Optimizing of Anaerobic Dynamic Membrane Bio-Reactors for the Production of Nutrient-Rich and Pathogen-Free Irrigation Water from Treated Sewage for Reuse

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COMMITTEE DECISION

Optimizing of Anaerobic Dynamic Membrane Bio-Reactors for the Production of Nutrient-Rich and Pathogen-Free Irrigation Water from Treated Sewage for Reuse

تحديد ظروف التشغيل المثلى للمفاعلات الحيوية الغشائية الديناميكية اللاهوائية المعالجة لمياه الصرف الصحي من أجل إنتاج مياه صالحة لري المزروعات غنية بالعناصر المسمدة وخالية من الكائنات الحية المسببة للأمراض

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This thesis was prepared under the main supervision of Prof. Dr. Nidal Mahmoud and has been approved by all members of the examination committee.

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The findings, interpretations, and conclusions expressed in this study don't necessarily express the views of Birzeit University, the views of the individual members of the MSc committee, or the views of their respective employers.

إهداء

للذي من بلغ الرسالة وأدى الأمانة معلم البشرية ونبي الرحمة ونور العالمين سيدنا محمد صلى الله عليه وسلم

للأرض المباركة، وطن الأنبياء، منبع العلماء ومنزل الشهداء فلسطيننا الحبيبة وقدسنا الغالي.

إلى من جعلوا دمائهم مهرا لفلسطين ومن رهنوا حياتهم ثمنا للحرية، شهداؤنا الأبرار وأسرانا البواسل.

إلى أقرب الناس لقلبي وأولاهم بحبي، إلى من علمني العطاء، إلى من كان دعاؤهم سر نجاحي إلى من نذروا أعمارهم لأجلنا والداي الكريمين أطال الله في أعمارهم وألبسهم ثوب العافية.

ولكم أخوتي وأخواتي وأنتم الأعز على قلبي رفقاء دربي وسندي.

إلى أعمدة العلم والمعرفة الذين سطروا لنا سبيل العلم أستاذتنا الأفاضل.

إلى كل باحث عن فكرة مضيئة تنير له زقاق الطريق

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List of Abbreviations

AF: Anaerobic Filter

AH: Anaerobic Hybrid

AnDMBR: Anaerobic Dynamic Membrane Bio-Reactor

AnMBR: Anaerobic Membrane Bio-Reactor

Avr.: Average

BOD: Biological Oxygen Demand

CFU/100ml: Colony Forming Unit Per 100 Ml

COD: Chemical Oxygen Demand

COD_{coll}: Colloidal COD

COD_{diss}: Dissolved COD

COD_{filt}: Filtered COD

COD_{sus}: Suspended COD

COD_{tot}: Total COD

d: Day

DM: Dynamic Membrane

Eff: Effluent

FC: Fecal Coliform

g: Gram

H: Hydrolysis

hr: Hour

HRT: Hydraulic Retention Time

in: Inch

Inf: Influent

L: Liter

m: Meter

mg: Milligram

ml: Milliliter

Nkj: Kjeldhal Nitrogen

nm: Nanometer

OLR: Organic Loading Rate

pH: Potential of Hydrogen

TSS: Total Suspended Solids

T_{ww}: Wastewater Temperature

T_{amb}: Ambient Temperature

UASB: Up-Flow Anaerobic Sludge Blanket

VSS: Volatile Suspended Solids

WWTP: Wastewater Treatment Plant

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ABSTRACT

As a result of the urgent need to provide new water sources and benefit from a large amount of wastewater returning, an AnDMBR system was installed and tested in Al-Tira wastewater treatment plant (WWTP) to opt for agriculture reuse under the climatic conditions and sewage characteristics of Palestine.

The process started up on January 1, 2020, and 25 samples were taken during the period July 22, 2020, to October 22, 2020, at ambient temperature 25-36 °C and wastewater temperature 20-30 °C. The characteristics of the WWTP influent were measured and calculated to study the efficiency of the MBR in treating wastewater. The strength classification of the wastewater varied from medium to strong strength based on the Chemical Oxygen Demand (COD) values.

The COD removal efficiency in the MBR system (92%) was better than the UASB reactor (85%) while the WWTP removal efficiency was the best which is 98%. The CODtot values were found near to the acceptable range for irrigation uses. The BOD_5 removal efficiency results showed that the MBR (84%) better than the UASB reactor (69%). The BOD_5 values are higher than the acceptable range (22.33±1.53) might be it is backward to the high value of pH.

The MBR removal efficiency of TSS and VSS were 82% and 84% and showed a higher performance than the UASB efficiency in this study and past studies. The pH value for MBR effluent was 7.6 (0.7) which is within the acceptable range for the irrigation uses (7.4-7.8). The fecal coliform (FC) was 2×10^5 CFU/100ml for MBR effluent which is near to the value of restricted irrigation ($\leq 10^5$ CFU/100ml).

The study concluded the need of improving the AnDMBR system and measuring more parameters to evaluate the performance of the system in treating wastewater and increase the efficiency of the membrane to obtain the study required needs.

CHAPTER ONE
INTRODUCTION

1.1 Background

The per capita water availability is too little in Palestine and is considered as one of the rarest in the world. This lack of water is because of two main reasons; the first and most important reason is the Israeli occupation and their constraints on both the water resources and its sector's development; the second reason is the natural factors such as population growth, higher standards of living, and expected climate change.

To minimize the scarcity effects of water scarcity availability in Palestine, the wastewater must be treated to and reused in irrigation. The wastewater reusing process will contribute to the financial sustainability of the collection and treatment systems through fees collected from the sales of remediated wastewater to agricultural and industrial firms. Besides, the reusing of remediated wastewater can improve agricultural yields in a significantly great way. In the West Bank, irrigated field crops, for example, produce an average yield 11 times greater than would be possible with rain-fed agriculture. Similarly, gross revenue from open-field irrigated agriculture is 10 to 11 times greater than that of rain-fed agriculture (ARIJ, 2015).

As a result of reusing the treated wastewater in irrigation, the income of poor farmers could be improved and promote development in other economic sectors in Palestine by raising the supply of domestic savings and capital formation.

The biggest hindrance in addition to the social and political unrest for the Palestinian Water Authority to provide comprehensive wastewater services is to afford the initial capital and operational costs. So, the provision of low-cost and effective wastewater treatment technologies will make wastewater treatment services more widespread either in Palestine or all over the world.

Many cases were found that used the conventional centralized treatment technologies in wastewater treatment process like the aerobic activated sludge process that is unsuitable for the features of the small communities, where this system entails the existence of sewage network. The use of this treatment system in Palestine is highly questionable because of the lacking adequate sanitation, especially for rural areas. So, decentralized wastewater treatment is regarded to be the most sustainable way of wastewater treatment for the unseeded localities (Al-Shayah, 2005).

In the anaerobic wastewater treatment, fossil energy is not needed in the process of organic matter oxidation. On the contrary, the stored chemical energy in the organic pollutants is converted into CH_4 biogas that could be utilized as an energy source. For that reason, anaerobic treatment has been considered a charming alternative over the past decades.

Anaerobic reactors require biomass at high concentrations due to the anaerobic microorganisms' low growth rate in a comparison with the aerobic. High-rate anaerobic processes are characterized by uncoupling of the solids retention time (SRT) from the hydraulic retention time (HRT). Efficient biomass retention through automatic freezing of anaerobic bacteria into biofilms, granular sludge, or flocks led to a rise in SRT, and a separation membrane could be used to retain biomass instead of freezing the biomass when this could not happen. In general, the interest in studying and applying anaerobic membrane bioreactors (AnMBRs) for wastewater treatment, whether municipal or industrial, is growing to benefit from wastewater instead of looking for a way to dispose of it and increase its burden. What distinguishes AnMBRs is that it merges the advantages of anaerobic processes with the production of treated water free of solids, this technology is a suitable alternative to independently control both HRT and SRT by providing complete biomass retention.

There is a common phenomenon that happens during the filtration process in the AnMBRs, which leads to the gathering of solid particles on the surface of the membrane, such as organic and inorganic materials and microbial cells, and with time the density of the accumulated material increases, which leads to the formation of a cake layer that limits the flux and controls fouling. The cake layer is the most important barrier for AnMBR as it forms a backing layer as if it were a woven filter or mesh cloth which led to the convention of so-called dynamic membrane (DM) filtration. So, the cake layer or DM has a significant role filtration process where it will be cost-effective in the treatment process by using cheap materials as supporting materials.

According to Ersahin et al. (2013), for the consolidation and formation of a successful DM layer, the use of a suitable kind of support material is an important issue, and its efficiency is regarded to the structure, such as pore size, yarn type, and availability. The most frequent types of support materials utilized in numerous studies, of MBR dynamic applications of both aerobic and anaerobic, are woven, and non-woven fabrics and mesh (Ersahin et al., 2012).

The municipal wastewater treatment by applying the dynamic membrane technology was discussed and presented in many experimental studies (Ho et al., 2007; Jeison et al., 2008; Zhang et al., 2011). The results of these studies showed the DM potential to achieve complete solid material retention by AnMBRs. Though, in both the mesophilic and thermophilic conditions, the DM could not reach a steady flux that ranged from 0.5 to 3 l/m^2. Based on a non-woven fabric support layer to treat municipal wastewater using AnDMBR, the COD removal rate was found of 87%. Zhang et al. (2011) studied the efficiency of the dynamic membrane by installing a DM module at the upper part of the UASB reactor with a mesh support material to filter the supernatant rather than the sludge. The authors found that the high values of flux (65 L/m^2) can be achieved in the long-term operation with a steady COD removal rate of 63.4%. These results showed that the efficiency in AnDMBR is lower than the efficiency of conventional AnMBR. According to our knowledge, the AnMBRs have not been tested for post-treating the pre-treated sewage in for instance an Up-flow Anaerobic Sludge Blanket (UASB) reactor.

AnDMBR is a low-cost technology based on easily available mono-mono fabric. Based on the previous works, the AnDMBR carries big potentials for sewage treatment and at a low cost. However, further investigations are still needed to apply the proposed technology in Palestine due to the concentrated collected sewage is very concentrated because of the water shortage, and the large temperature fluctuations due to the prevailing Mediterranean climate with hot dry summer and cold rainy winter. So far, the potential of the AnDMBR to remove pathogens is still to be investigated, so it will be emphasized in this research as the main innovative research item.

1.2 Thesis Aim

This study seeks to investigate the technical feasibility of the AnDMBR for further polishing anaerobically pre-treated sewage to opt agriculture reuse under the climatic conditions and sewage characteristics of Palestine and the achievable nutrient concentrations will be evaluated for the use of the treated effluents for ferti-irrigation in agriculture production. The process performance of the AnDMBR for sewage treatment will be assessed under Palestine's conditions in terms of COD and pathogen removal.

1.3 Objectives

The main objective of this study is to use AnDMBR in the pre-treated wastewater to be reused in agriculture irrigation. To achieve the main objective, the following specific objectives are tested:

1. The characteristics of municipal wastewater being treated by Al-Tira membrane bioreactor MBR will be analyzed and recorded.

2. The AnDMBR will be assembled and installed at the WWTP after the UASB reactor to test the performance of the treated wastewater.
3. The feasibility of the AnDMBR process will be evaluated by monitoring the process stability based on overall COD removal efficiencies.
4. The effluent wastewater after each step (UASB reactor, MBR, and WWTP effluent) will be compared by measuring the characteristics of each.
5. Comparative analysis of obtained results with local prescribed national standards destined for irrigation.

1.4 Thesis Structure

This thesis consists of five chapters. Chapter 1 is the research introduction in which the Background, aim of the research, and objectives are introduced. Chapter 2 provides a comprehensive literature review on the anaerobic system, UASB, AnMBR, and AnDMBR. Chapter 3 deals mainly with materials and methods used in this experimental research. The results and discussion will be presented in Chapter 4. Finally, the results, conclusions, and recommendations of this research are presented and discussed in Chapter 5.

CHAPTER TWO
LITERATURE REVIEW

Municipal wastewater is considered as a sort of low-strength wastewater differentiated through high particulate organic matter content and low organic strength. This kind of wastewater is the most abundant, so if this kind can be recycled to reuse again, the municipal wastewater treatment stations can become net producers of renewable energy. So, to improve energy sustainability and resource conservation suitable anaerobic technologies should be identified to recover the solubilized methane from treated wastewater.

Therefore, should be found the best energy production technology to transform the energy that is chemically bound in the organic part of the pollutants in wastewater into biogas as a source of renewable energy becoming increasingly valuable. Anaerobic treatment systems have many advantages that make them special amongst the several treatment technologies, also the use of these treatment systems have been encouraged by many researchers (Zhang, 2011; Conceicao et al., 2013; Hernandez and Rodrıguez, 2013; Goswami et al., 2018; Yurtsever et al., 2020) because of their advantages such as the low construction costs, small land requirements, plain operation and maintenance, energy generation in the form of biogas, low excess sludge production, pH stability and recovery time, and robustness in terms of COD removal efficiency. Several researchers have recommended anaerobic technology like Up-flow Anaerobic Sludge Blanket (UASB) reactor for the treatment of sewage in tropical and subtropical regions (Rizvi et al., 2013).

One of the technologies widely used overall the world is MBR technology to treat municipal and industrial wastewater because of its high efficiency and relatively low fluxes as a result of membrane fouling, also because of its removal efficiencies of the high microbial population in the cake layer which full of pollutants. To overwhelm the impediments faced in conventional MBRs the dynamic membrane (DM) technology could be used. One of the most important reasons for using DM technology is the low-cost of their support materials such as nylon or steel mesh, filter cloth, and nonwoven fabric are used to replace the micro or ultra-filtration membranes.

In this chapter, past studies related to Up-flow Anaerobic Sludge Blanket (UASB), Anaerobic Membrane Bio-Reactor (AnMBR) and its uses, Dynamic Membrane (DM) technology, Controlled Environment Agriculture (CEA), and the use of treated wastewater in agriculture will be discussed.

2.1 Anaerobic Digestion Process

Anaerobic systems have attracted great interest for treating municipal wastewater. Besides the recovery of the bound energy in the methane biogas, the implementation of anaerobic technology in treating municipal wastewater decreases the needed energy since energy for aeration is not needed to oxidize organic matter. Also, the anaerobic effluent is rich in ammonia and phosphates mineral nutrients which allow agricultural utilization of treated water for both irrigation and fertilization.

Anaerobic bio-transformation has occurred naturally everywhere. However, engineering applying of these microorganisms to treat wastewaters has been slow. Many obstacles have prohibited the easy exploiting of anaerobic attributes to wastewater treatment. Possibly the greatest obstacle may have been in capturing the distinctiveness of the anaerobic digestion process (Speece et al., 2005).

The degradation of organic materials found in wastewater will be easier because of the anaerobic fermentation and its biological processes and the oxidation, and these processes called Anaerobic Digestion (AD). The biological synthesis needs high energy for a consortium of anaerobic organisms accountable for oxidation and anaerobic fermentation to improve rapidly. So, these organisms need long solids retention time (SRT) and low hydraulic retention times (HRT) to breakdown the wastewater streams that rich in complex carbon molecules. The anaerobic oxidation process includes four primary steps; 1) Hydrolysis, 2) Fermentation (Acidogenesis), 3) Acetogenesis, and 4) Methanogenesis, Figure 2.1 shows these steps.

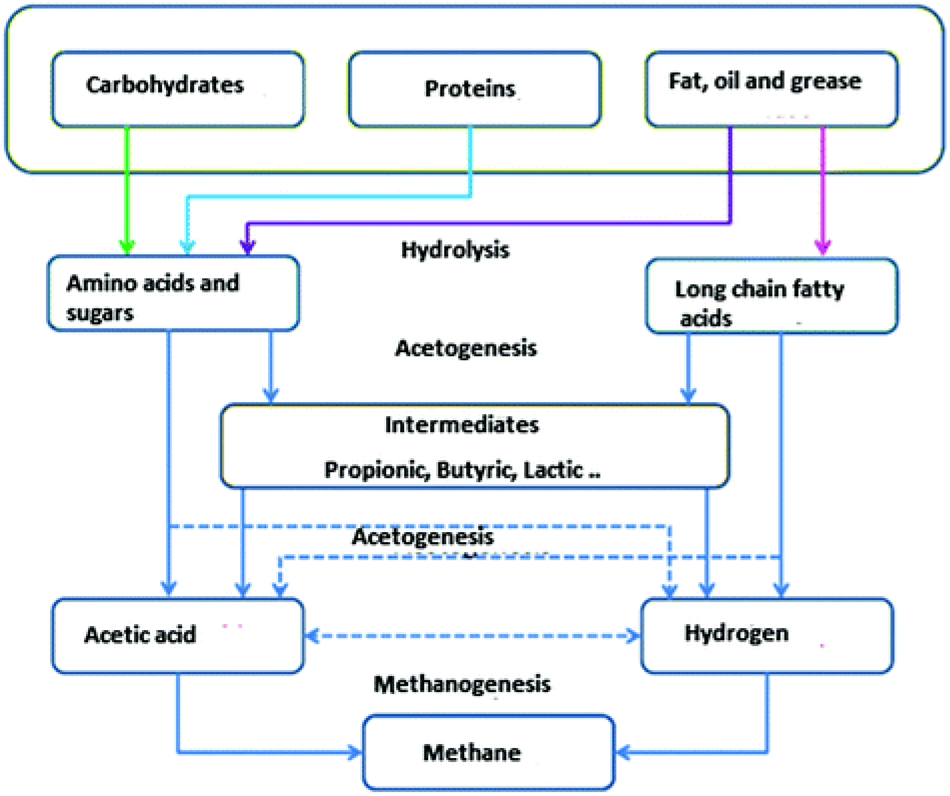

Figure 2. 1: Anaerobic Oxidation Process (Bajpai, 2017)

1. Hydrolysis: also called liquefaction or solubilization step. In this step, the big organic polymers are depolymerized by acidogenic bacteria into sugars, amino acids, glycerol, and long-chain fatty acids by hydrolytic exo-enzymes excreted by fermentative microorganisms. Hydrolysis is a relatively slow step and it can limit the rate of the overall anaerobic digestion process, especially when using solid waste as the substrate (Bajpai, 2017).

Various factors affected the hydrolysis rate such as pH, temperature, sludge retention time, product inhibition, the chemical composition of the substrate, particle size distribution, and bio-available surface area. One of the mathematical equation which used to measure the hydrolysis rate is shown in Eq. 2.1 (Al-Shayah, 2005) below. This relationship uses first-order kinetics and is considered the most often applied to explain the hydrolysis of particulate substrates during anaerobic digestion.

$$\frac{DX_{DEGR}}{DT} = -KH \times X_{DEGR} \text{...} \quad \text{EQ. 2.1 (Al-Shayah, 2005)}$$

where:

X_{DEGR}: Concentration biodegradable substrate (kg/m³),
t: Time (days), and
kh: first order hydrolysis constant (1/day).

