GRAVITATIONAL ULTRAFILTRATION OF RIVER WATER: FOULING AND CLEANING EFFICIENCY STUDY

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by

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LIST OF SYMBOLS

	Symbol	Unit
J	Flux	L/m^2.h @ LMH
A_m	Membrane area	m^2
V	Volume of filtrate generated	L
t	Process time	h
M_1	Initial molarity of ethanol	M
M_2	Final molarity of ethanol	M
V_1	Initial volume of ethanol	mL
V_2	Final volume of ethanol	mL
N	Number of hollow fiber PVDF membrane	pieces
R	Outer radius of PVDF membrane	m
h	Height of PVDF membrane	m
V_o	Volume of feed sample of river water	mL
M_o	Weight of initial and new glass fiber filter	g
M_1	Weight of glass fiber filter after being dried in the oven at 105 °C for 1 hr	g
M_2	Weight of glass fiber filter after being dried in the furnace 550 °C for 24 hr	g

LIST OF ABBREVIATIONS

DoE	Department of Environment (DoE)
GDU	Gravity Driven Ultrafiltration
WQI	Water quality index
MF	Micro-filtration
UF	Ultra-filtration
NF	Nano-filtration
RO	Reverse Osmosis
POU	Point of Use
MDGs	Millennium Development Goals
TOC	Total organic carbon
ULP	Ultra-low pressure
ATP	Adenosine triphosphate
RW	River water
PRW	River water pre-treated with biological sand filtration
RWA	River water with addition of sodium azide
MFDWW	Micro filtered dilution of oxygenated wastewater
RWHA	river water with increased concentration of humid acids
RWK	river water spiked with kaolin
MC	microcystins

CON	control treatment
LMA	living microcystis aeruginosa
DMA	dead microcystis aeruginosa
PES	Polyethersulfone
PVDF	polyvinylidene difluoride
PAC	powdered activated carbon
AER	anion exchange resin
GDBM	gravity-driven biomimetic membrane
BM	Biomimetic membrane
TMP	transmembrane pressure
TSS	Total suspended solid
MLSS	Mixed liquor suspended solid
MLVSS	Mixed liquor volatile suspended solid
COD	Chemical oxygen demand
TDS	Total dissolved solid (TDS)
SEM	Scanning electron microscope
FTIR	Fourier transform infrared spectrometers
LN	Liquid nitrogen
MBR	Membrane bio-reactor
BOD	Biochemical Oxygen Demand
NOM	Natural organic matter

ULTRAFILTRASI GRAVITASI AIR SUNGAI: MENGUMPUL DAN MEMBERSIHKAN KEBERKESANAN KAJIAN

ABSTRAK

Sistem Ultrafiltrasi Bergerak Graviti adalah teknologi yang menjanjikan yang dapat menghasilkan air minum kepada masyarakat tanpa elektrik dan rawatan air sisa yang betul. Projek ini memfokuskan pada pembinaan sumber bukan titik, sistem GDU jenis modular untuk menyaring air sungai menggunakan sungai Krian sebagai sumber air. Sistem GDU diuji dalam keadaan tekanan hidrostatik yang berkurang dan berterusan. Di bawah tekanan hidrostatik yang berkurang pada 40 cm, Fluks tertinggi dijumpai pada 0.58 LMH dan ia berkurang menjadi hampir sifar kerana pengurangan tekanan hidrostatik dan kehabisan air sungai dalam modul. Modul dapat memulihkan alirannya hingga 85.17% setelah dicuci semula selama 5 kitaran. Di bawah tekanan hidrostatik berterusan, didapati bahawa gentian berongga sepanjang 40 cm menghasilkan penstabilan fluks meresap terendah kerana tahap pengotoran yang lebih besar. Oleh itu, kecenderungan pengotoran lebih tinggi pada membran yang lebih panjang. Ini dapat dilihat melalui pencirian membran menggunakan SEM dan FTIR dengan membandingkan membran murni dengan membran yang kotor. Uji kualiti air menggunakan parameter yang berbeza digunakan untuk menentukan jumlah air sungai sebelum dan sesudah menjalani sistem GDU. Didapati jumlah parameter yang diuji pada air meresap lebih rendah dibandingkan dengan air sungai terutama pada molekul yang lebih besar. Kualiti meresap adalah selamat untuk aktiviti manusia mengikut garis panduan yang digariskan oleh WHO. Modul ini dapat memulihkan alirannya hingga 36.83,86.26 dan 94.32% masing-masing untuk 40,35 dan 30 cm selepas backwash selama 5 kitaran. Sistem GDU modular menjanjikan untuk menyediakan air bersih untuk masyarakat yang kekurangan kemudahan elektrik dan rawatan air.

