TREATMENT OF INDUSTRIAL TEXTILE WASTEWATER USING UF AND MF MEMBRANE FILTRATION

CHAN SEE YI

UNIVERSITI TUNKU ABDUL RAHMAN

TREATMENT OF INDUSTRIAL TEXTILE WASTEWATER USING UF AND MF MEMBRANE FILTRATION

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Chemical Engineering with Honours

Lee Kong Chian Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

May 2023

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

Signature : 

Name : CHAN SEE YI

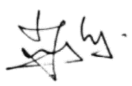
ID No. : 18UEB02055

Date : 20 May 2023

APPROVAL FOR SUBMISSION

I certify that this project report entitled **"TREATMENT OF INDUSTRIAL TEXTILE WASTEWATER USING UF AND MF MEMBRANE FILTRATION"** was prepared by **CHAN SEE YI** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Chemical Engineering with Honours at Universiti Tunku Abdul Rahman.

Approved by,

Signature : 

Supervisor : Ir. Chong Kok Chung

Date : 20 May 2023

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ABSTRACT

Textile industries are one of the greatest wastewater producers as they require a significant amount of water to be used in the dyeing and finishing processes of textile manufacturing. The number of unit operations in the technological process involved in textile industry are the variables that will affect water consumption in the textile industry. As a result, generally, a typical textile plant may consume a volume of water between 100,000 and 300,000 m^3 annually. As textiles address a substantial portion of human requirements, it is predicted that by 2050, there will be 160 million metric tonnes, three times as much clothing as there is today. Membrane technology in wastewater treatment is a recent interest arising technique garnering the industrial application's interest, owing to its ease of setup and low energy requirement. Crossflow membrane filtration is commonly used in the industry, attributed to its tangential flow across the membrane mechanism, leading to low fouling. This study investigated the textile wastewater's effluents using crossflow ultrafiltration (UF) and microfiltration (MF) membrane filtration. The effect of the operating parameter in terms of pressure and flow rate of the crossflow system was performed to evaluate its permeate flux performance. The water flux found in UF membrane increase significantly from 156.26 L/m^2hr to 591.98 L/m^2hr, and the water flux further increases constantly from 4 bar to 10 bar. Additionally, the flowrate positively affects the permeate flux, where the flux was enhanced from 651.01 L/m^2hr to 726.08 L/m^2hr when the flow rate increase from 2 LPM to 6 LPM. The water flux in MF membrane increases linearly and substantially from 1,046.39 L/m^2hr to 4,238.53 L/m^2hr with increasing pressure from 2 bar to 10 bar. Conversely, the water flux enhances slightly at the flow rate of 2 LPM to 3 LPM, and further rises sharply from 3 LPM to 5 LPM and lastly, slow down from 5 LPM to 6 LPM. The quality of the permeate after the filtration was adhere to the standard prescribed by the Department of Environmental, Malaysia. The results from this study suggested that crossflow membrane filtration system could be commercially feasible due to its permeate flux performance and superior permeate quality.

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LIST OF SYMBOLS / ABBREVIATIONS

α	Constitute the permeability constant
μ	Constitute the membrane porosity
η	Constitute the dynamic viscosity
τ	Constitute the tortuosity factor
χ	Constitute the dependent dimensionless constant of pore geometry
Ɛ	Membrane Porosity
Δl	Constitute the membrane thickness
ΔP	Constitutes the transmembrane pressure
NTU_i	Initial Nephelometric Turbidity Units (NTU)
NTU_f	Final Nephelometric Turbidity Units (NTU)
A	Effective Membrane Surface Area (m^2)
A_p	Constitute the spherical particles per unit surface area of volume
F	Constitute the overall membrane flux
J	Water Flux ($\frac{L}{m^2h}$)
Q	Volume Flux or Permeate Quantity (L)
r	Constitute the membrane pore radius
t	Sampling time (h)

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

Textile industries are one of the greatest wastewater producers as they require a significant amount of water to be used in the dyeing and finishing processes of textile manufacturing. The number of unit operations in the technological process, the product range, the bath ratio, the mass of fiber in relation to the bath volume, and the finishing machine are some variables that will affect water consumption in the textile industry. As a result, generally, a textile plant may consume a volume of water between 100,000 and 300,000 m^3 annually. According to Joanna and Renata (2021), apparel production has nearly doubled in the previous 15 years. As textiles address a substantial portion of human requirements, it is predicted that by 2050, there will be 160 million metric tonnes, three times as much clothing as there is today. The adverse environmental effects of the textile sector will considerably rise as a result. The number of contaminants and pollutants released with wastewater will increase, as well as the usage and consumption of water and energy.

Various biodegradable and non-biodegradable compounds, including heavy metals, high chemical oxygen demand (COD), high biochemical oxygen demand (BOD), dispersants, dyes, levelling agents, and others, are found in the effluents discharged by the textile industry. Due to inefficient dyeing techniques, many dyestuffs, in particular, are lost to wastewater throughout the textile processing process, which could cause significant health and environmental problems. Hence, removing the dyes from textile wastewater is compulsory and necessary before disposal (Singh et al., 2018). In textile wastewater treatment, generally, physical-chemical treatment was the standard and conventional treatment for handling textile waste. Even though the treated effluent from these processes can be safe enough to be discharged directly into the ocean or river, there is a growing interest in industrial wastewater reuse and recycling due to its numerous advantages (Ridha Lafi et al., 2018).

This report will focus on dyeing and finishing textile industrial wastewater that is located at Batu Pahat, Johor. Figure 1.1 below shows the current wastewater treatment process of the company. According to the steps of treatment of the industrial textile wastewater shown in Figure 1.1 below, the company wastewater treatment process can achieve effluent discharge that fulfilled the acceptable conditions of discharge of Environmental Quality (Industrial Effluent) Regulations 2009, Standard B requirement.

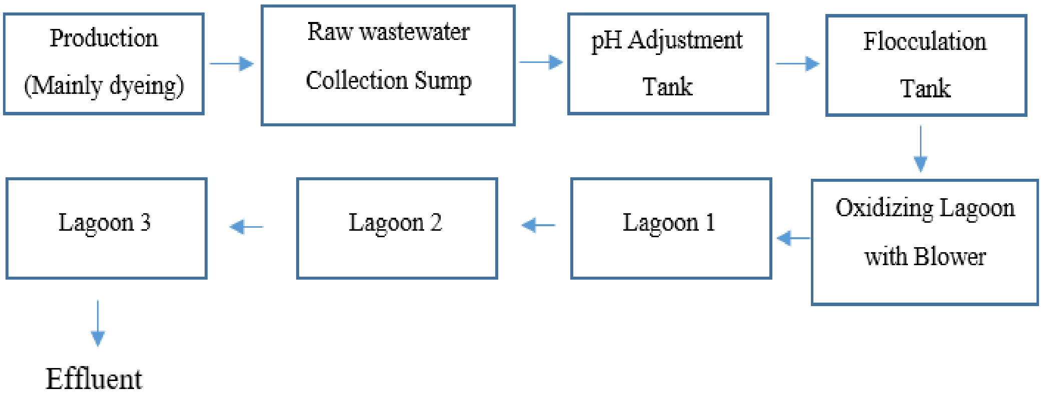

Figure 1.1: Treatment of Textile Wastewater in Dyeing and Finishing Textile Industrial.

Although the effluent from Lagoon 3 of the company already satisfied the acceptable level, the results are still unsuitable for reuse in the textile processes. However, the company wishes to consider recycling and reusing the treated effluent back to the process to be reused. In this case, the effluent from Lagoon 3 will be studied and investigated using cross-flow ultrafiltration (UF) and microfiltration (MF) membrane filtration so that the company can reuse the effluent. This recycling process can help to save costs and water as textile industries require tons of water for treatment. Besides, this could also reduce the impact on the environment.

In addition, recycled water is desired, and it carries several benefits. For instance, it can be used for several industrial purposes, which include the supplementation of cooling or boiler tower feed water, washing equipment, pH adjustment, vehicles and hardstands, fire protection, processing water, or process rinse water for the production lines in the manufacturing industry, toilet flushing usage, control of the dust, construction activities, concrete mixing, and so on.

This report will treat effluents from Lagoon 3 to fulfill the recycle measure and standard by using cross-flow ultrafiltration (UF) and microfiltration (MF) membrane filtration. UF and MF membrane filtration is a specialised membrane filtration technique that can improve the pressure-mediated suspension of solid and infectious waste in waste mixtures. After passing across ultrafiltration, an extremely pure and pathogenic waste-free product can be created. As ultrafiltration and microfiltration are in line with semipermeable membrane utilisation, its approach, and characteristics are relatively similar to membrane-based filtration. For example, the micellar-enhanced membrane may filter those complicated compounds in the wastewater by utilizing a pressure-driven ultrafiltration and microfiltration method.

1.2 Textile Industry Water Pollution in Malaysia

In Malaysia, water contamination is mostly brought on by point and non-point sources. Chemical industries, manufacturing plants, and sewage treatment plants are the primary sources, whereas diffused sources, including surface runoff and agricultural activities, are the non-point sources. Regarding the Regulation, there are currently 1000 small-scale apparel and textile factories in Malaysia exempt from the Manufacturing License requirement and 662 permitted enterprises overall (Mida, 2011). These clothing companies primarily operate in Pulau Pinang and Johor (Batu Pahat), producing clothing and accessories and engaging in spinning, weaving, knitting, dyeing, finishing, and garment manufacturing. Alternatively, Pulau Pinang, Selangor, and Perak are home to most textile businesses that use polymerisation, spinning, and weaving.

Pang and Abdullah (2010) reported that the textile sector barely made up about 0.1% of the industrial sources of scheduled solid waste produced in Malaysia in 2009. However, the total scheduled waste produced by the textile sector rose dramatically from 744 tonnes in 2007 to 1559 tonnes in 2009. Contrarily, 22% of Malaysia's total industrial wastewater production is made up of wastewater from textile finishing.

The textile industry might consume as much as 3000 m^3 of water. The majority of the sources of wastewater pollution from the textile sector are concentrated in Peninsular Malaysia, with Johor state having the highest percentage of sources at 28.6%, Pulau Pinang coming in second with a percentage of 28.2%, and Selangor coming in third with 15.6%. The amount of textile finishing facilities in Pulau Pinang, Johor, and Selangor (Figure 1.2).

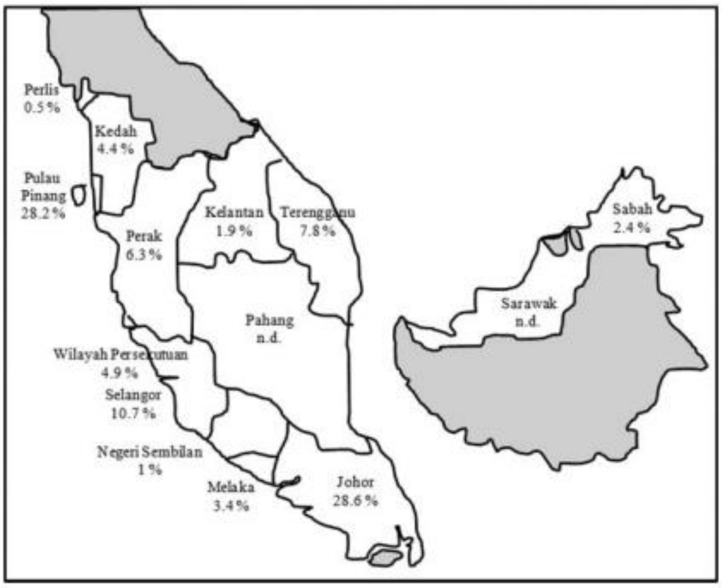

Figure 1.2: Textile Industry Water Pollution for Different States in Malaysia (Pang and Abdullah, 2010).

1.3 Importance of the Study

The importance of the study was to perform the cross-flow ultrafiltration (UF) and microfiltration (MF) membrane filtration processes to remove all the contaminants involved in the wastewater produced by the textile industry and fulfill the requirement and conditions to be recycled and reused back by the company. The selection of the most desired parameter, which is the pressure to be used in the process, and supplied wastewater flow rate, was studied to ensure the best separation performance could be achieved by using cross-flow membrane filtration. The contamination concentration of treated textile wastewater was measured to ensure the final results met the environmental guidelines. The study on membrane cleaning provided an understanding of the capability of membrane recovery.

Besides, this study may shed light on the textile company to investigate the performance of treating the effluent from Lagoon 3 using UF and MF membrane filtration and does these treatment process helps to satisfy the desired and expected result of the treated wastewater, whether the treated and improved quality of the textile wastewater desired to be reused and recycled in the textile company.

In this case, it may provide insight into the importance of the membrane-based separation processes as they have gradually emerged as an attractive and appealing alternative to the traditional separation processes in the treatment of wastewater because the removal of the colour of textile industrial wastewater by traditional treatment methods such as ozonation, bleaching, hydrogen peroxide or UV, and electrochemical techniques were found to be insufficient. This is because the majority of textile dyes have complex and intricate aromatic molecule structures that withstand deterioration. Hence, they are resistant to oxygen, light, and aerobic digestion. High removal efficiencies are made possible by membrane-filtration processes, which also allow for water reuse and some valuable waste elements.

In addition, this study is important because the recycling of high molecular weight and insoluble dyes such as indigo, disperse, auxiliary chemicals (polyvinyl alcohol) and water was carried out in the research recently, and it has been recycled successfully by using ultrafiltration. However, reverse osmosis and nanofiltration have effectively removed colour because they can remove low molecular weight and soluble dyes like acid, reactive, basic, and others that ultrafiltration is not able to achieve (Cheima, Lassaad, and Mahmoud 2005). Therefore, it is important to study and investigate the membrane to be used and the strength of UF and MF membranes compared to other filtration membranes.

1.4 Problem Statement

The problem statement, in this case, is regarding a textile and dyeing company. The company contains a series of treatments to treat the wastewater produced during the textile dyeing process of the company. Currently, the effluent discharged from the last step of the treatment, which is from Lagoon 3, has already fulfilled the Standard B of the Environmental Quality Regulation 2009. However, the textile company wishes to improve the wastewater treatment process so that the quality of the effluent from Lagoon 3 can be improved, fulfill the standard wastewater requirement, and become clean enough to be recycled and reused back in the process of the company as a huge amount of water is required in the textile manufacturing process.

The main problem for the majority of textile manufacturers is wastewater effluents that compose dye chemicals that are highly coloured and have a high amount of non-biodegradable substances, skyrocketing their biochemical and chemical oxygen demand. Most chemicals found in dye industry effluents are highly poisonous, teratogenic, and equally carcinogenic to plant and animal life (Ibrahim et al., 2017). Therefore, wastewater treatment in the textile industry is especially important. Although the current effluent from the textile industry we focused on in this case has fulfilled the standard of Standard B. However, it is still not clean enough to be reused by the company. The quality of water to be recycled and reused by the company need to have a higher quality and standard to ensure the quality of the textile produced will not be affected.

In addition, another problem in this study is investigating the performance of cross-flow UF and MF membranes. The most desired operating condition, such as the wastewater flow rate and pressure to be used with the UF membrane, will be investigated. Besides, MF membrane will also be employed to compare the studied parameters removal efficiency with UF membrane, which is one of the problem statements, in this case, to be identified. The characteristics and quality of the textile wastewater need to be analysed to determine the most desired performance to get the best result for the textile wastewater to be recycled back.

1.5 Aim and Objectives

According to the introduction and problem statement, as written above, the main objectives of this study are to identify the contaminant involved in the textile industry and investigate the efficiency of cross-flow filtration ultrafiltration (UF) and microfiltration (MF) membrane in treating textile wastewater to fulfill the recycling standard. There are three main objectives involved, as listed below:

(i) To analyse the composition of industrial textile wastewater.

(ii) To characterise the physical and chemical properties of ultrafiltration (UF) and microfiltration (MF).

(iii) To investigate the effect of operating parameters on the performance of the cross-flow UF and MF membrane filtration in the treatment of industrial textile wastewater.

1.6 Scope and Limitation of the Study

The scope of the study involves the investigation of the effluents of the textile wastewater industry and improving the quality of the effluents using Ultrafiltration (UF) and Microfiltration (MF) membrane filtration. The properties, characteristic, and parameter of the ultrafiltration and microfiltration membrane that govern the reaction and efficiency of textile effluent wastewater were investigated. Besides, the parameters that affect the ultrafiltration and microfiltration reaction are the pressure supplied, and supplied wastewater flow rate.

