THE PERFORMANCE OF MEMBRANE BIOREACTOR IN TREATING HIGH TEMPERATURE MUNICIPAL WASTEWATER

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To my first teacher, who taught me how to read and how to write. The person who dreamed to see me one day high educated. He left the life but his dream still alive.. To my uncle **Mubarak Salim Baawidhan**, I dedicate this humble work.

Abdullah Ali Al Amri
30 March 2010

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ABSTRACT

Membrane bioreactor (MBR) is a promising technology which has been applied to treat a wide range of municipal wastewater in different regions around the world. However, it has not yet been employed in arid and semi arid areas such as Arabic Gulf Cooperation Council States (AGCCS). The application of MBR process in treating high temperature municipal wastewater (HTMW) has not been documented and could pose as an obstacle. Therefore, the aim of this study was to investigate the effect of high temperature on MBR process in treating municipal wastewater. The objectives were to study the biomass properties, the membrane fouling tendency and the biological and final removal efficiencies (Bio and Fin R E) of COD, NH_3-N and turbidity. In this study, a 3.6 L lab-scale aerobic MBR was seeded with 1.5 L activated sludge inoculum from Oman and was fed with a real municipal wastewater from Taman Pulai Utama sewage treatment plant in Johor. The system was then run under four main experimental stages. For the first three stages, it was run at three various temperatures (25, 35 and 45°C) and two different fluxes (10 and 15 LMH). In the fourth stage, it was run at drastic temperature changes with constant flux (10 LMH). The study demonstrated that the increase in temperature caused biomass shock. This resulted in the biomass reduction, lowered sludge settling properties and higher supernatant's turbidity. Due to biomass reduction (low richness and diversity), DO and ML pH increased. The temperature increase led to increase in SMP carbohydrate and protein, and decrease in EPS protein. Biomass reduction, high pH, SMP concentration increase and EPS decrease were the factors that caused relatively high membrane fouling. TMP and BWP ascended critically with temperature and flux increase. The highest TMP values scored were 348 mbar at 10 LMH flux and 429 mbar at 15 LMH flux, and both of them were at 45°C. Membrane openings widen with temperature increase, thus membrane fouling tended to be internal rather than external at higher temperatures. As a result of biomass shock the removal efficiencies dropped temporarily and then improved gradually with the acclimatization despite the flux increase. COD Bio R E was 90%, 84% and 62%, while Fin R E was 95%, 91% and 79% at 25°C, 35°C and 45°C respectively. Both NH_3-N removal efficiencies were very high up to 100% at 25 and 35°C, while at 45°C they were 52% Bio R E and 56% Fin R E as high nitrification has not yet been achieved at high temperatures. Despite the higher biomass shock at drastic temperature changes stage, COD and turbidity Fin R E were very high up to 90% and 100% respectively, while NH_3-N Fin R E was nearly 50%. The viscosity decreased with the increased in temperature and SVI. In spite of the critical operating conditions, the use of hollow fiber membrane module was able to achieve comparatively good removal efficiencies, however at the highest temperature i,e (45°C) the membrane fouling was the highest.

