MODELLING AND EXPERIMENTAL VERIFICATION OF PORTABLE ULTRAFILTRATION SYSTEM FOR DRINKING WATER PRODUCTION

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MODELLING AND EXPERIMENTAL VERIFICATION OF PORTABLE ULTRAFILTRATION SYSTEM FOR DRINKING WATER PRODUCTION

ABSTRACT

Ultrafiltration (UF) effectively removes contaminants to yield clean drinking water by allowing water to flow through a semipermeable membrane which incorporate microscopic pores ranging from 0.01 to 0.1 μm. To determine the effectiveness of the portable system, water quality analysis has been carried out to determine if the system produce filtered water from a river, lake and synthetic water source achieving the drinking water standards.

The parameters examined are turbidity, color, presence of bacteria and the Water Quality Index (WQI) value. The results show that this portable UF (PUF) unit produces purified water that meets quality standards, achieving reduction in turbidity from 24.4 NTU of river water to less than 1 NTU, reduction in colour from 300 TCU of river water to less than 15 TCU and the WQI being upgraded from Class II to Class I grade water, which is from 86% to 94% for river water. Moreover, the system demonstrates its ability to produce microbiologically safe drinking water by eliminating the total coliform along with all *Escherichia coli (E-coli)* bacteria that come from the raw water sources.

A simple model of the system using Darcy's Law was also obtained to predict the permeate flux and transmembrane pressure (TMP). Initially, simulation was done using nominal value, as taken from the literature, four (4) parameters i.e. the membrane hydraulic resistance, initial rapid fouling constant, mass transfer coefficient and foulant bulk concentration. Using the Evolutionary Programming (EP) technique, an enhanced model with revised parameters was produced by reducing the error between the model with these nominal values and the experimental values.

The four parameters were optimized as input variables and interaction among them was observed, while TMP and permeate flux were considered as response attributes. With the updated model, the average error between the model and experiment was reduced from 32% to 9%. This was further validated with new data taken from experiment. This improved model with the updated parameter was then used to predict the TMP and compared with the experimental value. Contrasting the optimized model with the existing model indicates that the optimized model predicts the membrane performance better, making it competent as a reliable model for the purification of water using the in-house built portable UF (PUF) system while meeting water quality standard and the United Nations Sustainable Development Goals (SDG) on Drinking water, everyone should have equitable and universal access to safe and affordable drinking water by the year 2030.

Keywords: Portable, Ultrafiltration, Modelling, Water Quality, Experiment, Optimization

PEMODELAN DAN PENGESAHAN EKSPERIMEN SISTEM ULTRAFILTRASI MUDAH ALIH UNTUK PENGELUARAN AIR MINUMAN

ABSTRAK

Ultrafiltrasi (UF) membolehkan air mengalir melalui membran separa telap yang menggabungkan pori-pori mikroskopik berkisar dari 0.01 hingga 0.1 µm. Ini terbukti berkesan dalam menghapuskan pencemaran dan menghasilkan air minum yang bersih. Untuk menentukan keberkesanan sistem mudah alih tersebut, analisis kualiti air dijalankan untuk menentukan sama ada sistem menghasilkan air yang ditapis dari sungai, tasik dan sumber air sintetik kepada air memenuhi piawaian minimum. Parameter yang diperiksa ialah tahap kekeruhan, warna, kehadiran bakteria dan nilai indeks kualiti air (WQI).

Hasilnya menunjukkan bahawa unit UF mudah alih (PUF) ini menghasilkan air yang dibersihkan yang memenuhi kualiti dan piawaian serta mencapai pengurangan tahap kekeruhan daripada 24.4 NTU kepada kurang daripada 1 NTU untuk air sungai, pengurangan warna daripada 300 TCU kepada kurang dari 15 TCU untuk air Sungai dan WQI di tingkatkan dari Kelas II kepada Kelas I air, iaitu dari 86% kepada 94% untuk air sungai. Selain itu, peranti ini menunjukkan keupayaannya untuk menghasilkan air minum yang selamat secara mikrobiologi dengan menghapuskan jumalah koliform bersama-sama dengan semua bakteria *E-coli* yang berasal daripada sumber air mentah.

Model ringkas menggunakan Undang-undang Darcy juga diperolehi dengan meramalkan aliran resapan dan tekanan membran trans. (TMP). Pada mulanya simulasi dilakukan menggunakan nilai nominal untuk empat parameter iaitu rintangan hidraulik membran, kotoran tetap paling awal, koefisien pemindahan masa dan kepekatan kotoran pukal. Parameter yang diambil daripada hasil kajian ilmiah. Dengan mempertimbangkan ralat antara model dan nilai nominal dan nilai eksperimen, model yang lebih baik dengan

parameter yang dikemaskini diperolehi menggunakan pendekatan Program Evolusi (EP). Rintangan hidraulik membran, kotoran tetap paling awal, koefisien pemindahan masa dan kepekatan kotoran pukal dioptimumkan sebagai pembolehubah input dan interaksi antara mereka diamati, manakala TMP dan aliran resapan dianggap sebagai hasil akhir.

Dengan model yang telah dikemaskini, kesilapan purata antara model dan eksperimen berjaya dikurangkan daripada 32% kepada 9%. Ini telah disahkan dengan data baru yang diambil daripada eksperimen. Parameter baru ini kemudian disahkan dengan model untuk mendapatkan TMP. Membandingkan model yang dioptimumkan dengan model yang sedia ada menunjukkan bahawa model dioptimumkan meramalkan prestasi membran dengan lebih baik dan dengan itu menjadikannya berdaya saing sebagai model yang boleh dipercayai untuk penulenan air menggunakan sistem UF mudah alih (PUF) yang dibina sendiri sambil memenuhi piawaian kualiti air dan Matlamat Pembangunan Mampan (SDG) Pertubuhan Bangsa-Bangsa Bersatu mengenai Air Minuman, semua orang harus mempunyai akses yang saksama dan universal kepada air minuman yang selamat dan berpatutan menjelang tahun 2030.

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LIST OF SYMBOLS AND ABBREVIATIONS

C_b	:	Foulant bulk concentration (kg/m^3
J_v	:	Volumetric permeate flux (m/s)
k	:	Mass transfer coefficient (m/s)
m	:	The slope of the linear portion of TMP-time profile in constant flux (kPa/s)
$mi-1$	:	The slope of linear region of TMP-profile in constant flux
R_f	:	Fouling resistance (kPa s/m)
Rm	:	Total membrane resistance (kPa s/m)
R_{mi-1}	:	Cumulative resistance at time t_{i-1} (kPa s/m)
R_m^0	:	Membrane hydraulic resistance (kPa s/m)
Rmo	:	Membrane hydraulic resistance (kPa s/m)
R_m^*	:	Initial rapid fouling constant (kPa s/m)
R_{mx}	:	Initial rapid fouling constant (kPa s/m)
t	:	Time (s)
t_R	:	Duration of initial rapid fouling phase (s)
α	:	Fouling rate constant (kPa/m)

ΔP	:	Transmembrane pressure (kPa)
Δt	:	Small time increment (s)
$\Delta\pi$	:	Osmotic pressure (kPa)
AI	:	Artificial Intelligence
ANN	:	Artificial Neural Network
BOD	:	Biochemical Oxygen Demand
BSA	:	Bovine Serum Albumin
CCD	:	Carbonized Carbon Dots
COD	:	Chemical Oxygen Demand
DO	:	Dissolved Oxygen
DOE	:	Department of Environment
EA	:	Evolutionary Algorithm
EP	:	Evolutionary Programming
EPA	:	Environmental Protection Agency
GA	:	Genetic Algorithm
GP	:	Genetic Programming
HF	:	Hollow Fibre

MF	:	Microfiltration
Mg/l	:	Milligrams per litre
MINLP	:	Mixed Integer Non-Linear Programming
MOH	:	Ministry of Health
MY	:	Malaysia
NF	:	Nanofiltration
NH3-N	:	Ammonia Nitrogen
NSF	:	National Sanitation Foundation
NSGA-II	:	Non-dominated Sorting Genetic Algorithm
NTU	:	Nephelometric Turbidity Unit
NWQS	:	National Water Quality Standards for Malaysia
PAN–BC	:	Polyacrylonitrile/Biochar
PAN-CTN	:	Polyacrylonitrile/Chitosan
PAN–BC–LAC	:	PAN-BC Membrane
PEI	:	Polymer Polyethyleneimine
PEI-g-OC	:	Polyethylenimine-Grafted-Corncob
PEUF	:	Polymer Polyethyleneimine Enhanced Ultrafiltration
pH	:	Potential of Hydrogen

PPM	:	Parts per Million
PUF	:	Portable Ultrafiltration
RO	:	Reverse Osmosis
SIAN	:	Subindex for Ammonia Nitrogen
SIBOD	:	Subindex for Biochemical Oxygen Demand
SICOD	:	Subindex for Chemical Oxygen Demand
SIDO	:	Subindex for Dissolved Oxygen
SIpH	:	Subindex for pH
SISS	:	Subindex for Suspended Solids
SDG	:	Sustainable Development Goal
SDWA	:	Safe Drinking Water Act
TCU	:	True Colour Unit
TMP	:	Transmembrane Pressure
TSS	:	Total Suspended Solid
UF	:	Ultrafiltration
UK	:	United Kingdom
UN	:	United Nations
UNICEF	:	United Nations Children's Fund

US	:	United States
USEPA	:	United States Environmental Protection Agency
UV	:	Ultraviolet
VOCs	:	Volatile Organic Compounds
WHO	:	World Health Organization
WQI	:	Water Quality Index
WWTP	:	Wastewater Treatment Plant

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

This chapter firstly give a general background of this work which includes an overview of the water scarcity problem, and the problems in making produced drinking water achieve the quality standards. The problem statement that leads to the motivation and the necessity of this work are subsequently discussed in Section 1.2 while the research gaps are specified in Section 1.3. The objectives of this research work are shown in Section 1.4, the research contributions are outlined in Section 1.5 and lastly the scope and the thesis organization are given in Section 1.6.

1.1 Background

Water is essential for sustainable development as well as a key factor for human survival, socioeconomic development as well as for energy and food production. As highlighted by the United Nations (UN) since 2010, drinking water is one of the major fundamental human rights. In order to ensure sufficient, safe and affordable water access while improving worldwide health, education, and economic productivity, these rights represent among the major milestones for each nation including Malaysia. Hence, there is a need to have a balance between human and commercial needs in dealing with water resources, especially considering the high growth of the population worldwide (Lopes et al., 2022).

There are many people in the world who consume raw surface and groundwater, hence being likely to get infected with water-borne diseases by contamination from microbial organisms in human and animal wastes. Based on the United Nations Sustainable Development Goals (SDG) on Drinking water, everyone should have equitable and universal access to safe and affordable drinking water by the year 2030 (WHO, 2023b).

Therefore, a comprehensive water quality assessment is essential to provide uses the direction to deal with this problem. Geographically, socially and culturally, there have been significant differences between rural and urban areas; those who live in low-income or unofficial settlements typically have less access to better supplies of drinking water than others. (WHO, 2023a). As of 2020, according to UNICEF, there are 2 billion people or one in four people lacking safely managed drinking water services in the world including Malaysia, where only 94% of the population are supplied with safely managed water services (UNICEF, 2021).

Owing to the rapid population growth, urbanization and rising water needs from agriculture, industry, as well as the energy sectors, demand for water continues to rise (UN, 2023). River water quality is deteriorating in urban and rural areas as a result of natural and anthropogenic factors. To manage the water quality in river basins, it is crucial to understand the changes and factors affecting river water quality (Anh et al., 2023). Natural phenomena including rock weathering, evapo transpiration, atmospheric deposition, climate change, and natural disasters all affect the quality of river water. Industrial effluents, household wastes, agricultural practices including applying pesticides, fertilizers, and manures, as well as animal husbandry, irrigation, deforestation, and aquaculture, can all be considered anthropogenic causes. In general, almost all sources of water for domestic and human usage must be treated using proper technologies before being made available to the general public, since these polluting factors are primary causes for the reduction in water quality. Water treatment systems can basically be divided into two primary categories: conventional and non-conventional. A combination of physical, biological, and chemical processes are used in conventional water treatment, whereas more advanced technology is used in non-conventional water treatment.

Conventional water treatment methods involve mechanisms such as sedimentation, coagulation, filtration, flocculation, and disinfection whereas for non-conventional treatment, membrane-based technology is usually applied which includes microfiltration, ultrafiltration, nanofiltration, reverse osmosis, electrodialysis and membrane distillation. (Pakharuddin et al., 2021). However, consideration of factors related to geography, quality of the water sources, issues on costs and labour limit the widespread implementation of decentralized and localized drinking water treatment plants (Wu et al., 2023). Hence in general, the challenge is to supply an easy to transport yet inexpensive clean water treatment system by applying appropriate technology to those remote areas lacking from a centralized water supply network.

1.2 Problem Statement

Water pollution has lowered the overall quality of water resources which in turn has increased the number of people having limited availability to safe drinking water. People in the rural areas are mostly affected by this problem as the available water resources are normally contaminated. There are billions of people lack access to safe water and UN has set 6 targets to reach the universal access to drinking water, sanitation and hygiene by 2030 under its 'Goal 6 Targets'. In Malaysia, 13 tributaries and 36 rivers have been contaminated as a result of human activity including industrial, building, and agricultural operations within river catchments. This has left them with no choice but to drink the untreated groundwater, river water, or lake water that are easily accessible to them. These global concerns are also due to the complex nature and economic conditions existing in the rural areas relating to location, infrastructure, connectivity and quality of the water sources as well as issues on costs, labour, high energy consumption and large footprint. These issues in turn limit the widespread implementation of localized drinking water treatment plants. The untreated water for human consumption can be extremely toxic and harmful, raising additional questions about the safety of the drinking water in these rural areas. It is then possible that the absence of this centralized water delivery system in the rural areas would be replaced by small scale but cost-effective systems for water treatment, a system that can treat water from various water sources, basically a portable type of filtration system.

Ultrafiltration (UF) has been one of the widely used advanced filtration-based treatment methods in the past two decades and one of the most important technological advances in water treatment recently (Mierzwa et al., 2012). Particles and macromolecules can be eliminated from raw water using UF to provide drinkable water. Its portable-based system boasts a simpler operational system and exhibits efficiencies in treating water that is safe for human usage which makes it suitable for treating water sources in rural areas. UF process can be operated steadily without pretreatment and chemical cleaning, in many cases.

However, the quality of the purified water produced by any proposed filter systems potentially can be questioned in consideration to mitigate or prevent the health risks faced by consumers. Hence any system developed must ensure that the purified water produced achieves the legislative standard set. Hence validation of the purified water from any portable UF system must be performed to ensure its quality meets the drinking water standards set by the relevant governmental bodies.

Apart from the issues of water quality and portability, there is a lack of simple but accurate models to simulate the performance of UF portable systems which can be validated experimentally. There are also insufficient studies on the design of an inexpensive portable ultrafiltration water treatment unit that can purify water from various sources. Considering these factors, an advanced water treatment system such as a portable UF (PUF) that can treat water from various sources which is cost effective and can be easily modelled is a potential solution to be researched further.

1.3 Research Gap

Hence, this project aims at evaluating the filtration performance and efficiencies of an in-house built portable ultrafiltration system to treat water from various sources such as lake and river water. The water filtered from such a system has also to be checked for the presence of bacteria such as total coliform and *Escherichia coli* (*E.coli)* and the water quality produced from it also verified to make sure of its adherence to national and international water quality standards.

There has been numerous mathematical modelling approach of the Ultrafiltration (UF) that have been attempted, such as by using Artificial Neural Network (ANN). However, there are not many studies in the modelling of the UF using simple yet accurate standard models with optimal parameters representing the actual characteristics of the UF module. Hence there is an opportunity to close this gap in this work by using the Evolutionary Programming (EP) approach to optimize the relevant model parameters in order to obtain a simple but accurate model.

Furthermore, although some portable units are available in the market, very few detail studies of their performances have been published. This will be addressed in this work where detailed experiments on the in-house unit will carried out to validate its performance, water quality produced and the model development.

1.4 Research Objectives

The main goal of this work is to study the viability and performance of the in-house portable ultrafiltration (PUF) unit for drinking water production. In order to achieve this, there are a few specific objectives that have been established for this study based on the problem statements above, which include:

1. To conduct experiments to test the water quality using the portable UF (PUF) system in which the sources are from lake, river and synthetic water to make the water quality drinking standards. The parameters to be tested are the turbidity, colour, total suspended solids (TSS), pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammonia nitrogen content and bacteria.

2. To perform mathematical modelling of the portable UF system to predict the permeate and TMP.

3. To incorporate Evolutionary Programming (EP) to optimize the parameters of model and validate using the experimental results.

1.5 Research Contributions

Some of the research contributions in this work include:

1. Development of an inexpensive portable UF system which can be fully tested for its performance to treat various types of water while fulfilling the water quality drinking standards.

2. The simple model for this inbuilt portable ultrafiltration was also proposed and solved through software programming to predict permeate flux and TMP within the membrane.
3. Incorporation of Evolutionary Programming (EP) to upgrade the important parameters of the model and get an improved model representing the real PUF unit. This model has also been verified through experimental testing.

1.6 Thesis Organizations

Chapter 1 briefly described the overview and background of the study. Additionally, the problem statement, the objectives of the research and its contributions are also presented under this chapter. The water sources, water contamination, membrane-based treatment methods, the basics of ultrafiltration and literature reviews on various commercial portable ultrafiltration systems, water quality control and modelling with Evolutionary Programming (EP) for obtaining the optimized parameters of the ultrafiltration system are presented in Chapter 2.

In Chapter 3, various experiments on the portable ultrafiltration were carried out. Various water quality parameters are investigated using the appropriate equipment before and after the ultrafiltration system. In total, nine parameters have been measured namely the turbidity, colour, bacteria, chemical oxygen demand (COD), dissolved oxygen (DO), biochemical oxygen demand (BOD), ammonia nitrogen content, pH and total suspended solids (TSS) as well as the WQI parameter of measuring the quality of water produced from the unit. Subsequently, the proposed models based on simple principles were compared with the experimental data to perform optimization of the important parameters of the model using the EP method and validated further with the experimental tests in

Chapter 4. The water quality tests were also shown in this chapter. Chapter 5 concludes all the findings of this research work and includes its contributions and recommendations for future works.

CHAPTER 2: LITERATURE REVIEW

In the first session of Chapter 2, i.e., Section 2.1, the various water resources such as seawater, rainwater, water from the ground, surface water and municipal water are listed and their respective features are also mentioned. Section 2.2 explained on the water contaminants and the definition of contaminants by the Safe Drinking Water Act (SDWA) as established by the United States' Environmental Protection Agency (EPA). A table on the water contaminants group as per SDWA is also included. In Section 2.3, the membrane-based treatment methods used in the water treatment is discussed and in Section 2.4, Ultrafiltration as the most used methods in the production of potable water is discussed. Section 2.5 and 2.6 discussed respectively the Portable UF and Commercial Portable Ultrafiltration systems. Section 2.7 discusses on the water quality standard and Section 2.8 on the modelling of the portable ultrafiltration systems as well as on the Evolutionary Programming (EP) approach.

2.1 Water Sources

The earth's surface water is mainly found in the ocean (97.25%) also in the polar caps or sea ice cover and glaciers which make up for 2.05% of total surface water, while the remaining are found in the freshwater lakes, rivers and also water from the ground resources. There is sufficient and enough fresh water in the world, including water that contains small quantity of salt (with each liter of fresh water, there is less than 3 grams of salt) to meet the human needs. However, this fresh water is not available all the time and at all locations as required and it is also not well distributed globally. Hence, it is important to identify the water sources which will help to determine and classify the contaminant for water filtration.

Water from the sea, contains high salinity or high amounts of the dissolved salts which is considered as the most common water contaminants. In average, the salt contents are 30 grams to 50 grams of salt per kilogram of seawater. Because of high salt concentrations, seawater is not suitable for human consumption. When humans drink seawater, the kidneys are not able to remove the excess salt, resulting in dehydration instead of hydration and it needs to undergo the desalination process to enable it to be safe for drinking.

Rainwater, the other source of water normally have low pH (Potential of Hydrogen) value and because of this, rainwater is highly soft and has a small amount or zero Total Dissolved Solid (TDS) considering that it has not collected soluble matter from the soil and is therefore soft. However, it must still undergo some process to treat the water to make sure it is safe for drinking.

Water from the ground, i.e., the well water is the most commonly used water source. It is the water that occurs below the surface of the earth, where it occupies the spaces or cracks in soils or rocks. It serves as the primary source for 90% of the people in rural areas for their drinking water when they do not receive water from the municipal departments or private companies where about 42% of groundwater withdrawn worldwide is used for agriculture. This water resource plays a very vital role in sustaining communities as well as for agricultural purposes, especially in the areas where surface water reservoirs are limited.

Another source of water is the surface water, a type of water that is collected from rivers, wetlands, streams, lakes and also reservoirs. Surface water is conveniently accessible as compared to groundwater and humans put a heavy reliance on this source of water for their daily use. Surface water is considered another very important drinking water and agricultural source of water.

Municipal water supply or resource refers to any connection to the pipelines built and used to convey treated water to be used by humans. It is fully treated and processed before it is sent to industries and homes, which means that the majority of impurities are removed before it is consumed. The major sources of municipal water include huge wells, rivers, reservoirs or lakes.

The project's water sources are the lake, river, and synthetic water, chosen for their accessibility, ease of collection, and convenient preparation within the campus vicinity which is the Varsity Lake and Sungai Pantai.