2. Fermentation (Acidogenesis): the organics are transformed by acid-forming bacteria to higher organic acids such as propionic acid, butyric acid, acetic acid, hydrogen, and carbon dioxide. Then, acetogenic bacteria transfers the higher organic acids subsequently to acetic acid and hydrogen.

3. Acetogenesis: in this step, the hydrogen gas was formed and considered as a waste product of acetogenesis because it inhibited the metabolism of acetogenic bacteria but the methane-producing bacteria can consume it and converted it into methane. The end products of the acetogenesis stage depend on the bacteria type and the prevailing environmental conditions, like pH and temperature.

4. Methanogenesis: in this step, methanogenic bacteria produce methane gas by metabolizing formic acid (HCOOH), acetic acid (CH_3COOH), methanol (CH_3OH), carbon monoxide (CO), carbon dioxide (CO_2), and hydrogen (H_2) to methane (CH_4) via two ways; 1) aceticlastic methanogenesis and 2) hydrogenotrophic methanogenesis. The acetotrophic methanogens transform acetate into methane and carbon dioxide by splitting acetate into methane and carbon dioxide, this reaction responsible for 72% produced methane in anaerobic digestion. The other method, hydrogenotrophic methanogenesis, produced the residual methane by transform

hydrogen and carbon dioxide into methane. Both methane-producing reactions are shown (Tchobanoglous et al., 2014).

$CH_3COOH \rightarrow CH_4 + CO_2$ ……………………………………..…… Aceticlastic Methanogenesis

$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$ ………………………………. Hydrogenotrophic Methanogenesis

2.2 Up-flow Anaerobic Sludge Blanket (UASB) Reactor

Municipal wastewater treatment using anaerobic technology is found highly potential in most developing countries. Among the various anaerobic treatment technologies, the Up-Flow Anaerobic Sludge Blanket (UASB) process showed big potential, especially in developing countries owing to its numerous advantages UASB reactor has been recognized as cost-effective and appropriate sewage treatment process considering the environmental requirements in India (Makwana, 2017).

Many factors affecting the start-up of the UASB reactor including the presence of toxic compounds, wastewater characteristics, pH, acclimatization of seed sludge, loading rate, nutrients, hydraulic retention time (HRT), up-flow velocity (Vup), liquid mixing, and the design of the reactor, in addition, all of these factors influence the increase of sludge bed. The temperature considerably influences the growth and survival of microorganisms. Although anaerobic treatment is possible at all three temperature ranges (psychrophilic, mesophilic, and thermophilic). The low temperature usually leads to a decline in the maximum specific growth rate and methanogenic activity. Methanogenic activity at the low-temperature range is 10 – 20 times lower than the activity at 35°C, which requires a 10 – 20 times increase in the biomass in the reactor or to operate at higher sludge retention time (SRT) and hydraulic retention time (HRT) to achieve the same COD removal efficiency as that obtained at 35 °C (Rizvi et al., 2013).

HRT is one of the most important parameters affecting the performance of a UASB reactor when used for the treatment of municipal wastewater. V_{up} acts a significant role in trapping suspended solids (SS) and is directly related to HRT as the decrease in V_{up} leads to an increase in HRT, which leads to improved removal efficiency of suspended solids. In addition, the higher V_{up} values increase the removal efficiency of the COD in the reactor due to the reduction of the contact time between the sewage and the sludge as well as the sludge granules shattering which leads to the increased washout of the solids. (Rizvi et al., 2013).

2.2.1 An Overview of UASB Reactor Using

Lettinga and coworkers have developed the UASB reactor in the 1970s in the Netherlands and it was a distinctive sign in anaerobic wastewater treatment because it becomes the most widely applied system worldwide for treating sewage. Since the 1980s, several researchers had worked on the applicability of the UASB process for the treatment of sewage and found around 70% Chemical Oxygen Demand (COD) removal under tropical climate (Makwana, 2017).

What mainly distinguished the UASB reactor and led to its success, especially in developing countries, is the granular sludge, based on the wastewater characteristics, which can keep highly active biomass with excellent settling capabilities in the reactor.

2.2.2 Up-Flow Anaerobic Sludge Blanket (UASB) Process

The UASB reactor is a high rate system in which influent wastewater flows from the bottom and is distributed equally (Al-Shayah, 2005). Wastewater enters at the bottom of the reactor and flows upwards through a so-called “sludge blanket”, consisting of a granular sludge bed. UASB arrangement allows a highly effectual mixing between the biomass and the substrate, viz. wastewater, resulting in efficient anaerobic degradation. The sludge in the reactor removes the pollutants in wastewater, and so sludge quality and the contact between sludge and wastewater are the key factors leading to the success of UASB reactor. The produced biogas enhances mixing and contact between sludge and wastewater. The gas-liquid-solid three phases separator (GLS), at the top of the UASB reactor, separate biogas from liquid and sludge, and leads the biogas in an outlet. The typical geometric features of UASB reactor incorporating a height to width ratio of 0.2 - 0.5 and an upflow velocity of 0.5 - 1.0 m/h. Figure 2.2 shows a simplified scheme of a UASB reactor (Mainardis et al., 2020).

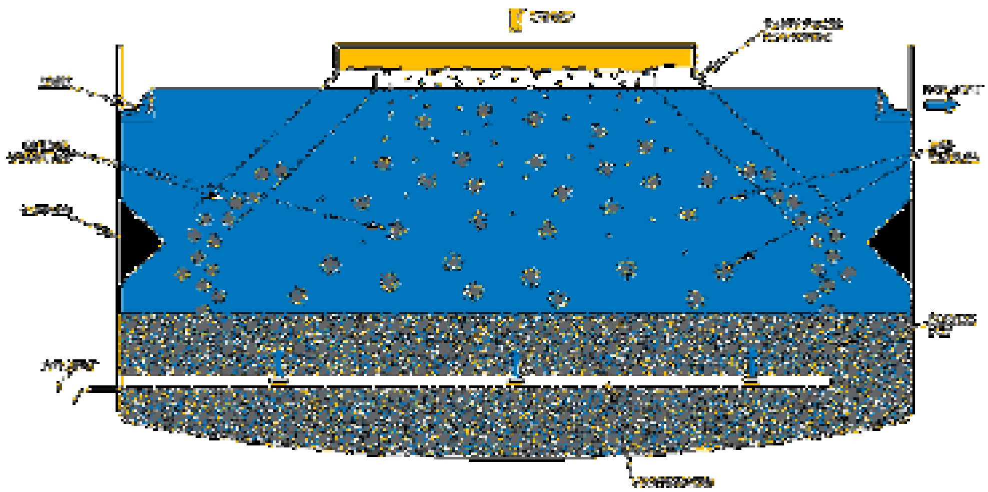

Figure 2. 2: Up-Flow Anaerobic Sludge Blanket (UASB) Reactor Process Scheme (Mainardis et al., 2020).

A well-operated UASB process shows the formation of a well-developed dense granulated sludge blanket which can take higher volumetric COD loadings than any other anaerobic processes (Makwana, 2017). Despite the UASB advantages in wastewater treatment, certain limitation of this technology limits its use, which needs more time to start-up than the start-up time of aerobic treatment. Many factors affected the initial start-up time includes requirements of active microbial population, consistent higher temperature, and wastewater being treated. Also, the temperature affected the efficiency of treatment.

Effluent from UASB reactors, however, rarely meets disposal standards/guidelines set by most governing agencies for discharge into surface water and re-use for agriculture purposes especially concerning organic content, suspended solids, nutrients, and pathogen content (Makwana, 2017).

2.2.3 Using UASB Reactors by Others

Al-Shayah (2005) investigated, in his master's thesis, the UASB reactor performance for community onsite municipal wastewater treatment where Mediterranean climate domains, by investigating the impact of HRT on the UASB-septic tank reactor performance. The outcomes presented that the COD is connected with the rise of temperature and microbial adaptation and the growth of biogas production affected by the environment and temperature. Finally, the UASB reactor was concluded to be an efficient system for decentralized-community-based pre-treating of domestic sewage in Palestine.

Rizvi et al. (2013) investigated the growth of sludge bed in UASB reactors seeded with activated sludge and cow dung (UASBCD)of dairy industry treatment (UASBASDIT) station, and studied the effect of several factors on its performance includes temperature, sludge age, and hydraulic retention time (HRT). The researchers found that both of the reactors' performance improved with an increase in the sludge age and temperature where the best sludge age ranged between 120 to 150 days and the best temperature was ranged between 25 to 30 C. Also the increase of HRT more than 9 hrs. will decrease the amount of the chemical oxygen demand (COD), total suspended solids (TSS), and sulfate removal efficiency.

Kulkarni (2016) presented a review of past studies on UASB reactors for wastewater and sludge treatment and found that the UASB reactors are a cost-effective solution in developing countries and small communities to treat wastewater problems, proper HRT should be implemented to give sufficient contact time between wastewater and bacteria, and it is necessary to prevent sudden changes in environmental conditions and wastewater characteristics. Also, the produced methane can be used as a fuel because of its high amount.

Makwana (2017) reported a review of the capability of electrochemical treatments to improve and treat the effluents from UASB reactors. The author found that the UASB reactor is the most widely in developing countries as a cost-effective and economic solution to treat the wastewater, but this treated wastewater did not meet disposal standards or guidelines especially concerning the organic content, suspended solids, nutrients, and pathogen content. So, the author tried to find a suitable post-treatment for the UASB reactor effluent to meet the standards and be good to reuse. This study concluded that the electrochemical treatments are all found to be effective on several effluents when taken as post-treatment for UASB effluent.

Mahmoud (2017) presented a review of a modified UASB-Digester system and investigated the results of this modification. The author found that the performance of the modified reactor was improved so that the UASB-Septic tank system is a good solution and can be designed in Palestine at two days HRT. Despite that, the modified UASB reactor effluents need a post-treatment unit to become better for reuse.

In this study, the growth of sludge bed in UASB reactors was investigated. The effect of the process conditions (hydraulic retention time, sludge age, and temperature) on the performance of these reactors were then examined. Also, the results will be used to show the compatibility of the treated wastewater with the standards and then a comparison will be developed between these results and AnDMBR results.

2.3 Anaerobic Membrane Bio-Reactors (AnMBR)

New technology was defined to treat the wastewater by one treatment step includes many standard operations; primary sedimentation which includes activated sludge aeration and sedimentation and tertiary media filtration, this technology called Membrane Bio-Reactors (MBRs). As such, New technology was appeared by combining the membrane filtration technology and anaerobic treatment process called Anaerobic Membrane Bioreactor (AnMBR), to maintain anaerobic microorganisms, and it had been successfully implemented at several scales. The membranes are made of semi-permeable materials so that AnMBR can be simply defined as *"a biological treatment process operated without oxygen and using a membrane to provide solid-liquid separation"* (Calabria, 2014).

2.3.1 An Overview of MBR

Using the membranes in MBRs, the physical separation and biological treatment for several pollutants were combined to treat the municipal and industrial wastewater, and this combination gave the MBRs a higher treatment quality compared to the conventional activated sludge process. Also, some of the MBR technology's advantages made it widely applied n treatment wastewater processes such as the simplicity of operating which is easy to use, the production of less sludge, the decreasing cost of its materials, and the increasingly stringent requirements of treated effluent quality. The AnMBR successfully treatment performance permits separation of HRT and SRT by granule formation or biofilm which helps in reducing the HRT while maintaining the SRT at a high value to manufacture an effluent of solids-free with a high removal rate of the COD.

Several studies and researches on the treatment of wastewater using AnMBR technology were discussed and reviewed by appearing the process developments, membrane fouling characterization, influencing factors, and process performance. Notwithstanding these important achievements, several barriers limit the use of AnMBR such as membrane fouling, low flux, and high costs.

Many challenges were faced in conventional municipal wastewater treatment processes because of their complexity because of particulate organic material with high fraction, moderate biodegradability, and low strength. Therefore, the particulate complex material hydrolysis into dissolved molecules under low-temperature turns to be the limiting step of the overall process rate, that leads to an accumulation of solids inside in the reactor and a reduction in organic matter conversion performance mutually with a reduction in methanogenic activity. Furthermore, because of the affinity of anaerobic biomass to substrate is low in comparison with aerobic bacteria, it is essentially difficult to reach low concentrations of COD in the effluent and to comply with the environmental rules for wastewater disposal and reuse.

AnMBR is considered a good municipal wastewater treatment process and a good substitutional to the traditional processes because of the ability to retain the biomass inside the reactor efficiently to afford an ideal situation for the degradation of organic material with no washout of suspended solids. As it is known, anaerobic sludge is characterized by its high viscosity in addition to the concentration of mixed liquor suspended solids (MLSS) and also contains large quantities of inorganic materials and biopolymers which lead to higher pollution than the activated sludge which considers a common phenomenon in AnMBRs.

When membranes are added to the anaerobic treatment of municipal wastewater, high effluent quality described by organic, solid, and biological parameters can be attained as compared to other anaerobic systems, and stable performance of the treatment process could be achieved to comply with strict discharge standards. Therefore, AnMBRs effluent (permeates) is sure of significance for use in agriculture because it helps in keeping the macronutrients in treated wastewater while at the same time removing pathogens. Besides, to achieve a high quality of treated wastewater in AnMBR, especially low-strength wastewaters, compared to conventional treatment processes (e.g. UASB reactors) the start-up time must be shorter.

Nonetheless, many critical barriers restrict the intensive use of AnMBRs such as high costs, low flux, and membrane fouling.

2.3.2 Membrane Bio-Reactor (MBR) Process

The membrane flux expresses the permeate velocity of the membrane and can be defined as *"the amount of material of material that passes through a unit area of membrane material per unit time"* (Calabria, 2014). Many elements affected the flux of any membrane process including 1) the resistance of membrane, 2) operational driving force per unit membrane area, 3) hydrodynamic conditions at the membrane-liquid interface, and 4) fouling and subsequent cleaning of the membrane surface.

The membrane processes have three streams including 1) feed stream, 2) concentrate (retentate) stream, and 3) permeate stream. Also, the membrane process has two main flow configurations; a) Dead-end operation and b) Cross-flow filtration. In the dead-end operation, the water had a low-content of solids because it lacked a concentrated stream so solutes are more likely to accumulate on the surface of the membrane, therefore the operating system based on 100% renewal of the feed water. Figure 2.3 shows a clarification of the dead-end operation.

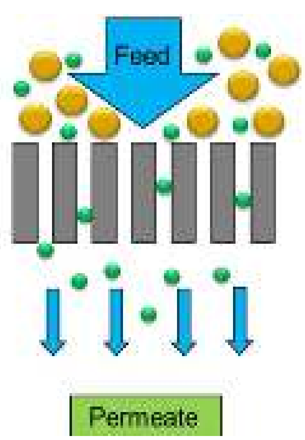

Figure 2. 3: Dead-End Operation (Ketola, 2016).

In the cross-flow filtration, the water had high solids concentrations with limited flux. The feed streams tangential to the membrane surface and afterwards distributed to two streams. The concentrate (a solution that does not permeate through the surface of the membrane) is recirculated and blended with the feed water, while the permeate flow is tracked on the other side (Mai, 2014). Figure 2.4 shows a clarification of the cross-flow filtration.

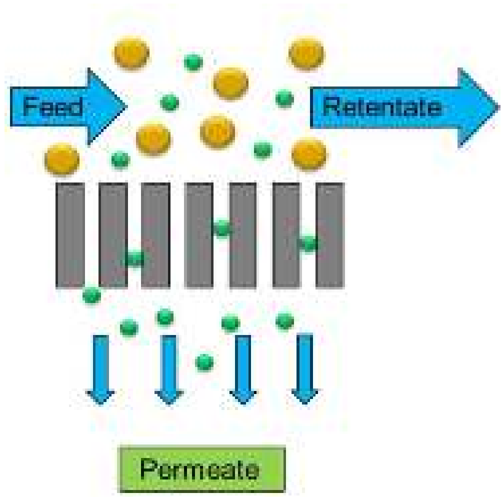

Figure 2. 4: Cross-Flow Filtration (Ketola, 2016).

The membrane processes, allowing separation in the liquid phase, have four categories based on their pore size and filtration mechanism. The membrane processes, enabling separation during the liquid phase, have 4 sections based on the filtration mechanism and pore size. These sections are 1) microfiltration membranes (0.025 - 10 µm pore size), 2) ultrafiltration (0.01 - 0.05 µm pore size), 3) Nano-filtration, and 4) reverse osmosis, the first two sections are the extreme ordinarily used membranes in treatment systems. Although, the membrane nature controls which materials will filter and which will be retained, where they are selectively separated depending on their molar masses, chemical affinity, particle size, and interaction with the membrane (Mai, 2014).

The membrane pore size is identified through its molecular weight cut-off (MWCO) by membrane manufacturers. The MWCO is expressed in Dalton (1 Da = 1g per 1 mol). The MWCO is defined as *"the molecular weight of the smallest component that will be retained with an efficiency of at least 90%"* (Mai, 2014). The size of standard particles is correlated to the pore size and MWCO of the membrane to remove these particles. For instance, the removal of solutes spectrum for membranes ranges from reverse osmosis (RO) to Nano-filtration (NF). Figure 2.5 presents the Cut-offs of various liquid filtration systems (Wikipedia.com).

1. Microfiltration Membranes (MF): this kind of filtration used a low pressure (less than 0.2 MPa) to remove particle sizes ranged from 0.025 µm to 10 µm from a liquid by crossing through a microporous membrane. A standard pore size range of the microfiltration membrane is 0.1 to 10 µm (Mai, 2014). The MF process has widespread uses in many sectors such as the food and dairy industry, biotechnology, and Filtration of protein solutions in addition to municipal wastewater reclamation, anoxic pond effluent treatment, and toxic component removal from drinking water.