ABSTRAK

Bioreaktor membran (MBR) merupakan satu teknologi yang berpotensi untuk mengolah air sisa munisipal dan telah diguna secara meluas di beberapa kawasan di dunia. Walau bagaimanapun teknologi ini belum digunakan di kawasan beriklim panas seperti "*Arabic Gulf Cooperation Council States*" (AGCCS). Aplikasi MBR yang masih belum diterokai untuk proses olahan air sisa munisipal bersuhu tinggi merupakan satu halangan. Oleh itu, tujuan kajian ini adalah untuk menyelidik kesan suhu tinggi terhadap proses MBR dalam olahan air sisa munisipal. Objektif kajian adalah untuk mengkaji sifat-sifat biojisim, kecenderungan kesumbatan membran dan kecekapan penyingkiran biologi dan penyingkiran akhir (Bio and Fin R E) COD, NH_3-N dan kekeruhan. Dalam kajian ini satu MBR aerobik berskala makmal, 3.6 L telah dibenihkan dengan 1.5 L inokulum enap cemar teraktif yang diperolehi dari Oman dengan suapan air sisa yang diambil dari loji kumbahan di Taman Pulai Utama, Johor. Seterusnya sistem tersebut beroperasi menggunakan empat peringkat ujikaji. Untuk tiga peringkat ujikaji, tiga suhu berbeza (25, 35 and 45°C) dan dua fluks (10 and 15 LMH) telah digunakan. Untuk peringkat keempat, reaktor beroperasi pada perubahan suhu mendadak dan fluks tetap (10 LMH). Kajian menunjukkan kejutan biojisim terjadi dengan peningkatan suhu. Ini menyebabkan pengurangan biojisim, penurunan sifat pemendapan enap cemar dan peningkatan kekeruhan supernatant. Disebabkan oleh pengurangan biojisim (rendahnya pengayaan dan kepelbagaian) nilai DO dan pH ML bertambah. Peningkatan suhu menyebabkan peningkatan karbohidrat dan protein dalam SMP serta pengurangan protein dalam EPS. Pengurangan biojisim, pH tinggi, peningkatan kepekatan SMP dan pengurangan EPS merupakan faktor yang mengakibatkan kesumbatan membran yang agak tinggi. TMP dan BWP meningkat dengan kritikal apabila suhu dan fluks meningkat. Nilai TMP yang tertinggi adalah 348 mbar pada fluks 10 LMH dan 429 mbar pada fluks 15 LMH di mana kedua-duanya diperolehi pada suhu 45°C. Pembukaan membran menjadi lebih luas dengan kenaikan suhu oleh itu kesumbatan membran berlaku secara dalaman dan bukan luaran pada suhu tingi. Kecekapan penyingkiran menurun untuk sementara waktu disebabkan oleh kejutan biojisim ini. Seterusnya kecekapan naik semula apabila berlaku penyesuaian walaupun terdapat peningkatan fluks. COD Bio R E adalah 90%, 84% dan 62%, sementara Fin R E adalah 95%, 91% dan 79% pada 2°C, 35°C dan 45°C. Kedua kecekapan penyingkiran NH_3-N adalah tinggi sehingga 100 % pada 25 dan 35°C, sementara pada 45°C kecekapan adalah 52% Bio R E dan 56% Fin R E kerana nitrifikasi masih belum tercapai pada suhu tinggi. Walaupun kejutan biojisim yang tinggi pada peringkat perubahan suhu mendadak, COD dan kekeruhan Fin R E adalah tinggi sehingga 90% and 100%, sementara NH_3-N Fin R E adalah 50%. Kelikatan berkurangan dengan peningkatan suhu dan SVI. Meskipun pada keadaan operasi kritikal, penggunaan modul membran gentian berongga telah dapat mencapai keberkesanan penyingkiran yang baik. Walau bagaimanapun, pada suhu 45°C, kesumbatan pada membran adalah yang tertinggi.

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LIST OF SYMBOLS

Φ_K	-	Gradient of Permeability
$\Phi_{TMP(CW)}$	-	TMP Gradient of Clean Water
Φ_{TMP}	-	Gradient of Wastewater
Φ_{FR}	-	Gradient of Fouling Rate
ΔP	-	TMP
°C	-	Centi Degrees
CO_2	-	carbon dioxide
°F	-	Fahrenheit
μ	-	Viscosity
Cb	-	Bulk MLSS Concentration
F/M	-	Food to Microroganisms Ratio
J	-	Oppositely Directed Membrane Permeation Velocity
J	-	Hydraulic Flux
J_c	-	Critical Flux
K_{CW}	-	Permeability of Clean Water
K_{Sludge}	-	Permeability of Sludge
n	-	Compressibility Factor
N_2	-	Nitrogen

