Faculty of Graduate Studies

M.Sc. Program in water and

Environmental Engineering

Evaluation of Operational Stress Conditions on a Pilot Scale MBR for Wastewater Treatment and Reuse

تقييم ظروف الإجهاد التشغيلية لمشاهدة مفاعل غشاء حيوي

في معالجة المياه العادمة وإعادة استخدامها

A Master Thesis Prepared By

Mazen Nazzal

Supervisor By

Dr. Rashed Al-Sa`ed

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The thesis was prepared under the supervision of Dr.Rashed Al-Sa'ed and has been approved by all members of the Examination Committee.

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The findings, interpretations, and conclusions expressed in this study do not necessarily express the views of Birzeit University, the views of individual members of the M.Sc. committee or the views of their respective employers.

DEDICATION

I dedicate my dissertation work to my family. A special feeling of gratitude to my Mother, my wife and my sons Yousef, Abd-Al-Rahman and to my sister and all my friends

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It would not have been possible to write this master thesis without the help and support of the kind people around me, to only some of whom it is possible to give a particular mention here.

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Abstract

Industrial wastewater treatment and management in Palestine is very limited. One of the larger seasonal industrial wastewater is olive mill wastewater (OMWW), the total amount of OMWW which produced in the West Bank is about (120000) cubic meter annually. OMWW had no pre-treatment or any type of treatment, all of this heavily polluted wastewater discharged into Wadi or into sewage network without permissions. These discharges could be the major sources of groundwater pollution or make a disturbance in WWTP operations.

The main goal of the research was to evaluate the operation stress on a pilot scale MBR system under normal and compare with heavy polluted (OMWW). The following objectives are investigated:

- Investigate the process performance and reclaimed water quality under normal operational conditions, the baseline data.
- Study the influence of stress conditions on the MBR operational performance.
- Investigate the impacts of toxic loading (phenols and COD) from olive oil mill wastewater on MBR process performance and removal rates of COD and nitrogen.

This research was accomplished by integrating a comprehensive data collection and analysis with a technical field work. For phase one sample is collected each week and the second phase two samples were taken every week.

The wastewater used for this study was formed Birzeit University Campus, which has low organic loading comparing with domestic wastewater (BOD 248 mg\L, COD 479 mg\L), and olive mill wastewater is fresh one collected from three phase method extraction olive.

Under normal and highly loaded conditions the removal rate was sufficient as treated technology flat sheet MBR was used.

There is comparison between the removal rates for normal and abnormal conditions for these parameters COD, BOD, TSS, NH_4^+, TKN and total phenol, the removal percentage was (94%, 90%, 93%, 93%, 71% and 98%), removal percentage for highly organic load conditions COD reduce by 35%, BOD almost 50%, TSS and NH_4^+ unchanged with 93%, TKN almost unchanged, but total phenol reduced by 9%. According to these analytical results of MBRs the effluent quality of Pilot scale is complying with set local effluent limits for agricultural irrigation grade (A) also, it has a good process performance of diluted OMWW treatment.

The flux of the MBR was affected after the OLR became higher exponentially, which is reduced 0.43 to 0.087 $L/m^2.d$, as a result of increased trans-membrane pressure increasing. Statistical analysis shows that HRT and MLSS the most important parameter effect of MBR fouling.

This study could help MBR WWTP operators to predict and control the MBR fouling according to operation parameters. Although, future studies can use the results of this thesis to identify a useful data about the monitoring and evaluation MBRs.

الملخص

تقييم ظروف الإجهاد التشغيلية لمشاهدة مفاعل غشاء حيوي في معالجة المياه العادمة وإعادة استخدامها

ان معالجة المياه العادمة الصناعية وإدارتها محدودة جدا في فلسطين. هذا وتشكل مياه الزيبار، المخلفات السائلة الناجمة عن عصر ثمار الزيتون، واحدة من أكبر المصادر الموسمية للمياه العادمة الصناعية. حيث تنتج الضفة الغربية وحدها حوالي ١٢٠ ألف متر مكعب من الزيبار في موسم الزيتون بمدة زمنية لا تتجاوز أربعة أشهر. يتم تصريف هذه المياه ذات المحتوى العضوي العالي الى الاودية او شبكات الصرف الصحي دون أي معالجة أولية تذكر.

الهدف الرئيس من هذه الدراسة هو تقييم الظروف التشغيلية لمحطة الاغشية الحيوية تحت الظروف الطبيعية ومقارنتها مع الظروف التشغيلية تحت الظروف الغير اعتيادية عند استخدام مياه صناعية ذات محتوى عضوي عالي وسام مثل الزيبار. حيث تم البحث في المواضيع التالية:

- البحث في اداء العمليات وجودة المياه المعالجة تحت الظروف الطبيعية حيث تم اعتماد نتائج التحليل كمرجعية في البحث.
- دراسة الظروف التشغيلية لمحطة الاغشية الحيوية.
- البحث في أثر الزيبار ذو المحتوى العضوي العالي والسام على اداء محطة الاغشية الحيوية .
- تقييم المياه المعالجة ومعدل ازالة الميكروبات.

تم انجاز هذا البحث من خلال جمع كمية من البيانات والتحليل نتيجة العمل الميداني. حيث تم جمع المعلومات في المرحلة الاولى من هذا البحث كل اسبوع وفي الجزء الثاني كانت مرتين بالأسبوع.

المياه العادمة المستخدمة في هذه الدراسة كانت من مياه الصرف الصحي في جامعة بيرزيت، حيث كانت ذات محتوى عضوي قليل مقارنة مع مياه الصرف الصحي المنزلي (BOD 248 mg\L, COD 479 mg\L)، كما تم استخدام زيبار جديد من محطة ذات ثلاثة مراحل لاستخراج الزيت.

كانت نتائج معدلات التخلص من الملوثات في الظروف الطبيعية وذات المحتوى العضوي العالي مرضية لتكنولوجيا المعالجة بالأغشية الحيوية.

في ما يلي مقارنة لنتائج معدلات الازالة للمياه ذات المحتوى الحيوي العادي والعالي للمؤشرات التالية (COD, BOD, TSS, NH_4^+, TKN, total phenol) وكانت نسب الازالة في المحتوى العضوي الطبيعي للمياه العادمة (94%, 98% , 71%, 93%, 93%, 90%) اما في حالة المحتوى العضوي العالي في (COD) نقص معدل الازالة ٣٥% و (BOD) كانت ٥٠% اما (TSS, TKN, NH_4^+) لم تتأثر اما الفينول فقد نقصت نسبة معدل الازالة حوالي ٩%.

اما بالنسبة للتدفق للأغشية الحيوية فقد تأثر عند زيادة المحتوى العضوي بشكل مضاعف حيث نقص من (٠.٤٣ الى ٠.٠٨٧ لتر/م^{٢}.يوم) مما ادى الى زيادة الضغط على الاغشية الحيوية.

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List of Abbreviations

BOD	Biochemical Oxygen Demand
BZU	Birzeit University
BZUTL	Birzeit University Testing Laboratories
COD	Chemical Oxygen Demand
D.O	Dissolved Oxygen
EC	Electrical Conductivity
F/M	Food to Mass
FC	Fecal Coliform
HRT	Hydraulic Retention Time
KW	Kilo Watt
LRV	Log Removal Values
MBR	Membrane Bioreactor
MCM	Million Cubic Meter
MF	Micro-filtration
MLSS	Mixed liquor suspended solids
NF	Nanofiltration
NH_4^+	Ammonium
OLR	Organic Loading Rate
OMWW	Olive Mill Wastewater
PCBS	Palestinian Central Bureau of Statistics
PES	Polyethersulfone
PLC	Programmable Logic Controller
PS	Palestinian Standards
PWA	Palestinian Water Authority
SRT	Sludge Retention Time
T	Temperature
TDS	Total Suspended Solid
TKN	Total Kjeldahl Nitrogen
TMP	Trans-Membrane Pressure
TN	Total Nitrogen
TPh	Total Phenol
TSS	Total Suspended Solids
UF	Ultra-Filtration
VSS	Volatile Suspended Solid
WHO	Water Health Organization
WWTP	Wastewater Treatment Plant

Chapter One

Introduction

1.1 Introduction

Water is the most important factor for living on Earth. As any country, Palestine needs water for life facilities, but with expansion and community growth water scarcity became more serious for Palestinians. In addition to the limitation of access to water sources by the Israelis, the only water source is the groundwater.

According to Palestinian Water Authority (PWA), the water available for drinking in West Bank that the Palestinians is estimated 175 MCM, beside the water scarcity, the domestic and industrial wastewater treatment is limited which increased of the water source pollution. Most of the domestic and industrial wastewater discharged to wadi's, and some of these discharged to sewer network without any pre-treatment especially olive mill wastewater (OMWW) by illegal connections. All wastewater treatment plants (WWTP) in Palestine does not design for the heavy pollutants like OMWW.

The use of membrane bioreactors (MBRs) for municipal wastewater treatment (WWTP) has expanded and lead to a significant knowledge expansion and experience related to their design and operation. In Palestine, three large-scale MBRs are under construction to cope with local and regional stringent discharge regulations and increased agricultural water demand. However, biofouling continues to hamper an increased implementation of MBR. Capacity building, networking and knowledge sharing are crucial considering capable wastewater professionals and needed knowledge to successfully design, monitor and operate MBRs. Knowledge must be enhanced by a basic understanding of pollutants removal, biofouling, and validation of MBRs performance to successfully implement and ensure their sustainability. Establishing a Research and development (R&D) group nucleus at BZU on MBR technology is crucial to obtain basic scientific and practical knowledge on the process performance of MBR system.

Ultrafiltration (UF) membranes are widely used in membrane bioreactor (MBR) facilities for wastewater treatment to cope with stringent effluent quality standards and protect public health and receiving environment. Membrane bioreactors are frequently used for advanced wastewater treatment producing a high-quality effluent suitable for water recycling in a variety of water reuse applications (Trinh et al., 2012). Lesjean et al. (2011) reported that MBRs are installed where biological nutrient removal is required and plant footprint is limited.

The main goal of water recycling schemes is public health protection through disease prevention caused by microbial pathogens (Jacangelo and Trussells, 2001). However, membrane fouling forms an essential problem in the process of its application and current research efforts focus on this issue. Current operational strategies to reduce UF membranes fouling in MBR facilities depend on deep scientific and engineering understanding of the interaction mechanisms between foulants and clean membrane surface as well as foulants and fouled membrane (Mutamim et al., 2013). The current study starts with compiling and evaluation of technical data from published studies pertaining to major factors behind possible impacts of operational stress conditions on membrane performance.

In this study, a pilot-scale membrane bioreactor (MBR), installed at Birzeit University campus will be monitored over a period exceeding 8 months. We argue that sudden hazardous events comprising high organic loads from olive mill wastewater (OMWW) may impact long life stability of the MBR through clogging and biofouling. To reduce possible negative stress effects and enhance the process reliability and system availability, scoring of sludge cake on the membrane through aeration and further chemical cleaning of UF membrane is crucial.

Finally, the future direction in research and development (R&D) on consequences of hazardous events on the performance of full-scale MBRs warrants further investigations. Therefore, the findings of this research study from a small pilot-scale MBR unit can be used facilitate improvements in the risk assessment and management of large-scale MBR facilities used for reclaimed water use in agricultural irrigation.

1.2 Problem Statement

In the current situations, the municipal sewage networks have illegal connections for industrial wastewater especially (OMWW) without any pre-treatment for short period of time -seasonal production- with high organic and inorganic load. This process has an enormous effect on the efficiency of WWTP and activity of micro-organism and the effluent quality. Moreover, the OMWW uncontrolled flow to treatment facilities causes serious problem and operation stress.

The most problem of OMWW extremely organic content, acidity pH (3-6), high phenols content which toxic to the organism and the big amount of solids (Tsagaraki et al., 2007).

Despite the significant contributions of the olive oil sector in the economic development of Palestine, it is becoming a source of serious environmental problems. Olive Mill Waste Water is disposed of untreated into the sewage network, cesspits or dumped in open areas without any consideration to its environmental impact on the groundwater, or land. The waste generated by the olive oil processing is estimated to be about 120,000 m3 and it is disposed of improperly into the environment (Olitreva, 2014).

1.3 Goal and Objectives

The main aim of this study is to investigate the robustness of an immersed pilot flat sheet membrane bioreactor (MBR) for reclaimed water recycling focusing on system performance and reliability under normal and hazardous operational conditions. To realize this aim, the following research objectives are identified:

- Investigate the process performance and reclaimed water quality under normal operational conditions, the baseline data.
- Study the influence of stress operational conditions (pH, mixed liquor suspended solids content) on the MBR performance and reclaimed water quality.
- Investigate the impacts of toxic loading (phenols and COD) from olive oil mill wastewater on process performance and sludge characteristics pertinent to membrane robustness and effluent quality.

1.4 Research Questions

Considering the above-mentioned problems, the main research questions are:

- What are the main causes behind possible performance reduction under normal and hazardous operational conditions?
- What are practical barriers methods to apply for avoiding system failure and associated effluent quality impairment?
- What are operational expenditures achievable under normal and hazardous operational conditions of the installed pilot-scale MBR system?

Therefore, this research study explores the performance of a pilot-scale MBR system treating domestic sewage form Birzeit University campus under sudden OMWW pollution loads. It is argued that the envisaged operational results from this study shall provide technical data and managerial options at urban MBR facilities used for domestic wastewater treatment and reclaimed water use in agricultural irrigation.

1.5 Thesis outline

This thesis consists of five chapters.

Chapter One: is an introduction to the research, including problem statement, research questions, and objectives.

Chapter Two: describes the literature review on industrial wastewater treatment, membrane process, membrane biofouling, and main factors effect on MBR.

Chapter Three: Are materials and methodology carried out in the research

Chapter four: provides analysis and discussion of efficiency for pilot-scale MBR treatment plants that exposure to heavy industrial pollution load (OMWW).

Chapter five: presents the conclusions and recommendations as an outcome of the thesis.

Chapter Two

Literature Review

2.1 Background

In the absence of legal control of industrial discharges into public sewerage networks, the generation of heavily polluted industrial wastewater with the variable volumetric flow and chemical composition constitutes a major challenge for the Palestinian municipalities. Impact recognition of illicit industrial discharges like olive mill wastewater (OMWW), tanning and stone cutting on the environment has forced regulatory water authority to issue stringent control rules for industrial pollution.

OMWW are produces from the extraction of olive oil the production of OMWW, by two method two phase (two stream production olive mill waste solid – crude olive cake- and liquid –olive mill effluent- in one stream and the olive oil line) and three phase (production three product olive oil, olive mill waste solid part, and the olive oil each one separate from the others), according to Cassano et al. (2011) (1.1-1.5) of the olive weight if the extraction method three phase method, according to PCBS (2011) the OMWW produced in West Bank estimated by (102764-140133) cubic meter annually.