The limitation of the study is, first, as the cross-flow unit employed in this work is a lab scale equipment, the controlled parameter of pressure and wastewater flow rate was restricted as it cannot operate at a relatively high value. As the main purpose of this study is to treat industrial scale textile wastewater, actual industrial results cannot be obtained. Lab scale results followed by a pilot scale study need to be carried out before being employed in the actual industrial real case situation.

Furthermore, the performance of the removal efficiency is affected by several operating parameters, such as the pH of the effluent, the contaminant concentration, temperature, and so on. However, due to the limited duration and controlled condition, the parameter under focus is the pressure and wastewater flow rate.

CHAPTER 2

LITERATURE REVIEW

2.1 Textile Industrial Wastewater

Industrial wastewater is the by-product of the majority of the processing industries. Consequently, wastewater is a significant environmental barrier to the growth and development of the textile industry, other than minor issues such as resource waste and solid waste management. Due to the textile industry utilising a lot of water throughout the dyeing, washing, and finishing processes, the textile processing industry is considered water-intensive (Hanife, Nouha, and Guleda, 2018). According to Chandrakant et al. (2016), the textile industry will employ a wide variety of synthetic dyes. Due to the adsorption and uptake of these synthetic dyes being poorly absorbed by fabrics, the textile industry discharges significant amounts of highly and brightly coloured wastewater. The photosynthetic ability of plants is significantly hampered and severely affected by this intensely coloured textile wastewater.

Furthermore, limited light penetration and oxygen consumption also affect aquatic life. Several types of marine life might also be fatal due to component metals and chlorine in synthetic dyes. According to Roop Kishor et al. (2021), Figure 2.1 below shows the overview and summary of several stages of industrial textile wastewater, its hazard and toxicity that affect the health of humans and the environment, and several commercial treatments. Therefore, before being discharged, textile wastewater must be treated.

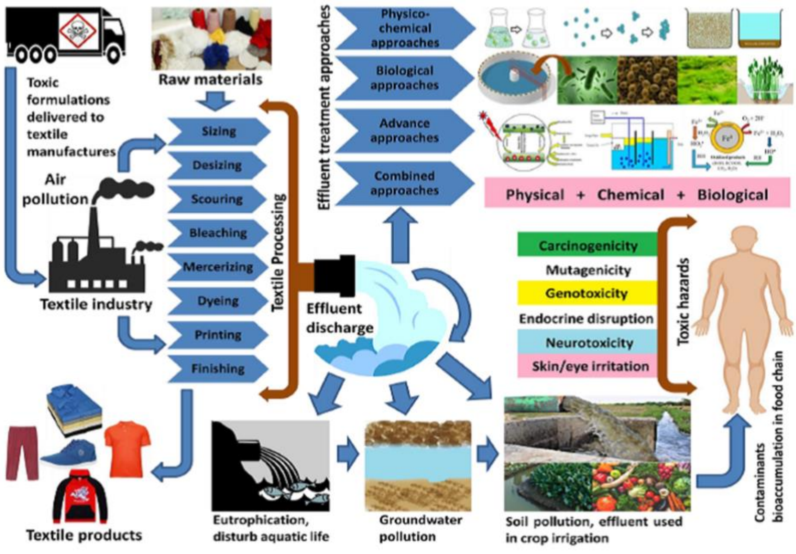

Fig. 1. Processing in textile industry, wastewater generation, its toxicity and various treatment approaches.

Figure 2.1: Overview of the Process in Textile Wastewater, Generation of Wastewater, Toxicity, and Several Typical Treatments (Roop Kishor, et al., 2021).

Both chemicals and water were extensively used in the textile industry. For example, detergents and caustic are used to remove dust, grit, oils, and waxes; bleach is used to improve whiteness and brightness; dyes, fixing agents, and numerous inorganic substances are used to provide the brilliant array of colours the market demands; size is added to improve weaving; oils are added to improve spinning and knitting, and latex and glues are used as binders. Furthermore, several specialty chemicals are employed, such as wetting agents, stain release agents, and softeners. As many chemicals are involved in textile processing, most of these chemicals end up in the final product, and the excess of these chemicals will be contained in the textile wastewater.

Many of the chemicals used serve an essential purpose, but they are washed out of the cloth or fabric. Table 2.1 below shows the loss percentage in the effluent of different dye classes and fibre types involved. Based on Douglas L (n.d.), to clean up the wastewater that is being discharged from the textile mills, the local government and state authorities have started to focus on the textile industry. Regulators pay special attention to toxicity caused by high salt content, irreversible COD, persistent BOD, effluent colour, and heavy metals. As a new discharge permit comes up for the mill, many people discover that the effluent discharged threatens the permit renewal.

Table 2.1: Percentage of Loss in the Effluent of Different Dye Classes and Fibre Types (Zaharia Carmen and Suteu Daniela, 2012).

Dye Class	Fibre Type	Fixation Degree (%)	Loss in Effluent (%)
Basic	Acrilic	95-100	0-5
Acid	Polyamide	80-95	5-20
Disperse	Polyester	90-100	0-10
Direct	Cellulose	70-95	5-30
Reactive	Cellulose	50-90	10-50
Dye Stuff	Cellulose	80-95	5-20
Sulphur	Cellulose	60-90	10-40
Metal Complex	Wool	90-98	2-10

2.1.1 General Treatment of Textile Industrial Wastewater

The majority of the dye waste and effluent produced by the textile industry is not from the dying operations but rather from the preparation activities. The primary components of dye effluent include salt, dyes, moderant, surfactants, and sizing agents. Due to their retardation and resistance to short-term anaerobic and aerobic treatment, conventional wastewater treatment plants are not suited for eliminating the reactive colours and dyes from textile effluent (Vikas Dinkar and Sandip, 2013). In textile industrial wastewater, a lot of toxic and poisonous chemicals are employed, which has increased environmental contamination. According to Saja Mohsen et al. (2020), several treatments can be used to treat textile wastewater. These can be categorised into three primary sections such as physical, chemical, and biological treatment methods. Physical treatment included flocculation, irradiation, adsorption, ion exchange, and membrane filtration, while chemical treatment included advanced oxidation, ozonation, and electrochemical degradation (Figure 2.2).

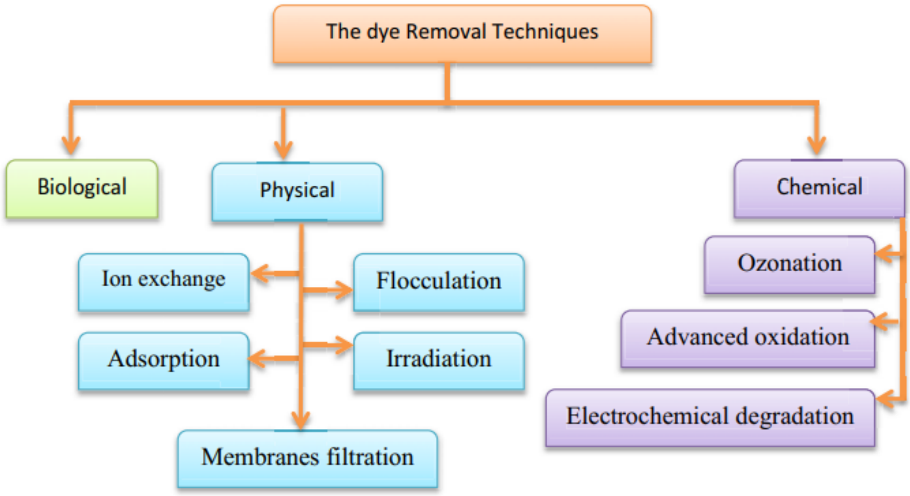

Figure 2.2: Classifying Techniques for Dye Removal (Saja, Jamal, and Talib, 2020).

Firstly, regarding the physical methods for the removal of organic dye pollutants from wastewater, these techniques are frequently utilised in the industry since they have a high potential for dye removal and incur a minimal running cost. Adsorption is a widely used technology for treating wastewater in the textile industry since it is one of the most reliable and successful methods for decolourising or removing dyes from textile effluents (Rummi Devi Saini, n.d). The procedure involves spreading wastewater soluble organic dyes from wastewater onto the surface of the solid, extremely porous adsorbent. Each compound to be removed is fully adsorbed to the adsorbent, and when the adsorbent is fully occupied, it should be replaced with new material since it has reached its maximum capacity. Besides, the other physical method is irradiation, which is better suited for decolourisation at a low volume with a wide range. Still, it requires very high dissolved oxygen to degrade dye in the textile effluents. Moreover, the physio-chemical combined treatment offers advantages over other typical treatment methods in the membrane processes. Examples include their capacity to recover dye components and valuable recyclable water, decrease freshwater consumption and wastewater treatment costs, modest disposal volumes that lower waste disposal, and so on.

The chemical treatment method is employed because physical procedures are ineffective at completely removing the dye from textile effluent and necessitate additional processing to remove solid waste, which drives up the cost of the treatment. Chemical treatments have their disadvantages, although they are frequently utilised due to their simplicity and cost advantages. The removal of organic contaminants often involves chemical techniques like flocculation and coagulation. Insoluble colors can be decomposed well by coagulation methods, however soluble pigments in textile effluent cannot.

Lastly, biological treatment is not cost-effective due to the involvement of microorganisms such as bacteria and fungi, making it not that common and popular. Aerobic and anaerobic breakdown by a combination of microorganisms may be a part of biological treatment. The biological method can effectively remove the chemical oxygen demand (COD) and turbidity but is not effective for decolourising textile effluent. The best configuration for decolourisation in biological treatment for textile effluent is a sequence of anaerobic followed by aerobic treatment.

2.2 Characteristics of Textile Wastewater

Based on the major trade organization for the sector is the American Dye Manufacturers Institute (ADMI), which claims that capital expenditures by domestic dyeing companies have surged recently, reaching $2.9 billion in 1995. It was discovered that the wastewater from the textile sector had many contaminants, including suspended solids and high total dissolved solids (TDS). Dispersants, levelling agents, carriers, salts, alkalis, acids, and different dyes are among the contaminants in dyeing effluents. The wastewater quality will vary depending on the method that creates the effluents. The majority of environmental concerns are related to the dyeing and finishing operations of the effluents, which include greater concentrations of biological oxygen demand (BOD), chemical oxygen demand (COD), heavy metals, suspended particles, and organic nitrogen. Generally, due to around 10 to 15 % of the dye being lost into wastewater during the dyeing operations, colour is often detectable at dye concentrations above 1 mg/L and has been observed in effluent from textile manufacturing at exceeding concentrations (Himanshu Patel, and Vashi, 2015).

In short, the wastewater effluent is typically viscous and brightly coloured due to the involvement of suspended particulates and dyestuff. In addition, regarding the heavy metal involved, sodium is the primary cation as sodium salts are frequently utilized in the processing units. Besides, wastewater also has a significant amount of chlorides, bicarbonate, sulphate, and nitrate, all of which have concentrations above 100 mg/L. Chromium is found in higher concentrations in heavy metals compared with other heavy metals like zinc, copper, manganese, iron, and lead. Lastly, the effluent contains high BOD and COD levels, indicating its polluting nature (Hus, Hussain, and Arif, 2004).

2.2.1 pH

Industrial textile effluent is frequently characterised by high pH, excessive salt and strong colour, particularly in the case of wastewater formed after dyeing. Lucyna et al. (2019) reported the most obvious properties of the textile wastewater matrix, especially in the case of reactive dyeing effluent, are salinity and very high pH. These parameters should be considered when choosing an effective treatment procedure. Although dye molecules are significantly impacted by pH, there is little evidence in the literature for research examining the long-term impact of pH on pond system performance and efficiency in terms of dye and other pollutants removal (Dina and Miklas, 2019).

2.2.2 Temperature

Mika et al. (2002) found that retention will be reduced as the temperature is raised until the membrane's critical temperature is reached. Following that temperature, the retention will be increased while the flux will even be reduced. Besides, the temperature will also affect the textile wastewater treatment using the adsorption method. For instance, in the adoption treatment using chitosan as an adsorbent, the results have shown that because chitosan can adsorb reactive dyes throughout a broad pH range and at high temperatures, it may remove reactive dyes from textile effluent. The analysis indicates that the shale was extremely efficient, and the ideal conditions for maximal adsorption were achieved at a temperature of 45 °C, an initial pH of 2, and 700 Pt-Co of the initial concentration (Yaseen and Scholz, 2018).

2.2.3 Conductivity

The electrical conductivity of effluent from all industries was in the range of 4,430 μS/cm to 8,710 μS/cm, with a mean value of 6,709.17 μs/cm. The quantity and kind of textile processing will determine the electrical conductivity of the effluent, which was found to be significantly higher such as more than 16 times than that of the water utilised (Hussain, and Arif, 2004).

2.2.4 Dissolved Oxygen

The amount of dissolved oxygen may have decreased due to high nutrients, Total Dissolved Solid (TDS), and Total Suspended Solid (TSS) in pure textile effluents. Textile wastewater had a lower dissolved oxygen concentration, 1.9 mg/L, than household wastewater at 2.98 mg/L (Alpha, 2021). There is a relationship between Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and dissolved oxygen. If untreated textile wastewater with high BOD values is discharged directly into surface water sources, it can quickly deplete dissolved oxygen levels. Moreover, biological life is harmful byeffluents with high COD levels (Somaji et al., 2013).

2.2.5 Chemical Oxygen Demand (COD)

The characteristics of textile wastewater reveals that the initial Chemical Oxygen Demand (COD) for effluent from various operations ranged from 800 to 30,000 mg/mL back then, while currently, the COD of textile wastewater was recorded as being between 1,600 to 3,200 mg/L (Hussain and Arif, 2022). The wastewater released from a dying process in the textile sector has a high COD level and normally exceeds the acceptable limits being 250 ppm due to the presence of dirt, grease, and dye bath additives nutrients (Singh, 2000). The COD value is more than the biological oxygen demand (BOD) readings. The wastewater has a higher chemical oxygen demand because it contains oxidizable components that are utilised at different stages of the process. The textile sector is more likely to be responsible for chemical pollutants rather than biological pollution, as evidenced by the higher chemical oxygen requirement. COD is described as the pollutant loads that result from each step in processing different raw materials. Consequently, COD elimination and more effective therapy are required (Dharmesh H. Sur and Mausumi, 2017).

2.2.6 Biochemical Oxygen Demand (BOD)

Biochemical Oxygen Demand (BOD) data extracted from the textile industry ranged from 500 to 1010 mg/L (Hussain and Arif, 2022). The organic matter that has not been oxidized will contribute to the BOD of the textile wastewater. Due to its high BOD, untreated textile effluent can quickly deplete dissolved oxygen if it is released into surface water sources (Himanshu Patel and Vashi, 2010). In addition, cotton is natural cellulose containing natural plant fiber. A portion of the cotton is removed during the various steps of the operations. The gum, starch, and enzymes are used to treat the fabric during the size and de-sizing processes, which are eventually flushed into the wastewater. This causes high biochemical oxygen demand. When synthetic fibers are used to make clothing, the biochemical oxygen demand values drop.

2.2.7 Total Nitrogen

Nitrogen may be found in a different forms, the primary source of nitrogen in textile wastewater is the nitrogen containing dyebath additives. Nitrogen-containing textile effluent should not just be released into the environment because it will speed up eutrophication. Additional issues arise because some nitrogen molecules, such as ammonia, nitrate, and nitrite, are hazardous to aquatic life or can induce illnesses in people who consume water contaminated with these substances (Mahdi, 2005). Generally, the procedures used in preparing, coating, printing, and dyeing are the sources of generating ammonia. The characterizations lead to the conclusion that wastewaters used in dyeing and printing include significant amounts of nitrogenous chemicals. Nitrite, nitrate, total Kjeldahl nitrogen (TKN), and ammonia are the most significant nitrogen components to assess in wastewater (Bisschops and Spanjers, 2003). By subtracting the ammonia content from the TKN, organic nitrogen is determined. Ion chromatography and the Kjeldahl method for nitrite and nitrate are two examples of techniques employed.