N_2O	-	Nitrogen Oxide
NH_3 N	-	Ammonia Nitrogen
NH_3 N	-	Ammonia Nitrogen
P	-	Phosphorus
PO_4^3	-	Orthophosphate
Q o	-	Flow Rate of Feed
Qw	-	Waste Activated Sludge Flowrate
Rm	-	Membrane Resistance
*R*t	-	Total Membrane Resistance
So	-	Influent COD
t	-	Temperature
TMP_{CW}	-	TMP of Clean Water
TMPf	-	TMP Values Obtained at the Final Flux Steps
TMPi	-	TMP Values Obtained at the Initial Flux Steps
TMP_{Sludge}	-	TMP of Sludge
US$	-	United States dollar
V	-	Volume of Aeration Tank
VL	-	Velocity
X	-	Mixed Liquor Suspended Solids
Xe	-	Effluent Suspended Solids
α	-	Specific Cake Resistance
α_c	-	Cake Resistance
θ	-	HRT

μm	-	Micrometer
ν	-	Permeate Volume Per Unit Area

LIST OF ABBREVIATIONS

AGCCS	-	Arabic Gulf Cooperation Council States
APHA	-	American Public Health Association
AS	-	Activated Sludge
BAS	-	Biofilm Airlift Suspension
BFB	-	Biofilm Fluidized Bed
Bio R E	-	Biological Removal Efficiency
BSA	-	Bovine Serum Albumin
BWP	-	Backwash Pressure
CO_2	-	Carbon Dioxide
COD	-	Chemichal Oxygen Demand
DDG	-	Omani Meteorological
DO	-	Dissolved Oxygen
DO	-	Direct Observation
DOTM	-	Direct Observation Through Membrane
EBPR	-	Enhanced Biological Phosphorus Removal
eEPS	-	Extracted EPS
eEPSc	-	Extracted EPS Carbohydrate
eEPSp	-	Extracted EPS Protein
Ef	-	Effluent

EGSB	-	Expanded Granular Sludge Blanket
EPS	-	Extracellular Polymeric Substances
ESEM	-	Scanning Electron Microscopy
Fin R E	-	Final Removal Efficiency
GAOs	-	Glycogen Accumulating Organisms
HRT	-	Hydraulic Retention Time
HTMW	-	High Temperature Municipal Wastewater
IC	-	Internal Circulation
In	-	Influent
kDa	-	Kilodalton
MBR	-	Membrane Bioreactor
MF	-	Microfiltration
ML	-	Mixed Liquor
ML_{COD}	-	Filterd Supernatant COD
MLSS	-	Mixed Liquor Suspended Solids
MLVSS	-	Mixed Liquor Volatile Suspended Solids
MRU	-	Membrane Research Unit
NF	-	Nanofiltration
NTU	-	Turbidity Unit
PAOs	-	Phosphate Accumulating Organisms
PES	-	Polyethersulfone
PHA	-	Poly-β-hyroxyalkanoates
PHA	-	Polyhydroxyalkanoates
PHB	-	Polyb hydroxybutyrate

RAS	-	Return's Activated Sludge
RO	-	Reverse Osmosis
SBR	-	Sequencing Batch Reactor
S_{COD}	-	Soluble Chemical Oxygen Demand
S_{COD}	-	Soluble COD
SMP	-	Soluble Microbial Products
SMPc	-	SMP Carbohydrate
SMPp	-	SMP Protein
SND	-	Simultaneous Nitrification and Denitrification
SRT	-	Sludge Retention Time
SS	-	Suspended Solids
SVI	-	Sludge Volume Index
TCOD	-	Total Chemical Oxygen Demand
TMP	-	Transmembrane Pressure
TOC	-	Total Organic Carbon
TSS	-	Total Suspended Solids
UAE	-	United Arab Emirates
UF	-	Ultrafiltration
USB	-	Upflow Sludge Blanket
UTM	-	Universiti Teknologi Malaysia
VLR	-	Volumetric Loading Rate
VLR	-	Volumetric Loading Rate
VSS	-	Volatile Suspended Solids

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CHAPTER 1

INTRODUCTION

1.1 Background

Membrane technology did not exist before the sixties of the last century (Richard, 2000). Despite that, Prof. Enrico Drioli in his keynote lecture at the Water Environment Membrane Technology Conference (2004) in Seoul said *"Membrane technology is the call for the future"*. Furthermore, Christian (2005) has reported that in three decades, 50% of all separation processes will be accomplished by membranes.