GRAVITATIONAL ULTRAFILTRATION OF RIVER WATER: FOULING AND CLEANING EFFICIENCY STUDY

ABSTRACT

Gravity Driven Ultrafiltration System is a promising technology which could produce potable water to the community with no electricity and proper wastewater treatment. This project focuses on the construction of the non-point source, modular type GDU system to filter the river water using the Krian river as source water. The GDU systems are tested under both depleting and constant hydrostatic pressure conditions. Under depleting hydrostatic pressure at 40 cm, the highest flux was found at 0.58 LMH and it reduce to almost zero due to reduction of hydrostatic pressure and exhaustion of river water in the module. The module can recover its flux up to 85.17% after being backwash for 5 cycles. Under constant hydrostatic pressure, it was found that 40 cm length hollow fibres produce the lowest permeation flux stabilization due to the larger extent of fouling. Therefore, the tendency for fouling is higher at longer membrane. This can be seen through the characterization of membrane using SEM and FTIR by comparing the pristine membrane with the fouled membrane. Water quality test using different parameters are used to determine the amount in the river water before and after undergoing GDU system. It was found out the concentration of parameters tested on the permeate water is lesser compared to the river water, especially on the bigger molecule. The quality of the permeate is safe for human activity according to the guideline outlined by WHO. The module can recover its flux up to 36.83,86.26 and 94.32% for 40,35 and 30 cm respectively after backwash for 5 cycles. The modular GDU system is promising to provide the clean water for the community that is deprived of electricity and water treatment facilities.

CHAPTER 1

INTRODUCTION

1.1 Background

Rapid urbanization has caused the reduction of quality of surface waters such as sea, river, and lake. According to the statistical data reported by Department of Environment (DoE) of Malaysia in 2009 the major causes of pollution of 52 rivers in Malaysia are mainly come from industrial areas, sewages, workshops, residential areas, animal husbandry activities, example pig farms, agricultural activities, landfills, plantation activities, market, food court and hawker stalls. The recent recurrence of river pollution in Selangor State, for example has interrupt the supply of clean water for the household. It is mainly contributed by the irresponsible human activities. In one of the researches, it was found that during the pandemic Covid-19, the implementation of the Movement Control Order indirectly improved the water quality index (WQI) of the river (Lee Goi, 2020).

Membrane separation processes such as ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO) are widely used for the treatment of river water for the removal of unwanted contaminant and microorganism. Water treatment based on membrane technology has significant advantages over the conventional method such as higher efficiencies and lower cost (Truttmann *et al.*, 2020). Selection of membrane can be based on type of pollutants and the pore size of the membrane. For example, pore size of ultrafiltration is bigger compared to both nanofiltration and reverse osmosis. Therefore, it cannot filter substance like metal ion, dissolved salts, pesticide, and herbicide. However, the disadvantage of using membrane-based process is the occurrence of fouling on the membrane, which later requires physical and chemical cleaning to ensure the continuity of the operation. This eventually resulting in high consumption of energy and the lifespan of membrane becomes shorter due to high pressure requirement (Truttmann *et al.*, 2020)

Recently, gravity-driven membrane filtration (GDM) process method is a promising technology for decentralised water treatment due to the absence of electricity usage. In order to provide efficient water treatment technology especially during natural disaster, the system must be able to mobilize around and also minimize dependent on electricity supply (Wang *et al.*, 2017). Besides, the smaller scale, Point of Use (POU) GDM will benefit the people from rural areas which has lower population density as well as deprived of electricity supply (Sobsey *et al.*, 2009). GDM requires lower energy consumption in surface water treatment because the only driving force is hydrostatic pressure or gravitational force. Besides, in the absence of high pressure driven force, GDM can achieve stable flux without physical and chemical cleaning for long period of operation. This results in lower maintenance cost that increases the its feasibility in developing countries especially in remote areas (Ding et al., 2017). Furthermore, GDM filtration is a robust system suitable for removing high turbidity from the feed water. Different article studied on the lifespan of GDM system with the wastewater treatment plant (WWTP) as the influent (Lee et al., 2020). Based on the reports, it was expected that the GDM could operate approximately 5 to 8 years depending on the frequency of usage (Tan, Lee and Mohamed, 2010). It was also mentioned that the maximum allowable of membrane usage can last 8.61 years for 25 L batches per day. Hence, it is more economical and affordable to apply this system for the household purpose. The productivity of the GDM system depends on the system design as well as the nature of the water characteristics.