2.2.8 Ammoniacal Nitrogen

Ammoniacal nitrogen, a measure of nitrogen, is a severe issue in many industrial wastewaters due to the limits of biological and traditional physicochemical approaches. The high ammonia and nitrogen wastewater would prevent natural nitrification, result in water hypoxia, reduce the ability to purify water, kill fish, and ultimately cause significant harm to the aquatic ecosystem (Luo et al, 2015). Generally, ammoniacal nitrogen is a measurement of nitrogenous organic matter in ammonia, a harmful pollutant that can directly poison humans and disturb the balance of aquatic ecologies. The ammoniacal nitrogen must be below 30–50 mg/L, while the maximum might change based on the area (Patil et al., 2021). Textile companies that use specialized chemicals to produce wastewater, such as nitrogenous fertilizers, dyes and pigments, typically have high ammoniacal nitrogen concentrations between 1,500 and 3,000 mg/L and require certain wastewater treatment options. Biological, physical, chemical, or a mix of these approaches are often used to remove ammoniacal nitrogen from wastewater.

2.2.9 Nitrate

Nitrogen that discharged from textile wastewater is undesirable to the ecosystem because these nutrients promote eutrophication. The nitrification process changes ammonia into a more oxidized nitrogen component, such as nitrite or nitrate, which is subsequently transformed into nitrogen gas during the subsequent denitrification phase (Mahdi, 2005). More than 100 mg/L of nitrate was discovered in the effluent from industries, and the content varies between 120 and 627 mg/L. In wastewaters, the source of nitrate is the contaminants in the chemicals employed in various operations. The colours used will cause nitrate levels to rise, as this nitrite ion serves as a functional group for several dyes (Hussain et al., n.d.).

2.2.10 Total Suspended Solids (TSS)

Total suspended solids (TSS) is a water quality parameter defined as the amount of material or substances suspended in a known volume of water that a filter can capture. In many industries, TSS measurements are employed. The degree of water pollution in a body of water may be related to it. TSS measurement is crucial in industrial settings because suspended particles can cause pipe damage and blockages (Mojahid et al., 2018).

2.2.11 Total Dissolved Solids (TDS)

Total dissolved solids (TDS) are inorganic substances dissolved in water, including salts, heavy metals, and small amounts of organic substances. Some of these substances, excluding the organic materials, occasionally found naturally in the environment and water, can be necessary for life. However, if consumed more than what the body requires, it may be dangerous. One of the main factors contributing to sedimentation and turbidity in drinking water is the total dissolved solids. TDS can lead to several ailments when not filtered (Shoukat Hussain, 2019).

2.2.12 Turbidity

Colloidal particles not immediately ready to settle out are present as pollutants in the wastewater. These particles contribute to the turbidity of the water and offer some stability risks. Various pollutants, including pathogenic organisms, may be present in turbidity. Turbidity is related to various contaminants hazardous to human health, including metals and several synthetic organic compounds. Therefore, it is essential to effectively eliminate turbidity to guarantee the removal of several associated pollutants. Additionally, efficient turbidity reduction may make subsequent water treatment operations easier (Aboulhassan and Benichou, 2017).

2.2.13 Apparent Colour and True Colour

Generally, pure textile wastewater had a greater colour concentration than domestic wastewater. For instance, the colour of pure textile wastewater was 2,800 Pt-co, but after adding 80% of domestic wastewater into it, the colour was reduced to 710 Pt-co (Alpha etal., 2021). Dissolved and suspended substances may contribute to the colour of the water. In addition, there is a difference between apparent colour and true colour when measuring the colour of water and wastewater. Apparent colour refers to the sample colour received, including colour from dissolved and suspended substances in the water. True colour refers to the colour of the water sample after it has been filtered to eliminate suspended substances like algae and turbidity induced particles. Only dissolved species, such as natural organic materials, chemicals, or minerals, give water its true colour (Thermo Scientific, 2020).

2.2.14 Zinc

Zinc discovered that the concentration was less than 18 µgm/L and commonly raging to 1535 µgm/L in the textile industries, indicating that the impurities in the chemicals utilized were the source of zinc in these sectors. Additionally, a process known as synthetic fibers is responsible for several zinc concentration releases. Metalized zinc is present in the dense rayon fibers. Therefore, it is probable that the process of making dense rayon fibers caused the zinc to end up in the wastewater. The process of making dense rayon fibers raises the content of zinc in the effluent.

2.2.15 Copper

Copper levels in textile wastewaters ranging from 6 to 311 µgm/L, copper contents in the chemicals used in textile industry consists of a very low concentration (Hussain, 2004). The use of copper complex dyes results in a greater concentration of about 31 µgm/L per unit. In short, the copper complex dyes were utilized due to the greater copper content.

2.3 Membrane Technologies in Wastewater Treatment

Membrane separation technology is a technique that uses continuous, permeable molecular structures known as membranes to selectively separate items and materials from specific media (Naresh et al., 2021). High efficiency, simple operation, space savings, ease of scaling up, and environmental friendliness are the characteristics of membrane technologies that make them appealing among several separation techniques available for wastewater treatment.

As a mill or industry might have a growing number of issues, membrane separations are developing to solve those problems. Colour removal, salt reduction and reuse, BOD reduction, PVA recovery, and latex recovery are some areas of problems that can be solved by membrane technologies (Douglas , n.d.). Membrane technology is distinctive in offering a return on investment to reduce pollution. Using membrane technology, valuable and expensive products can be recovered and utilised again, which helps save overall costs.

Figure 2.3 exhibit the comparison of the removal of several contaminants using different types of processes (V. Buscio et al., 2014). Membrane treatment overall processes the best result. In this line, numerous attempts to implement various wastewater treatment technologies, including coagulation-flocculation, conventional filtration, and biological treatment systems, among others, have been made over the years. Currently, as the industry develops rapidly and the number of wastewater increases, there is development and improvement for the existing technologies to meet and fulfil the reuse standards or current discharge. Membrane technology is one of the wastewater treatment techniques that has grown significantly over this period as it brings many benefits to wastewater treatment (Elorn and Sudesh, 2020). Membrane technology presents numerous opportunities for wastewater treatment due to the large equipment size reduction, low energy need, and cheap initial capital cost. Singh and Hankins (2016) reported membrane technology has the potential to close the gap between sustainability and economics, with the possibility of little or chemical use, environmental friendliness, and widespread accessibility. In recent years, membrane technology has proven to be a more practical solution in wastewater treatment operations.

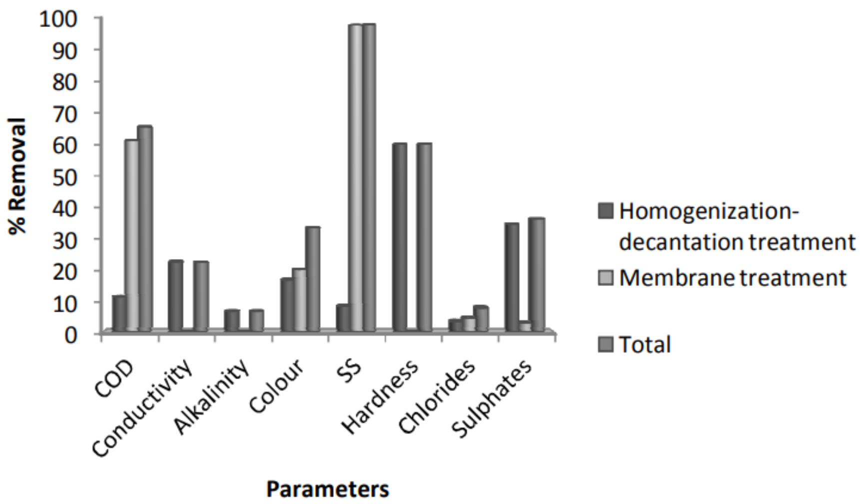

Figure 2.3: Percentage Removal of Contaminants in Several Treatments (V. Buscio et al., 2014).

Although membrane technology is not a recent development, the complexity and variety of present wastewater opportunities for further advancements in terms of effectiveness, space needs, permeate quality, and technical skill requirements. In order to improve the reduction of membrane fouling, which is a significant problem for membrane processes, membrane modules, and membrane elements are continuously modified. In several wastewater treatment plants, the possibility and potential for merging two or more membrane processes or other technologies like coagulation or adsorption are continuously being researched, developed, and deployed.

2.4 Cross-Flow Filtration and Conventional Flow Filtration

Generally, there are two common flow patterns of filtration: conventional flow filtration, also known as dead-end flow filtration, and cross-flow filtration (Figure 2.4).

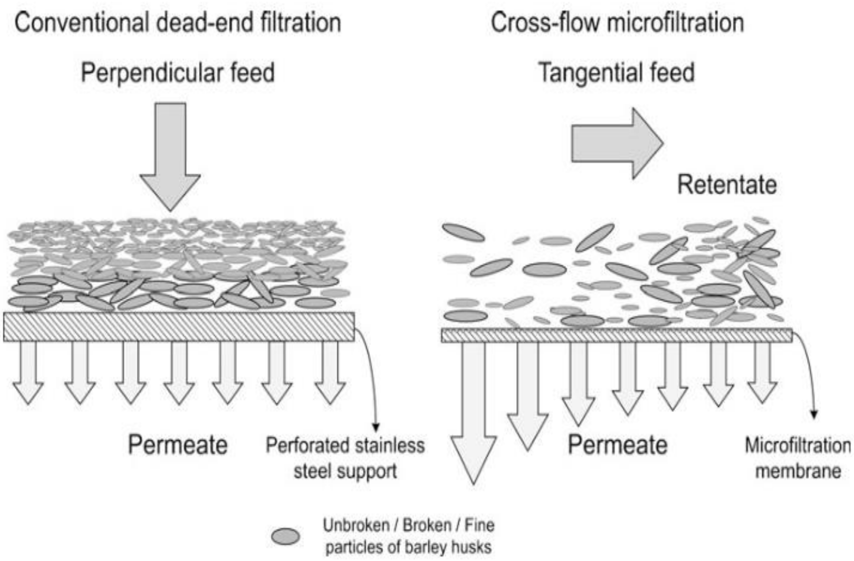

Figure 2.4: Diagram of Conventional Filtration and Cross-Flow Filtration (Alan, Nilo, and Isabel, 2014).

Cross-flow filtration happens when the flow is applied tangentially over the membrane surface (Huynh Cang Mai, 2017). As the feed flows across and goes over the membrane surface, filtrate travels through while concentrate collects at the other end of the membrane. The tangential flow produces a shearing effect on the membrane's surface, which lowers the fouling. High shear flow create a high-velocity gradient (Figure 2.5) that effectively prevents the particles from depositing on the surface of the filter medium and the filtrate will only form a very thin layer of solids and has very little flow resistance (Bott, 2000). On the other hand, dead-end filtration involves a perpendicular water flow to the membrane surface and pressure pushing the water through the membrane. The membrane allows the dead-end cell to flow through all the water that is added.

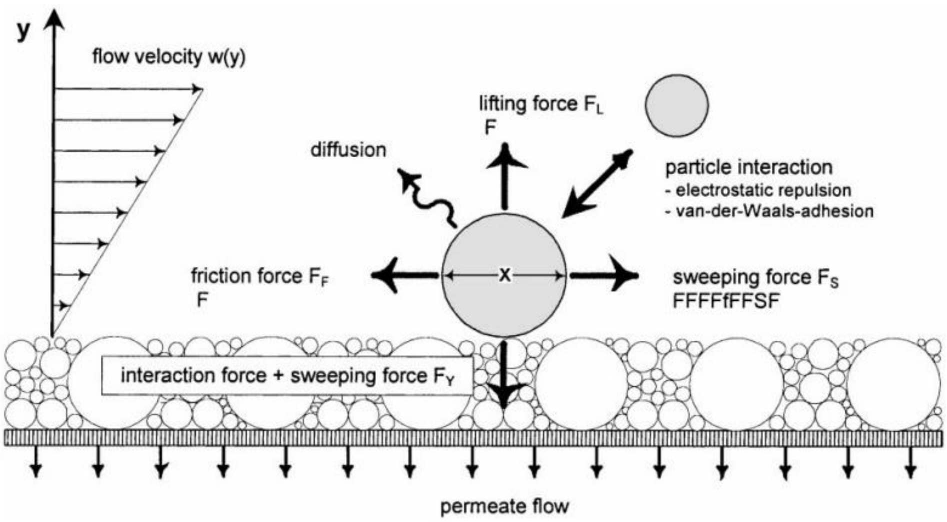

Figure 2.5: Cross-Flow Filtration Force Balance on a Particle (R. Bott, Langeloh, and Ehrfeld, 2000).

The conventional dead end flow is less desirable than cross-flow filtration in the industry due to the permeate flux does not drop as fast in cross-flow as it can remove build-up from the surface of the membrane. Cross-flow technology also contributes to reducing irreversible fouling, extending the membranes' lifespan. Dead-end filtration is normally will used in a batch-type process attributed to the separation involves a relatively low cost (Endre Nagy, 2019). Dead-end filtration primary drawbacks are severe membrane fouling and concentration polarisation, whereas cross-flow filtration is far less vulnerable to fouling because of the sweeping impact of the fluid phase's tangential flow.

Moreover, dead end flow filtration will cause filter cake more easily than cross-flow filtration. This filter cake is undesired as replacement, and maintenance will be required to replace the membrane that has filter cake as it will block the passage of the fluid and causes an increase in pressure. Hence, cross-flow filtration will be studied in this study as it brings much more benefits and is suitable for the process.

2.5 Types of Membrane

Water and wastewater treatment operations use and employ several different membrane types. In industries, the membrane separation techniques are reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF), and microfiltration (MF) (Alireza Zirehpour, and Ahmad, 2016).

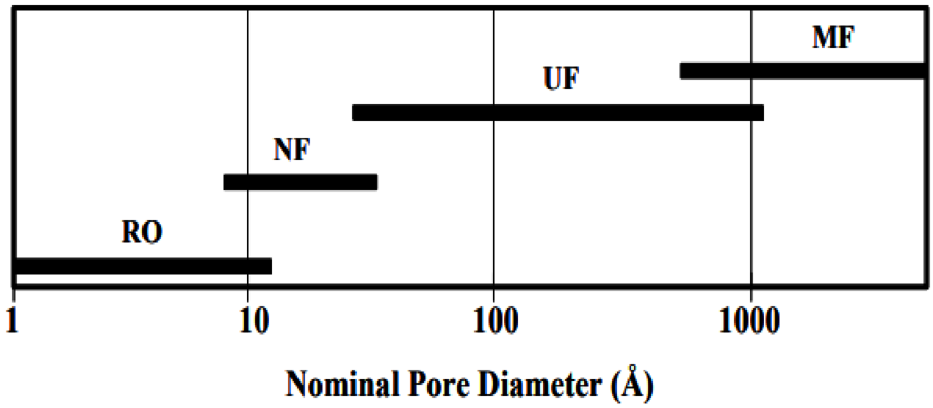

Figure 2.6: Nominal Pore Diameter for Each Types of the Membrane (Hisham et al., 2018).

The descending pore size from largest to smallest pore size is that firstly microfiltration (MF) membranes have the biggest pore size, which often rejects large particles and different microorganisms (Figure 2.6). MF membranes have a pore size between 0.05 to 10 µm (Muhammas, and Anderson, 1997). UF membranes have smaller pores than MF membranes, it can reject bacteria and soluble macromolecules like proteins in addition to big particles, germs, and bacteria. RO membranes, which are non-porous; they can filter out particles and a variety of low molar mass species like organic and salt ions. Lastly NF membrane, is also referred to as a "loose" RO membrane. Although this membrane has pores, those pores are so small that their performance falls between that of a RO membrane and a UF membrane. Pore size is the main difference in the operation and process of the membrane technology (Alireza Zirehpour and Ahmad, 2016). Table 2.2 summarises and compares the characteristics and properties of each type of membrane technology.

Table 2.2: Overview of Recognized Membrane Separation Technologies (Alireza Zirehpour and Ahmad, 2016).