The OMWW mainly consist of water (83-92%), inorganic salt (1-2%) and organic compounds (4-16%) have high concentration of pollution like biological oxygen demand (BOD) up to 100 g/L and chemical oxygen demand (COD) up to 200 g/L which is more than 200 times of municipal wastewater in Palestine (Dhaouadi and Marrot, 2008).

Membranes bioreactor is one of the newest technologies for wastewater domestic and industrial treatment (microfiltration, ultrafiltration, nanofiltration), the ultrafiltration submersible flat sheet membrane is used in this study as pilot scale.

In terms of pollution effect, $1m^3$ of olive mill wastewater (OMWW) is equivalent to 100 – 200 m^3 of domestic sewage. Its current uncontrolled disposal into public sewer networks, receiving water bodies and land application leads to severe environmental problems for the biological treatment process, ecosystem, and soil. Installed domestic and urban wastewater treatment plants in Palestine are designed not to receive industrial wastewater. Annually, municipalities with central sewerage networks suffer from regular illegal industrial connections with heavy organic and inorganic pollution loads. The results impaired effluent quality associated with increased operational costs at sewage works receiving pollution shock loads from the industrial sector. The potential impacts of sudden pollution loads from the industrial sector on the biological treatment process, irrespective of the technology applied, warrants further investigation.

The use of MBRs for municipal wastewater treatment has expanded and lead to a significant knowledge expansion and experience related to their design and operation. According to Al-Sa`ed (2016), there are in Palestine, three large-scale MBRs are under construction to cope with local and regional stringent discharge regulations and increased agricultural water demand. However, biofouling continues to hamper an increased implementation of MBR. Capacity building, networking and knowledge sharing are crucial considering capable wastewater professionals and needed knowledge to successfully design, monitor and operate MBRs. Knowledge must be enhanced by a basic understanding of pollutants removal, biofouling, and validation of MBRs performance to successfully implement and ensure their sustainability. Establishing an R&D group nucleus at BZU on MBR technology is crucial to obtain basic scientific and practical knowledge on the process performance of MBR system.

Several studies (Branch and Le-Clech, 2015; Hai et al., 2010; Knops, 2010; Mutamim et al., 2013; van den Akker et al., 2014), revealed that implementation of treatment barriers employed in MBRs require process validation aiming at provision of effective treatment and process stability. System validation is currently based on characterizing the log removal values (LRV) of microbial indicators (e.g. fecal coliforms) considering normal operating conditions. Microbial LRVs were quantified before and after a chemical membrane cleaning process, which has previously been flagged by laboratory-scale studies as a potentially hazardous scenario (Wu et al., 2010). However, regardless of the design, MBR systems are continuously subjected to deviations in operational conditions and the risk of treatment failures that may lead to impairment of reclaimed water quality (Trinh et al., 2014). Considering risk assessment management and apart from the normal operational conditions, WWTPs may experience regular hazardous events. These events are often short-term with long-term effects and routine water quality monitoring may not cover their possible effects. Identifying and understanding the stress effects caused by low or high shock load events are crucial for assessing process stability and system reliability pertinent to possible environmental and health risk hazards (Haas and Trussell, 1998; Yogalakshmi et al., 2007). Consequently, the assessment of these events has become an integral part within the water reuse schemes and incorporated in WHO guidelines for water recycling and the Australian validation of pathogens removals in wastewater treatment technologies (Organization, 2004; van den Akker et al., 2014).

Both guidelines and validation recommend characterizing LRV during normal and stress operational conditions that may disturb treatment performance and result in unsafe reclaimed water.

Today, the use of membrane-based technologies, more especially membrane bioreactors (MBRs), either as a main step in municipal wastewater treatment chain or as single post-treatment step has shown an innovative mean of achieving high quality reclaimed water suitable for multi-beneficial applications.

2.2 Membrane process

Membrane bioreactor is a new technology that gathering a conventional technology – activated sludge- with solid filtration, Instead secondary and primary clarifier. The separation process in the membrane is an important process in the bioreactor, which is integrated with biological processes (Liao et al., 2006).

The high importance of membrane bioreactor assimilates in retain biomass in the reactor and increasing the removal efficiency by filtering soluble organics (Ho and Sung, 2009).

Membranes classified according to pore size into microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), Table 1 shows the characteristics of different membrane.

Table 1 Characteristics of different membrane processes (Han (2013)

Parameter	MF	UF	NF
Operating Pressure(bar)	1-4	2-7	10-40
Pore size (µm)	0.1	0.01-0.05	0.001-0.01
MWCO rang (Dalton)	>300000	300000-100000	200000-20000
Size-cut-off-rang (µm)	0.1-20	0.005-0.1	0.001-0.01

According to Radjenović et al. (2008), the configurations of membranes in the bioreactor classified as external cross-flow MBRs, which situated outside the aeration basin and operated under pressure.

Submerged MBRs have membranes installed in the biological reactor and operated under vacuum. Figure 1 illustrates the submerged MBR and external MBR processes. The submerged MBRs consume lower energy than the external MBRs.

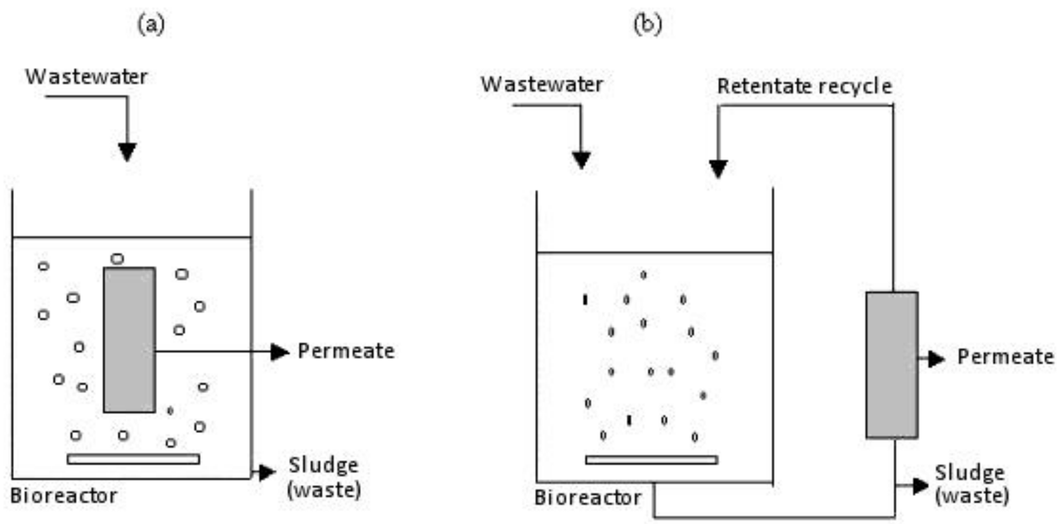

Figure 1 MBR configuration (a: submerged; b: external) (Han, 2013)

Also, MBR bioreactor can be divided into modules hollow fiber and flat sheet, are used in membrane bioreactors. Most of the membrane bioreactor used in treatment plant is hollow fiber that refers to low cost comparing with flat sheet membrane (Bodík et al., 2009; Hai et al., 2005).

For fouling modes, the hollow fiber membrane exhibited fouling with a cake layer. However, under the similar conditions, the flat sheet membrane suffered from fouling of pore blocking easily (Hai et al., 2005)

2.3 Membrane fouling

The fouling phenomena in membrane bioreactor defined as a reduction in permeate flux, increasing hydraulic membrane resistance or increasing in trans-membrane pressure (Donalson, 2009).

Membrane fouling is an inherent problem with membrane processes which not only impacts the long-term operational stability but also leads to significant operational costs due to added energy consumption and increased membrane replacement frequency (Arabi, 2009).

According to Han (2013), the fouling mechanism it is the accumulation and adsorption of salts and colloids on the membrane surface, which can close the membrane pores in this case the particles size is smaller than the membrane pores. On the other hand, the larger particles like sludge attached to membrane surface making the cake layer or from changes of the foulants composition on the long-term operation.

There are two types of fouling removable, irremovable and irreversible. Respectively the definition of each type of fouling the removable one which can be clean easily physically, irremovable needs a chemical cleaning to remove foulants from its pore, but the irreversible cannot be cleaning using any chemical or physical or any approach (Meng et al., 2009).

2.4 Main factor Stress effect on MBR

As all biological wastewater treatment system, MBR has design and operational parameter like (sludge retention time (SRT), hydraulic retention time (HRT), organic loading rate (OLR), food to mass ratio (F/M) and nutrient conditions. which is have a main role of MBR performance (Han, 2013).

Operation condition is (TMP), flux, and aeration. So that, MBR with high flux had rapid fouling and could use a critical flux to reduce the fouling (The critical flux concept defined as the limit below the fouling happened). According to the MBR complexity in membrane fouling, Jeison and van Lier (2007) was redefined the critical flux as a relation with trans-membrane pressure (TMP), which is the flux at the upper limit before the relation became nonlinear.

MBRs system can be aerobic either anaerobic. MBR aerobic systems work out to providing oxygen to biomass, mixing biomass, and prevention or reducing the MBR biofouling. As Liao et al. (2006) said in anaerobic system recirculation the biogas produced from biological degradation to achieve biomass mixing and reduction in biofouling for MBRs.

According to Khan and Visvanathan (2008), the intensive aeration rate can be reducing the biofouling rate. On the other hand, intensive aeration could have a negative impact on the cost-effectiveness that refers to increases in energy consumption, and fragmentation of sludge flocs, which can produce small particles that increasing fouling rate.

2.4.1 The organic loading rate

The organic loading rate (OLR) defines the influent organic concentration and the hydraulic retention time.

Jeong et al. (2007) reported that the permeate flux maintains higher when the OLR lower which is mainly when the OLR as F/M ratio higher the fouling will increase. In this study mainly OLR will be a low rate, which is referred to low organic content in wastewater produced in university community; this wastewater can be classified as weak wastewater. After the start-up phase, the OLR will increase suddenly during OMWW dose adding to MBR pilot scale.

2.4.2 The pH

There is less research about the effect of pH on the performance of aerobic MBR bioreactor pH one of the factors has an important role in biodegradation. As Iorhemen et al. (2016) reported lower pH increased attached extracellular polymeric substances to the membrane surface and increasing the fouling problem, which reduces the performance of MBRs. So, if the sock load or the influent has low alkalinity, the alkaline material should be added to mitigate the decreasing in MBR performance.

According to (Isma et al., 2011), to keeping pH value within the optimal range for MBRs some solution could be added to the system like NaOH - NaHCO3 solution.

2.4.3 Mixed liquor suspended solids content (MLSS)

One of the advantages of membrane bioreactor process it could work at higher mixed liquor suspended solids (MLSS) concentration. By increasing the MLSS the hydraulic retention time decreased which mean footprint scale for the treatment process. At all of these conditions, advantages Production of sludge will decrease (Trussell et al., 2007).

Bottino et al. (2009) reported that the membrane fouling increase significantly by increasing the MLSS concentration in MBR. On the other hand, the operation in a high MLSS concentration above 10 g/L will increase the viscosity which affects the membrane permeability (Trussell et al., 2007; Wu and Huang, 2009).

According to published literature, there is a limit of MLSS concentration to effect on MBR performance significantly, all of these studies mention that no effect or slightly effect when MLSS concentration (4-14 mg/L) (Iorhemen et al., 2016; Le-Clech et al., 2003; Rosenberger et al., 2005; Rosenberger et al., 2006).

2.4.4 Sludge retention time (SRT)

According to Zhang et al. (2006), SRT is an important factor has an impact on the performance of membrane bioreactors. Sludge retention time increasing will reduce the biofouling in the MBR, however, if the SRT time decrease less than 10 days the removal efficiency will be affected (Van den Broeck et al., 2012).

As reported (Sun et al., 2007), there is no deterioration of total organic compound removal efficiency, when SRT more than 10 days, removal efficiency more than 99 %.

2.4.5 Hydraulic retention time (HRT)

As reported Huang et al. (2011)when HRT was decreased, TMP increased faster. This phenomenon was due to the increase of biomass concentration resulted from an increase in OLR as the HRT was reduced, which greatly enhanced membrane fouling rate.

Chapter Three

Materials and Methods

3.1 Background

In order to achieve the investigated objectives, this study was carried out by establishing a baseline data through data collection by sampling the steady state condition for the MBR bioreactor pilot in Birzeit University camps. These data collections samples were followed by performing lab analysis to estimate the quality of effluent and influent. These data were used to characterize wastewater and treated wastewater and also to use the result as a reference for investigating the impact of toxic shock load on the performance of MBR.

The objectives of this data collection were to obtain realistic baseline data analyzed parameter that reflects the character of the used wastewater in this research. The sampling and lab analysis was to characterize wastewater in terms of total nitrogen (TKN), ammonia (NH_4^+), biological oxygen demand (BOD5), chemical oxygen demand (COD), total phenol, total suspended solids (TSS), total dissolved solids (TDS), volatile suspended solids (VSS) ,turbidity, conductivity, PH, temperature, total coliform and faecal coliform. This was achieved through collecting untreated wastewater and treads wastewater samples from equalization tank (MBR inlet) and MBR bioreactor outlet.

3.2 Methodology

A submerged flat sheet membrane bioreactor was installed with pore size 0.04 µm. the pilot was consist of an anoxic tank, aeration tank with submerged flat sheet membrane, air blowers, permeate pump, and the equalization tank, which exanimated the performance of membrane under normal conditions and under shock loads of toxic industrial wastewater.

This study was divided to two main phases, the first phase was steady-state conditions the pilot monitor the MBR system performance under normal conditions which is the baseline database for this study, and the second one is monitor the performance of the MBR under the multi-dose percentage of toxic loads (OMWW).

3.3 Description of MBR pilot scale plant

The system consisted of aerobic reactor with effective volume 1.6 cubic meters with flat sheet (Polyethersulfone, PES) submerged membrane with surface area 3.5 m2 and pore size 0.04 µm as shown in figure (2) and figure (3), the submerged pump was pumped automatically from the main equalization tank to pilot anoxic reactor which was controlled by level sensor and controller within the (PLC) unit.

