OPERATIONAL PERFORMANCE OF HOLLOW FIBRE FOR WATER TREATMENT SYSTEM

ROSDIANAH BINTI RAMLI

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ROSDIANAH BINTI RAMLI

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ROSDIANAH BINTI RAMLI
MK1211003T

(Tandatangan Pustakawan)

Tarikh: 23 Mei 2017

(Prof. Madya Dr. Nurmin Bolong)
Penyelia

DECLARATION

I hereby declare that the material in this thesis is my own except for quotations, excerpts, equations, summaries and references, which have been duly acknowledged.

13 April 2017

Rosdianah binti Ramli

MK1211003T

CERTIFICATION

NAME : **ROSDIANAH BINTI RAMLI**

MATRIX NO. : **MK1211003T**

TITLE : **OPERATIONAL PERFORMANCE OF HOLLOW FIBRE FOR WATER TREATMENT SYSTEM**

DEGREE : **MASTERS DEGREE IN CIVIL ENGINEERING**

VIVA DATE : **15TH DECEMBER 2016**

CERTIFIED BY;

1. SUPERVISOR Signature

Associate Professor Dr. Nurmin Bolong

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13 April 2017

ABSTRACT

Innovation such as mobile water treatment unit brings water treatment system to a new level of convenience for its user, especially in rural areas. Having compact and self-supporting configuration, hollow fibre membrane became a choice as a filter media for mobile water treatment system. In this study, polyvinylidene fluoride (PVDF) ultrafiltration hollow fibre (UF-HF) membrane module was designed for application in mobile water treatment unit system; catering for domestic and lightweight surface water treatment based on prime feature of a common mobile water treatment system. Two types of UF-HF membrane modules were prepared with two different number of fibre i.e. 15 and 30 fibres, resulting in effective membrane areas of $0.0153m^2$ and $0.0305m^2$. A UF-HF membrane module was integrated in membrane testing rig operated under varying transmembrane pressure (TMP), feed water temperature, and feed water quality (turbidity). It was found that the optimum TMP is between 2.8 to 3.2 bars while the module performed steadily at temperature of 22 to 27°C. At varying feed water quality, both modules were able to remove 96% turbidity regardless of the initial turbidity value. In a short-term operation of surface water treatment, a maximum of 0.073 L/min filtered water was able to be produced by a UF-HF membrane module while the recorded specific permeate flux dropped at 33% at the end of the operation. Water recovery recorded was below 10% with the energy consumption of 41%. This reduces the possibility of concentration polarisation on the membrane module. Moreover, the UF-HF membrane module had shown good treatment efficiency for surface water where total suspended solids were removed completely, plus more than 30% of biochemical oxygen demand, chemical oxygen demand, and ammoniacal nitrogen. Dissolved oxygen and pH were enhanced by more than 5%. In conclusion, the designed UF-HF membrane module can be upgraded for the use of water treatment system in rural areas.

ABSTRAK

PRESTASI OPERASI MEMBRAN GENTIAN GERONGGANG UNTUK APLIKASI DI DALAM SISTEM RAWATAN AIR

Sistem rawatan air mudah alih menjadikan sistem perawatan air sebagai kemudahan yang baru untuk penggunanya, terutamanya di kawasan luar bandar. Dengan kelebihan konfigurasi seperti kepadatan dan kebolehan berdiri sendiri, membran gentian geronggang menjadi pilihan sebagai medium penapis untuk sistem rawatan air mudah alih. Dalam penyelidikan ini, modul membran gentian geronggang ultrafiltrasi (UF-HF) polyvinylidene fluorida (PVDF) direka bentuk untuk aplikasi unit sistem rawatan air mudah alih; untuk penggunaan rawatan air permukaan domestik berdasarkan ciri-ciri prima sebuah sistem rawatan air mudah alih. Dua jenis modul disediakan dengan bilangan membran berbeza iaitu 15 dan 30, yang mana luas membran berkesan adalah 0.0153m^2 dan 0.0305m^2. Modul membran UF-HF dipasang pada pelantar ujian yang beroperasi dalam keadaan tekanan antara membran (TMP), suhu air yang berubah, dan kekeruhan air yang berbeza. Nilai TMP optima adalah di antara 2.8 sehingga 3.2 bar manakala modul UF-HF memberikan prestasi cemerlang pada suhu 22 ke 27°C. Kecekapan penyingkiran kekeruhan oleh modul UF-HF adalah 96% tanpa mengira nilai asal kekeruhan air. Dalam operasi merawat air permukaan dalam jangka pendek, modul UF-HF menghasilkan maksima 0.073 L/min air bersih, yang mana nilai flux pengeluaran spesifik yang dicatatkan menurun dengan kadar sebanyak 33% sepanjang operasi. Pemulihan air yang dicatatkan adalah di bawah 10% manakala penggunaan tenaga sepanjang operasi adalah 41%. Ini mengurangkan kadar kemungkinan berlakunya kepekatan polarisasi pada membran. Seterusnya, modul UF-HF tersebut juga menunjukkan peratusan penapisan yang tinggi untuk air permukaan di mana pepejal terampai berjaya ditapis sepenuhnya, dan lebih daripada 30% keperluan oksigen biokimia, keperluan oksigen biokimia dan ammonia nitrogen berjaya ditapis. Manakala, nilai oksigen terlarut dan pH ditingkatkan sebanyak 5%. Kesimpulannya, modul UF-HF untuk sistem rawatan air mudah alih di dalam pengajian ini boleh dinaiktaraf untuk penggunaan di kawasan luar bandar.

