal cannot be achieved because a part of the total flow from the aerobic reactor is not recycled to the anoxic reactor but instead exits the system with the effluent (Henze et al., 2008).

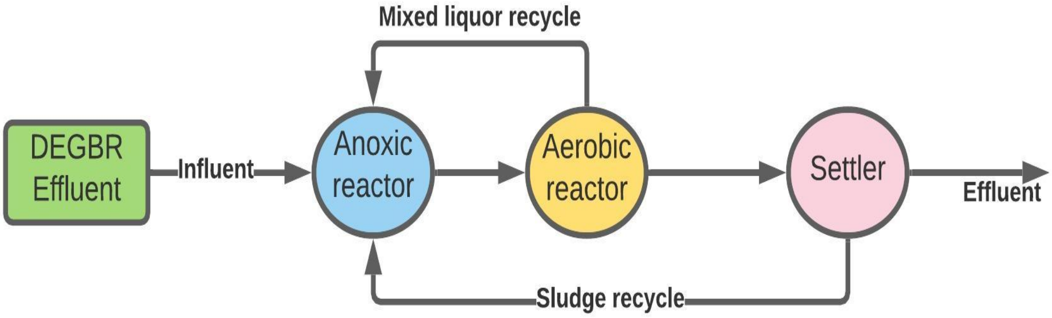

Figure 2:7:MLE system for nitrification and denitrification

Phosphorus can be removed biologically through enhanced biological phosphorus removal, exploiting the ability of polyphosphate-accumulating organisms (PAOs) to take up P in excess of metabolic requirements and accumulate it intracellularly as polyphosphate (Mino et al., 1995). This metabolic phenotype is facilitated by a continuing cycle of provision of organic carbon, mainly in the form of volatile fatty acids (VFAs) to the microorganisms, and then exposure of the organisms to first anaerobic and then aerobic conditions. Organic carbon is often the limiting substrate for both denitrification and P removal, and many wastewater treatment plants add extra carbon for denitrification to balance the processes. A combination of denitrification and enhanced biological phosphorus removal in one process could offer substantial savings on carbon for the overall nutrient removal process, which makes this approach highly attractive (Meyer et al., 2005).

The performance of the membrane is mainly characterized by the permeate flux and retention properties (Marchesi et al., 2021). Membrane separation has one particular advantage over other separation processes such as distillation, crystallization and adsorption because it relies on physical separation without phase change and usually no addition of chemicals. Therefore, energy consumption is usually much lower compared to distillation and crystallization (Mai, 2013). Two main MBR configurations exist: side stream and submerged, as shown in Figure 2:8. A recirculation pump provides cross-flow velocity in the side stream configuration to reduce blockage by suspended solids on the membrane surface. The side stream MBR is widely used in industrial wastewater treatment but has a higher energy demand. On the other hand, the submerged MBR operates at lower flux and offers higher permeability. They are often used in municipal wastewater treatment. Coarse aeration is provided to the system to reduce fouling as well as provide oxygen to the biomass (Le-Clech et al., 2005).

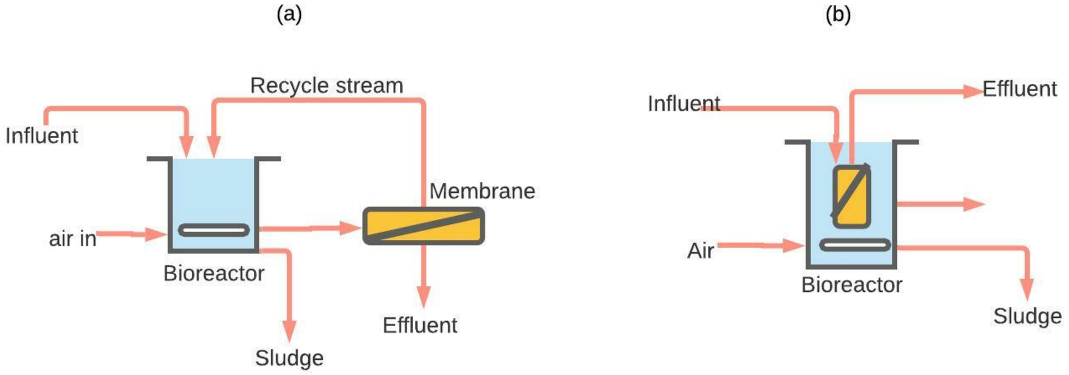

Figure 2:8:AnMBR configurations (a) side stream configuration (b) submerged configuration

2.9 Applications of membranes in the wastewater treatment

Pressure-driven membrane processes such as microfiltration (MF), ultrafiltration (UF), reverse osmosis (RO), and nanofiltration (NF) are widely studied for wastewater treatment and they rely on hydraulic pressure to achieve separation (Ezugbe Obotey and Rathilal, 2020). Membrane filtration is one of the most emerging technologies to produce high-quality water because it utilizes zero chemical constituents and offers enormous advantages over conventional methods (Fatima et al., 2021). Mostly used membrane filtration in wastewater treatments are RO, UF and MF. Although reverse osmosis (RO) is a well-established technology for water reuse and desalination (Bunani et al., 2015, Tchobanoglus et al., 2003) it is still limited by its high energy consumption and operating costs as the flow is against the pressure gradient.

An alternative is the use of low-pressure RO (LPRO) membranes which have been developed to reduce the RO operation pressure when maintaining high rejections to small soluble organic molecules and ionic species (Ozaki et al., 2000, Venzke et al., 2017, Innes et al., 2021). The operation pressure is an important operation parameter of LPRO, which affects the filtration productivity (flux), membrane fouling, and energy consumption. The performance of RO in the treatment of secondary effluent of SWW was reported by (Bohdziewicz and Sroka, 2005) to remove organic matter and the removal efficiencies of BOD, COD, TN, and TP were found as 50.0, 85.8, 90.0, and 97.5%, respectively. It was concluded that LPRO was a suitable technique for the post-treatment of AWW effluent.

A study done by (Yordanov, 2010) on the performance of the UF membrane treating AWW showed BOD and COD removal efficiencies of around 97.8–97.89 to 94.52–94.74%, whereas TSS and FOG removal were 98 and 99%, respectively (Musa and Idrus, 2021). Pressure driven membrane processes have proven to be successful in the separation of valuable organic and inorganic compounds in black liquor as well as being energy-efficient in several studies (Valderrama et al., 2021, Zhang et al., 1997, de Morais Coutinho et al., 2009). In recent studies, separation processes are being coupled to improve effluent quality. For example, UF/NF combinations have been reported to be a promising solution in wastewater with high amounts of organic material such as black liquor. In these cases, UF is used as a pre-treatment for NF (Valderrama et al., 2021, Beier, 2007).

The ultrafiltration (UF) pre-treatment and the control of the operation pressure were found to be essential for mitigating LPRO membrane fouling. Water quality analyses showed that an integrated process of the UASB + UF + LPRO could achieve an effluent quality characterized by concentrations of 10.4–12.5 mg/L of chemical oxygen demand (COD), 1.8–2.1 mg/L of total nitrogen (TN), 1.3–1.8 mg/L of ammonia nitrogen (NH_3-N) and 0.8–1.2 mg/L of total phosphorus (TP) (Innes et al., 2021).

Coskun et al. (2016) studied the PSW treatment using laboratory-scale membrane processes. Their study reported that UF as pretreatment improved the removal efficiencies for NF and RO processes; NF reduced almost 90% of COD, RO removed 97.4% of COD, and the UF pretreatment resulted in higher final fluxes 8.1 and 5.7 times more for NF and RO, respectively, than for those without UF.

Ionic species can be removed to meet the reuse requirements of brewery wastewater effluent discharge by the inclusion of reverse osmosis into the treatment chain (Bunani et al., 2015, Innes et al., 2021). Verhuelsdonk et al. (2021)did an economic analysis on brewery wastewater reuse and reported that UASB wastewater could be treated to drinking water quality with a yield of 63% by using an MBR + UF + RO system.

A comparison study was done by Skoczko et al. (2020)to compare the modernized vs conventional treatment methods on a newly modernized wastewater treatment plant. On the basis of the conducted research, it was noted that the operation of the plant after modernization was more cost-intensive. There were additional electricity costs due to ensuring adequate pressure on the membranes. Nevertheless, the obtained results of the removal of contaminants showed BOD removal over 99.0%, COD removal of 99.0% ,TSS 99.5% and removal degree of biogenic compounds also increased and exceeded 98%. Although the membranes have been well researched and are still being improved, it still shows high operational costs due to aeration and membrane fouling.is still a major drawback.

2.10 Membrane preservation, fouling and cleaning methods

The accumulation of particulates such as fats, grease, protein and organic matter can cause build up on the membrane material resulting in the membrane fouling and wetting which is a huge economic influence on the use of membranes as they account for 72% of the capital investment.(Brennan et al., 2021a). The types of foulants which may interfere with membrane performance include chemical foulants such as scaling, physical foulants such as deposition of particles, biological foulants such as microbes and organic fouling which interact with the membrane material (Brennan et al., 2021b). Membrane wetting is the process in which membrane materials lose their hydrophobicity and allow for liquids to penetrate the membrane pores resulting in a direct liquid flow from feed through the wetted pores, substantially deteriorating permeate quality (Brennan et al., 2021b).The fouling and wetting of membrane materials impairs the membrane performance and shortens membrane lifetime, thereby reducing NH3 recovery from AWW.

To reduce fouling and wetting, membranes can be cleaned. Several chemical and physical cleaning methods were developed to remove membrane fouling. The membrane cleaning process is affected by different factors. The type and mode of cleaning for example, physical cleaning, doesn’t really retrieve membrane permeability effectively as it only removes loose particles. Temperature is considered as another factor that may take effect on the membrane cleaning strategy. Increasing temperature is substantial for cleaning the fouling membrane by increasing solubility due to reactivity of functional groups at high temperatures of the organic matters and increasing mass transfer dispersive with mechanical destabilization of biofilm layers on the membrane surface (Yadav et al., 2020) Increasing the pH has a direct proportion with membrane cleaning efficiency as well (Ang et al., 2006). For instance, increasing pH from 4.9–11.0 will affect the cleaning percentage from 25%–44% and, at pH 11, are very easy to break down the gel layer on the membrane surface when compared to the lower pH (Yadav et al., 2020). Table 2:4 below shows some of the membrane cleaning methods used to reduce fouling and improve membrane life in membrane technology.

Table 2:4:Membrane cleaning methods used in membrane technology

Industry	Membrane process type	Chemicals used	Result	Reference
Municipal **(drinking water treatment systems)**	Ultrafiltration (UF)	Membrane vibration +coagulation. coagulants, such as Al (III) and Fe (III) compounds, were added to the influent	Membrane rotation speed of 60 r/min, the permeate flux increased by 90% and the organic removal by 35%, with a 40 mg/L coagulant dosage, with an additional 70% increase of flux and a 5% increment of organic removal to 80% was obtained.	(Yu et al., 2021)
Food industry (fruit juice concentration)	Forward Osmosis	Pretreatment by microfiltration before FO process	There was an attractive interaction between the FO membrane and orange juice foulants. Eliminating those foulants using the microfiltration pre-treatment weakened such an attractive interaction and effectively prevented the fouling layer from growing, leading to a lower process resistance and, finally, resulting in a great improvement of concentration efficiency	(Li et al., 2021)
Food industry	Electrodialysis with bipolar membranes (EDBM)	Pulsed electric field (PEF) mode, which consists in the application of constant current density pulses during a fixed time (Ton) alternated with pause lapses (Toff)	Both a long pause and high flow rate contribute to a more effective decrease in the concentration of protons and caseinate anions at the BPM surface: a very good membrane performance was achieved with 50 s of pause duration of PEF and a flow rate corresponding to Reynolds number = 374	(Nichka et al., 2021)

Municipal wastewater	Membrane Bio-Reactors (MBRs)	Examines the effect of operating conditions on fouling of membrane Bio-Reactors (MBRs). Conditions such as: diminishing DO, recirculating rate and controlled growth of filamentous microorganisms were optimised	The diminishing of DO in the recirculated sludge improved denitrification, and resulted in lower concentrations of $N\text{-}NO_3^-$ and TN in the effluent of the Control-MBR. Furthermore, the recirculation rate of $Q_r = 2.6 \cdot Q_{in}$, resulted in improved performance regarding the removal of $N\text{-}NH_4^+$	(Gkotsis et al., 2021)
Second effluent of sewage with Activated sludge	FO	Physical cleaning Air scouring	-	(Yu et al., 2016)
PSW	UF, MF	Sodium hypochlorite, citric acid, sodium hydroxide, and ultrapure water	Recovered 95% of water flux	(Marchesi et al., 2021)
PSW	UF	Electrocoagulation pre-treatment	Pre-treatment approaches can be adopted to alleviate fouling before the membrane filtration process.	(Sardari et al., 2018)

2.11 Recommendations and future perspectives

1. There are numerous NF membranes available in the market, but only some of them can resist harsh operating conditions (such as extreme pH) (Valderrama et al., 2021). Further studies can be carried out to produce membranes that are stable and not susceptible to fouling in high pH conditions.

2. For high quality effluents, a novel MBR called the osmosis membrane bioreactor (OMBR) has been developed and to promote wastewater treatment and reuse (Yadav et al., 2020). In OMBR, FO membrane module is displaced in the wastewater. Combined with biological treatment, water from the mixed liquor is forced to transfer through the semipermeable membrane to the draw side under the osmotic pressure gradient. The pollutants, activated sludge and solids are all rejected by the membrane. The superior performance of OMBR over conventional MBR has been demonstrated in previous research (Yadav et al., 2020). This OMBR can be integrated into the proposed system of this review instead of UF. This will reduce overall running costs incurred through high energy consumption, the cost for chemical cleaning, and membrane life which are limitations in pressure-driven membrane processes

3. Several studies reported that chemical cleaning could achieve highly efficient membrane cleaning from organic foulant, which may have a strong interaction to the membrane surface (Valladares Linares et al., 2013, Yoon et al., 2013, Valladares Linares et al., 2012, Wang et al., 2015). Although chemical cleaning is a viable option, it does not provide the eco-friendliness and biological treatment options the world is moving towards and this might cause an environmental problem as the effluent stream may be discharged containing chemicals. Hence more physio- biological pretreatment options and parameter optimization can be a way to ensure limited fouling and maintaining a minimal pollution footprint.

2.12 Conclusion

Whilst biological processes such as anaerobic and aerobic digestion provide the much-needed benefits of being environmentally friendly and economical, they still fall short in nutrient removal, digesting FOGs and removing suspended solids. The choice of the reactor also affects the composition of the effluent, the costs incurred during operation and the space required. Anaerobic digestion is very sensitive, involving different bacterial groups (methanogenic, acetogenic, etc.), which all have different optimum conditions. These bacteria are inhibited by process parameters such as temperature, pH, VFA concentrations etc. Therefore, it is paramount to maintain stable operating conditions in the digester. The DEGBR gives numerous advantages such as ease of operation and lowers energy requirements for pumping, as the water is aided by gravity and also provides turbulent mixing through the recycled stream. In contrast, the up-flow reactors such as the EGSB and the UASB experience poor reactor performance caused by a high up-flow velocity, biomass washout and higher energy requirements to oppose gravity and compensate for head losses to friction. The DEGBR has become more favorable for treating high strength wastewater. Adding a pre-treatment stage before anaerobic digestion, where enzymes are used to hydrolyze and break down FOGs, increases biogas production, improves reactor performance and results in ease of operation. Other post anaerobic digestion treatment stages such as nitrification, denitrification, membrane filtration and ultraviolet radiation can be added to improve the removal efficiency of P, C and N, as well as help meet the regulation standards.