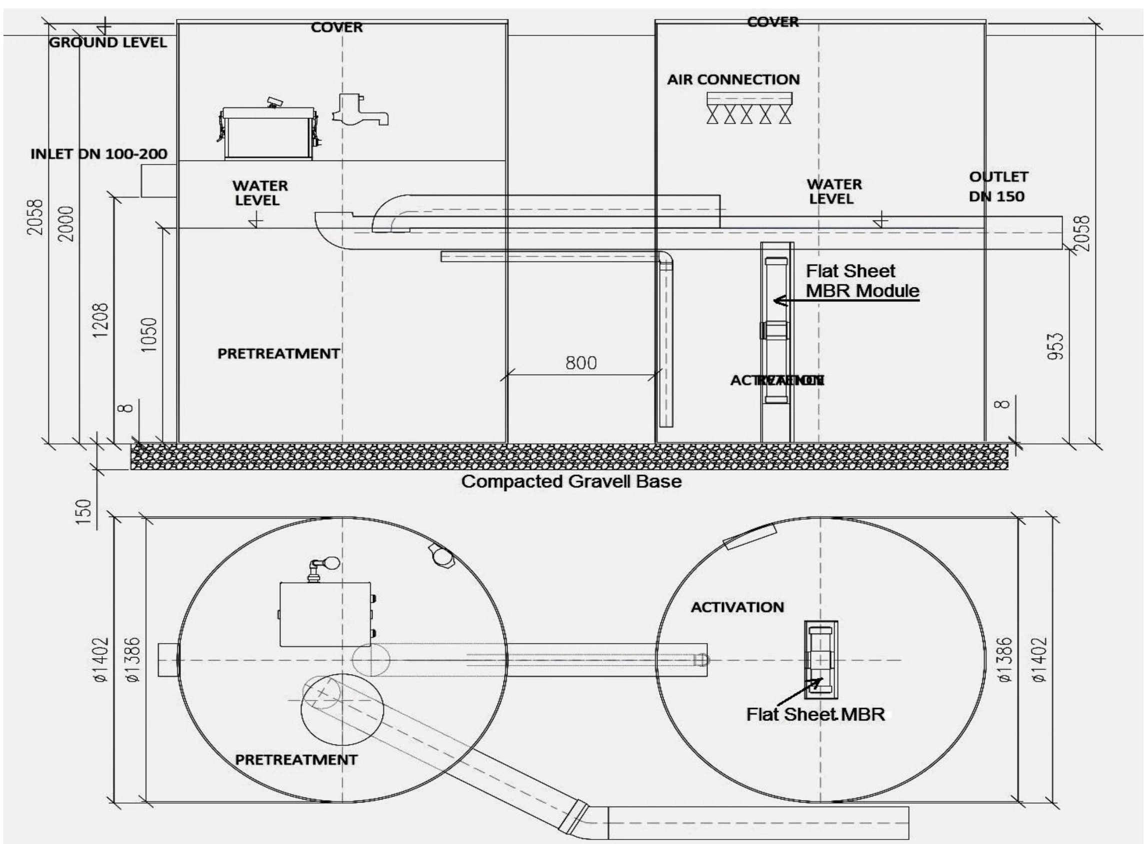

Figure 2 pilot scale schematic in BZU campus

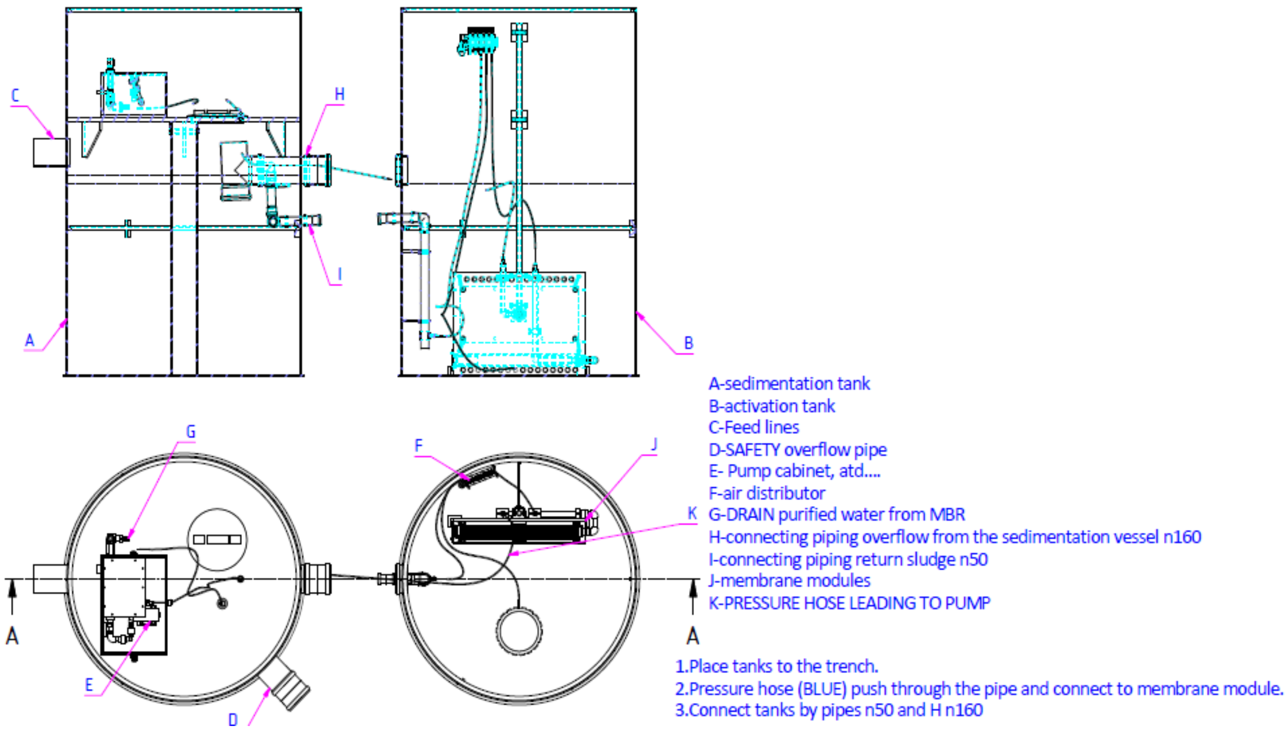

Figure 3 Flat sheet MBR pilot scale components in BZU campus

The dissolved oxygen (DO) was above 2.0 mg\L, membrane flux as manufacture was 350L\d.m2. The trans-membrane pressure (TMP) as an indicator of the extent of membrane fouling was continually monitored by a pressure sensor. The system was automatically supervised by a programmable logic controller (PLC) system. In figure (4) below the start-up phase is shown

Figure 4 Flat sheet MBR pilot scale in BZU campus

To determine the organic, inorganic and physical properties for influent and effluent for this research at steady state condition to be used as baseline data for comparison these properties under normal condition and under toxic shock load condition, samples were taken form equalization tank, effluent port, aerobic and form anoxic tank these samples were analysed in Birzeit University laboratory.

During monitored to steady state condition for the pilot a lot of operation problem happened, like a lake of fine screen, the acidity of wastewater refers to chemical discharged from chemistry labs, oils from mechanical labs.

Data collection under normal conditions:

- Influent and effluent (permeate) flow was monitor and calculated.
- The electrical consumption recorded.
- Grab sample was taken and analyzed for (BOD, COD, TKN, pH, T, NH_4^+, TSS, TDS, EC, Total coliform and fecal coliform) to obtain the baseline for the MBR system.

Data collection under toxic shock load conditions: (olive mill waste impact)

- Shock load was been added as dosage for one week for each of these doses.
- The first dose as a percent of the total volume of the aerobic reactor (1.6 m^3) was 1.25% of total volume.
- The second dose as a percent of the total volume of the aerobic reactor (1.6 m^3) was 2.5% of total volume.
- The third dose as a percent of the total volume of the aerobic reactor (1.6 m^3) was 5% of total volume.
- Fourth and final dose as a percent of the total volume of the aerobic reactor (1.6 m^3) was 10% of total volume.

- For each week a grab samples will be taken and analyze for (BOD, COD, TKN, PH, T, NH4, TSS, TDS, EC, Total coliform and fecal coliform) and monitor the permeate flow (flux rate) which is the indirect measure for sludge cake occur, and evaluate performance for the MBR reactor and effluent quality.

3.4 Analytical method

All measurements and analysis for different samples parameters were analyzed in BZULAB each one as mentions below.

3.4.1 Measurement of physical parameters

All physical (total dissolved solids (TDS), pH, electrical conductivity (EC), temperature (T) and dissolved oxygen) parameter for effluent, influent and aeration tank was measured on site using conductivity meter for (EC, TDS, T), dissolved oxygen measured by (HACK HQ10) oxygen meter and pH was measured using (Metrohm-691).

3.4.2 Measurement of chemical parameter

All chemical parameter was analyzed according to standard methods, Biological Oxygen Demand (BOD_5) 5210 B, Chemical Oxygen Demand (COD) - section 5220 D, Closed Reflux, Colorimetric Method-, Ammonia (NH_4-N) Nesslerization method, total Keldgal nitrogen, and total phenol (APHA, 2005).

3.5 Feed water quality

In this study, normal wastewater is used which is collected from the whole facility of the Birzeit University, (chemistry labs, medical labs, toilets, washbasin, cleaning activity, and kitchens). This wastewater is discharged either by gravity or by pumping to the main equalization tank, which is the main source for this study.

According to this study, the used wastewater characteristics were as shown in the Table (2), which is the average of twenty grab sample.

Table 2 Feed wastewater characteristics

Parameter	Average Concentration (mg\L)	Minimum Concentration (mg\L)	maximum Concentration (mg\L)	Number of samples
BOD_5	248	195	280	19
COD	479	325	620	19
pH	6.67	5.68	7.63	19
TSS	207	157	284	19
TDS	644	384	969	19
NH_4^+	61.8	44.3	113	19
TN	81.5	71.31	145.33	19
Total Phenol	0.1	0.083	0.12	19

All parameter was been with a normal value for domestic wastewater except the total nitrogen, which is referring to the culture and uses in this community.

Chapter Four

Results and Discussion

4.1 Background

The main objective of the study was to assess to investigate the robustness of an immersed pilot flat sheet membrane bioreactor (MBR) for reclaimed water recycling focusing on system performance and reliability under normal and hazardous operational conditions and used reclaimed water in agriculture. All Detailed information of sampling and analytical results is presented in attached annexes as following:

- Results of data collection (Annex A) including:
    - Dissolved Oxygen.
    - Biological Oxygen Demand.
    - Chemical Oxygen Demand.
    - Ammonium.
    - Total Keldgal nitrogen.
- Physical properties (Annex B).
- Mass and solid properties (Annex C).
- Phenol and OMWW properties (Annex D).

4.2 Data collection

The pilot-scale MBR was run for 215 days with 60 days without samples which is refer to university closing The experiment was run 127 days for the normal condition as a baseline sample was taken every week, and run for 30 days under for abnormal condition the toxic dose of OMWW.

Samples were analyzed in BZULAB finding physical, chemical and biological parameter as shown in annexes.

4.3 Treated wastewater quality under normal conditions:

At the first phase of this study, the treated water quality is investigated under the normal condition and evaluation their result with Palestinian standards for reclaimed water.

Table 3 Agricultural Ministry standard (Palestinian specification No.34-2012)

Parameter (mg\L)	Treated water quality			
	High quality (A)	Good quality (B)	Medium quality (C)	Low quality (D)
DO	>1	>1	>1	>1
BOD	20	20	40	60
COD	50	50	100	150
NH_4^+	5	5	10	15
TN	30	30	45	60
Total Phenol	0.002	0.002	0.002	0.002
TSS	30	30	50	90
TDS	1200	1500	1500	1500
pH*	6-9	6-9	6-9	6-9
FC**	200	1000	1000	1000

* unit less, ** (CFU/100mm)

4.3.1 Biological oxygen demand removal

The biological oxygen demand (BOD) as shown in the figure (5) below BOD concentration in influent was 195-280 mg/L and the effluent concentration was 3.7-13 mg/L with removal efficiency more than 94% according to Palestinian agricultural ministry, this treated water can be used as a water source for irrigation.

This result obtained same as the mentioned result by Dancova et al. (2008), the removal rate of BOD 91%-98%.

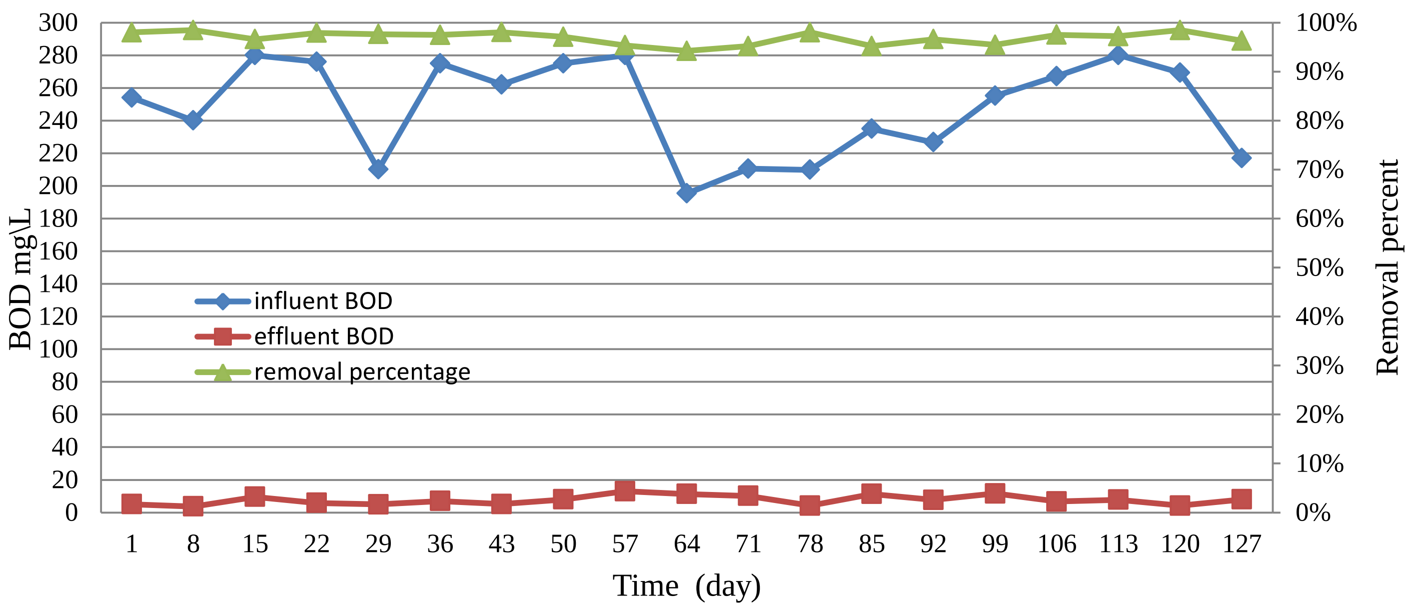

Figure 5 Influent and effluent BOD concentration and removal percentage under normal condition

4.3.2 Chemical oxygen demand removal

The chemical oxygen demand (COD) as shown in the figure (6) below COD concentration in influent was 325-617 mg/L and the effluent concentration was 17-52 mg/L with removal efficiency more than 90% according to Palestinian Agricultural Ministry, this treated water can be used as a water source for irrigation.