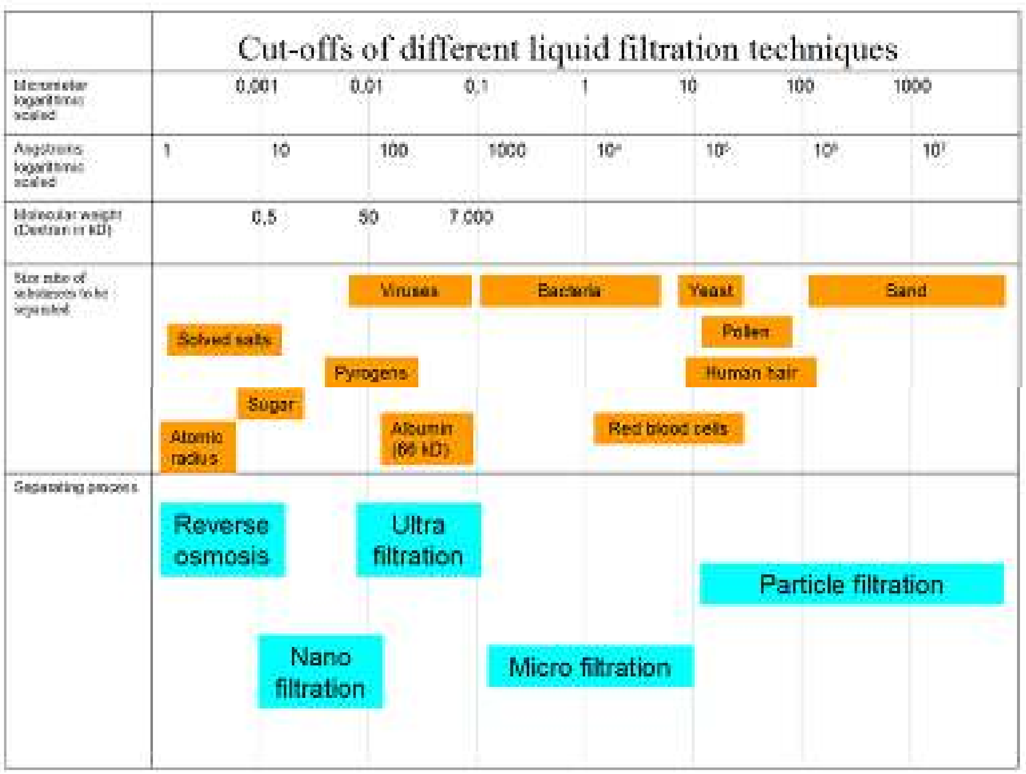

Figure 2. 5: Cut-offs of Different Liquid Filtration Technique (wikipedia.com).

2. Ultrafiltration (UF): in this filtration, the particles are measured by the molecular weight of rejected molecules from the membrane pores. The molar masses of the particles must be ranged from 1 to 300 kDa to be separated, also the pore size of UF is 0.01 micron and the applied pressures must be more the 1 MPa (Mai, 2014). The suspended solids (SS) with MWCO more than 300 kDa are retained which is helped in recovering the valuable contaminants in process wastewater streams and production of potable water.

3. Nano-filtration (NF): this filtration was begun in the 1980s and utilized treating the fresh groundwater and surface water. The NF uses pressures between 4 and 20 MPa to retain the dissolved molecules with molar masses between 350 and 1000 Da. NF removes most organic molecules, nearly all viruses, most of the natural organic matter, and a range of salts. Also, removes divalent ions, which make water hard, so it is often used to soften hard water.

4. Reverse Osmosis (RO): RO membranes are thick membranes and do not have clear pores, unlike UF and MF membranes. In these membranes, the process will need a pressure ranged from 20 to 80 MPa, also it is refuse the monovalent ions and small contaminants from solvents. The solution-diffusion caused the RO mass transfer based on its mechanism, charge exclusion, physical-chemical interactions between solute, solvent, and the membrane, and size exclusion. RO is most commonly known for its use in drinking water purification from seawater, removing the salt and other substances from water (Mai, 2014). Table 2.1 presents a summary of the four filtration processes with the size of materials retained, driving force, and type of membrane (Mai, 2014).

The driving force for processes involving membrane filtration and reverse osmosis is normally a gradient of transmembrane pressure (TMP) (Calabria, 2014). The cumulating of biological and precipitated solids on the membrane surface could affect the TMP, this cumulating is known as fouling. Also, Fouling is various from clogging, where clogging is connected with insufficient hydrodynamic performance.

Table 2. 1: The Size of Materials Retained, Driving Force, and Type of Membrane (Mai, 2014).

Process	Min. Particle Size Removed	Applied Pressure	Type of Membrane
Microfiltration	0.025 - 10 µm Micro-particles	(0.1 – 0.5 bar)	Porous
Ultrafiltration	5 - 100 nm Macromolecules	(0.5 - 9 bar)	Porous
Nano-filtration	0.5 - 5 nm Molecules	(4 - 20 bar)	Porous
Reverse Osmosis	< 1 nm Salts	(20 - 80 bar)	Nonporous

The major disadvantage of MBR operation is the fouling. When the fouling increased and accumulated on the membrane the flux and permeate of the membrane will be decreased. Thus, the operating costs of an MBR would be increased. Also, the fouling will change the membrane properties such as surface characteristics, membrane pore size, the hydrodynamic profile of the MBR, and characteristics of solvents and solutes in the feed. Fouling contains colloidal particles, inorganics, and organic macromolecules. Any changes in localized concentration and pH can lead to precipitate the salts and hydroxides (so-called concentration polarization). The internal fouling caused by accumulation on the membranes with larger pore size while the biofilm layer will be accumulated on the smaller pore sizes. However, the biofilm layer can be used as an additional filtration (Calabria, 2014).

The fouling can be decreased depending on the design of the membrane, effective air scouring, and biological process in addition to the using of cleaning processes to remove the fouling from membranes.

2.3.3 Cleaning Methods

The membranes need to clean continuously from fouling, and the methods of cleaning membranes based on the nature of fouling. Hence, the cleaning could be carried out chemically or physically. The physical techniques of membrane cleaning, which are related to membrane operation, include membrane relaxation, membrane backwashing, and interim increase of the rate of shear to detach the cake layer built on the surface of the membrane, also the membranes can be removed physically and cleaned using water jets.

Martinez-Sosa et al. (2011) studied the results of operating an anaerobic submerged membrane bioreactor (AnSMBR) on a pilot-scale to treat a mixture of municipal wastewater and glucose for 206 days and evaluated its performance at several fluxes, biomass concentrations, and gas sparing velocities (GSV) (GSV was used to control fouling). The authors were used physical cleaning to clean the membrane from fouling after 156 days and found that the efficiency of cleaning was almost 100% which indicates that no irreversible fouling was developed inside the pores of the membrane.

Physical cleaning effectiveness will decline with operation time as more irreversible fouling accumulates on the membrane surface. Thus, besides the physical cleaning, chemical cleaning may also be recommended. The chemical cleaning includes the chemical enhanced backwash, that is, a low concentration of chemical cleaning agent is added during the backwashing period. The main cleaning agents in chemical cleaning are alkali oxidants such as NaOH, H_2O_2, and NaOCl, for organic fouling, and acid cleaning agents such as HCl, H_2SO_4, and citric acid, for inorganic fouling. The chemical cleaning methods differ from each other based on every membrane supplier proposes its chemical cleaning recipes.

Li et al. (2019) studied the effect of chemical cleaning using Hydrogen peroxide (H_2O_2) and Sodium hypochlorite (NaClO) for an ultrafiltration (UF) system in water and wastewater treatment. The authors found that the efficiency of cleaning of NaClO was higher than H_2O_2 at the pH range from 3 to 9, but the H_2O_2 cleaning efficiency increased to a level of 91.4% compared with that of NaClO at pH 11. Besides, H_2O_2 treatment at pH 11 significantly increased the negative charge of humic substance (HS) molecules, decomposed high molecular weight molecules, and reduced its fouling potential. Therefore, considering the treatment of cleaning waste and cleaning efficacy, H_2O_2 cleaning under strongly alkaline conditions can be a good choice for HS-fouled membrane.

Some of the chemical cleaning methods are insufficient to clean the fouling in UASB reactors, so other than these traditional methods of cleaning, other advanced methods were proposed as efficient cleaning techniques such as cleaning by nitric oxide, exopolymers enzymatic disruption of and bacteriophages. Furthermore, characteristics of membrane material act as a critical part of the use of various chemicals for cleaning.

The regular maintenance cleaning for membranes at moderate concentrations of chemicals can restrain permeability loss through a long-term operation due to the difficulty of removing the fouling using chemicals. Furthermore, a regular cleaning using solutions that are diluted spends 30% reagents lower than infrequent cleaning which is used for instance biennially or quarterly utilizing high-strength reagents.

The influence of cleaning agents on integrity and the lifetime of the membrane is considered the greatest concern in chemical cleaning. Ayala et al. (2011) reported that 6 – 7 years' lifetime of a membrane can be attained in aerobic MBRs with no a considerable decrease of permeability and integrity when frequent chemical cleaning is performed.

2.3.4 Factors Influencing the AnMBRs Performance Treating Municipal Wastewater

The AnMBR process is affected by several factors such as temperature, HRT, up-flow velocity, OLR, etc. Some of the key operational parameters will be discussed below and show their influence on AnMBR processes optimization.

1. Temperature: AnMBRs can be operated under psychrophilic (10°C–20°C), mesophilic (20°C–45°C), and thermophilic (45°C–60°C) temperature conditions. Most AnMBRs that treat industrial wastewaters have been operated in either mesophilic (37°C–40°C) or thermophilic (50°C–60°C) range. For domestic wastewater treatment, the pilot-scale AnMBRs were operated in a temperature range of 9–35 °C (Bokharya, 2020). The influence of temperature on the rates of biological reaction is of key influence on the biological treatment process efficiency. Usually, the biological activity reduces when the temperature reduces, which leads to a reduction in the removal efficiencies of the COD. Also, the temperature has an influence on several factors such as biogas solubility, inorganic compounds solubility, as well as the settling properties of the sludge as a consequence of changing the viscosity of water.

   Evans (2019) studied the impact of temperature on AnMBR performance to treat the domestic wastewater by using three AnMBR reactors at the same conditions with one difference which is the temperature. The author found that the production of methane at 35°C and 25 °C is close together, 109 CH_4/kg COD and 114 CH_4/kg COD respectively, but at 15°C was produced a small amount of methane which is 64 L CH_4/kg COD. The study concluded that the energy can be saved by unheated the reactor to 35°C as happening in conventional reactors, energy savings could especially be significant if the wastewater is already near 25°C for a portion of the year.

2. Organic Loading Rate (OLR): it determined the capacity of microorganisms and the number of volatile solids (VS) that can be handled by the bioreactor system over a specific period

(Bokharya, 2020), also the OLR based on the treated influent's kind. The ideal ranges of OLR for industrial water and domestic water for pilot-scale were (1–20) kg $COD/m^3/d$ and found (0.6 - 3) kg $COD/m^3/d$ respectively. The ORL range for industrial wastewater is much higher than the domestic.

It is supposed that an increase in ORL will also increase the amount of biogas under normal operating conditions. The operating of AnMBR at a high ORL will have resulted in a high biomass concentration which leads to a large permeate flux. Thus, the membrane fouling will be increased and the membrane operation will be disrupted in the long term. AnMBR processes have the positive feature of tolerating alteration in the organic loading like tolerance to changes in temperature. Organic loadings rates to AnMBR in the range of 0.5 to 12.5 kg/m^3 were applied for domestic wastewater treatment. The AnMBR system achieved COD removal efficiency of 97%, and COD concentration in the effluent of less than 20 mg/L (Musa et al., 2018).

3. Hydraulic Retention Time (HRT): from an economic aspect HRT is a significant parameter that has a big impact on costs. Hu and Stuckey (2006) investigated the performance of the anaerobic MBR when run at an ambient temperature of 35 °C and the authors found the COD amount increased insignificantly while the HRT reduced as a consequence of HRT increase. Chu et al. (2008) also investigated the influence of HRT on a membrane-instrumented to EGSB reactor performance of several temperatures and they showed that the efficiency of COD removal was not influenced by HRT at temperatures higher than 15 °C, also, it was observed an efficiency increasing in COD removal with HRT increase at a temperature of 11 °C which indicates the importance of HRT at low temperatures. The authors controlled HRT, independent from up-flow velocity, by effluent recirculation to the reactor. But, when recirculation is not applied in up-flow reactors, the impacts of HRT and up-flow are inversely interrelated to each other.

4. Up-flow Velocity (Vup): it is an important parameter having two opposing effects on the biological removal efficiency in up-flow reactors. An increase in the Vup may enhance mixing providing better substrate–biomass contact. On the other hand, increasing Vup may deteriorate the removal efficiency by exceeding the settling velocity of particles, resulting in the detachment of the captured solids due to high hydraulic shear force. Different up-flow velocities were applied in Chu et al. (2008) study by using effluent recirculation in a membrane-coupled EGSB reactor, and a better COD removal performance was achieved at higher up-flow velocities. In addition to significant enhancement in the removal efficacy of COD, a slight increase was observed in Vup at 25 °C comparing with a higher increase at 11 °C, this increase illustrated the vital need for sufficient hydraulic mixing at lower temperatures.

5. Sludge Characteristics: the operational conditions and the bioreactors type affecting the fraction of nutritional requirements and slow-growing bacteria. Various types of research are asserting an activity loss of biomass, especially of propionate degrades in AnMBRs, and this may be due to the lysis of the cells under high shear or disruption of the juxta-positioning of the hydrogen-producing bacteria and hydrogen trophic methanogens, enlarging the interspecies hydrogen transfer distance. On the other hand, Jeison et al. (2009) preserved both methanogenic and acetogenic activities in a crossflow AnMBR system applying liquid superficial velocities of 1 – 1.5 m/s and gas slug up-flow velocities of 0.1 m/s. Soluble microbial products (SMP) of a parallel operating UASB system were even lower than those of the cross-flow anaerobic MBR sludge using propionate as the substrate.

Several studies of the AnMBR treating municipal wastewater were focused on the microbial species composition of the biomass suspension and the fouling layer. Ho and Sung (2009) noticed that soluble microbial products (SMP) of the bio-solids adhered to the surface of the membrane was less than the bulk sludge biomass in an AnMBR. Therefore, suspended sludge showed a clear effect as a biofilm for biological removal comparing with the attached bio-solids which didn't show a clear effect. Lin et al. (2013) studied the sludge concentration influence in AnMBRs treating and the results showed that the COD concentrations have a relative steadiness independent from the fluctuations in sludge concentrations during the range of (6.4 to 9.3) g MLSS/L. Zhang et al. (2011) studied the fouling layer features and the sludge in the bulk liquid in an AnDMBR where removal is attained by a biofilm called cake layer which is created by bulk sludge. The microorganisms' types in the dynamic cake layer were revealed to be dissimilar to the sludge in the bulk space, and the activity was found bulk sludge higher than the dynamic cake layer as a result of the cake layer compactness which caused suppression of the mass transfer.

2.3.5 Factors Influencing the AnMBRs performance Treating Municipal Wastewater

The flux decline acts a key act in the identification of the desired membrane area, especially in long-term operation, because of its importance for AnMBRs treating municipal wastewaters feasibility and applicability. Therefore, the behavior of membrane fouling and mechanisms are influenced by various factors like properties of sludge, characteristics of the membrane, and operational conditions. Till now, membrane fouling in AnMBRs is not completely clear as a consequence of the complexity of membrane fouling, membrane materials, operational conditions diversity, and configurations in various published literature.

After identifying the main parameters that affect the performance of biological treatment, the main factors affecting filtration capacity in AnMBRs for treating domestic sewage will be elaborated hereafter.

2.3.5.1 Membrane Characteristics

1) Material: The AnMBR fouling degree is affected by the features of membrane material where the membranes with organic matters show a fouling behavior different from the inorganic. Organic membrane pollution is caused mainly by the formation of the cake layer while inorganic membrane pollution is caused mainly by inorganic deposition. Gao et al. (2011) examined variations in the rates of fouling and the composition of foulant layer contains 2 various organic materials. The study results showed that the pollution of ultrafiltration membranes of the polyvinylidene fluoride (PVDF), when coated with polyether block amide, is occurred slower than when used the uncoated polyetherimide (PEI), that relies upon the impact of membrane material on fouling. Moreover, the authors identified notable variations in the bacterial composition of various membrane materials, where the Bacteroidetes existed in the fouling layer of the PEI membrane while did not exist in the PVDF membrane. Besides, the authors noted that the interactions between microbial communities and the surface of the membrane may be influenced by membrane material.

2) Module Type and Configuration: Several membrane configurations are applied in AnMBRs such as hollow fiber, flat sheet, and tubular membranes, by various types of module configurations such as external cross-flow and submerged methods. Each of them has various configurations, for example, the submerged AnMBRs can be immersed in a separate membrane tank or immersed directly into the bioreactor. In general, hollow fiber and flat sheet membranes are preferred for submerged AnMBRs, while the AnMBRs with external cross-flow can be constructed using tubular membranes too. The properties of bulk sludge, fouling of membrane, and the attainable flux can be affected by the different hydrodynamic conditions of both the AnMBRs external cross-flow and submerged because of the extent of applicable shear rate. The

external cross-flow AnMBRs require a lower membrane area comparing with the submerged. Despite this, because of the high flow, the cross-flow pumps required energy will be high to be pumped to provide suitable force of hydraulic shear.

Martin-Garcia et al. (2013) compared specific energy demands for various AnMBR configurations for municipal wastewater treatment and the results showed that the submerged configuration needs 0.3 kW h/m³ and the external cross-flow configuration needs 3.7 kW h/m³. The use of small diameter tubular membranes may be decreased the amount of pumping energy and increased the membrane module of the parking area. On the other side, anaerobic biomass might be disrupted due to high hydraulic shear force and produce small particles, which lead to substantial fouling of the membrane. Also, the high hydraulic shear force may decrease the biological activity of anaerobic biomass.

An et al. (2009) examined the impact of various diameters of tubular membrane (3.0, 1.9, 1.2 mm), on an external cross-flow filtration performance in AnMBR for municipal sewage treatment. The authors found that the differences in transmembrane pressure (TMP) were alternately connected with the differences in the diameter of the tube, this fact was correlated to the buildup of particles that happened in the lumen. The large particles can block the small diameter tube, which leads to a significant membrane clogging comparing with the tubes with a larger diameter. The blockage of small diameter tubes led to an uneven flux distribution along with the membrane module and an improvement in the local flux, which finally caused more significant membrane clogging comparing with the larger diameter tube.

2.3.5.2 Operational Conditions

1) Shear Rate: it is very important to clean the formed cake layer on the surface of the membrane to achieve a stable performance of the AnMBRs. Two principle mechanisms may be

used to limit the particles deposition by providing shear on the surface of the membrane and limit their communication with the membrane, these mechanisms are cross-flow and biogas sparging. Choo et al. (2000) showed that the increase of the cross-flow velocity can reduce the cake layer resistance, where the fraction of the flux and small size particles positively correlated with the cake layer while the shear rate negatively correlated with the cake layer. While the shear rate can reduce the cake resistance and fouls and enhance the flux, it has a certain limit for gas sparging rate and cross-flow velocity.