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CHAPTER 3

RESULTS

MULTI-INTEGRATED SYSTEMS FOR TREATMENT OF ABATTOIR WASTEWATER

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CHAPTER 3: RESULTS AND DISCUSSION

3.1 Introduction

The water crisis has become an increasing problem worldwide. A statement by United Nations (UN) in 2016 estimated that two thirds of the world population will have no access to portable water by the year 2025 due to increase in population and urbanization. Another brief given by the world commission on water estimated that, water usage will increase worldwide by approximately 50% by year 2034 (Vergili *et al.*, 2012). With an increase in demand and no increase in portable water sources, this has led to an uneven distribution and competition of the natural water resources amongst different sectors. Already 2.1 billion people especially in developing countries such as Africa and the middle east are living without safe drinking water at home, and nearly 4 billion people experience severe water scarcity at least 1 month of every year (Ezugbe and Rathilal, 2020).

In south Africa especially, the majority of the water is consumed by the agricultural and industrial sectors which provide the most revenue income to the South African government. As with any process that consumes fresh water, large quantities of contaminated water are produced as a byproduct. In relation to other industries, abattoirs consume large quantities of water to maintain clean and sanitized environments for their meat processing.

The availability and affordability of poultry products makes the poultry industry one of the highly growing industrial sectors in the world (Meiramkulova, Zorpas, *et al.*, 2020). Poultry abattoir industries consume about 26 L of potable water per bird and is approximated that broilers consume 1.6 to 2.0 times as much water of feed on a weight basis. This high water consumption is characterized by the fact that water is a critical nutrient in bird metabolism and nutrition (Meiramkulova, Zorpas, *et al.*, 2020; Gutu *et al.*, 2021). Consequently, the more water is consumed, the more wastewater generated which is characterized by high pollution strength from organic matter such as undigested food, blood, fats, oil, and grease (FOG) and lard, loose meat, paunch, colloidal particles, soluble proteins, manure, grit, and suspended materials (Gutu *et al.*, 2021).

High strength pollutants come with an expense attached to their removal processes from wastewater. Due to the costs associated with pollutant removal from the water, the south African government has posed stringent laws on the quality of effluent that can be discharged by industries into the municipal body. High penalties are charged to companies/parties as a result of noncompliance.

In their efforts to avoid being heavily fined or the possibility of getting shut down for not meeting discharge standards, industries have been trying to find more adaptive and cost effective, easy ways to treat their effluent streams. Generally, companies are just aiming to meet the discharge standards and if the water has the possibility to recycle and reuse onsite.

Although it may sound simple, finding the balance between high removal efficiency, smaller footprint, low environmental impact and cost effectiveness can pose to be a great challenge. Many treatment methods have been reported in literature but they all fall short in one way or another. Each process and method aren't always ideal for every wastewater type.

Most industries that have high organic content waste water resort to the aerobic and anaerobic digestion processes. They offer benefits of ease of use and production of less chemical waste which is difficult to treat. AD is well suited for high strength wastewater due to low energy requirement, the potential of biogas production as a renewable energy, and low surplus sludge production which not only can destroy most of the pathogens present in the sludge but could also help to reduce possible odor problems (Liew *et al.*, 2020; Shende and Pophali, 2021). However, AD process on its own cannot remove all of the pollutants in the wastewater.

Multiple stages can be introduced as tertiary cleaning to further remove pollutants. But how many is multiple and how many stages can be added without compromising on profits? And how many is too little to meet the discharge standards? The aim is for the municipal body to receive fewer toxic loads hence overall the environmental impact these pollutants pose will be reduced.

Most of the research on wastewater treatment involves the study of different contaminants, the effects of operating variables, and the efficiency of the processes. However, there are limited studies on the economic information and analysis, reaction mechanisms, and kinetic modeling that may help to estimate the costs of different technologies for scale-up and industrial applications (Bustillo-Lecompte, Mehrvar and Quiñones-Bolaños, 2014) There is generally little information in the peer-reviewed literature on costs, but rather more on energy demand and process parameters (Lo, McAdam and Judd, 2015).

This study focuses on a multi integrated system (MIS) pilot plant to treat poultry abattoir wastewater. According to (Dlamini *et al.*, 2021; Dyosile *et al.*, 2021; Meyo *et al.*, 2021), removal percentages of >90 % were observed in organic matter removal using a similar pilot plant set up. It can be proven that this multistage system can treat wastewater to meet the City of Cape Town municipality (CoCT) discharge standards but what these studies failed to mention was at what cost? If the costs of running the plants exceed the penalties imposed by the governing bodies, less people/ industries will see the need to treat water onsite which isn't a sustainable option for the environment in the long run. Hence, there is dire need for sustainability methods but above all, cost effective and easy to operate too.

3.2 Objectives

- To characterizes the abattoir wastewater
- To optimize the pre-treatment stage using the Eco-flush reagent
- To identify the conditions the micro-organisms in the Eco-flush perform best at (whether they are anaerobes or aerobes or facultative microorganisms)
- To assess the effectiveness of the DEGBR and the whole system on the removal of the BOD, COD, TSS, TN, ammonia, orthophosphates and smells
- To assess any problems or drawbacks on the system performance and recommend ideas on improvement
- To determine whether the final effluent complies with the water municipal discharge regulations

3.3 Experimental methods and procedures

The process flow diagram of the study is shown on Figure 3:1 below.

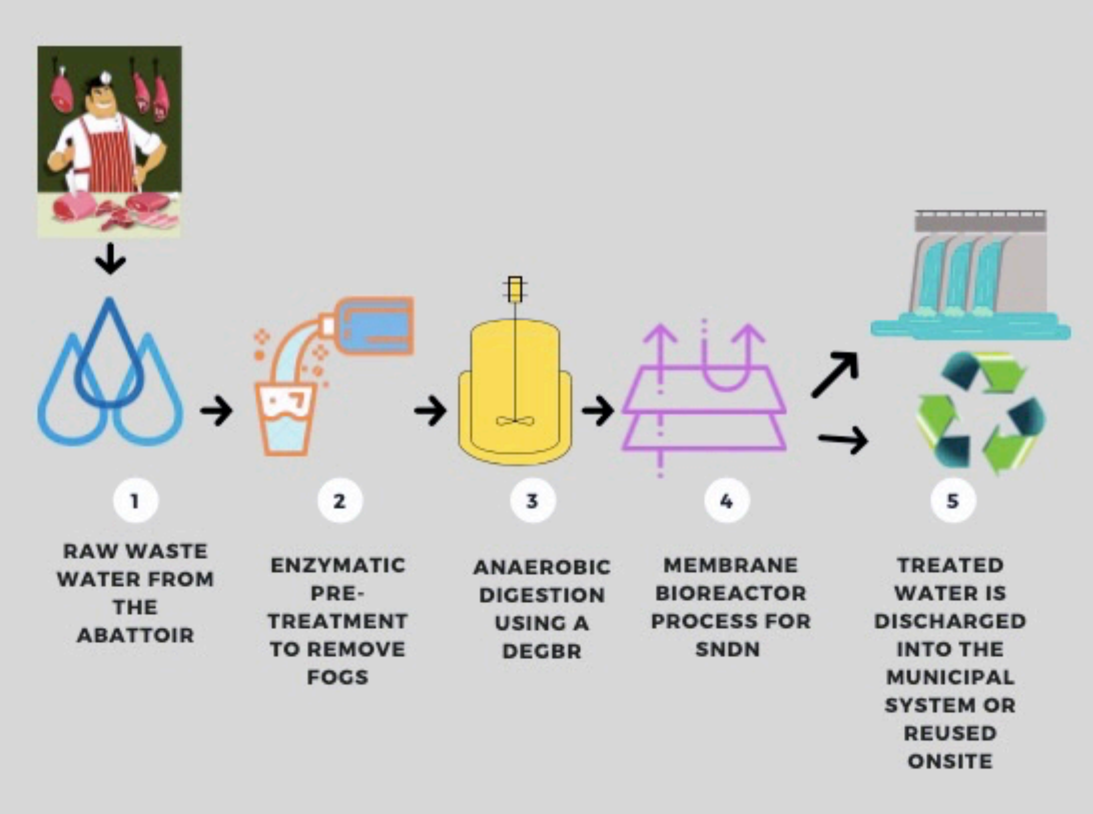


Figure 3:1: Process flow diagram of the proposed study for treatment of abattoir wastewater

3.3.1 Raw wastewater collection and storage

The raw wastewater used as part of this experiment was collected at a local poultry abattoir located in Cape Town, South Africa. The sampling times were either during slaughtering or cleaning processes. The sampling point was a stream between the abattoir and the clarification tank. The raw wastewater was poured into and stored in 20 L polystyrene containers. The containers were stored in a refrigerator at 4ºC. Each batch was analyzed according to Table 3:3 below which shows the ranges of characteristics of the raw wastewater used in this study.

3.3.2 Pretreatment

The raw wastewater was treated using the Eco-flush Bioremediation agent from Mavu technologies to bioremediate the fats before treating anaerobically with the DEGBR. A 20L polystyrene bucket was used as a reactor. 15L of raw wastewater and 150mL of eco flush were reacted. The process is aerobic. Air was supplied through a rubber tubing to the 25L polystyrene containers. Air stones were attached to the ends of the tubing to ensure even distribution of the air. The raw was aerated for 24hrs to allow the activation of the enzymes and biodegradation of FOGs. Another 24hrs were allowed for settling and reduction of the dissolved oxygen levels. The pretreated water was then sieved using 3 Madison test sieves of 100 micron ,75micron and 53 microns layered on top of one another. Figure 3:2 below shows the difference between the raw wastewater being treated and after being sieved. The sieved suspended solids remain on the sieve as shown by Figure 3:3. The sieved water was used as a feed to the anaerobic digestion process.

Figure 3:2: Pre-treatment stage of raw wastewater before and after sieving

Figure 3:3: Suspended solids collected after sieving the pre-treated water

3.3.3 Downflow Expanded Granular Bed Reactor (DEGBR) inoculation and operating conditions

The granules used for the inoculation were collected from Anheuser-Busch InBev SA, Newland Cape Town. The granules were stored in a closed 20L polystyrene container at 25 degrees Celsius until they were used in the DEGBR. The DEGBR was filled with about 400grams pea gravel in the bottom cylinder to help retain the granules. The reactor was allowed to heat up using a heat exchanger to about 30ºC. 400mL of granules were added together with 200ml of baby formula with a concentration of 0,75g/mL to provide food for the granules whilst acclimatizing. The reactor was inoculated for 72hrs and then the pretreated wastewater was fed into the reactor. The reactor operating parameters are shown in Table 3:1.

Table 3:1: Operating conditions for Anaerobic digestion using a DEGBR

Parameter	Operating condition
Volume of reactor	2L
Working volume of reactor	1.8L
HRT	3.6hr
OLR	21.3gCOD/L.d
Temperature range	28 ºC- 40 ºC
pH range	5.7-6.7
Inlet flow rate	0.50L/h

Outlet flowrate	0.42L/h
Recycle flowrate	2.04L/h

3.3.4 Membrane Bioreactor (MBR) inoculation

The MBR is composed of the anoxic tank and the aerobic tank housing the submerged membrane. There is a recycle from the aerobic side to the anoxic side and the two tanks overflow into each other. 100mL of granules were added to the anoxic side. The aerobic side had 300mL of sludge granules. 200mL of eco flush was added to both tanks. To inoculate the sludge granules, 10L of the DEGBR effluent were mixed with 10L of fresh water then added to the granules and eco flush. The reactors were left to acclimatize for 72hrs before running fully. The operating conditions were as shown in Table 3.2.

Table 3:2: MBR operating conditions and specifications

Parameter	Operating condition
Volume of anoxic tank	33L
Volume of aerobic side	69L
Preservation of membrane	Glycerin 20% / sodium benzoate 3%
Nominal membrane area	0,37m2
Membrane pH range	2-11
Membrane T range	5 ºC- 40ºC
Max TMP	-400mbar
Membrane sheets	3 sheets of 2mm thickness
Inlet flow rate	0.72L/h
Outlet flow rate	0.504L/h
Recycle flow rate	1.60L/h
Membrane pore size	0,04µm

3.3.5 Ultra Violet (UV) system

A UV sterilizer system of 62,5mm diameter by 590mm in length was used. The UV bulb was housed in a quartz sleeve. The power was turned on and water was allowed to flow though the UV lamb which produces the ultraviolet light for the disinfection of the MBR effluent.

3.3.6 Sampling and analysis

The sampling was done 3 times a week from the feed tank, DEGBR effluent and MBR effluent. When a new batch of raw was introduced, samples were taken as well. The pH and temperatures were taken on a daily basis. A weekly representative was sent to an accredited laboratory for analysis of fats oils and grease (FOGs), chemical oxygen demand (COD), biological oxygen demand (BOD), total suspended solids (TSS), total nitrogen (TKN), orthophosphates as P, nitrates, nitrites and ammonia.

3.3.7 Economic analysis

An economic analysis was mainly carried out to focus on operational and maintenance costs. In line with Bustillo-Lecompte, Mehrvar and Quiñones-Bolaños, (2016), costs related to installments and capital acquiring were not considered in this study since the industry and potential users will be able to have a standardized procedural comparison basis. The costs of every stage from pretreatment to the UV system was considered to actually determine cost per stage.

The operational costs were related to electricity consumed, replacement of UV lamps, membrane cleaning chemicals as well as purchasing of the Eco flush, a bioremediation agent. The costs of running the equipment was calculated per year assuming 22 hours in a day and 360 days in a year to account for routine maintenance and minor plant shut downs. The cost of electricity was taken to be R3,31/kWh based on the municipality prices as of November 2021. The following equation 3:1 was used to calculate the yearly electricity running cost:

$$\frac{Cost\ in\ Rand}{year} = Equipment\ wattage(kW) \times Electricity\ cost\ \left(\frac{RkW}{hr}\right) \times \frac{22hr}{day} \times \frac{360days}{year}$$

Equation 3:1: Running costs per year

The other costs for chemicals were obtained from the suppliers and used as quoted.

3.4 Results and discussion

The raw wastewater collected at the local poultry abattoir was tested before being pretreated and the results are shown in Table 3:3 below. More samples were taken from the DEGBR, anoxic stage, membrane stage and UV stage. The MBR effluent was compared against the raw, City of Cape Town (CoCT) discharge standards, the department of water and sanitation (DEWA) water act standards as well as the South African National standards (SANS) for portable water quality as shown in Table 3:3. According to the data in Table 3:3, our effluent met almost all of the CoCT discharge standards and the DEWA standards except for Ortho Phosphates and ammonia. The water has potential to be used for irrigation for agricultural purposes.