Process	Reverse osmosis (RO)	Nanofiltration (NF)	Ultrafiltration (UF)	Microfiltration (MF)
Driving force	7 – 75 bar	2 – 40 bar	0.5-10 bar	0.1-3 bar
Separation Mechanism	Solution-diffusion	Solution-diffusion	Molecular Sieve	Molecular Sieve
Membrane Type	Thin-film composite membrane	Thin-film composite membrane or asymmetric polymer composite	Ceramic membrane or asymmetric polymer composite	Ceramic membranes or Symmetric polymer
Material Passed	Water	Monovalent salts, Water	Dissolved salts, Water	Dissolved solutes, Water
Material Retained	Dissolved salts	Glucose, micro pollutants, lactose, salt	Macromolecul es, colloids	Bacteria, Suspended solids

2.5.1 Ultrafiltration (UF) Membrane Filtration

Predominantly, ultrafiltration (UF) devices in wastewater treatment are typically used to recover and reuse water that contains almost no physical particles. UF is a type of membrane filtration in which factors like pressure or concentration gradients cause a separation using a semipermeable membrane. Water and low molecular weight will pass through the membrane in the permeate, while suspended particles and solutes with high molecular weight are kept as retentate.

UF is a membrane filtration procedure that uses hydrostatic pressure to push and force liquid against a semipermeable membrane, similar to RO(Jean Michel et al., 2016). The size of the molecules it retains on the semipermeable membrane, ultrafiltration is similar to reverse osmosis, microfiltration, or nano filtration and their concepts and mechanism are similar (Jean Michel et al., 2016). UF membrane is typically specified by the specific molecular weight cut off (MWCO), and it has pores size between 0.002 – 0.5 µm. The process creates water with extremely high purity and low silt density by creating a pressure-driven barrier to suspended particles, bacteria, viruses, endotoxins, and other pathogens in the wastewater (Schuster and Sleytr, 2001).

Membrane processes once thought to be only useful for desalination, are now often used to remove bacteria and other microorganisms, particulate matter, and naturally occurring organic material, which can alter the colour, taste, and odour of water and interact with disinfectants to produce disinfection by-products (DBP).

2.5.2 Ultrafiltration Principle and Mechanism

The principle of the UF process schematic diagram is shown in Figure 2.7 (Li et al., 2009). The driving force of this process is the pressure difference produced by the two sides of the membrane. The mechanism of UF is that the sizes of solutes will be dragged due to the fluid flow to the opening of the pores of several different diameters (Yurity and Andrew, 2013). Solutes smaller than the membrane pore diameter and the solvent in the raw material liquid pass through the pores from a region of the high-pressure side to the low pressure side. However, solutes with equal to or larger molecular weight than the pore size are entirely trapped and plugged into the pore mouth of the membrane.

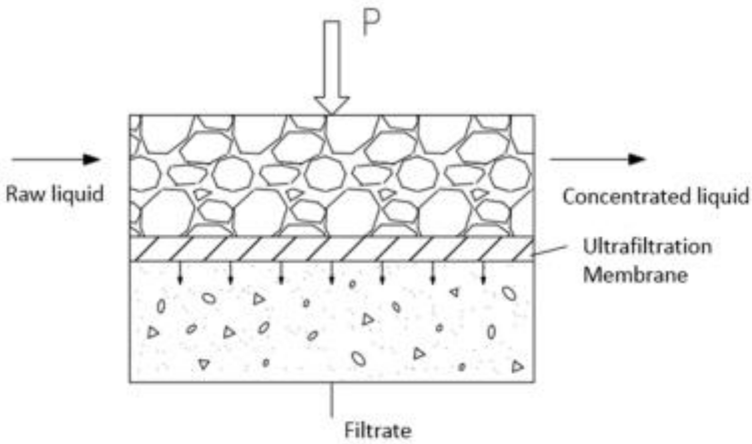

Figure 2.7: Principle of Ultrafiltration Process Schematic Diagram (Li et al., 2009).

To summarize, the membrane only allows small molecular substances, inorganic salts, and water to pass through during fluid flow, while larger molecules like colloids and suspended solids are blocked, as illustrated in Figure

2.8. The main mechanism for retaining these particles is physical screening, although some smaller particles may not be trapped due to their size. Nevertheless, the membrane still has a significant separating effect, possibly due to chemical characteristics like electrostatic effects on the membrane surface. There are three main retention mechanisms of ultrafiltration membranes: adsorption on the membrane's surface and pores, pore retention, and removal of mechanical pores on the membrane surface.

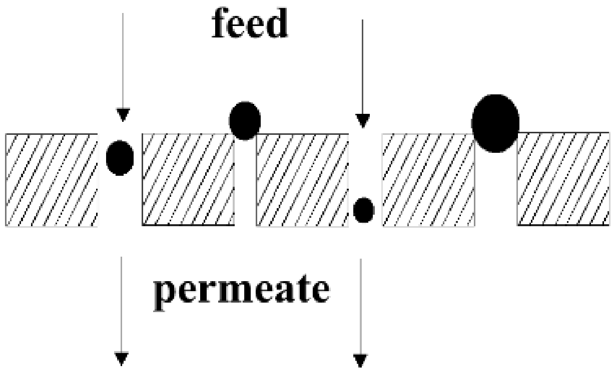

Figure 2.8: Schematic Diagram of Different Sizes of Pores and Block the Solutes Completely (Yurity S., and et al., 2013).

2.5.3 Microfiltration (MF) Membrane Filtration

MF is one of the earliest membrane processes driven by pressure; however, when it comes to the filtration of macromolecules and suspensions (Georges, Robert, and Andrew, 1994). MF is characterised by crossflow mode in flat or cylindrical geometries, low-pressure operation, and high permeation fluxes. Membrane separation is used on a variety of feed streams, including gases and colloids. In order to separate small particles, MF membranes are employed in addition to conventional filtration. MF membranes are used to retain colloidal particles as large as several micrometers (Eykamp, 1995). Moreover, the primary limitation of microfiltration is membrane fouling caused by the accumulation and infiltration of macromolecules, colloids, and particles into the microporous membrane. Microfiltration is a membrane technology that uses microporous membranes to retain suspended colloids and particles in the size range of approximately 0.1 to 20 mm. Unlike RO and UF, microfiltration typically operates at very high permeation fluxes, ranging from 10^{-4} to 10^{-2} m/s for unfouled membranes, and relatively low transmembrane pressures, generally below 50 psi (Georges et al., 1994). In terms of pore size, microfiltration membranes have the largest pores, followed by ultrafiltration (UF) membranes.

Two primary broad categories of MF membranes are ceramic and polymeric, each of which has benefits and drawbacks (Zhao et al., 2013). Chemically and thermally stable ceramic MF membranes have good longevity, although they are less flexible, less productive, and more expensive. The structural geometry of pores, macro-void creation, thickness factor, and matching pore size distribution contribute to the low permeability and high fouling properties of porous polymeric membranes produced using the well-known phase inversion process.

2.5.4 Microfiltration Principle and Mechanism

The sieving mechanism is commonly used in MF to separate the materials. Anisotropic and isotropic membranes can both be used for MF; however, the separation layer should ideally be between 10 and 50 micrometers (μm) and 1 micrometer (μm), respectively (Norfazliana et al., 2018). As mentioned above, microfiltration membranes typically operate under pressure and have pores with a size between 0.1 and 10 μm. According to Randeep and Mihir (2019), the relationship of equation 2.1 shown below can be used to calculate the overall membrane flux of a microfiltration membrane:

$$F = \alpha \, . \, \Delta P \tag{2.1}$$

Where,

F constitutes the overall membrane flux;

α constitutes the permeability constant;

ΔP constitutes the transmembrane pressure.

Generally, the pores of these membranes are typically considered to be cylindrical and uniform, so that the Hagen-Poiseuille equation and the Kozeny-Carman equation can be used to calculate various membrane properties. In the relationship of equation 2.2 shown below, the Hagen-Poiseuille connection can be applied as given:

$$F = \frac{\eta\, r^2\, \Delta P}{8\, \eta\tau\, \Delta l} \tag{2.2}$$

Where,

μ constitutes the membrane porosity;

r constitutes the membrane pore radius;

η constitutes the dynamic viscosity;

Δl constitutes the membrane thickness;

τ constitutes the tortuosity factor.

Moreover, if feed particles are considered to be spherical and aggregate, the Kozeny-Carman equation that is shown as equation 2.3 below can be used in the microfiltration membrane system as shown in the following relation:

$$F = \frac{\mu^3\, \Delta P}{\chi\, \eta\, A^2\, \Delta x} \tag{2.3}$$

Where,

χ constitute the dependent dimensionless constant of pore geometry;

A_p constitute the spherical particles per unit surface area of volume.

In short, the membrane flow is related to the membrane's structural characteristics, including porosity (μ) and pore size (r), according to the Hagen-Poiseuille equation and KozenyCarman equation. Therefore, a microfiltration membrane with a narrow pore size distribution and high porosity is necessary to have an overall effective membrane flow.

2.6 Parameter Studies

2.6.1 Effect of Commercial Filtration Membrane

Synthetic organic polymers such as polyamide (PA), Polyester sulfone (PES), Polysulfone (PS), Poly vinylidene fluoride (PVDF), Polyacrylonitrile (PAN), Regenerated cellulose (RC), and Cellulose acetate (CA) are commonly used to manufacture NF, RO, UF, and MF membranes. The same materials are often used to produce both MF and UF membranes, but they undergo different membrane formation conditions, leading to different pore diameters and sizes. PVDF, PS, and PAN are typical polymers used for MF and UF membranes, while UF membranes also commonly use PES material. PS or CA membranes coated with aromatic polyamides are typically used for RO membranes. NF membranes can be modified versions of UF membranes, such as sulfonated polysulfone (PS) or cellulose acetate (CA) blends like RO membranes, polyamide composites, or both (Alyson and Benny, n.d.).

Commercial UF and MF membranes are made from various polymers, ranging from entirely hydrophilic polymers like CA to fully hydrophobic polymers like PP and PE. PES, PS, PVDF and PAN fall somewhere in between these two extremes. Although these polymers are hydrophobic, additives such as pore formers, co-polymers, or post-treatment can be added to modify the membrane properties. The membrane polymer must be cost-effective for large-scale applications. Initially, commercial products in the wastewater and water industry were based on PS, CA, and PP, but currently, most of the market is supplied by products and goods using PES and PVDF. Table 2.3 provides an overview of the characteristics and properties of UF and MF membranes.

PES is a widely used polymer in the industry due to several characteristics (Pearce, 2007). Firstly, it can be co-dissolved with other polymers, making it a suitable choice for polymer blend membranes. This allows for modification and improvement of the hydrophilic properties of the final membrane. Wet spinning is advantageous because it enables pore size and other membrane properties to be adjusted depending on the spinning conditions chosen. PES can also be made hydrophilic by combining it with specific polymers, providing the advantages of cellulose acetate's hydrophilicity while avoiding its limitations, such as low tolerance for caustic cleaning agents and biodegradability. Additionally, PES's properties can be modified by blending with other polymers, making it ideal for polymer blending and ultrafiltration. In the water treatment industry, both the PS and PES polymer families, as well as PVDF, are becoming the preferred choices. These polymers possess excellent properties, including high UF ratings, the ability to generate hydrophilic membranes, and exceptional chemical resistance and tolerance.

Table 2.3: Ultrafiltration and Microfiltration Properties and Specification (NoHwa Lee, Gary, and et al., 2004).

At pH 7.0 and 5 mM KCI.

Membrane Type	Ultrafiltration (UF)		Microfiltration (MF)	
	Hydrophilic	**Hydrophobic**	**Hydrophilic**	**Hydrophobic**
Pore size	100 kDa	100 kDa	0.22 mm	0.22 mm
Membrane code	YM100, Millipore	PES, Orelis	GSWP, Millipore	GVHP, Millipore
Materials	Regenerated cellulose	PES	Mixed cellulose ester	PVDF
Pure water permeability	15.7 (gal/ft^2 day psi) / 372 (L/m^2 h bar)	5.15 (gal/ft^2 day psi) / 122 (L/m^2 h bar)	158.9 (gal/ft^2 day psi) / 3770 (L/m^2 h bar)	36.1 (gal/ft^2 day psi) / 856 (L/m^2 h bar)
Roughness	22.9	6.4	96.7	94.1
Contact angle	18˚	58˚	19˚	83˚
Zeta potential (mV)[a]	-3	-32	+20	-7

2.6.1.1 ME010 (MF membrane, PES material)

Typically, MF membrane acts as a pre-treatment for other separation techniques like ultrafiltration. Particle sizes utilised for MF membrane typically vary from 0.1 to 1 μm. These membranes can pass through water, monovalent species, inorganic salt, suspended solids, and tiny colloids while blocking suspended solids, bacteria, and other macromolecule colloids. MF systems operate at comparatively low pressures, typically 0.3-7 bar, compared to ultrafiltration systems.

Spiral MF membranes are available in various pore sizes and membrane materials. They have an ideal surface area-to-volume ratio and a compact design. The feed spacer material's thickness allows for the feed channel height (from 13 to 120 mil), which aids in adjusting the liquid's viscosity or solids content. Due to the minimal energy demand and superior hydrodynamics provided by this design element. Acid or caustic resistant, fouling resistant, or high temperature membrane materials are offered to satisfy some specific applications.

2.6.1.2 UE050 (UF membrane, PES material)

UF membranes typically have a molecular weight cut-off ranging from 1,000 to 200,000 Dalton, and they employ a pressure-driven membrane technique to separate solution components based on their molecular shape and size. The membrane retains larger solute species, which are recovered as saturated retentate, while smaller solute species and solvent pass through the membrane and are collected as permeate under an applied pressure differential across the membrane. UF membranes have a small size and a high surface-to-volume ratio, and the feed channel height can be adjusted by changing the thickness of the feed spacer material, typically from 13 to 120 mil, to modify the liquid's viscosity or particle concentration. This design element, combined with low energy requirements, results in good hydrodynamics. Additionally, UF membranes can be made from materials that are resistant to caustic or acidic environments, high temperatures, or fouling to meet specific application needs, similar to MF membranes discussed earlier.

2.6.2 Effect of Flow Rate

The effectiveness of the process when ultrafiltration and microfiltration is used to treat the aqueous effluent solution containing organic dyes depends on the fluid flow through the membrane module (Majewska, Winnicki, and Wisniewki, 1988). Since the deposited materials are continuously removed, higher shear rates at the membrane surface are crucial for preventing membrane fouling because they lower the hydraulic resistance of the fouling layer. A too low velocity causes concentration polarisation and fouling to rise, which causes the flux to drop quickly and necessitates frequent cleaning. The permeate flux generally improves as the cross-flow rate increases (Nisha, and Dianne, 2003).

2.6.3 Effect of Pressure

With the aid of the ultrafiltration process in treating a dye of aqueous inkjet colourant, the results demonstrate that raising the pressure will cause the permeate flow to rise by an average of 6 % (Zambujo, 2012). The findings imply that operating at 40 bar has no advantages for removing contaminants. At 40 bar pressure, contaminants generally had a slower removal rate. For instance, a 3% increase in metal ion rejection was observed. The findings are a result of the polarisation concentration phenomenon and the molecular aggregation the dye molecule forms on the membrane surface. With a rise of 25% in the permeate colour losses, the process yield at 40 bar was reduced. The amount of water used during diafiltration is greater under these circumstances. The results were interpreted to mean that the process would not be significantly improved by greater pressure.

Loss of colour due to permeation. The run at 40 bar exhibits more colour losses than the run at 30 bar, resulting in a 25% increase in colour loss. It has been demonstrated that increasing pressure does not always result in a greater elimination of contaminants. Higher fluxes do not result in higher impurity removal since the resistance on the membrane surface increases due to the concentration polarisation phenomena and the dye molecules' propensity to combine with other macromolecules. It is determined that more wash volumes are needed while operating at a greater pressure (Zambujo, 2012).

2.6.4 Effect of Concentration

Zhou (2012) reported cross-flow filtration is a rapid method for separating a specific portion of a sample, such as colloidal fraction, and can be easily customized for different applications. Adjusting the concentration factor (CF) enhances retention of smaller or larger colloidal particles. The range of CF also offers other benefits, such as enabling analysis of samples from estuaries with high concentrations of dissolved organic matter (COM) and marine samples with low COM using the same tools.

Concentration polarization is a common phenomenon in all crossflow filtration techniques, where the solute or particle concentration is higher near the membrane surface than in bulk. This occurs when the membrane has varying permeability for different solution or suspension elements. The subsequent concentration layer at the membrane surface increases filter resistance, decreasing permeate flow through the membrane (Song and Elimelech, 1995). Since high permeate rate is desirable in filtration operations, concentration polarization is an important consideration.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Materials Involved in the Project

There are two types of membranes used in this study, namely a UF membrane (UE050) and an MF membrane (ME010) (Table 3.1). Each membrane underwent investigation for 5 sets of pressure and 5 sets of wastewater flow rate, respectively, to obtain the best performance and optimum operating conditions.