Furthermore, a dense consolidated cake layer which is difficult to detach may consist because of high shear rates where it can spur the microbial flocs break-down of and rise of the resistance of the cake layer because of the selective fine particles accumulation in the cake layer as well as membrane pores over long period of operation which called the shear rate dilemma. At the high cross-flow velocities, the TMP can be kept for a long period but this process led up to high pollution because of small-sized particles precipitation inside the pores and on the surface of the membrane.

Also, the period and frequency of the shear rate that is applied may affect filterability. Vyrides and Stuckey (2009) stated that shifting between the biogas sparging modes; the continuous and the intermittent (ON for 10 min and OFF for 5 min) led to a little rise in TMP. Though, it enhanced the DOC removal rate in submerged AnMBR as a consequence of the creation of a thicker cake layer on the surface of the membrane. At these circumstances, a higher rate of bio-degradation was noted since the "food" was subjected to a dense.

2) Flux: to avert severe fouling in the filtration system, an efficient method must be followed. For example, the operation lower than the significant flux, which depends on the features of the membrane, the sludge characteristics, and the operating conditions. The growing flux led to an

unsteady operation because of the high and uncontrolled fouling rate indeed at higher gas sparging velocities (Martinez-Sosa et al., 2011).

3) Operation Mode: backwashing and relaxation are considered a strategy to reduce fouling, and the improvement of the backwash duration led to enhance the flux. The increase of the relaxation time led to enhancement in the permeate flux recovery and increase in permeability in addition to the effective removal of the cake layer from the surface of the membrane throughout the relaxation period (Chu et al., 2005). Gimenez et al. (2011) conducted an AnMBR pilot-scale provided with membranes of hollow fiber to treat the municipal wastewater. The authors found a flux of 10 L/m^2 h at an MLSS concentration of 22 g/L and with the help of relaxation, backwash, and degasification cycles the fouling was prevented. Besides that, a comparison was done by An et al. (2009) between relaxation, backwash, and continuous filtration modes by maintaining the TMP low for a longer time in all modes and then compare between them to choose the best mode.

4) Temperature: the effect of the temperature is on the viscosity of the filtered liquid, the rate of the biodegradation process, and the solubility of various compounds and gases. Despite the importance of temperature in the wastewater treatment process, it is difficult to change the temperature of the wastewater. Also, the increase of the solids content and the reduction in temperature can cause an increase in sewage viscosity (Martinez-Sosa et al., 2011).

5) Upflow Velocity (Vup): the increase in shear stress will lead to having a positive influence of the Vup on filterability. With the increase of the Vup, the permeability will increase too, which goes back to the impact of the shear of higher Vup. The drop of flux indicates the drop of Vup advising the insufficiency of shear force resulting from the high Vup to reduce the formation of cake layer. The reason for this is attributed maybe to an enhanced thickness of the cake layer and the strong adhesion of the foulants to the membrane surface (Chu et al., 2005).

6) Solids Retention Time (SRT): the key parameter that influences the flux with values usually falling at higher SRTs. The anaerobic systems' operation will become possible at the ambient temperatures when the SRT is roughly twice higher under mesophilic conditions. As a rule of thumb, SRT should be at least three times the doubling of the slowest growing organism responsible for bioconversion. The high capability of solids retention in membrane systems makes membranes ideally suited for anaerobic treatment of municipal wastewaters especially at low temperatures when the degradation rate of suspended solids (SS) and colloidal materials is the rate-limiting step. Since the particulate organics would also be retained in the reactor, they can eventually be further hydrolyzed and degraded. However, although membrane processes result in solids retention independently of temperature. The activity limitation of anaerobic microorganisms at low temperature might yield high colloidal and soluble solids in anaerobic effluents, increasing membrane fouling propensity (ÖZGÜN, 2015).

Huang et al. (2011) presented that higher SRTs, for more than 30 days, higher protein / carbohydrate (P / C) ratio were produced in extracellular polymeric substances (EPS) and lower P / C ratio in soluble microbial products (SMP), and this led to in severe fouling. Despite that, Herrera-Robledo et al. (2010) examined the impact of SRT in the ultrafiltration membrane which was used for polishing of the UASB reactor effluent, in both operations short-term and long-term. The study results showed that the SRT did not impact the quality of the effluent and the fouling rate. In the shorter filtration period, the flux was decreased and the TMP was increased, which leads to the assuming of a more rigid and strong fouling layer structure was developed in the system having long SRTs.

Hydraulic Retention Time (HRT): differences in HRT may change the MBR fouling ability. A limited number of studies have recorded the HRT influence in the types of a membrane coupled sludge bed reactor. Amongst them, An et al. (2009) study, this study related the HRT decreasing from 10 to 5.5 hours led to a reduction in the removal of solids by the bioreactor. Nonetheless, due to the separation of the membrane, the performance of the reactor was completely steady. Alongside that, Lew et al. (2009) noted that the fouling in the membrane was positively related to the concentration of the particulate matter arriving the membrane.

2.3.5.3 Sludge characteristics

Extracellular polymeric substances (EPS) are considered as the most important factor of sludge concerning membrane fouling, either bound or soluble. The soluble type called soluble microbial products (SMP). The severe fouling is happened because of the cake layer formation, which is formed by the absorption of SMP and EPS and the accumulation of membrane interior pore. The operational parameters like SRT, temperature, pH, OLR, and shear rate are considered the key significant factors affecting the composition and concentration of EPS and SMP. The reason for the considering of EPS which excreted from the microbial cells has an important impact on the fouling goes back to the increase of both the resistance of filtration and the mixed liquor viscosity.

Chu et al. (2005) estimated and calculated the number of EPS from both sludge that existed on the membrane surface and granules in an AnMBR. The authors assumed that EPS impacted the resistance of the cake layer by filling the spaces between the particles leading to an extreme decrease in the flux. Additionally, the liquor viscosity in the reactor was the constant through the operation period. Thus, the EPS influence is just on filtration resistance.

In Herrera-Robledo et al. (2010), the SMP was grouped into two predominant fractions including high and low molecular weight SMP, the high molecular weight SMP was connected with long SRT, incomplete organic matter hydrolysis, and rate limitations of anaerobic microorganisms at low temperatures of less than 20 °C.

Furthermore, Gao et al. (2011) observed that EPS is principally formed of proteins and considered the principal cause of fouling formation in AnMBRs. Besides, the authors observed variations in community structure between biomass suspension and the cake. Furthermore, not necessary to find the bacteria in both the suspension and fouling layer. The study resulted in the indication that some kinds act a direct role in fouling, for example through the membrane surface attaching including some that are probably to act the main part in the metabolism of inlet organic substances, act an indirect role or less important. So, if this hypothesis is right, the cells are selectively combined inside the layer of fouling.

2.4 Dynamic Membrane Technology

As mentioned before, there are two categories of membrane fouling; the pore-clogging and the cake of layer formation, which is known for its contribution to filtration resistance in MBRs, in both aerobic and anaerobic reactors. Besides, this layer is known as a secondary filter which is called a dynamic membrane (DM) due to its ability to reject several pollutants and pathogens. The use of the well-formed DM layer in aerobic dynamic membrane bioreactors (DMBR) and anaerobic dynamic membrane bioreactors (AnDMBRs) has many advantages such as low-cost membrane, high flux, and easy cleaning.

Though stated by the DM technology studies are limited, most of the researches have essentially focused on the aerobic DMBRs applications from 2000 AD onwards, while the AnDMBRs researches picked up the pace only after 2010 (Hu et al., 2017). The new studies of the AnDMBR process concentrate on its wastewater treatment performance, feasibility, influencing factors, bulk sludge characterization, the anaerobic bioreactor, and membrane module optimization, and the properties of the DM layer.

The given attention to the filtration process using the DM system is very limited (on all sides such as the characterization of the cake layer, the mechanism of its formation, the process of producing, and collecting biogas). Besides, previous references and studies on the subject of AnDMBR and its development method are insufficient as it needs more effort by researchers to work to enhance the application of this technology.

2.4.1 Integration of Several Anaerobic Reactors with MBR and DMBR

The kinds of anaerobic bioreactors involve an up-flow anaerobic sludge blanket reactor (UASB), a completely stirred tank reactor (CSTR), a fluidized bed reactor (FBR), an expanded granular sludge bed reactor (EGSB), and others. It should be noted here that most of the anaerobic bioreactor types have been successfully linked with MBRs to create different AnMBRs. Nonetheless, to date, only the UASBs and CSTRs have been combined with the DM filtration technology to create AnDMBRs (Hu et al., 2017).

The UASB reactor integrated into membrane separation can be used as a sensible choice to decrease the suspended solids concentration that have been sent to the membrane, considering the sludge bed would entrap most of the particulate matter by adsorption and biodegradation. In the bottom of the UASB reactor and inside the thick sludge bed, all of the biological processes will take place. The UASB reactor is considered suitable for the first step of municipal wastewater treatment because of its ability to remove physically particulate organics. So, this reactor can be used before the use of membrane as a biofilter to maintain the membrane from exposure to high suspended solids concentrations. For example, in Kleerebezem and Macarie (2003) study, the biomass concentrations were found with a range of 20 - 30 g/L, and the suspended solids concentrations found in the effluent after crossing the UASB reactor was below 1 g/L. Also in An (2009) study, the concentration of the total suspended solids (TSS) in a UASB reactor was ranged 11 - 32 g/L whereas the TSS concentration in the effluent was found lower than 50 mg/L. The results showed that the UASB Reactor can trap the solids in the effluent and control their quantity and properties, and these results demonstrate that the HRT and Vup of UASB membrane reactors are the most important parameters that serve to determine effluent efficiency (ÖZGÜN, 2015).

One of the studies that focused on the integration between UASB and AnMBR is Liao et al. (2006), the authors are proposed to eliminate the necessity in the UASB for a separator of gas-liquid–solids (GLS separator) and reduce the UASB reactors capital and installation costs using the membrane coupled UASB systems. Furthermore, increasing SRT drives to large biomass concentrations in the UASB reactor will decrease the organic fouling, and thus UASB reactor effluents with low COD concentrations.

Some studies have indicated that membrane filtration was used after the UASB systems in order not to restore concentrate into the bioreactor again as it was applied in AnMBRs as shown in Figure 2.6 (ÖZGÜN, 2015). The main advantages of this method are the ability to control hydraulics easily and saving the dilution rate as a bacterial selection criterion. Though, the disadvantage of this method is exposing the membrane to high-concentrations of suspended solids which leads to concentrated them in the tank of concentrate collection.

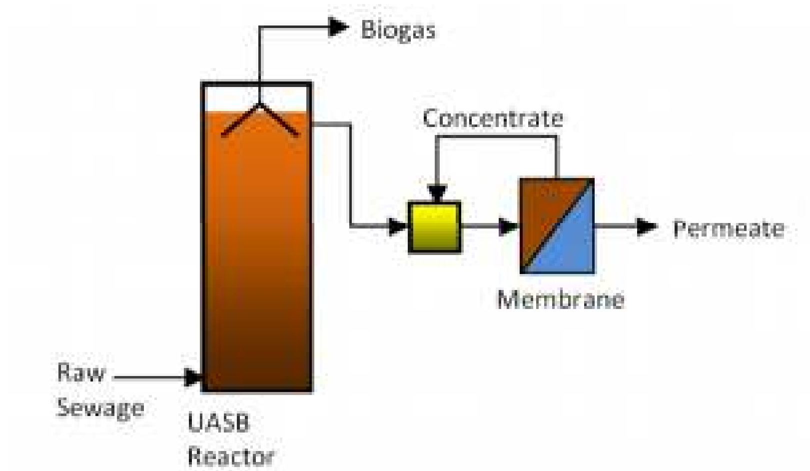

Figure 2. 6: UASB Post Effluent Polishing Using Membrane (ÖZGÜN, 2015).

On the other hand, AnDMBR configurations can be developed using all kinds of bioreactors and work on coupling submerged and side-stream membrane configurations, also these developments can be verified in the future (Hu et al., 2017). The modules of the membrane have three kinds: hollow fiber, flat sheet, and tabular. The hollow fiber DM modules are not reportedly used due to the complicated fabrication procedures and the low intensity of DM support material. The other kinds (flat-sheet and tabular) have been implemented in AnDMBR including both submerged and side-stream configurations. The DM modules used in the past studies were configured manually because of their unavailability. Also, a small number of authors used tubular DM modules in their studies to develop AnDMBRs because of the difficulty of tabular modules assembling compared to flat-sheet modules. The tubular DM is similar in structure to flat-sheet DM but it differs from the traditional tubular microfiltration and ultrafiltration membranes because of containing a double-faced filter with a large inner and outer diameter configured outside of the supporting skeleton.

The widely used DM modules, flat-sheet, are made up of inner and outer layers of support material and a frame. The use of the frame is to hold the inner and outer supporting layers together.

The material of the frame is alike to that of the traditional flat-sheet UF / MF films, involving stainless steel and PVC, and in addition to other materials. The inner layers' materials must have chemical stability and high density to be utilized to support the outer layers. Therefore, the materials which mostly used are stainless steel (for instance, large-porous 10 mm). While the materials of the outer layer use so-called support materials, involving woven and non-woven fabrics and mesh to support the DM layer for efficient separation of solid-liquid in both aerobic DMBRs and AnDMBRs (Hu et al., 2017). Past studies showed that the flat-sheet module and the tubular module essentially utilized in submerged AnDMBRs more than in side-stream because of the unsuitability of their present structure to use in side-stream AnDMBR configuration.

2.4.2 AnDMBR by Others

Zhang et al. (2011) studied the fouling of the membrane after treating the municipal wastewater by operating AnDMBR for 11 months with a high flux of 65 L/(m^2h). The results showed that the fouling contains two layers a tightly bound internal layer and a loosely bound outer layer, and the foulants were found in the membrane chambers. In a comparison with the bulk sludge, membrane foulants in the internal layer and the membrane chamber were found to have more fine particles. The study concluded that the Dacron mesh could not achieve a good refusal of soluble macromolecules, which drove to low soluble microbial products and extracellular polymeric substances contents in the membrane fouling layers but high contents in the foulants in membrane chambers. Also, the membrane foulants had some different communities and lower activities compared with the bulk sludge.

Ersahin et al. (2016) investigated the role and characteristics of the DM layer in AnMBR by operating a submerged AnDMBR to treat concentrated wastewater. The authors found that the DM layer has an important role in the treatment process and filtration performance and the removal of organic matter. The DM layer was formed based on both organic and inorganic matter. in general, this study presented knowing of the structure of dynamic membrane layer in the AnDMBR which maybe lead to increase the use of this technology in the future.

Hu et al. (2017) presented a review of dynamic membrane (DM) module, bioreactor configurations, and DM layer formation and cleaning. And then the AnDMBR process for wastewater treatment and concerning pollutant removal, DM filterability, biogas production, and potential advantages over the conventional anaerobic membrane bioreactor (AnMBR) was presented. Besides, the important factors affecting the treatment process and performance. Finally, the challenges faced and perspectives regarding the future development of the AnDMBR process to promote its practical applications are presented.

Quek et al. (2017) investigated the ability to apply DM technology in UASB and DMF-coupled processes for municipal wastewater treatment. The authors showed that the coupled process and removal efficiencies of over 64 and 86% for TCOD and TSS, respectively. The authors found that if the pore size increased the fouling rate will be increased too, also a 67% increase in operating flux resulted in a 25% increase in fouling rate. The study resulted in the DMF with Mesh 300 support layer and operating at 100 L/m^2-h was the most effective configuration for treating the effluent of the UASB operated with an HRT of 6 h. In general, the coupled process improved the system robustness and reduced variability of the treated effluent.

Yang et al. (2019) investigated the ability to the treatment of the domestic wastewater using Up-flow AnDMBR at ambient temperature (20–25 °C) and various HRT (8 h, 4 h, 2 h, and 1 h). The authors found that the decrease in HRT will appear raises in solvent microbial materials in the liquid phase and accumulation of tryptophan protein-like substances and aromatic protein-like substances in the DM layer, mainly when the HRT was reduced to 1 h. Whilst the up-flow

AnDMBR proved appropriate to the wastewater treatment at ambient temperature with short HRTs. The HRT limit for maintaining stable operation can be 2 hours.

Berkessa et al. (2020) studied and investigated the performance and microbial community structure of the AnDMBR to treat textile wastewater. The reactor showed excellent soluble COD and color removal of 98.5% and >97.5%, respectively. DM layer grown over the 3D printed dynamic membrane support showed decent rejection for high molecular weight compounds more than 20 kDa and the TSS rejection by the DM layer was more than 98.8%. Gel permeation chromatography analysis of EPS and effluent samples revealed EPS accounted for more than 76.7% of molecular weight fractions less than 20 kDa that end up in the effluent.

2.5 Economic Feasibility of AnMBRs Process

Financial aspects are considered a major certain standard for the process selection between competing technologies. Due to the large influent flow rate of municipal wastewater a new interest in using the treated wastewater in irrigation has appeared, but it required high membrane surface areas. So, must study the feasibility of the pumps energy-consuming and the whole cost including the cleaning agents and the additional membrane system devices. Nevertheless, the studies about any economic information are limited for municipal wastewater treatment using AnMBRs. The main factor to define the economic feasibility is the reduced flux which leads to an increase in the costs of AnMBR technology due to the requirement of higher suction pressure, the need for membrane replacement and cleaning continuously, the larger surface area of membranes, and more intensive biogas recycling.

Lin et al. (2011) estimated the submerged AnMBR system economic feasibility depending on the overall costs of treating municipal wastewater whereas they are denoted by the summation of capital costs (involves membranes, plant equipment, tanks costs) and the operational costs (include chemicals, sludge disposal, and power). The authors found that the largest costs are membrane costs of 72% then pursued by the tank construction and screens costs. The noted low fluxes stay the barrier for the submerged AnMBRs potential application in treating municipal wastewater due to the costs of the membrane are correlated linearly for the suitable flux. For example, should preserve the membranes from damage and increase their life by applying a coarse screening pursued by a fine screening in full-scale systems, alike aerobic MBRs. The most important operational cost is gas scouring energy. Because of the risen energy, blower, and sludge disposal costs, the measured AnMBRs' operational costs were three times lower than those for aerobic MBRs. Furthermore, the produced methane could be used as a source of energy which leads to a decrease in the AnMBR operational costs. Martin et al. (2011) studied the feasibility and found that the energy demand correlated to the aerobic MBRs was two to three times higher than the energy demand correlated to AnMBRs fouling control. Owing to the reported lower fluxes for AnMBRs in previous studies, the capital costs associated with the aerobic MBRs may be lower than the membranes associated costs.