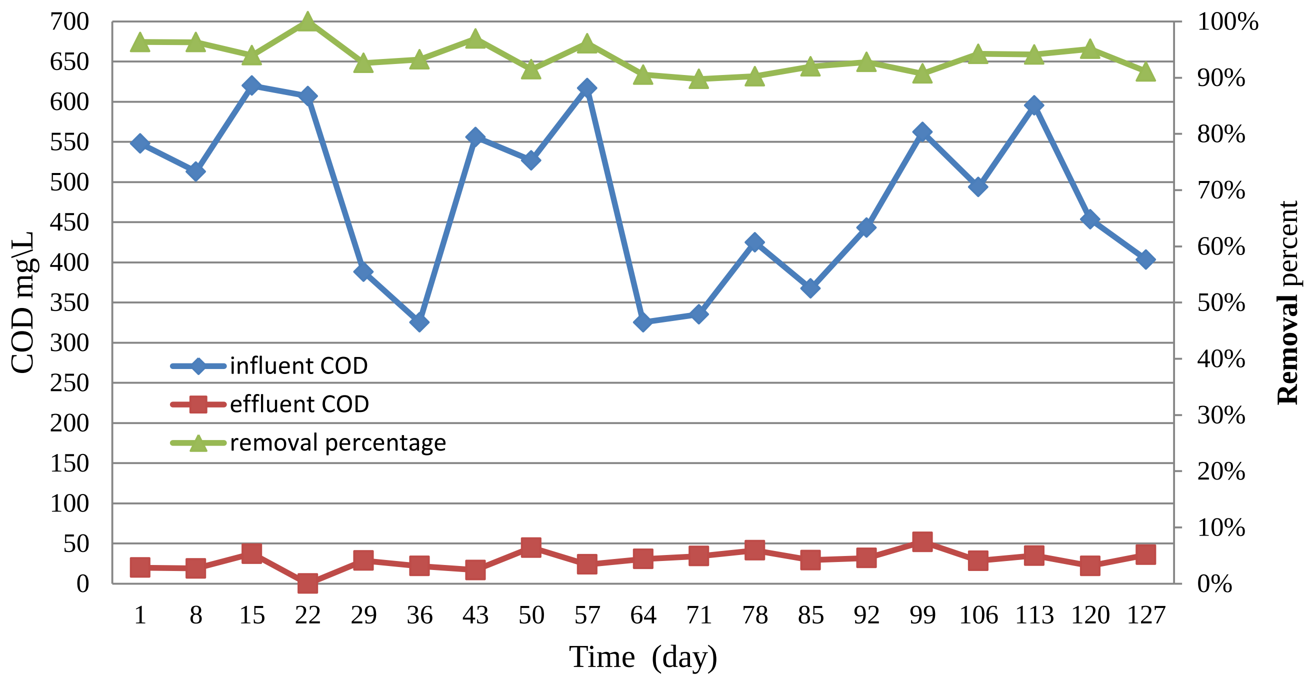

Figure 6 Influent and effluent COD concentration and removal percentage under normal condition

4.3.3 Total suspended solids removal

The total suspended solids (TSS) as shown in the figure (7) below, TSS concentration in influent was 157-284 mg/L and the effluent concentration was 5-12 mg/L with removal efficiency more than 93% according to Palestinian Agricultural Ministry, this treated water can be used as a water source for irrigation.

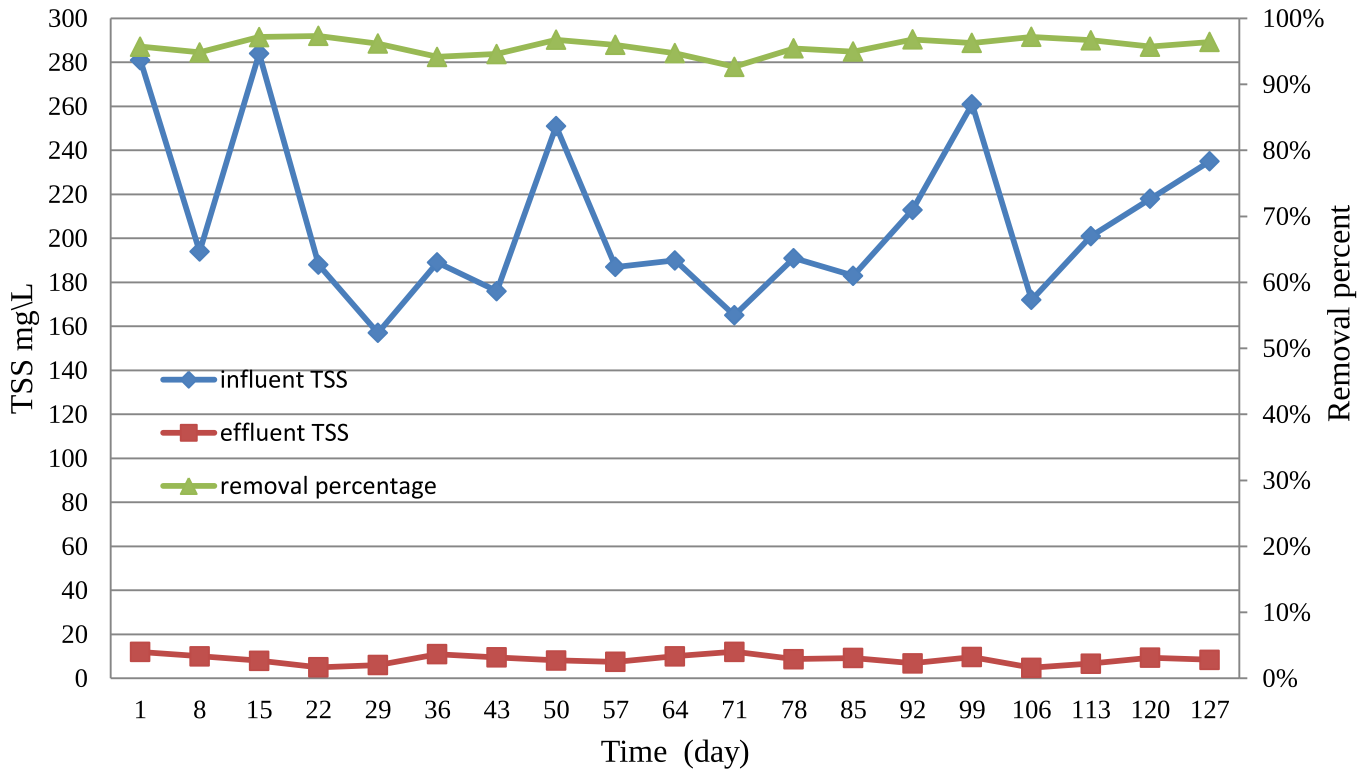

Figure 7 Influent and effluent TSS concentration and removal percentage under normal condition

4.3.4 Ammonium removal

Ammonium (NH_4^+) as shown in the figure (8) below concentration in influent was 44-113 mg/L and the effluent concentration was 0-5 mg/L with removal efficiency more than 93% according to Palestinian Agricultural Ministry, this treated water can be used as a water source for irrigation.

As Dancova et al. (2008) and Abegglen et al. (2008) reported the NH_4^+ removal rate for domestic wastewater about 98%.

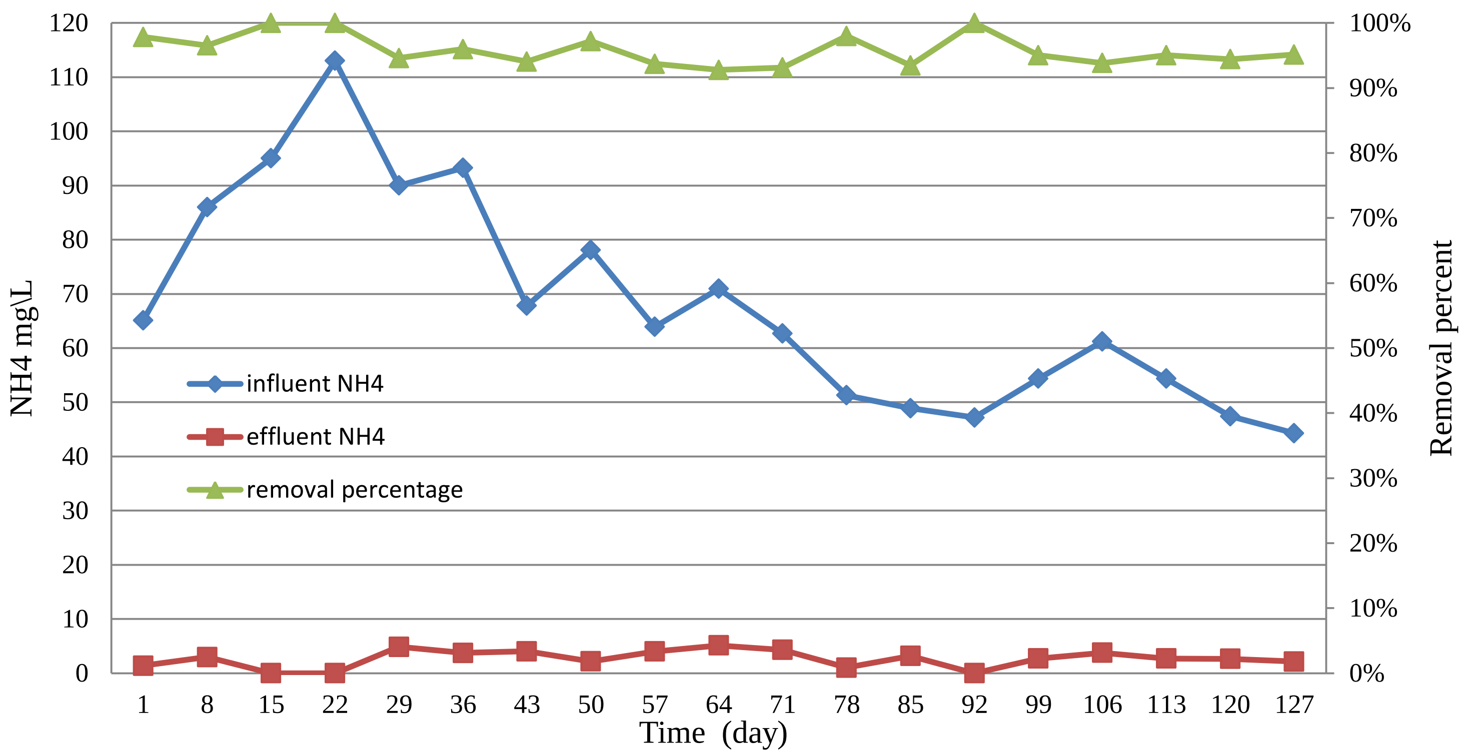

Figure 8 Influent and effluent NH_4^+ concentration and removal percentage under normal condition

4.3.5 Total Kjeldahl nitrogen removal

Total Kjeldahl nitrogen removal (TKN) as shown in the figure (9) below, TKN concentration in influent was 71-145 mg/L and the effluent concentration was 14-36 mg/L with removal efficiency more than 71% according to Palestinian Agricultural Ministry, this treated water can be used as a water source for irrigation.

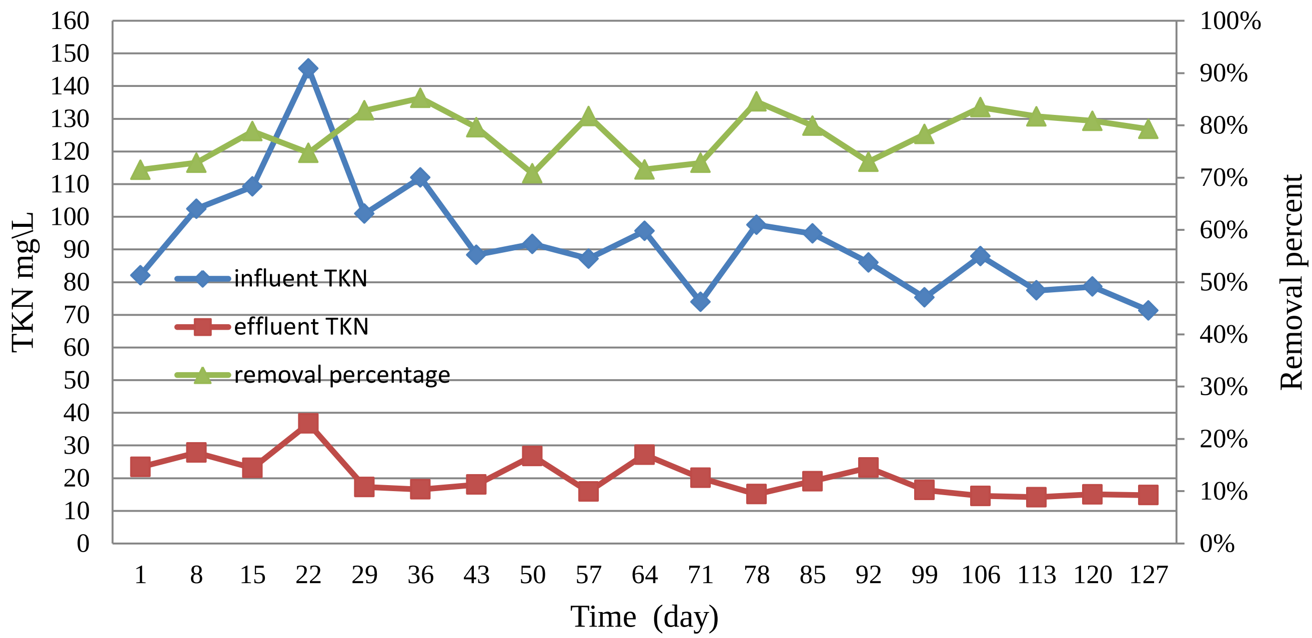

Figure 9 Influent and effluent TKN concentration and removal percentage under normal conditions

4.3.6 Total Phenol

After analyse samples of phenol which is usually found in industrial wastewater, total phenol (TPh) was found in the influent wastewater as shown in the figure (10) below, TPh concentration in influent was 83-120 µg/L and the effluent concentration was 0-2.2 µg/L with removal efficiency more than 98% according to Palestinian Agricultural Ministry, this treated water can be used as water source for irrigation.