2.2 Water Contamination

The Safe Drinking Water Act (SDWA) by the United States' Environmental Protection Agency (EPA) establishes protective drinking water standards for more than 90 contaminants. Contaminants are defined as material or substance present in the water regardless of the concentration and can either be physical, biological, chemical or radioactive in nature. The regulated contaminants under the SDWA fall into six main groups (EPA, 2024) as listed in **Table 2.1**

Table 2-1: Water Contaminants Group

Group	Description
Microorganisms	These include bacteria, viruses, and other pathogens that can cause waterborne diseases
Disinfectants	These are chemicals used to treat water, but they can also form byproducts that need regulation
Disinfection byproducts	These are compounds produced when disinfectants react with organic matter in water
Inorganic chemicals	Examples include heavy metals like lead, arsenic and mercury
Organic chemicals	These encompass an extensive range of synthetic as well as the natural compounds; i.e.; the pesticides, solvents and also the industrial chemicals
Radionuclides	These are radioactive elements that can naturally occur or can be a result from human activities

The contamination of drinking water that exceeds the approved levels can potentially result in a lot of health issues. As per the World Health Organization (WHO), in the year 2022, there were at least 1.7 billion people in the world whose drinking water source have been contaminated with faeces. This microbial contamination (resulted from this contamination) of drinking-water exposes huge safety risk to these people. WHO also highlighted that globally in 2022, only 73% or 6 billion people obtained drinking-water that are safely being managed, in other words, the drinking water located on premises and are readily-available, as well as one that is contaminants-free while the rest still depend on natural source of water which can contain any of the contaminants in **Table 2.1**.

2.3 Membrane-based Treatment Methods

Semi-permeable membrane with different pore sizes are normally used in the process of water filtration (Mulder, 1996). Microfiltration has pore diameters that range from 1 micron to 0.1 micron and this can completely block the bacteria, and partially block the viruses and is a membrane filtration method that is driven by pressure. As for the ultrafiltration, this type of filter has pore diameters that are ranging from 0.1 microns to 0.005 microns and is capable to completely filter germs and also viruses. Whereas for nanofiltration, its purification range is from 0.5 nanometers to 5 nanometers. As a result, nanofiltration is not a suitable choice to desalinate or to remove salt from seawater. Reverse osmosis membrane's range of pore diameters is from 0.5 nanometer until 0.15 nanometer, which allows it to remove the most of the salt contents from the feed water under high pressure differences (Peter-Varbanets et al., 2009). **Figure 2.1** shows the membrane filtration regimes range of these different processes.

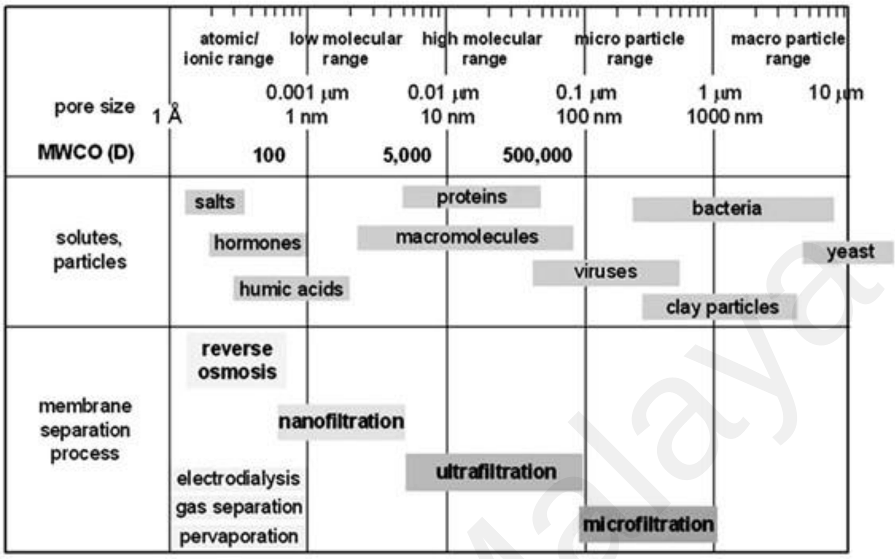


Figure 2-1: The pore sizes for every membrane filtration system

As shown in **Table 2.2**, there exist different driving forces in the membranes' separation mechanism involving the differences in pressure, chemically based potential differences, electrically based potential gradient, or differences in temperature across the membrane (Peter-Varbanets et al., 2009). In this work, we focus on membrane technology involving ultrafiltration that utilizes the mechanism of pressure differences using river water from Sungai Pantai, lake water from Varsity Lake in which both locations are within the vicinity of the university and synthetic water.

Table 2-2: Membrane Technology Separation Mechanism

Driving Force	Membrane Technology
Pressure Difference or Hydraulic Pressure	Microfiltration (MF) Ultrafiltration (UF) Nanofiltration (NF) Reverse Osmosis (RO)
Chemically Based Potential Difference	Forward Osmosis Vapour Permeation Pervaporation Dialysis
Electrically Based Potential Gradient	Membrane Electrolysis Electro-deionization
Difference in Temperature	Membrane Distillation

2.4 Ultrafiltration (UF) Method

Ultrafiltration (UF) is a highly used method in the potable water production as this type of filtration filters the total suspended solids (TSS), turbidity, organic matters, and microorganisms, etc. from the source water (Yang et al., 2021). Ultrafiltration uses pressure or concentrated gradient in order to separate two fluids by using a semi-permeable membrane. Since early 1970s, microfiltration (MF) and ultrafiltration (UF) have turned into separation technologies that are mature (Cheryan, 1998). The first applications using UF were mainly in dairy industry as mentioned by (Glover & National Institute for Research in, 1985). The ultrafiltration technology's advantages over traditional approaches includes the UF capability to produce clean water with good quality, operating techniques that are mild, high in selectivity, upgradeable system that are readily available, and design that is compact and space efficient (Huang et al., 2015). Physical blockade filtration is used in removing the microorganism from the water and the hollow fibre UF membrane technology is able to provide clean water using this effective technique. **Figure 2.2** shows the mechanism of the hollow fiber ultrafiltration unit.

Figure 2-2: Hollow fiber Ultrafiltration system mechanism.

In the UF operation, there are two types of modes normally used; one is the dead-end filtration and crossflow filtration as illustrated in **Figure 2.3**. that may have an impact on the production rate of the water, the tendency of fouling as well as the consumption of the energy in different ways.

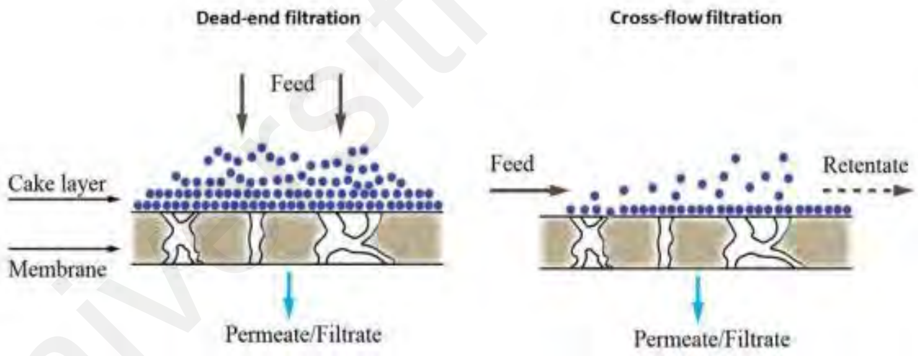


Figure 2-3: The UF Separation Process Operation Modes

The comparison between both the ultrafiltration operation modes types is shown in **Table 2.3** (Duong et al., 2017).

Table 2-3: Comparison between the types of Ultrafiltration Operation Modes

Dead End Filtration	Cross Flow Filtration
The fluid that is to be filtered is being fed perpendicularly to the filter element	The fluid that is to be filtered is being fed parallelly to the filter element
It is a simple operation for both laboratory and medical filtration	It minimises the membrane irreversible fouling
Its concentrated feed has a high product recovery rate	It improves the lifespan of the filter media due to the reduction in the build-up of the filter cake
Lower capital cost	Higher capital cost

In dead-end mode, or also being called as direct-flow mode, all the water that are introduced into the membrane pass through the membrane onto the side of the filtrate. On the membrane surface, all the debris in the feed water accumulate and is then removed by the backwash from the side of the filtrate. The cross flow is normally used for applications that have solid load that is very high, and this mode prevent the contaminants excessive build-up on the surface of the membrane.

2.5 Classification of Ultrafiltration (UF) Systems

The ultrafiltration units can be further classified in terms of its portability and versatility into 3 types, i.e.; portable, mobile and modular units. These individual classifications can be seen in **Table 2.4**. However, the portable purifiers units have attracted the most attention from among these classes due to its simplicity of deployment during emergency, its movability, its usage convenience, and ease of maintenance. With only small amount of investments, the portable treatment devices are very useful for applications in households which provides a feeling of ownership, especially in rural areas. Basically, these portable units also give less difficulties in its transport and installation (Venkatesha et al., 2014).

There are a handful of various types of portable water filters that are available and have varying degrees of effectiveness in the market and can be utilized with other purification systems.

Table 2-4: The Classification of the Water Purifying Device

Classification	Description
Portable unit	Lighter and small in size that is suitable for single users. It provides drinkable water for individuals use.
Mobile unit	Big in size and is a more substantial unit. It is installed on a vehicle and can have a size range of a bicycle to a huge truck or a vessel.
Modular unit	This unit cannot be transported or moved to new locations without being dismantled and reassembled the parts at the new locations.

Table 2.5 shows some portable water filters and their essential features, mentioned in journals, which are not available on a commercial scale but mainly operated in the research laboratory or on a pilot plant scale.

Table 2-5: Portable Water Filters from Literature

Model	Features	References
Portable First-Response Water Purifier	The multi-stage filter constitutes fabric filter, the sand filter that is coated with graphene-oxide, vetiver grass filter and UV filtration system	Akshay et al., 2020
Portable Water Purification Device	A combination of filter pads that have five layers; i.e.; the activated carbon, zeolite, silica sand, mineral sand and the bioball. Using the polyacrylonitrile/biochar (PAN–BC) and polyacrylonitrile/chitosan (PAN–CTN) composite membranes, this device was made through the electrospinning and subsequently the laccase was then immobilized on PAN–BC membrane PAN–BC–LAC	El-Harbawi et al., 2010, Taheran et al., 2019
Portable Solar-Thermal Purification Device	This device is created by using polyethylenimine-grafted-corncob (PEI-g-OC) which is an agricultural biomass-derived material which incorporated a carbonized carbon dots (CCD) @wooden sponge evaporator.	Shen et al., 2021, Zhao et al., 2023
UF-membrane facilities in Azuay, Ecuador	Installed by AQUAPOT and the unit can meet the drinking water standard used by the rescue team as well as the disinfected water for medical purpose at a maximum production of 1000 L h^{-1}. It uses HF ultrafiltration (UF) membrane module with the total stands at 100 kDa cut off	Arnala et al., 2006, Barbot et al., 2009
Small Portable Water Treatment Unit	Developed using approximately 500 liter per day of the production capacity. The tubular ceramic membrane combined together with the process of anodic oxidation and were used by water treatment mobile unit and is powered by the solar power panel. It is a highly stable production with good result in the sediments, bacteria, colloidal material, and virus removal evidenced by the results from the tests performed in laboratory on various kinds of surface water and also on the wastewater treatment plant (WWTP) effluent.	Groendijk & de Vries, 2009
Portable Aqua Unit for Lifesaving (PAUL)	The "WaterBackpack," or PAUL, is a compact and lightweight (23 kg) membrane filtering device. It was created at the University of Kassel, Germany. It typically filters far more than 1,200 liters of water per day and up to 6,000 liters per day. The membrane has a roughly ten-year lifetime. Depending on the level of raw water contamination, it is advised to service or clean the filter on a regular basis every few months.	Paul, 2024

2.6 Commercial Portable Ultrafiltration Units

There are various types of commercial portable ultrafiltration devices available in the market at the moment globally and in Malaysia as well. However, details of these devices are limited as in their brochures, catalogues and website as shown in **Table 2.6**.

Table 2-6: The commercially available portable ultrafiltration devices in markets

Product							
Name	LG Puri Care	Cuckoo Grande	Panasonic UF Alkaline	Coway Neo	Sawyer	Portawell	Survivor Filter PRO
Process	UF Membrane	Nano Membrane Filter	UF Membrane	RO Membrane Filter	Micro Filtration Membrane	Ceramic Membrane	UF Membrane
Type	4-Stage Filtration	3-Stage Filtration	4 Stages of Filtration	3-Stage Filtration	Tap Filter Type	2 Stages of Filtration	Pump-Typed
Filter Capacity	2 L per Minute	Tank Capacity: 7.6 L	6000 L Capacity	Tank Capacity: 5.8 L	1900 L/Day	230 L per Hour	0.5 L per Minute
Weight	6 kg	18.5 kg	3.8 kg	18 kg	0.15 kg	4.54 kg	0.36 kg
Bacteria Removal	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The LG model has 4 stages filtration system with auto UV sterilization function (LG, 2024). It is tankless which mitigate risk of microorganism growth. The 4 stages of filtration involve Pre-Carbon-Block+ system as the first step where it removes 9 types of heavy metals (mercury, lead, iron, aluminum, copper, arsenic, cadmium, zinc and manganese) and followed by the Ultrafiltration steps where the second step is to remove the various germs and particles, the third and fourth is removal of norovirus and harmful contaminants respectively.

The Grayl Ultrapress model is a bottle type ultrafiltration device and has a filter capacity of 40 gallons. It is capable in removing the bacteria, protozoa and virus's pathogen and contaminants such as Biological, Chemical, Heavy Metals and Sediments. This model uses Mechanical, Carbon and Ceramic filtration processes.

The Portawell model uses a pump-dual filtration system and has filter capacity 40 gallons to 60 gallons per hour. It has the capability to remove bacteria, viruses, cysts and 200+ contaminants. This device uses Mechanical, Carbon and Ceramic filtration process.

Survivor Filter PRO model has the pre-filter capacity of 100,000 litre, carbon filter capacity of 2,000 litre and ultra filter capacity of 100,000 litre. It is capable to remove bacteria, protozoa and 99% of all biologicals. This device uses Carbon and Ultrafiltration process.

Platypus Gravity Water Filter model is a gravity type filtration device with filter capacity of 1500 litre. It removes bacteria, protozoa and biologicals contaminants, and uses the hollow fiber membrane process.

The Coway model with a tank capacity of 5.8 litres is able to remove particulates, volatile organic compounds (VOCs) chlorine and both organic and inorganic impurities (Coway, 2024). This device is capable to reduce viruses and bacteria by way of using electromagnetic forces and to remove materials of smell induction in order to improve the water taste and also to prevent the microorganism's growth inside the water tank.

Sawyer model is a straw type device and weights 2 oz. It has a filter capacity of 100,000 gallons and is capable to remove the bacteria and protozoa pathogen. It can also remove the biological and microplastics contaminants. It has USEPA Guide Standard certification and uses the electro adhesion plus activated carbon process.

The Lifestraw model is a gravity type device and weights 7 oz. It has filter capacity of 528 gal and is capable to remove the bacteria and protozoa pathogen. It can also remove the biologicals contaminants. It uses NSF (National Sanitation Foundation) Certifications and uses the activated carbon plus ion exchange plus microfilter process.

The Cuckoo system with a tank capacity of 7.6 litres has 6 stages of filtration systems with 3 filters for clean drinking water (Cuckoo, 2023). The first stage is to remove dust and floating matters. The second until fourth stage is to eliminate residual chlorine, Volatile Organic Compounds (VOCs) and fine particles. The fifth and sixth stage helps to filter out minute particles and various bacteria such as colon bacillus, bacillus pyocyaneus, staphylococcus aureus and Norovirus.

The Panasonic system has a 5-stage filtration system with UV sterilization lamp and MF membrane filter cartridge that thoroughly eliminates harmful substances. The UV lamp has a germicidal action which means users can enjoy safe water without having to boil it. The MF cartridge has a 12000 L long-life water purification capability. This device uses certified activated carbon which is tested and certified by the NSF International standards.

The common features of all the commercially available portable ultrafiltration devices are that they use membrane-based filtration and multistage filtration and are capable of removing bacteria. The differences noted in each device are the stages, the devices' filter capacities, and the weight.

2.7 Water Quality Standard

2.7.1 The Water Quality Index (WQI)

The WQI model is an instrument used extensively to assess the water quality. The water quality standards established locally is used in parallel with the WQI model as a mean to assess both the surface water and groundwater quality globally. The objective of the WQI is to provide a simple way to communicate and disseminate information on the water quality to the public, governments, and scientists. The WQI compressed a series of complex data on water quality into a single value, hence it is easy to comprehend and to compare among various water sources.

Apart from that, there are six water quality parameters included in this index which are pH (Potential of Hydrogen), DO (Dissolved Oxygen), BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), TSS (Total Suspended Solid) and NH3-N (Ammonia-Nitrogen) content. It is usually used by the Department of Environment (DOE) of Malaysia as a tool to ascertain the potential issues on water quality and established a guidance on the process of decisions making related to management of the water and the basis for environmental protection. **Table 2.7** shows the WQI classification as set by the DOE of Malaysia (Department of Environment, 2025).

Table 2-7: WQI Classification by the DOE of Malaysia

Parameter	Unit	Classes				
		I	II	III	IV	V
pH (Potential of Hydrogen)	-	More than 7	6 to7	5 to 6	Less than 5	More than 5
DO (Dissolved Oxygen)	Mg/L	More than 7	5 to7	3 to 5	1 to 3	Less than 1
(BOD) Biochemical Oxygen Demand	Mg/L	Less than1	1 to 3	3 to 6	6 to 12	More than 12
(COD) Chemical Oxygen Demand	Mg/L	Less than 10	10 to 25	25 to 50	50 to 100	More than100
(TSS) Total Suspended Solid	Mg/L	Less than 25	25 to 30	50 to 150	150 to 300	More than 300
(NH3-N) Ammonia Nitrogen	Mg/L	Less than 0.1	0.1 to 0.3	0.3 to 0.9	0.9 to 2.7	More than 2.7
Water Quality Index (WQI)	Percentage (%)	More than 92.7	76.5 to 92.7	51.9 to 76.5	31.0 to 51.9	Less than 31.0

2.7.2 The Standards For Drinking Water Quality

The water we drink and consume on daily basis ought to be coming from the treated source and must comply with the set of standards established for safe drinking water quality to prevent bacteria and viruses causing diseases from entering our body. In average, a healthy adult human being needs approximately 1.5 litre water on a daily basis, and as main constituent, water percentage stands at 60% of the human body. Therefore, attention and focus must be placed on the quality of water that we drink from the aspects of water sanitation and hygiene regularly. (Jéquier et al., 2009).

The World Health Organization (WHO) has provided worldwide guidelines along with the framework on the drinking water quality considering multiple aspects and parameters for safe production of drinking water. Nevertheless, it worth to note that it also depends on the countries globally that have different sources of water, different pollution types and different state and condition of the raw water. In Malaysia, the Department of Environment (DOE) is the government agency that is responsible to ensure that the public water consumed in the country is safe.

Table 2.8 below highlights the comparison of the drinking water quality index for MY (Malaysia), UK (United Kingdom), US (United States of America) and WHO (World Health Organization). Complete details of the comparison are shown in **Appendix A**.

Table 2-8: Comparison of drinking water quality index for MY, UK, US & WHO

Parameter	Drinking Water Quality Standards			
	Malaysia	**United Kingdom**	**US**	**WHO**
	Maximum Acceptable Value			
Total Coliform	0/100 millimeter	0/100 ml	0	0/100 ml
E.coli	0/100 millimeter	0/100 ml	0	Not Applicable
Turbidity	5 NTU	1 NTU	Not Applicable	5 NTU
Colour	15 TCU	Acceptable to consumers and no abnormal change	15 (colour units)	Not Applicable
pH	6.5 - 9.0	6.5 - 9.5	6.5 - 8.5	6.5 - 8
Total Suspended Solid	25 mg/l	Not Applicable	Not Applicable	Not Applicable
Dissolved Oxygen	>7 mg/l	Not Applicable	Not Applicable	Not Applicable
Ammonia	1.5 mg/l	0.5 mg/l	Not Applicable	1.5 mg/l
Chemical Oxygen Demand	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Biological Oxygen Demand	Not Applicable	Not Applicable	Not Applicable	Not Applicable

Malaysia has established drinking water quality standards in accordance to the standard suggested by Australia and WHO. The quality of the surface water can be upgraded gradually to a higher water class by using the standard values for a total of 72 characteristics in six water usage classes, in accordance to the National Water Quality Standards. Other details are also shown in the Appendices where **Appendix B** shows the drinking water parameters per class and **Appendix C** shows the water classes and its usage.

2.8 Modelling and Optimization of Various UF Systems

The mathematical model appropriate for the continuous cross-flow ultrafiltration system with numerous solutes has been developed by (Ahmad et al., 2006). Through software programming, various Artificial Neural Network modules have been developed to simulate the ultrafiltration process of aqueous BSA solutions via membranes made of poly-ether sulfone (Curcio et al., 2005).

A study by (Gaudio et al., 2023) compares several Artificial Neural Networks (ANNs) and uses genetic algorithm (GA) as the optimization approach in order to forecast and manage the permeate flux reduction in cross-flow UF systems using a step procedure. To forecast the polarization layer behaviour in a dynamic UF, two hybrid mathematical models were created and fine-tuned by (López-Murillo et al., 2021).

