Faculty of Engineering

Modelling and Investigating the Impact of Process Control Devices on the Ultrafiltration Membrane Performance

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgement has been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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DEDICATION

This thesis is a symbol of appreciation to people who help the author to complete the project.

(Supervisor, Family and Friends)

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ABSTRACT

The current research aims to address the problem of Ultrafiltration Membrane's (UFM) low productivity in producing clean water that affect the water demand. The novelty of this research is of increasing productivity at a minimum energy consumption performance at optimum clean water production by UFM in association process of control devices (PCD). Experimental research has conducted with UFM, PCD, feed water pump and clean water storage tank. The experimental runs were estimated by central composite design (CCD) and optimization was determined by design of experiments (DOE). The experiment was divided into the three main steps. Step one assesses the effect of the PCD on permeate flux [$m^3(sqm)^{-1}$] by operating the system without, and then with PCD. Step two evaluates the impact of PCD on energy consumption rate [$kW(m^3)^{-1}$] using a similar two-phase approach. Step three aims to optimize UFM performance by adjusting and analyzing feed water pressure (bar), energy consumption rate [$kW(m^3)^{-1}$] and permeate flux [$m^3(sqm)^{-1}$]. The experimental findings demonstrated that PCD devices have significantly impacted on saving 31.6% in permeate flux wastage at a P-value < 0.05. Additionally, the PCD has significantly (at P-value < 0.05) contributed to produce clean water at energy consumption rate 0.43 $kW(m^3)^{-1}$.The optimum performance (at P-value < 0.05) of UFM in association with PCD was 0.68 $m^3 (sqm)^{-1}$ clean water production per square meter of membrane surface area at 1.5 bar optimum pressure and 0.42$kW(m^3)^{-1}$ energy consumption rate. The R^2 statistic of the regression was 0.8993, which is good fit of the regression, meaning is the output is 89.93% associated with inputs. The research findings have a few implications in contributing to achieve higher productivity in clean water production by UFM, which will obviously reduce the water crisis, water production cost. This finding would be a reference for policy makers and government agencies involved in clean water sustainability (SDG 6). In conclusion, this

research has provided valuable insights into the impact of process control devices and UFM on optimization of clean water at a minimum energy consumption rate. The performance optimization of UFM by the process control devices are the Novelty of this work. indeed, this study suggests for further research in this field for developing a robust model.

Keywords: UFM, process control devices, permeate flux, energy consumption, performance, optimum, modelling

Menentukan Kesan Peranti Kawalan Proses Terhadap Prestasi Membran Ultrafilter Dalam Pengeluaran Air Bersih

ABSTRAK

Penyelidikan semasa bertujuan untuk menangani masalah produktiviti rendah membran Ultrafiltrasi dalam pengeluaran air bersih yang mempengaruhi permintaan air. "Novelty" penyelidikan ini adalah untuk meningkatkan produktiviti pada prestasi penggunaan tenaga minimum pada pengeluaran air bersih optimum oleh membran Ultrafiltrasi (UFM) dalam proses peranti kawalan (PCD). Penyelidikan eksperimen telah dijalankan dengan UFM, PCD, pam air suapan dan tangki simpanan air bersih. Rancangan eksperimen ini telah dianggarkan oleh reka bentuk komposit pusat (CCD) dan pengoptimuman telah ditentukan oleh reka bentuk eksperimen (DOE). Eksperimen ini dibahagikan kepada tiga langkah utama. Langkah pertama menilai kesan PCD pada fluks air bersih [$m^3(sqm)^{-1}$] dengan mengoperasikan sistem tanpa dan kemudian dengan PCD. Langkah kedua menilai kesan PCD pada kadar penggunaan tenaga [$kW(m^3)^{-1}$] menggunakan pendekatan dua fasa yang serupa. Langkah ketiga bertujuan untuk mengoptimumkan prestasi UFM dengan melaraskan dan menganalisis tekanan air suapan (bar), kadar penggunaan tenaga [$kW(m^3)^{-1}$] dan fluks [$m^3(sqm)^{-1}$]. Penemuan eksperimen menunjukkan bahawa peranti PCD mempunyai kesan yang ketara dalam menjimatkan 31.6% fluks pada nilai $P < 0.05$. Selain itu, PCD telah menyumbang dengan ketara (pada nilai $P < 0.05$) dalam pengeluaran air bersih pada kadar penggunaan tenaga 0.43 $kW(m^3)^{-1}$. Prestasi optimum (pada nilai $P < 0.05$) UFM yang berkaitan dengan PCD adalah 0.68 $m^3(sqm)^{-1}$ pengeluaran air bersih per meter persegi kawasan permukaan membran pada tekanan optimum 1.5 bar dan kadar penggunaan tenaga 0.42 $kW(m^3)^{-1}$. Statistik R^2 regresi adalah 0.8993, yang menunjukkan kesesuaian yang baik bagi regresi, bermakna output adalah 89.93% berkaitan dengan input.