Table 3.1: Membrane Used in This Project.

Membrane	**Membrane Type**	**Membrane Material**	**MWCO (Dalton)**	**Flux rate (LMH) at 25 ˚C, 0.35 MPa**	**Supplier**	**Typical application**
UF membrane	UE050	Polyether sulfone (PES)	50,000	260	RisingSun Membrane Technology (Beijing) Co., Ltd.	Colour removal, enzyme concentration, clarification of beverage, NF or RO Pre-treatment
MF membrane	ME010	Polyether sulfone (PES)	-	>320	-	Pharmaceutical/ Biotech; Enzyme clarification; Separation of protein; NF or RO Pre-treatment

3.2 Sand Filtration

Pre-treatment is the procedure carried out before membrane filtration is accomplished. This procedure can be used to reduce the amount of particles and microorganisms present in water and should be the initial step in the membrane filtration of highly contaminated feed water. Pre-treatment that works can cut down on regular cleaning and downtime for the system. Generally, effective pre-treatment takes place when membrane cleaning is decreased to at least 4 times annually. In this case, sand filtration will serve as pre-treatment before the treatment of cross-flow filtration treatment using UF and MF membrane to remove the large particles, large suspended solids and so on to protect and prolong the useable lifetime of the membrane. Sand filters are made up of two to three foot deep beds of sand or other suitable granular material. A liner consisting of concrete, plastic, or another impermeable material houses the filter materials. In industry, the filter's location usually will be located above ground, partially above ground, or below ground. Besides, the type of filter surface single pass or covered depend on the design. Ventilation is necessary to maintain aerobic conditions if it is covered. The performance of UF is significantly improved by removing these contaminants (Zheng et. al., 2009). Figure 3.1 below shows the set-up of sand filtration as pre-treatment of the textile effluent that will be employed in this experiment.

Figure 3.1: Set-up of Sand Filtration.

3.3 Experimental Setup

The study involved preparing and examining UF membrane (UE050) and MF membrane (ME010) to determine their respective characteristics. To remove impurities and contaminants from the textile wastewater, sand filtration was conducted as a pretreatment. Next, each membrane was tested in a cross-flow unit using specific parameters such as pressure and wastewater flow rate. The performance of the treated water was assessed by calculating Water Flux (J) and Removal Efficiency (%). Subsequently, the optimal operating pressure for UF and MF membrane was determined for a specific set of water characteristics. The optimal operating wastewater flow rate was determined for a specific set of effluent or water sample characteristics to evaluate all relevant physiochemical characteristics parameters.

3.3.1 Schematic Diagram

The overall Schematic diagram of the project is summarized in Figure 3.2 below.

Preparation of membrane involved.

- UF membrane (UE050)
- MF membrane (ME010)

↓

Characterization of UE050 and ME010 membranes.

- Membrane morphology (SEM)
- Membrane porosity
- Pore size

↓

Collect textile wastewater from Lagoon 3, and pass through a Sand Filtration System. Parameter testing involved.

↓

Parameter Studies

- Effect of commercial filtration membrane (UF and MF membrane)
- Effect of Supplied Pressure (2, 4, 6, 8, 10 bar)
- Effect of Wastewater Supplied Flow Rate (2, 3, 4, 5, 6 LPM)

↓

Calculate the Water Flux (J) and Removal Efficiency (%) for every controlled condition.

↓

Characterization of Water Sample for the Best Performance Operating Parameter for both Membranes.

- pH (pH meter)
- Temperature (Thermometer)
- Conductivity (Conductivity Meter)
- Dissolved Oxygen (Dissolved Oxygen Meter)
- Biochemical Oxygen Demand, BOD (Dissolved Oxygen Meter)
- Chemical Oxygen Demand, COD (Spectrophotometer, reactor block)
- Total Nitrogen (Spectrophotometer)
- Ammoniacal Nitrogen (Spectrophotometer)
- Nitrate (Spectrophotometer)
- Total suspended solid
- Total dissolved solid
- Turbidity (Turbidity meter)
- Colour (ADMI) (Spectrophotometer)
- Colour (Pt-co) (Spectrophotometer)
- Zinc (Spectrophotometer)
- Hardness, Ca/Mg (Spectrophotometer)

Figure 3.2: Overall Flow Chart and Parameters of Membrane Filtration.

3.3.2 Cross-Flow

Figure 3.3 below shows the cross-flow filtration unit for the membrane filtration process of treating textile wastewater. A big tank is involved at the bottom part of the cross-flow unit and is to be filled with the textile wastewater that will be examined with the membrane involved (Figure 3.4). A pump is used to suck out the water from the tank and carry it to cross-flow with the membrane. Permeate of the membrane will be collected. Besides, the cross-flow unit consists of two bypasses that aim to control the desired pressure, wastewater flow rate, and the system's safety.

The study involved adding the effluent from Lagoon 3 of the textile industry into the cross-flow filtration system and examining two types of membranes, namely the UE050 UF membrane and ME010 MF membrane were placed in the container shown in Figure 3.4. Each type of membrane underwent examination under 5 sets of pressure values, while the wastewater flow rate was maintained at a constant 6 LPM. Additionally, 5 sets of wastewater flow rate values were used while the pressure was set to the previously determined best operating pressure. The optimal operating parameters for each membrane type were determined, and sets of wastewater characteristics were investigated. This process was conducted to complete the textile effluent treatment and collect permeate samples for further analysis of the contaminant parameters.

Figure 3.3: Cross-Flow Unit.

Figure 3.4: Membrane Holder.

3.4 Characterisation of Membrane

Ultrafiltration membrane (UE050) and Microfiltration membrane (ME010) were investigated using a variety of analyses in order to study and have a better understanding of their physical and chemical properties.

3.4.1 Scanning Electron Microscope (SEM) Analysis

Scanning electron microscopy (SEM), is a powerful and potent analytical technique that may be used to analyze various materials at high magnifications and provide high-resolution images. SEM is a method frequently used to identify solid materials' morphology, topology, and fine surface structure (Khaled, 2019). The membrane morphology was analyzed in this case. A sample is scanned using electron beams in the scanning electron microscopy. An electron gun fires these beams and then accelerates as they pass through the column of SEM. SEM works by detecting the high-energy electrons that are released from the sample's surface when exposed to a tightly concentrated electron stream from an electron gun. This electron beam is concentrated in a narrow area on the sample surface using the SEM objective lens. The best images can be obtained by optimizing variables such as the size of the aperture, the accelerating voltage involved, and the working distance between the sample and the electron gun.

3.4.2 Membrane Porosity

The membrane porosity (Ɛ) was determined by dividing the pore volume by the porous membrane's total volume, which is a gravitational method (Ahmad, 2012). It was evaluated by weighting each of the dried samples (W_2), soaking it into iso-butanol with 98% purity for two hours to fill in all the pores, and drying the surface for 10 minutes at the air hood until no dropping of the solution from the membrane, and then reweighting it (W_1). The values for Ɛ were then calculated using equation 3.1 below.

$$\varepsilon = \frac{\frac{(W_1 - W_2)}{\rho_b}}{\frac{(W_1 - W_2)}{\rho_b} + \frac{(W_2)}{\rho_{PES}}} \text{ x } 100\ \% \quad (3.1)$$

Where,

Ɛ represent to membrane porosity,

W_1 represent the wetted membrane weight (g)

W_2 represent the dry membrane weight (g)

ρ_{PES} represent the density of PES (1.37 g/cm^3)

ρ_b represent the density of iso-butanol (0.802 g/cm^3)

3.4.3 Water Flux

The analysis of water flux is a kind of water permeability test that was used to investigate the permeability performance of the UF membrane and MF membrane under different controlled parameters. It is a common method to determine the performance of the filtration method, and it represents the flow rate of the water sample applied per unit surface area of the membrane. The test is to evaluate the efficiency of the cross-flow filtration of the membranes by investigating the flux of treated water. Generally, the higher water flux is favourable as wastewater can be treated at a higher rate. The effective membrane surface area was determined, and the sampling time to obtain 200 mL of treated water was measured and recorded. This information is then used to determine the water flux using Equation 3.2 below.

$$J = \frac{Q}{At} \tag{3.2}$$

Where,

J = Water Flux ($\frac{L}{m^2h}$)

Q = Volume Flux or Permeate Quantity (L)

A = Effective Membrane Surface Area (m^2)

t = Sampling time (h)

3.4.4 Removal Efficiency (%)

Removal Efficiency needs to be investigated as it defines the effectiveness of the separation process in the filtration system. The removal efficiency refers to the proportion of material that is filtered out by the system compared to the amount of material that enters the system. All water samples that have been treated underwent a determination of removal efficiency to investigate their removal performance. For instance, Turbidity with the unit of NTU is used in the calculation of removal efficiency that determines the amount of NTU that has been removed. This amount of turbidity (NTU) is determined by using a Nephelometer. Equation 3.3 below shows the equation for the calculation of the separation efficiency.

$$\text{Removal Efficiency (\%)} = \frac{NTU_i - NTU_f}{NTU\ i} \text{ x } 100\ \% \tag{3.3}$$

Where,

NTU_i = initial Nephelometric Turbidity Units (NTU)

NTU_f = final Nephelometric Turbidity Units (NTU)

3.5 Characterisation of Water Sample

The treated textile industrial wastewater was investigated using a variety of analyses in order to study and have a better understanding of the treatment efficiency and quality of the treated effluents. A total of 16 physiochemical parameters will be involved in the water quality analysis.

3.5.1 pH Meter

The treated water's pH value will be measured using a pH meter. A pH meter is equipment that detects the activity of hydrogen ions in the solution and hence measures the acidity or alkalinity of the solution. The pH scale, which typically varies from 1 to 14, is used to describe the level and degree of hydrogen ion activity. In addition, calibration of the pH meter is required before the measurement; the electrode needs to be placed in a buffer solution with three distinct pH values, such as pH 4, pH 7, and pH 10. This calibration is to maintain accuracy and consistency to obtain reliable results (Sciencing, 2022).

3.5.2 Thermometer

The temperature of the effluents was investigated by using the thermometer. Generally, the freezing point and boiling point are measured in studies using a laboratory thermometer. Besides, it is also employed to determine the temperature of products which is the treated wastewater that has to undergo the cross-flow filtration unit in this case. In addition, a thermometer measures the temperature in the range of -10 ˚C to 110 ˚C.

3.5.3 Conductivity Meter

Conductivity is one of the physiochemical parameters of water samples determined by the conductivity meter. Conductivity is the ability of the material, such as metals, solutions, or gases, to conduct the electrical current and electricity, while the conductivity of the treated water was examined in this case to identify the quality of the water. Then, a conductivity meter was employed to determine the conductivity of the respective solutions. Since all materials can conduct electrical currents, the extent of this capacity will vary.

3.5.4 Dissolved Oxygen Meter

The dissolved oxygen meter is used in this case to determine the value of the water sample's Dissolved Oxygen and Biological Oxygen Demand (BOD) of the water sample. The testing method of the Dissolved Oxygen is by using the

Diaphragm Electrode Method, while Dilution Method was used to determine the BOD with the aid of a dissolved oxygen meter. The dissolved oxygen meter is a portable or benchtop device, sensors, and probes used to evaluate the amount of dissolved oxygen in the water and other solutions. It is frequently used as an instrument to evaluate the oxygen saturation levels or the BOD which measures the sample of biodegradable material (Fisher Scientific, n.d.). Generally, there are three types of measurement methods of dissolved oxygen such as optimal or electrochemical sensor, Colorimetric Method, and Winkler Titration, which is a traditional method (Fondriest Environment, 2022).

3.5.5 Spectrophotometer

The equipment utilized to determine various physicochemical parameters of water samples in this study is the spectrophotometer. It is capable of measuring parameters such as Chemical Oxygen Demand (COD) using the USEPA1 Reactor Digestion Method, Total Nitrogen using Persulfate Digestion Method, Ammoniacal Nitrogen using Salicylate Method, Nitrate using Cadmium Reduction Method, Apparent Colour, True Colour, Zinc using USEPA Zincon Method, and Hardness using Calmagite Colorimetric Method. The spectrophotometer functions by measuring the photons absorbed by a sample solution after passing a light beam through it and measuring its intensity. The device can also estimate the quantities of a known chemical compound based on the intensity of the detected light. UV-visible spectrophotometers are commonly used in water quality analysis, which employ light in the ultraviolet range of 185 to 400 nm and the visible range of 400 to 700 nm on the electromagnetic radiation spectrum. Conversely, IR spectrophotometers use light over the infrared range of 700 to 15,000 nm of electromagnetic radiation spectrum (LibreTexts, 2022). In this study, UV-visible spectrophotometer was utilized for analysis.

3.5.6 Turbidity Meter

Turbidity measures the water clarity in rivers, streams, oceans, and lakes. In this study, the turbidity of the treated water was examined using a turbidity meter to determine the filtration efficiency. Turbidity is the quantity of light that suspended particles in a water sample scatter or obstruct. Low turbidity is found in clear water, whereas high turbidity is found in cloudy or muddy water. Particles of dirt, organic debris, metals, or similar materials suspended in the water column will generate turbidity.

Besides, the units of the turbidity meter depend on the angle of the detector and the wavelength of the light. Nephelometric Turbidity Units (NTU) is the common turbidity measure used in this study. The nephelometric approach contrasts the quantity of light scattered in a reference solution with how light is dispersed in a water sample. Turbidity is frequently measured with an electronic handheld meter. A Secchi disc or other comparable equipment may also be used to conduct the measurements.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Characterisation of UF and MF membrane

4.1.1 Morphology of UF and MF membrane

The essential aspects of both UF and MF membranes are their top surface and cross-section structures, which indicate how well the membrane functions in the mechanisms of permeation and rejection. SEM images shown in Figure 4.1 (a) to (c) revealed the structural morphology of the unused inner surface commercial ultrafiltration membrane (UE050) in the magnification of 5,000X, 15,000X, and 25,000X, respectively. The scanning electron demonstrates that the PES material UF membrane surface structure was relatively dense and smooth. The distribution of pores on the UF membrane surface is generally homogeneous. Besides, Figure 4.2 (a) – (b) shows the SEM top surface image of the original PES material UF membrane from the previous literature studies (Salgin et al., 2006; Zhao et al., 2012). The UF membrane utilized in this study (Figure 4.1) appears to have lesser pores, leading to lesser membrane porosity than the reported in literature (Figure 4.2). UF membranes with greater pores can typically offer greater flux rates and higher permeability than membranes with lesser pores. In contrast, membranes with more pores may also be more subject to fouling and clogging, which can lower their performance and durability. In order to optimise the performance between durability and reliability, the ideal pore size and pore density of a UF membrane must be carefully selected according to the specific application and operating conditions.

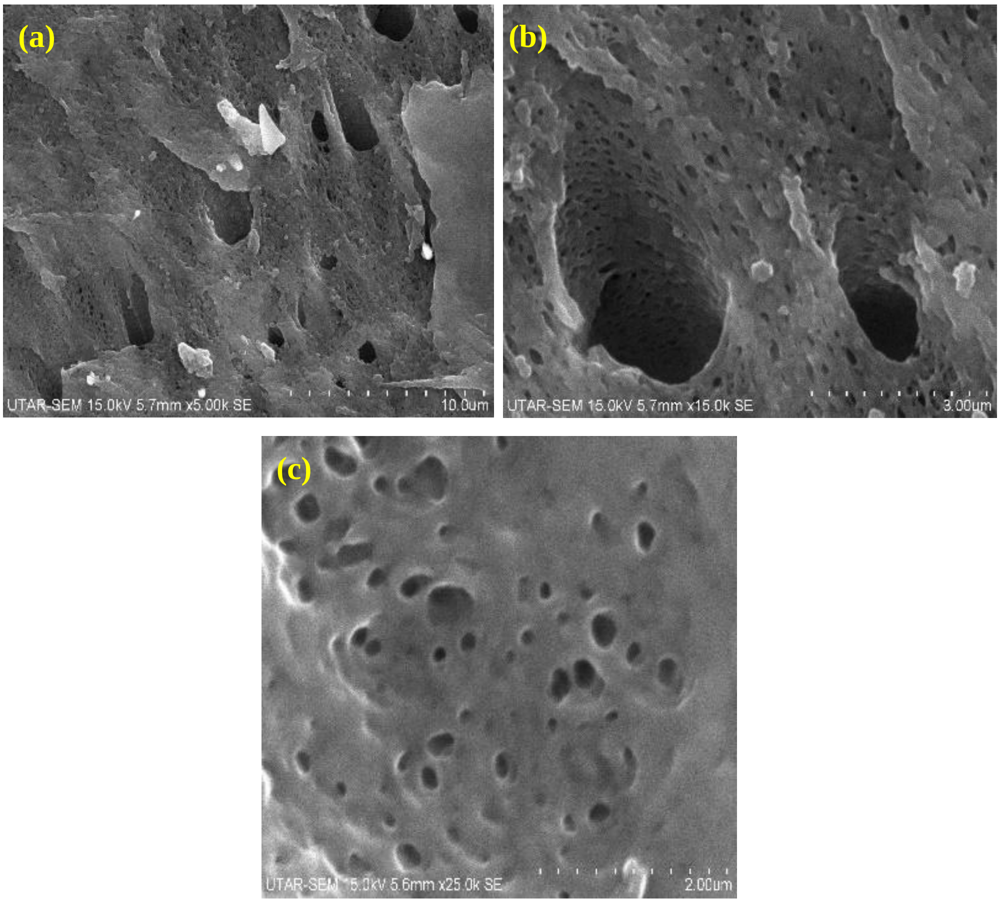

Figure 4.1: SEM Image of (a) Commercial UF Membrane (5,000X) (b) Commercial UF Membrane (15,000X) (c) Commercial UF Membrane (25,000X).