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LIST OF ABBREVIATIONS

AN	-	Ammoniacal Nitrogen
BOD	-	Biochemical Oxygen Demand
COD	-	Chemical Oxygen Demand
DO	-	Dissolved Oxygen
DOE	-	Department of Environment
FWT	-	Feed Water Temperature
HF	-	Hollow Fibre
MF	-	Microfiltration
NTU	-	Nephelometric Turbidity Unit
PVC	-	Polyvinyl chloride
PVDF	-	Polyvinylidene fluoride
TMP	-	Transmembrane Pressure
TSS	-	Total Suspended Solids
UF	-	Ultrafiltration

LIST OF SYMBOLS

A_m	-	Effective membrane area
d_o	-	Outer diameter of fiber
E_{uf}	-	Energy consumption
J	-	Membrane flux
J_{sp}	-	Specific membrane flux
L	-	Effective length of fiber
L_p	-	Pure water permeability
n	-	Number of fiber
$\emptyset$	-	Packing density
Q_f	-	Feed flow rate
Q_p	-	Permeate flow rate
Q_r	-	Retentate flow rate
R	-	Water recovery
R_m	-	Intrinsic membrane resistance
R_t		Total membrane resistance
ΔP	-	Transmembrane pressure
μ	-	Water dynamic viscosity

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CHAPTER 1

INTRODUCTION

1.1 Research Background

It is crucial for water to be treated by means of filtering or disinfection because water is one of the basic necessities for life on Earth. With water source depletion due to water scarcity and water quality decrement, the demands for water treatment also increases (Mierzwa *et al.*, 2008; Kim *et al.* 2012). Moreover, contaminated and polluted water could cause water-borne disease (Peter-Varbanets *et al.*, 2009) to human and animals aside of having bad taste and smells. Furthermore, water-borne diseases such as cholera and typhoid can cause death. For that reason, water treatment is vital to ensure the water is clean enough for everyday use and free of water-borne pathogenic microorganisms transmission (Gerba *et al.*, 2008).

Conventionally, water has been treated primarily using physical-chemical treatment such as sand filtration, disinfection i.e. chlorination and coagulation-flocculation via sedimentation process. With technology advancement and cost reduction, membrane technology in separation and purification has gained favour in the water and wastewater treatment industry (Choi *et al.* 2005; Zularisam *et al.*, 2006; Loo *et al.* 2012). Not only that, membrane technology has received more interest in recent years due to stringent standard for water supply and effluent discharge.

Water treatment comes in various types where it can be an onsite water treatment unit or a plant and it can also be a mobile (transportable) unit. However, although water treatment plants can supply sufficient amount of clean water to the targeted residents, problems in water supply shortage could still occur due to other reasons such as pipe bursts. Pipe or water tank contamination could also cause problem to consumer because the water supplied is no longer clean or safe for use due to heavy metals contaminations. Water supply from a water treatment plant could be disrupted by natural disaster too. For example, it was reported that more than 20,000 consumers in Kundasang region suffered water disruption after 5.9 Richter scale earthquake on 5th June 2015. This was caused by the damage of the underground pipes and water tanks. If the disaster was in larger scale, say stronger earthquake, it does not only cause infrastructure damage but as well as limiting access to the impacted regions (Loo *et al.*, 2012). It was also deliberated that such conditions could be limiting the size and weight of water treatment unit that could be transported to the impacted regions.

With the ever-decreasing quality of water sources and low access to clean water, the pressure on equipment suppliers to provide suitable processes is also increasing. Human needs for clean water at home and work have created huge demand for relatively simple filters. Moreover, households in the urban area are most likely to own a simple water treatment unit for their daily use as well as drinking. These smaller in size water treatment units have gained their popularity with the rise of technology in filtration. However, the cost of owning one small water treatment unit can reach up to minimum of RM800 per unit.

Nonetheless, such costly water treatment unit is not practicable for consumers in the rural area. The cost itself indeed a major concern, while some rural areas might not even have proper water supply to begin with. Their sources of water supply are usually well and river, but these sources might be contaminated with arsenic-contaminants (Oh *et al.*, 2000), natural organic matter (NOM) (Bodzek and Konieczny, 1998; Zhang *et al.*, 2003; Chiemchaisri *et al.* 2008) and even algae (Mierzwa *et al.*, 2008).