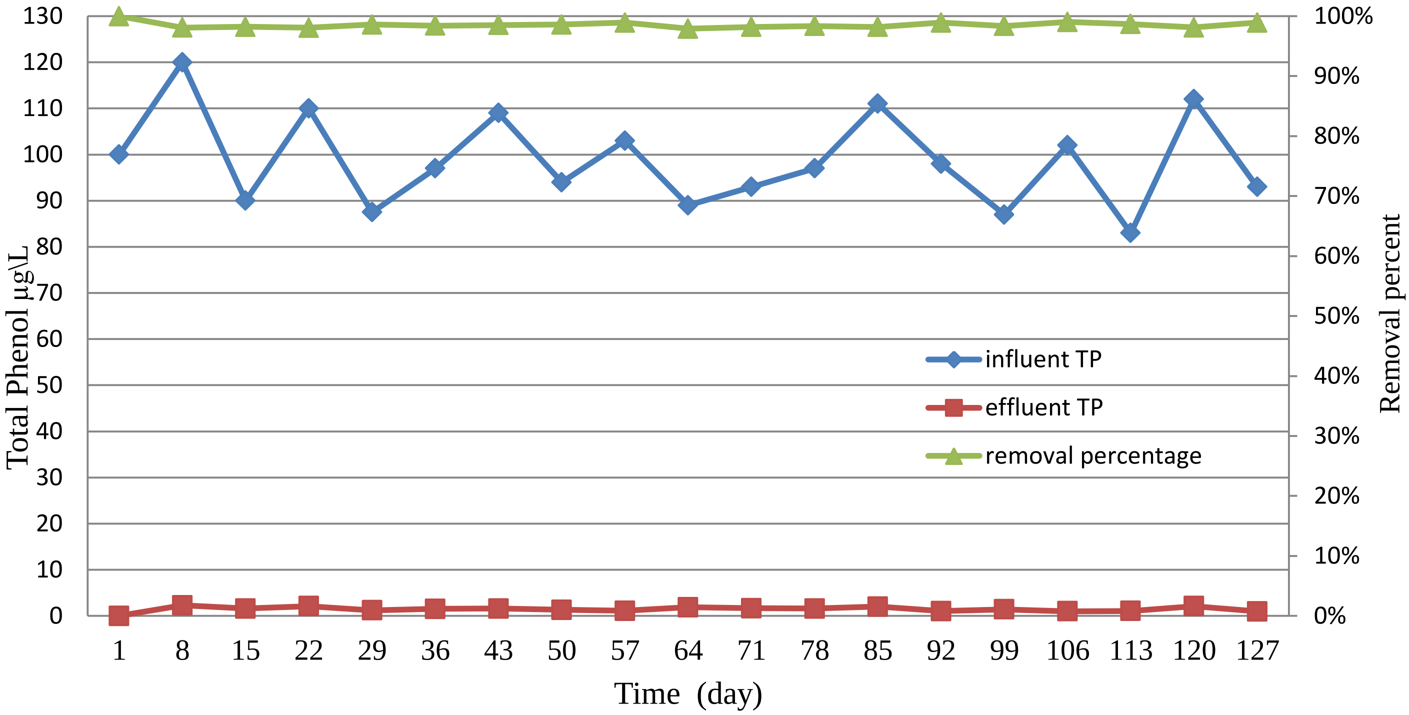

Figure 10 Influent and effluent total phenol concentration and removal percentage under normal conditions

According to the analyzed data which obtain under normal conditions the removal of BOD, COD, TSS, NH_4^+, and TKN was (94%, 90%, 93%, 93% and 71%) respectively. And the effluent concentration in mg\L was BOD <20, TSS<30 and NH_4^+ <=5 for all samples, but COD (52mg\L > 50mg\L) and TKN (37 mg\L > 30mg\L) which is less than standard for irrigation only one of the samples became higher than limits, but according to Palestinian Standard Institution, if the samples go out the limits do not exceed 20% of samples then it is accepted.

4.3.7 Dissolved oxygen and pH

AS figure (11) shows pH was been highly variance accordance to the property of committee wastewater production sometimes the chemical labs used highly acidic or alkaline materials, which is moving forward to the wastewater treatment plant, but the effect is reduced due to the equalization tank.

D.O. was been variance from 7.5-2 mg\L, as shown in figure (11), which is high variance but is above the minimum limits.

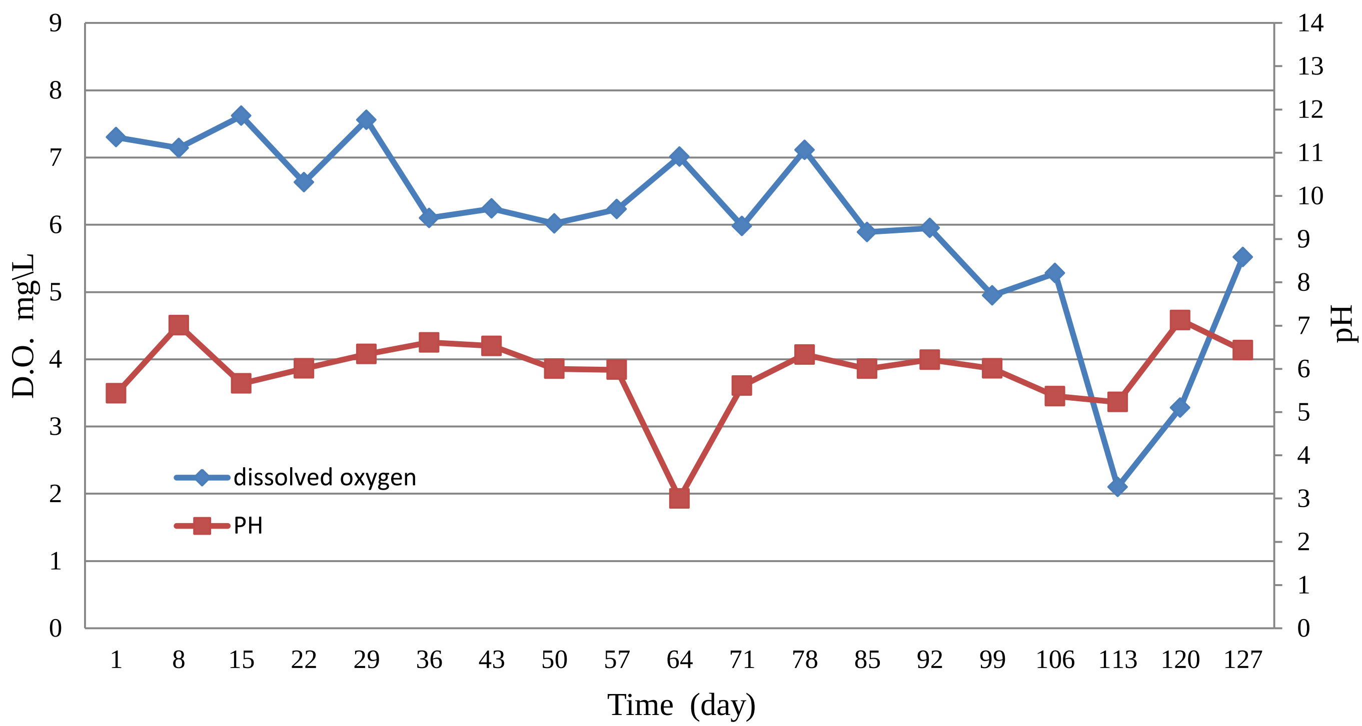

Figure 11 Dissolved oxygen concentration and pH value under normal conditions

In energy consumption per day was about (4 KW/day), which is mean that each one cubic meter of treated water consumes about 20 KW and the energy consumption is about (0.33 KW\h), and the energy consumption is referred to pumps used and the permeate flow quantity.

These quality results of this study indicate of the high efficiency of MBR process in wastewater treatment under normal conditions, the MBR effluent was with high quality for all chemical, biological and physical parameters of treated wastewater according to Agricultural Ministry standard could be used for irrigation with high-quality grade (A).

4.4 Treated wastewater quality under toxic loading conditions

As one of the goals of this study was investigate the MBR performance under abnormal conditions (Olive mill wastewater) this study investigated according to toxicant loading rate as a percentage of the total volume of the reactor, in other words using the wastewater as diluted water for high loading and toxic wastewater.

Fresh Olive mill wastewater was collected from three phase centrifugal squeezer in Ramallah – Palestine and analyze in BZULAB to determine the properties of it.

Characteristics of twenty samples average wastewater and OMWW average for four samples was used in the second part of this study was as shown below in table (4).

Table 4 Characteristics of wastewater and OMWW

Parameter	Average Concentration WW (mg\L)	Concentration OMWW(g\L)
BOD_5	248	49
COD	479	129
PH	6.67	4.94
TSS	207	48
TDS	644	60
NH_4^+	61.8	1.3
TN	81.5	1.6
Total Phenol	0.1	3.26

For the doses was 1.25% (20L), 2.5% (40L), 5% (80L), 10% (160L) of reactor volume respectively, olive mill wastewater adds to the anoxic zone of the pilot to be diluted. These doses were added at day 3, 10, 18, and 25 of the experiment; samples were taken and analyzed twice for each dose after addition. The impact on performance and treated quality will be discussed below briefly.

4.4.1 BOD and COD removal under abnormal conditions

The biological oxygen demand (BOD) as shown in the figure (12) below BOD concentration in influent was (225-5157) mg/L and the effluent concentration was (5.3-2105) mg/L with removal efficiency more than 59% according to Palestinian Agricultural Ministry, this treated water cannot be used as water source for irrigation, but if farther treatment proceeds it could be used.

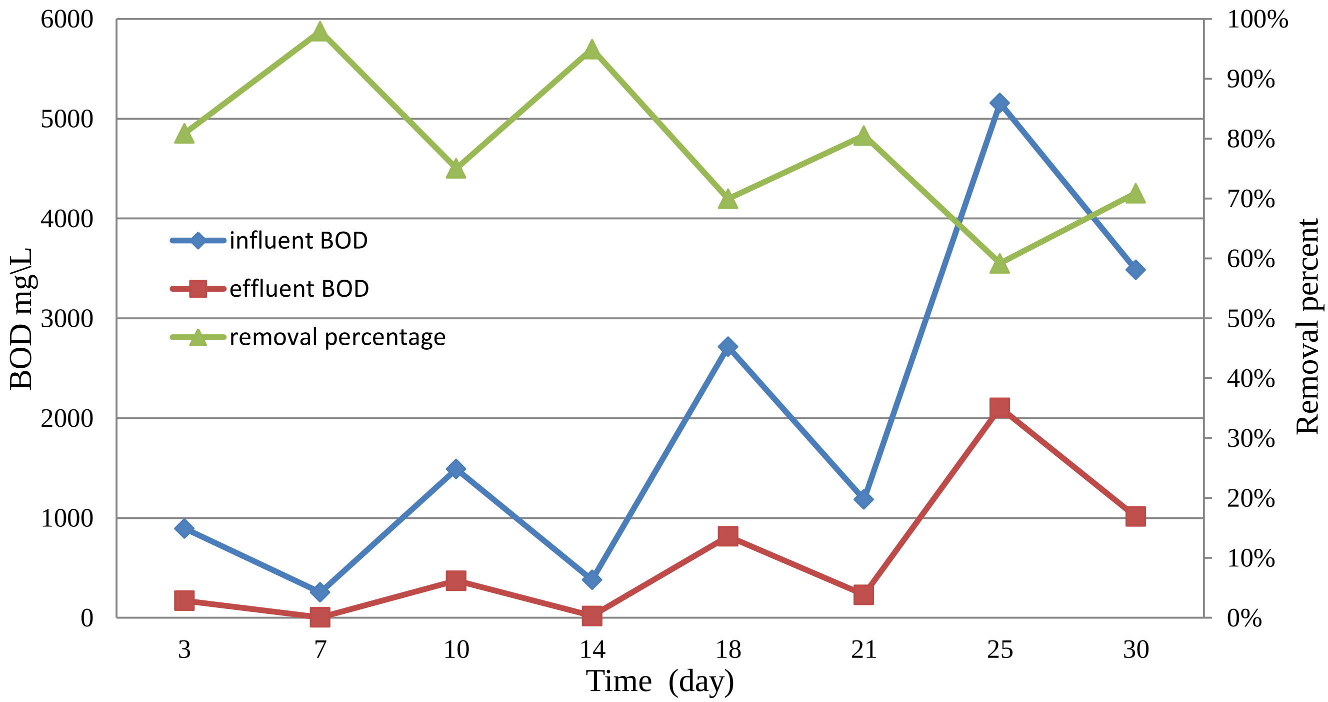

Figure 12 Influent and effluent BOD concentration and removal percentage under abnormal condition

The chemical oxygen demand (COD) as shown in the figure (13) below COD concentration in influent was (520-8463) mg/L and the effluent concentration was (32-4354) mg/L with removal efficiency more than 49 % according to Palestinian Agricultural Ministry, this treated water can be used as water source for irrigation.

As Dhaouadi and Marrot (2008) reported the COD removal efficiency range (81% to 37%) for ceramic external MBR. However, the removal efficiency related to the COD concentration in the inlet to the reactor, which is decreasing with increasing COD concentration. This study shows the same result although the difference between MBR configuration.

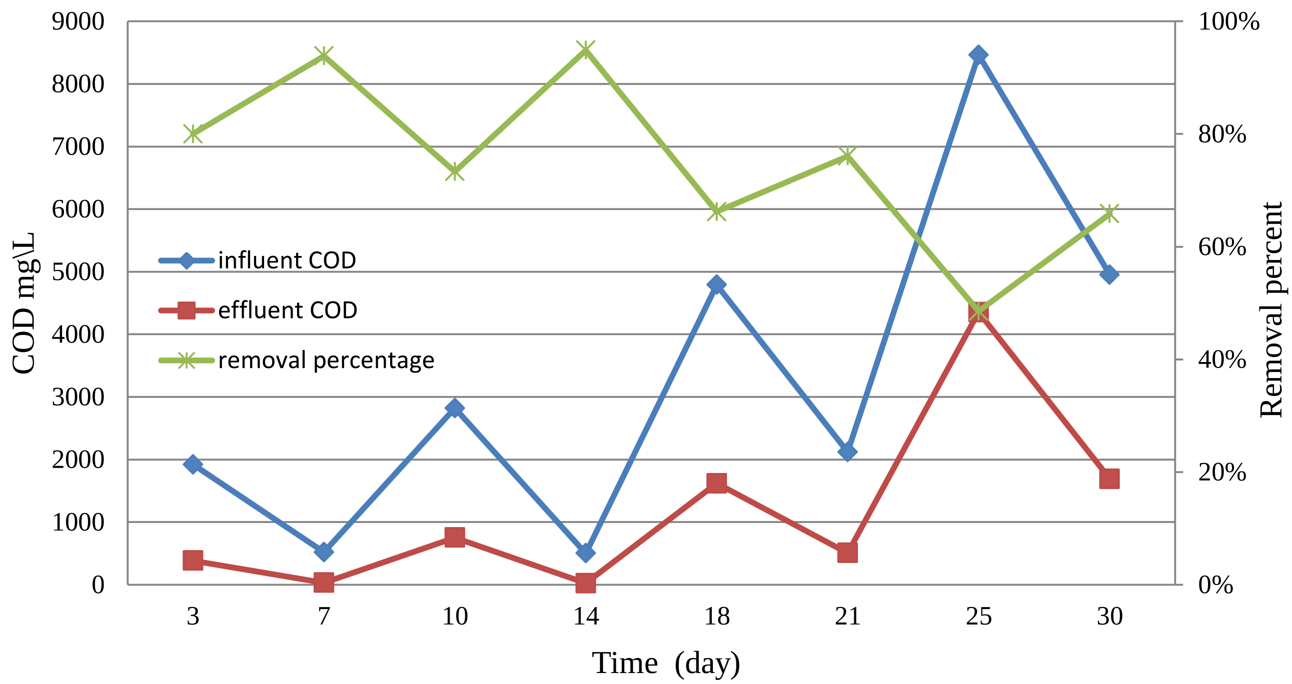

Figure 13 Influent and effluent COD concentration and removal percentage under abnormal condition

4.4.2 Total suspended solids removal under abnormal conditions

The total suspended solids (TSS) as shown in the figure (14) below, TSS concentration in influent was (240-4962) mg/L and the effluent concentration was (10-15) mg/L with removal efficiency more than 93% according to Palestinian Agricultural Ministry, this treated water can be used as water source for irrigation. It seems from this study the TSS performance does not affect the high load.