(Badrnezhad et al., 2014) has optimized and modelled cross-flow ultrafiltration utilizing a hybrid neural network-genetic algorithm technique. To maximize the preservation of reactive red 120 (RR 120) dye from its aqueous solutions by polymer (polyethyleneimine (PEI)) upgraded ultrafiltration (PEUF), a stochastic genetic algorithm (GA) based technique in addition to artificial neural network (ANN) was used (Dasgupta et al., 2017). Additionally, the electrodeposition process stage of the polymer-supported (NSGA-II) system are subjected to a neuro-evolutionary modelling technique (Llanos et al., 2013).

Evolutionary programming (EP) is a method for simulating evolution that iteratively produces progressively acceptable solutions in the context of a stationary or nonstationary environment and the intended fitness function. The Standard EP uses the identical four elements which are common to every evolutionary algorithms (EAs): initialization, variation, evaluation, and selection (Fogel, 2012).

A new approach called fast evolutionary programming (FEP) is used to predict nonlinear and chaotic time series by figuring out the model phases and parameters of decreased parameter bilinear (RPBL) models. Using a novel mutation operator, FEP is an evolutionary programming (EP) algorithm variation on the traditional approach. According to (Chellapilla and Rao, 1998), this novel mutation operator makes it easier for EP to break out of local minima, which leads to a noticeably faster convergence to the ideal solution. Additionally, there is DARWIN, an effective evolutionary algorithm designed to simulate the functional connection that characterizes a time series' behavior in symbolic form (Alvarez et al., 2001).

The empirical modelling of chemical process systems can also be done with evolutionary programming (Greeff & Aldrich, 1998). This study suggests using Bayesian networks in conjunction with evolutionary programming to predict consumer responses to direct marketing (Cui et al., 2006). The method for automatically designing the best fuzzy rule bases for control and modeling using evolutionary programming is presented in that work (Hwang, 1999). Evolutionary programming modifies the fuzzy rule base's parameter and structure at the same time. An extensive selection of evolutionary algorithms, including Differential Evolution, Evolutionary Programming, Genetic Algorithms, and Evolutionary Strategies have been applied by the researchers (Cheong & Lai, 2007).

In another work, the resulting Mixed Integer Non-Linear Programming (MINLP) issue was addressed by means of an evolutionary algorithm applied to the main membrane system with the boundary conditions at the membrane wall (Schmidt et al., 2012). As the result indicates, the optimal model derived from Genetic Programming (GP) and Genetic Algorithm (GA) optimization has strong generalization abilities and is capable of making precise predictions about the values of current data records. One of the examples of parameter optimization for GA is during ultrafiltration for inulin powder (Demirci et al., 2023).

Basically, most of the approaches for UF systems apply the AI-based techniques which is data extensive and time consuming in nature. For our work involving calculation of the permeate flux and TMP values, we utilize a model based on basic hydraulic fundamentals which is simpler and applies directly for our portable system. However, since these model are applicable to their specific application, the parameters have to be adapted to relate to our in-built UF system and we have applied the EP to optimize the important parameters of the model.

2.9 Summary

Water is an essential need for humans and the whole chapter describes on the global water sources, the water contamination factors, water treatment methods using membrane technologies, explanation on Ultrafiltration (UF), the two modes of UF and their respective features and comparisons. Subsequently, the availability of different portable UF is shown and the commercially available portable UF in Malaysia and global markets listed. Another section discusses on water quality standards and index computation, comparing them with the UK, the US, and WHO. Finally, modelling of portable UF systems as found in the literature is reviewed.

Basically, despite the wide variety of portable UF systems available on the market, detailed studies on their capabilities, performance and quality of water produced are not available. Basic models of the PUF systems, validated with actual data have also not been found in the open literature. Here our work focused on developing a simple, inexpensive portable UF system which can be tested in the lab on their performance while also developing simple accurate models that can simulate the actual operation of the system with experimental validation.

In the framework of a stationary or nonstationary environment and the desired fitness function, evolutionary programming (EP) is a technique for modeling evolution that iteratively generates increasingly acceptable solutions. These models are suitable for their particular use; however, the parameters must be modified to correspond with our built-in UF system, and we have utilized the EP to optimize the model's key parameters.

CHAPTER 3: METHODOLOGY

The first section of this chapter covers the system's description as in Section 3.1. Secondly, section 3.2 and 3.3 discussed the preparation of the water samples and the experimental procedures respectively. Next section 3.4 discussed on the water quality standard procedure. Finally, section 3.5 focuses on the mathematical modelling and parameter optimization aspects.

Flow chart of the methods used to meet the objectives is as below **Figure 3.1**:

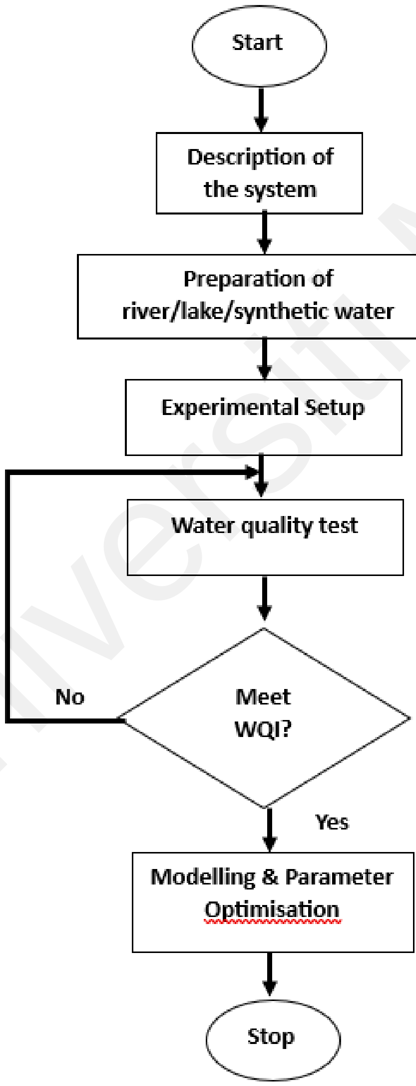


Figure 3-1: Methodology flow chart

3.1 Description of The System

Figure 3.2 show the schematic diagram for the in-built Portable UF. As shown in **Figure 3.3**, the filtration system's equipment is integrated into a transportable unit which is perfect for medium-scale operation. Pumps, UF membrane, a UV water sterilizer, and valves are all contained within the box. One pump is used for the normal filtering and the other for backwash, where the UF membrane is utilised for the filtration of the inlet water source and the valve regulates the water flow based on the mode of operation.

The pumps and valve of the portable UF unit are powered by electricity. There are two knobs that we can turn: knob 1 controls which valve will open or close, and knob 2 allows us to select the filtration or backwash by activating the appropriate pump. These knobs are situated in the front panel of the device. Others included on the front panels are the digital meters to measure pressure at the outlet backwash, pressure of inlet water, pressure of outlet water and flow through the filter. The internals of the PUF can be seen in **Figure 3.4**.

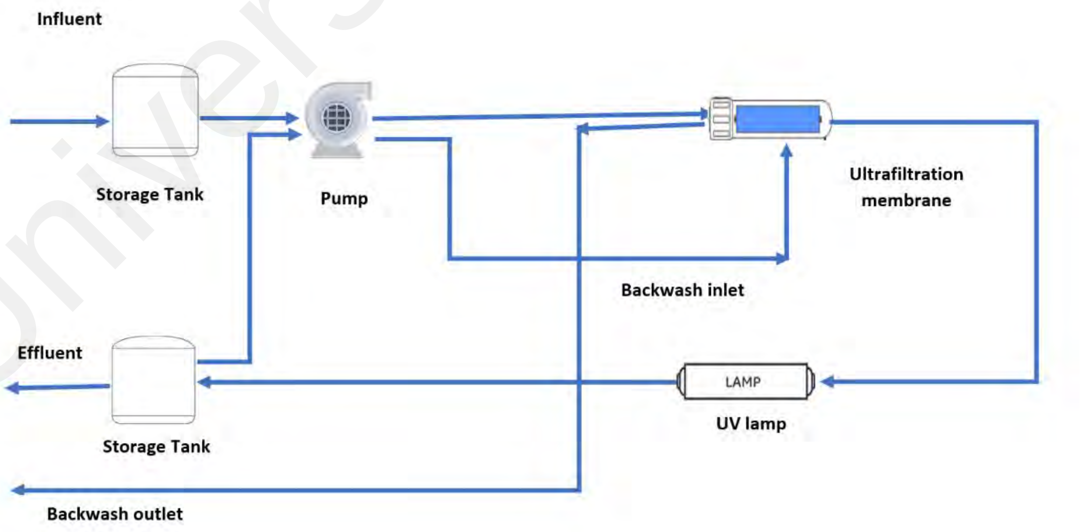


Figure 3-2: Schematic diagram for the in-built Portable UF with UV disinfection

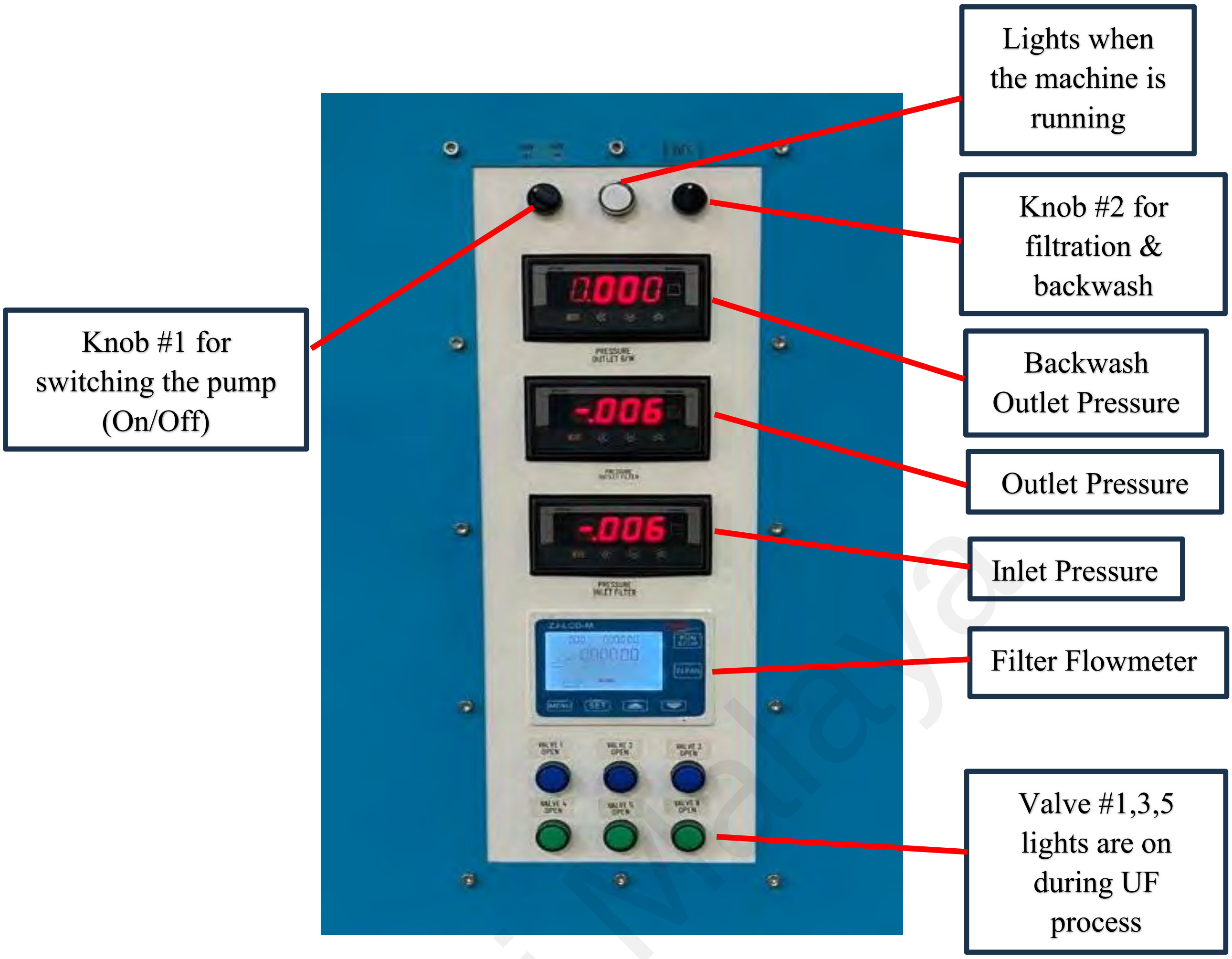


Figure 3-3: External of the Portable UF Water Filter Unit with the control panel

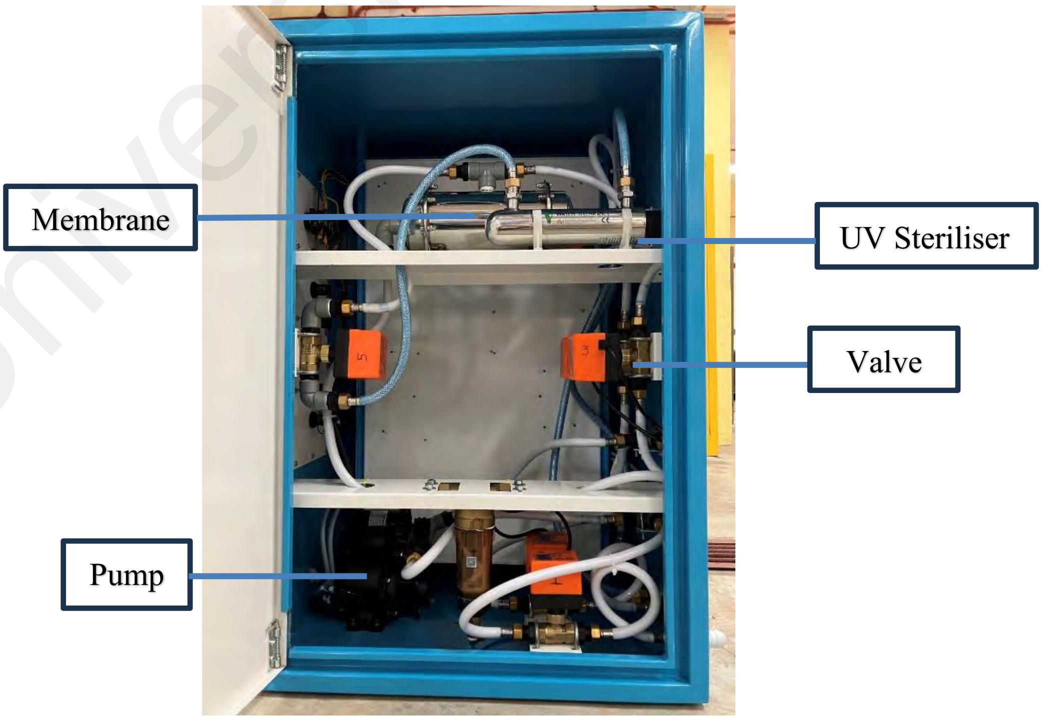


Figure 3-4: Internal of the Portable UF Water Filter Unit

3.2 Preparation of The Water Source for Filtration

The water sample used to run the experiments involving this portable UF (PUF) systems are from 3 sources. One is collected from the river within the university, i.e., Sungai Pantai, the other is collected from the university lake, i.e., Tasik Varsity. The third is the water prepared synthetically by adding soils collected from the vicinity of the lake and adding to the piped water. **Figure 3.5** shows the location of lake and river water sources used for sampling. The lake water is taken from Varsity Lake located at (30º 25’27.52”N, 101º 25’53.89”E) on 3rd May 2024 at 12.30pm and the river water is taken from Sungai Pantai on 3rd May 2024 at 1.00pm. The weather condition during when the samples taken from both location are sunny and the samples were taken three times. **Figure 3.6** shows all three samples used for the experiment.

Varsity Lake | **Sungai Pantai**

Figure 3-5: Location of Varsity Lake and Sungai Pantai

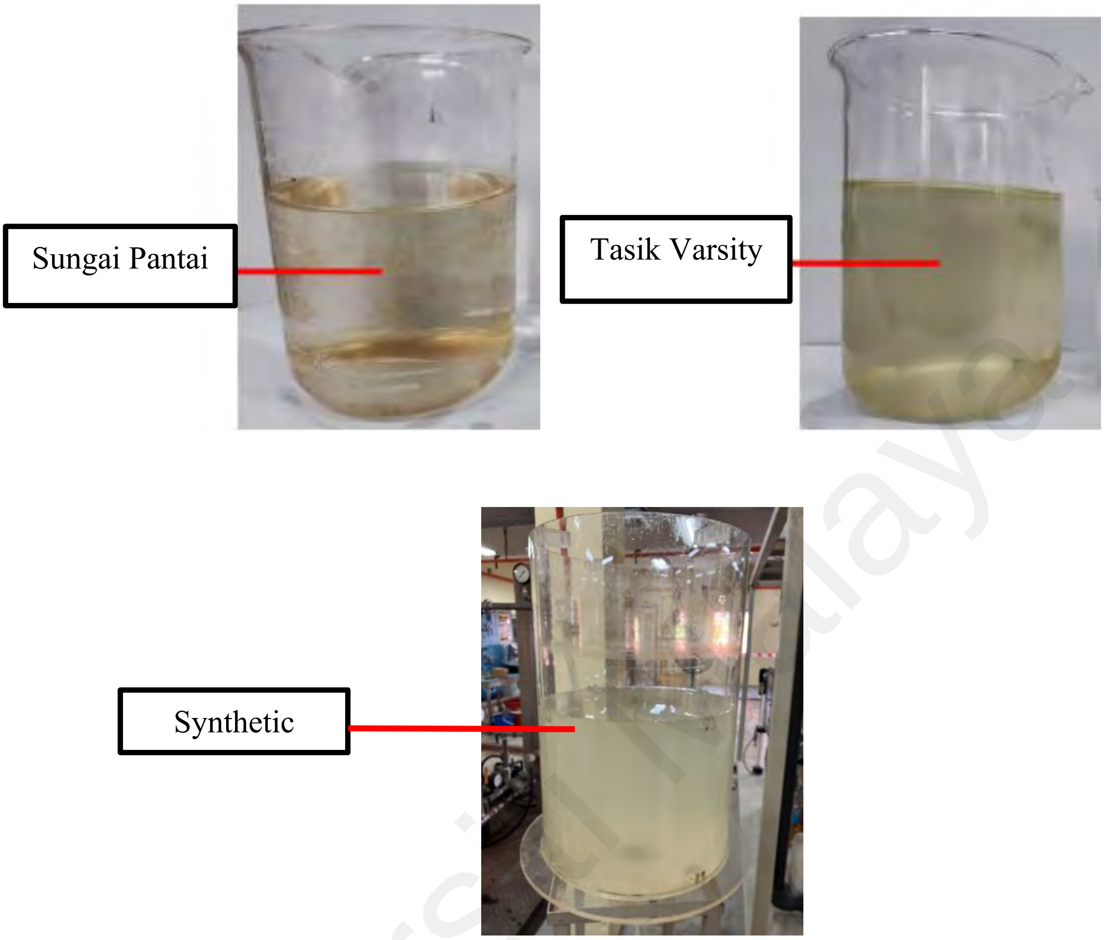


Figure 3-6: River water, lake water and synthetic water test samples

3.3 Experimental Setup and Procedure of The Portable PUF System

The experiments were carried out using the membrane module in the dead-end mode utilizing the system in a single-pass open circuit as illustrated in **Figure 3.2**. The feed tank, the pump unit, UV sterilizer and the ultrafiltration membrane system are the primary components of this system that produce drinkable water. All the general parameters of the PUF system such as material of shell are explained in **Table 3.1**. Supplier of the UF membrane is AMGO Malaysia and the manufacturer of the membrane is from South Korea.

Table 3-1: UF membrane parameters and operation conditions

Item	Description
Material of Shell	304 stainless steel (food-grade)
Intake Pressure	1 to 3 bar
Intake Temperature	5 to 45 degree Celcius
Filtration Precision	0.01 micron
Inlet / Outlet Size (Inch)	0.5 inches
Backwash Mode	Manual
Membrane Service Life	2 to 3 years
Filtration Technology	Ultrafiltration (UF)

Before the experiment begins, a test is performed by using the raw feed water on the portable system to test the electrical connection and to make sure all equipment, i.e., pump and PUF filter are functioning well. In the experiment, the water test samples were placed in the storage tank and then passed through the UF unit using the pump located in the box. The filtered water was collected in the final storage tank and this was done continuously until the experiment was done. The quality of the water obtained was determined by taking samples from the effluent storage tank and analyzed by the specific instruments.

As such, the setup of the portable device is ensured with the connection of power supply and all the connection pipes are secured and confirmed with nil leakage. The pump is initiated once the 'C' button on the control panel is pressed, post which the sample water was then pumped into the unit. The process will then cease once the 'OFF' button on the control panel is pressed. By pressing the 'B' button on the control panel, the backwashing of ultrafiltration membrane is accomplished. The system was totally drained and backwashed with clean water for several minutes following each run. For the filtration experiments to be considered reasonably reproducible, each one was run at least twice.

3.4 Water Quality Test

Using a variety of water test kits, we conducted our experiments to check the quality of the water based on major parameters, including turbidity, color, TSS, pH, DO, ammonia, COD, BOD, and the presence of bacteria (total coliform and e-coli). Subsequently, the WQI is computed to ascertain the treated water's category concerning its appropriateness for human ingestion. The purpose of water quality assessment is to ascertain whether the filtered water (effluent) produced by the portable filter unit satisfies the standards and requirement for drinking water guidelines established by WHO and is safe to be consumed. The quality test and calculation done for the influent and effluent water are given in the next few sections.