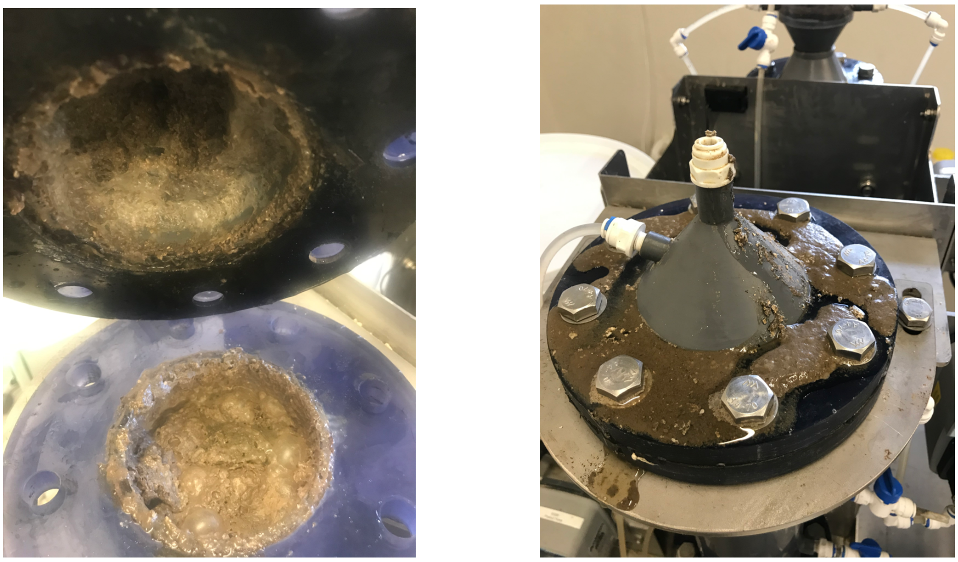
Table 3:3: Characteristics of abattoir wastewater in comparison to discharge standards and MBR effluent of the study

Parameter	Raw wastewater (This study)	CoCT discharge limits (2013)	DEWA National Water Act (1998)	SANS portable water quality	Week 17 MBR effluent (This study)
pH	2.3-3.6	5.5-12	5.5-9.5	9.7	7.38
TSS (mg/L)	272-456	1000	25	-	3
COD (mg/L)	3460-7230	5000	75	-	411
FOGs (mg/L)	28-153	400	2.5	-	0.92
Alkalinity (mg/L)	416-989	-	-	-	168
NO_2 (mg/L)	< 0.03	-	<15	0.9	0.84
NO_3 (mg/L)	<0.18	-	<15	11	5.4
Ammonia (mg/L)	160-274	-	<3	1.5	34.5
TP (mg/L)	94-225	25	<10	-	65

Ecoli (MPN/100mL)	250	1000	1000	-	5

3.4.1 Pretreatment

FOGs are a problem especially in high strength wastewaters such as dairy, abattoir and cheese whey wastewater. These FOGs have been reported to contribute to operational problems in the use of high rate anaerobic bioreactors (Liew *et al.*, 2020). In support with (Cheng *et al.*, 2020), excessive FOG levels can block the transfer rates of oxygen to microorganisms, cause biomass washout due to overgrowth of filamentous bacteria as well as long term system failures due to blockages as well as unpleasant odors. Figure 3:4A shows the blockages that can occur due to excessive FOGs in the feed water which as a result caused pressure build up and leakages in the reactor, Figure 3:4B.



A

B

Figure 3:4: Clogging of the DEGBR from FOGs (A) and Sludge washout due to pressure build up in system (B)

To improve the system efficiency, a biological pretreatment system that has low energy requirements, no chemicals and mild environmental conditions can be used to improve the hydrolysis stage of AD which is known to be the rate limiting stage (Liew *et al.*, 2020). If hydrolysis is improved the anaerobic digestion is also improved resulting in a higher biogas production and removal efficiency. In this study, an Eco flush bioremediation agent was used for the pretreatment stage as it uses microorganisms with high ability to hydrolyze the complex slow hydrolyzing FOGs.

As can be seen on Figure 3:5, the removal efficiency of FOGs was >90% for almost the full length of the runs except for weeks 6,12,15 and 16 where the removal was below 20% which in turn resulted in the reactor clogging as shown by previous Figure 3:4. This inconsistency could have resulted from not enough aeration being supplied to the aerobes during the 24hr reaction period. The bacteria found in the eco flush is mainly targeting the FOGs and this can be clearly seen on the graph of Figure 3:5 since all of the other parameters had a removal from as low as 2% to 70% with FOGs having the highest removal of close to 100%.

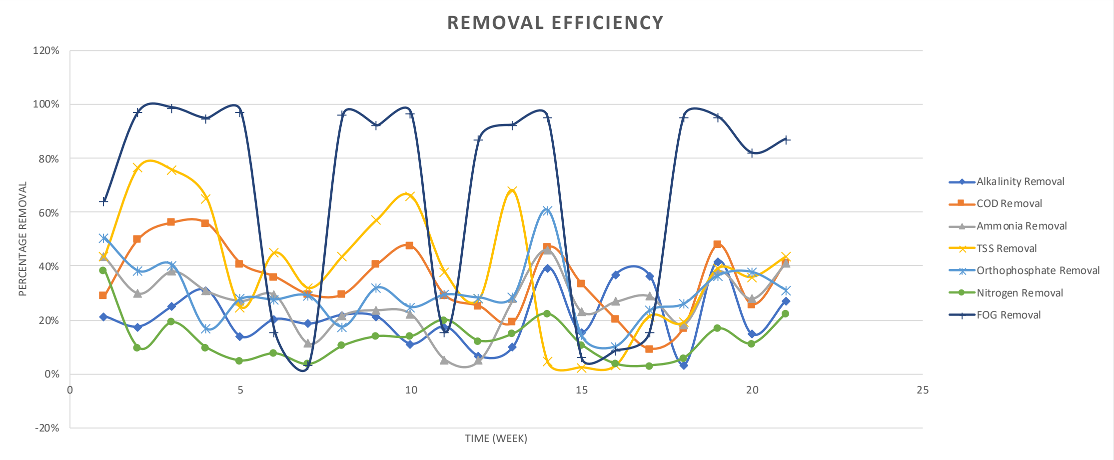


Figure 3:5: Removal efficiency of the pre-treatment stage using Eco flush

3.4.2 Anaerobic digestion

In AD processes, it is vital to maintain a volatile fatty acids (VFA)/alkalinity ratio of <0.4 to avoid acidification in the process (Shende and Pophali, 2021). Abattoir wastewater contains a high organic nitrogen concentration as high as 1100mg/L which results in ammonification during hydrolysis (Shende and Pophali, 2021). Shende et al, 2021 also added that the ammonia will react with carbon dioxide produced during AD to form ammonium bicarbonate which contributes to alkalinity in the reactor which can counteract VFAs and as a result the VFA/alkalinity ratio can be maintained without a challenge. As shown on Figure 3:6, the alkalinity removal was generally between 0-20% throughout which can be a sign of stability in our reactor as not much acidity was present and a fairly stable pH was maintained inside the reactor. It can be observed though, on weeks 15 and 16, the alkalinity of the water increased by about 60%. This could have been as a result of introducing a new batch of raw which was sampled when the abattoir was being cleaned and high amounts of cleaning detergents were present. It can also be noted that throughout the course of the experiment, the removal efficiencies of orthophosphate, nitrogen, alkalinity and ammonia were all ranging from as low as 0-20% except for weeks 17-19 where a shoot up was recorded and it went back to the lower ranges again. This could have been due to a change in reactor conditions such as acidification, temperature. Furthermore, it was observed that during those same weeks, maintenance of the reactor product pumps was carried out which resulted in longer HRTs and longer recycling times since the product pumps were switched off and no product was being pumped out. If the sampling was done as soon as the pumps were switched on, the effluent collected would have had more contact with the biomass for longer periods compared to the other previous Weeks's samples. The sampling of the reactor effluent would have been consistent if the reactor was given time to pump out then carry out sampling after a day or so. The TSS, COD and FOG removal efficiencies were between 10-90%, 10-90% and 40-100% respectively. The inconsistencies could have been due to an inefficient pre-treatment stage which resulted in reactor instability and poor removal efficiencies. According to (Liew *et al.*, 2020), high rate anaerobic digestion removes 80% COD. A similar study done by (Dyosile *et al.*, 2021) recorded a COD, TSS, FOG removal of up to 87% ,93% and 90% respectively with an OLR of 18-45g COD/L.d. Another study using the DEGBR for treatment of slaughterhouse wastewater reported FOG, COD, TSS removal averaging 89±2.8%, 87±9.5% and 94±3.7% respectively (Dlamini *et al.*, 2021). Furthermore, it was observed that the results are consistent with these studies.

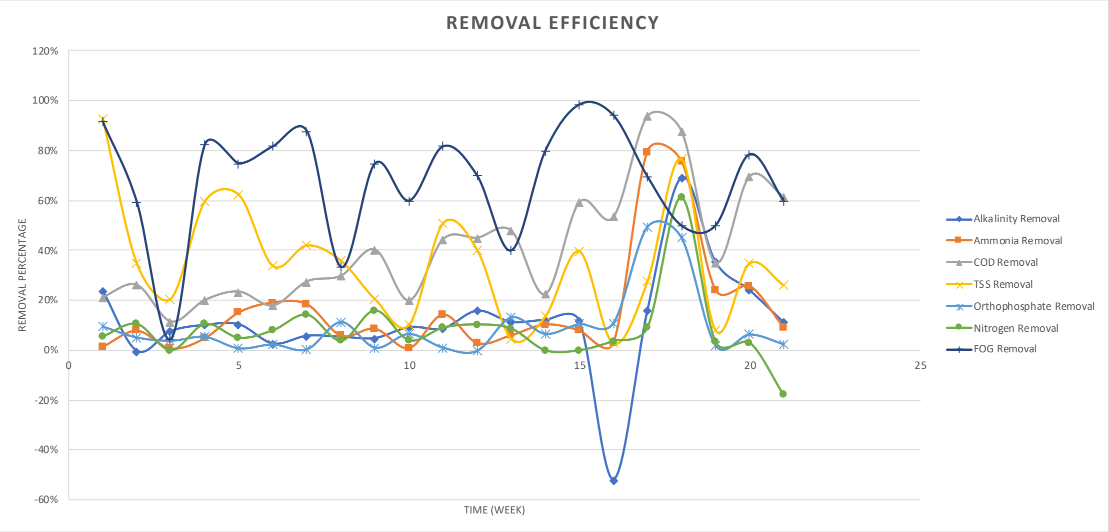


Figure 3:6: Removal efficiency of the anaerobic digestion process in the DEGBR

3.4.3 MBR system

The MBR system consists of two reactor tanks partially separated to one another. There is an anoxic side and an aerobic side which houses the ultrafiltration membrane system. The MBR influent is the product of the DEGBR. The performance of the membrane filtration process is highly affected by the presence of high amounts of suspended solids (Meiramkulova, Devrishov, *et al.*, 2020). In relation to this statement, it can be observed on Figures 3:7 and 3:8 which represent the performance of the individual anoxic and aerobic tanks of the MBR respectively, when the TSS removal is very low e.g. week 3 to 5, the removal of all the parameters also drop to as low as <10%. Hence, TSS removal in feed water prior to a membrane filtration treatment process is very important to improve membrane flux especially for highly polluted wastewater such as the slaughterhouse activities (Mehta, Saha and Bhattacharya, 2017; Meiramkulova, Devrishov, *et al.*, 2020).

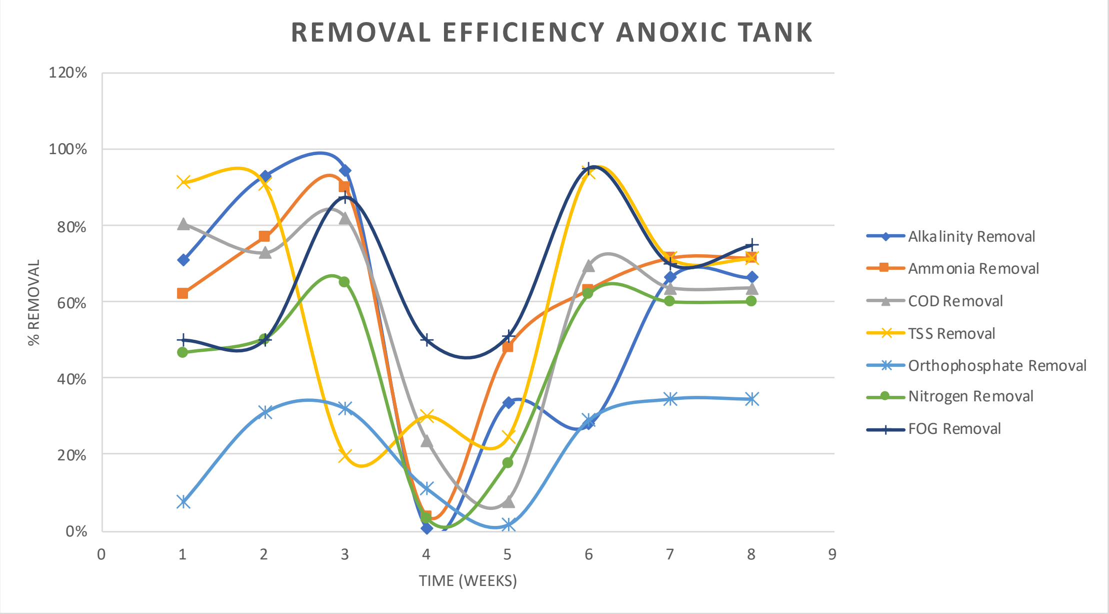


Figure 3:7: Removal efficiency of the anoxic tank in the MBR

Since membranes are prone to fouling, aeration is required in the aerobic side to scour the cake layer on the surface of the membrane which can help with high levels of TSS. For both tanks, the orthophosphate removal is barely >30%. This shows our system is incapable of removing phosphorus. A separate anaerobic tank has to be added before the anoxic tank for phosphorus removal. The removal of ammonia usually occurs through conversion to nitrite and nitrate by a nitrification process under anoxic conditions (Pahlavanzadeh *et al.*, 2018).

The level of simultaneous nitrification and denitrification occurring in the aerated MBR reactor fluctuates according to the oxygen level within the bulk liquid and the denitrification potential which is sorely dependent on available COD (Sarioglu *et al.*, 2008). Low DO levels in the range of 0.3–0.6 mg/l increases the denitrification potential dramatically triggering up to more than 30mg/l of nitrate uptake within the MBR, whilst DO levels in the range of 1.5 – 3.5 mg/l reduces the nitrate uptake to levels in between 10–20 mg/l (Sarioglu *et al.*, 2008). The DO levels of both the anoxic and aerobic tanks in this study were averaging 2,5-2,8mg/L and this can be noted by the high amount of nitrates and nitrites in the effluent as shown in Table 3:3 above for week 17 results, suggesting there was reduced uptake during denitrification and some of the nitrates ended up in the product.

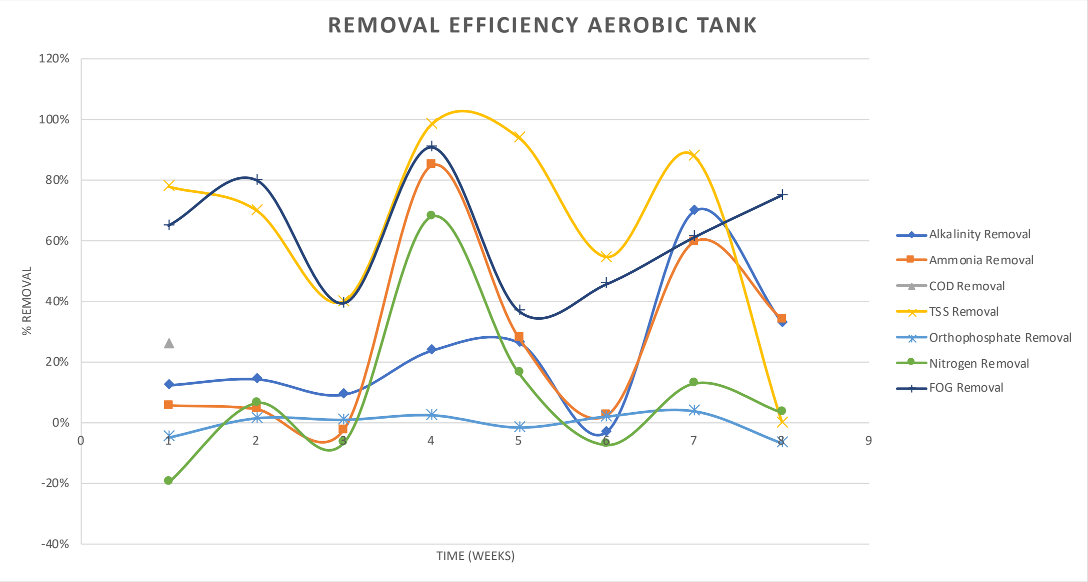


Figure 3:8: Aerobic membrane tank removal efficiency using ultrafiltration process

3.4.4 Multi Integrated Systems (MIS)

Based on the results of the individual systems, anaerobic digestion is incapable of removing the inorganic content in abattoir wastewater to make it safe for re-use or even for discharging into the environment. Multi integrated systems offer the benefit of combining two or more processes together to improve removal efficiency. Three alternatives were explored and their economic analysis was done to determine a better option in terms of efficiency and economic viability. The 3 processes were: 1) raw + AD which represented the pretreatment stage and the anaerobic reactor 2) raw + AD+ anoxic and lastly 3) raw + AD + anoxic + membrane which represented the whole system setup of the pilot plant. The idea was to compare the removal efficiencies across these biological processes and see if adding more stages really made that much of a difference. Figures 3:9 - 3:12 represent the comparative results of the three processes in terms of COD, FOG, nitrogen and alkalinity removal efficiencies.