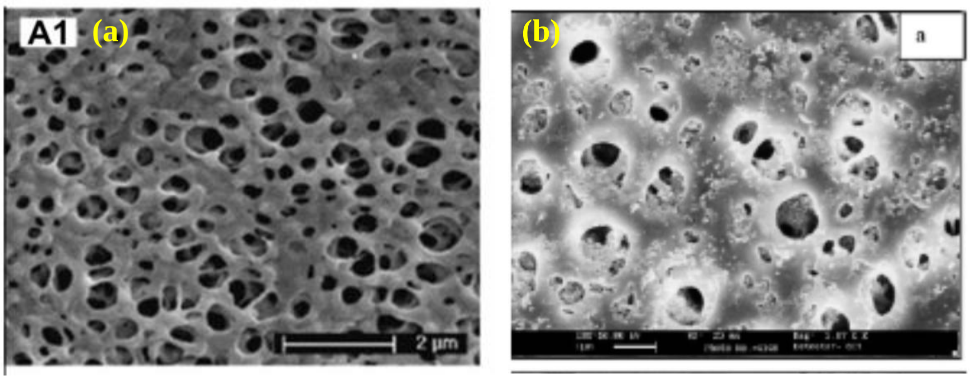

Figure 4.2: SEM Image of (a) Original PES Material UF Membrane (Zhao et al., 2012) (b) Clean PES Material UF Membrane (Salgin et al., 2006).

Figure 4.3 (a) – (c) shows the SEM images of the structural morphology of the unused inner surface commercial microfiltration membrane (ME010) in the magnification of 700X, 2,500X, and 5,000X, respectively. It can be seen that the ME010 membrane has a larger pore size compared to the UF membrane from Figure 4.1 (a) – (c) as with 700X magnification of MF membrane, the pore structure already can be seen clearly while the UF membrane pore structure can only be seen with a magnification of 5,000X. The texture and roughness of the MF membrane can be seen in the surface morphology in Figure 4.3 (a) – (c). The membrane surface appears to be a smooth surface that can help prevent the formation of fouling layers; however, a rough surface can increase the surface area available for particle capture. Moreover, Figure 4.4 (a) – (b) shows the top surface SEM image of the PES material MF membrane from the Journal Article (Gao et al., 2019; Elele et al., 2019). It appears that the structure of the pores of the utilized MF membrane (Figure 4.3) and the Journal Article MF membrane (Figure 4.4). Both Figures 4.3 and 4.4 show that the pore structure is irregularly shaped. Irregularly shaped pores may be more efficient at capturing particles due to the increased surface area available for adsorption than circular pores structure.

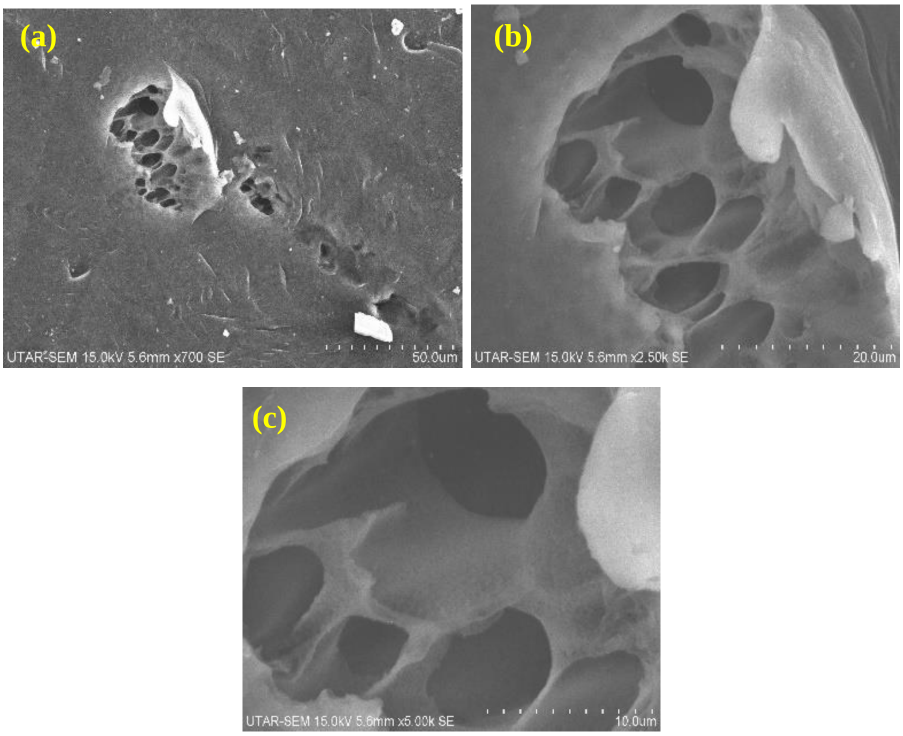

Figure 4.3: SEM Image of (a) Commercial MF Membrane (700X) (b) Commercial MF Membrane (2,500X) (c) Commercial MF Membrane (5,000X).

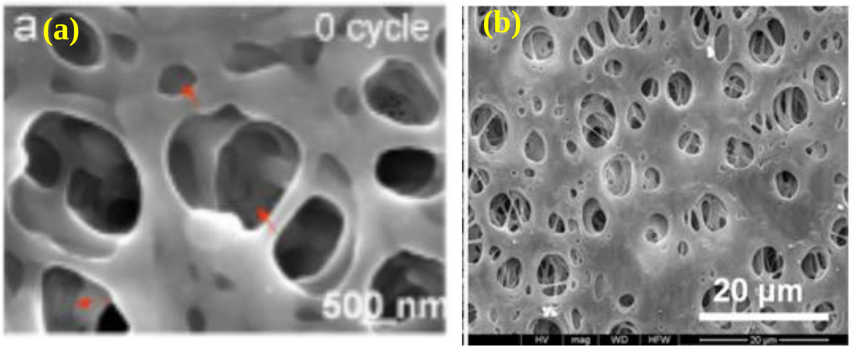

Figure 4.4: SEM Image of (a) Original PES Material MF Membrane (Gao et al., 2019) (b) Original PES Material MF Membrane (Elele et al., 2019).

The cross-section structure of the membranes was observed by scanning electron microscopy (SEM) after fracturing in the liquid nitrogen. The cross-section was coated with a thin gold layer. Figure 4.5 (a) – (b) illustrates the SEM cross-sectional images of commercial UF membrane (UE050) in the a magnification of 300X and 400X, respectively, while Figure 4.6 (a) – (b) illustrates the SEM cross-sectional image of commercial MF membrane (ME010) in the magnification of 300X and 400X respectively.

Based on the morphological analysis, it was observed that the membranes in this study exhibited an asymmetric structure, which is typical of UF and MF membranes. Specifically, all of the membranes had a dense top layer with a sponge-like structure and a porous sublayer with a finger-like structure. This sublayer provided mechanical support, while the dense top layer regulated the permeation and rejection of solutes (Hossein et al., 2015). Additionally, the sublayer exhibited macro voids and finger-like cavities.

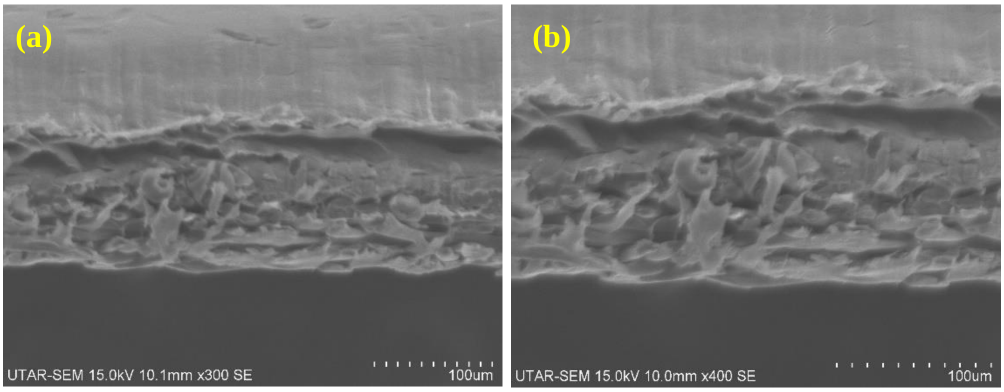

Figure 4.5: The SEM cross-sectional Images of (a) Commercial UF Membrane, UE050 (300X) (b) Commercial UF Membrane, UE050 (400X).

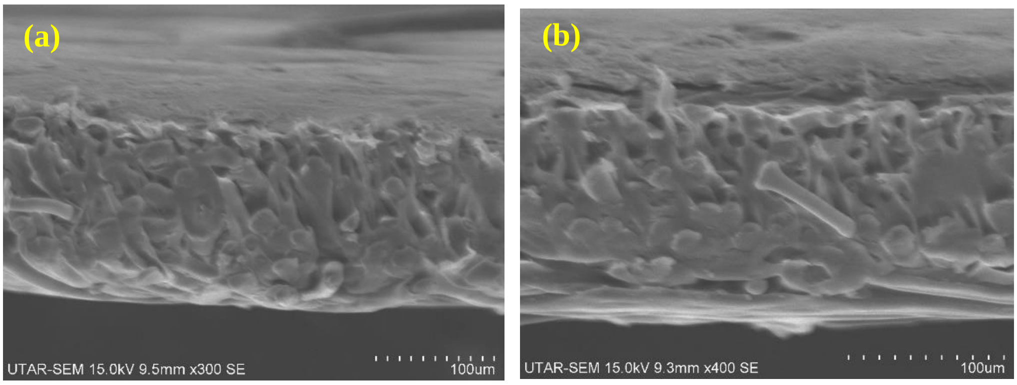

Figure 4.6: The SEM cross-sectional Images of (a) Commercial MF Membrane, ME010 (300X) (b) Commercial MF Membrane, ME010 (400X).

4.1.2 Membrane Porosity

The membrane porosity obtained for the UE050 and ME010 membranes is 27.52% and 31.01%, respectively (Table 4.1). According to a study by Hossein et al. (2015), the produced UF membranes exhibited a porosity ranging from 70% to 80%. Membranes with PES material have an overall porosity of 80.50 % (Gohari et al., 2015). The membrane porosity for both of the membranes is relatively low, with ME010 slightly higher than UE050. ME010 has a slightly larger membrane porosity due to the larger pore size compared to UE050. Low membrane porosity is preferred because it aids in the retention of unwanted particles and impurities, allowing for excellent selectivity and purity of the desired product. This is particularly significant in situations like water treatment when it is essential to eliminate pollutants like bacteria and viruses.

Table 4.1: Detailed Information and Membrane Porosity Obtained for UF and MF Membrane.

	UF (UE050)	**MF (ME010)**
Membrane Porosity, Ɛ	27.52%	31.01%

4.1.3 Pore Size

The pore size distribution plot of the UF membrane (UE050) in microns was studied and shown in Figure 4.7. The results indicate that the pore size falls under 0.07 to 0.47 µm with the average pore size for UF membrane (UE050) of 0.2 µm. Generally, the pore size of the UF membrane is 0.002 – 0.5 µm, which is available to remove colloidal particles and macromolecules (Spivakow and Shkinew, 2005). UF membranes with different pore sizes may be due to the manufacturer that produces the UF membrane. However, UF membranes (UE050) of 0.2 µm utilised in this study is considered larger pore size in UF membrane that will not be suitable for all applications. For instance, the typical size range of viruses is 0.03 to 1.0 µm, and the typical size range of bacteria is 0.5 to 20 µm (Spivakow and Shkinew, 2005). Hence, a UF membrane (UE050) with a pore size of 0.2 µm would be better suited for applications where the objective is to remove bigger particles from a liquid, including proteins or suspended solids.

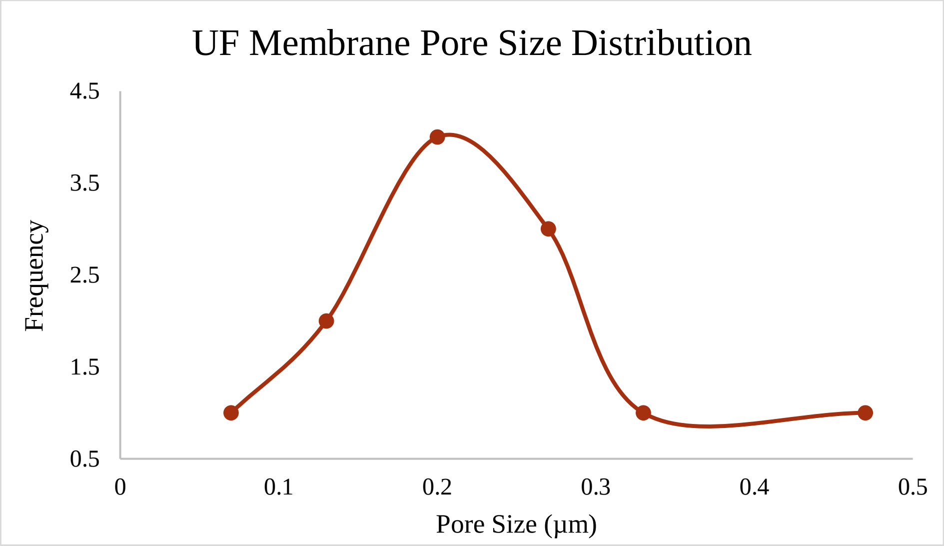

Figure 4.7: Pore Size Distribution Plot of UF Membrane in Microns (µm).

The pore size distribution plot of the MF membrane (ME010) in microns was studied and shown in Figure 4.8. The results indicate that the pore size falls under 1.6 to 7.6 µm, with the average pore size for MF membrane (ME010) of 2.4 µm. Generally, the pore size of the MF membrane is in the range of 0.1 to 10 µm (Parimal, 2020). The difference in pore size of MF membrane might vary depending on several variables, including the manufacturing process, the membrane material used, and the operating conditions. Bigger pore sizes are subjected to remove larger particles, such as suspended solids, while smaller pore sizes aim to eliminate tiny objects, such as viruses or bacteria.