3.4.1 Turbidity

Turbidity is a vital standard parameter for the water's light-transmitting properties. The turbidity parameter is measured in order to determine the water discharge quality in terms of residual and colloidal suspended particles. To determine the portable unit's capacity to minimize turbidity in raw water from multiple sources, a water sample is measured prior to and subsequent to filtration. The water that has been collected before and after the UF system was then transferred to a 10 ml bottle sample and tested for turbidity using the TUB-430 EZ DO Turbidity Meter (**Figure 3.7**). The unit calculates the average reading, which is then stored for data analysis.

Figure 3-7: TUB-430 EZ DO Turbidity Meter

3.4.2 Colour

To monitor the appearance of water for drinking purpose due to aesthetic reasons, colour is generally used. By using the colorimeter, the colour of water can be measured in the true colour unit (TCU). The HACH DR/890 colorimeter (**Figure 3.8**) instrument measures the influent and the effluent water that was extracted from the UF system and transferred to a 10ml sample bottle. The instrument's program number is set to number 19, to enable the instrument to measure the colour in Pt Co unit.

Figure 3-8: DR/890 colorimeter

3.4.3 Water Quality Index (WQI)

The Water Quality Index (WQI) attributes quality value to a collection of quantitative factors taken together. The final index is typically made up of sub-index values that are allocated to every pre-identified parameter by comparing its measurement with a rating curve that is specific to that parameter. These values may also be weighted. In order to ascertain the raw water samples' class of water quality conforming to the national water quality standards, water quality characteristics tests are typically performed on them (Carolyn et al., 2020). The WQI (Khalil et al., 2011) explains the biological, chemical, and physical properties of water in relation to the intended uses as well as list of standards. The WQI technique summarizes the entire data from each parameter and offers it as a summative, simply understandable number for regular customers. This number is then further categorized as follows.

WQI (1) = (0.22 * SIDO) + (0.16 * SIBOD) + (0.16 * SICOD) + (0.15 * SIAN) + (0.16 * SISS) + (0.12 * SIpH) (1)

Where SI stands for the Subindex for each parameter, and (*) denotes multiplication. The multipliers are the value concerning the respective parameters with a total value of where,

SIDO Subindex for Dissolved Oxygen (22%)

SIBOD Subindex for Biochemical Oxygen Demand (19%)

SICOD Subindex for Chemical Oxygen Demand (16%)

SIAN Subindex for Ammonia Nitrogen (15%)

SISS Subindex for Suspended Solids (16%)

SIpH Subindex for pH (12%)

When the class of classification falls between 60 and 80, the water is classified as slightly contaminated by the DOE Water Quality Index Classification; when the value falls between 0 and 59, the water is classified as polluted. The water is deemed clean when the value falls between 81 and 100 (DOE, 2024).

3.4.3.1 Total Suspended Solid (TSS)

Precise measurement of TSS is one of the most crucial metrics for maintaining the health of the aquatic ecosystem. In water, TSS are made up of both organic and in organic particles. The amount of TSS in the water will also have an impact on its turbidity. Program Number 94 is used to measure the TSS in the sample using the HACH DR/890 colorimeter (**Figure 3.8**). For the calibration procedure, the sample cell was first placed into the cell holder after being filled with 10 milliliters of distilled water. To get 0 mg/L as a reference point, the colorimeter cap was placed over the sample cell. The sample was subsequently moved to a different sample cell and put into the cell holder. To obtain the average TSS value, the tests were repeated three times.

3.4.3.2 Potential Hydrogen (pH)

Potential hydrogen, or pH, is a unit of measurement for the concentration and activity of hydrogen ions in a substance. Higher pH values (or more basic or alkaline) are associated with fewer hydrogen ions, whereas lower pH values (or more acidic) are associated with more hydrogen ions. It is crucial for the current study to look into how pH affects portable ultrafiltration.

In order to determine whether the portable filtration machine was successful in removing particle matter from the water samples and to make sure the pH was within a reasonable range; the water's pH was measured both before and after filtration. The pH values of various water sources are tested in the lab before and after the PUF using an EZDO pH Meter (**Figure 3.9**).

Figure 3-9: EZDO pH Meter

3.4.3.3 Dissolved Oxygen (DO)

DO refers to the level of free, non-compound oxygen that is present in water or other liquids. Thus, DO is an important consideration when assessing the quality of water because it has an impact on the aquatic life. It is also crucial to investigate the DO dynamics since they are impacted by a variety of environmental elements in real-time DO content prediction (Yin et al., 2021). The amount of oxygen dissolved in water is referred to as "dissolved oxygen" (DO), and it is expressed in milligrams per liter (mg/L) or parts per million (PPM). The amount of dissolved oxygen can be found by utilizing a dissolved oxygen meter and sensor. Where the YSI Pro20 portable DO meter and the 50 ml sample bottle are used to collect samples of the influent and effluent. (**Figure 3.10**).

Figure 3-10: YSI Pro20 portable DO meter

The YSI Pro20 is a reliable and easy-to-use tool for measuring dissolved oxygen. A few drops of electrolyte are added to the probe membrane to calibrate the device. After immersing the probe in the sample, the amount of oxygen that diffuses into the probe (sensor) across the permeable membrane is measured to determine the DO measurement in milligrams per liter. When the readings are stabilized, the DO and outside temperature are noted.

3.4.3.4 Biochemical Oxygen Demand (BOD)

The amount of oxygen used by bacteria and other microorganisms during the aerobic (oxygen-containing) decomposition of organic matter at a given temperature is known as biochemical oxygen demand, or BOD. The sample was kept for five days at 20^0C in a dark incubator after the initial Dissolved Oxygen (DO) measurement. The portable DO was then utilized once more to measure the final DO concentration after a period of five days. The BOD reading was then obtained by deducting the final DO reading from the original DO reading.

3.4.3.5 Chemical Oxygen Demand (COD)

In surface water (lakes, rivers, etc.) and wastewater, the amount of oxidizable contaminants and organics that can be consumed by processes in a measured solution is indicated by a measurement called chemical oxygen demand, or COD. The COD is generally stated as the mass of oxygen consumed over the volume of solution, or milligrams per litre (mg/L) in SI units.

Using the instrument called ‘Multiparameter Photometer HI 83099’ (**Figure 3.11**), the COD of the collected water can be calculated. Before collecting the COD reading, the ‘COD Medium Range Reagents Vials - HI93754B-25’ (**Figure 3.12**) is used to react with the test samples. The COD vials are then digested for two hours at 150°C in the COD reactor (**Figure 3.13**). After removing the vials, the temperature is allowed to decrease for 20 minutes. The COD reading can be obtained by inserting the vial chamber into the photometer. The sample water's reading is taken and recorded for data analysis.

Figure 3-11: Multiparameter Photometer HI 83099

Figure 3-12: COD Medium Range Reagents Vials – HI93754B-25

Figure 3-13: COD Reactor

3.4.3.6 Ammonia Nitrogen Content

Ammonia nitrogen is a precursor for the synthesis of nucleotides and amino acids and also necessary for many biological activities. It is created in soil by bacterial activities and is a byproduct of the nitrogen cycle in the environment. The ammonia nitrogen content is determined with the Multiparameter Photometer HI 83099 (**Figure 3.11**).

Ten millilitres of the unreacted sample were put into a cuvette as well as the holder. Next, the Multiparameter Photometer HI 83099 instrument reading was then zeroed as a blank sample and the lid was closed. Subsequently the cuvette was removed and four drops of the first reagent HI 93715A-0 (**Figure 3.14**) were added followed by four drops of the second reagent HI 93715B-0 (**Figure 3.14**). After replacing the cap, the solution is mixed. Once the cuvette has been reinserted into the photometer, a timer of three minutes is set and the meter displayed the ammonia nitrogen concentration in mg/L.

Figure 3-14: Ammonia Reagents – HI 93715A-0 and HI 93715B-0

3.4.4 Presence Of Bacteria

The ultrafiltration membrane is used to filter out the germs in water since their presence poses a health risk to humans. Because UF function as complete physical barriers, they are appropriate for clarifying and disinfection. As demonstrated in **Figure 3.15**, tests were carried out to ascertain the presence of bacteria using 3M Total Coliform (CC) and E-Coli (EC) Petri films, respectively, before and after the filtration procedure.

Figure 3-15: 3M Total Coliform Petri (CC) & *E-Coli* (EC)

The test is conducted by placing the 3M Total Coliform and E-Coli Petri film on a level surface. Top film was then lifted, and a pipette was positioned perpendicular to the inoculation area and subsequently 1 milliliter of sample or diluted sample is dispensed on the center of the bottom film. After that, the sample was covered with roll-top film to make sure it stayed in place and avoid trapping air bubbles. Extra caution is essential to prevent the top film from being dropped. After that, the inoculum was covered and the 3M Petrifilm Spreader was placed on top of the film, flat side down. Before the gel formed, pressure was gently applied to the 3M Petrifilm Spreader inside the circular area to make sure the inoculum was distributed evenly. After that, the spreader was raised without swaying or slipping.

All told, it takes one minute of waiting for the gel to form. After that, the plates were incubated with the clear side facing up and in stacks of up to 20 plates in an incubator for 24 hours at a temperature of 35°C for total coliform detection, and 48 hours for E. coli detection of the samples in the stacks. The colony of bacteria is then counted based on the number of colonies that appeared on the total coliform Petri film after 24 hours and the E-coli Petri film after 48 hours. One colony is indicated by a dot and each dot on the petri film must be counted. The existence of the dots provides evidence of the presence of total coliform bacteria and E-coli bacteria in the water samples. The presence of total coliforms in the water appears as red colonies whereas the presence of E. coli appears as blue colonies.

3.5 Modelling and Parameter Estimation

3.5.1 Modelling For Permeate Flux and TMP During Filtration

In this study, the PUF model involves the 800L per hour membrane capacity applicable from 2 to 3 bars as per specification. The PUF membrane model is made of hollow fibre UF membrane with filtration precision of 0.01-micron, intake temperature of 5 to 45 degree Celsius and inlet/outlet size of 0.5 inches as summarised in **Table 3.1** with the principle mode of purification using internal pressure (Amgo, 2014).

Concentration polarization and membrane fouling cause the transmembrane pressure (TMP) to rise under constant flux ultrafiltration. Darcy's Law can be used to determine the hydraulic reversible resistance and irreversible resistance based on the TMP and flow data (Meng et al., 2019). The model below, which is a modified version of the osmotic pressure-resistance model (Kanani, et al., 2007), can be used to explain how TMP increases over time:

$$\Delta P = \Delta\pi + J_v\,(R_m^0 + R_m^* + \alpha t) \qquad (2)$$

Where;

ΔP = Transmembrane pressure (kPa)

$\Delta\pi$ = Osmotic pressure (kPa)

J_v = Volumetric permeate flux (m/s)

R_m^0 = Membrane hydraulic resistance (kPa s/m)

R_m^* = Initial rapid fouling constant (kPa s/m)

α = Fouling rate constant (kPa/m)

t = Time

Here R_m^0 is dependent on the membrane-foulant system, whereas R_m^* is a membrane attribute. The present model considers such a process as composed of several short constant flux phases in an attempt to explain the variation in the permeate flow during constant pressure ultrafiltration.

This method is justified by the fact that the attenuating character of the permeate flux decline occurs in a process that is under constant pressure, meaning that the rate at which permeate flux decreases is proportional to the decrease in permeate flux magnitude. A previous article (Ghosh, 2002) used constant flux studies to experimentally demonstrate that the rate constant for membrane fouling (α) and the osmotic pressure ($\Delta\pi$) were strong factors affecting the permeate flux J_v, both increasing with an increase in flux.

The osmotic pressure and fouling rate constants for a specific membrane–foulant system were determined during a series of constant flux tests. The data from the constant flux tests is then used to forecast the decline in permeate flux over time for the identical membrane–foulant system operating in the constant pressure mode. The starting flux in constant pressure ultrafiltration is assumed in the suggested model to be equal to the flow of pure water (or buffer) of a new membrane at the operating pressure (Kanani, 2007).

The system considered the interaction of the three main elements: osmotic pressure (resulting from concentration polarization), resistance caused by membrane fouling, and permeate flux. It takes some time for the foulant's concentration polarization layer to form. The osmotic pressure model can be used to express the permeate flux:

$$J_v = \frac{\Delta P - \Delta\pi}{R_m} \tag{3}$$

Where R_m = Total membrane resistance (kPa s/m)

R_m can be expressed as the sum of R_m^0 (the resistance of the unfouled membrane) and R_f changes with time due to the deposition and adsorption of foulant. R_f in constant flux ultrafiltration is expressed as (Ghosh, 2002)

$$R_f = R_m^* + \alpha t \tag{4}$$

Where;

$\alpha = m/J_v$

R_f = Fouling resistance (kPa s/m)

It was found that R_m^* was independent of the flux while ***m*** depended on the permeate flux. The current approach is based on transposing Eq. (2) to the form shown below which is proposed for modelling permeate flux changes under constant pressure ultrafiltration.

$$J_{v,i} = \frac{\Delta P - \Delta\pi_{i-1}}{R_{mi-1} + ((R_m^*\,\Delta t)/t_R) + ((m_{i-1}\,\Delta t)/J_{v,i-1})} \tag{5}$$

Where;

t_R = Duration of initial rapid fouling phase (s)

Δt = Small time increment (s)

m = Slope of the linear portion of TMP-time profile in constant flux ultrafiltration (kPa/s)

The cumulative resistance at time $(ti - 1)$ is represented as R_{mi-1}. R_m^* is assumed to have a linear distribution during the time period, which corresponds to the first fast fouling phase's duration. This is in line with the conclusion that was mentioned (Ghosh, 2002). Here, $(mi - 1)$ is the slope of linear region of TMP–time profile in constant flux ultrafiltration experiment at flux $J_{v,i-1.}$ while Δt is the time step of the ultrafiltration process during which the permeate flux is assumed to be constant.

Eq. (5) is used to calculate the permeate flux until t = t_R, after which the following equation is used:

$$J_{v,i} = \frac{\Delta P - \Delta\pi_{i-1}}{R_{m_{i-1}} + ((m_{i-1}\,\Delta t)/J_{v,i-1})} \tag{6}$$

Where;

$\Delta\pi_{i-1}$ = Osmotic pressure at time t_{i-1} (kPa)

R_{mi-1} = Total membrane resistance at time t_{i-1} (kPa s/m)

m_{i-1} = Slope of linear region at time t_{i-1} (kPa/s)

$J_{v,i-1}$ = Flux at time t_{i-1} (m/s)

Because of the initial rapid fouling, the resistance rose more quickly in the first few minutes of ultrafiltration. Following this, the rate of rise in fouling resistance decreased over time, making the growth more gradual. This can be understood in terms of the flux-dependent fouling rate as mentioned by (Ghosh, 2002), i.e., that fouling rate falls as permeate flux falls. **Table 3.2** summarizes all the equations used to obtain the TMP and the flux of the portable ultrafiltration system.

Table 3-2: Model Equations

No.	Equation	Description	Reference
2	$\Delta P = \Delta\pi + J_v\,(R_m^0 + R_m^* + \alpha t)$	To measure the transmembrane pressure (kPa)	Kanani, 2007
3	$J_v = \dfrac{\Delta P - \Delta\pi}{R_m}$	To measure the volumetric, permeate flux (m/s)	Ghosh, 2002
4	$R_f = R_m^* + \alpha t$	To measure the fouling resistance (kPa s/m)	Kanani, 2007
5	$J_{v,i} = \dfrac{\Delta P - \Delta\pi_{i-1}}{R_{mi-1+}\,((R_m^*\,\Delta t)/t_R) + ((m_{i-1}\,\Delta t)/J_{v,i-1})}$	To measure the permeate flux decline in constant pressure UF	Kanani, 2007
6	$J_{v,i} = \dfrac{\Delta P - \Delta\pi_{i-1}}{R_{m_{i-1}} + ((m_{i-1}\,\Delta t)/J_{v,i-1})}$	To measure the permeate flux decline in constant pressure UF	Kanani, 2007

In this work, the model equations in **Table 3.2** were solved simultaneously to predict the TMP and the permeate flux.

3.5.2 Parameter Estimation Using Evolutionary Programming

The parameters used in these model equations is based on the nominal values as given in the literature (Kanani et al., 2007). However, the UF system in the literature is slightly different in terms of its properties and characteristics from the portable system in our study. In our study, the parameter concerned are membrane hydraulic resistance, initial rapid fouling constant, mass transfer coefficient and foulant bulk concentration. Here the parameters need to be adapted to our own system which is done by the use of evolutionary programming approach as described next.

Evolutionary computation approaches involve various kinds of algorithms called evolutionary-based algorithms that is inspired by biological evolution in nature (Demirci et al., 2023).

EP based on the global path planning optimization is utilised in this work. The EP with flexibility in the solution representation is an extension of the GA, as suggested by Fogel (Fogel, 1999). In EP, only the evolution process is carried out through the use of mutation operators; there is no crossover operator. Optimal behaviour is discovered via robust evolutionary programming even during the changing environment. Starting with random strategies, evolution on its own brings about appropriate techniques for solving the current problem (Fogel, 1991)

Figure 3.16 shows the Evolutionary Programming flowchart is used to optimize the parameter in our model. First, we did the initialization of the four important parameters which are *Rm0 (*membrane hydraulic resistance (kPa s/m)), *Rmx (*initial rapid fouling constant (kPa s/m)), *k (*mass transfer coefficient (m/s)) and particle *4 is Cb (*foulant bulk concentration (kg/m^3).

Mutation serves as the primary variation operator, as individuals within the population—specifically, the parameter sets in this case—are regarded as belonging to a certain species rather than the same species. Offspring are produced through a (μ + μ) survivor selection process. In this strategy, μ offspring are generated from μ parents. Subsequently, the best μ sets are selected from the combined pool of μ parents and μ children to form the next generation of the relevant variables.

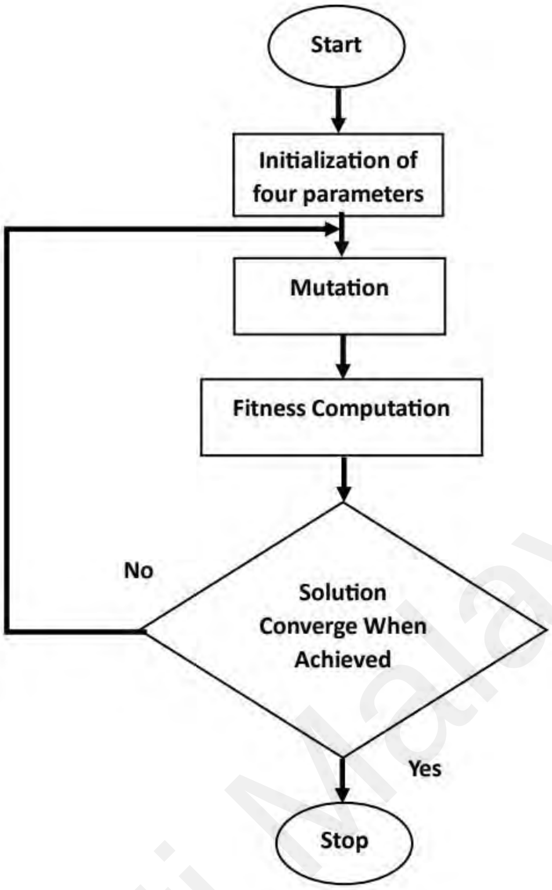


Figure 3-16: Evolutionary Programming flowchart

There are in total 5 sets of programming to identify the particle. The first set is known as 'First Stage'. We need to define the parameter as the first step in this stage. The parameters to be optimized are known as particles in which we have in total 4 particles in this study as shown in **Table 3.3** below:

Table 3-3: Particles in the First Stage of Evolutionary Programming

Particles	**Description**
Particle 1	*Rm0 (*membrane hydraulic resistance (kPa s/m))
Particle 2	*Rmx (*initial rapid fouling constant (kPa s/m))
Particle 3	*k (*mass transfer coefficient (m/s))
Particle 4	*Cb (*foulant bulk concentration (kg/m^3))

For TMP, it is fixed at 105 kPa and the time step, deltaT is fixed at 360. The next step is Initialization in which five formulas are established. The formulas are to calculate the value for Jv0, m0, alpha0, Cw0 and DeltaPi0. In the Subsequent step we need to start the Initial Program to calculate t(i) and Rm(i) for the i value to be equivalent to 1. In the Main Program step, we are calculate the value for t(j) and Rm(j) to ascertain the value of j from the range of 2 until 25. The second set of the programming is known as the 'Main Body'. In this stage we execute the Initialization, where we are defining the data value from 'ExpData.xlsx' file i.e. the data derived from the experiment. We perform the programming for particles no. 1 until 200, and these 200 particles will go through the programming 'First Stage'. Next, we will calculate the absolute data error for (data-Jv). The sum of errors will be multiplied by 10000 due to its small value. For each loop, we will clear the flux (J_v), slope (*m*), foulant wall concentration *Cw*, rate constant x time (αt). Post which, the third set known as 'EP' is executed.

During this Initialization, the total number of particles are 200, the value of iteration maximum is 100000 and B is 0.005. For each of the 4 particles the problem-specific variables is set. With respect to Rm0, the problem that needs to be optimized has one parameter, with lower and upper bounds of 100000 and 500000, respectively. With respect to the Rmx, the problem that needs to be optimized has also one parameter, with lower and upper bounds of 490000 and 500000, respectively. The number of parameters in the issue to be optimized for the k is 1, its upper and lower limits are set at 0.5*10^-5 and 1*10^-5, respectively. In the case of the Cb, the problem to be optimized has also one parameter, with an upper bound of one and lower bounds of 0.5 for the parameters.