As Awan et al. (2015) reported the efficiency of MBR removal rate about 100% for industrial wastewater, Melin et al. (2006) said the same for MBR removal rate for suspended solids for municipal wastewater with 99%, which is almost same as the result obtained in this study.

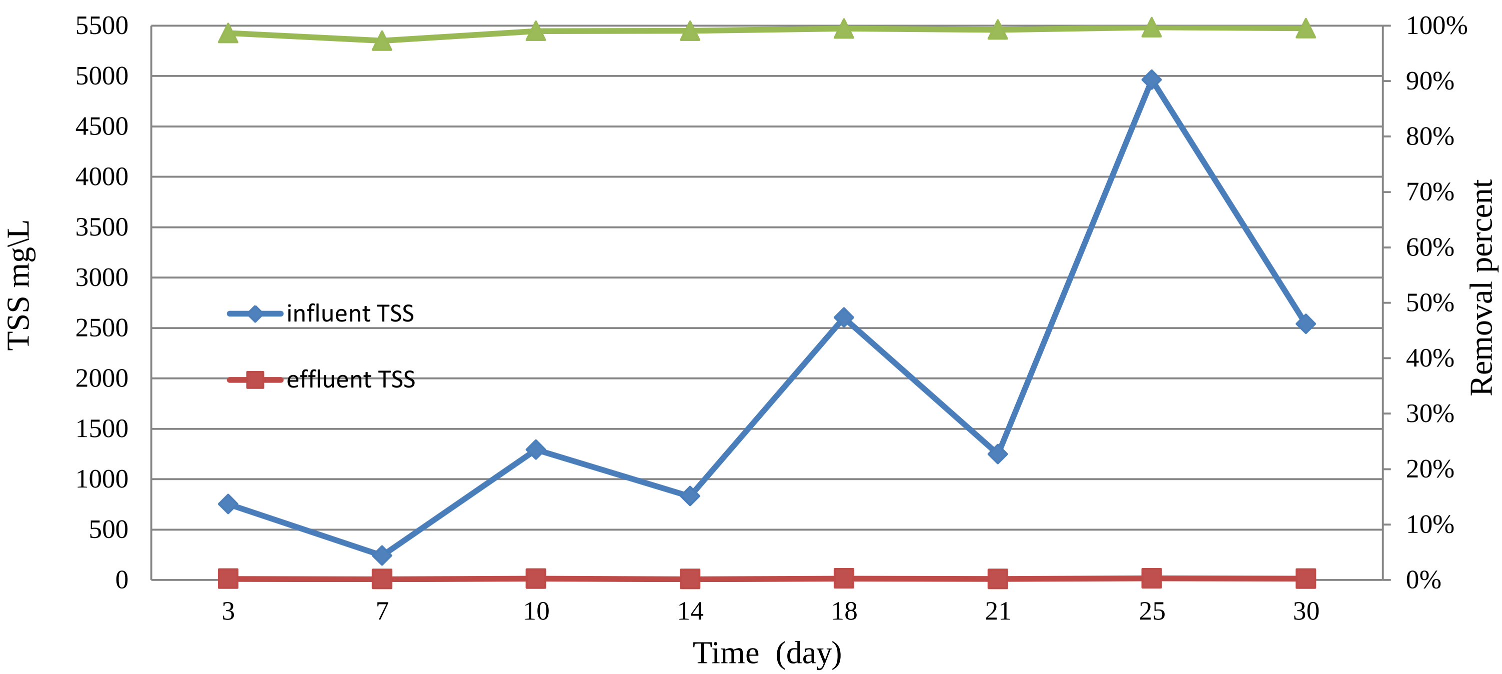

Figure 14 Influent and effluent TSS concentration and removal percentage under abnormal condition

4.4.3 Ammonia and TKN removal under abnormal conditions

Ammonia (NH_4^+) as shown in the figure (15) below, NH_4^+ concentration in influent was (76-188) mg/L and the effluent concentration was (2-7.5) mg/L with removal efficiency more than 95% according to Palestinian Agricultural Ministry, this treated water can be used as water source for irrigation.

Total Kjeldahl nitrogen removal (TKN) as shown in the figure (16) below, TKN concentration in influent was (75-232) mg/L and the effluent concentration was (15-77) mg/L with removal efficiency more than 67% according to Palestinian Agricultural Ministry, this treated water can be used as water source for irrigation.

As Knops (2010) reported the NH_4^+ removal rate for hollow fiber is about 90% -50% and total nitrogen about 70 % removal rate.

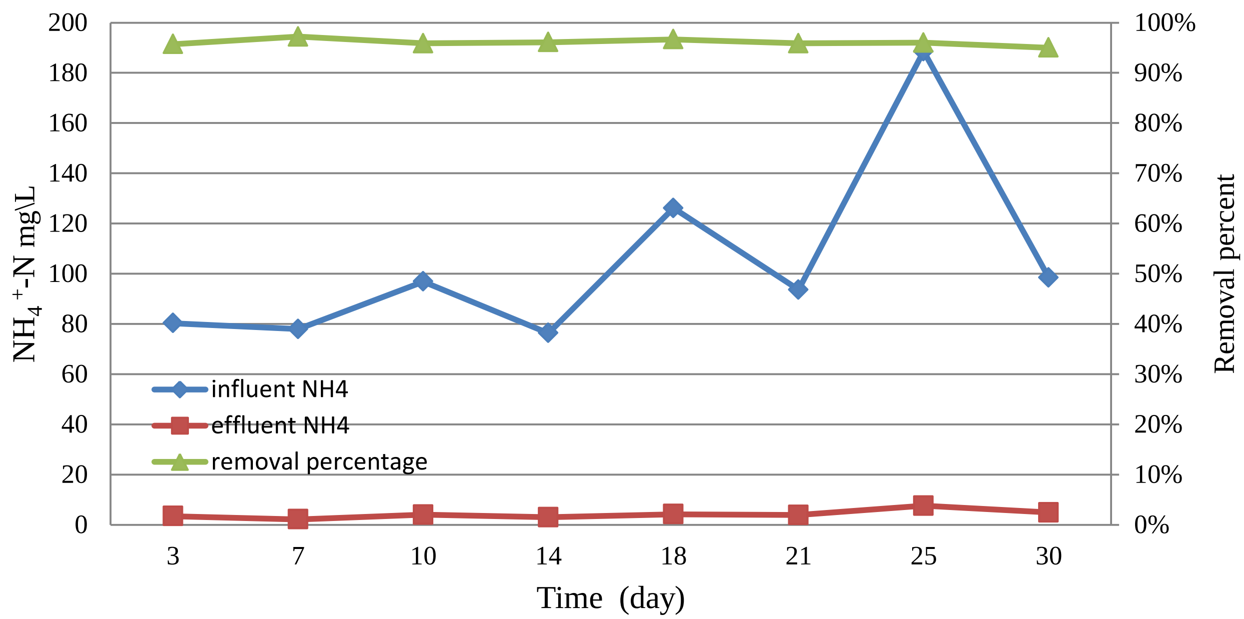

Figure 15 influent and effluent NH_4^+ concentration and removal percentage under abnormal condition

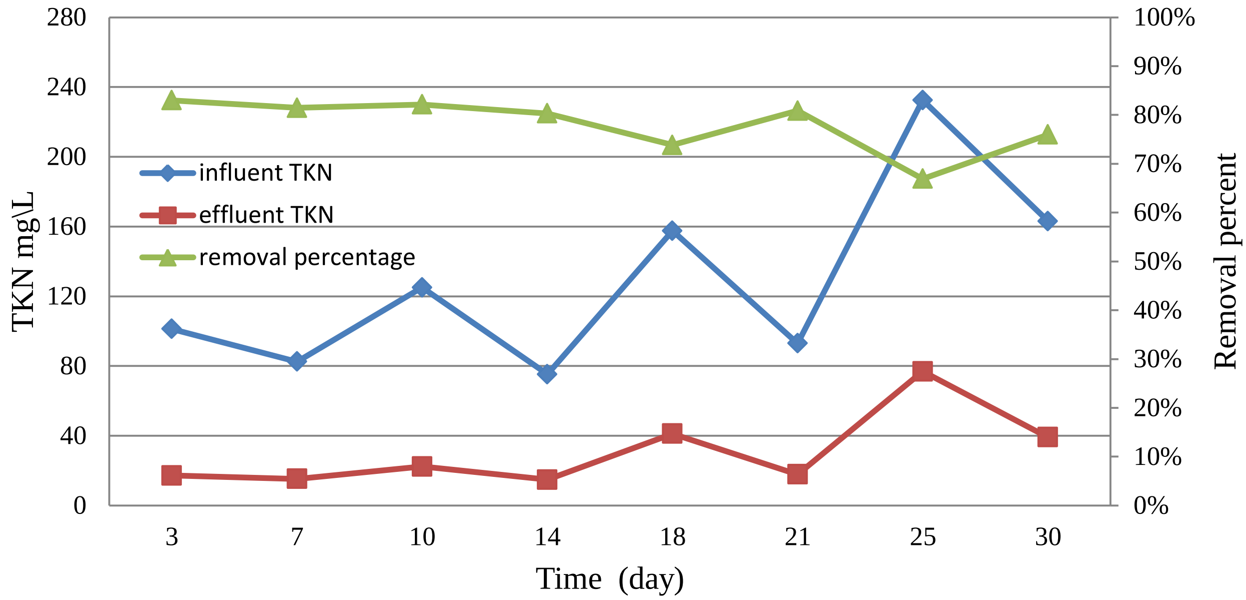

Figure 16 Influent and effluent TKN concentration and removal percentage under abnormal condition

4.4.4 Total Phenol

After analyse samples of phenol which are usually found in industrial wastewater, total phenol (TPh) was found in the influent wastewater as shown in the figure (17) below, TPh concentration in influent was (23-225) mg/L and the effluent concentration was (2-23) mg/L with removal efficiency more than 89%, which is close to Dhaouadi and Marrot (2008) result .according to Palestinian Agricultural Ministry, this treated water can be used as water source for irrigation.

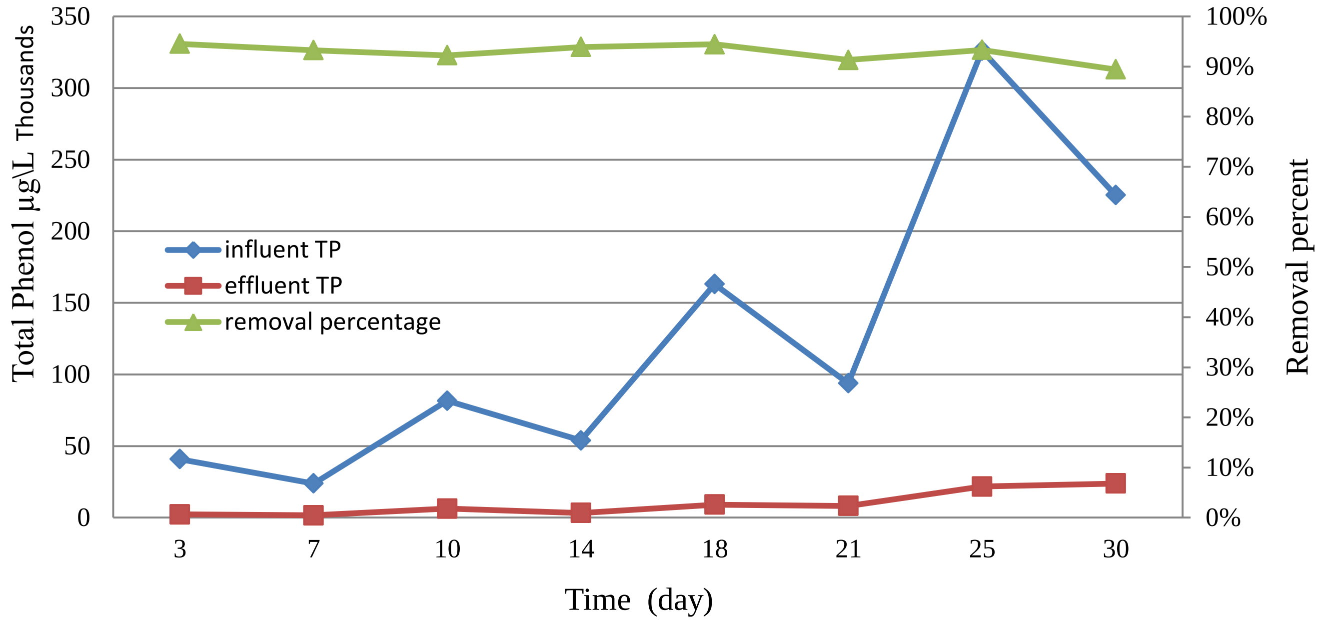

Figure 17 Influent and effluent TPh concentration and removal percentage under abnormal condition

4.4.5 Dissolved oxygen and pH

PH was been variance accordance to the acidity of OMWW, which is moving forward to the wastewater treatment plant as shown below in figure (17).

As shown in figure (18), D.O was highly decreased due to oil layer existing in OMWW, so that the efficiency of dissolving oxygen decreasing highly with increasing OMWW dose increase.