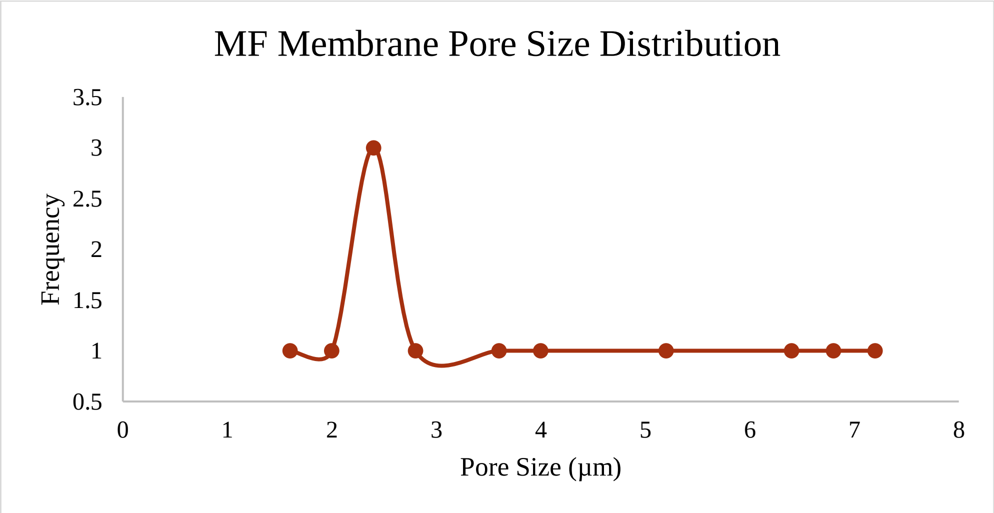

Figure 4.8: Pore Size Distribution plot of MF Membrane in Microns (µm).

4.2 Characterization of Raw Textile Wastewater and Pre-treatment

After the membrane filtration treatment, the quality of the raw textile wastewater was examined to determine the parameters listed in Table 4.2 below. These parameters are essential to identify as they involve a guideline limitation in Environmental Quality (Industrial Effluent) Regulations 2009, Standard B requirement (Environment Quality Act, 1974). Generally, the quality of textile wastewater will defer from time to time based on the product they carried out during that specific range of time. A total of an approximately 30 L textile wastewater before discharge downstream of the river was collected from a textile industry located at Batu Pahat, Johor, on 3rd January 2023 for the analysis. The main purpose of analyzing the effluent textile wastewater is to be used to compare it with the final result obtained after the membrane treatment to identify the removal efficiency. In addition, it is notable that the colour of the textile wastewater is relatively low in colour unit of American Dye Manufacturers' Institute (ADMI) at a value of 20. However, the colour in Platinum-Cobalt Scale (Pt-co) is relatively large, recorded at 339. ADMI analyses the colour that, particularly dyes, and organic matter, contribute to water or wastewater. Consequently, a low ADMI amount implies that the organic matter or dyes that give a solution its colour are in low concentrations. Contrarily, Pt-co assesses the colour depth or intensity and is sensitive to organic and inorganic components that affect colour. As a result, a solution with a high Pt-co value likely contains a lot of inorganic and organic material that affects colour. Generally, a solution can contain little dye or organic material with a low ADMI value but still have a lot of inorganic material, which gives the solution its colour with a high Pt-co value.

In this project, a lab-scale study of actual real-life wastewater treatment was conducted. Therefore, the textile wastewater was pre-treatment using sand filtration to mimic the industrial wastewater treatment process. The parameters tested after the sand filtration, such as total suspended solids and turbidity, obviously decreased values. The significant effect of sand filtration on removal efficiency involved COD of 42.55%, TSS of 75.76%, turbidity of 78.10%, and colour (Pt-co) of 59.10%. On the other hand, sand filtration does not significantly affect several parameters such as conductivity with a removal efficiency of 1.06%, colour (ADMI) with a removal efficiency of 5%, and hardness with a 4.35% removal efficiency. However, the overall results show that sand filtration plays a big role as primary treatment of the wastewater to remove the large particles before undergoing secondary treatment with UF or MF membrane (Bikash, and Iswar, 2021). Besides, Figure 4.9 shows textile wastewater's physical appearance before and after sand filtration. It is obvious that the amount of large solid particles and colour of the wastewater was reduced. Total suspended solid was reduced from 44 mg/L to 10.67 mg/L, and turbidity was reduced from 45.67 mg/L to 10 mg/L. The Pt-co has decreased from 339 to 138.67, while in terms of ADMI, it has reduced from 20 to 19.

Table 4.2: Results of Raw Textile Wastewater and After Pre-Treatment of Sand Filtration.

Parameter	Raw Result	Sand Filtration Result	Removal Efficiency (%)	Standard B
pH	6.77	7.06	-	5.50 – 9.00 (Factory)
Temperature (°C)	24.90	25.0	-	< 40.00
Conductivity (µs/cm)	1194.00	1181.33	1.06	-
Dissolved oxygen (%)	2.84	7.43	61.78	-
BOD_5	-	-	-	< 50.00
COD (mg/L)	94.00	54.00	42.55	-
Total Nitrogen (ppm)	12.30	7.40	39.84	-
Ammoniacal Nitrogen (ppm)	0.00	0.00	0.00	< 20.00
Nitrate (ppm)	0.99	0.18	81.82	-
Total Suspended Solid (mg/L)	44.00	10.67	75.76	< 100.00
Total Dissolved Solid (mg/L)	1242.00	1230.00	0.97	-
Turbidity (NTU)	45.67	10.00	78.10	-
Colour (ADMI)	20.00	19.00	5.00	< 200.00
Colour (Pt-co)	339.00	138.67	59.10	-
Zinc (mg/L)	<0.0002	<0.0002	<0.0002	< 2.00
Copper (mg/L)	0.17	0.12	29.09	< 1.00
Hardness (mg/L)	46.00	44.00	4.35	-

Figure 4.9: Physical Appearance Before (Left) and After Sand Filtration (Right).

The turbidity removal efficiency by sand filtration of 78.10% can be supported by commercial sand; each sand granule size varies from 0.35 mm to 1.2 mm. Colloidal clay is not included as a layer in this experiment. Bellamy et al. (1985a) reported that in slow sand filtration experiments, colloidal clay caused poor turbidity removals, in the range of 27 to 39%, in slow sand filtration studies. Nonetheless, 96.8 to 98% of particles with sizes between 6.35 and 12.7 μm were efficiently reduced. Similarly, Fogel et al. (1993) discovered that the source water had a high concentration of colloidal matter, with 34.4% of all particles having a diameter of less than 5 μm, leading to unsatisfactory turbidity reductions of 55%.

The removal of colour is relatively poor under sand filtration, with a removal efficiency of 5% ADMI colour removal and an average removal percentage of 59.10% Pt-co colour removal. An aesthetic indicator of water quality, colour is a stand-in for an organic indicator. The minor removal efficiency of colour in ADMI might be due to the removal of pigments, dyes, and organic compounds. Sand filtration is a physical filtration method used to mostly remove suspended solids from water, along with some organic matter. It is not aimed at removing dissolved organic materials, such as dyes. On the other hand, the higher removal efficiency of colour in Pt-co might be due to the retaining and trapping of particles and dyes that are yellowish in colour by sand filtration, as Pt-co colour evaluates a liquid’s yellowness. Montgomery (1985) reported organic humic compounds predominantly cause colour. It is believed that colour is challenging to remove in slow sand filters due to the stabilizing tendency of humic compounds on dissolved particles. Additionally, Ellis (1985) reported 30% of actual colour is typically removed in slow sand filters. Slow sand filtration inadequate capacity to remove organic colour and dissolved organic carbon is a typical cause of the technique's declining use in the United Kingdom (Lambert and Graham, 1995).

4.3 Performance of UF and MF under Constant Flow Rate and Pressure

To investigate the difference between the UF and MF membranes, a constant flow rate (6 LPM) and pressure (2 bar) were set as default to obtain the results. In this study, the UF membrane of UE050 will be referred to as the UF membrane and the MF membrane of ME010 will be referred to as the MF membrane throughout the following discussion. UF and MF membrane water flux and permeability are tabulated in Table 4.3. Water fluxes can be defined as the hourly water flow through the membrane's surface area (i.e., L/m^2hr) and the filtered water permeating through the membrane (Peter, 2021). Both the water flux and permeability of the MF membrane are higher than the UF membrane. This is because the pore size of the MF membrane is larger than the UF membrane; hence the wastewater can pass through the membrane and be collected at the permeate within a shorter period where larger pore size presents a greater flow rate (Masoud, et al., 2019). The higher the water flux, the more desired, as more treated water can be collected within a shorter period. On the other hand, although the performance of water flux for the MF membrane is better, the separation efficiency in terms of turbidity of the MF membrane of 56.67% is lower than the UF membrane of 60.00%, which will be further discussed below.

Table 4.3: Water Flux and Permeability of UF and MF Membrane under Constant Condition.

	Water Flux (L/m^2hr)	**Permeability (L/m^2hrbar)**
UF	159.38	79.69
MF	956.70	478.35

Figure 4.10 below summarised the comparison of UF and MF membranes for all the studied parameters in a chart graph. It is noticeable that the UF membrane will have better overall performance compared to the MF membrane. Firstly, the removal efficiency of UF and MF membrane for COD is 59.87% and 45.06%, respectively. Due to the UF membrane lower cut-off than the MF membrane, which was too wide to trap the COD-causing particles, COD was eliminated more with UF than with the MF membrane.

In terms of hardness, the removal efficiency for both UF and MF membranes is the same at only 2.27 %. It is well known that chemical additives are the general method for removing hardness, and this experiment evaluated and contrasted how well UF and MF membranes performed at removing hardness. This result raises concerns about removing such hardness by utilizing ultrafiltration and microfiltration since removing hardness in the form of calcium carbonate using filtration methods is challenging. This hardness trend relates to the raw water 0.56 mg/L iron content, and iron oxidation may lead to precipitation and removal as hardness by multi-media sand filters and ultrafiltration (Sanaz et al., 2015). Hence, the hardness removal efficiency for both UF and MF membranes is similar and relatively low.

Furthermore, in terms of colour (ADMI), UF and MF membranes have removal efficiency of 21.05% and 10.53%, respectively. While for colour (Pt-co), UF and MF membranes have a removal efficiency of 43.27% and 28.85%, respectively. This could be due to the pore size and shear force. UF membrane that has smaller pore sizes allows UF membranes to capture and remove smaller colour particles that would pass through the larger pores of MF membranes. Besides, cross-flow UF membranes operate under higher shear force conditions than MF membranes. The cross-flow of the liquid across the UF membrane surface produces a larger shear force, which can aid in more effectively dislodging and removing the coloured particles.

In terms of total suspended solids, UF and MF membranes have a removal efficiency of 46.88% and 40.63%, respectively. In terms of turbidity, UF and MF membrane have separation efficiency of 60.00% and 56.67%, respectively. Devaisy et al. (2022) founds MF membrane with a pore size of around 200 nm and a UF membrane of around 3 nm reject micro-pollutants predominantly by size exclusion; however, both membranes will generate a similar outlet quality. This can be noticed from the result that UF membranes carry better removal efficiency for turbidity and total suspended solids than MF membranes. The significant removal of COD, colour, and turbidity even with MF could be attributed to the addition of sieve retention; adsorption is the other organic matter removal process. Adsorption involves particles being trapped inside the membrane structure, enabling the removal of particles smaller than the membrane pores (Guo et al. 2009). The primary method for removing organic matter in MF and UF is sieve retention, in which particles are held on the membrane surface (Guo et al. 2009).

Table 4.4: Results of UF and MF Parameters under Constant Flow Rate and Pressure.

Parameter		**UF**		**MF**	
	Initial	**Final**	**Removal Efficiency (%)**	**Final**	**Removal Efficiency (%)**
pH	7.06	7.65	-	7.44	-
COD (mg/L)	54.00	21.67	59.87	29.67	45.06
Colour (ADMI)	19.00	15.00	21.05	17.00	10.53
Colour (Pt-Co)	138.67	78.67	43.27	98.67	28.85
Hardness (mg/L)	44.00	43.00	2.27	43.00	2.27
Total Suspended Solid (mg/L)	10.67	5.67	46.88	6.33	40.63
Turbidity (NTU)	10.00	4.00	60.00	4.33	56.67

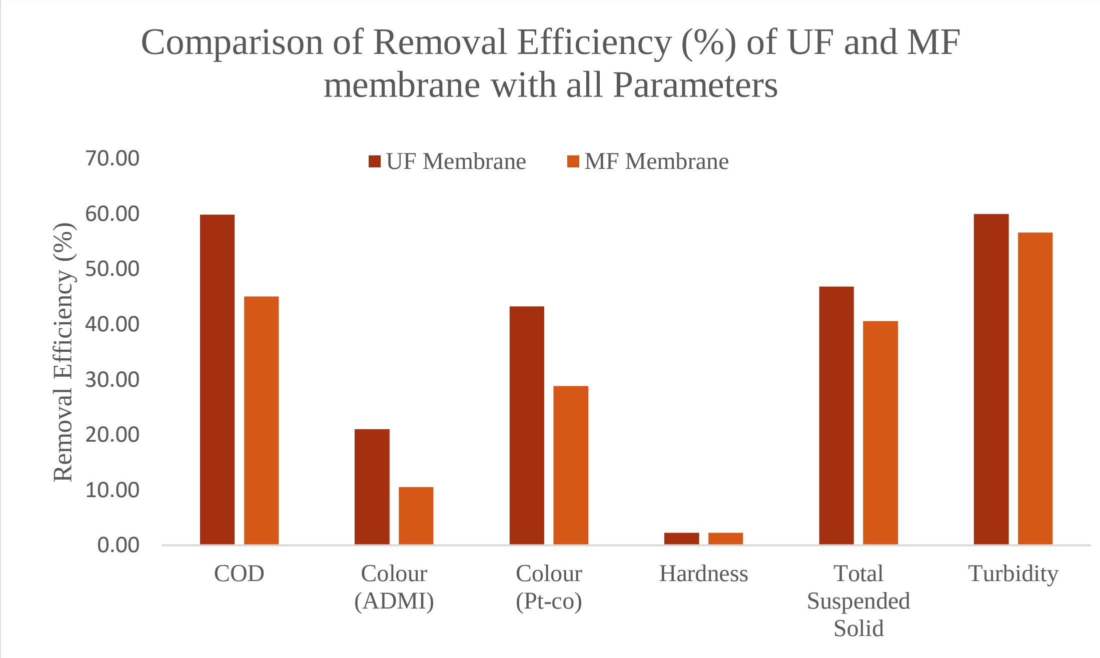

Figure 4.10: Comparison of Removal Efficiency (%) of UF and MF Membrane under Constant Operating Condition.

In short, compared to MF membranes, UF membranes have a lower flux decrease rate and a better flux recovery, but the permeate production rate of UF membranes is generally lower than MF membranes (Byung et al., 1997). Even though the water flux is lower in UF than in MF, the separation efficiency of the UF membrane still makes the UF membrane better than the MF membrane. Spivalov et al. (2005) reported similar findings where MF membrane is generally used to eliminate particles larger than 0.5 µm. UF membrane filters with pore sizes ranging from 0.002 to 0.5 µm are offered to effectively remove macromolecules and colloidal particles, which cannot be filtered by MF membrane. Furthermore, UF and MF membranes are required to filter bacteria of size range 0.5 to 20 µm while only the UF membrane can remove viruses with a size range of 0.03 to 1 µm. In short, by comparing UF and MF membranes under constant conditions, the UF membrane performs better than the MF membrane.

4.4 Performance of UF Membrane in Textile Wastewater

4.4.1 Pressure

The pressure of the cross-flow filtration supplied was varied in the range of 2 bar, 4 bar, 6 bar, 8 bar, and 10 bar with a constant flow rate of 6 LPM. Flow rate of 6 LPM was set as it is the middle range value for lab scale cross-flow filtration flow rate, and various pressure can be run in this flow rate.

The outcome of the experiment regarding the effect of pressure on water flux and separation efficiency of UF membrane under various pressure was illustrated in Table 4.5. When pressure increases from 2 bar to 4 bar, the water flux enhances dramatically from 156.26 L/m^{2}hr to 591.98 L/m^{2}hr, and the water flux further increases constantly from 4 bar to 10 bar (Figure 4.11). At lower pressure, the water flux increased with the increasing filtration pressure, while at higher pressure, it remained nearly and became almost constant regardless of filtration pressure (Nakamura, 2013).

Table 4.5: Water Flux and Permeability of UF Membrane under The Effect of Pressure.