For Set 'EP', the value *xy* was calculated from value 2 until the iteration reaches its maximum. We need to define the particles' maximum and minimum, the objective function's maximum and minimum post which we need to mutate Particle 1, Particle 2, Particle 3 and Particle 4 to select the best value, and subsequently mutate the updated particles and perform the (Repeated Stage) set. Eventually we will sort and select the best particle and finally we validate if Objective Function achieved its target. The fifth stage is known as 'Repeated Stage' where we repeat the programming of the first stage but using the new mutated particles. The simulation ends when all the 4 particles (membrane hydraulic resistance, initial rapid fouling constant, mass transfer coefficient and foulant bulk concentration) converged i.e when the sum of error of the response variable is below the set criteria. The MATLAB Program for Ultrafiltration Parameter Optimization is shown in **Appendix D**.

3.6 Summary

This chapter begins with the description of the UF portable system and followed by the functions description the UF device (internal and external). Subsequently, the setup and procedure for conducting the experiments are explained and how the water quality test procedures are performed. The test devices used, and the standard procedures involved measuring the water characteristics are described. The methods of calculating the WQI, and the details of the mathematical modelling for the flux and TMP calculation is shown. Finally, the parameters estimation for four specific parameters using Evolutionary Programming is described in detail. To achieve the objectives, the experiment was conducted to validate the model with the new improvised parameter using the Evolutionary Programming (EP) approach and comparison with the nominal parameter values are also shown.

CHAPTER 4: RESULTS AND DISCUSSION

In this chapter, the results from the water quality tests are discussed for the river water, lake water and synthetic water, namely turbidity, colour, presence of bacteria, Biochemical Oxygen Demand (BOD), pH, Dissolved Oxygen (DO), Total Suspended Solid (TSS), Chemical Oxygen Demand (COD), and Ammonia Nitrogen content. The data obtained from these experiments are analyzed and discussed in this chapter.

The calculation of the WQI is then discussed in Section 4.3. The simulation results are discussed under Section 4.4 which include the change of flux and transmembrane pressure (TMP) with time together with the experimental results. In the same section, experiment to validate the model with the new improvised parameter using the Evolutionary Programming (EP) approach and comparison with the nominal parameter values are also shown.

4.1 Synthetic Water Test Result In The Lab

The water sample to perform the tests are taken from the Varsity Lake (Tasik Varsity) and river water (Sungai Pantai) located at the university campus. The samples were taken on 3rd May 2024 and named River Influent, River Effluent, Lake Influent, Lake Effluent, Synthetic Influent and Synthetic Effluent. The turbidity of the lake water and river water are measured to be at 16.5 NTU and 24.4 NTU, respectively. However, due to the difficulties in getting enough quantity of the lake and river water especially to run the flux and TMP results continuously, we have prepared synthetic water as well. The other challenges faced are the logistic issue to transport more than 500 liter of river water for each experiment and the safety issue in extracting the water including the lack of basic water safety and swimming techniques. The synthetic water was prepared by mixing soil from the varsity lake water and manipulating the soil amount in 60 L of tap water to obtain various turbidity values. Soil near the Varsity Lake was taken for three times. **Table 4.1** shows the relationship result between the soil concentration and the turbidity of synthetic water obtained. The turbidity of the prepared synthetic water turbidity increases proportionately as the soil concentration increases.

Table 4-1: Synthetic water test result in the lab

Soil weight in 60 liter water (g)	Concentration (g/L)	Turbidity (NTU)
10	0.167	17.22
15	0.250	25.30
20	0.333	35.60
30	0.500	51.30

We have chosen the synthetic water with turbidity of about 25 NTU in all the future experiments since it is close to the turbidity of the river water, i.e., Sungai Pantai which is 24.4 NTU. During the experiment for the determination of flux and TMP, this is the water used to top up the river water when it is finished during the continuous experimental run. **Figure 4.1** shows the water appearance after treatment.

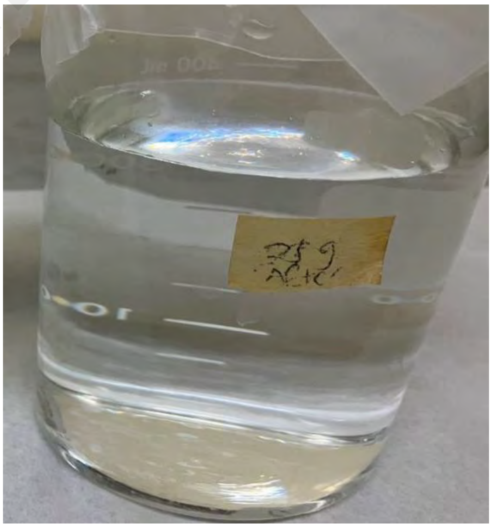


Figure 4-1: Water appearance after treatment

4.2 Water Quality Test

4.2.1 Turbidity

The cloudiness of water caused by particles, such as bacteria, chemical precipitates, and suspended solids, is known as turbidity. **Figure 4.2** shows the efficiency of the PUF in removing particle matter as well as reducing the turbidity of the three samples of water. In analyzing the quality, the turbidity of the water is one of the most vital factors as it shows the total amount of suspended material impacting the water quality.

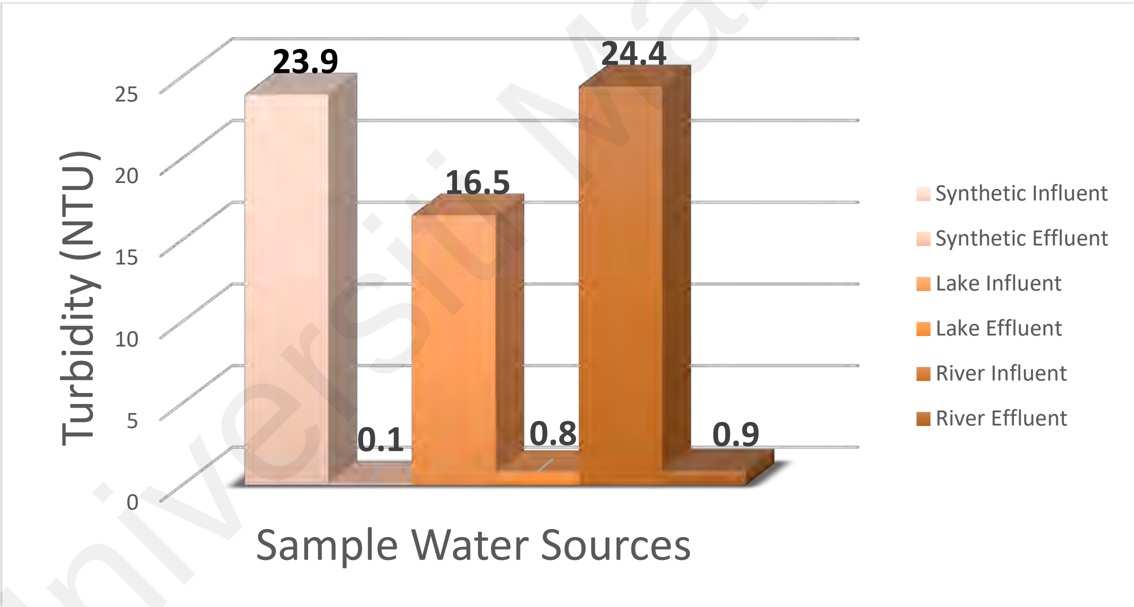


Figure 4-2: Turbidity data for lake, river and synthetic water

As shown in **Figure 4.2**, the water turbidity decreases significantly after going through the membrane. Based on the result of the experiment, the filtered water turbidity is close to 0 NTU and this is evidence that the turbidity is improved through the portable ultrafiltration membrane.

There are mechanisms contributing to the significant reduction in the turbidity reading which are the membrane structure where there are many materials such as cellulose acetate, ceramic, and polyether sulfone, are used to make ultrafiltration membranes in which membranes have pores that let water and other tiny solutes flow through while holding onto bigger particles like bacteria, colloids, and suspended solids. Another mechanism is pressure-driven process where the feed water forced through the membrane during ultrafiltration's operation due to pressure. Larger particles are held on the feed side while the water is forced across the membrane by the pressure differential. Separation mechanism is another mechanism where size exclusion, in which particles bigger than the membrane pore size are prevented from passing through, is the primary method of separation. Furthermore, because the membrane surface may reject or attract charged particles, electrostatic interactions and adsorption may also be involved. Also, during turbidity removal, when water is successfully clarified as it flows over the ultrafiltration membrane, which traps suspended solids that cause turbidity. As a result, the water quality improves and the turbidity levels decrease. Under cleaning and maintenance mechanism, reduced efficiency might result from membranes becoming clogged with residual particles over time. Maintaining membrane function and extending its lifespan requires routine cleaning with chemical agents or backwashing.

The turbidity of lake water, river water and synthetic water in the influent to the unit (0.25 g/L) are 16.5 NTU, 24.4 NTU and 23.9 NTU respectively. The turbidity of the sampled lake, river and synthetic water was reduced by 95 %, 96% and 99 % using the PUF with an effluent turbidity of 0.8 NTU, 0.9 NTU, and 0.1 NTU respectively. Although initially turbidity levels was high the filtration process was highly effective to drop the values below 1 NTU. This indicates the ability of the portable UF device to remove these particles effectively and improve the overall water quality. Hence, the normal potential water contaminants risk to human health can be significantly reduced by the portable UF as well as the ability of the device to produce water within the drinking water standards.

4.2.2 Colour Rejection

Colour is formed by the impurities in the water which is directly related to the water turbidity. DR/890 Colorimeter using PGRM 19 (Program 19) is a tool used to measure the water's colour, of which the measurement unit is true colour unit (TCU). Based on the experimental results, the colour of the filtered water has been reduced and this shows that the portable ultrafiltration membrane rejects the colour significantly as per the MOH drinking water specification, and guidelines which has to be below than 15 TCU. The result of the experiment for all 3 water samples is shown in **Figure 4.3** as below:

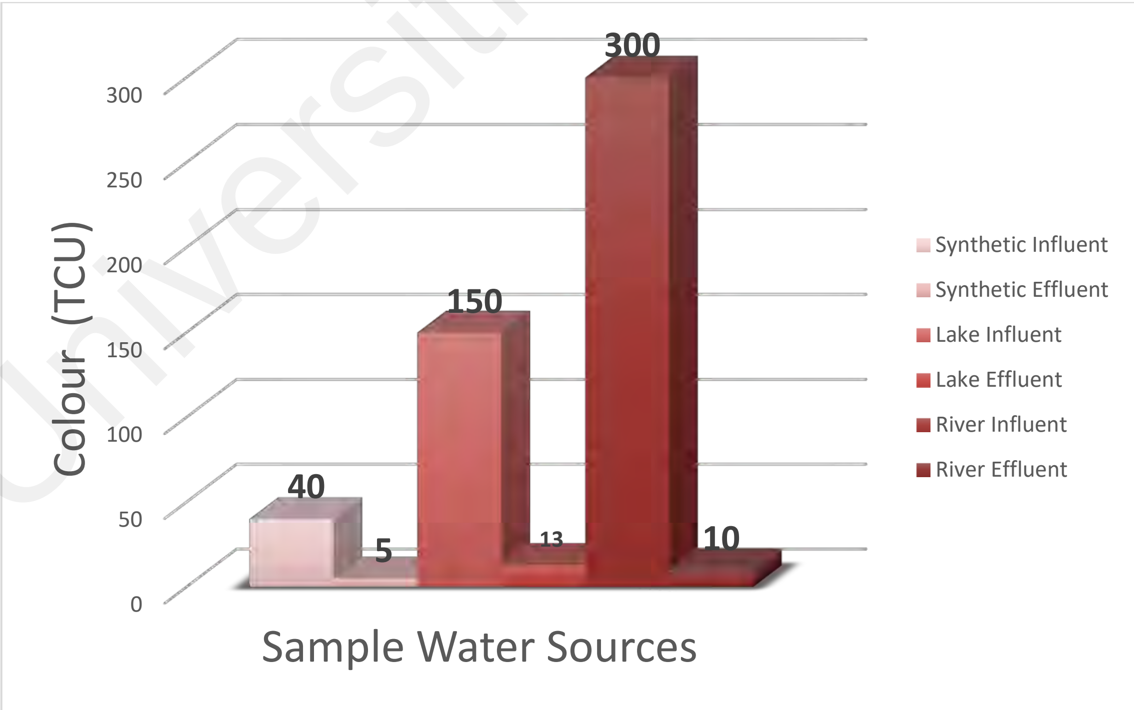


Figure 4-3: Colour Analysis for Influent and Effluent Stream

From **Figure 4.3**, the colour of the lake, river and synthetic water incoming into the UF system are (150, 300 and 40) TCU respectively. According to the Water Quality Standards (WQS), the drinking water color level is to be lesser than 15 TCU. The PUF device is able to reduce the colour of the effluent from the UF system from the different types of water by (92, 97 and 87) % respectively by reducing the colour of the effluent stream to (13, 10 and 5) TCU correspondingly. Although with the high inlet colour levels, the filtration process proves to be effective in reducing the colour content. This shows the capability of the UF to remove suspended matters effectively such as the natural occurrence of the organic materials which is a factor that contributes to the water colouration as well as its ability to achieve water with drinking quality.

4.2.3 Dissolved Oxygen (DO)

The first parameter in calculating the Water Quality Index is DO which refers to the amount of oxygen present in water allowing for aquatic organisms to respire, which contributes to 22 percent of the total WQI value. In addition to acting as an indication of pollution and nutrient enrichment, DO has a direct impact on the wellbeing of aquatic ecosystems. The river, lake, and synthetic water samples had DO values of 6.9 miligram/liter, 7.4 miligram/liter, and 7.1 miligram/liter prior to passing through the UF system test, respectively. These values are indicative of healthy water ecosystems.

Based on the experiment results shown in **Figure 4.4**, the portable UF device is able to increase the Dissolved Oxygen of river, lake and synthetic water by (4, 3 and 5) % correspondingly to produce higher DO solution of 7.2 mg/L, 7.6 mg/L and 7.4 mg/L respectively. The result also shows that all the effluent meets the DO requirements for drinking water which is more than 7 mg/L as set in the DOE WQI Class I criteria.

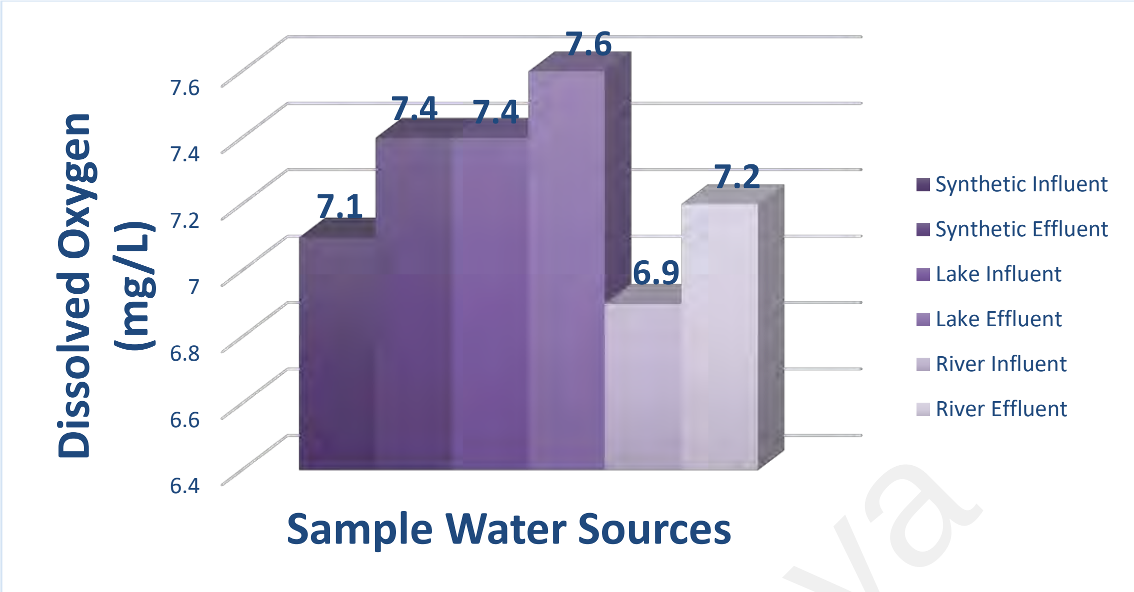


Figure 4-4: Dissolved Oxygen Data for Influent and Effluent Stream

4.2.4 Biochemical Oxygen Demand (BOD)

Five days into the incubation period, the DO is measured once more to determine the biochemical oxygen demand (BOD), which accounts for 19% of the total WQI value. The quantity of oxygen required by microorganisms to break down waste is measured by the BOD. When there is a lot of organic waste in the water, the need for oxygen increases because the bacteria will decompose as a result. The low reading of BOD is due to the sample having low organic matter in which the amount of oxygen that bacteria use to break down organic material is measured by BOD. The BOD will naturally be low if there is minimal organic matter. Another reason is due to insufficient microorganisms in the sample as the decomposition will be slower.

In conclusion, elevated BOD indicates extremely contaminated, low-quality water. The original BOD of the river water, lake water, and synthetic water samples were, correspondingly, 1.0 mg/L, 1.4 mg/L, and 1.3 mg/L before the filtration as shown in **Figure 4.5**. According to the experiment's findings, the portable UF device further reduce the BOD of lake, synthetic, and river water by 14%, 58%, and 61%, respectively. This results in reduced BOD solutions of 0.9 mg/L, 0.6 mg/L, and 0.5 mg/L. Subsequently, it is determined that the BOD of all effluents is less than 1 mg/L, which is the minimum BOD criterion for drinking water as specified in the DOE's WQI Class I water classification.

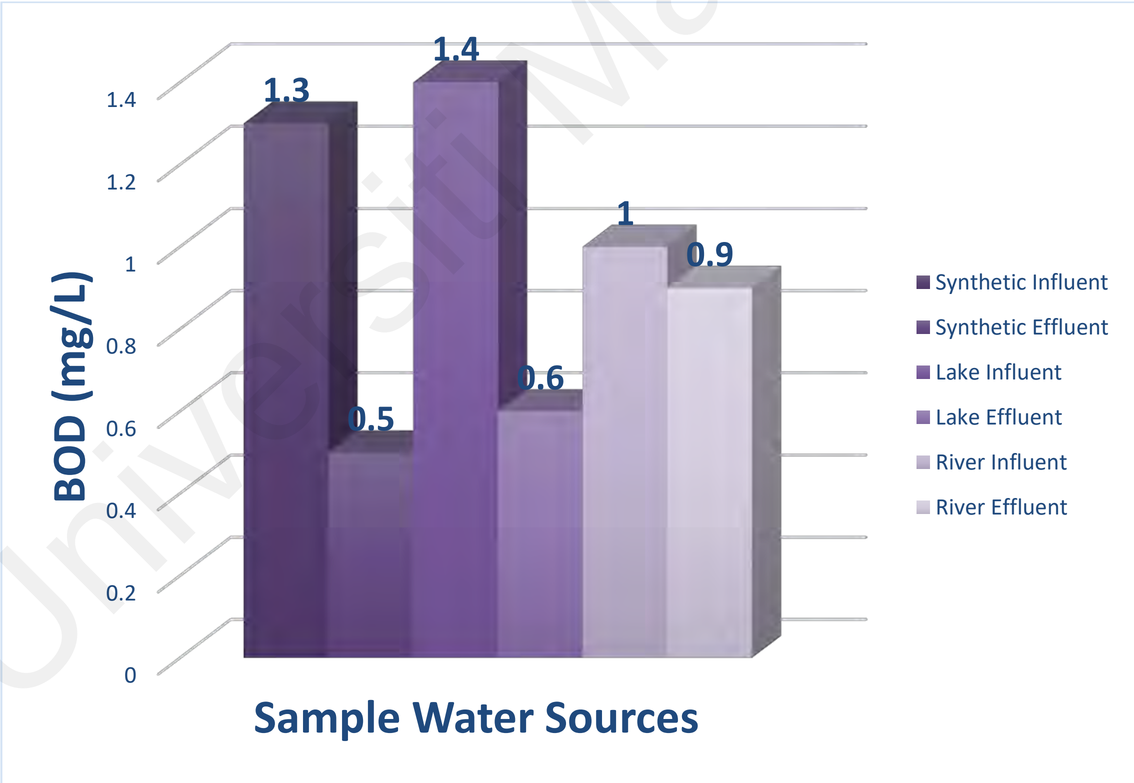


Figure 4-5: BOD for Influent and Effluent from Different Water Sources

4.2.5 Chemical Oxygen Demand (COD)

The COD, which accounts for 16% of the total WQI, is a measure of the amount of oxygen used when oxidant-type substances chemically oxidizes organic materials in water bodies. High COD levels in water indicate the substantial presence of organic molecules, such as runoff from agricultural fields, sewage, and wastewater effluents. The COD will be low if the water sample has very little organic matter or pollutants in it.

Through their breakdown, all of these substances have the potential to exhaust the resources and supply of dissolved oxygen in water bodies, endangering aquatic life as a whole. According to results shown in **Figure 4.6**, the PUF unit can lower the COD value of river water, lake water, and synthetic water by 58%, 42%, and 10% to COD of 15, 11, and 9, respectively from the initial COD of 36 mg/L, 19 mg/L, and 10 mg/L, respectively.