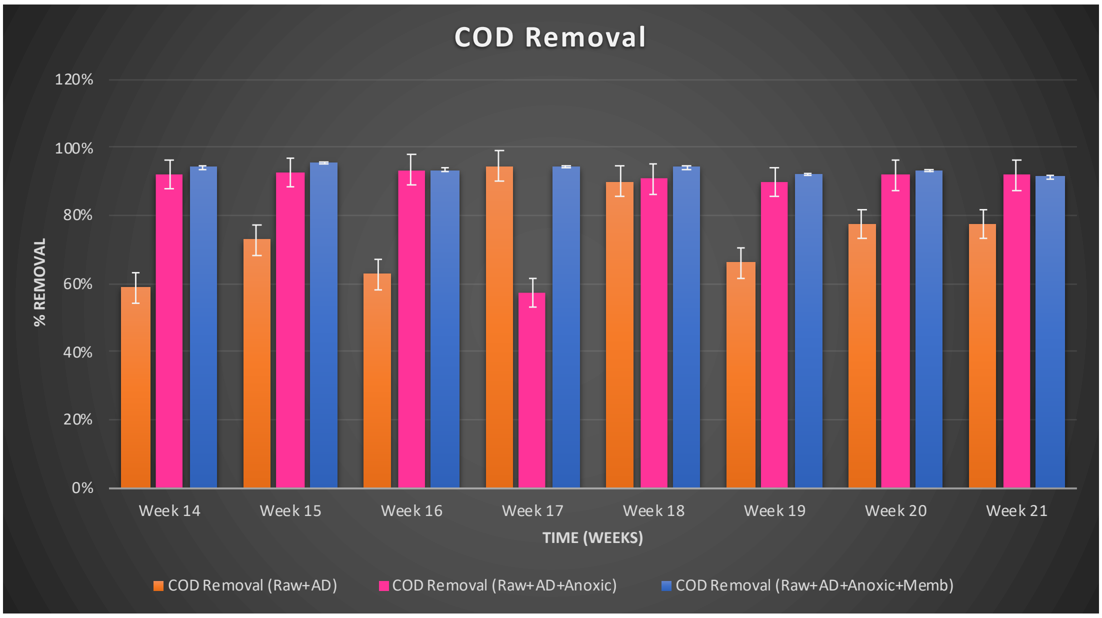


Figure 3:9: Comparison of COD removal across three different combined processes

According to Figure 3:9, the COD removal efficiency of 60-90% was observed in the anaerobic digestion process. Both the anoxic tank and the membrane had similar removal efficiencies of >90% except for week 17 which could have been sue to a new batch being introduced or plant failure and it can be seen on all Figures from 3:9 – 3:12 that it is an anomaly. The FOG removal was >98% throughout the operation of the plant as shown by Figure 3:10. This proves that the eco flush is efficient as a pretreatment stage and is a crucial step to ease of plant operation as most of the FOGs would have already been removed before AD and less clogging and shut downs will occur.

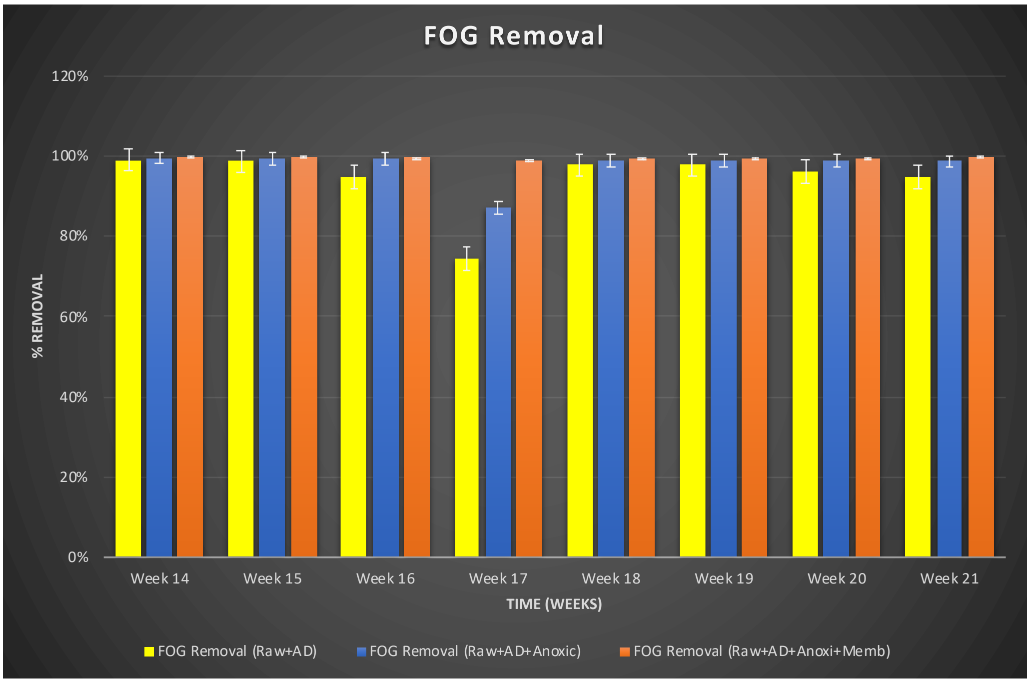


Figure 3:10: Comparison of FOG removal across three different combined processes

Figure 3:11 shows that nitrogen removal was ranging between 10-20% for the Raw + AD process, 15-70% for Raw-anoxic and 50-75% when the membrane ultrafiltration process was added. The addition of an extra aerobic tank to house the membranes only made a smaller difference in maximum removal efficiencies. The same trend can be seen on Figure 3:12 which shows alkalinity removal efficiencies. It really did not make a huge impact by adding an additional separate tank. This could have been due to the fact that the two tanks overflow into each other and the recycle stream was also mixing the two tanks at a faster rate than the influent stream to the MBR itself which resulted in two tanks being fully mixed and functioning as one. This issue could have also contributed to the rise in nitrates and nitrites in the effluent stream of the MBR as shown on previously on Table 3:3.

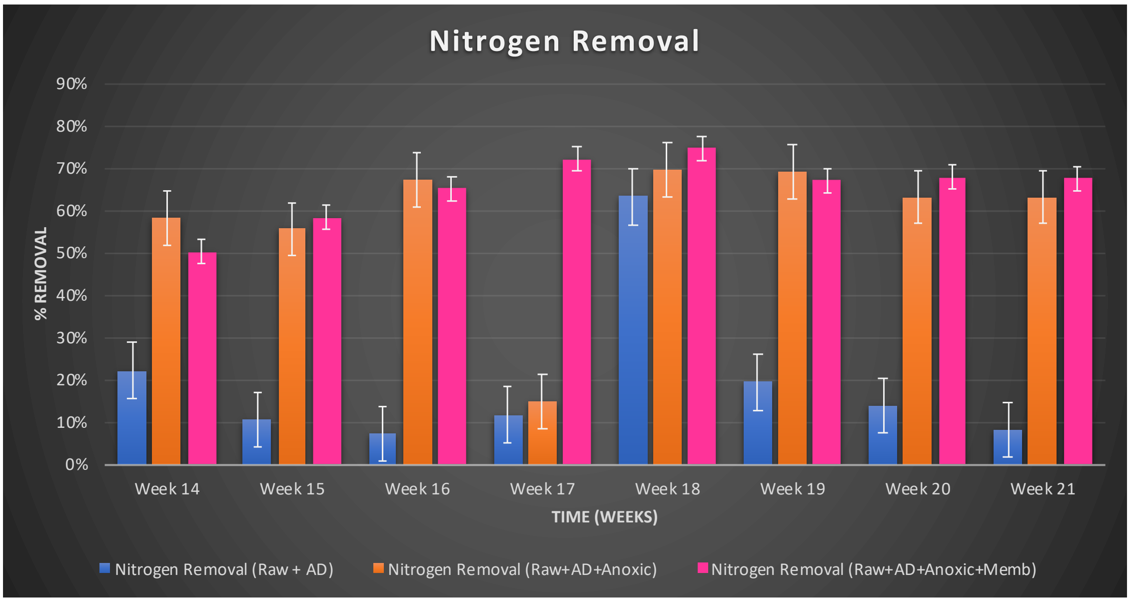


Figure 3:11: Comparison of Nitrogen removal across three different combined processes

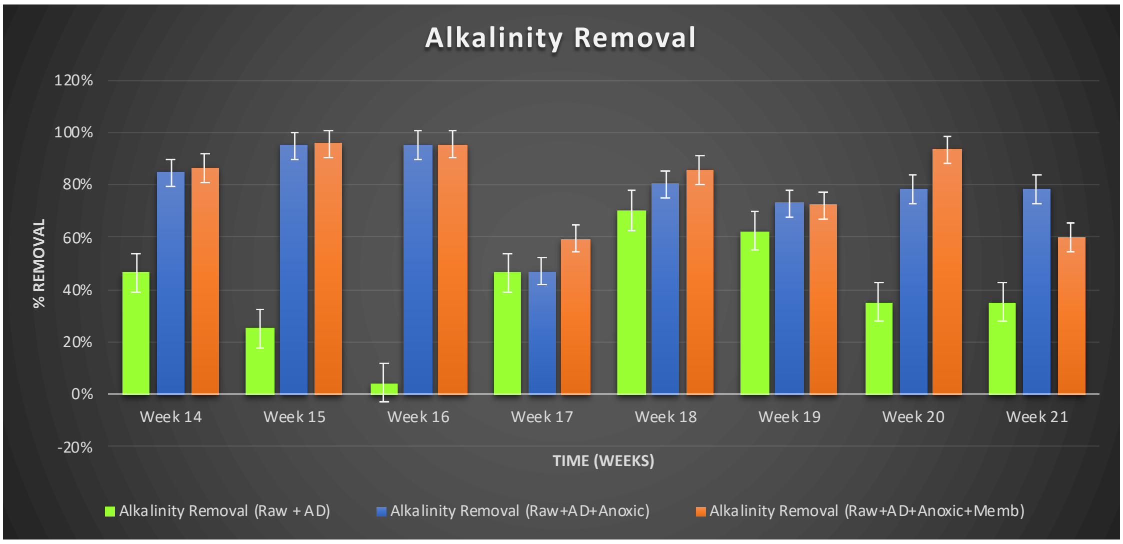


Figure 3:12: Comparison of alkalinity removal across three different combined processes

Although the raw to membrane process has higher removal efficiencies, on an economical aspect, if having two separate tanks did not increase the efficiency greatly, one tank can be used for both nitrification and denitrification to occur simultaneously. Simultaneous nitrification and denitrification (SND), is said to be an economically effective and space-saving technology (Tian *et al.*, 2018). Compared to traditional biological nitrogen removal processes, the SND system represents some significant advantages. First, SND eliminates the need for a separate anoxic zone, inducing simplified operating procedures and a smaller footprint. It is estimated that the SND system reduces 40% of COD demand during denitrification and saves 25% of aeration energy (Tian *et al.*, 2018). Simultaneously, the SND system can complete the nitrification and denitrification process under the neutral pH with less demand for alkalinity but certain factors would have to be monitored such as C/N ratio, temperature, MLSS (Tian *et al.*, 2018).

Figure 3:13 shows the overall efficiencies of the lab scale plant from raw up to the MBR. This process combination is without doubt the best one out of the 3 or single processes separately. However minor adjustments can be done to accommodate for phosphorus removal which has the lowest removal efficiencies out of all parameters of <60%. FOG, TSS and COD have the highest removal efficiencies of 100%, 98% (except for week 3 due to plant failure and maintenance) and >90% respectively. Ammonia removal was between 80-90% and nitrogen removal was ranging between 50-70%. The HRT and OLR was kept constant for the system at 3,6hr and 21,3gCOD/L. d respectively.

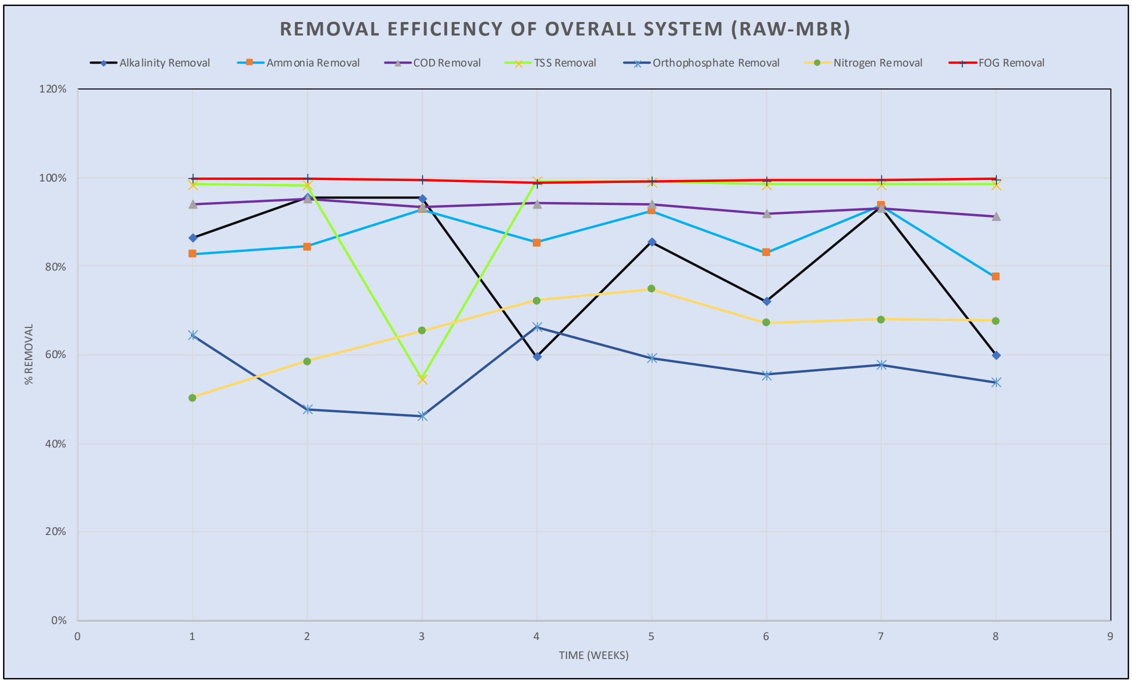


Figure 3:13: Overall performance of the system from the pre-treatment of raw to MBR stage

A UV system was introduced to see if the potential of reusing the water could be viable after pathogens had been removed. The MBR effluent was passed through the UV system and the presence of E. coli was tested before and after. The removal efficiencies were all >97% except for week 4 samples which could have been due to contamination during sampling Figure 3:14. The water has potential to be used for irrigation purposes after the UV system.