1.2 Problem Statement

During monsoon season, the heavy downpour caused the flooding in the East Coast of Malaysia (D/iya *et al.*, 2014). Flooding caused the poor hygiene of the natural water resources due to the microbial contaminations. Besides, the access to potable water is also limited as the water treatment site is off operation due to unavailability of electricity and power generation. This limitation makes flood victim are exposed to the danger of untreated water because of shortage of clean water supply. Hence, flood victims are vulnerable to water-borne diseases such as cholera, diarrhoea, hepatitis A and dysentery due to consumption of contaminated water source (Pal *et al.*, 2018). In Nigeria, 86 % of its population are affected by water-related diseases besides the problem of taste, colour and odour water which led to the failure in fulfil the requirement of Millennium Development Goals (MDGs) (Ahmad, 2017)**.** Under such circumstances, water treatment is necessary. However, the water treatment process must be able to operate at lowest possible energy requirement.

In this case, an alternative method to overcome the problem of accessing drinkable water during flood is by designing a modular gravitational driven membrane system. The installation of this flexible membrane system and treatment of water can be decentralised to produce clean water. This modular system can be operated without electricity, easy to clean, portable with flexible scale. However, such system normally produce water with low productivity due to the absence of hydraulic pressure. The hydrostatic pressure which depends on the height of the column and the porosity of the membrane must be balanced between quality and quantity. In one hand, the membrane with bigger pore size could provide higher water flux but lower water quality, on the other hand, the membrane with tighter pore size is having lower flux but better quality.

Besides the productivity, the lifespan of the membrane is also very limited. Due to its operation in dead end mode, the hydrodynamic condition on the membrane surface is very poor that the scoring effect to prevent the foulant layer is almost disappear. In a long run, the membrane is susceptible to serious fouling phenomenon that further reduce the membrane productivity. In that case, material engineering or proper pre-treatment method is required to prolong the lifespan of the membrane. Furthermore, its performance is also affected by the quality of the feed water that make the selection of membrane material becomes crucial.

Therefore, this work focuses on determining the gravity-driven Ultrafiltration performance using river water as feed. Since fouling membrane problem cannot be avoided although it occurs at low pressure, the work aims to analyse the extent or how far the fouling can occur and the cleaning efficiency and reusability of this membrane via cleaning method.

1.3 Objectives

1. To investigate the membrane rejection based on different parameters tested using the river water.
2. To study the efficacy of backwash cleaning towards the flux recovery
3. To evaluate the modular performance (Flux profile) in filtering the river water under depleting hydrostatic pressure and continuous supply of river water with different hollow fiber PVDF membrane length

CHAPTER 2

LITERATURE REVIEW

2.1 Type of Pressure Driven Membrane Process

Membrane is a thin layer of semi-permeable material that separates substances. Generally, membrane filtration is a technique for separating particles in liquid or gas mixtures based on size, solubility, and charge. This process is applied in variety of applications especially wastewater treatment which aims to remove bacteria, microbes, particles, and natural organic material that may give unpleasant colour, taste, and odour to the water and react with disinfectants to generate disinfection by-products. The use of pressure which is a form of potential difference causes the movement of molecules against the concentration gradient. Hence, larger particles have higher possibility to retain on the surface of semi-permeable membrane which is known as retentate while smaller molecules penetrate the membrane into the permeate. Basically, permeate is cleaned water whereas retentate is concentrated solution which require further treatment before disposal. Four typical pressure-driven membrane processes are microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO).**Table 2.** 1 depicts the characteristics of each processes (Bruggen *et al.*, 2003);

Table 2. 1:Characteristic of membrane processes

	Microfiltration (MF)	Ultrafiltration (UF)	Nanofiltration (NF)	Reverse Osmosis (RO)
Permeability (L/h.m^2.bar)	> 1000	10 – 1000	1.5 – 30	0.05 – 1.5
Pressure (bar)	0.1 – 2	0.1 – 5	3 – 20	5 – 120
Pore size (nm)	100 – 10000	2 – 100	0.5 – 2	< 0.5
Rejection	• Particles	• Multivalent ion • Macromolecules • Particles	• Multivalent • Small organic compounds • Macromolecules • Particles	• Monovalent ions • Multivalent ions • Small organic compounds • Macromolecules • Particles
Separation mechanism	Sieving	Sieving	Sieving-charge effect	Solution-diffusion
Applications	Clarification, pre-treatment removal of bacteria	Removal of macromolecules, bacteria and viruses	Removal of multivalent ions and small organics	Ultrapure water and desalination