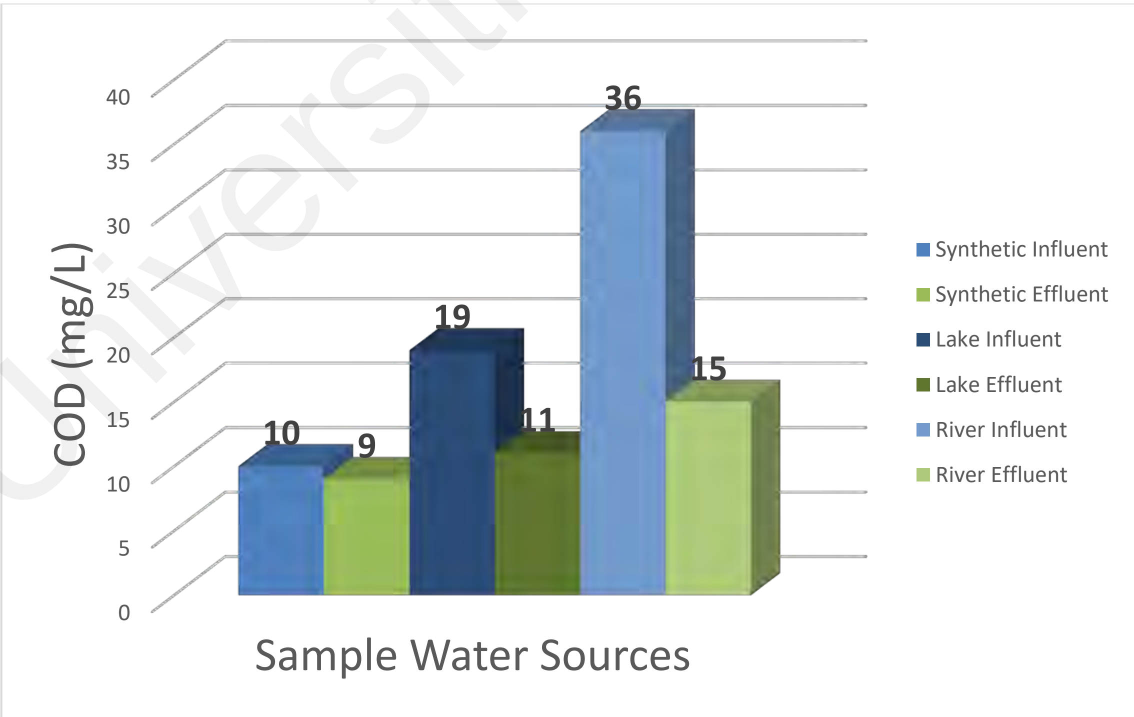


Figure 4-6 COD for Influent and Effluent from Different Water Sources

4.2.6 Ammonia Nitrogen (NH3-N)

The amount of ammonia nitrogen (NH3-N), which makes up 15% of the total WQI, is used to quantify the organic ammonia and nitrogen content in water that is brought about by pollution from sewage and fertilizer emissions. Prior to the test, the initial value of ammonia nitrate in the river water sample was 0.3 mg/L; however, samples of the lake water contained no ammonia nitrate, due to their natural built up.

According to the trial depicted in **Figure 4.7**, the portable UF device can extract 67% of the ammonia nitrate from the river water, resulting in an effluent with a 0.1 mg/L ammonia nitrate content. This satisfies the DOE's WQI Class I water classification, which limits ammonia nitrate to less than 0.1 mg/L.

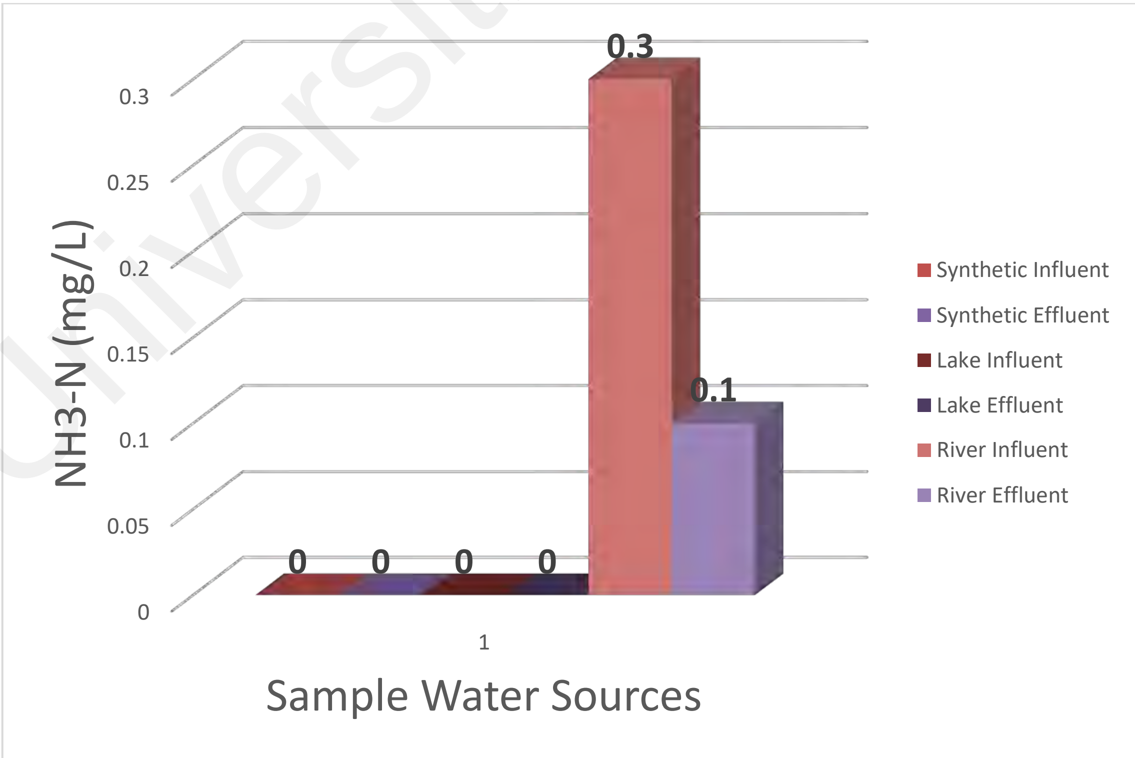


Figure 4-7: NH3-N for Influent and Effluent from Different Water Sources

4.2.7 Total Suspended Solid (TSS)

Both organic and inorganic solid components suspended in water combine to generate total suspended solid, or TSS, which makes up 16% of the total WQI. Light penetration reduction, temperature changes and filling channels are among the physical changes in water caused by the TSS.

The initial TSS of the river, lake, and synthetic water samples were, respectively, 5 mg/L, 20 mg/L, and 4 mg/L before the experiment. According to the experiment's findings described in **Figure 4.8**, the portable UF unit can reduce the amount of suspended solid in river, lake, and synthetic water by 97% to less than 0.5 mg/L, 0 mg/L, and 0 mg/L, respectively. The TSS is removed by filtration mechanism. Under pressure, water passes through UF membranes, and the membrane pores serve as a physical barrier that traps bacteria, bigger macromolecules, and suspended particles while permitting water and dissolved chemicals to pass through.

It is concluded that the total suspended solids (TSS) of all effluents satisfies the TSS threshold for drinking water, which is less than 25 mg/L under the WQI Class I water classification.

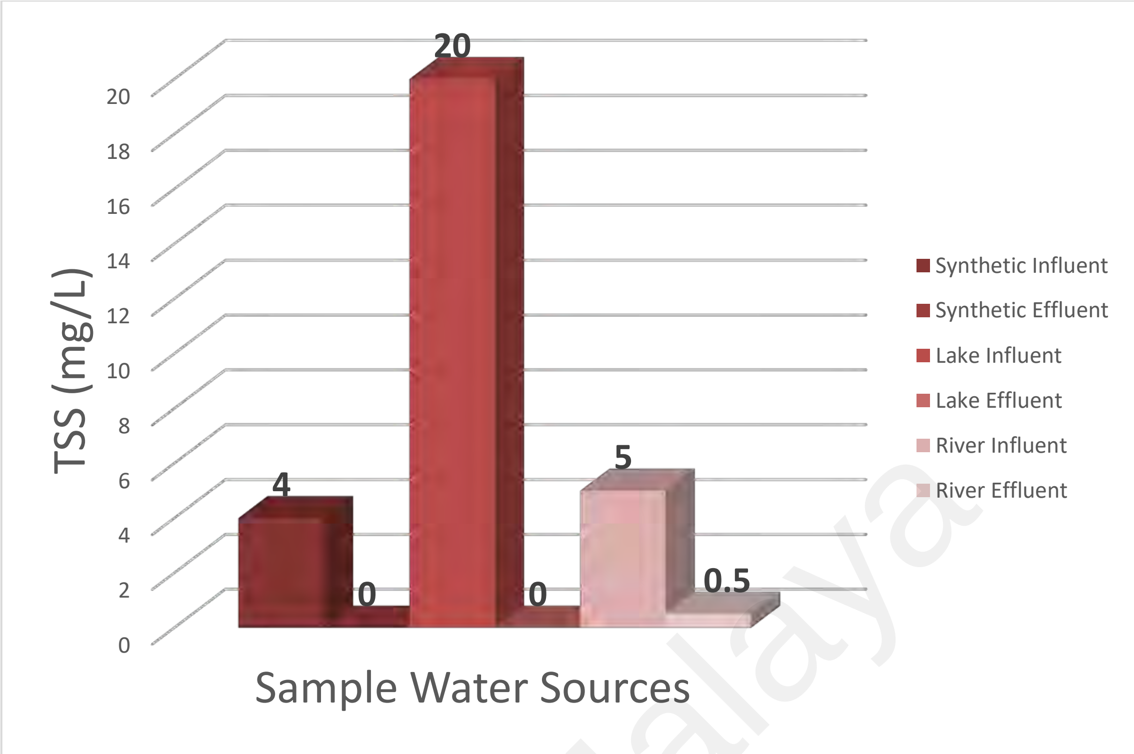


Figure 4-8: TSS for Influent and Effluent from Different Water Sources

4.2.8 Potential Hydrogen (pH)

The last parameter in the WQI is Potential Hydrogen or pH which constitutes 12% of the total WQI. The hydrogen concentration scale is used to determine whether a substance is acidic or alkaline i.e. pH of below than 7 denotes acidity, whereas a pH of more than 7 denotes alkalinity. The river water, lake water, and synthetic water samples had initial pH values of 8.1, 8.6, and 8.5, respectively, which are alkaline, before the test. The experiment's findings in **Figure 4.9** below show that the portable UF device can raise the pH of river, lake and synthetic water by 11%, 8%, and 6%, respectively, to create more neutral solutions with pH of 7.2, 7.9, and 8.0 respectively. These values which is slightly higher than 7 satisfies the fundamental requirements for drinking water according to the DOE Class 1 water classification. We may deduce that the pH of the filtered water and the feed water has not changed significantly.

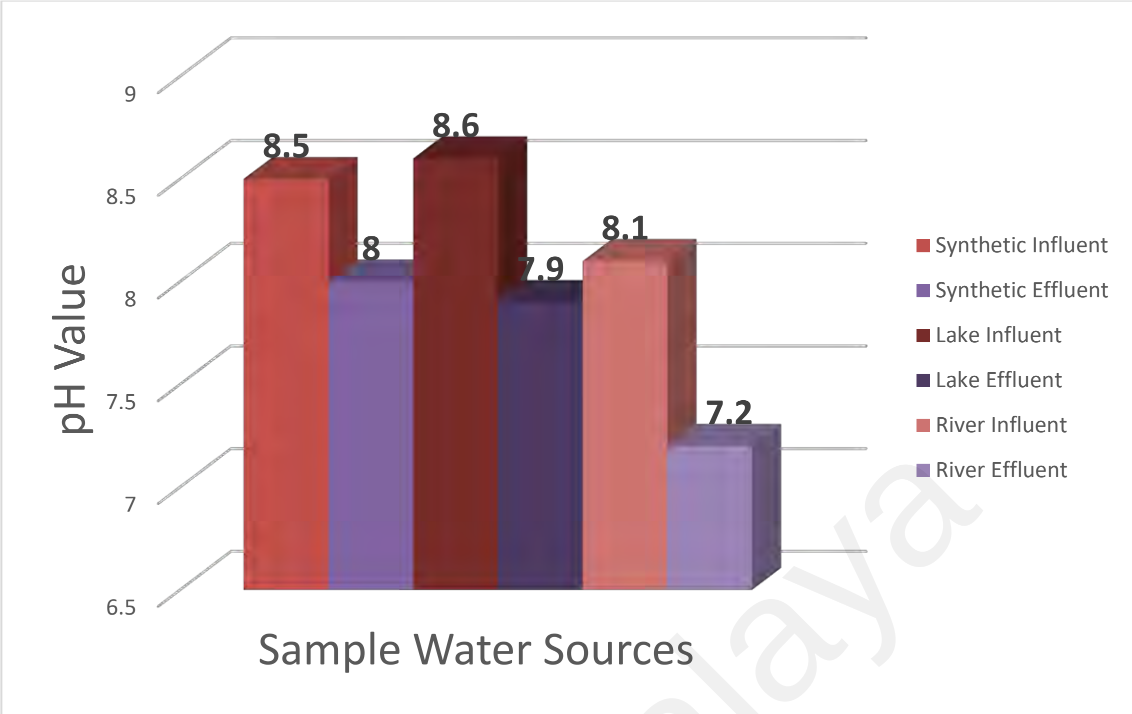


Figure 4-9: pH for Influent and Effluent from Different Water Sources

4.2.9 Presence Of Bacteria

To assess quality of the water produced by the PUF in terms of hygiene standards, bacteria such as total coliform and *Escherichia coli (E-coli)* are tested for their presence. The interpretation of the presence of total coliforms and *Escherichia coli* involves analyzing the presence and characteristics of bacterial colonies on the petrifilm plates. The presence of total coliforms in the water appears as red colonies whereas the presence of *Escherichia coli* appears as blue colonies, with varying sizes, shapes, and gas bubbles within or surrounding these colonies. Normally the growth area in circles of the petrifilm plate is approximately 20 cm^2 in size and therefore the average number of colonies per square can be subsequently multiplied by 20 to ascertain the estimation count of colonies per plate from the AOAC® official procedure.

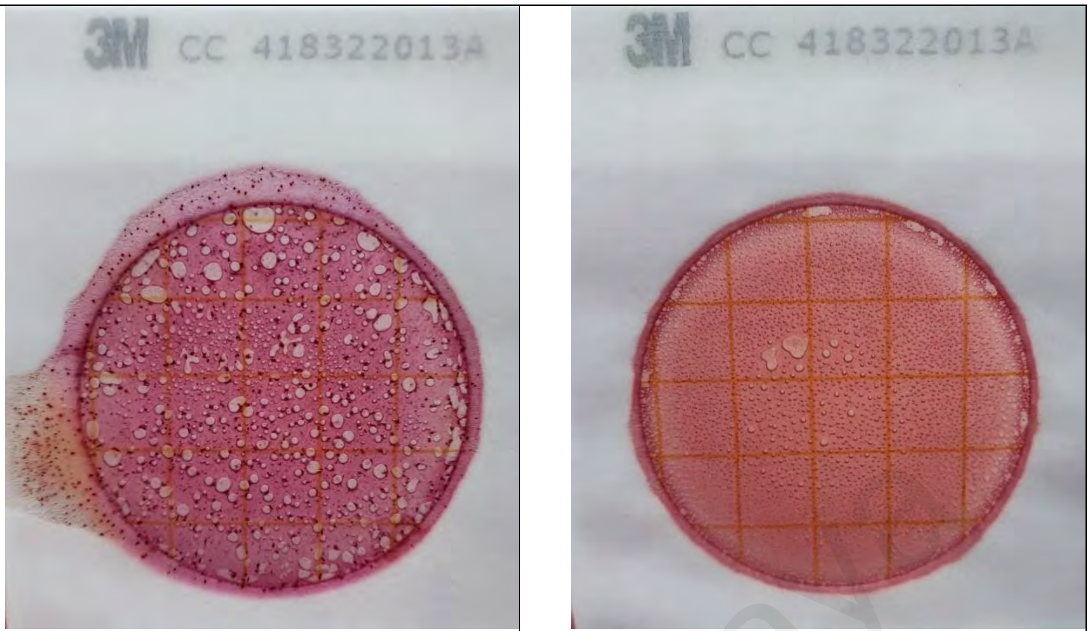
However, those that appear as a foam dam are not to be considered and removed from the final count. The test result is summarised as per **Table 4.2** which gives the influent and effluent count of the presence of coliform and *Escherichia coli* in the river water and lake water samples which were taken on 3rd May 2024. **Figure 4.10**, **Figure 4.11, Figure 4.12** and **Figure 4.13** show the results on the plate for all these cases.

Table 4-2: The bacteria test result from the river and lake water

Figure	Type	Type of Bacteria	Influent (count)	Effluent (count)
4.10	River Water	Total Coliform	140	0
4.11	Lake Water	Total Coliform	80	0
4.12	River Water	E. Coli	20	0
4.13	Lake Water	E. Coli	30	0

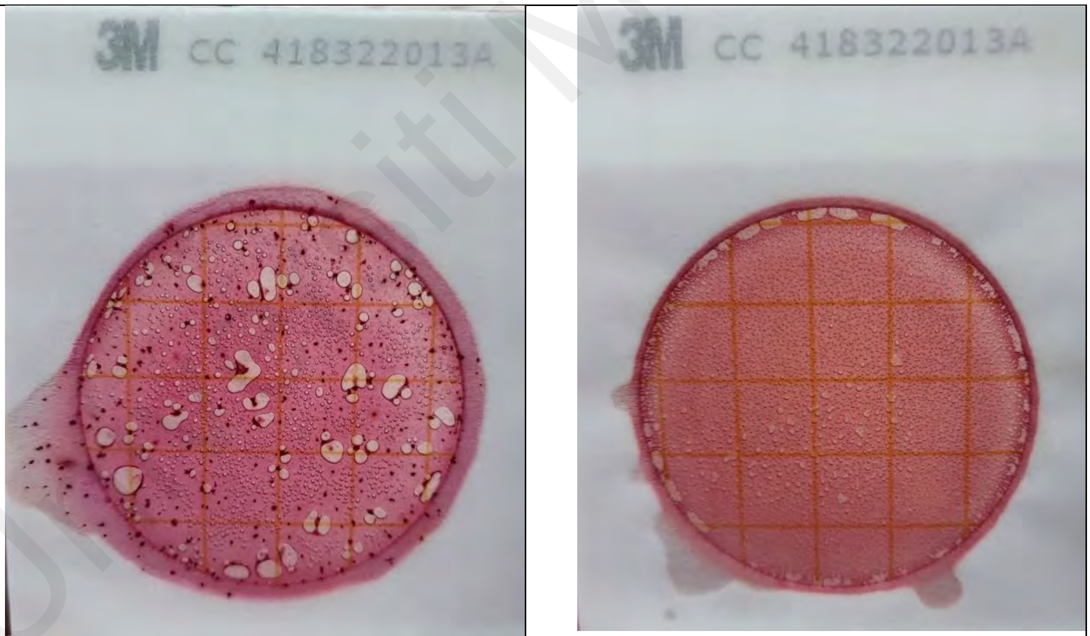
In general, the causes of high total coliform colonies in the water sources can vary depending on various factors including the specific conditions of the environment, human activities, and geographical factors. However, according to WHO, there should be no measurable total coliform or Escherichia coli bacteria in every 100 mL of drinking water.

These results clearly show no presence of total coliform and Escherichia coli colonies in the effluent of the filtration unit for both cases. This demonstrate that the PUF has been effective in capturing bacteria and other microorganisms from contaminated water sources to produce safe drinking water while meeting the drinking water standards required for a filtration system.