Fortunately, water treatment system can be minimised or compacted into a smaller size unit. In Bangladesh, a team of researchers developed water treatment unit coupled with bicycle pumping system to provide clean water supply from tube well (Oh *et al.*, 2000). There are different other forms researched and developed too (Groendijk and de Vries, 2009; Barbot *et al.*, 2009). Innovation of compact water treatment system with mobility as shown by Barbot *et al.* (2009) brings the water treatment to another level of convenience where such system can be easily brought to any natural water source i.e. river and lake. Not only it can be used in rural area, it can also be used during and after disaster such as the tsunami that hit Malaysia in 2004.

Interestingly, most of these innovations are utilising membrane as the main filter media to treat water. This might be due to its effectiveness and easy to use feature. As water treatment filter media, membrane has shown potential in treating surface water, groundwater as well as seawater. Among four membrane configurations, hollow fibres membrane is commonly used for ultrafiltration design which is sufficient for natural water source treatment (Yeh, Cheng, and Wu, 1998). With highest packing density, ease of backwashing, self-supporting and compact design (Thakur and De, 2012; Childress *et al.*, 2005), hollow fibres membrane is a good choice for mobile water treatment system. Incorporating hollow fibres membrane into mobile water treatment system would benefit the population in rural areas and the country as well.

1.2 Problem Statement

Sabah is the second largest state in Malaysia with approximately 70% of the area in the state is rural area. Even though Sabah has six water treatment plants, the access to clean water in rural area is still limited. This is caused by lacked of piped water access and untreated natural water sources. Furthermore, rural area such as Pitas has no proper roadway in and out. Therefore, providing clean water via modular water truck is difficult and costly.

As discussed earlier, innovation of mobile water treatment system is an alternative that could help the rural population in Sabah, Malaysia while also providing additional benefits such as water distribution infrastructure utilization that might prevent logistics distribution. However, it is also essential to choose the right filter medium and based on its advantages, hollow fibre membrane was studied in this research.

1.3 Objectives

The main goal of this study is to study the operational performance of ultrafiltration hollow fibres membrane for mobile water treatment system unit in treating surface water. In order to achieve this main objective, it was divided into three specific objectives as follow:

1. To design and develop ultrafiltration hollow fibres (UF-HF) membrane module for mobile water treatment system application.
2. To determine the effects of operating parameters on operational performance (in terms of permeate flux) of the developed membrane modules.
3. To determine the performance of the developed UF-HF membrane module in surface water treatment operation in terms of permeate flux, clean water production, water recovery and energy consumptions.

1.4 Scope of Work

The ultrafiltration hollow fibres (UF-HF) membrane was obtained commercially before developing it based on the design that will be discussed in Chapter 3. The design of membrane module is made based on its application in mobile water treatment system unit. Thus, development of the modules is in compliance of the mobile water treatment characteristics.

In this study, mobile water treatment system is defined as a transportable unit with ease to deploy, stand alone, low cost and easy to use. To accommodate such application, the UF-HF membrane module was designed in small-scale consisting of maximum 30 fibres per bundle.

The operating parameters investigated in this study are transmembrane pressure (TMP), feed water temperature (FWT) and feed water turbidity. This investigation is focused on their effects on membrane permeate flux.

The feed water samples taken for water treatment operation using UF-HF membrane module were surface water. Performance of the membrane module during operation was investigated in terms of permeate flux, clean water production, water recovery and energy consumption. In addition to the operational performance, the treatment efficiency was also evaluated.

1.5 Significance of Study

With the outcome of this study, it is hoped that a simplistic mobile water treatment system design can be proposed for the benefit of the nation. Such system can help to provide easier access to clean water for population in rural area. It can be used for everyday activity such as cleaning and watering plants and also useful for the rural area healthcare i.e. Klinik Desa, which requires clean water the most. Furthermore, with the development of such system in Malaysia, the country can have its own mobile water treatment technology that could be useful, even during disaster. The country can also reduce cost of purchasing and importing foreign water treatment technology.

1.6 Thesis Outline

The body of this thesis was divided into 5 main chapters covering from introduction of the study to the conclusions obtained from the study.

Chapter One presents the background of the study emphasizing the importance of clean water access and the lack of it in rural areas, particularly in Sabah. Mobile water treatment is recommended and thus this study is aimed to investigate on the performance of hollow fibres membrane utilised in a mobile water treatment system. The scope and significance of this study were also discussed in Chapter One.

In Chapter Two, literature review on membrane technology in water treatment application is provided. This gives insights on the general aspects of membrane as well as on its operation in water treatment system, befitting the scope of this study. Related previous works are included for support and more understanding of the topics.

Research methods conducted to achieve the research objectives are discussed in details in Chapter Three. By referencing to the previous works discussed in Chapter Two beforehand, experimental workflow, materials and analysis methods were designed based on the scope of study.

Following next is the presentations of results obtained from the works conducted in Chapter Four. The results were analysed and discussed with reference to the literature review.

Last but not least, conclusions drawn from the analysis and discussions are summarised in the final chapter, Chapter Five. This chapter also includes recommendations for future works.