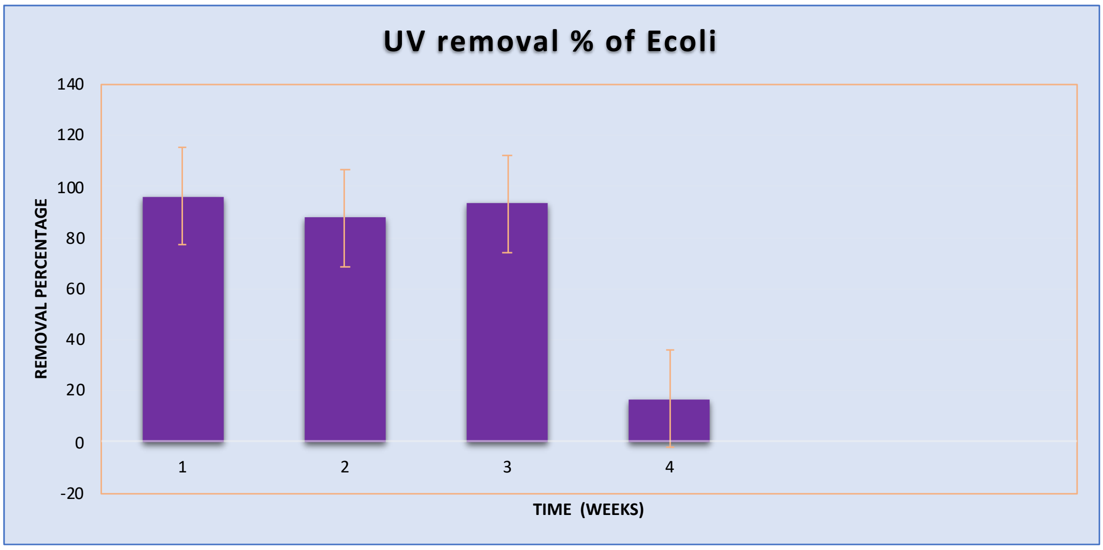
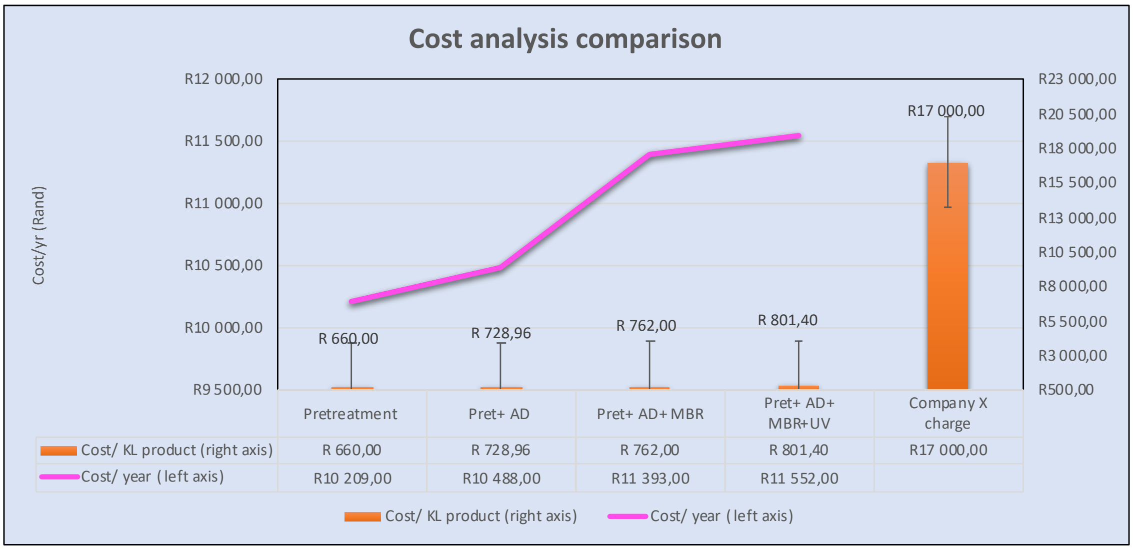


Figure 3:14: Removal efficiency of E.coli using a UV system after MBR stage

3.4.5 Cost analysis

In all industrial applications, cost plays a major role in decision making. Operational expenses of three processes were compared on how expensive they can be but also regarding their removal efficiencies. As more stages were added, it can be expected for the yearly running expenses to increase as well. A huge price increase in yearly costs was seen when the MBR stage was added after the raw+ AD system as shown in Figure 3:15. It can be justified since the MBR system is renowned to having high capital costs and high energy consumption which proves a critical challenge due to the higher investment needed to build up a wastewater treatment plant as well as to factor in the major maintenance involving the replacement of membrane elements(Muhamad Ng *et al.*, 2021). The issue of high costs associated with membranes will always be a major drawback but we cannot ignore the benefits in removal efficiencies provided by the addition of an MBR stage after the AD. If the cost was considered per kiloliter of product, the price increase of adding the MBR stage after AD is only by 4% more and that of adding the UV stage is 5% more. These prices were compared to a local waste management company. For their charge of R425 per 25L sample to collect and dispose of waste, it would cost the abattoir about R17 000/KL which is 20 times more than the Pretreatment to UV system.



	Pretreatment	Pret+ AD	Pret+ AD+ MBR	Pret+ AD+ MBR+UV	Company X charge
🟧 Cost/ KL product (right axis)	R 660,00	R 728,96	R 762,00	R 801,40	R17 000,00
Cost/ year (left axis)	R10 209,00	R10 488,00	R11 393,00	R11 552,00	

Figure 3:15: Cost comparison of different treatment alternatives and combinations of Multi Integrated Systems

3.5 Summary

The objective of this study was to evaluate the operating costs of treating abattoir wastewater using combined biological processes. The processes were evaluated based on removal efficiency and cost of treating wastewater/KL. The process with the most removal efficiencies was the raw-AD-MBR and the effluent met the municipal discharge standards. A potential for reuse onsite for irrigation can be explored if a UV system is added and an anaerobic stage for phosphorus removal could be added before the MBR. The removal efficiencies for FOGs, TSS, COD, ammonia and E. coli were 100%, 98%, >90%, 80-90%, >97% respectively. The pilot plant achieved that at a price of R801,40/KL.

3.6 References

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CHAPTER 4

CONCLUSIONS & RECOMMENDATIONS

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CHAPTER 4: RECOMMENDATIONS AND CONCLUSIONS

The conventional biological process of nitrogen removal is based on complete nitrification in an anaerobic environment followed by heterotrophic denitrification in an anoxic environment (Silveira *et al.*, 2021). Although this setup is widely used, it has some major drawbacks such as it consumes high energy, high oxygen demand, requirements for exogeneous organics as electron donors as well as not being effective for treating high strength wastewater such as abattoir (Silveira *et al.*, 2021). The experimental data I this study does supports these claims. There are two options that could be explored 1) combining the two tanks to a one step process, it will be economically advantageous but the removal efficiencies might not improve, 2) try partial nitrification-anammox (PN/A) which has been increasingly used for treatment of abattoir wastewater which offer the advantages of reduced aeration demands, less sludge is produced and less need for organic supplementation (Li *et al.*, 2020).

The optimization of AD processes has been mainly focused on the operational parameters such as reactor configuration, mixing, temperature, pH, feed characteristics (Ferguson, Villa and Coulon, 2014). Co-digestion of the abattoir wastewater with different waste materials has been effective and has a number of potential benefits in AD such as improvement in the overall availability of nutrients and the dilution of inhibitory compounds (Ferguson, Villa and Coulon, 2014).

Other studies have demonstrated the benefit of operating at low solids concentrations, which reduces energy for both mixing and biological (or process) aeration (Fletcher, Mackley and Judd, 2007; Lo, McAdam and Judd, 2015). A feed into the MBR can be diluted to control the amount of sludge and suspended solids in the aeration tank housing the membrane. This will help with prolonging membrane shelf life as well besides the above-mentioned advantages. Less fouling will occur and less routine maintenance will be required on a regular basis.

The pretreatment stage using the Eco flush is an aerobic process. Despite the process being effective in removing the FOGs, the high levels of DO in the pretreatment tank can inhibit the AD stage which thrives in the absence of oxygen. Despite letting the dissolved oxygen decrease on its own for 24hrs, not all of it can be released. Hence, purging can be tried which involves the displacement of one gas with another for example using nitrogen or hydrogen to displace the oxygen after pretreatment stage.

CHAPTER 5

BIBLIOGRAPHY

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CHAPTER 6

APPENDICES

PLEASE ZOOM OUT FOR A CLEARER PICTURE

RAW-DEGBR EFFLUENT (WEEK 14-21)

		Week 14					Week 15					Week 16					Week 17				
		Raw Wastewater		DEGBR (OUT)		Removal	Raw Wastewater		DEGBR (OUT)		Removal	Raw Wastewater		DEGBR (OUT)		Removal	Raw Wastewater		DEGBR (OUT)		Removal
	Units	Lovibond	Waterproof	Lovibond	Waterproof		Lovibond	Waterproof	Lovibond	Waterproof		Lovibond	Waterproof	Lovibond	Waterproof		Lovibond	Waterproof	Lovibond	Waterproof	
pH	-	-	6,4	4,37	6,41		-	6,4	4,7	6,9		-	6,4	4,92	7,08		-	6,25	5,19	6,96	
ORP	mV	456	-	153	-		456	-	135	-		456	-	121	-		547	-	105	-	
DO	mg/L	2	-	0,5	-		2	-	0,7	-		2	-	1	-		1	-	0,8	-	
TDS	mg/L / ppm	694	368	170ppm	1,12ppt		694	368	206ppm	1,32ppt		694	368	217mS	1,39ppt		806ppm	444ppm	269	1,65ppt	
Salinity	ppm	-	359	-	1,13ppt		-	359	-	1,36ppt		-	359	-	1,44ppt		-	436ppm	-	1,73ppt	
Conductivity	µS	-	734	-	2,23mS		-	734	-	2,62mS		-	734	-	2,78mS		-	889	-	3,23mS	
Temp	°C	14,3	25	18,2	25		14,3	25	17,9	25		14,3	25	17,5	25		14,3	25	17	25	
Alkalinity as CaCO3 (Titrando)	mg/L	715		381		47%	635		475		25%	989		947		4%	416		222		47%
Ammonia (NH3) as N	mg/L	214		103		52%	176		124		30%	223		158		29%	235,2		34		86%
Nitrate (NO3) as N	mg/L	<0.18		<0.18		-	<0.18		<0.18		-	<0.18		<0.18		-	<0.18		5.7		-
Chemical Oxygen Demand (Unfilter	mg/L	6230		2570		59%	6230		1690		73%	5240		1950		63%	7230		405		94%
Suspended Solids	mg/L	262		216		18%	289		170		41%	262		247		6%	438		249		43%
Nitrite (NO2) as N	mg/L	<0.01		<0.01		-	<0.01		<0.01		-	<0.01		<0.01		-	<0.01		0.83		-
Orthophosphate (PO4) as P	mg/L	225		82,3		63%	123,6		94,8		23%	124,7		99,7		20%	196		75,9		61%
Nitrogen (N) Total (Spectroquant M	mg/L	270		210		22%	280		250		11%	280		260		7%	340		300		12%
Fat, Oils & Grease	mg/L	220		2		99%	153		2		99%	153		8		95%	78		20		74%

		Week 18					Week 19					Week 20					Week 21				
		Raw Wastewater		DEGBR (OUT)		Removal	Raw Wastewater		DEGBR (OUT)		Removal	Raw Wastewater		DEGBR (OUT)		Removal	Raw Wastewater		DEGBR (OUT)		Removal
	Units	Lovibond	Waterproof	Lovibond	Waterproof		Lovibond	Waterproof	Lovibond	Waterproof		Lovibond	Waterproof	Lovibond	Waterproof		Lovibond	Waterproof	Lovibond	Waterproof	
pH	-	-	6,25	5,26	7,09		-	6,25	5,07	6,96		-	6,25	5,46	7,24		-	6,25	4,9	7,49	
ORP	mV	547	-	111	-		547	-	108	-		547	-	89	-		547	-	122	-	
DO	mg/L	1	-	0,8	-		1	-	1,1	-		1	-	0,47	-		1	-	0,5	-	
TDS	mg/L / ppm	806ppm	444ppm	269	1,69ppt		806ppm	444ppm	281ppm	1,79ppt		806ppm	444ppm	307ppm	1,96ppt		806ppm	444ppm	291ppm	1,92ppt	
Salinity	ppm	-	436ppm	-	1,76ppt		-	436ppm	-	1,87ppt		-	436ppm	-	2,08ppt		-	436ppm	-	2,02ppt	
Conductivity	µS	-	889	-	3,36mS		-	889	-	3,58mS		-	889	-	3,95mS		-	889	-	3,84mS	
Temp	°C	14,3	25	18,8	25		14,3	25	19	25		14,3	25	21,3	25		14,3	25	25,8	25	
Alkalinity as CaCO3 (Titrando)	mg/L	656		195,1		70%	969		364		62%	969		628		35%	969		628		35%
Ammonia (NH3) as N	mg/L	243		48		80%	273,6		128		53%	273,6		146		47%	273,6		146		47%
Nitrate (NO3) as N	mg/L	<0.18		39		-	<0.18		<0.18		-	<0.18		<0.18		-	<0.18		<0.18		-
Chemical Oxygen Demand (Unfilter	mg/L	7230		727		90%	7230		2450		66%	7230		1630		77%	7230		1630		77%
Suspended Solids	mg/L	345		65		81%	345		193		44%	345		144		58%	345		144		58%
Nitrite (NO2) as N	mg/L	<0.01		4.1		-	<0.01		<0.01		-	<0.01		<0.01		-	<0.01		<0.01		-
Orthophosphate (PO4) as P	mg/L	203,9		82,9		59%	225		140		38%	225		131		42%	225		151		33%
Nitrogen (N) Total (Spectroquant M	mg/L	350		128		63%	360		290		19%	360		310		14%	360		330		8%
Fat, Oils & Grease	mg/L	89		2		98%	89		2		98%	78		3		96%	78		4		95%

RAW- ANOXIC TANK (WEEK 14-21)

		Week 14					Week 15					Week 16					Week 17				
		Raw Wastewater		ANOXIC (OUT)		Removal	Raw Wastewater		ANOXIC (OUT)		Removal	Raw Wastewater		ANOXIC (OUT)		Removal	Raw Wastewater		ANOXIC (OUT)		Removal
	Units	Lovibond	Waterproof	Lovibond	Waterproof		Lovibond	Waterproof	Lovibond	Waterproof		Lovibond	Waterproof	Lovibond	Waterproof		Lovibond	Waterproof	Lovibond	Waterproof	
pH	-	-	6,4	4,94	6,83		-	6,4	4,31	6,44		-	6,4	5,22	7,02		-	6,25	5	6,78	
ORP	mV	456	-	117	-		456	-	159	-		456	-	104	-		547	-	118	-	
DO	mg/L	2	-	3	-		2	-	3	-		2	-	2,7	-		1	-	2,5	-	
TDS	mg/L / ppm	694	368	115,2	796ppm		694	368	135ppm	698ppm		694	368	537pppm	717ppm		806ppm	444ppm	105ppm	740ppm	
Salinity	ppm	-	359	-	800ppm		-	359	-	702ppm		-	359	-	716ppm		-	436ppm	-	642ppm	
Conductivity	µS	-	734	-	1593µS		-	734	-	1,85mS		-	734	-	1434µS		-	889	-	1480µS	
Temp	°C	14,3	25	19,6	25		14,3	25	19,3	25		14,3	25	19,2	25		14,3	25	19,2	25	
Alkalinity as CaCO3 (Titrando)	mg/L	715		110		85%	635		32,2		95%	989		48,8		95%	416		220		47%
Ammonia (NH3) as N	mg/L	214		38,8		82%	176		28,5		84%	223		15,5		93%	235,2		225		4%
Nitrate (NO3) as N	mg/L	<0.18		69,1		-	<0.18		66,7		-	<0.18		52,2		-	<0.18		<0.18		-
Chemical Oxygen Demand (Unfilter	mg/L	6230		497		92%	6230		456		93%	5240		344		93%	7230		3090		57%
Suspended Solids	mg/L	262		18		93%	289		15		95%	262		198		24%	438		174		60%
Nitrite (NO2) as N	mg/L	<0.01		38,2		-	<0.01		5,3		-	<0.01		4,6		-	<0.01		<0,01		-
Orthophosphate (PO4) as P	mg/L	225		76,1		66%	123,6		65,4		47%	124,7		67,7		46%	196		67,5		66%
Nitrogen (N) Total (Spectroquant M	mg/L	270		112		59%	280		124		56%	280		91		68%	340		290		15%
Fat, Oils & Grease	mg/L	220		1		100%	153		1		99%	153		0,99		99%	78		10		87%