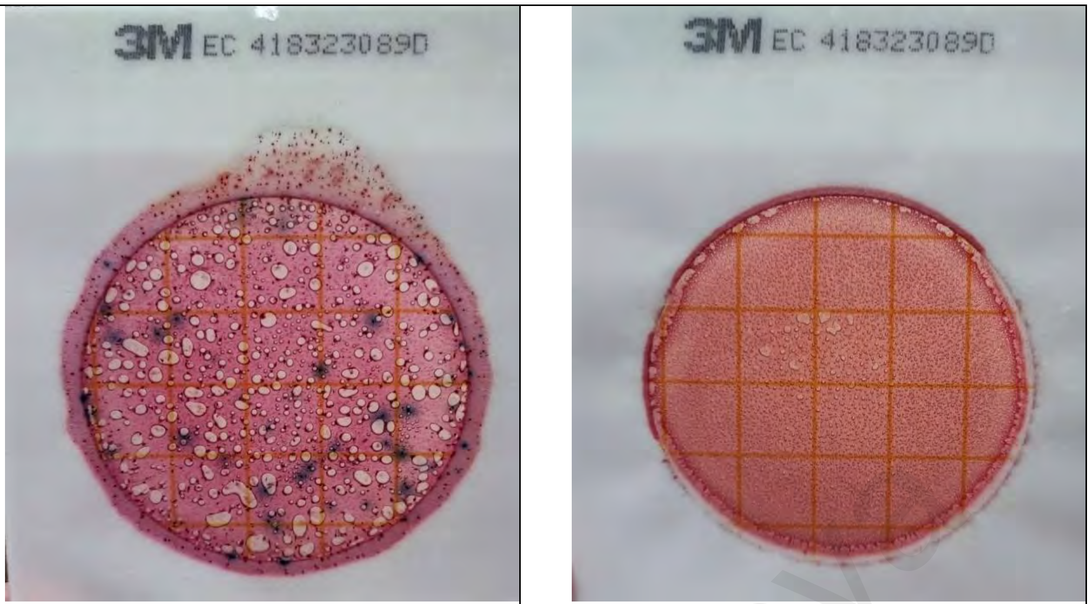
Before UF	After UF

Figure 4-10: Result of total coliform incubation of Sungai Pantai water



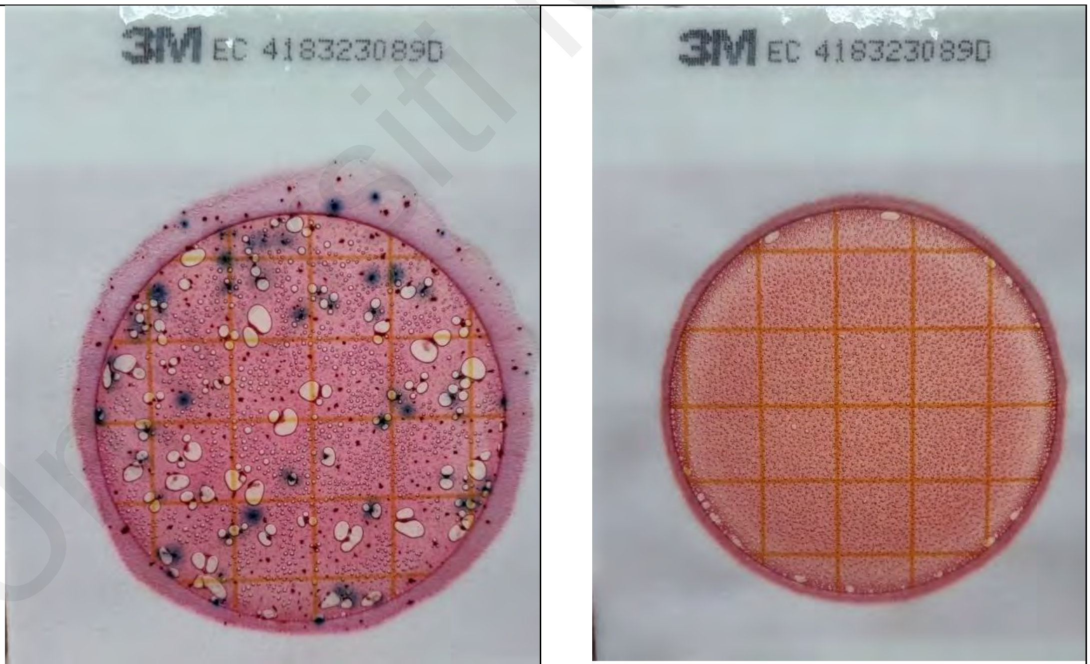
Before UF	After UF

Figure 4-11: Result of total coliform incubation of Tasik Varsity water



Before UF | After UF

Figure 4-12: Result of *E. coli* incubation of Sungai Pantai water



Before UF | After UF

Figure 4-13: Result of *E. coli* incubation of Tasik Varsity water

4.3 Water Quality Index

Using the Malaysia's Water Quality guidelines, six water quality parameters are measured to determine the level of the water quality (WQI). These six parameters are pH, TSS, COD, BOD, DO and NH3-N content. The quality of water is graded based on the WQI scale, in which the value of 0 meant worst water quality and value of 100 represents best water quality standards. **Figure 4.14** shows the improvement of the WQI parameter after the filtration process using our PUF device.

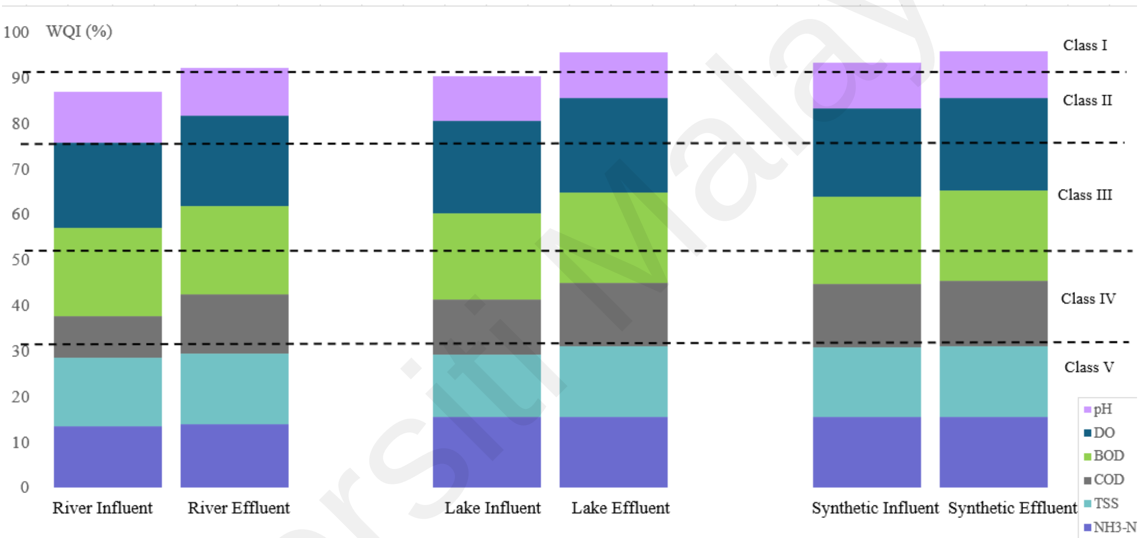


Figure 4-14: WQI Improvement of Portable UF for Different Water Resources

The WQI of river water increased from 86% to 94%, lake water from 90% to 97%, and simulated lake water from 93% to 97% by using the portable UF equipment, as shown in **Figure 4.14**. For the record, the raw water is fairly not of high quality as the BO, COD and ammonia reading are not meeting the drinking water standard. It has been demonstrated that the portable UF raise the WQI of Class II to Class I by 8%, 6%, and 2% for river, lake, and simulated lake water, respectively. Waterbodies with a Class I classification are of extraordinary quality and are regarded as safe to drink. Nonetheless, Class II water includes the majority of river, lake, and raw water supplies today, where further treatment is still necessary before consumption. As a result, the portable UF device's goal of producing Class I certified clean drinking water is accomplished in this study.

4.4 Modelling and Experimental Result

In the simulation study, the performance of the membrane unit for the change of trans membrane pressure (TMP) and permeate flux with time is carried out using the models given in Chapter 3. This experiment has been performed in two stages in which the first experiment is changing the permeate flux with constant TMP and the second experiment is change of trans membrane pressure under constant flux rate. Once this experiment has been concluded, a comparison using the nominal parameter values versus the improved model with new updated parameters has been performed in the subsequent steps.

4.4.1 Improved Modelling Using the EP Approach

Initially the simulation was done to get the time dependent response of the flux and TMP through the PUF system based on the models shown in chapter 3. This model was utilise parameters based on the nominal values taken from the literature (Kanani, 2007) (Ghosh, 2002) which is different from our inbuilt unit in terms of membrane set up and properties. Hence certain parameters contained in the model of the unit have to be different as well. The four parameters involve include the membrane hydraulic resistance, initial rapid fouling constant, mass transfer coefficient and foulant bulk concentration. The results of the model using the nominal parameters can be seen in **Figure 4.15** for the flux rate.

The figure shows the expected flux decrease with time in the PUF due to the membrane fouling as the filtration occurs. However when the modelling results were compared with the experimental results, the average error obtained was quite high as seen in **Figure 4.16.** This is expected since the model was based on the filtration parameters from the literature which was under different conditions from our own in-built system.

The Evolutionary Programming (EP) method was then applied on the difference in error between modelling and the experimental results to get the updated improved parameters of the model for particle 1, particle 2, particle 3 and particle 4. Please refer **Table 3.3** for details for each particle. From the optimization cycle using the EP method, the new updated parameters obtained as shown in **Table 4.3** which also shows the nominal parameters. The results of the improved model using the updated parameters can be seen in **Figure 4.17** which shows the results for the flux rate to be much closer to the experimental results. Further experimental data were also then taken to validate the improved model to determine the robustness of the improved model. **Figure 4.18** shown the time profiles of flux derived from improved model and validation data by experiment. The flux dropped significantly due to membrane fouling which then resulted in the increase in transmembrane pressure (TMP). To overcome the drop in flux, a regular scheduled backwash needs to be performed. For all graphs, every time step represents 6 minutes (360 seconds) time interval. The nominal flow rate of experimental conditions is at 3.4 L per minute, and the TMP is at 105 kPa.

Table 4-3: Optimized parameter for nominal and improved model

Parameter values	particle1	particle2	particle3	particle4	TMP
Nominal values	1.40E+06	3.86E+05	9.95E-06	0.3729	105
Improved values	1.47E+06	2.68E+04	9.22E-06	0.0052	105

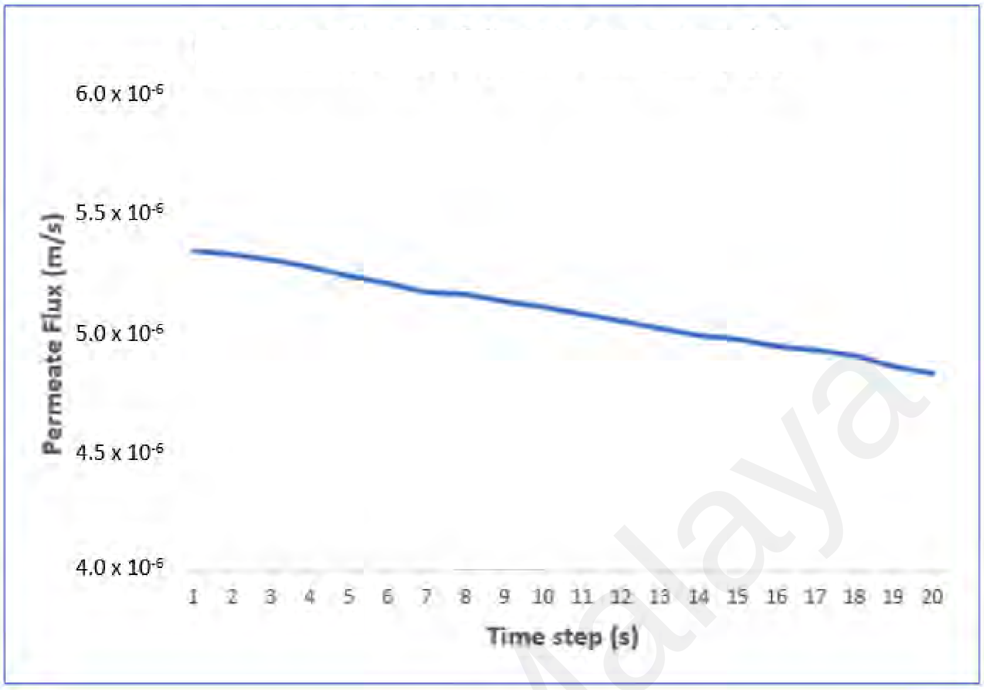


Figure 4-15: Time profiles of flux derived from the nominal model

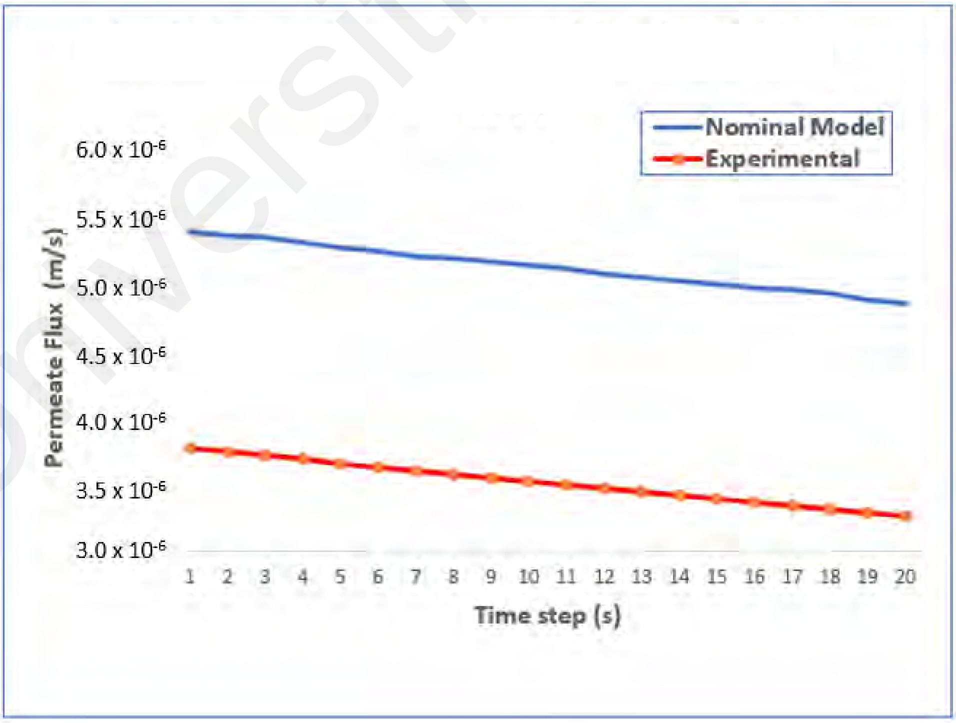


Figure 4-16: Time profiles of flux derived from nominal model and experimental

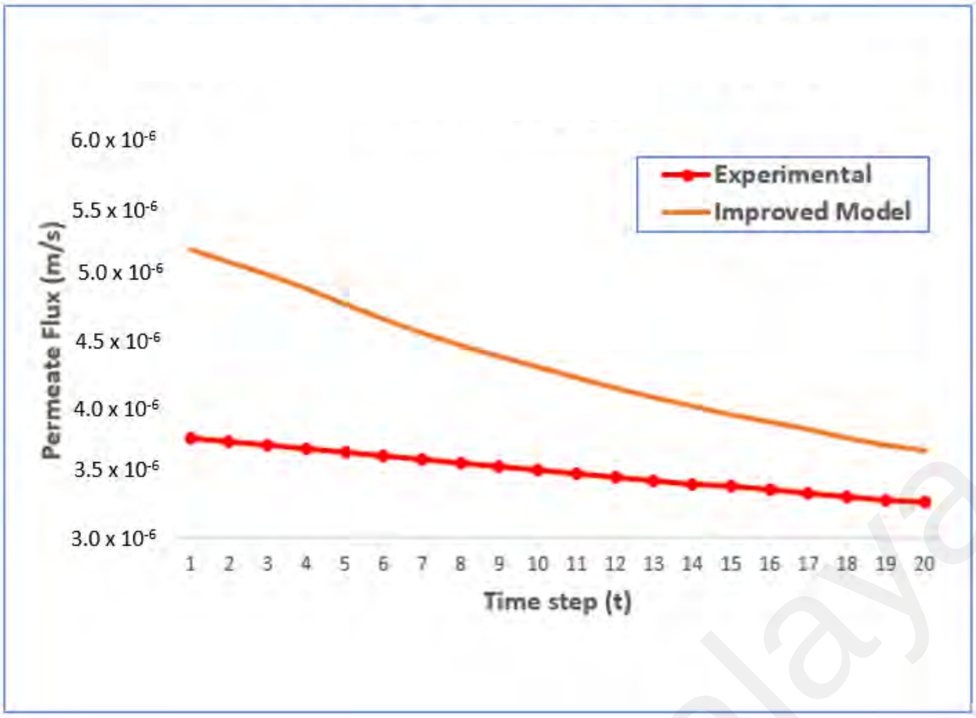


Figure 4-17: Time profiles of flux derived from improved model and experimental

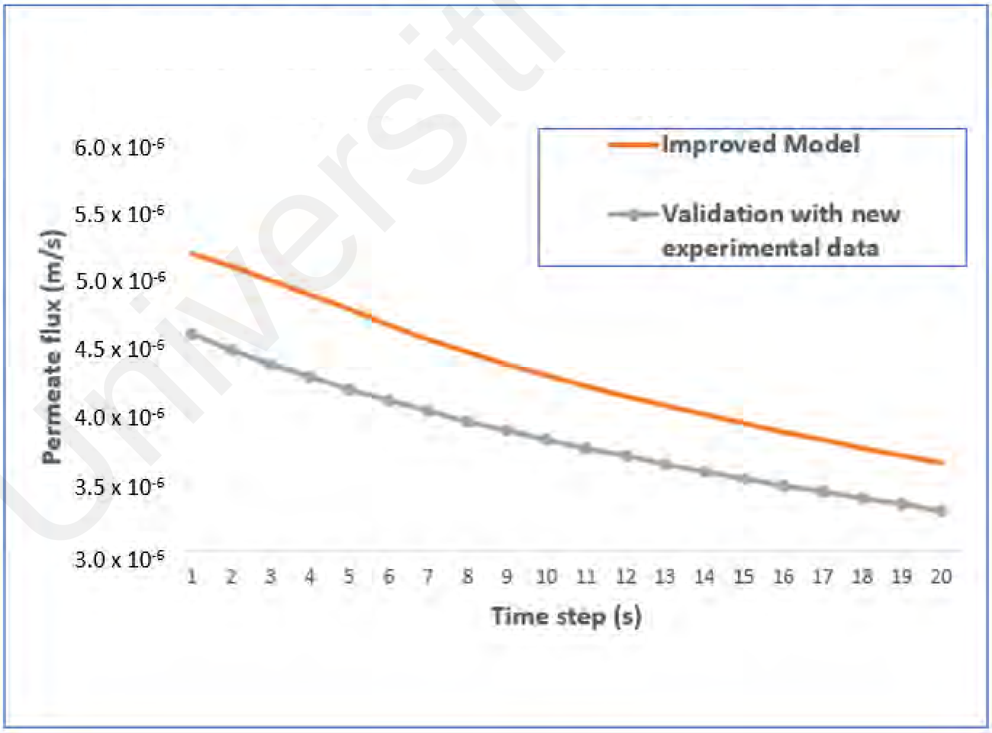


Figure 4-18: Time profiles of flux derived from improved model and validation

4.4.2 TMP Change with Time Using the Improved Model

In this work we developed a mathematical model for the rise in trans membrane pressure during constant flow ultrafiltration. **Figure 4.19** illustrates the impact of TMP versus time on the PUF membrane's modelling done in the previous section. The TMP increases with time which is to be expected due to the accumulation of particles on the membrane i.e. fouling as time progresses. We obtained the time profiles of TMP from the permeate flux improved model by utilizing the same four parameters that were obtained from the EP procedure before. This model to predict TMP was then compared with the experimental value and the results shown in **Figure 4.20,** which shows similar profile and values from both results with an average error of about 9%. The statistical significance of the 9% error reduction is based on the literature reference that the amount of error that is acceptable depends on the experiment, but a margin of error of 10% is generally considered acceptable (Helmenstine., 2024). The data obtained from the experiment was not smooth since the data is taken of discrete values from the digital instruments to measure TMP and also fluctuates slightly as normally exists in real experiments.