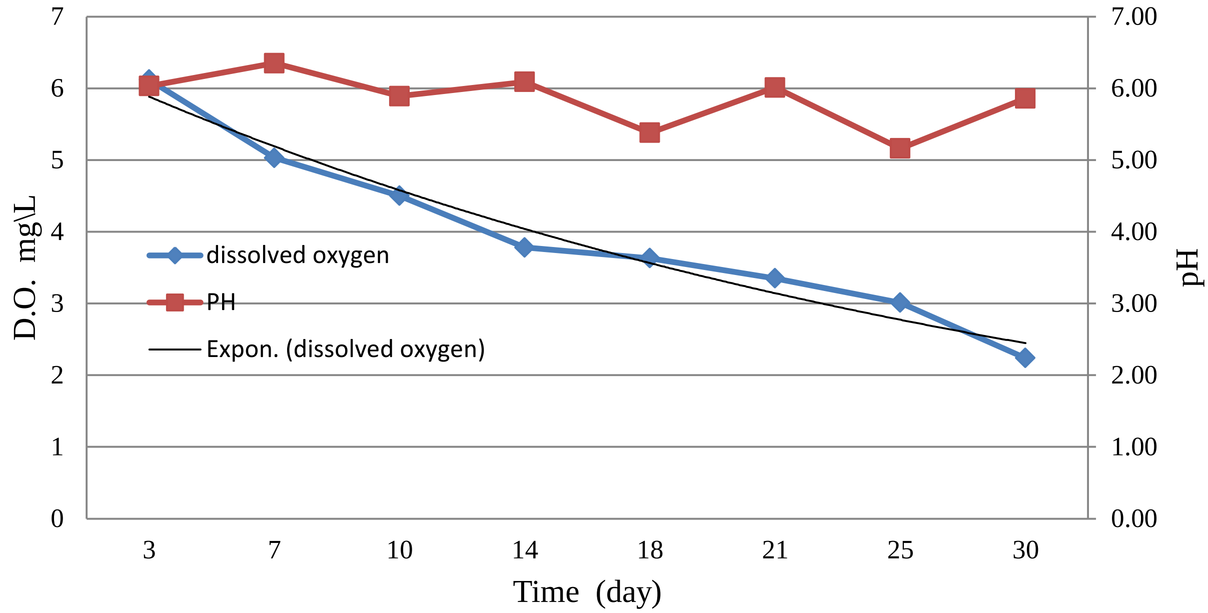

Figure 18 Dissolved oxygen concentration and pH value under abnormal condition

4.4.6 Membrane flux permeate

As mentioned before Jeong et al. (2007) said that the permeate flux decrease with highly OLR. As shown in figure (19) below the permeate flux decrease exponentially with increasing OLR which is referred to the soluble microbial products attached to MBR increasing with higher OLR.

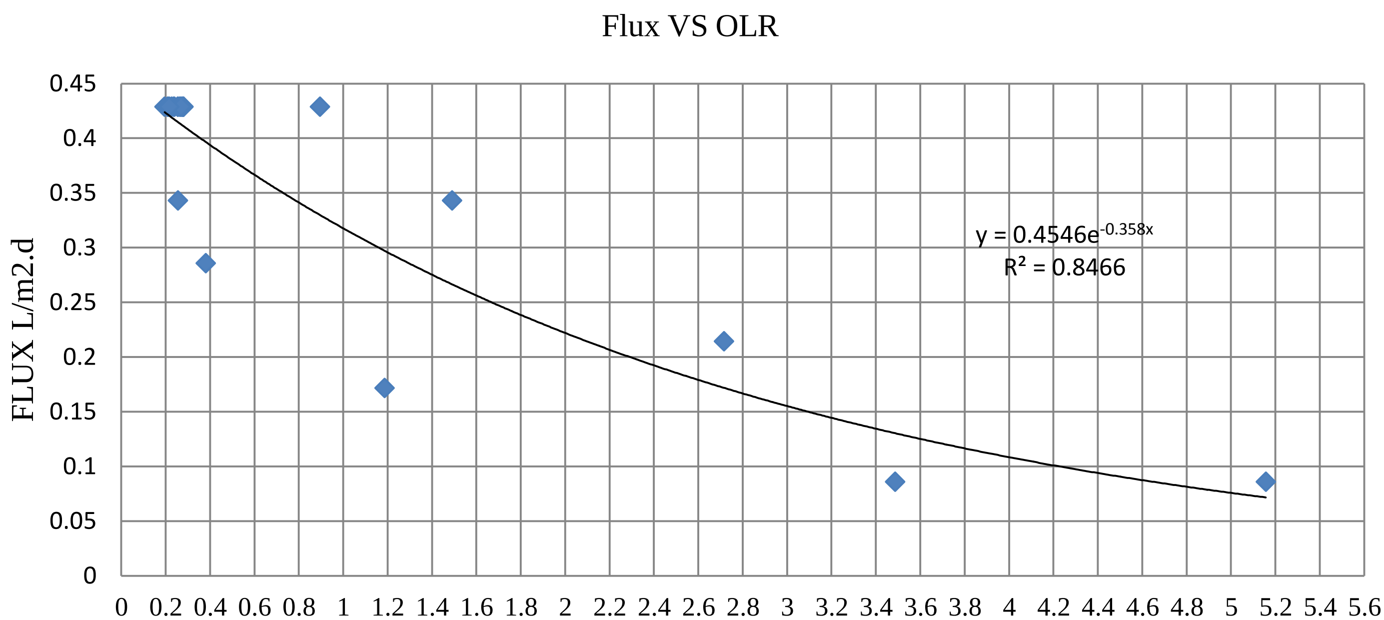

Figure 19 Flux versus OLR

According to these result for treated water under abnormal condition, the MBR system was stable until the OMWW doses reach up to 2.5% (20 L) of the volume of reactor except for phenol.

For the toxic dose of OMWW reach to 10% of reactor volume some parameter does not affect or slightly affected (TKN, NH_4^+, TSS) the other parameter was affected and the effluent has high concentration like (BOD, COD, and total phenol).

4.5 Parameter Correlations

After obtaining the result from the analysis, all these results were analyzed using SPSS software (Statistical Package for the Social Science) to find the correlation between variables, that believes the effect on MBR fouling or it could give an indication about it.

In this study, the SRT considered as constant for 25 days but the other variables OLR, MLSS, TDS, TSS and TMP. The statistical analysis shows that OLR, MLSS, HRT, TDS, and TSS in the aeration tank are highly correlated with the flux of confidence more than 90%.

It seems form table (5) below, that increasing the OLR, MLSS, TDS, TSS, and HRT has a highly negative effect on flux that is an indication of biofouling. So that, when these parameters increase the biofouling and TMP increase and the flux decrease. All of these results in this study are matching with another researcher

So that the equation of flux from the linear regression is

$$F = 0.637 + 0.005 \times OLR - 0.052 \times MLSS - 1 \times TSS \times 10^{-1} - 1.16 \times TDS \times 10^{-6} - 0.016 \times HRT$$

F is Flux (L/m2.d), OLR is organic loading rate (kgBOD\m3.d), MLSS is mixed liquor suspended solid (g\L), TDS is total suspended solid (mg\L), and HRT is hydraulic retention time (day).

This equation could help to predict clogging and the parameters could lead to biofouling before it happened according to data in the field.

Table 5 Correlations of parameters

		FLUX	T aeration	OLR	MLSS	SLR	HRT	pH aeration	TSS	TDS aeration
FLUX	Pearson Correlation	1	-0.017	-0.892**	-0.993**	-0.273	-0.922**	0.084	-0.893**	-0.948**
	Sig. (2-tailed)		0.932	0.000	0.000	0.168	0.000	0.677	0.000	0.000
	N	27	27	27	27	27	27	27	27	27
T aeration	Pearson Correlation	-0.017	1	-0.018	0.034	0.116	-0.048	-0.036	-0.014	-0.024
	Sig. (2-tailed)	0.932		0.930	0.865	0.563	0.811	0.858	0.946	0.907
	N	27	27	27	27	27	27	27	27	27
OLR	Pearson Correlation	-0.892**	-0.018	1	0.851**	0.463*	0.925**	-0.162	0.987**	0.976**
	Sig. (2-tailed)	0.000	0.930		0.000	0.015	.000	.419	.000	.000
	N	27	27	27	27	27	27	27	27	27
MLSS	Pearson Correlation	-0.993**	0.034	0.851**	1	0.288	0.879**	-0.063	0.855**	0.918**
	Sig. (2-tailed)	.000	.865	.000		0.145	0.000	0.756	0.000	0.000
	N	27	27	27	27	27	27	27	27	27
SLR	Pearson Correlation	-0.273	0.116	0.463*	0.288	1	0.167	-0.053	0.453*	0.367
	Sig. (2-tailed)	0.168	0.563	0.015	0.145		0.405	0.793	0.018	0.060
	N	27	27	27	27	27	27	27	27	27
HRT	Pearson Correlation	-0.922**	-0.048	0.925**	0.879**	0.167	1	-0.126	0.894**	0.937**
	Sig. (2-tailed)	0.000	0.811	0.000	0.000	0.405		0.532	0.000	0.000
	N	27	27	27	27	27	27	27	27	27
pH aeration	Pearson Correlation	0.084	-0.036	-0.162	-0.063	-0.053	-0.126	1	-0.164	-0.151
	Sig. (2-tailed)	0.677	0.858	0.419	0.756	0.793	0.532		0.412	0.453
	N	27	27	27	27	27	27	27	27	27
TSS	Pearson Correlation	-0.893**	-0.014	0.987**	0.855**	0.453*	0.894**	-0.164	1	0.986**
	Sig. (2-tailed)	0.000	0.946	0.000	0.000	0.018	0.000	0.412		0.000
	N	27	27	27	27	27	27	27	27	27
TDS aeration	Pearson Correlation	-0.948**	-0.024	0.976**	0.918**	0.367	0.937**	-0.151	0.986**	1
	Sig. (2-tailed)	0.000	0.907	0.000	0.000	0.060	0.000	0.453	0.000	
	N	27	27	27	27	27	27	27	27	27

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 6 SPSS Variables Entered/Removed

Model	Variables Entered[a]	Variables Removed	Method
1	TDS aeration, MLSS, HRT, OLR, TSS		Enter

a. All requested variables entered.
b. Dependent Variable: FLUX

Table 7 SPSS Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.999a	0.998	0.997	0.00546

a. Predictors: (Constant), TDS aeration, MLSS, HRT, OLR, TSS

Table 8 Coefficients of linear regression

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.637	0.012		53.380	0.000
	OLR	0.005	0.010	0.057	0.540	0.595
	MLSS	-0.052	0.003	-0.773	-17.853	0.000
	HRT	-0.016	0.005	-0.181	-3.038	0.006
	TSS	-1.014E-5	0.000	-0.103	-0.506	0.618
	TDS aeration	-1.159E-6	0.000	-0.024	-.118	0.907

a. Dependent Variable: FLUX

This study led to that under the operating conditions have only one big problem which is the acidity of wastewater under this condition NaOH add to the system as alkaline substances to increase pH value to 6.5, MLSS concentration still low comparing with MBR plant that refer to low LOR condition and low hydraulic retention time (1day).

Chapter Five

Conclusions and Recommendations

5.1 Conclusions

The main objective of this study was to evaluate an immersed pilot flat sheet membrane bioreactor (MBR) performance and reliability under normal and hazardous operational conditions. This was achieved through data collection survey and technical field study. Based on the results of the study, the following conclusions were drawn:

- The membrane biofouling became higher when the OLR increasing and removal rate for COD decreasing reverse with increasing OLR.
- The Hydraulic Retention Time and Mixed liquor suspended solids could be the most critical process parameters that may affect on the efficiency of MBRs.
- Results analysis of MBR on process performance and effluent quality of Pilot scale is complying with set local effluent limits for agricultural irrigation.
- Olive mill wastewater dosing has impacts process performance for removal rate of (Phenol, D.O., BOD, and pH) and the reclaimed water could not use for irrigation.

5.2 Recommendations

These recommendations are made to mitigate the impact of toxic loading on WWTP specially MBR and are also considered as a potential source of support for future studies. These recommendations address the following issues regarding the wastewater management:

- In case of flat sheet membrane no backwash happened, for to reduce the biofouling it is recommended to relax the system to clean the system physically, to reduce the chemical cleaning.

- Construction of an equalization tanks before the WWTP, and an additional reservoir at the end of the treatment plant to reduce the low effluent quality to move forward wadi or irrigation.

- Wastewater has been used as a source of irrigation. In addition to providing a low-cost water source, the use of treated wastewater for irrigation in agriculture.

- Industries should be encouraged to recycle part of their wastewater and to treat the remainder to meet standards set for ultimate wastewater reuse or disposal.

- To respond to the "Polluter pay principle"; Wastewater from industries with significant pollution should be treated separately to standards, encouraged to recycle part of their wastewater, irrigation or to allow its safe disposal.

- To improve quality of effluent if toxic flow like OMWW insert to influent using the recirculation of effluent to WWTP or improve quality using another compartment of treated effluent.

- Developing new laws and regulations to control illegal connection of OMWW to domestic sewage network especially at the OMWW season.

- Raise public awareness targeting the public and decision-makers on groundwater and natural resources issues.

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ANNEX (A)

Annex (A) Phase one chemical characteristics data

Date	Experiment day	D.O.				COD			BOD5			(TN) Total Nitrogen			NH4-N		
		Influent WWTP	Effluent WWTP	Aeration	Inlet of the day	Influent WWTP	Effluent WWTP	Elimination Rate COD	Influent WWTP	BOD Effluent WWTP (<2 mg/l)	Elimination Rate BOD	Influent WWTP	Effluent WWTP	Elimination Rate TN	Influent WWTP	Effluent WWTP	Elimination Rate
		mg/l	mg/l	mg/l	m^3	mg/l	mg/l	%	mg/l	mg/l	%	mg/l	mg/l	%	mg/l	mg/l	%
3/1/2016	1	0.73	7.30	8.20	1.5	548.0	20.0	96%	254	5.1	98%	82.10	23.42	71%	65.10	1.400	98%
3/8/2016	8	0.98	7.14	8.40	1.5	513.0	19.0	96%	240	3.7	98%	102.43	27.83	73%	86.00	2.970	97%
3/15/2016	15	1.20	7.62	8.83	1.5	620.0	37.3	94%	280	9.6	97%	109.23	23.11	79%	95.00	BDL	100%
3/22/2016	22	1.23	6.63	7.23	1.5	607.0	BDL	100%	276	5.8	98%	145.33	36.74	75%	113.00	BDL	100%
3/29/2016	29	1.12	7.56	8.22	1.5	388.0	28.7	93%	210	5.0	98%	100.90	17.31	83%	90.00	4.870	95%
4/6/2016	36	1.00	6.10	6.18	1.5	325.3	22.0	93%	275	7.0	97%	112.00	16.54	85%	93.25	3.760	96%
4/13/2016	43	0.70	6.24	6.40	1.5	556.0	17.0	97%	262	5.2	98%	88.35	18.03	80%	67.81	4.030	94%
4/20/2016	50	0.50	6.02	6.70	1.5	527.0	44.9	91%	275	8.0	97%	91.67	26.78	71%	78.11	2.190	97%
4/27/2016	57	1.60	6.23	7.12	1.5	617.0	24.0	96%	280	13.0	95%	87.19	15.89	82%	63.92	4.020	94%
5/4/2016	64	0.75	7.01	7.99	1.5	325.3	30.8	91%	195	11.3	94%	95.63	27.20	72%	70.93	5.130	93%
5/15/2016	71	0.71	5.98	6.60	1.5	335.3	34.3	90%	211	10.1	95%	73.89	20.10	73%	62.66	4.300	93%
5/30/2016	78	0.99	7.11	7.81	1.5	425.0	41.5	90%	210	4.2	98%	97.56	15.09	85%	51.28	1.030	98%
7/1/2016	85	1.00	5.89	6.47	1.5	367.3	29.4	92%	235	11.3	95%	94.87	19.03	80%	48.89	3.190	93%
7/7/2016	92	1.21	5.95	6.53	1.5	443.2	31.9	93%	227	7.7	97%	85.98	23.20	73%	47.18	BDL	100%
7/13/2016	99	0.84	4.95	5.15	1.5	562.1	52.1	91%	255	11.6	95%	75.27	16.34	78%	54.34	2.700	95%
7/25/2016	106	1.31	5.28	5.75	1.5	493.6	28.5	94%	267	6.7	97%	87.95	14.55	83%	61.23	3.780	94%
8/5/2016	113	1.13	2.10	2.75	1.5	595.3	35.0	94%	280	7.8	97%	77.45	14.17	82%	54.34	2.700	95%
8/14/2016	120	1.28	3.28	3.83	1.5	453.5	22.1	95%	269	4.2	98%	78.62	15.06	81%	47.41	2.650	94%
8/28/2016	127	1.64	5.52	6.47	1.5	403.5	35.9	91%	217	8.1	96%	71.31	14.78	79%	44.30	2.150	95%