Penemuan penyelidikan ini mempunyai beberapa implikasi dalam menyumbang kepada peningkatan produktiviti dalam pengeluaran air bersih oleh UFM, yang secara jelas akan mengurangkan krisis air, kos pengeluaran air. Penemuan ini akan menjadi rujukan untuk pembuat dasar dan agensi kerajaan yang terlibat dalam kelestarian air bersih (SDG 6). Kesimpulannya, penyelidikan ini telah memberikan pandangan berharga tentang kesan peranti kawalan proses dan UFM terhadap pengoptimuman air bersih pada kadar penggunaan tenaga minimum. Pengoptimuman prestasi UFM oleh peranti kawalan proses adalah kebaruan kerja ini. Malah, kajian ini mencadangkan penyelidikan lanjut dalam bidang ini untuk membangunkan model yang kukuh.

Kata kunci: *Membran ultrafilter, peranti kawalan proses, fluks, penggunaan tenaga, prestasi, optimum, pemodelan*

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LIST OF ABBREVIATIONS

AFM	Analogue Flow Meter
CAC	Command and Control
CCD	Central Composite Design
CLC	Close Loop Control
CMA	Critical Material Attributes
CMF	Crossflow Membrane Filtration
CP	Concentration Polarization
CPP	Critical Process Parameters
CQA	Critical Quality Attributes
CU	Capacity Utilization
CUF	Capacity Utilization Factor
CV	Control Valve
DCS	Distributed Control System
DOE	Design of Experiments
ECMT	Energy Consumption and Monitoring Technology
HMI	Human Machine Interface
I&C	Instruments and Control
RSM	Response Surface Methodology
SDG	Sustainable Development Goals
J	Permeate Flux
MF	Microfiltration
MFM	Microfiltration Membrane

MTDP	Maximum Target Desired Profile
NDP	Net Driving Pressure
NFM	Nanofiltration Membrane
NRW	Non-Revenue Water
OP	Osmotic Pressure
Pa	Pascal
PG	Pressure Gauge
pH	Potential of Hydrogen
PID	Proportional, Integral and Derivative
PLC	Programmable Logic Controller
RM	Ringgit Malaysia
RO	Reverses Osmosis
SS	Suspended Solids
TMP	Transmembrane Pressure
TDS	Total Dissolve Solids
TSS	Total Suspended Solids
UF	Ultrafiltration
UFM	Ultrafiltration membrane
TMP	Transmembrane Pressure
VFD	Variable Frequency Drive
WWTP	Wastewater Treatment Plant

CHAPTER 1

INTRODUCTION

1.1 Introduction

Chapter 1.0 describes the objective of this study, which is focused on determining the impact of process control devices on the performance of UFM in clean water production. This research is an experimental work, which aims to evaluate the process control devices on the productivity in permeate flux production by UFM, to demine the impact of process control devices on the energy consumption in permeate flux production, and finally optimizing the performance of UFM with respect to permeate flux and energy consumption. The chapter is structured as follows: Section 1.2 provides an overview of the research background. Sections 1.3 and 1.3.1 present the problem statement and research questions, respectively. The research objective is explicitly stated in Section 1.4, while the scope of the research is specified in Section 1.4.1. Sections 1.5 and 1.6 are dedicated to outlining the hypotheses and highlighting the novelty of this research. The structure of the thesis is elucidated in Section 1.7, and a summary of the chapter is presented in Section 1.8.