Achilli et al. (2011) studied the operational costs and a comparison was done between the treating municipal wastewater for both an aerobic MBR and AnMBR. They noticed that the AnMBR operational costs were lower than that the aerobic MBR operational costs because of the excess sludge management of the aerobic MBR. Nevertheless, the anaerobic MBR system needed a longer adaptation time for steady operation than the aerobic MBR. Also, Lin et al. (2011) produced an analysis involving the impact of differences in different parameters like HRT, membrane price, flux, interest, gas specific demand per unit of the membrane, and membrane lifetime, and then summarized that the highest impact on the total costs of the life cycle returned to the influent flow after it defined the system capacity and footprint.

Additionally, all changes in the system such as the applicable flux, membrane lifetime, membrane cost, and moderate effect of interest will affect the costs while the specific gas demand per unit and HRT have a lower impact on costs. More researches on economic analysis are required to keep up with the accelerated growth and application of AnMBR technology, especially in full-scale systems.

2.6 Problems Encountered and Future Perspectives

2.6.1 Problems Encountered

When taking into account the achievement of high-quality effluent and its reuse after treatment, will help in the development of the existing anaerobic with membranes treatment processes and make them of vital importance (ÖZGÜN, 2015).

Although the effluents of AnMBR are appropriate for irrigation due to free of the pathogen, the application of this technology not yet turn into real due to reluctance due to membrane fouling problems and the novelty of the system. Thus, AnMBR systems should make use of advantages gained from the technical developments to abate fouling. One of the major reasons for fouling is inorganic fouling due to the precipitation of struvite ($MgNH_4PO_4.6H_2O$), ($K_2NH_4PO_4$), and/or ($CaCO_3$) where during the anaerobic digestion, this precipitation releases phosphate and ammonia from organic phosphorus and nitrogen while the changes in alkalinity generation and CO_2 partial pressure in AnMBRs increase the pH.

Salazar-Pelaez et al. (2011) evaluated the precipitation of struvite and found that the precipitation of the struvite would be unlikely to occur in the municipal wastewater due to its status of under-saturated with lower concentrations of NHþ4, Mg+, and PO_2 comparing with the industrial wastewater. In addition to these ions' concentrations, the properties of the membrane can act an important role in the precipitation of struvite. As a result of the irreversible fouling phenomenon, long-term studies must be examined using AnMBRs for treating the municipal wastewaters. In general, the use of the treated municipal wastewater in agricultural irrigation faces some affairs concerning the toxic material removal like the endocrine disrupting compounds. Also, the discharges of industrial wastewater to public sewer network can bring serious problems like toxicity and overloading of the wastewater treatment plants. (ÖZGÜN, 2015). Besides that, in Saddoud et al. (2006) study showed the use of an AnMBR provided with a cross-flow ultrafiltration module and examined the municipal wastewater treatability which contains the discharges of industrial wastewater full of toxic materials. Moreover, Ellouze et al. (2009) examined the effluents of the AnMBR system and noted that there is residual toxicity was passed through the membrane in the treated wastewater because of the precipitation of toxic dissolvable compounds from discharges of industrial wastewater into the sewer.

However, the anaerobic MBR effluent was found to be remarkably fewer toxic than the traditional processes effluent. Several studies discuss the removal of endocrine-disrupting chemicals in MBR systems to treat municipal wastewater. Phenolic compounds, estrogens, and phthalates can be cleared using aerobic MBRs more effectively than using the conventional systems by biodegradation, membrane rejection mechanisms, and adsorption. Nonetheless, restricted information around their fate and biodegradation in the AnMBRs.

2.6.2 Future Perspectives

Due to the great importance of AnMBR technology and its ability to reduce cost and obtain high water efficiency, researchers should be urged to study many kinds of research on the possibility of applying this technology to purify municipal and industrial wastewater, especially at low temperatures, where the significant decrease in the rate of hydrolysis of solids is considered typically at ambient temperatures because of the low activity of anaerobic microorganisms. The loss of methane during the low-temperature treatment process is also an issue of concern due to the solubility of methane in the liquid at low temperatures (ÖZGÜN, 2015).

The AnMBR technology, alternative membrane materials, membrane integration possibilities, and reactor types must take place of interest for further development in wastewater treatment technologies in the future. The use of DM technology will be reduced the capital costs correlated with the buying and rehabilitation of membranes because it concentrates on the usage of fabrics or meshes as a support material rather than real normal membranes is earning more attention in the application for AnMBR.

Till now, many trials have been made to use anaerobic dynamic membrane reactors. These attempts showed promising removal efficiency that is equivalent to conventional membranes. Though, more research is needed to elucidate the dynamic cake layer formation mechanisms and to efficiently control them for practical application (ÖZGÜN, 2015).

CHAPTER THREE
MATERIALS AND METHODS

In this chapter, the materials and methodology will be presented to explain the used process.

3.1 Wastewater Treatment Plant Description

The selected treatment plant is in Ram Allah/Palestine which is called Al-Tira Wastewater Treatment Plant (WWTP). Al-Tira WWTP is considered the first of its kind in Palestine and the adjacent countries and one of the latest technologies used in such plants, which works to treat wastewater at a rate of 2,200 m^3/day, and the treated effluent is used for all types of agriculture irrigation where it is classified as A class according to the international standards, so this water is appropriate for non-specified irrigation, and it can be mixed with groundwater without risk. Al-Tira WWTP works with organic membrane technology, and this technology is not used in the region, which is considered one of the latest technologies used in such plants. This WWTP is composed of an aerobic MBR system that was fed with sieved influent of a 2mm pore size. Also, the WWTP had installed two UASB reactors with a working volume of 140 L. The design parameters (flow rate, HRT, height, and diameter) of the UASB reactors will be shown in Table 3.1 below.

Table 3. 1: The Design Parameter of UASB Reactor

Design Parameter	Unit	UASB reactor
Flow rate	L/d	177
HRT	D	1
Height	m	2.50
Diameter	m	0.30

3.2 Experiment Setup and Procedure

For this study, one of the UASB reactors that exist in Al-Tira WWTP was used and upgraded to AnDMBR and it was served with domestic wastewater from the main wastewater trunk at the WWTP. The UASB reactor and AnDMBR were operated and started up in January of 2020 at ambient temperature treating sieved domestic sewage, which is variated between 25-36 °C. First, the wastewater was pumped into a 300 L plastic holding Tank from the screens after preliminary treatment, then three peristaltic pumps were separately used to feed wastewater into the UASB reactors and to collect permeate line with a flow rate range of 5 - 500 ml/min., the wastewater had stayed in the reactor for 24 h. The influent was distributed in the UASB reactors through a Polyvinyl chloride (PVC) tube with 4 outlets located 5cm from the bottom and installed along the reactor. After that, the effluents will flow to the second tank for a while and then will be flowed into the membrane by a flow of 124 L/d. Finally, the effluent will have flowed to the third tank. Figure 3.1 shows the AnDMBR form which is composed in Al-Tira WWTP. Appendix A Table A-1 page 1 shows the schematic diagram of the experimental set-up.

The samples of this experiment were taken by emerging lines from the three tanks and they were batch packed in sterile plastic containers and then directly analyzed. The generated biogas from the reactor was measured continuously by gas counters (Ritter, Milligas Counter, MGC-1 PMMA) and then a 16% of NaOH solution was displaced to measure methane quantities and held the CO_2 in the solution.

Figure 3. 1: The AnDMBR Process.

The AnDMBR was equipped with a rectangular membrane module, this membrane had two filtering sides. A mono-mono filament woven fabric, made of polypropylene material, which is made in Lamp BV/Netherlands, with an average pore size of 10µm, was used as the support material, Figure 3.2 shows the used membrane module in the study. Besides, frequent flushing was applied to control both the dynamic cake layer thickness on the surface of the woven fabric and the TMP, so the dynamic membrane (DM) component was operated in cycles of filtration and flushing.

Figure 3. 2: The Rectangular Membrane Module.

Generally, the starting off daily monitoring was begun when the experiment starts, which includes the measurements of the temperature of ambient and the production of the biogas.

3.3 The Experiment Sampling

In this study, the number of collected samples was approximately 25 samples for 1) the influent to Al-Tira WWTP, 2) the influent to the UASB reactor, 3) the UASB reactor effluent, 4) the AnDMBR effluent, and 5) Al-Tira WWTP effluent. These samples were taken in a period of four months (from July to October of 2020) and they were taken 2 to 3 times per week with a volume of 1 L for each and then these samples were kept at 4ºC until they were analyzed. The wastewater and ambient temperatures in the WWTP were measured daily by an alcohol thermometer. The samples were analyzed to measure the wastewater characteristics including COD_{tot}, COD_{sus}, COD_{coll}, COD_{diss}, BOD_5, TSS, VSS, pH, and FC according to standard methods (APHA, 2005).

3.4 Analytical Methods

The analytical methods are divided into two parts; chemical analysis and physical analysis. These analyses will be discussed to measure the characteristics of the samples for the study.

3.4.1 The Chemical Analyses

These analyses will be done according to the standard methods (APHA, 2005) to measure the following parameters:

1. The Chemical Oxygen Demand (COD)

The COD was analyzed using the reflux method by acid destruction at a temperature of 150 ℃ for 120 min. The absorbance was then measured by a spectrophotometer at 600 nm wavelength. The samples were filtered through (595½) 4.4 µm paper filters to measure the total

COD (COD_{tot}) and paper-filtered COD (COD_{filt}), also a filter of 0.45-µm was used to measure the dissolved COD (COD_{diss}). Besides, to measure the suspended COD (COD_{sus}) and colloidal COD (COD_{coll}) Equations 3.1 and 3.2 will be used.

$COD_{sus} = COD_{tot} - COD_{filt}$ ……………………… Equation 3.1 (APHA, 2005)

$COD_{coll} = COD_{filt} - COD_{diss}$ ……………………… Equation 3.2 (APHA, 2005)

2. Biological Oxygen Demand (BOD)

The BOD was measured for all samples using BOD bottles, where after diluting the wastewater, it was put in the bottles then the initial dissolved oxygen was measured. The final dissolved oxygen was measured after 5 days of incubation at a temperature of 20 °C.

3.4.2 The Physical Analyses

These analyses will be done according to the standard methods (APHA, 2005) to measure the physical parameters:

1. Total Suspended Solids (TSS)

Total suspended solids are one of the quality parameters used to evaluate the quality of wastewater. The TSS is the dry-weight of suspended particles, that are not dissolved, in a sample of water that can be trapped by a filter that is analyzed using a filtration apparatus (Wikipedia, 2010). TSS was measured using an oven drying at 105 °C.

2. Volatile Suspended Solids (VSS)

Volatile suspended solids are a water quality measure obtained from the loss on ignition of the mass of measured total suspended solids. This ignition generally takes place in an oven at a temperature of 550 °C (Wikipedia, 2010).

3. pH

pH is a scale used to specify the acidity or basicity of samples. All of the samples were examined to determine the pH values by pH meter (HACH).

3.4.3 Microbiological Research

The fecal coliform (FC) is considered as a quality measurement for the wastewater where it indicates contamination and microorganism for other pathogens that may be present in feces in the wastewater. The fecal coliforms should be removed when the treated wastewater is going to be reused for unrestricted irrigation (Mahmoud, 2017). However, FC's existence in water does not necessarily designate the existence of feces and may not be directly harmful. There are several studies with detailed information about the FC tests theoretical background, used method, and used probes.

3.5 Calculations

Removal Efficiency

The removal efficiency was calculated to compare between the parameters of treated wastewater before (Influent) and after (Effluent) the UASB reactor, MBR, and WWTP efficiency, Equation 3.3 was used to measure the removal efficiency.

$Removal\ Efficiency\ (\%) = \frac{Influent - Effluent}{Influent} \times 100\%$........Equation 3.2 (Al-Jamal, 2005).

CHAPTER FOUR
RESULTS AND DISCUSSION

In this chapter, all of the measured results are discussed and presented. The removal efficiency of parameters which was measured will be presented and compared to show the efficiency of the water after treatment and the ability to use it in agricultural irrigation.

4.1 Influent Sewage Characteristics

Municipal wastewater is mainly comprised of water (99.9%) together with relatively small concentrations of suspended and dissolved organic and inorganic solids. Based on these concentrations, Table 4.1 is used to determine the strength of municipal wastewater in this study which influent to Al-Tira WWTP.

Table 4. 1: Major Constituents of Typical Domestic Wastewater (Darwish, 2014).

Constituent	Concentration, mg L^{-1}		
	Strong	Medium	Weak
Total solids	1200	700	350
Dissolved solids (TDS)	850	500	250
Suspended solids	350	200	100
Nitrogen (as N)	85	40	20
Phosphorus (as P)	20	10	6
Chloride	100	50	30
Alkalinity (as $CaCO_3$)	200	100	50
Grease	150	100	50
BOD_5	300	200	100

The strength classification of the wastewater was determined based on COD values of the raw wastewater in this study which varied from medium to strong strength. Table 4.2 presents the characteristics of the raw wastewater which includes COD values (total, suspended, colloidal, and dissolved), BOD5, NKj, phosphorous, sulfate, ammonia, and solids, all of these results were measured from 25 samples conducted in the period from 22th of July/2020 to 22th of October/2020.

Table 4. 2: The Characteristics of the Raw Wastewater.

Parameter	No. of Samples	Range	Average	STD
COD Total (mg/l)	25	903-1293	1058.28	109.81
Suspended(mg/l)	25	433-722	570.52	83.09
Colloidal (mg/l)	25	136-331	193	46.74
Dissolved (mg/l)	25	198-377	294.76	45.34
BOD_5 (mg/l)	10	409-593	493.9	55.16
COD/BOD	10	1.89-2.51	2.12	0.22
TSS (mg/l)	12	496-888	658	112.45
VSS (mg/l)	12	328-792	524.67	129.61
TSS/VSS	12	72.73-91.43	80.11	5.73
pH	15	6.43-7.64	7.28	0.36
Tww C	25	20-30	29.96	3.28
Tamb. C	25	25-36	24.68	3.06
FC (CFU/100ml)	3	84×10^5-148×10^5	119×10^5	32.419×10^5

The COD portions' results for Al-Tira WWTP influent are compared with the results of Ramallah that mentioned in Mahmoud et al. (2003) study. Based on that, the COD_{sus} forms the highest fraction of the COD_{tot} which approximately equals 53.91% (570.52 mg/l), and this value higher than the reported value in Mahmoud et al. (2003) study which was 50.28%. Also, the COD_{coll} represents 18.24% (193 mg/l) of the COD_{tot}, and this value higher than the reported value in Mahmoud et al. (2003) study which was 14.82%. While the COD_{diss} value is 27.85% (294.76 mg/l) which is lower than the reported value in Mahmoud et al. (2003) study which was 34.91%. Generally, the results show that the percentage particulate COD (colloidal and suspended) of total COD for this study is 72% which is higher than the value of Ramallah of 65%, which indicates the pollution of organic matter by water became more serious.

The TSS and VSS values of this study are high where the TSS of 658 (112.45) mg/l and VSS of 524.67 (129.61) mg/l, but in a comparison with the results of TSS and VSS in the study of Mahmoud et al. (2003) they showed lower values. The Coefficient of Variation (CV) rate was used to compare between the results of TSS and VSS and showed that the TSS CV rates are 17.1% for

WWTP and 27% for Mahmoud et al. (2003), while the VSS CV rates are 24.7% for WWTP and 35.8% for Mahmoud et al. (2003). The high VSS values of Al-Tira WWTP indicates high lipids content.

4.2 Performance of MBR

The performance of the used MBR in this study will be shown by analyzing the results of tests that were used to determine the characteristics of the treated wastewater and measuring the removal efficiency, and then compare between the efficiency rates of effluents for the UASB reactor, the MBR, and the WWTP.

4.2.1 COD Removal Efficiency

The removal efficiency measured using Equation 3.3 for the COD parameter to compare the treated wastewater and show the efficiency of using membranes. Table 4.3 shows the averages of COD values for the influent to Al-Tira WWTP, the influent to the UASB reactor, the UASB reactor effluent, the AnDMBR effluent, and Al-Tira WWTP effluent. Also, the Figure 4.1shows the COD_{tot} values for 25 samples of the UASB reactor effluent, MBR effluent, and WWTP effluent, these results showed a decrease in COD_{tot} values which indicates a better efficiency of the treated wastewater. According to the characteristics of treated wastewater used for irrigation mentioned in Hidri et al. (2013) the COD_{tot} value is near to the acceptable range (96.33±13.32 mg/l) which indicates the system needs some modifications or improvements to reach the required needs.

Table 4. 3: The COD Values for Influent and Effluent in this Study.

		WWTP Influent	Model Influent	Reactor effluent	MBR Effluent	WWTP Effluent
COD	Total	1058.28	716.76	336.48	154.32	23.12
	Suspended	570.52	319.44	112.80	46.56	-
	Colloidal	193	138.36	75.64	40.04	-
	Dissolved	294.76	259.08	146.76	68.36	-

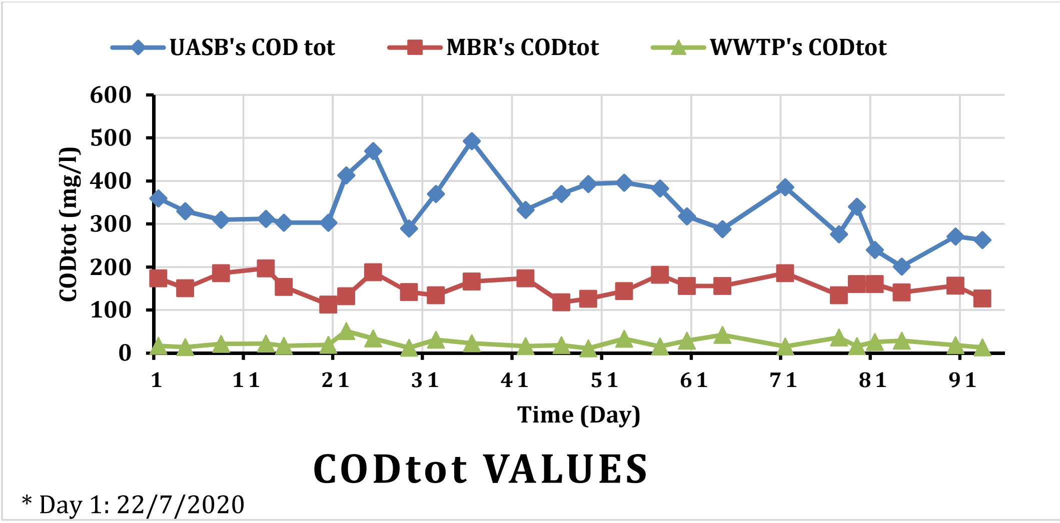

Figure 4. 1: The COD_{tot} Values for UASB Reactor, MBR, and WWTP.