		Week 18					Week 19					Week 20					Week 21				
		Raw Wastewater		ANOXIC (OUT)		Removal	Raw Wastewater		ANOXIC (OUT)		Removal	Raw Wastewater		ANOXIC (OUT)		Removal	Raw Wastewater		ANOXIC (OUT)		Removal
	Units	Lovibond	Waterproof	Lovibond	Waterproof		Lovibond	Waterproof	Lovibond	Waterproof		Lovibond	Waterproof	Lovibond	Waterproof		Lovibond	Waterproof	Lovibond	Waterproof	
pH	-	-	6,25	5,57	7,29		-	6,25	5,86	7,62		-	6,25	5,75	7,47		-	6,25	5,94	8,19	
ORP	mV	547	-	88	-		547	-	68	-		547	-	76	-		547	-	66	-	
DO	mg/L	1	-	1,6	-		1	-	1,6	-		1	-	1,13	-		1	-	0,65	-	
TDS	mg/L / ppm	806ppm	444ppm	109	841ppm		806ppm	444ppm	151ppm	1,09ppt		806ppm	444ppm	144ppm			806ppm	444ppm	177ppm	1,34ppt	
Salinity	ppm	-	436ppm	-	849		-	436ppm	-	1,11ppt		-	436ppm	-			-	436ppm	-	1,38ppt	
Conductivity	µS	-	889	-	1689		-	889	-	2,17mS		-	889	-			-	889	-	2,69mS	
Temp	°C	14,3	25	24,1	25		14,3	25	22	25		14,3	25	23,1	25		14,3	25	25,1	25	
Alkalinity as CaCO3 (Titrando)	mg/L	656		129		80%	969		262		73%	969		210		78%	969		210		78%
Ammonia (NH3) as N	mg/L	243		24,9		90%	273,6		47		83%	273,6		41,5		85%	273,6		41,5		85%
Nitrate (NO3) as N	mg/L	<0.18		3,9		-	<0.18		2.9		-	<0.18		4.2		-	<0.18		4.2		-
Chemical Oxygen Demand (Unfilter	mg/L	7230		669		91%	7230		738		90%	7230		590		92%	7230		590		92%
Suspended Solids	mg/L	345		49		86%	345		11		97%	345		41		88%	345		41		88%
Nitrite (NO2) as N	mg/L	<0.01		2.2		-	<0.01		1.9		-	<0.01		1.5		-	<0.01		1.5		-
Orthophosphate (PO4) as P	mg/L	203,9		81,6		60%	225		102		55%	225		98,7		56%	225		98,7		56%
Nitrogen (N) Total (Spectroquant M	mg/L	350		105		70%	360		110		69%	360		132		63%	360		132		63%
Fat, Oils & Grease	mg/L	89		0,98		99%	89		0,92		99%	78		0,9		99%	78		1		99%

RAW-MBR EFFLUENT (WEEK 14-21)

		Week 14					Week 15					Week 16					Week 17				
		Raw Wastewater		MBR (OUT)		Removal	Raw Wastewater		MBR (OUT)		Removal	Raw Wastewater		MBR (OUT)		Removal	Raw Wastewater		MBR (OUT)		Removal
	Units	Lovibond	Waterproof	Lovibond	Waterproof		Lovibond	Waterproof	Lovibond	Waterproof		Lovibond	Waterproof	Lovibond	Waterproof		Lovibond	Waterproof	Lovibond	Waterproof	
pH	-	-	6,4	6,41	7,31		-	6,4	4,48	6,59		-	6,4	5,28	6,91		-	6,25	5,57	7,28	
ORP	mV	456	-	96	-		456	-	146	-		456	-	103	-		547	-	86	-	
DO	mg/L	2	-	3,3	-		2	-	4,03	-		2	-	3,5	-		1	-	2,8	-	
TDS	mg/L / ppm	694	368	113	729ppm		694	368	97ppm	638ppm		694	368	805ppm	666ppm		806ppm	444ppm	111ppm	730ppm	
Salinity	ppm	-	359	-	732ppm		-	359	-	639ppm		-	359	-	661ppm		-	436ppm	-	732ppm	
Conductivity	µS	-	734	-	1500		-	734	-	1289		-	734	-	1323		-	889	-	1467	
Temp	°C	14,3	25	16,7	25		14,3	25	16,3	25		14,3	25	18	25		14,3	25	15,5	25	
Alkalinity as CaCO3 (Titrando)	mg/L	715		96,5		87%	635		27,6		96%	989		44,3		96%	416		168		60%
Ammonia (NH3) as N	mg/L	214		36,7		83%	176		27,3		84%	223		15,9		93%	235,2		34,5		85%
Nitrate (NO3) as N	mg/L	<0.18		70		-	<0.18		66,6		-	<0.18		43,1		-	<0.18		5.4		-
Chemical Oxygen Demand (Unfilter	mg/L	6230		369		94%	6230		291		95%	5240		344		93%	7230		411		94%
Suspended Solids	mg/L	262		4		98%	289		4,5		98%	262		119		55%	438		3		99%
Nitrite (NO2) as N	mg/L	<0.01		43		-	<0.01		6.0		-	<0.01		4.6		-	<0.01		0.84		-
Orthophosphate (PO4) as P	mg/L	225		79,8		65%	123,6		64,5		48%	124,7		67,1		46%	196		65,9		66%
Nitrogen (N) Total (Spectroquant M	mg/L	270		134		50%	280		116		59%	280		97		65%	340		94		72%
Fat, Oils & Grease	mg/L	220		0,35		100%	153		0,2		100%	153		0,6		100%	78		0,92		99%

		Week 18					Week 19					Week 20					Week 21				
		Raw Wastewater		MBR (OUT)		Removal	Raw Wastewater		MBR (OUT)		Removal	Raw Wastewater		MBR (OUT)		Removal	Raw Wastewater		MBR (OUT)		Removal
	Units	Lovibond	Waterproof	Lovibond	Waterproof		Lovibond	Waterproof	Lovibond	Waterproof		Lovibond	Waterproof	Lovibond	Waterproof		Lovibond	Waterproof	Lovibond	Waterproof	
pH	-	-	6,25	5,69	7,38		-	6,25	1,94	7,69		-	6,25	5,22			-	6,25	5,71	8,12	
ORP	mV	547	-	78	-		547	-	67	-		547	-	110			547	-	71	-	
DO	mg/L	1	-	2,4	-		1	-	2,3	-		1	-	2,4			1	-	1,95	-	
TDS	mg/L / ppm	806ppm	444ppm	106ppm	728ppm		806ppm	444ppm	142ppm	conversion		806ppm	444ppm	140ppm	conversion		806ppm	444ppm	163	1,12ppt	
Salinity	ppm	-	436ppm	-	729ppm		-	436ppm	-	conversion		-	436ppm	-	conversion		-	436ppm	-	1,15ppt	
Conductivity	µS	-	889	-	1465		-	889	-	1,84mS		-	889	-	conversion		-	889	-	2,24mS	
Temp	°C	14,3	25	17,4	25		14,3	25		25		14,3	25	19,9			14,3	25	19,8	25	
Alkalinity as CaCO3 (Titrando)	mg/L	656		95,1		86%	969		270		72%	969		63,8		93%	969		387		60%
Ammonia (NH3) as N	mg/L	243		18		93%	273,6		46		83%	273,6		16,8		94%	273,6		61,2		78%
Nitrate (NO3) as N	mg/L	<0.18		39		-	<0.18		4,4		-	<0.18		5,6		-	<0.18		12,3		-
Chemical Oxygen Demand (Unfilter	mg/L	7230		427		94%	7230		577		92%	7230		494		93%	7230		628		91%
Suspended Solids	mg/L	345		3		99%	345		5		99%	345		5		99%	345		5		99%
Nitrite (NO2) as N	mg/L	<0.01		4.1		-	<0.01		2,9		-	<0.01		0,87		-	<0.01		16,9		-
Orthophosphate (PO4) as P	mg/L	203,9		82,9		59%	225		100		56%	225		95,1		58%	225		104		54%
Nitrogen (N) Total (Spectroquant M	mg/L	350		88		75%	360		118		67%	360		115		68%	360		116		68%
Fat, Oils & Grease	mg/L	89		0,62		99%	89		0,5		99%	78		0,35		100%	78		0,25		100%

ANOXIC – MBR EFFLUENT (WEEK 14-21)

		Week 14					Week 15					Week 16					Week 17				
		ANOXIC (IN)		MBR (OUT)		Removal	ANOXIC (IN)		MBR (OUT)		Removal	ANOXIC (IN)		MBR (OUT)		Removal	ANOXIC (IN)		MBR (OUT)		Removal
	Units	Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P	
pH	-	4,94	6,83	6,41	7,31	-	4,31	6,44	4,48	6,59	-	5,22	7,02	5,28	6,91	-	5	6,78	5,57	7,28	-
ORP	mV	117	-	96	-	-	159	-	146	-	-	104	-	103	-	-	118	-	86	-	-
DO	mg/L	3	-	3,3	-	-	3	-	4,03	-	-	2,7	-	3,5	-	-	2,5	-	2,8	-	-
TDS	mg/L / ppm	115,2	796ppm	113	729ppm	-	135ppm	698ppm	97ppm	638ppm	-	537pppm	717ppm	805ppm	666ppm	-	105ppm	740ppm	111ppm	730ppm	-
Salinity	ppm	-	800ppm	-	732ppm	-	-	702ppm	-	639ppm	-	-	716ppm	-	661ppm	-	-	642ppm	-	732ppm	-
Conductivity	µs	-	1593	-	1500	-	-	1,85mS	-	1289	-	-	1434	-	1323	-	-	1480	-	1467	-
Temp	˚C	19,6	25	16,7	25	-	19,3	25	16,3	25	-	19,2	25	18	25	-	19,2	25	15,5	25	-
Alkalinity as CaCO3	mg/L	110		96,5		12%	32,2		27,6		14%	48,8		44,3		9%	220		168		24%
Ammonia (NH3) as N	mg/L	38,8		36,7		5%	28,5		27,3		4%	15,5		15,9		-3%	225		34,5		85%
Nitrate (NO3) as N	mg/L	69,1		70		-	66,7		66,6		-	52,2		43,1		-	<0.18		5.4		-
Chemical Oxygen Demand	mg/L	497		369		26%	456		291		36%	662		344		48%	3090		411		87%
Suspended Solids	mg/L	18		4		78%	15		4,5		70%	198		119		40%	174		3		98%
Nitrite (NO2) as N	mg/L	38,2		43		-	5,3		6.0		-	4.6		4.6		-	<0,01		0.84		-
Orthophosphate	mg/L	76,1		79,8		-5%	65,4		64,5		1%	67,7		67,1		1%	67,5		65,9		2%
Nitrogen (N) Total	mg/L	112		134		-20%	124		116		6%	91		97		-7%	290		94		68%
Fat, Oils & Grease	mg/L	1		0,35		65%	1		0,2		80%	0,99		0,6		39%	10		0,92		91%

		Week 18					Week 19					Week 20					Week 21				
		ANOXIC (IN)		MBR (OUT)		Removal	ANOXIC (IN)		MBR (OUT)		Removal	ANOXIC (IN)		MBR (OUT)		Removal	ANOXIC (IN)		MBR (OUT)		Removal
	Units	Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P	
pH	-	5,57	7,29	5,69	7,38	-	5,86	7,62	1,94	7,69	-	5,75	7,47	5,22		-	5,94	8,19	5,71	8,12	-
ORP	mV	88	-	78	-	-	68	-	67	-	-	76	-	110		-	66	-	71	-	-
DO	mg/L	1,6	-	2,4	-	-	1,6	-	2,3	-	-	1,13	-	2,4		-	0,65	-	1,95	-	-
TDS	mg/L / ppm	109	841ppm	106ppm	728ppm	-	151ppm	1,09ppt	142ppm	conversion	-	144ppm	conversion	140ppm	conversion	-	177ppm	1,34ppt	163	1,12ppt	-
Salinity	ppm	-	849	-	729ppm	-	-	1,11ppt	-	conversion	-	-	conversion	-	conversion	-	-	1,38ppt	-	1,15ppt	-
Conductivity	µs	-	1689	-	1465	-	-	2,17mS	-	1,84mS	-	-	conversion	-	conversion	-	-	2,69mS	-	2,24mS	-
Temp	˚C	24,1	25	17,4	25	-	22	25		25	-	23,1	25	19,9		-	25,1	25	19,8	25	-
Alkalinity as CaCO3	mg/L	129		95,1		26%	262		270		-3%	210		63,8		70%	578		387		33%
Ammonia (NH3) as N	mg/L	24,9		18		28%	47		46		2%	41,5		16,8		60%	92,6		61,2		34%
Nitrate (NO3) as N	mg/L	3,9		39		-	2,9		4,4		-	4,2		5,6		-	0.73		12,3		-
Chemical Oxygen Demand	mg/L	669		427		36%	738		577		22%	590		494		16%	654		628		4%
Suspended Solids	mg/L	49		3		94%	11		5		55%	41		5		88%	5		5		0%
Nitrite (NO2) as N	mg/L	2.2		4.1		-	1,9		2,9		-	1,5		0,87		-	0,86		16,9		-
Orthophosphate	mg/L	81,6		82,9		-2%	102		100		2%	98,7		95,1		4%	97,5		104		-7%
Nitrogen (N) Total	mg/L	105		88		16%	110		118		-7%	132		115		13%	120		116		3%
Fat, Oils & Grease	mg/L	0,98		0,62		37%	0,92		0,5		46%	0,9		0,35		61%	1		0,25		75%

DEGBR- ANOXIC TANK (WEEK 14-21)