1.2 Background of Research

This research endeavors to confront the prevalent challenge of subpar performance in clean water production, a significant obstacle hindering the attainment of a sustainable and reliable clean water supply for safeguarding public health. To fulfill the research objective specifically, enhancing the efficiency of the UFM system process control devices have been employed. These devices play a pivotal role in mitigating water and energy wastage while concurrently optimizing the overall performance of the UFM.

Water plays an indispensable role in meeting the daily needs of all living organisms on this planet in which its absence would inevitably lead to the extinction of life (Ross, 2022). Water sources are leveraged for the socio-economic development (Mannina et al., 2022). Sarawak is blessed with vast natural water resources, primarily sourced from rivers and drains. In regards water supply, it should not be a problem, but the opposite seems to be the case with the water crisis being reported every year, affecting thousands of people who endure water shortages (Abdul Rahman et al., 2023). Contrary to expectations and standard measurements, this state should not be experiencing a water crisis (Elena et al., 2023).

There are 222 water-stressed areas identified by the Sarawak State Authorities (Borneo Post Online, 2018). The clean water crisis in Sarawak has been attributed to inadequate water management, water pollution, and inefficiencies in water production. The primary sources of pollution include industrial wastes, household garbage dumps, palm oil mill effluent, oil and chemical spills, hospital wastes, and sewage dumps. These factors collectively exert a substantial impact on the production of clean water in the region (Zainal Abidin, 2015).

Various incidents of water contamination have also been reported as a result of waste disposal from the manufacturing industries which includes palm oil mills, livestock, construction, and oil spills. All these pollutants are affecting the ability of treatment plants to treat polluted water (Dalun & Abdullah, 2021). A few studies on clean water supply constraint issues demonstrated that the poor productivity of existing water treatment plants is also responsible for the water crisis in the state (Rahman et al., 2021).

Several factors contributing to the shortage in clean water supply have been identified. The increased demand for water, driven by population growth, rapid expansion of unregulated areas, and industrialization, stands out as a primary cause. Firstly, the escalation of industrialization and the expansion of irrigated agriculture further intensify the strain on water resources. Additionally, a significant factor exacerbating the shortage is the slower growth rate of clean water production in comparison to the escalating demand for water.

While Sarawak is endowed with abundant natural water resources, the data reveals a significant impact on numerous communities across different regions owing to a shortage of clean water. This issue can be attributed to various constraints, such as the absence of suitable technology, inefficiencies in water resource development, and the inability to harness natural water sources due to pollution (Subramaniam et al., 2020; Chew et al., 2021).

Advanced filtering techniques called UFM are used to remove dissolved molecules, bacteria, and particles from liquids, usually water. These membranes are efficient at eliminating pollutants like bacteria, viruses, colloids, and suspended particles because their pore diameters fall between 0.01 and 0.1 micrometres. UFM have extensive application in diverse industries such as biotechnology, food and beverage processing, pharmaceuticals, and water and wastewater treatment. Because of their many advantages—including high filtration efficiency, low energy consumption, and low-pressure operation—they are a well-liked option for applications needing high-purity water (Ma, B., et al., 2019).

Given this background, the central question emerges: "***Can the performance and energy consumption rates reach their optimum levels through the use of ultra-filter membrane***, *thereby achieving the research objectives*?" This study is meticulously crafted to provide a comprehensive answer to this inquiry. To achieve this goal, the research combines a comprehensive literature review with an experimental investigation employing