The removal rate for the COD_{tot} using the MBR equals approximately 85% which is lower than the COD_{tot} removal rate of WWTP of 98%, these rates indicate the high efficiency of the WWTP which is better than the MBR. Figure 4.2 compares the removal rates of COD values (total, suspended, colloidal, and dissolved) for UASB reactor, MBR, and Al-Tira WWTP, where the lowest removal efficiency is related to UASB reactor with a removal rate of 68% for the COD_{tot}.

The removal rates of the COD_{sus}, $COD_{coll.}$, and $COD_{diss.}$ using MBR are approximately 92%, 79%, and 77% respectively. While the removal rates of the COD_{sus}, $COD_{coll.}$, and $COD_{diss.}$ using UASB reactor are approximately 80%, 61%, and 50% respectively. These results indicate the high performance of the MBR in a comparison with the UASB reactor. Appendix B Table B-1 page 2 will show more details about the COD values for influent wastewater and Table B-2 page 3. will show more details about the COD values for effluent wastewater from (UASBR, MBR, and WWTP).

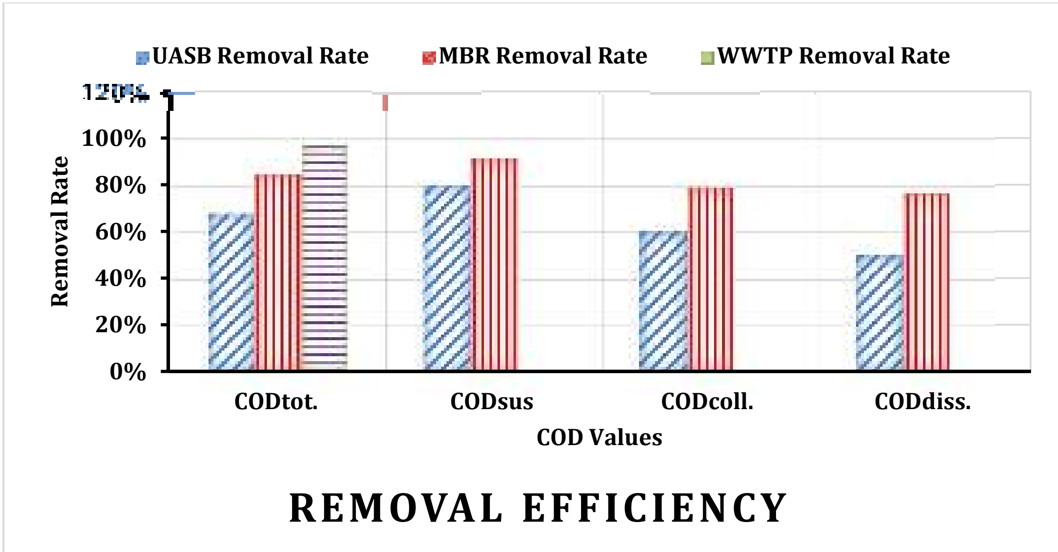

Figure 4. 2: The Removal Efficiency of COD Values.

4.2.2 BOD Removal Efficiency

The BOD_5 was used as a measure of the biodegradable organic matter in the wastewater, wherein this study the BOD_5 values measured for the UASB reactor and MBR for 10 samples. Figure 4.3 shows the values of BOD_5 for the samples after each step where the average BOD_5 values for the UASB reactor equals 152.9 (31.8) mg/l while for the MBR equals 76.8 (16.88) mg/l. The CV rates were used to compare these values which showed that the CV rates of BOD_5 values for UASB and MBR equals 20.80% and 21.98% respectively which indicate a better performance of the treated wastewater after using MBR. According to the characteristics of treated wastewater used for irrigation mentioned in Hidri et al. (2013) the BOD_5 values are higher than the acceptable range (22.33±1.53) might be it is backward to the high value of pH.

The removal efficiency of the BOD_5 values for the UASB reactor and MBR was measured and compared, where the removal rate for the reactor was 69% while for MBR was 84% which indicates better efficiency in treating wastewater using the MBR. Figure 4.4 shows the removal efficiency in all samples using both treatments and the average values for both too. Appendix C Table C-1 page 4 shows more details about the values of BOD_5 for each step.

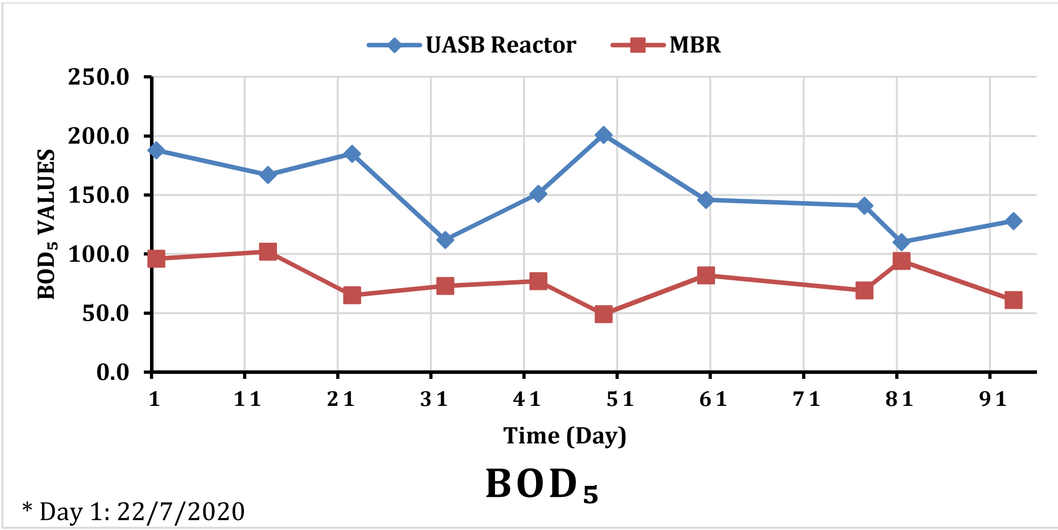

Figure 4. 3: The BOD_5 Values for UASB Reactor and MBR.

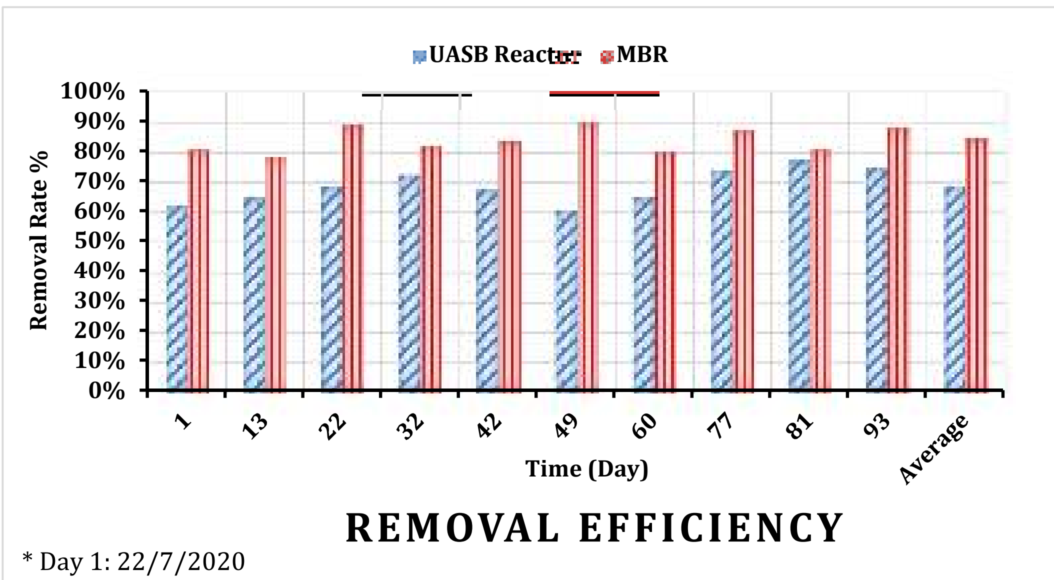

Figure 4. 4: The Removal Efficiency of BOD_5Values.

4.2.3 TSS and VSS Removal Efficiency

Removal of suspended solids in reactors occurs by physical processes such as settling, adsorption, and entrapment. SS removal in reactors depends on the type of sewage, temperature, and the combined effect of the sludge bed height and the liquid up-flow velocity (Vup) in the reactor, the latter parameter related to the hydraulic retention time (HRT) and the reactor height (AlShayah, 2005).

The removal of suspended solids is one of the main objectives of wastewater treatment, so in this study, the values of TSS were measured and the efficiency of the reactor, MBR, and WWTP was identified. 12 samples were tested to identify the treated wastewater efficiency, Figure 4.5 shows the TSS values for all samples after each step where the average TSS for the UASB reactor was 194.1 (64.6) mg/l and the average of TSS for MBR was 115.3 (25.4) mg/l. The CV rates were used to compare these values which showed that the CV rates of TSS values for UASB and MBR equals 33.3% and 22% respectively which indicate a better performance of the treated wastewater after using MBR.

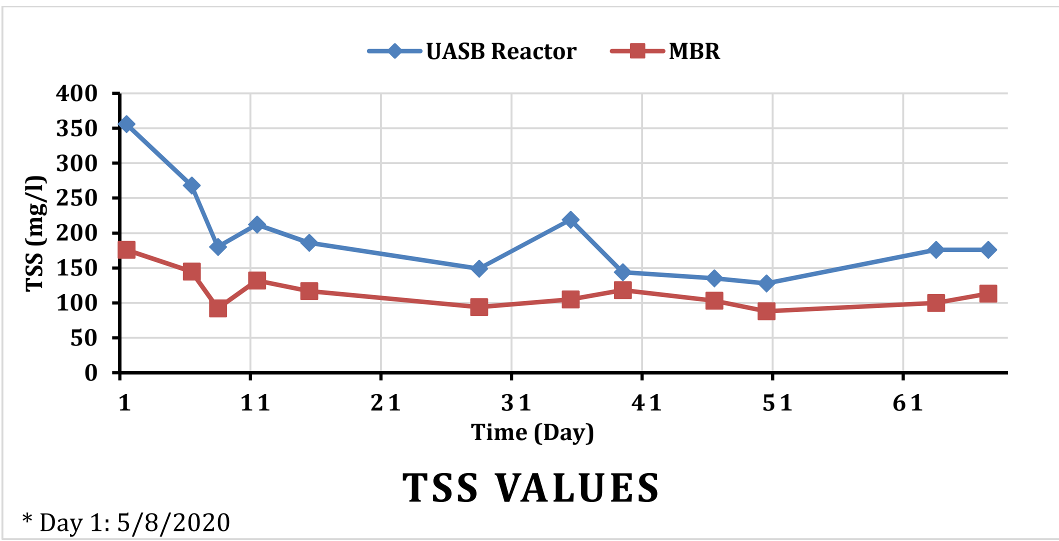

Figure 4. 5: The TSS Values for UASB Reactor and MBR.

The removal efficiency of the TSS values for the UASB reactor and MBR was measured and compared, where the removal rate for the reactor was 71% while for MBR was 82% which indicates better efficiency in treating wastewater using the MBR. According to Al-Jamal (2005), the removal efficiency of the UASB reactor was about 78% and the MBR removal efficiency in this study is higher which indicates better performance in the removal of the suspended solids. Figure 4.6 shows the removal efficiency in all samples using both treatments and the average values for both too. Appendix D Table D-1 page 5 shows more details about the values of TSS for each step.

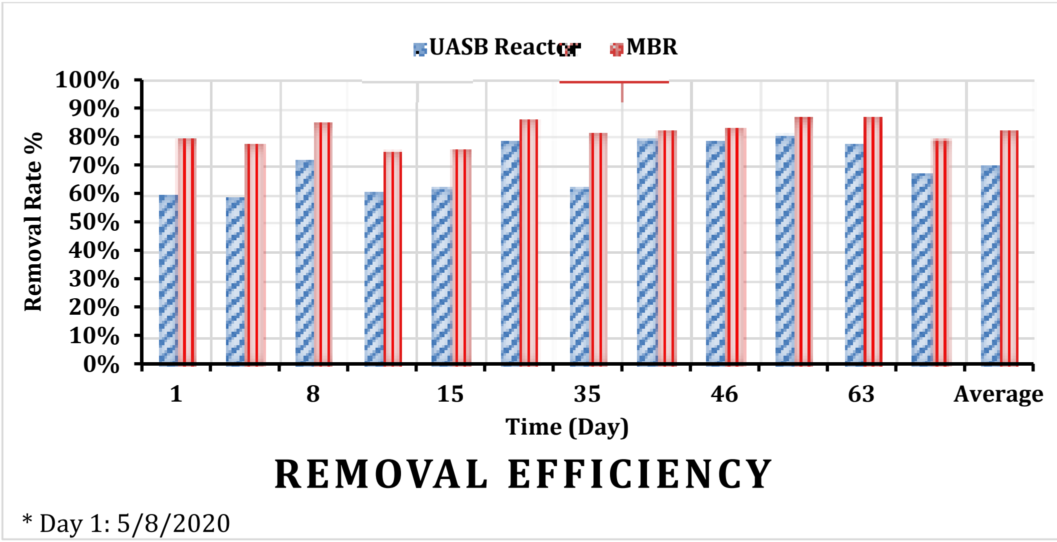

Figure 4. 6: The Removal Efficiency of VSS Values.

Figure 4.7 shows the VSS values for all samples after each step where the average VSS for the UASB reactor was 96.8 (9.5) mg/l and the average VSS for MBR was 82.5 (21.6) mg/l. The CV rates were used to compare these values which showed that the CV rates of VSS values for UASB and MBR equals 10% and 26% respectively, which the variation indicates far values than the average value which caused a difference in CV rates.

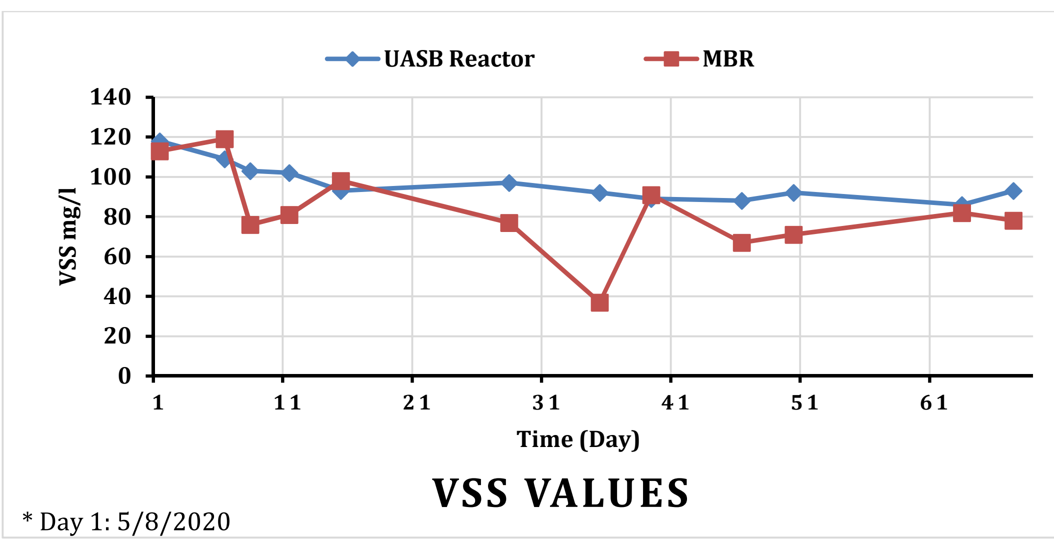

Figure 4. 7: The VSS Values for UASB Reactor and MBR.

The removal efficiency of the VSS values for the UASB reactor and MBR was measured and compared, where the removal rate for the reactor was 82% while for MBR was 84% which indicates a convergent efficiency in treating wastewater. According to Al-Jamal (2005), the removal efficiency of the UASB reactor was about 78% and the MBR removal efficiency in this study is higher which indicates better performance in the removal of the suspended solids. Figure 4.8 shows the removal efficiency in all samples using both treatments and the average values for both too. Appendix D Table D-2 page 5 shows more details about the values of VSS for each step.

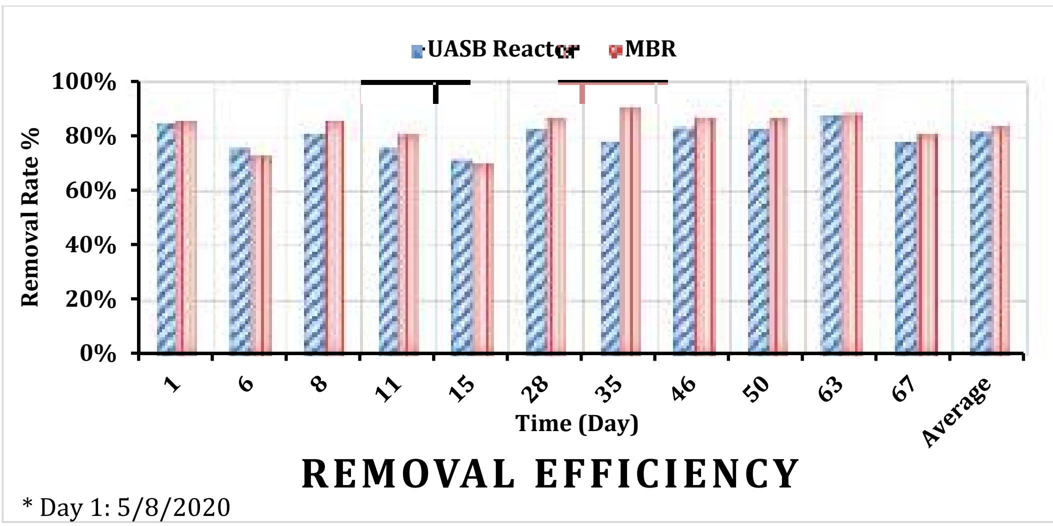

Figure 4. 8: The Removal Efficiency of VSS Values.

4.2.4 pH Values

the importance of the pH value returns to the methanogenesis which needs to maintain a high pH rate in a natural rate that ranged from 6.3-7.8 (Al-Jamal, 2005). In this study, the pH values were measured for 15 samples and found similar to each other where the average pH values for UASB reactor, MBR, and WWTP are 7.07 (0.36) mg/l, 7.64 (0.7) mg/l, and 7.31 (0.45) mg/l respectively, and convergent to the WWTP influent average value which is 7.28 (0.36) mg/l. The highest value returns to the MBR and according to Hidri et al. (2013) it is in the acceptable range for the irrigation uses (7.4-7.8), Figure 4.9 shows the pH values for influent and effluent. Appendix E Table E-1 page 6 shows more details about the values of pH for each step.