		Week 14					Week 15					Week 16					Week 17				
		DEGBR (IN)		ANOXIC (OUT)		Removal	DEGBR (IN)		ANOXIC (OUT)		Removal	DEGBR (IN)		ANOXIC (OUT)		Removal	DEGBR (IN)		ANOXIC (OUT)		Removal
	Units	Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P	
pH	-	4,37	6,41	4,94	6,83	-	4,7	6,9	4,31	6,44	-	4,92	7,08	5,22	7,02	-	5,19	6,96	5	6,78	-
ORP	mV	153	-	117	-	-	135	-	159	-	-	121	-	104	-	-	105	-	118	-	-
DO	mg/L	0,5	-	3	-	-	0,7	-	3	-	-	1	-	2,7	-	-	0,8	-	2,5	-	-
TDS	mg/L / ppm	170ppm	1,12ppt	115,2	796ppm	-	206ppm	1,32ppt	135ppm	698ppm	-	217mS	1,39ppt	537pppm	717ppm	-	269	1,65ppt	105ppm	740ppm	-
Salinity	ppm	-	1,13ppt	-	800ppm	-	-	1,36ppt	-	702ppm	-	-	1,44ppt	-	716ppm	-	-	1,73ppt	-	642ppm	-
Conductivity	µs	-	2,23mS	-	1593µS	-	-	2,62mS	-	1,85mS	-	-	2,78mS	-	1434µS	-	-	3,23mS	-	1480µS	-
Temp	˚C	18,2	25	19,6	25	-	17,9	25	19,3	25	-	17,5	25	19,2	25	-	17	25	19,2	25	-
Alkalinity as CaCO3	mg/L	381		110		71%	475		32,2		93%	947		48,8		95%	222		220		1%
Ammonia (NH3) as N	mg/L	103		38,8		62%	124		28,5		77%	158		15,5		90%	234		225		4%
Nitrate (NO3) as N	mg/L	<0.18		69,1		-	<0.18		66,7		-	<0.18		52,2		-	5.7		<0.18		-
Chemical Oxygen Demand	mg/L	2570		497		81%	1690		456		73%	1950		344		82%	4050		3090		24%
Suspended Solids	mg/L	216		18		92%	170		15		91%	247		198		20%	249		174		30%
Nitrite (NO2) as N	mg/L	<0.01		38,2		-	<0.01		5,3		-	<0.01		4,6		-	0.83		<0,01		-
Orthophosphate (PO4) as P	mg/L	82,3		76,1		8%	94,8		65,4		31%	99,7		67,7		32%	75,9		67,5		11%
Nitrogen (N) Total	mg/L	210		112		47%	250		124		50%	260		91		65%	300		290		3%
Fat, Oils & Grease	mg/L	2		1		50%	2		1		50%	8		0,99		88%	20		10		50%

		Week 18					Week 19					Week 20					Week 21				
		DEGBR (IN)		ANOXIC (OUT)		Removal	DEGBR (IN)		ANOXIC (OUT)		Removal	DEGBR (IN)		ANOXIC (OUT)		Removal	DEGBR (IN)		ANOXIC (OUT)		Removal
	Units	Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P	
pH	-	5,26	7,09	5,57	7,29	-	5,07	6,96	5,86	7,62	-	5,46	7,24	5,75	7,47	-	4,9	7,49	5,94	8,19	-
ORP	mV	111	-	88	-	-	108	-	68	-	-	89	-	76	-	-	122	-	66	-	-
DO	mg/L	0,8	-	1,6	-	-	1,1	-	1,6	-	-	0,47	-	1,13	-	-	0,5	-	0,65	-	-
TDS	mg/L / ppm	269	1,69ppt	109	841ppm	-	281ppm	1,79ppt	151ppm	1,09ppt	-	307ppm	1,96ppt	144ppm		-	291ppm	1,92ppt	177ppm	1,34ppt	-
Salinity	ppm	-	1,76ppt	-	849	-	-	1,87ppt	-	1,11ppt	-	-	2,08ppt	-		-	-	2,02ppt	-	1,38ppt	-
Conductivity	µs	-	3,36mS	-	1689	-	-	3,58mS	-	2,17mS	-	-	3,95mS	-		-	-	3,84mS	-	2,69mS	-
Temp	˚C	18,8	25	24,1	25	-	19	25	22	25	-	21,3	25	23,1	25	-	25,8	25	25,1	25	-
Alkalinity as CaCO3	mg/L	195,1		129		34%	364		262		28%	628		210		67%	628		210		67%
Ammonia (NH3) as N	mg/L	48		24,9		48%	128		47		63%	146		41,5		72%	146		41,5		72%
Nitrate (NO3) as N	mg/L	39		3,9		-	<0.18		2.9		-	<0.18		4.2		-	<0.18		4.2		-
Chemical Oxygen Demand	mg/L	727		669		8%	2450		738		70%	1630		590		64%	1630		590		64%
Suspended Solids	mg/L	65		49		25%	193		11		94%	144		41		72%	144		41		72%
Nitrite (NO2) as N	mg/L	4.1		2.2		-	<0.01		1.9		-	<0.01		1.5		-	<0.01		1.5		-
Orthophosphate (PO4) as P	mg/L	82,9		81,6		2%	144		102		29%	151		98,7		35%	151		98,7		35%
Nitrogen (N) Total	mg/L	128		105		18%	290		110		62%	330		132		60%	330		132		60%
Fat, Oils & Grease	mg/L	2		0,98		51%	20		0,92		95%	3		0,9		70%	4		1		75%

FEED TANK – DEGBR EFFLUENT (WEEKS 1-21)

		Week 1					Week 2					Week 3					Week 4					Week 5					Week 6					Week 7				
		Feed Tank (IN)		DEGBR (OUT)		Removal	Feed Tank (IN)		DEGBR (OUT)		Removal	Feed Tank (IN)		DEGBR (OUT)		Removal	Feed Tank (IN)		DEGBR (OUT)		Removal	Feed Tank (IN)		DEGBR (OUT)		Removal	Feed Tank (IN)		DEGBR (OUT)		Removal	Feed Tank (IN)		DEGBR (OUT)		Removal
	Units	Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P	
pH	-	-	6,78	-	6,89	-	-	5,96	-	6,33	-	-	6,22	-	6,18	-	-	5,85	-	6,21	-	-	5,64	-	5,97	-	0,925	5,42	0,32	6,05	-	0,48	5,52	1,56	6,42	-
ORP	mV	448	-	491	-	-	578	-	584	-	-	558	-	589	-	-	596	-	575	-	-	488	-	419	-	-	440,5	-	389	-	-	355	-	269	-	-
DO	mg/L	1,6	-	2	-	-	1,2	-	1,8	-	-	2,2	-	2,5	-	-	2,2	-	2,5	-	-	1,2	-	2,8	-	-	1,55	-	1,97	-	-	0,77	-	2,07	-	-
TDS	(mg/L) / ppm	159 (ppm)	894	164ppm	924ppm	-	164 (ppm)	917	166ppm	914ppm	-	143 (ppm)	791	144ppm	831ppm	-	171 (ppm)	957	177ppm	997ppm	-	190 (ppm)	1,2 ppt	207ppm	1,33ppt	-	205 ppm	1,29ppt	210ppm	1,4ppt	-	206 ppm	1,37ppt	215	1,44ppt	-
Salinity	ppm	-	907	-	936	-	-	930	-	927ppm	-	-	795	-	838	-	-	971	-	1,01ppt	-	-	1,24 ppt	-	1,37ppt	-	-	1,,40ppt	-	1,46ppt	-	-	1,41ppt	-	1,49ppt	-
Conductivity	µs	-	1799	-	1844	-	-	1832	-	1827	-	-	1582	-	1661	-	-	1914	-	1996	-	-	2,4 mS	-	2,65mS	-	-	2,59mS	-	2,81mS	-	-	2,73mS	-	2,87mS	-
Temp	°C	13,6	25	12,5	25	-	12,6	25	13	25	-	13,2	25	13,8	25	-	14	25	13,3	25	-	18	25	19	25	-	17,8	25	17,4	25	-	18,6	25	18,03	25	-
Alkalinity as CaCO3	mg/L	549		419		24%	536		538		0%	464		429		8%	550		495		10%	605		543		10%	628		612		3%	653		616		6%
Ammonia (NH3) as N	mg/L	131		129		2%	126		116		8%	121		120		1%	141		134		5%	144		122		15%	156		126		19%	227		185		19%
Nitrate (NO3) as N	mg/L	<0,18		<0,18		-	<0,18		<0,18		-	<0,18		<0,18		-	<0.18		<0.18		-	<0.18		<0.18		-	<0.18		<0.18		-	<0.18		<0.18		-
Chemical Oxygen Demand	mg/L	1650		1300		21%	3110		2300		26%	2730		2420		11%	2750		2200		20%	3680		2820		23%	3990		3280		18%	4400		3190		28%
Suspended Solids	mg/L	179		13		93%	106		69		35%	111		88		21%	159		64		60%	343		129		62%	251		166		34%	311		180		42%
Nitrite (NO2) as N	mg/L	<0,03		<0,03		-	<0,,3		<0,03		-	<0,03		<0,13		-	<0.01		<0.01		-	<0.01		<0.01		-	<0.01		<0.01		-	<0.01		<0.01		-
Orthophosphate (PO4) as P	mg/L	46,9		42,4		10%	63,1		59,8		5%	58,5		56,2		4%	77,1		72,9		5%	90,8		90		1%	98,8		96,4		2%	98,3		97,8		1%
Nitrogen (N) Total	mg/L	180		170		6%	190		170		11%	170		170		0%	190		170		11%	200		190		5%	250		230		8%	280		240		14%
Fat, Oils & Grease	mg/L	10		0,83		92%	2		0,81		60%	0,9		0,86		4%	4		0,7		83%	2		0,5		75%	66		12		82%	148		18		88%

		Week 8					Week 9					Week 10					Week 11					Week 12					Week 13					Week 14				
		Feed Tank (IN)		DEGBR (OUT)		Removal	Feed Tank (IN)		DEGBR (OUT)		Removal	Feed Tank (IN)		DEGBR (OUT)		Removal	Feed Tank (IN)		DEGBR (OUT)		Removal	Feed Tank (IN)		DEGBR (OUT)		Removal	Feed Tank (IN)		DEGBR (OUT)		Removal	Feed Tank (IN)		DEGBR (OUT)		Removal
	Units	Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P	
pH	-	1,88	5,83	2,87	6,55	-	2,06	5,86	2,99	6,63	-	2,29	6,27	2,74	6,6	-	2,92	6,24	3,75	6,97	-	3,6	6,34	4,33	7,19	-	4,23	6,51	4,92	7,36	-	2,83	5,17	4,37	6,41	-
ORP	mV	288	-	236	-	-	282	-	235mV	-	-	260mV	-	164	-	-	227	-	189	-	-	195	-	154	-	-	162	-	122	-	-	231	-	153	-	-
DO	mg/L	0,5	-	0,27	-	-	0,4	-	0,1	-	-	1,3	-	0,53	-	-	1,23	-	0,53	-	-	0,77	-	1	-	-	0,57	-	0,53	-	-	0,6	-	0,5	-	-
TDS	(mg/L) / ppm	192 ppm	1,21ppt	203ppm	1,33ppt	-	181ppm	1,12ppt	195ppm	1,25ppt	-	193ppm	1,16ppt	206ppm	1,22ppt	-	192ppm	1,18ppt	207	1,33ppt	-	195ppm	1,19ppt	214ppm	1,32ppt	-	194ppm	1,24ppt	241ppm	1,56ppt	-	140ppm	864ppm	170ppm	1,12ppt	-
Salinity	ppm	-	1,24ppt	-	1,38ppt	-	-	1,14ppt	-	1,29ppt	-	-	1,17ppt	-	1,26ppt	-	-	1,21ppt	-	1,38ppt	-	-	1,22ppt	-	1,38	-	-	1,28ppt	-	1,62ppt	-	-	878ppm	-	1,13ppt	-
Conductivity	µS	-	2,42mS	-	2,65mS	-	-	2,22mS	-	2,51mS	-	-	2,17mS	-	2,42mS	-	-	2,35mS	-	2,67mS	-	-	2,37mS	-	2,55mS	-	-	2,48mS	-	3,12mS	-	-	1731	-	2,23mS	-
Temp	°C	16	25	17	25	-	17,2	25	18	25	-	15,9	25	16,1	25	-	15,8	25	18,9	25	-	16,23	25	17,5	25	-	18,03	25	19	25	-	15,5	25	18,2	25	-
Alkalinity as CaCO3	mg/L	626		593		5%	632		602		5%	713		648		9%	695		635		9%	788		664		16%	732		650		11%	433		381		12%
Ammonia (NH3) as N	mg/L	200		188		6%	195		178		9%	199		197		1%	229		196		14%	230		223		3%	179		168		6%	115		103		10%
Nitrate (NO3) as N	mg/L	<0.18		<0.18		-	<0.18		<0.18		-	<0.18		<0.18		-	<0.18		<0.18		-	<0.18		<0.18		-	<0.18		<0.18		-	<0.18		<0.18		-
Chemical Oxygen Demand	mg/L	4400		3090		30%	3700		2210		40%	3280		2630		20%	3240		1800		44%	3420		1880		45%	2800		1460		48%	3310		2570		22%
Suspended Solids	mg/L	256		164		36%	195		155		21%	155		139		10%	204		100		51%	236		141		40%	84		80		5%	250		216		14%
Nitrite (NO2) as N	mg/L	<0.01		<0.01		-	<0.01		<0.01		-	<0.01		<0.01		-	<0.01		<0.01		-	<0.01		<0.01		-	<0.01		<0.01		-	<0.01		<0.01		-
Orthophosphate (PO4) as P	mg/L	114		101		11%	94,6		93,5		1%	104		97,1		7%	95,6		94,5		1%	97,1		97,2		0%	90,6		78,6		13%	88,2		82,3		7%
Nitrogen (N) Total	mg/L	260		250		4%	250		210		16%	250		240		4%	264		240		9%	290		260		10%	230		210		9%	210		210		0%
Fat, Oils & Grease	mg/L	6		4		33%	12		3		75%	5		2		60%	66		12		82%	10		3		70%	15		9		40%	10		2		80%

		Week 15					Week 16					Week 17					Week 18				
		Feed Tank (IN)		DEGBR (OUT)		Removal	Feed Tank (IN)		DEGBR (OUT)		Removal	Feed Tank (IN)		DEGBR (OUT)		Removal	Feed Tank (IN)		DEGBR (OUT)		Removal
	Units	Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P	
pH	-	3,01	5,58	4,7	6,9	-	4,1	5,77	4,92	7,08	-	3,66	5,49	5,19	6,96	-	3,67	5,49	5,26	7,09	-
ORP	mV	228	-	135	-	-	169	-	121	-	-	191	-	105	-	-	193	-	111	-	-
DO	mg/L	0,8	-	0,7	-	-	0,45	-	1	-	-	1,2	-	0,8	-	-	1,03	-	0,8	-	-
TDS	(mg/L) / ppm	172ppm	1,04ppt	206ppm	1,32ppt	-	144,5	1,18ppt	217mS	1,39ppt	-	241ppm	1,43ppt	269	1,65ppt	-	255ppm	1,64ppt	269	1,69ppt	-
Salinity	ppm	-	1,05ppt	-	1,36ppt	-	-	1,21ppt	-	1,44ppt	-	-	1,5ppt	-	1,73ppt	-	-	1,71ppt	-	1,76ppt	-
Conductivity	µS	-	2,07mS	-	2,62mS	-	-	2,36mS	-	2,78mS	-	-	2,86mS	-	3,23mS	-	-	3,23mS	-	3,36mS	-
Temp	℃	13,9	25	17,9	25	-	16,5	25	17,5	25	-	14	25	17	25	-	16,9	25	18,8	25	-
Alkalinity as CaCO3	mg/L	537		475		12%	623		947		-52%	264		222		16%	634		195,1		69%
Ammonia (NH3) as N	mg/L	135		124		8%	163		158		3%	167		34		80%	198		48		76%
Nitrate (NO3) as N	mg/L	<0.18		<0.18		-	<0.18		<0.18		-	<0.18		5.7		-	<0.18		39		-
Chemical Oxygen Demand	mg/L	4150		1690		59%	4180		1950		53%	6570		405		94%	6010		727		88%
Suspended Solids	mg/L	282		170		40%	254		247		3%	344		249		28%	279		65		77%
Nitrite (NO2) as N	mg/L	<0.01		<0.01		-	<0.01		<0.01		-	<0.01		0.83		-	<0.01		4.1		-
Orthophosphate (PO4) as P	mg/L	106		94,8		11%	112		99,7		11%	150		75,9		49%	151		82,9		45%
Nitrogen (N) Total	mg/L	250		250		0%	270		260		4%	330		300		9%	330		128		61%
Fat, Oils & Grease	mg/L	144		2		99%	140		8		94%	66		20		70%	4		2		50%