First systematic studies of membrane phenomena are ascribed to the 18th-century philosophers and scientists, when Abbe Nolet in 1748 found the word *osmosis* to describe permeation of liquid through a diaphragm (Richard, 2000). The same researcher also reported that, through the 19^{th} and early 20^{th} centuries membranes had no industrial or commercial applications, but they were used as laboratory tools to study physical and chemical theories. Loeb-Sourirajan in the early 1960's, through his process, for creating defect-less and high flux reverse osmosis membrane, managed to transform membrane filtration from a laboratory technique to an industrial application (Wallace, 1967).

Since 1960 interest in membrane filtration process has grown gradually, and membrane technology now is the object of substantial universal research, development, commercial activity and full-scale application (Joël *et al.*, 1996). Hence, membrane filtration is on the edge of becoming a mainstream filtration process and it is already competing with the conventional system techniques (Christian, 2005).

Many researchers have defined membrane with different words. Joël *et al.* (1996) defined it as a thin layer of material that is capable of separation materials as a function of their physical and chemical properties when a driving force is applied across the membrane. Otherwise, membranes are often most of the times the first choice because of their decreasing costs, superior performance for improving a broad range of water qualities, use of less disinfection chemicals and smaller storage tanks, and feed facilities (Christian, 2005).

Membrane filtration process has been utilized in a big range of applications. Membrane bioreactor (MBR) is one of them. MBR is a modification of the conventional activated sludge system (AS), which uses membrane instead of a clarifier to accomplish the process of separating treated water from the mixed liquor (Cicek *et al.*, 1999). MBR technology combines the biological degradation process by AS with a direct solid-liquid separation by micro or ultrafiltration membrane technology (with a pore-size range of 0.05 to 0.4 μm) (Pierre *et al.*, 2006). The application of AS in wastewater treatment dates back to the late 1800s, upon the introduction of filters, contact beds, trickling filters and septic tanks. Two decades later, the first full scale fill and draw AS plant treating 80,000 gpd was built in Salford, England in 1914 (Ng., 2002). By Smith et al. in 1969, the membrane application in wastewater treatment was first described when the sedimentation in the AS was replaced by ultrafiltration.

Unlike the conventional AS process which depends on a gravity settlement, MBR uses membrane filtration unit for the separation of biomass. Therefore, it is competent to complete biomass retention in the bioreactor and thus to retain potentially pathogenic organisms (Seung., 2004). In AS system, only the fraction of activated sludge that forms flocs and settles can be retained. While in MBR all components of the biomass that are larger than the membrane cut-off are retained. Thereby, MBR produces a high-quality and cell-free effluent, and reduces the need for disinfection necessities of treated wastewater effluents (Cote *et al.*, 1998; Jefferson *et al.*, 2000). Long sludge retention time (SRT) in the MBR process averts the washout of slow-growing microorganisms such as nitrifying bacteria and other bacteria responsible for degrading complex compounds. Therefore, MBRs enhance the nitrifying function and complex organic contaminant degradation ability compared to a conventional biological wastewater process of AS system at short HRT (Muller *et al.,* 1995). Beside the superior effluent quality and the absolute control of solids retention and hydraulic retention times, the smaller volume and footprint is one of the main advantages of MBR.