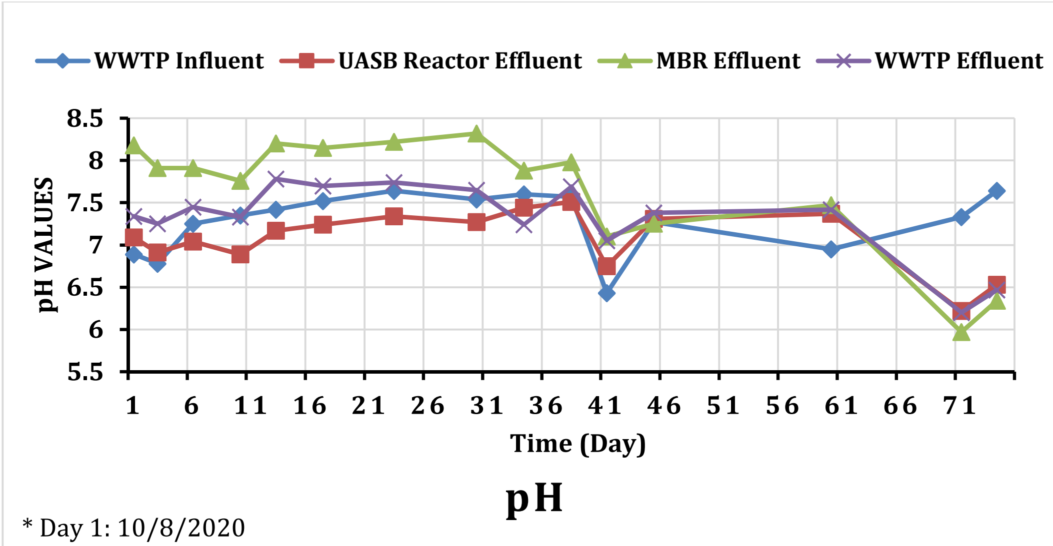

Figure 4. 9: The pH Values for Influent and Effluent through the Process.

4.2.5 The Fecal Coliform (FC)

As mentioned before, the FC is the quality measurement for the wastewater which indicates contamination and microorganism for other pathogens that may be present in feces in the wastewater. In this study, the FC values were measured for 3 samples. The average of FC for the WWTP influent was 119×10^5 CFU/100ml and decreased after the treatment steps. The FC values for the effluent of UASB reactor, MBR, and WWTP were 137.47×10^5 CFU/100ml, 2×10^5 CFU/100ml, and 10 CFU/100ml, these results showed that the WETP is the best way to treat the wastewater. Appendix E Table E-2 page 6 shows more details about the values of FC for each step. According to Blumenthal et al. (2000), the guideline limit for fecal coliform bacteria in restricted irrigation is $\leq 10^5$ CFU/100ml which is near to the MBR FC value, which indicates the need to modify or improve the system of the membrane to achieve the required need.

4.3 Summary of Results

The operation and startup of Al-Tira WWTP and the MBR were done on January 1, 2020, and continued until now. The samples were taken 2-3 times per week at the ambient temperature of 25-36 °C, where the total number of samples was 25 samples during the period July 22, 2020, to October 22, 2020. All of the results measured and calculated in this study for the UASB reactor, MBR, and Al-Tira WWTP will be summarized and listed in Table 4.4.

Table 4. 4: The Summery of the Results.

Parameter	**UASB Reactor**	**MBR**	**Al-Tira WWTP**
COD_{tot} (mg/l)	336.48	154.32	23.12
COD_{sus} (mg/l)	112.8	46.56	-
COD_{coll} (mg/l)	75.64	40.04	-
COD_{diss} (mg/l)	146.76	68.36	-
BOD_5 (mg/l)	152.9	76.8	-
COD/BOD	2.19	2.01	-
TSS (mg/l)	194.1	115.3	-
VSS (mg/l)	96.8	82.5	-
VSS/TSS	53.1	72.1	-
pH	7.07	7.64	-
FC (CFU/100ml)	137.47×10^5	2×10^5	10

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

In this chapter, the conclusion and the recommendations will be presented.

5.1 Conclusions

The MBR is one of the new technologies used to treat wastewater with higher efficiency than the previous technologies. So, a pilot system of UASB-AnDMBR was used for the treatment of municipal WW from Al-Tira suburb from January 1, 2020 until now, and compared with reclaimed water from the large scale MBR facility. Based on the obtained results, the following conclusions can be stated:

1. The average result of COD_{tot} is 154.32 mg/l obtained from 25 samples analyzed, revealed that the removal efficiency of MBR (85%) is better than the UASB reactor (68%) and the COD_{tot} is near to the acceptable range for irrigation uses (96.33±13.32 mg/l).
2. Based on the COD values, the strength classification of the wastewater varied from medium to strong strength (700-1200 mg/l).
3. The average result of BOD_5 is 76.8 (16.88) mg/l obtained from 10 samples analyzed, revealed that the removal efficiency for the MBR (84%) higher than the UASB reactor (69%).
4. The BOD_5 values are higher than the acceptable range (22.33±1.53) might be it is backward to the high value of pH.
5. The average result of TSS is 115.3 (25.4) mg/l obtained from 12 samples analyzed, revealed that the removal efficiency for the MBR (82%) higher than the UASB reactor (71%).
6. The average result of VSS is 96.8 (21.6) mg/l obtained from 12 samples analyzed, revealed that the removal efficiency for the MBR (84%) higher than the UASB reactor (82%).
7. The average result of pH 7.64 (0.7) obtained from 15 samples analyzed, revealed that the pH values is within the acceptable range (7.4-7.8).

8. The average result of fecal coliform (FC) test is 2×10^5 CFU/100ml obtained from 3 samples analyzed, revealed that the FC value is near to the guideline limit for fecal coliform bacteria in restricted irrigation is $\leq 10^5$ CFU/100ml, which indicates the system under investigation.

5.2 Recommendations

Seeking to have more accuracy in the results of tests for the MBR and because of the restricted conditions, the following recommendations are made:

1. The system of AnDMBR is small and experimental so it needs to be bigger with a bigger capacity and check all the conditions that might have affected the process performance.
2. Assure of the cleanliness of the equipment inside the laboratory and the calibration of all devices used to assure of their efficiency to obtain the most accurate results.
3. Study more chemical parameters to achieve the best evaluation of treating wastewater such as Nitrogen removal (NH^+ and NKj) and Phosphorus (Total PO_4 and PO_4^{3-}) removal.
4. Economic feasibility must be made for each of the UASB reactor, MBR, and WWTP to determine which of them is the best in terms of treatment cost as well.

REFERENCES

Al-Jamal W. (2005). *Community Onsite Anaerobic Sewage Treatment in a UASB-Septic Tank System: System behavior during the winter period in Palestine.* Unpublished Master's Thesis, Birzeit University, Birzeit, Palestine.

Alnour B., Esmat M., Youngseck H., Faisal H., and Baoqiang L. (2020). Anaerobic membrane bioreactors: Basic process design and operation. *Current Developments in Biotechnology and Bioengineering*, 2020 (2), pp 25-54. Available on: https://doi.org/10.1016/B978-0-12-819852-0.00002-6.

Al-Shayah, M. (2005). Community On-site Anaerobic Sewage Treatment in a UASB-Septic Tank System. Unpublished Master's Thesis. Birzeit University, Birzeit, Palestine.

Amine C., Nihel B. A., and Jerome H. (2012). Analysis of fouling Mechanisms in Anaerobic Membrane Bioreactors. *Water Research*, 46 (2012), pp 2637-2650.

ARIJ (2015). Status of The Environment in The State of Palestine, 2015, Publications of the Applied Research Institute – Jerusalem (ARIJ), 195 pp.

Bajpai P. (2017). Basics of Anaerobic Digestion Process. *Springer Briefs in Applied Sciences and Technology*, 2017 (2), pp 7-12.

Berk Z. (2009). *Food Process Engineering and Technology*, Chapter 10, Membrane Process, pages 233-257. Available on: https://doi.org/10.1016/B978-0-12-373660-4.00010-7.

Berube P. R., Hall E. R., and Sutton P. M. (2006). Parameters Governing Permeate Flux in an Anaerobic Membrane Bioreactor Treating Low-Strength Municipal Wastewaters: A Literature Review. *Water Environment Research*, 78 (8), pp 887-896.

Chimuca J. F. J., de Sousa J. T., Lopes W. S., Leite V. D., and do Canto C. S. A. (2020). Decentralized treatment of domestic sewage in dynamic membrane bioreactor Jacob Fortuna. *Desalination and Water Treatment*, 197 (2020), pp 76-89.

Chun-Feng C., Yu-You L., Kai-Qin X., Yoshitaka E., Yuhei I., and Hai-Nan K. (2008). *International Journal of Hydrogen Energy*, 33 (2008), pp 4739–4746.

Du X., Shi Y., Jegatheesan V., and Haq I. U. (2020). A Review on the Mechanism, Impacts, and Control Methods of Membrane Fouling in MBR System. *Membranes*, 2020, 10, 24, pp 1-33.

Ersahin M. E., Tao Y., Ozgun H., Spanjers H., and van Lier J. B. (2016). Characteristics and Role of Dynamic Membrane Layer in Anaerobic Membrane Bioreactors. *Biotechnology and Bioengineering*, 113 (4), pp 761-771.

Florian B., Judita L., Arie Z., Alfons S., and Caroline P. (2017). Membrane Fouling and Chemical Cleaning in Three Full-Scale Reverse Osmosis Plants Producing Demineralized Water. *Journal of Engineering*, 2017 (6356751), pp 1-14. Available on: https://doi.org/10.1155/2017/6356751.

Gao W. J., Lin H. J., Leung K. T., Schraft H., and Liao B. Q. (2011). Structure of Cake Layer in a Submerged Anaerobic Membrane Bioreactor. *Journal of Membrane Science*, 374 (2011), pp 110-120.

Goswami L., Kumar R. V., Borah S. N., Manikandan N. A., Pakshirajan K., and Pugazhenthi G. (2018). Membrane bioreactor and integrated membrane bioreactor systems for micropollutant removal from wastewater: A review. *Journal of Water Process Engineering.* 26 (2018), pp 314-328.

Herrera-Robledo M., Morgan-Sagastume J. M., and Noyola A. (2009). Biofouling and Pollutant Removal During Long-Term Operation of an Anaerobic Membrane Bioreactor Treating Municipal Wastewater. T*he Journal of Bioadhesion and Biofilm Research*, 26 (1), pp 23-30.

Hidri Y., Fourti O., Eturki S., Jedidi N., Charef A., and Hassen A. (2014). Effects of 15-year application of municipal wastewater on microbial biomass, fecal pollution indicators, and heavy metals in a Tunisian calcareous soil. *Journal of Soils and Sediments*, (2014), pp 155–163.

Ho J., and Sung S. (2009). Effects of solid concentrations and cross-flow hydrodynamics on microfiltration of anaerobic sludge. *Journal of Membrane Science*, 345 (2009), pp 142-147. Available on: https://doi.org/10.1016/j.memsci.2009.08.047.

Hu A. Y., and Stuckey D. C. (2006). Treatment of Dilute Wastewaters Using a Novel Submerged Anaerobic Membrane Bioreactor. *Journal of Environmental Engineering © ASCE*, 132 (2), pp 190- 198.

Hu Y., Wanga X. C., Ngo H. H., Sun Q., and Yang Y. (2017). Anaerobic dynamic membrane bioreactor (AnDMBR) for wastewater treatment: A review. Bioresource Technology, (2017), pp 1-49. Available on: http://dx.doi.org/10.1016/j.biortech.2017.09.101.

Huang Z., Ong S. L., and Ng H. Y. (2011). Submerged anaerobic membrane bioreactor for low-strength wastewater treatment: Effect of HRT and SRT on treatment performance and membrane fouling. *Water Research*, 45 (2011), pp 705-713.

Jeon S., Rajabzadeh S., Okamura R., Ishigami T., Hasegawa S., Kato N., and Matsuyama H. (2016). The Effect of Membrane Material and Surface Pore Size on the Fouling Properties of Submerged Membranes. *Multidisciplinary Digital Publishing Institute (MDPI),* 602 (8), pp 1-11.

Jorge C. (2014). Wastewater Nutrient Recovery Using Anaerobic Membrane Bioreactor (AnMBR) Permeate for Hydroponic Fertigation. Unpublished Master's Thesis, University of South Florida, Florida, USA.

Kang I., Yoon S., and Lee C. (2002). Comparison of the Filtration Characteristics of Organic and Inorganic Membranes in a Membrane-Coupled Anaerobic Bioreactor. *Water Research*, 36 (2002), pp 1803–1813.

Kulkarni S. J. (2016). An Insight into Research and Studies on UASB Reactor for Wastewater Treatment. *International Journal of Science and Healthcare Research*, 1 (3), pp 29-34.

Lew B., Tarreb S., Beliavski M., Dosoretz C., and Green M. (2009). Anaerobic Membrane Bioreactor (AnMBR) for Domestic Wastewater Treatment. *Desalination Journal*, 243 (2009), pp 251-257.

Libing C., and Shuping L. (2006). Filtration Capability and Operational Characteristics of Dynamic Membrane Bioreactor for Municipal Wastewater Treatment. *Separation and Purification Technology*, 51(2006), pp 173-179. Available on: https://doi.org/10.1016/j.seppur.2006.01.009.

Lide C., and Howard N. (2014). Anaerobic Digestion Basics. Published by the University of Idaho, 6 pp.

Lin H., Peng W., Zhang M., Chen J., Hong H., and Zhang Y. (2013). A review on anaerobic membrane bioreactors: Applications, membrane fouling, and future perspectives. *Desalination Journal*, 314 (2013), pp 169-188.

Mahmoud N. (2017). Anaerobic Sewage Pre-Treatment in Palestine: Process Performance, Energy Recovery, and Methane Gas Emission. T*he 1st International Conference on Climate Change – Palestine*, pp 15-22.

Mahmoud N., Amarneh M., Al-Sa'ed R., Zeeman G., Gijzen H., and Lettinga G. (2003). Sewage characterization as a tool for the application of anaerobic treatment in Palestine. *Environmental Pollution*, 126 (2003), pp 115–122.

Mai Z. (2014). *Membrane Processes for Water and Wastewater Treatment: Study and Modeling of Interactions Between Membrane and Organic Matter*. Published Doctoral Thesis, Central Pris, Paris, France.

Makwana A. (2017). Up-flow Anaerobic Sludge Blanket Reactor Effluent and Electrochemical Treatments: An Overview. *International Journal of Science and Research (IJSR)*, 6(2), pp 2042-2044.

Martinez-Sosa D., Helmreich B., Netter T., Paris S., Bischof F., and Horn H. (2011). Pilot-scale anaerobic submerged membrane bioreactor (AnSMBR) Treating Municipal Wastewater: The Fouling Phenomenon and Long-Term Operation. *Water Science and Technology*, 64 (9), pp 1804-1811.

Martinez-Sosa David, Helmreich Brigitte, Netter Thomas, Paris Stefania, Bischof Franz, and Horn Harald (2011). Anaerobic Submerged Membrane Bioreactor (AnSMBR) for Municipal Wastewater Treatment Under Mesophilic and Psychrophilic Temperature Conditions. *Bioresource Technology,* 102 (2011), pp 10377-10385.

Martin-Garcia I., Mokosch M., Soares A., Pidou M., and Jefferson B. (2013). Impact on reactor configuration on the performance of anaerobic MBRs: Treatment of settled sewage in temperate climates. *Water Research*, 47 (2013), pp 4853-4860.

Meng F., Zhang H., Yang F., and Liu L. (2007). Characterization of Cake Layer in Submerged Membrane Bioreactor. *Environmental Science and Technology*. 41 (11), pp 4065-4070.

Mohamed D., Hassan A., Abdel Nasser M., Ashraf H., and Basem S. (2014). Reclaimed wastewater for agriculture irrigation in Qatar. *Global Journal of Agricultural Research and Reviews*, 3 (1), pp 106-120.

Nassar A. (2019). Effect of Irrigation with Treated Wastewater Using Surface and Subsurface Drip Irrigation Systems and Different Irrigation Quantities on Pearl Millet Productivity and Water Use Efficiency. Unpublished Master's Thesis. Birzeit University, Birzeit, Palestine.

ÖZGÜN H. (2015). *Anaerobic Membrane Bioreactors for Cost-Effective Municipal Water Reuse*. unpublished Master's Thesis, Istanbul Technical University, Istanbul, Turkey.

Quek P., Yeap T., and Ng H. Y. (2017). Applicability of up-flow anaerobic sludge blanket and dynamic membrane-coupled process for the treatment of municipal wastewater. *Appl Microbiol Biotechnol*, (2017), 10 pp.

Rizvi H., Ahmad N., Abbas F., Bukhari I., Yasar A., Ali S., Yasmeen T., and Riaz M. (2013). Start-up of UASB reactors treating municipal wastewater and effect of temperature/sludge age and hydraulic retention time (HRT) on its performance. *Arabian Journal of Chemistry*, 8 (2015), pp 780-786.

Salahaldin A., Mohammed B., Choon A. N., and Sumathi S. (2017). Applicability of anaerobic membrane bioreactors for landfill leachate treatment: Review and opportunity. *IOP Conf. Series: Earth and Environmental Science*, 140 (2018), pp 1-8.

Sehweil S. (2013). Institute of environmental and water studies (IEWS) Wastewater Reuse for Irrigation Purposes on Soil Conditioned with Zeolite. Birzeit University, Birzeit, Palestine.

Sethunga G. S. M. D. P., Rongwong W., Wanga R., and Baea T. (2017). Optimization of Hydrophobic Modification Parameters of Microporous Polyvinylidene Fluoride Hollow-Fiber Membrane for Biogas Recovery from Anaerobic Membrane Bioreactor Effluent. *Journal of Membrane Science*, 548 (2017), pp 510-518. Available on: https://doi.org/10.1016/j.memsci.2017.11.059.

Siddiqui M. A., Dai J., Guan D., and Chen G. (2018). Exploration of the Formation of Self-Forming Dynamic Membrane in an Upflow Anaerobic Sludge Blanket Reactor. *Separation Purification Technology.* (2018), 29 pages. DOI: https://doi.org/10.1016/j.seppur.2018.11.065.

Speece R. E., Boonyakitsombut S., Kim M., Azbar N., and Ursillo P. (2006). Overview of Anaerobic Treatment: Thermophilic and Propionate Implications. *Water Environment Research*, 78 (5), pp 460-473.

Tay M. F., Liu C., Cornelissen E. R, Wu B., Chong T. H. (2017). The Feasibility of Nanofiltration Membrane Bioreactor (NF-MBR) + Reverse Osmosis (RO) Process for Water Reclamation: Comparison with Ultrafiltration Membrane Bioreactor (UF4 MBR) + RO Process. *Water Research*, 129 (2018), pp 180-189.