2.2 Gravitational Driven Membrane Filtration

Gravity-driven membrane (GDM) filtration is a self-contained process in which low permeate flux can be maintained by using hydrostatic pressure as driving force (Tobias and Bérubé, 2020). Conventional ultrafiltration is operating around 0.2 to 1.0 bar which eventuates flux values ranging from 50 to 100 liter per square meter per hour (LMH) (Pronk, Ding, Morgenroth, Derlon, Desmond, Burkhardt, Wu and Anthony G. Fane, 2019) whereas GDM system is operated at ultra-low pressure ranging from 40-100 mbar. In terms of energy consumption, the GDM method uses just 3–10% of the energy utilized in standard UF pre-treatment (Akhondi *et al.*, 2015), therefore its permeate flow is about an order of magnitude lower than that of typical UF pre-treatment (Xu *et al.*, 2012). The GDM system is driven by the height difference between the feed tank and the membrane unit.

2.2.1 Type of Gravity Driven Membrane and its performance

Low-pressure membrane filtration, also known as microfiltration (MF) and ultrafiltration (UF), is one of the most significant innovations in water treatment due to its excellent pathogen removal effectiveness and simpler modular construction (Shao *et al.*, 2019). In one of the works, Peter-Varbanets *et al.*, (2010) performed the study on flux stabilization for ultra-low-pressure ultrafiltration with different hydrostatic pressure of 40, 150, 250 and 500 mbar. It was found out that the hydrostatic pressure of feedwater did not bring significant changes on the flux stabilization as shown in **Figure 2.1** although there was slight reduction of flux when increasing the hydrostatic pressure.

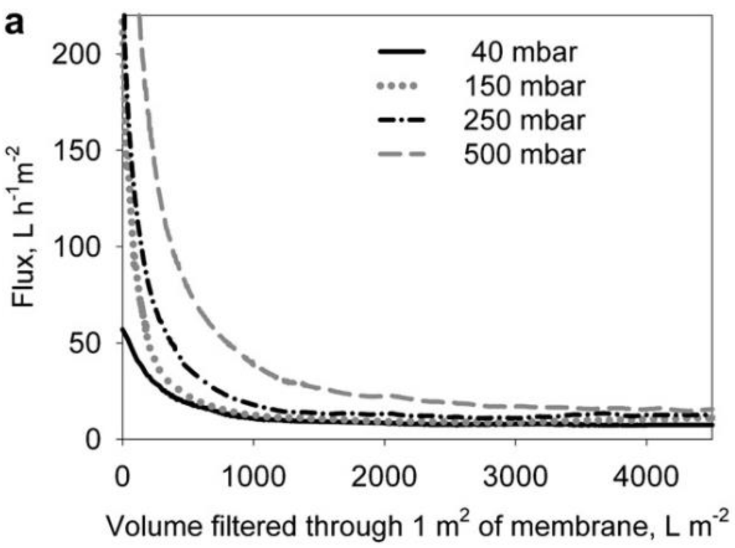

Figure 2. 1:Effect of hydrostatic pressure on flux stabilization of ultrafiltration membrane(Peter-Varbanets *et al.*, 2010)

Flat sheet UF membrane with dead-end configuration were proposed to treat four types of surface water namely natural river water, natural lake water, diluted wastewater, and disinfected river water (addition of sodium azide). The obtained results showed that flux of the system drop significantly for the first 3 days (Peter-Varbanets *et al.*, 2010). However, it was observed that river water recorded the highest flux stabilization values at 7-10 L.$h^{-1}m^{-2}$ after day 7 onwards, followed by lake water (5-6 $h^{-1}m^{-2}$) and diluted wastewater (4-7 $h^{-1}m^{-2}$). It can be concluded that diluted wastewater suffers higher flux decline compared to river and lake water. The factor that affects the values of flux stabilization was the amount of total organic carbon (TOC). A hypothesis was made, as the higher TOC value, the lower flux stabilization value obtained. **Figure 2.** 2 showed the membrane flux during 30 days of dead-end operation for different water types.