In recent years, MBR technology has been playing a very important role in water and wastewater treatment. Presently, MBR technology is more widely applied due to the development of less expensive membranes, the lack of fresh water and the surge in water reuse. Therefore, it has been used to treat a wide range of municipal and industrial wastewaters. Currently, there are more than 1000 MBR plants installed in Asia, Europe, and North America with many newly proposed or under construction (Schier *et al.,* 2009).

1.2 Problem Statement

MBR is an ideal option for municipal and industrial wastewater treatment applications, particularly in mesophilic condition. It has been exploited widely to treat various kinds of wastewater in many cities around the world. Nevertheless, MBR has not yet been utilized in the treatment applications of high-temperature (35 °C and above) municipal wastewater.

There are numerous high-temperature wastewaters in the practical life, and they are from different sources. In general, wastewaters can be divided into two main types according to the source, industrial wastewater and municipal wastewater. The high-temperature industrial wastewaters are such as from pulp, paper, newspaper and distillery industries. On the other side, the high-temperature municipal wastewaters are normal municipal wastewaters (sewage) affected by the atmosphere temperatures. For example, municipal wastewater in the arid and semi-arid regions, a type of which is the Arabic Gulf Cooperation Council States (AGCCS) wastewater, particularly during the summer time.

AGCCS is located in the Arabian Peninsula in the Middle East, to the south of Iran. It consists of six countries, which are Saudi Arabia, Oman, UAE, Qatar, Bahrain and Kuwait. The majority of AGCCS lands are deserts and semi-arid territories with a dry-hot climate and high temperatures in the summer time. It is one of world areas, where temperatures above 48°C/120°F are not exceptional. In the Omani capital city Muscat, the temperatures during the summer time vary from 40 to 50°C. In Saudi Arabia, the average summer temperature is 45°C, but temperatures up to 54°C are common. In Kuwait, the temperatures during the summer time continues rising up to 53°C under the shade (Department of Economic Studies and Statistics, 2006; Omani Meteorological DDG, 2008) (Fig 1.1). According to the first source, climatic conditions are contributed to the absence of permanent rivers, water bodies, minimal rainfall and limited amount of groundwater. These factors are behind the lack of water and water resources in AGCCS. As a result, the limited natural water resources give a significant importance for the applications of water conservation and wastewater/seawater treatment in AGCCS.