Ursula B., Duncan M., Anne P., Guillermo R., and Rebecca S. (2000). *Guidelines for the Microbiological Quality of Treated Wastewater Used in Agriculture: Recommendations for Revising WHO Guidelines*. Bulletin of the World Health Organization, 78(9), pp 1104-1116.

van Lier J. (2008). High-rate anaerobic wastewater treatment: diversifying from end-of-the-pipe treatment to resource-oriented conversion techniques. *Water Science & Technology—WST*, 57 (8), pp 1137-1148. Available on: https://doi.org/10.2166/wst.2008.040.

Vyrides I., and Stuckey D. C. (2009). Saline sewage treatment using a submerged anaerobic membrane reactor (SAMBR): Effects of Activated Carbon Addition and Biogas-Sparging Time. *Water Research*, 43 (2009), pp 933–942.

Xie K., Li H., Mahendran B., Bagley D. M., Leung K. T., Liss S. N., and Liao B. Q. (2010). Performance and fouling characteristics of a submerged anaerobic membrane bioreactor for kraft evaporator condensate treatment. *Environmental Technology Journal*, 31 (5), pp 511-521.

Yifru B., Binghua Y., Tengfei L., Veeriah J., and Yang Z. (2020). Treatment of anthraquinone dye textile wastewater using anaerobic dynamic membrane bioreactor: Performance and microbial dynamics. *Chemosphere*, 238 (2020), pp 1-11.

Yu A. Y., FengLin Y., Benjamin B., and FookSin W. (2009). Municipal Wastewater Treatment Using a UASB Coupled with Cross-Flow Membrane Filtration. *Journal of Environmental Engineering © ASCE*, 135 (2), pp 86-91.

Yurtsever A., Basaran E., and Ucar D. (2020). Process optimization and filtration performance of an anaerobic dynamic membrane bioreactor treating textile wastewaters. *Journal of Environmental Management*, 273 (2020), pp 1-8.

Zhang X., Wang Z., Wu Z., Wei T., Lu F., Tong J., and Mai S. (2011). Membrane fouling in an Anaerobic Dynamic Membrane Bioreactor (AnDMBR) for Municipal Wastewater Treatment: Characteristics of Membrane Foulants and Bulk Sludge. *Process Biochemistry* Journal, 46 (2011), pp 1538-1544.

APPENDICES

Appendix A

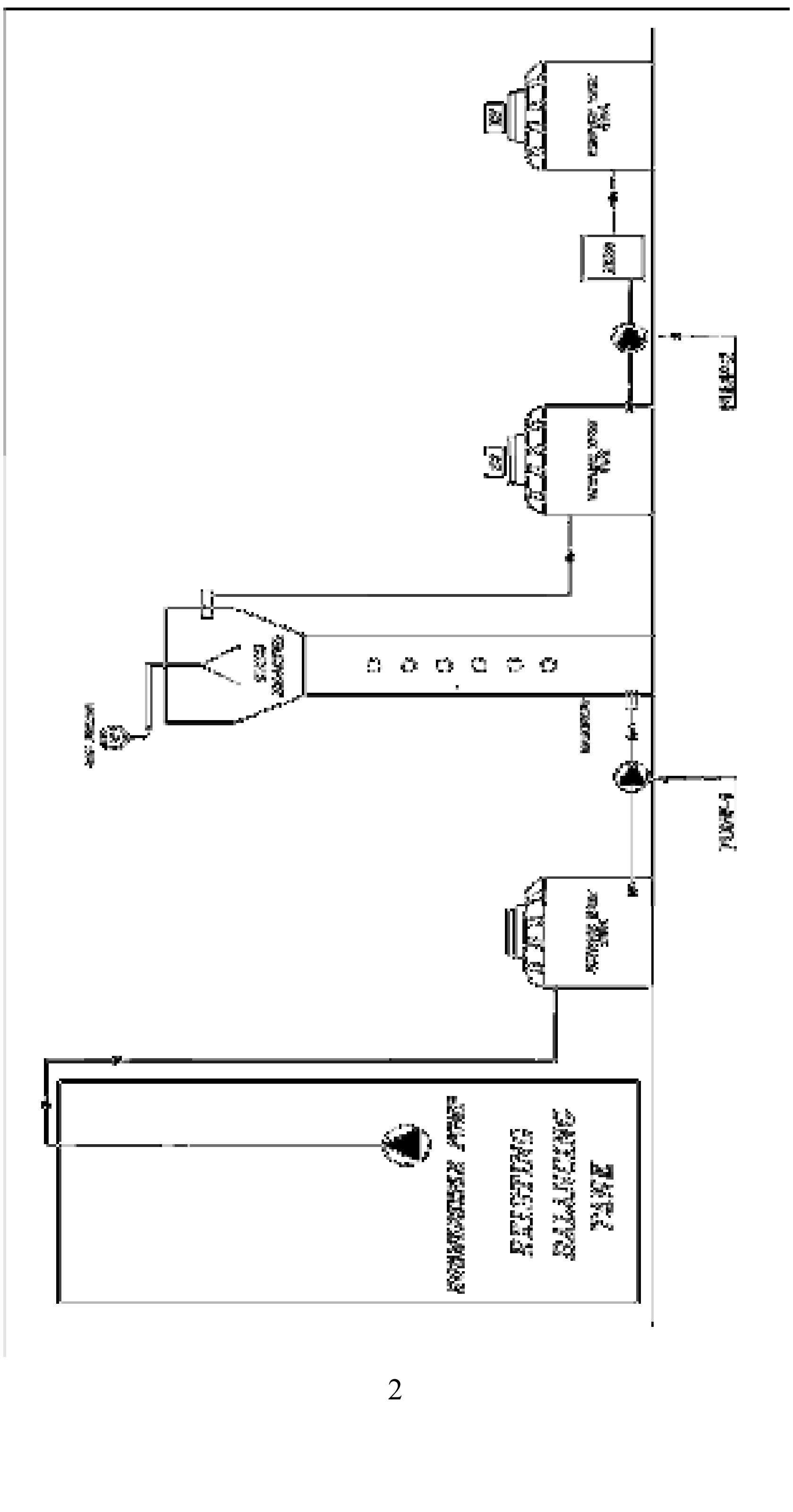
EXISTING
BALANCING
TANK
PUMP-1
PUMP-2

Figure A- 1: Schematic Diagram of the Experimental Set-Up (Not To Scale).

Appendix B

Table B- 1: The COD (mg/l) Values for Influent Wastewater.

Sample No.	Date	Air Temp	Water Temp	WWTP Influent				Model Influent (to Reactor)			
				COD total	COD sus.	COD coll.	COD diss.	COD total	COD sus.	COD coll.	COD diss.
1	22.7.2020	30	26	956	498	163	295	730	313	128	289
2	25.7.2020	31	26	1022	517	183	322	700	325	103	272
3	29.7.2020	34	28	1043	561	177	305	760	371	119	270
4	3.8.2020	28	23	987	528	161	298	756	383	111	262
5	5.8.2020	27	21	976	532	168	276	730	369	108	253
6	10.8.2020	25	21	1230	711	199	320	806	388	132	286
7	12.8.2020	28	22	1193	668	203	322	866	414	173	279
8	15.8.2020	30	26	999	487	175	337	726	329	133	264
9	19.8.2020	36	29	1021	607	141	273	754	386	135	233
10	22.8.2020	33	28	903	519	136	248	683	299	125	259
11	26.8.2020	30	24	1103	584	213	306	780	376	167	237
12	1.9.2020	32	25	933	521	162	250	713	311	164	238
13	5.9.2020	33	28	1170	666	223	281	810	329	184	297
14	8.9.2020	36	30	1293	709	213	371	826	399	121	306
15	12.9.2020	32	28	1096	617	181	298	804	403	123	278
16	16.9.2020	34	29	1083	650	152	281	766	369	118	279
17	19.9.2020	33	26	993	471	209	313	744	228	198	318
18	23.9.2020	28	23	1106	544	245	317	792	299	144	349
19	30.9.2020	29	22	1133	643	292	198	646	341	138	168
20	6.10.2020	27	22	1280	722	331	227	660	263	199	198
21	8.10.2020	28	25	1015	571	244	200	637	299	137	203
22	10.10.2020	26	20	923	479	160	284	577	224	157	196
23	13.10.2020	27	20	1067	542	183	342	494	171	107	216
24	19.10.2020	27	23	927	433	166	328	511	178	113	220
25	22.10.2020	25	22	1005	483	145	377	648	219	122	307

Table B- 2: The COD (mg/l) Values for Effluent Wastewater.

Sample No.	Date	Air Temp	Water Temp	UASB Effluent				MBR Effluent				WWTP Effluent
				COD total	COD sus.	COD coll.	COD diss.	COD total	COD sus.	COD coll.	COD diss.	COD total
1	22.7.2020	30	26	360	143	99	118	174	58	42	74	17
2	25.7.2020	31	26	330	105	69	156	151	65	29	57	14
3	29.7.2020	34	28	310	106	87	117	186	42	33	111	21
4	3.8.2020	28	23	312	97	74	141	197	65	43	89	22
5	5.8.2020	27	21	303	88	91	124	154	39	55	60	17
6	10.8.2020	25	21	303	79	53	171	113	26	32	51	19
7	12.8.2020	28	22	413	156	94	163	132	41	38	53	51
8	15.8.2020	30	26	470	153	112	205	188	65	53	70	34
9	19.8.2020	36	29	290	102	39	149	142	47	28	67	12
10	22.8.2020	33	28	370	105	78	187	134	49	37	48	31
11	26.8.2020	30	24	493	171	107	215	166	63	55	48	23
12	1.9.2020	32	25	333	121	89	123	174	45	66	63	16
13	5.9.2020	33	28	370	134	101	135	118	19	34	65	18
14	8.9.2020	36	30	393	176	81	136	126	31	27	68	11
15	12.9.2020	32	28	396	151	68	177	144	49	24	71	33
16	16.9.2020	34	29	383	121	87	175	182	53	41	88	15
17	19.9.2020	33	26	318	109	87	122	156	70	69	17	29
18	23.9.2020	28	23	288	106	62	120	156	64	39	53	42
19	30.9.2020	29	22	386	160	74	152	186	50	55	81	15
20	6.10.2020	27	22	276	102	76	98	134	52	27	55	36
21	8.10.2020	28	25	340	89	51	184	160	31	23	106	16
22	10.10.2020	26	20	240	39	22	163	160	26	21	113	26
23	13.10.2020	27	20	201	57	59	85	141	32	29	80	29
24	19.10.2020	27	23	271	83	76	112	157	43	59	75	18
25	22.10.2020	25	22	263	67	55	141	127	39	42	46	13

Appendix C

Table C- 1: The BOD (mg/l) and COD/BOD Values for Influent and Effluent Wastewater.

SAMPLE	DATE	BOD				COD			
		WWTP Influent	Model Influent	UASB	MBR	WWTP Influent	Model Influent	UASB	MBR
1	22.7.2020	499	341.0	188.0	96.0	956.0	730.0	360.0	174.0
2	3.8.2020	478	382.0	167.0	102.0	987.0	756.0	312.0	197.0
3	12.8.2020	593	414.0	185.0	65.0	1193.0	866.0	413.0	132.0
4	22.8.2020	409	358.0	112.0	73.0	903.0	683.0	370.0	134.0
5	1.9.2020	472	344.0	151.0	77.0	933.0	713.0	333.0	174.0
6	8.9.2020	515	431.0	201.0	49.0	1293.0	826.0	393.0	126.0
7	19.9.2020	419	360.0	146.0	82.0	993.0	744.0	318.0	156.0
8	6.10.2020	548	323.0	141.0	69.0	1280.0	660.0	276.0	134.0
9	10.10.2020	488	299.0	110.0	94.0	923.0	577.0	240.0	160.0
10	22.10.2020	518	310.0	128.0	61.0	1005.0	648.0	263.0	127.0

SAMPLE	DATE	COD/BOD			
		WWTP Influent	Model Influent	UASB	MBR
1	22.7.2020	1.92	2.141	1.915	1.813
2	3.8.2020	2.06	1.979	1.868	1.931
3	12.8.2020	2.01	2.092	2.232	2.031
4	22.8.2020	2.21	1.908	3.304	1.836
5	1.9.2020	1.98	2.073	2.205	2.260
6	8.9.2020	2.51	1.916	1.955	2.571
7	19.9.2020	2.37	2.067	2.178	1.902
8	6.10.2020	2.34	2.043	1.957	1.942
9	10.10.2020	1.89	1.930	2.182	1.702
10	22.10.2020	1.94	2.090	2.055	2.082

Appendix D

Table D- 1: The TSS (mg/l) Values for Influent and Effluent Wastewater.

Sample Number	Date	WWTP Influent	Model Influent	UASB Effluent	MBR Effluent
1	5.8.2020	888	560	356	176
2	10.8.2020	665	490	268	145
3	12.8.2020	640	407	180	92
4	15.8.2020	539	414	212	132
5	19.8.2020	496	404	186	117
6	1.9.2020	705.0	591.0	149.0	94.0
7	8.9.2020	586.0	491.0	219.0	105.0
8	12.9.2020	696.0	587.0	144.0	118.0
9	19.9.2020	641.0	522.0	135.0	103.0
10	23.9.2020	680.0	561.0	128.0	88.0
11	6.10.2020	812.0	632.0	176.0	100.0
12	10.10.2020	548.0	348.0	176.0	113.0

Table D- 2: The VSS (mg/l) Values for Influent and Effluent Wastewater.

Sample Number	Date	WWTP Influent	Model Influent	UASB Effluent	MBR Effluent
1	5.8.2020	792	512	118	113
2	10.8.2020	448	392	109	119
3	12.8.2020	552	308	103	76
4	15.8.2020	421	340	102	81
5	19.8.2020	328	301	93	98
6	1.9.2020	583.0	441.0	97.0	77.0
7	8.9.2020	428.0	382.0	92.0	37.0
8	12.9.2020	549.0	501.0	89.0	91.0
9	19.9.2020	529.0	402.0	88.0	67.0
10	23.9.2020	544.0	408.0	92.0	71.0
11	6.10.2020	704.0	532.0	86.0	82.0
12	10.10.2020	418.0	299.0	93.0	78.0

Appendix E

Table E- 1: The pH Values for Influent and Effluent Wastewater.

Sample	Date	WWTP Influent	Model Influent	UASB Effluent	MBR Effluent	WWTP Effluent
1	10.8.2020	6.89	6.49	7.09	8.18	7.34
2	12.8.2020	6.78	6.87	6.91	7.91	7.25
3	15.8.2020	7.25	6.98	7.04	7.91	7.45
4	19.8.2020	7.35	7.18	6.89	7.76	7.33
5	22.8.2020	7.42	7.23	7.17	8.2	7.78
6	26.8.2020	7.52	7.33	7.24	8.15	7.7
7	1.9.2020	7.64	7.3	7.34	8.22	7.74
8	8.9.2020	7.54	7.25	7.27	8.32	7.65
9	12.9.2020	7.6	7.39	7.44	7.88	7.24
10	16.9.2020	7.57	7.44	7.51	7.98	7.69
11	19.9.2020	6.43	6.65	6.75	7.1	7.05
12	23.9.2020	7.27	7.2	7.31	7.25	7.38
13	8.10.2020	6.95	7.3	7.37	7.47	7.42
14	19.10.2020	7.33	6.42	6.22	5.97	6.2
15	22.10.2020	7.64	6.7	6.53	6.34	6.47

Table E- 2: The FC (CFU/100ml) Values for Influent and Effluent Wastewater.

Sample	Date	WWTP Influent	Model Influent	UASB Effluent	MBR Effluent	WWTP Effluent
1	10.10.2020	14800000	21000000	20400000	-	-
2	13.10.2020	12500000	5000000	20300000	-	-
3	19.10.2020	8400000	10400000	540000	200000	10

تحديد ظروف التشغيل المثلى للمفاعلات الحيوية الغشائية الديناميكية اللاهوائية المعالجة لمياه الصرف الصحي من أجل إنتاج مياه صالحة لري المزروعات غنية بالعناصر المسمدة وخالية من الكائنات الحية المسببة للأمراض

إعداد

أسحار حبيشة

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المشرف

أ. د. نضال محمود

الملخص

نتيجة للحاجة الملحة لتوفير مصادر مياه جديدة والاستفادة من كمية مياه الصرف الصحي الكبيرة العائدة، تم تركيب واختبار نظام AnDMBR في محطة معالجة مياه الصرف الصحي الطيرة للتحقق من الجدوى الفنية لـ AnDMBR لتنقية مياه الصرف الصحي المعالجة اللاهوائية وذلك لإعادة استخدامها في الري الزراعي في ظل الظروف المناخية وخصائص الصرف الصحي في فلسطين.

بدأت العملية في 1 يناير 2020 ، وتم أخذ 25 عينة خلال الفترة من 22 يوليو 2020 إلى 22 أكتوبر 2020 ، في درجة حرارة محيطة 25–36 درجة مئوية ودرجة حرارة مياه الصرف 20–30 درجة مئوية. تم قياس وحساب خصائص محطة معالجة مياه الصرف الصحي المؤثرة لدراسة كفاءة MBR في معالجة مياه الصرف الصحي. واستناداً إلى قيم COD ، تفاوت تصنيف القوة لمياه الصرف الصحي من قوة متوسطة إلى قوية. كانت كفاءة إزالة COD في نظام MBR (92٪) (أفضل من مفاعل UASB (85٪) بينما كانت كفاءة الإزالة لمحطة معالجة مياه الصرف الصحي الأفضل بنسبة (98٪). تم العثور على قيم CODtot بالقرب من النطاق المقبول لاستخدامات الري. أظهرت نتائج كفاءة إزالة BOD_5 أن MBR (84٪) أفضل من مفاعل UASB (69٪). قيم BOD_5 أعلى من النطاق المقبول (22.33 ± 1.53) وقد يكون سبب ذبك راجعًا إلى القيمة العالية للرقم الهيدروجيني. كانت كفاءة الإزالة في الـMBR لـ TSS و VSS هي 82٪ و 84٪ وأظهرت أداءً أعلى من كفاءة UASB في هذه الدراسة والدراسات السابقة. كانت قيمة الأس الهيدروجيني لمخلفات MBR حوالي 7.6 وهي ضمن النطاق المقبول لاستخدامات الري 7.6 ± 0.2. كان القولون البرازي (FC (2 × 10 CFU / 100 مل لتدفق MBR وهو قريب من قيمة الـ FC للري المقيد ($\leq 10^5$CFU / 100ml).خلصت الدراسة إلى ضرورة تحسين نظام AnDMBR وقياس المزيد من المتغيرات لتقييم أداء النظام في معالجة المياه العادمة وزيادة كفاءة الغشاء لتحقيق الاحتياجات المطلوبة للدراسة.