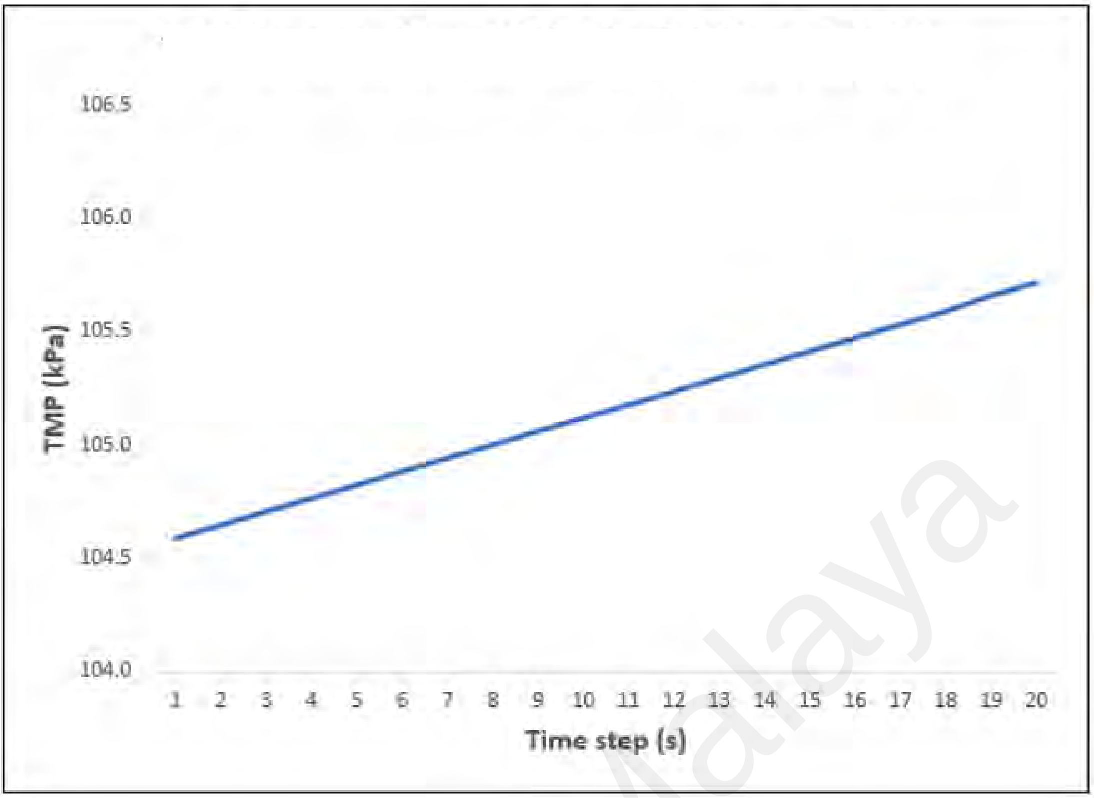


Figure 4-19: Time profiles of TMP derived from the improved model

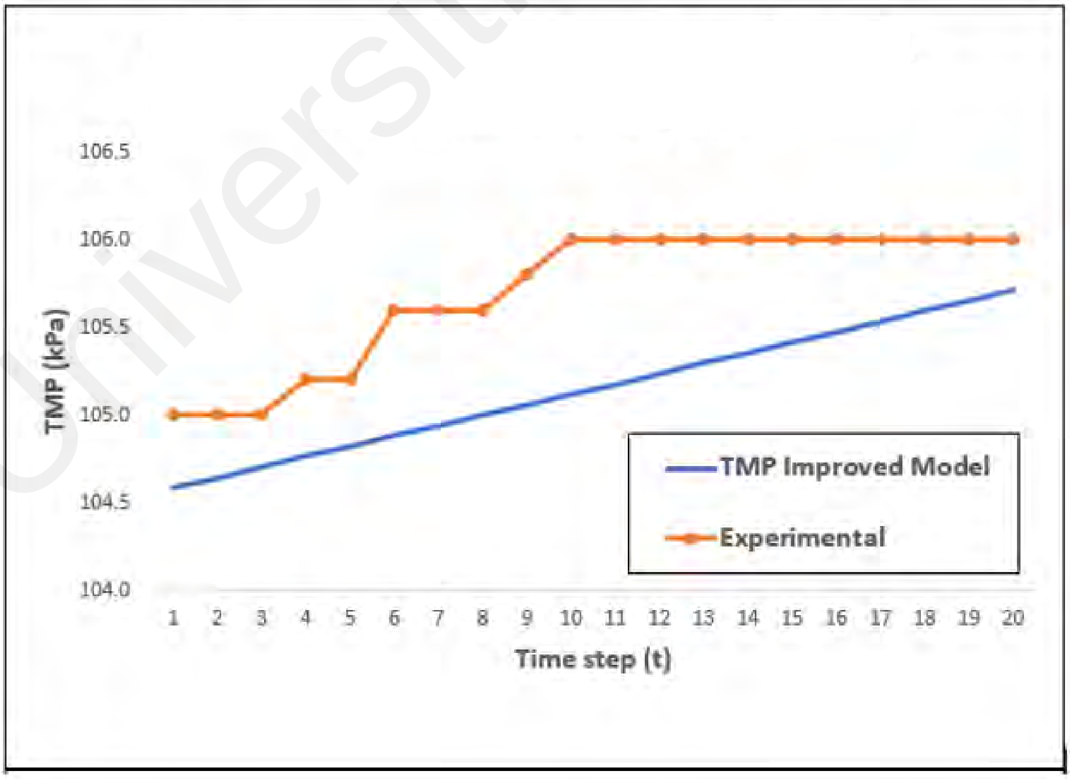


Figure 4-20: Time profiles of TMP derived from improved model and experimental.

Hence in general it was shown that the prediction of the improved model and the experiment findings agreed well in both permeate flux and TMP predictions in terms of profile and value. This validates the accuracy of the simple model of the PUF system obtained from simple fundamentals and through optimizing the parameters with the EP method. With optimized parameters, the performance of the portable UF system will be improved which will result in the increased efficiency of the portable UF system. This will ensure higher productivity of safe drinking water especially for the benefit of people in the rural area.

CHAPTER 5: CONCLUSION AND FUTURE WORKS

The final chapter of the dissertation aims to summarize the main contributions of this research work and the main findings of the work. The conclusions provide an overview of the experiments conducted to test the water quality from the portable UF system, the mathematical modelling that is performed on the portable UF system and the incorporation of the Evolutionary Programming (EP) as a method to improve the model and validate the experimental results.

5.1 Conclusion

The results from this work show that the portable UF device produced drinking water that met DOE and WHO standards. Due to the portable UF device's efficiency, effluent turbidity below 1 NTU has been achieved by reducing the turbidity of river water, lake water, and synthetic water by 96%, 95%, and 99%, respectively. Additionally, it achieved effluent colour below 15 TCU by reducing the colour of lake water, synthetic water, and river water by 92%, 87%, and 97%, respectively.

Additionally, it raised the WQI of Class II water sources to safe Class I drinking water by 7.8%, 5.7%, and 2.4%, respectively for the lake, river, and synthetic water (average increase of 5.3%). The portable UF system also showed that it could remove all E. coli and total coliform bacteria from the lake and river water, producing drinking water that is microbiologically safe. Hence, the filtered water from this PUF is deemed to be safe for human consumption, having met the national drinking water standard from these findings.

From the model obtained for the portable UF system it was found that the membrane hydraulic resistance, initial rapid fouling constant, mass transfer coefficient and foulant bulk concentration were four parameters that had to be optimized using the EP approach when TMP and permeate flux were considered as response attributes. With the updated model, the average error between the model and experiment was reduced from 32% to 9%. This was further validated with new data taken from experiment. This new parameter was also then verified with the model to obtain the TMP. Contrasting the optimized model with the existing model indicates that the optimized model predicts the membrane performance better and thereby making it competent as a reliable model for purification of water using the in-house built portable UF (PUF) system. It was shown that the prediction of the improved model and the experiment findings agreed well in both permeate flux and TMP predictions in terms of profile and value. This validates the accuracy of the simple model of the PUF system obtained from simple fundamentals and through optimizing the parameters with the EP method.

5.2 Research Novelty and Contributions

Some of the novelty and contributions of this work include;

1. The development of an inexpensive, in-house built portable UF system that has been thoroughly evaluated for its performance to see how well it treats different kinds of water while meeting drinking water quality standards.

2. Formulation of a simple but accurate model for this inbuilt portable ultrafiltration unit, allowing for the prediction of TMP and permeate flux within the membrane.

3. The application of the Evolutionary Programming (EP) approach, to update the parameter of the model to produce an improved model that closely resembles the

actual PUF unit and which has been validated by the experimental testing. This will allow us to get quick predictions of the performance of the unit without having to run experimental tests all the time.

5.3 Recommendation

There are still many issues to be resolved in this research work which will further improve the design and performance of this in-house built system. The future work that can be carried out include

1. Study of the improvement in the performance of the system if an optimized backwash process is introduced.
2. Implementing AI methods in determining the optimal backwash duration and interval.
3. Optimization of the parameters can be done with AI techniques as well.
4. Test the unit filter with other sources of water such as groundwater, raw water, and run-off water from agricultural farms to achieve the drinking water standards.

REFERENCES

Ahmad, A. L., Chong, M. F., & Bhatia, S. (2006). Ultrafiltration modeling of multiple solutes system for continuous cross-flow process. *Chemical Engineering Science*, *61*(15), 5057-5069. https://doi.org/10.1016/j.ces.2006.03.017

Akshay, P., Shreekanth, S., Rajesh, R., & Prasad, G. (2020). Portable and efficient graphene-oxide based multistage filtration unit for water purification. *Materials Today: Proceedings*, *26*, 2344-2350. https://doi.org/10.1016/j.matpr.2020.02.504

Alvarez, A., Orfila, A., & Tintore, J. (2001). DARWIN: An evolutionary program for nonlinear modeling of chaotic time series. *Computer Physics Communications*, *136*(3), 334-349. https://doi.org/https://doi.org/10.1016/S0010-4655(01)00154-0

Amgo. (2024). *Amgo*. https://www.amgo.com.my/?q=product_sub&pc=13 (accessed on 10 December 2024).

Anh, N. T., Can, L. D., Nhan, N. T., Schmalz, B., & Luu, T. L. (2023). Influences of key factors on river water quality in urban and rural areas: A review. *Case Studies in Chemical and Environmental Engineering*, *8*. https://doi.org/10.1016/j.cscee.2023.100424

Arnala, J. M., Sancho, M., García-Fayos, B., Lora, J., & Verdú, G. (2006). UF-designed facility location protocol for a potable water treatment in developing countries. *Desalination*, *200*(1-3), 322-324. https://doi.org/10.1016/j.desal.2006.03.322

Badrnezhad, R., & Mirza, B. (2014). Modeling and optimization of cross-flow ultrafiltration using hybrid neural network-genetic algorithm approach. *Journal of Industrial and Engineering Chemistry*, *20*(2), 528-543. https://doi.org/https://doi.org/10.1016/j.jiec.2013.05.012

Barbot, E., Carretier, E., Wyart, Y., Marrot, B., & Moulin, P. (2009). Transportable membrane process to produce drinking water. *Desalination*, *248*(1-3), 58-63. https://doi.org/10.1016/j.desal.2008.05.038

Carolyn, K. M. W., Junaidi, M. U. M., Hashim, N. A., Hussain, M. A., Mohamed Zuki, F., Mohamed Jan, B., Nasir, N. A. A., & Ahmad, A. L. (2020). Purification of lake water using a PES hollow fiber membrane. *Water Supply*, *20*(2), 529-537. https://doi.org/10.2166/ws.2019.184

Chellapilla, K., & Rao, S. S. (1998). Optimization of bilinear time series models using fast evolutionary programming. *IEEE Signal Processing Letters*, *5*(2), 39-42. https://doi.org/10.1109/97.659546

Cheong, F., & Lai, R. (2007). Simplifying the automatic design of a fuzzy logic controller using evolutionary programming. *Soft Computing*, *11*(9), 839-846. https://doi.org/10.1007/s00500-006-0135-x

Cheryan, M. (1998). *Ultrafiltration and microfiltration handbook*. CRC press.guoas

Coway. (2024). Coway (MALAYSIA). https://www.coway.com.my/about#marketshare (accessed on 10 December 2024).

Cuckoo. (2023). *Cuckoo Water Purifiers - Beyond Drinking Water*. CUCKOO International (MAL) Sdn. Bhd. https://www.cuckoo.com.my/products/water-purifiers (accessed on 10 December 2024).

Cui, G., Wong, M. L., & Lui, H.-K. (2006). Machine Learning for Direct Marketing Response Models: Bayesian Networks with Evolutionary Programming. *Management Science*, *52*(4), 597-612. https://doi.org/10.1287/mnsc.1060.0514

Curcio, S., Scilingo, G., Calabrò, V., & Iorio, G. (2005). Ultrafiltration of BSA in pulsating conditions: an artificial neural networks approach. *Journal of Membrane Science*, *246*(2), 235-247. https://doi.org/10.1016/j.memsci.2004.09.004

Dasgupta, J., Sikder, J., & Mandal, D. (2017). Modeling and optimization of polymer enhanced ultrafiltration using hybrid neural-genetic algorithm based evolutionary approach. *Applied Soft Computing*, *55*, 108-126. https://doi.org/https://doi.org/10.1016/j.asoc.2017.02.002

Demirci, K., Zungur-Bastıoğlu, A., Görgüç, A., Bayraktar, B., Yılmaz, S., & Yılmaz, F. M. (2023). Microwave irradiation, evolutionary algorithm and ultrafiltration can be exploited in process intensification for high-purity and advanced inulin powder production. *Chemical Engineering and Processing - Process Intensification*, *194*. https://doi.org/10.1016/j.cep.2023.109565

Department of Environment M, 2025. Standard-kualiti-air-sungai-kebangsaan-dan-indeks. Official Portal, Department of Environment, Ministry Of Natural Resources And Environmental Sustainability.

Duong, H., Cong Nguyen, N., Uan, D., & Son, L. (2017). Membrane processes and their potential applications for fresh water provision in Vietnam.

El-Harbawi, M., Sabidi, A., Kamarudin, E., Hamid, A., Harun, S., Nazlan, A., & Yi, C. (2010). Design of a portable dual proposes water filter system. *Journal of Engineering Science and Technology*, *5*.

EPA. (2024). *National Primary Drinking Water Regulations*. United States Environmetal Protection Agency. https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations

Fogel, D. B. (1991). The Evolution of Intelligent Decision Making in Gaming. *Cybernetics and Systems*, *22*(2), 223-236. https://doi.org/10.1080/01969729108902281

Fogel, G. B. (2012). Evolutionary Programming. In *Handbook of Natural Computing* (pp. 699-708). https://doi.org/10.1007/978-3-540-92910-9_23

Fogel, L. J. (1999). *Intelligence through simulated evolution: Forty years of evolutionary programming*. John Wiley & Sons, Inc.

Gaudio, M. T., Curcio, S., Chakraborty, S., & Calabrò, V. (2023). Application of Artificial Neural Networks for Modelling and Control of Flux Decline in Cross-Flow Whey Ultrafiltration. *Processes*, *11*(4). https://doi.org/10.3390/pr11041287

Ghosh, R. (2002). Study of membrane fouling by BSA using pulsed injection technique. *Journal of Membrane Science*, *195*(1), 115-123. https://doi.org/https://doi.org/10.1016/S0376-7388(01)00550-6

Glover, F. A., & National Institute for Research in, D. (1985). *Ultrafiltration and reverse osmosis for the dairy industry*. National Institute for Research in Dairying.

Greeff, D. J., & Aldrich, C. (1998). Empirical modelling of chemical process systems with evolutionary programming. *Computers & Chemical Engineering*, *22*, 995-1005.

Groendijk, L., & de Vries, H. E. (2009). Development of a mobile water maker, a sustainable way to produce safe drinking water in developing countries. *Desalination*, *248*(1-3), 106-113. https://doi.org/10.1016/j.desal.2008.05.044

Guo, W., Ngo, H.-H., & Li, J. (2012). A mini-review on membrane fouling. Bioresource technology, 122, 27-34.

Helmenstine, A. (2024). *Sources of Error in Science Experiments*. Science Notes and Projects https://sciencenotes.org/error-in-science/ (accessed on 10 December 2024).

Huang, Y. F., Ang, S. Y., Lee, K. M., & Lee, T. S. (2015). Quality of Water Resources in Malaysia. In T. S. Lee (Ed.), Research and Practices in Water Quality (Vol. 3). Intechopen. https://www.intechopen.com/chapters/47539

Hwang, H.-S. (1999). Automatic design of fuzzy rule base for modelling and control using evolutionary programming.

Jéquier, E., & Constant, F. (2009). Jéquier E, Constant F. Water as an essential nutrient: the physiological basis of hydration. Eur J Clin Nutr 64, 115-123. *European journal of clinical nutrition*, *64*, 115-123. https://doi.org/10.1038/ejcn.2009.111

Kanani, D. M., & Ghosh, R. (2007). A constant flux based mathematical model for predicting permeate flux decline in constant pressure protein ultrafiltration. *Journal of Membrane Science*, *290*(1-2), 207-215. https://doi.org/10.1016/j.memsci.2006.12.030

Khalil, B., Ouarda, T. B. M. J., & St-Hilaire, A. (2011). Estimation of water quality characteristics at ungauged sites using artificial neural networks and canonical correlation analysis. *Journal of Hydrology*, *405*(3-4), 277-287. https://doi.org/10.1016/j.jhydrol.2011.05.024

Llanos, J., Rodrigo, M. A., Cañizares, P., Furtuna, R. P., & Curteanu, S. (2013). Neuro-evolutionary modelling of the electrodeposition stage of a polymer-supported ultrafiltration–electrodeposition process for the recovery of heavy metals. *Environmental Modelling & Software*, *42*, 133-142. https://doi.org/https://doi.org/10.1016/j.envsoft.2013.01.001

LG. (2024). *LG Water Purifiers*. https://www.lg.com/my/water-purifiers (accessed on 10 December 2024).

Lopes, R. H., Silva, C., Silva, I. S., Salvador, P., Heller, L., & Uchoa, S. (2022). Worldwide Surveillance Actions and Initiatives of Drinking Water Quality: A Scoping Review. *Int J Environ Res Public Health*, *20*(1). https://doi.org/10.3390/ijerph20010559

López-Murillo, L. H., Grisales-Díaz, V. H., Pinelo, M., & Prado-Rubio, O. A. (2021). Ultrafiltration intensification by dynamic operation: Insights from hybrid modeling. *Chemical Engineering and Processing - Process Intensification*, *169*. https://doi.org/10.1016/j.cep.2021.108618

MathWorks. (1994-2023). *About MathWorks*. The MathWorks, Inc. Retrieved 25 January 2023 from https://www.mathworks.com/company.html

Meng, S., Zhang, M., Yao, M., Qiu, Z., Hong, Y., Lan, W., Xia, H., & Jin, X. (2019). Membrane Fouling and Performance of Flat Ceramic Membranes in the Application of Drinking Water Purification. *Water*, *11*(12). https://doi.org/10.3390/w11122606

Mierzwa, J. C., da Silva, M. C. C., Veras, L. R. V., Subtil, E. L., Rodrigues, R., Li, T., & Landenberger, K. R. (2012). Enhancing spiral-wound ultrafiltration performance for direct drinking water treatment through operational procedures improvement: A feasible option for the Sao Paulo Metropolitan Region. *Desalination*, *307*, 68-75. https://doi.org/10.1016/j.desal.2012.09.006

Mulder, M. (1996). *Basic Principles of Membrane Technology*. Springer Netherlands. https://books.google.com.my/books?id=SP2_GYvL384C

Pakharuddin, N., Fazly, M., Sukari, S., & Zamri, F. (2021). Water treatment process using conventional and advanced methods: A comparative study of Malaysia and selected countries. *IOP Conference Series: Earth and Environmental Science*, *880*, 012017. https://doi.org/10.1088/1755-1315/880/1/012017

Panhwar;, M. A., Panhwar;, F., Zhao;, G., & Pirzada, N. (2018). A Low-Cost Portable Device for Combined Hemodialysis and Ultrafiltration. *International Journal of Applied Engineering Research*, *13*(7), 5400-5403.

PAUL. (2024). *PAUL waterbackpack*. The WaterBackpack Company GmbH. http://waterbackpack.org/ (accessed on 10 December 2024).

Peter-Varbanets, M., Zurbrügg, C., Swartz, C., & Pronk, W. (2009). Decentralized systems for potable water and the potential of membrane technology. *Water Research*, *43*(2), 245-265. https://doi.org/https://doi.org/10.1016/j.watres.2008.10.030

Schmidt, P., Becker, M., Priske, M., Hamers, B., Kreis, P., & Górak, A. (2012). Process design of integrated reaction and membrane separation by organic solvent nanofiltration using evolutionary algorithms. In *22nd European Symposium on Computer Aided Process Engineering* (pp. 727-731). https://doi.org/10.1016/b978-0-444-59520-1.50004-x

Shen, C., Wu, S., & Meng, Q. (2021). Construction of portable drinking water device using an agricultural biomass-derived material of polyethylenimine-grafted-corncob. *Food Control*, *130*. https://doi.org/10.1016/j.foodcont.2021.108375

Taheran, M., Kumar, P., Naghdi, M., Brar, S. K., Knystautas, E. J., Verma, M., & Surampalli, R. Y. (2019). Development of an advanced multifunctional portable water purifier. *Nanotechnology for Environmental Engineering*, *4*(1). https://doi.org/10.1007/s41204-019-0054-6

UN. (2023). *Sustainable Development Goals. Goal 6: Ensure Access to Water and Sanitation for All*. United Nations. Retrieved 26th January 2023 from https://www.un.org/sustainabledevelopment/water-and-sanitation/

UNICEF, W. (2021). PROGRESS ON HOUSEHOLD DRINKING WATER SANITATION.

Venkatesha, R., Rao, A., & Kedare, S. B. (2014). *Portable Water Purifiers*. https://doi.org/10.13140/RG.2.1.3000.3605

WHO. (2023a). *Drinking Water*. Retrieved 13 September 2023 from https://www.who.int/news-room/fact-sheets/detail/drinking-water

WHO. (2023b). *SDG Target 6.1 | Drinking water*. World Health Organization. Retrieved 26th January 2023 from https://www.who.int/data/gho/data/themes/topics/indicator-groups/indicator-group-details/GHO/sdg-target-6.1-drinking-water

Wu, Q., Chen, C., Zhang, Y., Tang, P., Ren, X., Shu, J., Liu, X., Cheng, X., Tiraferri, A., & Liu, B. (2023). Safe purification of rural drinking water by biological aerated filter coupled with ultrafiltration. *Sci Total Environ*, 161632. https://doi.org/10.1016/j.scitotenv.2023.161632

Yang, J., Monnot, M., Eljaddi, T., Ercolei, L., Simonian, L., & Moulin, P. (2021). Ultrafiltration as tertiary treatment for municipal wastewater reuse. *Separation and Purification Technology*, *272*. https://doi.org/10.1016/j.seppur.2021.118921

Yin, L., Fu, L., Wu, H., Xia, Q., Jiang, Y., Tan, J., & Guo, Y. (2021). Modeling dissolved oxygen in a crab pond. *Ecological Modelling*, *440*. https://doi.org/10.1016/j.ecolmodel.2020.109385

Zhao, X., Chen, Y., Lin, P., Su, H., & Chen, Y. (2023). A portable high-performance self-insulated solar evaporator based on wooden sponge for seawater desalination and wastewater purification. *Desalination*, *556*. https://doi.org/10.1016/j.desal.2023.116549

Zhao, X., Chen, Y., Lin, P., Su, H., & Chen, Y. (2023). A portable high-performance self-insulated solar evaporator based on wooden sponge for seawater desalination and wastewater purification. *Desalination*, *556*. https://doi.org/10.1016/j.desal.2023.116549