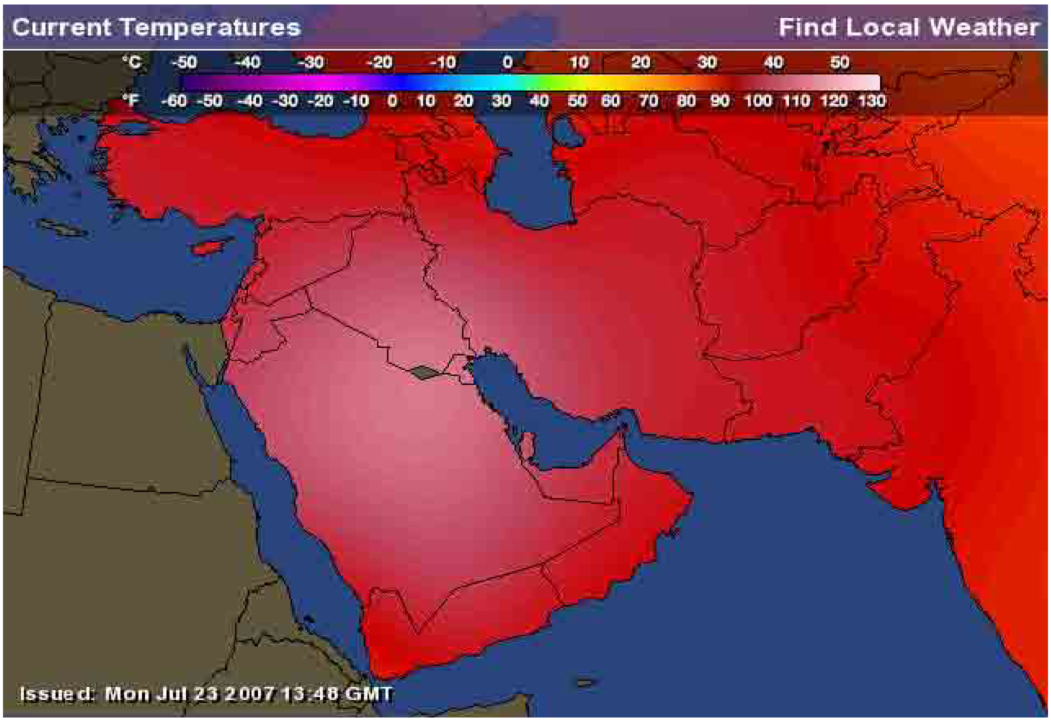

Figure 1.1 The temperatures map in AGCCS and Middle East. (http://www.findlocalweather.com/weather_maps/imagefetch.php?size=640x480&type=currents&img=mide_temperature_i1.png)

Although, AGCCS are considered an underdeveloped countries, they are still clean countries and there are a real concern and conservation for the environment and the public health. Many programs have been developed in AGCCS, to enhance the public aware about the environment, especially water-resources. Therefore, they have been founding organizations for environment and water-resources protection and establishing projects on seawater desalination and wastewater treatment.

In fact, there is a big usage of membranes for water and seawater treatment (desalination) in AGCCS, but not for wastewater treatment. Except Al-Ansab MBR treatment plant in Muscat city, which is under construction there is no full-scale MBR plants in AGCCS. Notwithstanding, the many properties of MBR, it has not yet gained popularity in AGCCS, where conventional AS treatment systems are still widely used. Therefore, it is very important and necessary to study the feasibility of

MBR in treating high-temperature municipal wastewater, especially when there are no real studies on such subject.

Many researchers have been exploring the different applications of MBR process during last two decades. Majority of them focused on the performance of MBR at mesophilic conditions and low temperatures (Darren *et al.*, 2005; Aloice and Tatsuya, 1996; Zhang *et al.*, 2006). Groups of researchers have studied the efficiency of MBR in treating various kinds of industrial wastewater, while other groups were involved in investigating the phenomena of membrane fouling (Ognier *et al.*, 2002; Pierre *et al.*, 2006; Fangang *et al.*, 2006). In spite of the efforts spent on studying the applications of MBR in treating high temperature industrial and synthetic wastewater (João *et al.*, 2005 Zhang *et al.,* 2005; Kurian & Nakhla, 2006;), the application of MBR in treating high temperature municipal wastewater remains very limited. Therefore, this study is conducted to investigate such area of knowledge in details (for more details see Table 2 in chapter 2).

1.3 Aim and Objectives

Despite the big number of the previous studies related to the subject of MBR applications, the knowledge area of MBR treating high temperature municipal wastewater (HTMW) has not yet been investigated before this study. The question of *"What is the effect of temperature on the performance of MBR system treating municipal wastewater"* has not yet been answered. Thus, the overall aim of this research was to study and evaluate the feasibility of MBR process application in treating high-temperature municipal wastewater for the purpose of reuse and recycle. This can be achieved by the following specific objectives:-

I. To study the effect of high temperatures on the process of biodegradation (biological removal efficiency) and membrane filterability (final removal efficiency) in MBR system treating municipal wastewater, in terms of Chemical oxygen demand, Ammonia nitrogen, Suspended solids, Turbidity and Effluent colour.

II. To study the effect of high temperatures on the biological properties in terms of Biomass growth, Sludge volume index, Hydraulic viscosity, Soluble microbial products and Extracellular polymeric substances ratio, pH and Supernatant turbidity.

III. To investigate the phenomena of membrane fouling at high temperature conditions in terms of Soluble microbial products and Extracellular polymeric substances ratio, and Transmembrane pressure and Backwash pressure, and to determine the dominant fouling factors.