		Week 19					Week 20					Week 21				
		Feed Tank (IN)		DEGBR (OUT)		Removal	Feed Tank (IN)		DEGBR (OUT)		Removal	Feed Tank (IN)		DEGBR (OUT)		Removal
	Units	Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P	
pH	-	3,77	5,56	5,07	6,96	-	3,94	5,93	5,46	7,24	-	3,69	5,86	4,9	7,49	-
ORP	mV	187	-	108	-	-	180	-	89	-	-	195	-	122	-	-
DO	mg/L	1,3	-	1,1	-	-	1,03	-	0,47	-	-	1	-	0,5	-	-
TDS	(mg/L) / ppm	258ppm	1,64ppt	281ppm	1,79ppt	-	270ppm	1,77ppt	307ppm	1,96ppt	-	254ppm	1,67ppt	291ppm	1,92ppt	-
Salinity	ppm	-	1,7ppt	-	1,87ppt	-	-	1,87ppt	-	2,08ppt	-	-	1,74ppt	-	2,02ppt	-
Conductivity	µS	-	3,23mS	-	3,58mS	-	-	3,52mS	-	3,95mS	-	-	3,34mS	-	3,84mS	-
Temp	℃	16,5	25	19	25	-	20,6	25	21,3	25	-	21,7	25	25,8	25	-
Alkalinity as CaCO3	mg/L	563		364		35%	826		628		24%	706		628		11%
Ammonia (NH3) as N	mg/L	169		128		24%	197		146		26%	161		146		9%
Nitrate (NO3) as N	mg/L	<0.18		<0.18		-	<0.18		<0.18		-	<0.18		<0.18		-
Chemical Oxygen Demand	mg/L	3770		2450		35%	5370		1630		70%	4240		1630		62%
Suspended Solids	mg/L	210		193		8%	221		144		35%	195		144		26%
Nitrite (NO2) as N	mg/L	<0.01		<0.01		-	<0.01		<0.01		-	<0.01		<0.01		-
Orthophosphate (PO4) as P	mg/L	143		140		2%	140		131		6%	155		151		3%
Nitrogen (N) Total	mg/L	300		290		3%	320		310		3%	280		330		-18%
Fat, Oils & Grease	mg/L	4		2		50%	14		3		79%	10		4		60%

RAW- PRETREATMENT STAGE (WEEK 1-14)

		Week 1					Week 2					Week 3					Week 4				
		Raw Wastewater		Feed Tank		Removal	Raw Wastewater		Feed Tank		Removal	Raw Wastewater		Feed Tank		Removal	Raw Wastewater		Feed Tank		Removal
	Units	Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P	
pH	-	-	6,62	-	6,78	-	-	6,62	-	5,96	-	-	6,62	-	6,22	-	-	6,62	-	5,85	-
ORP	mV	524	-	448	-	-	524	-	578	-	-	524	-	558	-	-	524	-	596	-	-
DO	mg/L	1,6	-	1,6	-	-	1,6	-	1,2	-	-	1,6	-	2,2	-	-	1,6	-	2,2	-	-
TDS	mg/L / ppm	85ppm	521ppm	159 (ppm)	894	-	85ppm	521ppm	164 (ppm)	917	-	85ppm	521ppm	143 (ppm)	791	-	85ppm	521ppm	171 (ppm)	957	-
Salinity	ppm	-	506ppm	-	907	-	-	506ppm	-	930	-	-	506ppm	-	795	-	-	506ppm	-	971	-
Conductivity	µs	-	1046	-	1799	-	-	1046	-	1832	-	-	1046	-	1582	-	-	1046	-	1914	-
Temp	℃	13,7	25	13,6	25	-	13,7	25	12,6	25	-	13,7	25	13,2	25	-	13,7	25	14	25	-
Alkalinity as CaCO3	mg/L	698		549		21%	650		536		18%	620		464		25%	798		550		31%
Ammonia (NH3) as N	mg/L	232		131		44%	180		126		30%	196		121		38%	204		141		31%
Nitrate (NO3) as N	mg/L	<0,18		<0,18		-	<0,18		<0,18		-	<0,18		<0,18		-	<0,18		<0.18		-
Chemical Oxygen Demand	mg/L	2320		1 650		29%	6230		3110		50%	6230		2730		56%	6230		2750		56%
Suspended Solids	mg/L	317		179		44%	456		106		77%	456		111		76%	456		159		65%
Nitrite (NO2) as N	mg/L	<0,03		<0,03		-	<0,03		<0,,3		-	<0,03		<0,03		-	<0,03		<0.01		-
Orthophosphate (PO4) as P	mg/L	94,8		46,9		51%	102		63,1		38%	98		58,5		40%	92,5		77,1		17%
Nitrogen (N) Total	mg/L	292		180		38%	210		190		10%	210		170		19%	210		190		10%
Fat, Oils & Grease	mg/L	28		10		64%	78		2		97%	78		0,9		99%	78		4		95%

		Week 5					Week 6					Week 7				
		Raw Wastewater		Feed Tank		Removal	Raw Wastewater		Feed Tank		Removal	Raw Wastewater		Pretreatment		Removal
	Units	Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P	
pH	-	-	6,62	-	5,64	-	-	6,53	0,925	5,42	-	-	6,53	0,48	5,52	-
ORP	mV	524	-	488	-	-	483	-	440,5	-	-	483	-	355	-	-
DO	mg/L	1,6	-	1,2	-	-	2,1	-	1,55	-	-	2,1	-	0,77	-	-
TDS	mg/L / ppm	85ppm	521ppm	190 (ppm)	1,2 ppt	-	86ppm	548ppm	205 ppm	1,29ppt	-	86ppm	548ppm	206 ppm	1,37ppt	-
Salinity	ppm	-	506ppm	-	1,24 ppt	-	-	543ppm	-	1,,40ppt	-	-	543ppm	-	1,41ppt	-
Conductivity	µs	-	1046	-	2,4 mS	-	-	1086	-	2,59mS	-	-	1086	-	2,73mS	-
Temp	℃	13,7	25	18	25	-	14,1	25	17,8	25	-	14,1	25	18,6	25	-
Alkalinity as CaCO3	mg/L	702		605		14%	788		628		20%	802		653		19%
Ammonia (NH3) as N	mg/L	198		144		27%	221		156		29%	256		227		11%
Nitrate (NO3) as N	mg/L	<0,18		<0.18		-	<0,18		<0.18		-	<0,18		<0.18		-
Chemical Oxygen Demand	mg/L	6230		3680		41%	6230		3990		36%	6230		4400		29%
Suspended Solids	mg/L	456		343		25%	456		251		45%	456		311		32%
Nitrite (NO2) as N	mg/L	<0,03		<0.01		-	<0,03		<0.01		-	<0,03		<0.01		-
Orthophosphate (PO4) as P	mg/L	125,8		90,8		28%	136,4		98,8		28%	138,2		98,3		29%
Nitrogen (N) Total	mg/L	210		200		5%	270		250		7%	290		280		3%
Fat, Oils & Grease	mg/L	78		2		97%	78		66		15%	153		148		3%

		Week 8					Week 9					Week 10					Week 11					Week 12					Week 13					Week 14				
		Raw Wastewater		Feed Tank		Removal	Raw Wastewater		Feed Tank		Removal	Raw Wastewater		Feed Tank		Removal	Raw Wastewater		Feed Tank		Removal	Raw Wastewater		Feed Tank		Removal	Raw Wastewater		Feed Tank		Removal	Raw Wastewater		Feed Tank		Removal
	Units	Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P	
pH	-	-	6,53	1,88	5,83	-	-	6,53	2,06	6,63	-	-	6,53	2,29	6,27	-	-	6,53	2,92	6,24	-	-	6,4	3,6	6,34	-	-	6,4	4,23	6,51	-	-	6,4	2,83	5,17	-
ORP	mV	483	-	288	-	-	483	-	282	-	-	483	-	260mV	-	-	483	-	227	-	-	456	-	195	-	-	456	-	162	-	-	456	-	231	-	-
DO	mg/L	2,1	-	0,5	-	-	2,1	-	0,4	-	-	2,1	-	1,3	-	-	2,1	-	1,23	-	-	2	-	0,77	-	-	2	-	0,57	-	-	2	-	0,6	-	-
TDS	(mg/L) / ppm	86ppm	548ppm	192 ppm	1,21ppt	-	86ppm	548ppm	181ppm	1,25ppt	-	86ppm	548ppm	193ppm	1,16ppt	-	86ppm	548ppm	192ppm	1,18ppt	-	694	368	195ppm	1,19ppt	-	694	368	194ppm	1,24ppt	-	694	368	140ppm	864ppm	-
Salinity	ppm	-	543ppm	-	1,24	-	-	543ppm	-	1,29ppt	-	-	543ppm	-	1,17ppt	-	-	543ppm	-	1,21ppt	-	-	359	-	1,22ppt	-	-	359	-	1,28ppt	-	-	359	-	878ppm	-
Conductivity	µS	-	1086	-	2,42mS	-	-	1086	-	2,51ms	-	-	1086	-	2,17mS	-	-	1086	-	2,35mS	-	-	734	-	2,37mS	-	-	734	-	2,48mS	-	-	734	-	1731	-
Temp	℃	14,1	25	16	25	-	14,1	25	17,2	25	-	14,1	25	15,9	25	-	14,1	25	15,8	25	-	14,3	25	16,23	25	-	14,3	25	18,03	25	-	14,3	25	15,5	25	-
Alkalinity as CaCO3	mg/L	802		626		22%	802		632		21%	802		713		11%	843		695		18%	843		788		7%	815		732		10%	715		433		39%
Ammonia (NH3) as N	mg/L	256		200		22%	256		195		24%	256		199		22%	242		229		5%	242		230		5%	248		179		28%	214		115		46%
Nitrate (NO3) as N	mg/L	<0,18		<0.18		-	<0,18		<0.18		-	<0,18		<0.18		-	<0.18		<0.18		-	<0.18		<0.18		-	<0.18		<0.18		-	<0.18		<0.18		-
Chemical Oxygen Demand	mg/L	6230		4400		29%	6230		3700		41%	6230		3280		47%	4560		3240		29%	4560		3420		25%	3460		2800		19%	6230		3310		47%
Suspended Solids	mg/L	456		256		44%	456		195		57%	456		155		66%	327		204		38%	327		236		28%	262		84		68%	262		250		5%
Nitrite (NO2) as N	mg/L	<0,03		<0.01		-	<0,03		<0.01		-	<0,03		<0,01		-	<0.01		<0.01		-	<0.01		<0.01		-	<0.01		<0.01		-	<0.01		<0.01		-
Orthophosphate (PO4) as P	mg/L	138,2		114		18%	138,2		94		32%	138,2		104		25%	135,4		95,6		29%	135,4		97,1		28%	127,2		90,6		29%	225		88,2		61%
Nitrogen (N) Total	mg/L	290		260		10%	290		250		14%	290		250		14%	330		264		20%	330		290		12%	270		230		15%	270		210		22%
Fat, Oils & Grease	mg/L	153		6		96%	153		12		92%	153		5		97%	78		66		15%	78		10		87%	200		15		93%	220		10		95%

		Week 15					Week 16					Week 17					Week 18					Week 19					Week 20					Week 21				
		Raw Wastewater		Feed Tank		Removal	Raw Wastewater		Feed Tank		Removal	Raw Wastewater		Feed Tank		Removal	Raw Wastewater		Feed Tank		Removal	Raw Wastewater		Feed Tank		Removal	Raw Wastewater		Feed Tank		Removal	Raw Wastewater		Feed Tank		Removal
	Units	Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P		Lovi	W.P	Lovi	W.P	
pH	-	-	6,4	3,01	5,58	-	-	6,4	4,1	5,77	-	-	6,25	3,66	5,49	-	-	6,25	3,67	5,49	-	-	6,25	3,77	5,56	-	-	6,25	3,94	5,93	-	-	6,25	3,69	5,86	-
ORP	mV	456	-	228	-	-	456	-	169	-	-	547	-	191	-	-	547	-	193	-	-	547	-	187	-	-	547	-	180	-	-	547	-	195	-	-
DO	mg/L	2	-	0,8	-	-	2	-	0,45	-	-	1	-	1,2	-	-	1	-	1,03	-	-	1	-	1,3	-	-	1	-	1,03	-	-	1	-	1	-	-
TDS	(mg/L) / ppm	694	368	172ppm	1,04ppt	-	694	368	144,5	1,18ppt	-	806ppm	444ppm	241ppm	1,43ppt	-	806ppm	444ppm	255ppm	1,64ppt	-	806ppm	444ppm	258ppm	1,64ppt	-	806ppm	444ppm	270ppm	1,77ppt	-	806ppm	444ppm	254ppm	1,67ppt	-
Salinity	ppm	-	359	-	1,05ppt	-	-	359	-	1,21ppt	-	-	436ppm	-	1,5ppt	-	-	436ppm	-	1,71ppt	-	-	436ppm	-	1,7ppt	-	-	436ppm	-	1,87ppt	-	-	436ppm	-	1,74	-
Conductivity	µS	-	734	-	2,07mS	-	-	734	-	2,36mS	-	-	889	-	2,86mS	-	-	889	-	3,23mS	-	-	889	-	3,23mS	-	-	889	-	3,52mS	-	-	889	-	3,34mS	-
Temp	℃	14,3	25	13,9	25	-	14,3	25	16,5	25	-	14,3	25	14	25	-	14,3	25	16,9	25	-	14,3	25	16,5	25	-	14,3	25	20,6	25	-	14,3	25	21,7	25	-
Alkalinity as CaCO3	mg/L	635		537		15%	989		623		37%	416		264		37%	656		634		3%	969		563		42%	969		826		15%	969		706		27%
Ammonia (NH3) as N	mg/L	176		135		23%	223		163		27%	235,2		167		29%	243		198		19%	273,6		169		38%	273,6		197		28%	273,6		161		41%
Nitrate (NO3) as N	mg/L	<0.18		<0.18		-	<0.18		<0.18		-	<0.18		<0.18		-	<0.18		<0.18		-	<0.18		<0.18		-	<0.18		<0.18		-	<0.18		<0.18		-
Chemical Oxygen Demand	mg/L	6230		4150		33%	5240		4180		20%	7230		6570		9%	7230		6010		17%	7230		3770		48%	7230		5370		26%	7230		4240		41%
Suspended Solids	mg/L	289		282		2%	262		254		3%	438		344		21%	345		279		19%	345		210		39%	345		221		36%	345		195		43%
Nitrite (NO2) as N	mg/L	<0.01		<0.01		-	<0.01		<0.01		-	<0.01		<0.01		-	<0.01		<0.01		-	<0.01		<0.01		-	<0.01		<0.01		-	<0.01		<0.01		-
Orthophosphate (PO4) as P	mg/L	123,6		106		14%	124,7		112		10%	196		150		23%	203,9		151		26%	225		143		36%	225		140		38%	225		155		31%
Nitrogen (N) Total	mg/L	280		250		11%	280		270		4%	340		330		3%	350		330		6%	360		300		17%	360		320		11%	360		280		22%
Fat, Oils & Grease	mg/L	153		144		6%	153		140		8%	78		66		15%	89		4		96%	89		4		96%	78		14		82%	78		10		87%