ANNEX (B)

Annex (B) Phase one Physical characteristic data

		Temperature			Conductivity			TDS			pH value			Turbidity	
Date	Experiment day	Aeration tank	influent WWTP	Effluent WWTP	Influent WWTP	Effluent WWTP	Aeration	Influent WWTP	Effluent WWTP	Aeration	influent WWTP	Effluent WWTP	Aeration	influent WWTP	Effluent WWTP
		°C	°C	°C	ms/cm						-	-	-	NTU	NTU
3/1/2016	1	15.3	16.3	17.0	1261	721	1029	631	361.0	514	7.54	5.43	5.70	54.90	0.50
3/8/2016	8	16.1	16.7	16.9	1295	890	1012	647	444.0	572	7.35	7.01	7.05	61.32	0.47
3/15/2016	15	16.4	17.1	17.0	1284	914	1015	642	457.0	507	7.30	5.66	5.75	57.90	0.59
3/22/2016	22	17.2	17.1	18.0	1935	875	974	969	437.0	486	6.85	6.01	6.33	73.10	1.04
3/29/2016	29	16.4	15.9	17.0	1800	900	995	900	449.0	499	6.80	6.34	6.78	93.20	0.67
4/6/2016	36	15.2	15.7	13.0	1385	974	1020	793	486.0	511	7.01	6.61	6.70	55.01	0.82
4/13/2016	43	15.8	16.4	15.1	1640	908	1125	805	454.0	562	5.90	6.53	6.89	43.97	0.90
4/20/2016	50	16.8	16.4	16.0	1419	764	1000	716	380.0	501	6.05	6.00	6.10	92.21	0.58
4/27/2016	57	17.0	18.0	17.2	1247	1000	1042	649	500.0	523	6.20	5.98	6.23	48.80	0.68
5/4/2016	64	22.3	22.3	23.1	1380	980	1364	690	490.0	690	6.20	3.00	3.60	52.10	1.12
5/15/2016	71	20.4	21.1	22.8	1306	770	1272	653	385.0	636	6.53	5.61	5.83	68.20	1.05
5/30/2016	78	22.7	23.9	24.3	1160	784	1267	580	392.0	634	7.01	6.33	6.75	51.32	0.95
7/1/2016	85	23.1	22.8	25.0	1157	899	1139	580	450.0	571	6.60	6.00	6.33	63.10	0.86
7/7/2016	92	26.5	25.5	27.1	1145	956	1101	573	478.0	550	7.63	6.21	6.69	62.00	1.01
7/13/2016	99	28.0	28.4	30.3	1105	920	972	550	456.0	487	5.68	6.01	6.02	42.53	1.14
7/25/2016	106	28.5	28.0	29.0	1004.00	865.00	914.00	502.00	432.0	453.00	6.21	5.37	5.90	46.12	0.53
8/5/2016	113	29.3	28.7	30.6	1135.00	887.00	996.00	569.00	443.0	498.00	5.90	5.23	5.36	81.22	0.71
8/14/2016	120	28.9	28.4	31.0	767.00	756.00	756.00	384.00	378.0	378.00	7.06	7.13	7.20	55.11	1.12
8/28/2016	127	29.4	28.6	31.0	806.00	836.00	856.00	403.00	415.0	428.00	6.82	6.43	6.60	49.01	0.59

ANNEX (C)

Annex (C) Phase one mass and solid characteristics data

Date	Experiment day	TDS			TSS			Mixed Liquor Suspended Solids MLSS	Sludge index	BOD-Load	SLR	Sludge age	suspended filtrated solids				TMP	KWH counter	Power consumption	HRT
		Influent WWTP	Effluent WWTP	Aeration	Influent WWTP	Effluent WWTP	Elimination Rate TSS	Aeration	Aeration	BOD - Load COD/2- Load	Sludge Loading Rate	Sludge age SA	Effluent WWTP <30 mg/l)	Influent WWTP	Effluent WWTP					
					mg/l	mg/l		g/l	ml/g	kg/d	kg/kg*d	d	mg/l	µg/l	µg/l		bar	KW	kw/h	day
3/1/2016	1	631	361.0	514	281.0	12.0	96%	2.62	57.3	0.38	0.087	25.0	12.0	100	BDL	100%	-0.10	187.89	187.89	1.12
3/8/2016	8	647	444.0	572	194.0	10.0	95%	3.12	80.1	0.36	0.069	25.0	10.0	120	2.29	98%	-0.25	222.12	34.23	1.12
3/15/2016	15	642	457.0	507	284.0	8.0	97%	3.62	66.3	0.42	0.069	25.0	8.0	90	1.60	98%	-0.23	256.20	34.08	1.12
3/22/2016	22	969	437.0	486	188.0	5.0	97%	3.82	60.2	0.41	0.065	25.0	5.0	110	2.12	98%	-0.15	291.30	35.10	1.12
3/29/2016	29	900	449.0	499	157.0	6.0	96%	3.62	82.9	0.32	0.052	25.0	6.0	88	1.22	99%	-0.12	326.98	35.68	1.12
4/6/2016	36	793	486.0	511	189.0	11.0	94%	3.22	77.6	0.41	0.076	25.0	11.0	97	1.54	98%	0.20	361.67	34.69	1.12
4/13/2016	43	805	454.0	562	176.0	9.5	95%	3.42	73.1	0.39	0.068	25.0	9.5	109	1.60	99%	-0.22	397.54	35.87	1.12
4/20/2016	50	716	380.0	501	251.0	8.1	97%	2.61	95.8	0.41	0.094	25.0	8.1	94	1.32	99%	-0.25	431.32	33.78	1.12
4/27/2016	57	649	500.0	523	187.0	7.5	96%	3.32	75.3	0.42	0.075	25.0	7.5	103	1.12	99%	-0.30	462.52	31.20	1.12
5/4/2016	64	690	490.0	690	190.0	10.0	95%	3.12	80.1	0.29	0.056	25.0	10.0	89	1.87	98%	-0.40	497.60	35.08	1.12
5/15/2016	71	653	385.0	636	165.0	12.1	93%	3.02	115.9	0.32	0.062	25.0	12.1	93	1.66	98%	-0.40	530.06	32.46	1.12
5/30/2016	78	580	392.0	634	191.0	8.7	95%	3.64	123.6	0.31	0.051	25.0	8.7	97	1.59	98%	-0.15	556.98	26.92	1.12
7/1/2016	85	580	450.0	571	183.0	9.2	95%	2.92	119.9	0.35	0.072	25.0	9.2	111	2.01	98%	-0.10	583.65	26.67	1.12
7/7/2016	92	573	478.0	550	213.0	6.8	97%	2.87	115.0	0.34	0.071	25.0	6.8	98	1.05	99%	-0.32	609.75	26.10	1.12
7/13/2016	99	550	456.0	487	261.0	9.7	96%	2.93	109.2	0.38	0.078	25.0	9.7	87	1.43	98%	-0.28	635.99	26.24	1.12
7/25/2016	106	502.00	432.0	453.00	172.0	4.8	97%	3.28	106.7	0.40	0.073	25.0	4.8	102	1.00	99%	-0.12	662.62	26.63	1.12
8/5/2016	113	569.00	443.0	498.00	201.0	6.7	97%	3.55	84.5	0.42	0.070	25.0	6.7	83	1.09	99%	-0.29	690.78	28.16	1.12
8/14/2016	120	384.00	378.0	378.00	218.0	9.3	96%	3.58	89.4	0.40	0.067	25.0	9.3	112	2.11	98%	-0.25	717.11	26.33	1.12
8/28/2016	127	403.00	415.0	428.00	235.0	8.4	96%	3.62	96.7	0.33	0.054	25.0	8.4	93	BDL	100%	-0.17	744.53	27.42	1.12

ANNEX (D)

Annex (D) Phase two chemical characteristics data

		D.O.				COD			BOD5			(TN) Total Nitrogen			NH4-N		
Date	Experiment day	Influent WWTP	Effluent WWTP	Aeration	Inlet of the day	Influent WWTP	Effluent WWTP	Elimination Rate COD	Influent WWTP	BOD Effluent WWTP (<2 mg/l)	Elimination Rate BOD	Influent WWTP	Effluent WWTP	Elimination Rate TN	Influent WWTP	Effluent WWTP	Elimination Rate
		mg/l	mg/l	mg/l	m³	mg/l	mg/l	%	mg/l	mg/l	%	mg/l	mg/l	%	mg/l	mg/l	%
10/1/2016	OMW1-1	0.80	6.12	6.20	1.5	1920	384	80%	896	171.5	81%	101.2	17.20	83%	80.31	3.43	96%
10/4/2016	OMW1-2	0.92	5.03	5.74	1.2	520.0	32.1	94%	255	5.3	98%	82.5	15.30	81%	77.92	2.16	97%
10/7/2016	OMW2-1	1.03	4.50	4.90	1.2	2820.0	752	73%	1491	372.0	75%	125.0	22.34	82%	96.83	3.99	96%
10/11/2016	OMW2-2	0.87	3.78	4.04	1.0	502	25.8	95%	381	19.2	95%	75.2	14.82	80%	76.36	2.98	96%
10/15/2016	OMW3-1	1.20	3.63	3.96	0.8	4792	1620	66%	2716	816.0	70%	157.5	41.20	74%	126.09	4.21	97%
10/20/2016	OMW3-2	0.96	3.35	3.80	0.6	2121	508	76%	1186	231.0	81%	92.99	17.81	81%	93.62	3.87	96%
10/25/2016	OMW4-1	0.58	3.01	3.57	0.3	8463	4354	49%	5157	2105.0	59%	232.5	76.88	67%	188.56	7.56	96%
10/30/2016	OMW4-2	1.05	2.24	2.98	0.3	4951	1692	66%	3487	1015.0	71%	163.0	39.16	76%	98.45	4.9	95%

Annex (D) Phase two physical characteristics data

		Temperature			Conductivity			TDS			pH value			Turbidity	
Date	Experiment day	Aeration tank	influent WWTP	Effluent WWTP	Influent WWTP	Effluent WWTP	Aeration	Influent WWTP	Effluent WWTP	Aeration	influent WWTP	Effluent WWTP	Aeration	influent WWTP	Effluent WWTP
		°C	°C	°C	ms/cm						-	-	-	NTU	NTU
10/1/2016	OMW1-1	25.5	25.0	26.0	2477	1638	2601	1245.00	823.0	1307.00	6.78	6.03	6.45	192.0	0.61
10/4/2016	OMW1-2	26.3	26.7	27.6	1556	760	1967	782.00	382.0	989.00	7.02	6.35	6.74	123.0	0.48
10/7/2016	OMW2-1	23.9	23.4	24.5	4945	2986	5372	2485.00	1501.0	2700.00	6.23	5.89	6.12	250.0	0.68
10/11/2016	OMW2-2	22.4	22.6	23.1	2594	1755	5249	1304.00	882.0	2638.00	6.97	6.09	6.51	152.0	0.52
10/15/2016	OMW3-1	23.5	23.0	25.1	7414	4477	9271	3726.00	2250.0	4659.00	6.21	5.38	5.95	280.0	1.60
10/20/2016	OMW3-2	21.4	21.7	22.6	5150	3698	7242	2588.00	1858.0	3639.00	6.82	6.01	6.42	187.0	0.90
10/25/2016	OMW4-1	19.9	20.4	21.0	14964	11613	19398	7520.00	5836.0	9748.00	5.94	5.16	5.65	343.0	2.50
10/30/2016	OMW4-2	21.4	28.6	31.0	9538	4344	12201	4793.00	2183.0	6132.00	6.24	5.86	6.08	219.0	1.20

Annex (D) Phase two mass and solid characteristics data

Date	Experiment day	TDS			TSS			Mixed Liquor Suspended Solids MLSS	Sludge index	BOD-Load	SLR	Sludge age	filtrated suspended solids				TMP	KWH counter	Power consumption	HRT
		Influent WWTP	Effluent WWTP	Aeratin	Influent WWTP	Effluent WWTP	Elimination Rate TSS	Aeration	Aeration	BOD - Load COD/ 2- Load	Sludge Loading Rate	Sludge age SA	Effluent WWTP <30 mg/l)	Influent WWTP	Effluent WWTP					
					mg/l	mg/l		g/l	ml/g	kg/d	kg/kg* d	d	mg/l	µg/l	µg/l		bar	KW	kw/h	day
10/1/2016	OMW1-1	1245	823	1307	752	10	99%	3.88	90.2	1.344	0.206	25.0	10.0	40837	2238	95%	-0.15	761.28	16.75	1.40
10/4/2016	OMW1-2	782	382	989	240	6.54	97%	5.19	106.0	0.306	0.035	25.0	6.5	23845	1605	93%	-0.25	783.67	22.39	1.40
10/7/2016	OMW2-1	2485	1501	2700	1292	12.32	99%	6.02	113.0	1.789	0.177	25.0	12.3	81587	6340	92%	-0.33	804.29	20.62	1.68
10/11/2016	OMW2-2	1304	882	2638	830	7.84	99%	6.34	102.5	0.381	0.036	25.0	7.8	53851	3284	94%	-0.40	824.01	19.72	2.24
10/15/2016	OMW3-1	3726	2250	4659	2602	13.76	99%	6.78	95.9	2.037	0.179	25.0	13.8	163080	9091	94%	-0.45	845.92	21.91	2.80