IV. To evaluate the performances of MBR process treating high temperature municipal wastewater under two different (high and low) membrane hydraulic fluxes.

V. To study the effect of drastic temperature changes on the performance of MBR process treating municipal wastewater, in terms of Removal efficiencies, Biological properties and Membrane fouling phenomena at low membrane hydraulic flux.

1.4 Scope of the Study

The main aim of this research is to study and investigate the performance of MBR process in treating HTMW under two different hydraulic fluxes. To achieve the main aim and the specific objectives of this research, the scope of the work includes the following tasks.

A significant work has been conducted on MBR applications for high temperature wastewater treatment. However, the relationship between temperature and MBR process in municipal wastewater treatment has not yet been fully studied. Many areas need to be investigated such as the relationship between the temperature and each of AS properties, biological removal efficiency, final removal efficiency, membrane fouling. The effect of drastic temperature changes on the MBR process is also required more investigations. Therefore, this research was initiated by conducting a thorough literature review on the use of MBR applications for different kinds of high temperature wastewater treatment. Operational factors that affect the process, removals efficiencies, membrane fouling phenomena and biomass characterization are the issues have been extracted from the literature review. This literature review found out unanswered questions related to the application of MBR in treating HTMW. Therefore, this study has been carried out to present reliable answers for such questions.

Based on the research objectives, the second task was involved in setting up and developing an appropriate lab-scale system to conduct the experimental study. This system was a submerged aerobic MBR and it was equipped with an aeration system and heating system. The plan of experimental work included operating of three different temperature stages (25, 35 and 45 °C) and one drastic temperature changes stage. A 3.8 litre lab-scale glass reactor was seed with an inoculum of AS (seed sludge). The inoculum was obtained from the return's activated sludge (RAS) line of Al-Ansab municipal wastewater treatment plant at Muscat City in Oman. The system was fed with a screened row wastewater obtained from Pulai Utama full scale municipal wastewater treatment plant. To increase the concentration of the feed wastewater it was mixed with a certain quantity of synthetic wastewater. All analytical measurements performed in this study were conducted according to *Standard Methods for Examination of Water and Wastewater* (APHA, 2005).

The third task contained the analysis of the results that were obtained from the experimental work. This task included also a detailed discussion of the analysis. Finally, the main findings of this study were summarized in a conclusion to present the study contribution in view of the objectives.

1.5 Research Significance

The urgent need to fresh water resources and good-quality treated water in AGCCS and other regions around the world could obviously reflect the importance and the significance of this research. The main obstacle preventing MBR technology from reaching AGCCS is the unknown end of the direction of treating HTMW by using MBR system. Therefore, discovering such area of knowledge and answering such important questions of this application would be very helpful in making the correct decision. In specific, the importance of this study is as follows:-

I. This study fills an important gap found clearly in the literature of MBR process.

II. This study answers the question of *"What is the performance of MBR in treating HTMW"?*

III. This study evaluates the effect of high temperatures and drastic temperature changes at different hydraulic fluxes on the MBR process.

IV. This study provides a complete view about the possibility of MBR application in treating HTMW and suggests the reliable solutions to enhance the process and overcome the potential problems.

1.6 Organization of the Thesis

This thesis consists of six chapters. The first chapter introduces the technology of membrane bioreactor and its importance in wastewater treatment. It also includes the problem statement and the objectives, significance and the scope of the study. Chapter 2 gives an overview of the theoretical background of studies conducted on wastewater treatment systems, especially compact systems. It reviews the various issues of MBR and its applications. Chapter 3 presents a perspective and an outline of the study, materials and methods as well as detailed procedures of each experiment conducted.

The fourth chapter analyses the results of the experimental studies that have been illustrated in chapter 3. It also discusses the results obtained from MBR application in treating municipal wastewater at temperatures of 25 °C, 35 °C and 45 °C and at drastic temperature changes condition. The last chapter presents the conclusions of this study and the recommendations for future works.

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