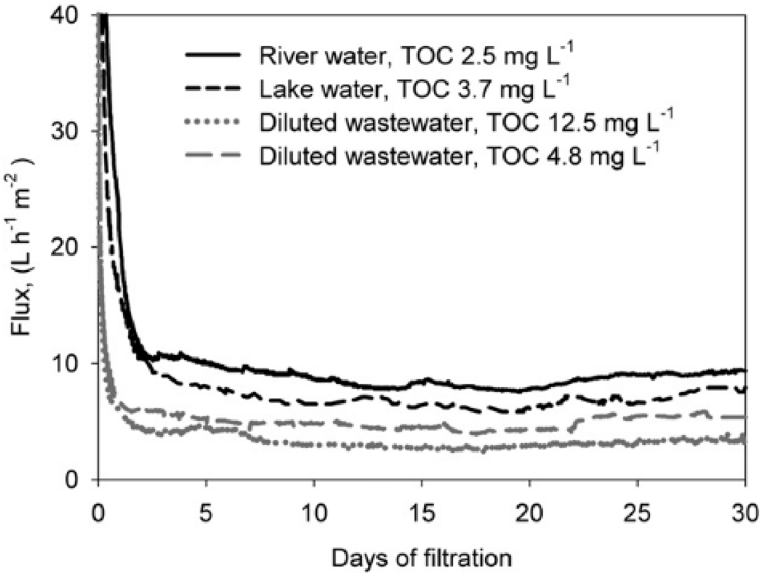

Figure 2. 2:Membrane flux during 30 days of dead-end operation for different water types.

Another study was carried out using GDM system as pre-treatment for seawater reverse osmosis. The experiment was carried out at different hydrostatic pressure of 40 and 100 mbar and temperature of 21 °C (Akhondi *et al.*, 2015).The same trend was occurred as the flux exhibited significant drop on early stage of filtration and achieved stable flux after few days. However, GDM system at 40 mbar hydrostatic pressure produced lower flux compared to filtration at 100 mbar as shown in **Figure 2.** 3 below.

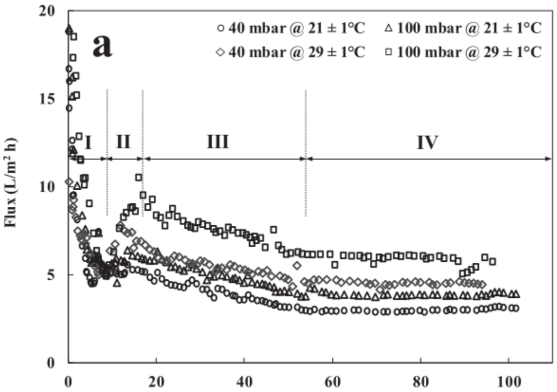

Figure 2. 3:Flux profile of GDM system at different hydrostatic pressure (Akhondi *et al.*, 2015)

Furthermore, another study was made on the natural river water and disinfected river water to determine the impact of biological activity on the resistance of the fouling layer (Peter-Varbanets *et al.*, 2010). It was observed that resistance kept on increasing for system with addition of sodium azide whereas natural river water recorded constant resistance value. The trend happened due to decrease in concentration of cellular adenosine triphosphate (ATP) for disinfected river water. This led to cells deactivation but remain intact and not decomposing.

Peter-Varbanets et al., (2011) studied on mechanism of membrane fouling during ultra-low pressure (ULP) ultrafiltration. It involved 7 types of water namely river water (RW), river water pre-treated with biological sand filtration (PRW), river water with addition of sodium azide (RWA),3 different dilution rates of wastewater diluted with river (DWW), 3 different dilution rates of microfiltered, oxygenated wastewater (MFDWW), 3 different concentration of river water with increased concentration of humid acids (RWHA) and 3 different concentration of river water spiked with kaolin (RWK). All feed waters were tested with flat sheet polyethenesulfone (PES) membrane. The objective was to determine the flux stabilization and impact of biopolymer, dissolved and colloidal humid acid and inorganics particles on fouling mechanisms. The result showed that flux stabilization was observed for RW, PRW and RWK after an initial flux decrease for 2–3 days. MFDWW flux was stabilized although fluctuations could be observed, with a considerable flux increase after 30 days of operation. It was observed that the more stable the flux, the low flux values were obtained with increasing TOC.

It was also interesting to note that different amount of kaolin added to river water did not influence the flux stabilization. However, it had significant impact on PRW, DWW and RWHA. Hence, different water quality brings distinctive influence on the flux stabilization. In terms of biopolymer effect, the flux decline and increase the resistance of the fouling layer was due to deposition of this polymer on the membrane surface that led to gel layer formation. PRW, RW and MFDWW showed uniform decrease in flux as the concentration of biopolymer increased.

Flux stabilization was not influenced by humid acid, but it led to the increased of turbidity due to aggregation of humic acid. Lastly, flux stabilization was not influenced by the deposition of inorganic particle indicate that the specific resistance of the cake layer formed by inorganic particles is considerably lower than the resistance caused by natural organic matter (NOM). **Table 2.** 2 shows the summary of performance of membrane for small GDM system using different feed waters.