Parameter	2 bar	4 bar	6 bar	8 bar	10 bar
Water flux (L/m2.hr)	156.26	591.98	746.21	842.14	912.85
Permeability (L/m2.hr.bar)	78.13	147.99	124.37	105.27	91.29

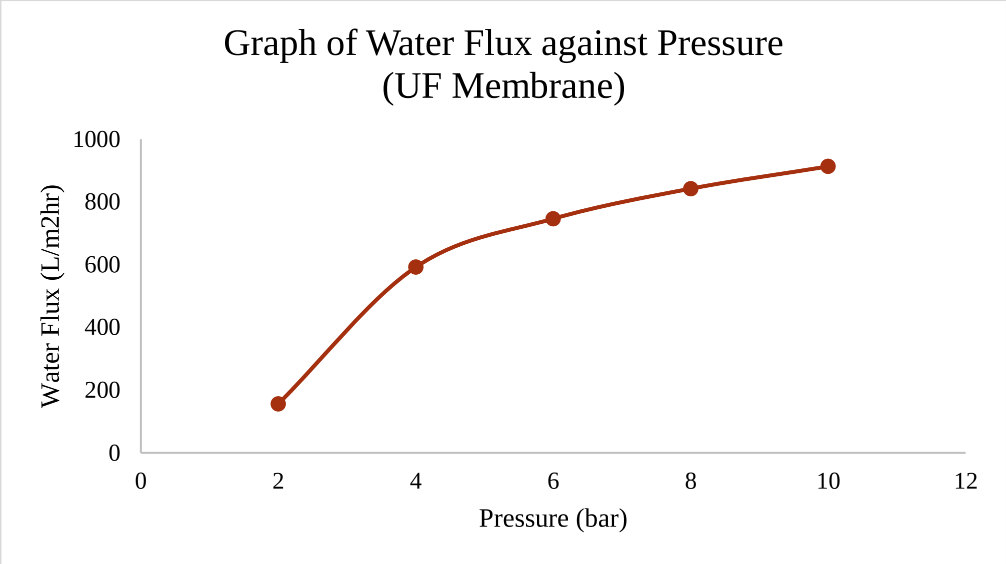

Figure 4.11: Effect of Pressure Supplied on UF Membrane Affects The Water Flux.

Figure 4.12 illustrated the studied parameter results of removal efficiency obtained for UF membranes under different pressure, as illustrated in the chart graph. Firstly, cross-flow UF filtration does not affect the pH of the wastewater, and the pH range from 7 to 8 under every set pressure. Then, the results show that the COD amount decreases with increased pressure supplied. With increasing pressure, COD removal effectiveness fell. Oktav and Ozer (2007) discussed that this results from the fouling layer being scraped and carried through at more significant pressures that organic material is deposited there. This technique causes collected material to be transported into permeate. Thus, the COD concentration of the permeate rises.

Moreover, a noticeable reduction in colour can be obtained with colour in Pt-co, with the highest removal efficiency of 93.75 % at 6 bar. The removal efficiency of colour in Pt-co increases linearly from 2 bar to 6 bar and drops from 6 bar to 10 bar. A pressure of 6 bar is found to be most favourable for the decolourization of the textile wastewater with the highest removal efficiency. The increase in mechanical compaction that causes a rise in membrane density can be used to explain this result. In actuality, this mechanism tends to lower pore size, which slows down the pace at which dissolved solutes diffuse through the membrane (Desa et al., 2020). On the other hand, the removal efficiency of colour in ADMI is generally low, and the removal trend cannot be identified due to the low removal efficiency obtained. The highest removal efficiency is 21.05% at 2 bar. Pt-co determines the colour of pale yellow to amber liquids, while ADMI is used to identify the colour of dark liquids such as inks, dyes, and paints. The low removal efficiency may be due to the initially detected ADMI colour amount already relatively low with 19 ADMI; therefore, the final results obtained after cross-flow UF filtration are not that obvious. Regarding hardness, the removal efficiency is relatively low for all the pressure, as cross-flow UF membrane filtration does not significantly affect hardness removal efficiency. Then, the removal efficiency of Total Suspended Solid increases linearly with the increase in pressure from 2 bar to 8 bar; however, it drops at 10 bar. Turbidity reduces with increasing pressure and drops slightly after reaching the highest point at 6 bar.

In the parameter of colour (Pt-co), total suspended solids, and turbidity, we notice that the removal efficiency increases from 2 bar to 6 or 8 bar and decreases at 10 bar. Besides, the water flux increases rapidly from 2 bar to 4 bar and turns to increase slowly from 6 bar to 10 bar. This phenomenon is due to the concentration polarization that happens when a concentration gradient caused by the build-up of suspended particles on the membrane surface lowers the permeate flux. As a result, the feed solution turbidity may rise as the concentration of suspended particles increases, which causes the removal efficiency drops at high pressure of 10 bar. Besides, similar findings were discussed by Hong et al. (2020), where when the pressure load is high, the change in particle group composition is more noticeable, attributed to the larger particle breakage rate will be. It is possible to assume that as the feed solution passes across the membrane surface at high pressure, it is subjected to more shear stress. More suspended particles may flow through the membrane, and increasing turbidity leads to breaking big suspended particles into smaller ones.

In short, it appears that the UF membrane, under a constant flow rate of 6 LPM, highest pressure set of 10 bar, will give the highest water flux, which is desired. However, a middle to high range of pressure, which is 6 bar, has the best overall performance as a pressure setting of 6 bar also has a relatively high water flux of 746.21 $L/m^2.hr$. Besides, the colour and turbidity removal efficiency is the highest. Concentration polarization that leads to fouling may occur at a pressure of around 8 bar to 10 bar, which causes the water flux trend to become slower and removal efficiency to drop. However, the effect of concentration polarization is minor and insignificant as water flux and removal efficiency drop not dramatically but only slightly.

Table 4.6: Results of UF Membrane under Different Pressure

Parameter	Initial	2 bar Final	2 bar Removal Efficiency (%)	4 bar Final	4 bar Removal Efficiency (%)	6 bar Final	6 bar Removal Efficiency (%)	8 bar Final	8 bar Removal Efficiency (%)	10 bar Final	10 bar Removal Efficiency (%)
pH	7.06	7.65	-	7.73	-	7.74	-	7.98	-	7.81	-
COD (mg/L)	54.00	21.67	59.87	24.00	55.56	26.00	51.85	33.00	38.89	41.00	24.07
Colour (ADMI)	19.00	15.00	21.05	18.00	5.26	17.00	10.53	19.00	0.00	19.00	0.00
Colour (Pt-Co)	138.67	78.67	43.27	13.00	90.63	8.67	93.75	19.67	85.82	13.67	73.08
Hardness (mg/L)	44.00	43.00	2.27	32.00	27.27	36.00	18.18	43.00	2.27	36.00	9.09
Total Suspended Solid (mg/L)	10.67	5.67	46.88	3.00	71.88	2.30	78.44	1.67	84.38	2.33	59.38
Turbidity (NTU)	10.00	4.00	60.00	3.33	66.67	2.90	71.00	3.00	70.00	3.00	66.67

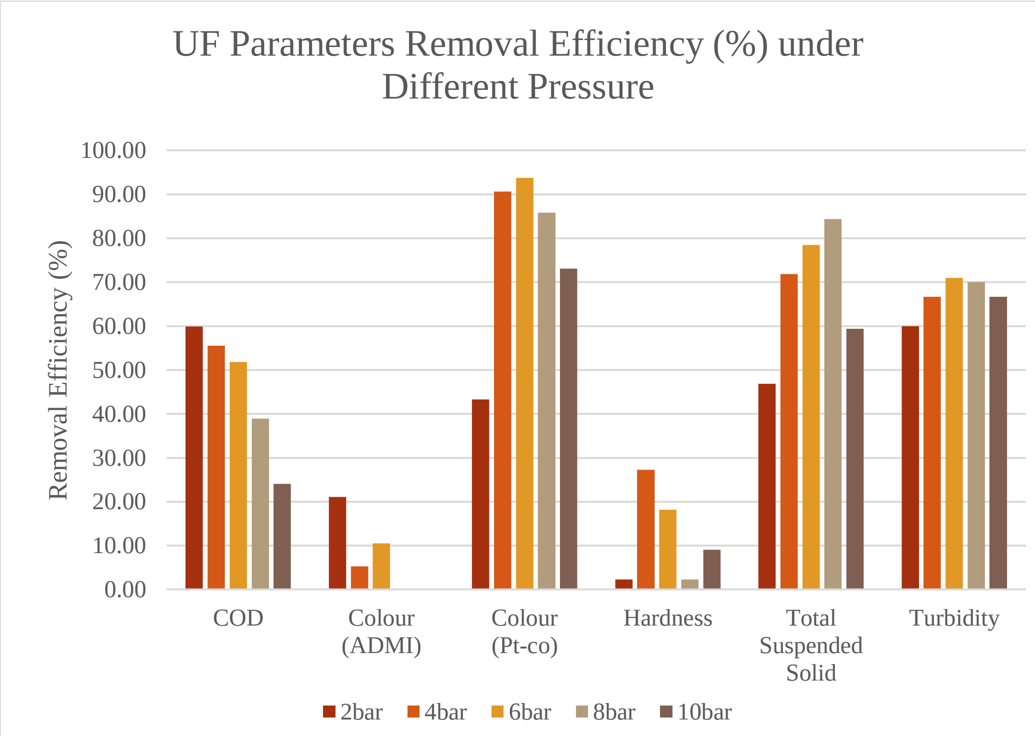

Figure 4.12: Summary of Studied Parameters Removal Efficiency (%) of UF Membrane.

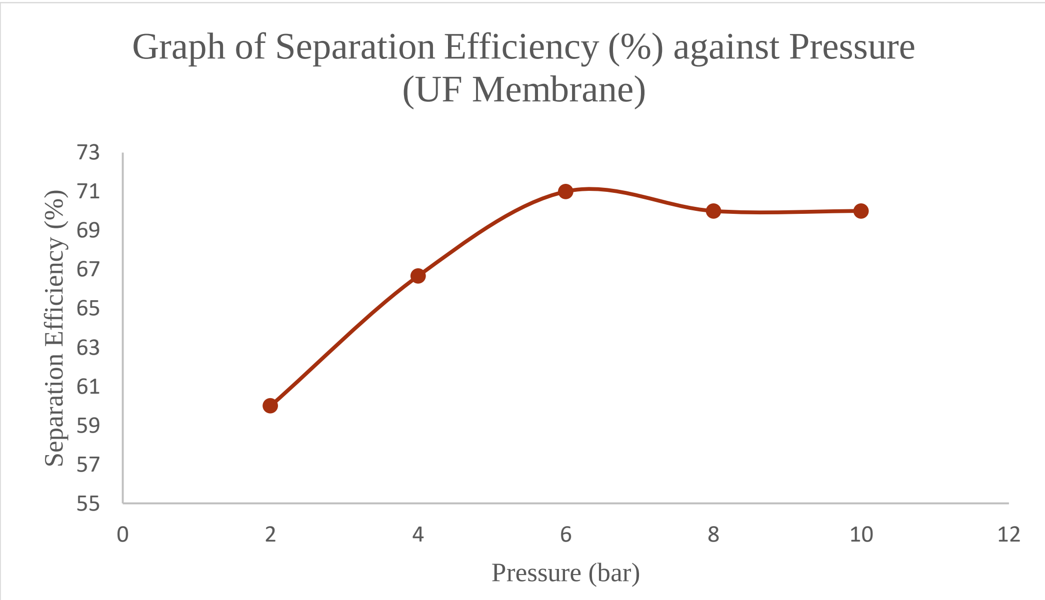

Figure 4.13: Separation Efficiency (%) of UF Membrane under Varies Pressure.

4.4.2 Flow Rate

The textile wastewater sample was treated by keeping the constant pressure of 6 bar based on the optimum performance obtained from the previously studied UF membrane about the effect of pressure and then varying the supplied flow rate at 2 LPM, 3 LPM, 4 LPM, 5 LPM, and 6 LPM.

The outcome of the experiment regarding the water flux and permeability is illustrated in Figure 4.14. The water flux was enhanced from 651.01 L/m^2hr to 805.76 L/m^2hr when adjusting the flow rate from 2 LPM to 3 LPM. Then, the water flux generally increases from 3 LPM to 5 LPM and drops slightly at 6 LPM. The cross-flow velocity will increase with the increase in the flow rate supplied. The increased forced convection of the solutes due to increased cross-flow velocity enhances the capacity of solutes for transport from the membrane surface to the bulk feed (Oktav and Ozer, 2008). Subsequently, this leads to decreased concentration polarization and increased permeate flux, which explains the water flux grew from 2 to 5 LPM. The concentration polarization layer close to the membrane surface is relatively thin, and the water flux is rather steady at low flow rates. The concentration polarization layer, however, may thicken as the flow rate goes up, limiting the membrane effective pore size and decreasing the water flux. Giacobbo et al. (2018) reported the critical flux is commonly described as the flux that causes the first deviations from the linearity of flux with transmembrane pressure. Below this critical flux, theoretically, essentially, no fouling occurs, whereas fouling can be seen above it. Fouling appears to occur above 5 LPM, which leads to a decrease in water flux for the cross-flow UF membrane.

Table 4.7: Water Flux and Separation Efficiency of UF Membrane under Constant Condition at Varies Flow Rate.

Parameter	2 LPM	3 LPM	4 LPM	5 LPM	6 LPM
Water flux (L/m^2.hr)	651.01	805.76	816.72	821.21	726.08
Permeability (L/m^2.hr.bar)	108.50	134.29	136.12	136.87	121.01

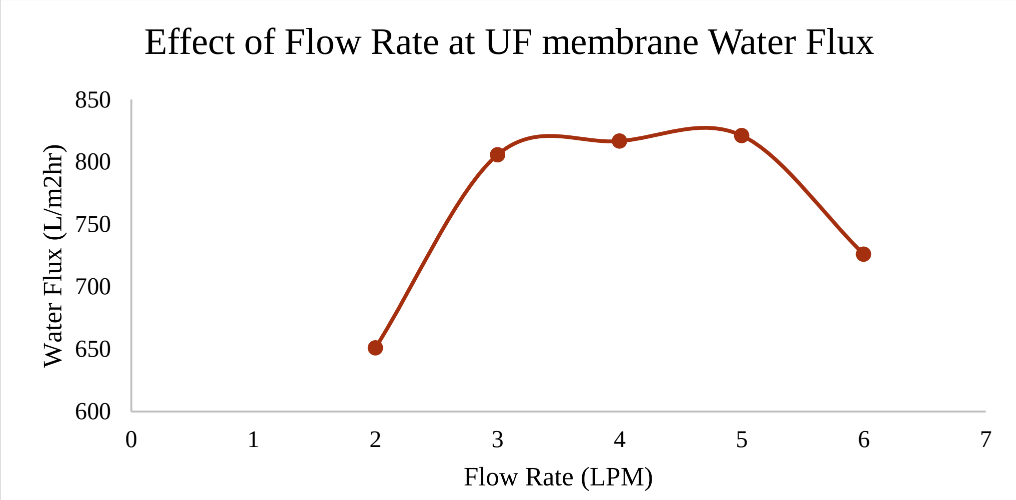

Figure 4.14: Effect of Flow Rate Supplied on UF Membrane Affects the Water Flux.

Figure 4.15 illustrates the removal efficiency of the studied parameters under different flow rates. Similar to the study of the effect of pressure, cross-flow UF filtration does not affect the pH of the sample. Therefore the pH obtained for all the studied flow rates is between neutral pH ranges of 7 to 8. Besides, it was observed that when the flow rate increases, the removal efficiency COD increases. An increase in cross-flow velocity carried on the decrease in the concentration polarization on the membrane surface and when the concentration of the solutes was reduced, the concentration in the permeate dropped (Koyuncu and Topacik, 2003).

In terms of colour, colour in ADMI have a quite constant removal efficiency of 10.53%; however, a lower removal efficiency of 5.26% at 2 LPM. ADMI is the colourimetric method that examines the colour of the water at a wavelength of 390–455 nm and is employed to identify the presence of both synthetic and natural organic colorants, such as lignin, tannins, and humic and fulvic acids. In this study, the initial colour in ADMI was low at 19 ADMI; hence UF cross-flow filtration cannot effectively remove the colour. In addition, Figure 4.15 shows that the removal efficiency of colour in Pt-co decreased from 94.71% at 2 LPM to 81.49% at 6 LPM. It was highly anticipated that the removal efficiency of colour would drop with an increase in flow rate since the slower flow rate was associated with a longer residence time. This longer residence time indicates that the solution containing untreated wastewater takes longer to exit the reactor (Mohsen and Kambiz, 2019). In terms of hardness, the removal efficiency decreased from 22.73% at 2LPM to 4.55% at 5LPM and maintained a constant of 4.55% at 6LPM. In general, with lower flow rates, the feed solution remains in the membrane module for longer, allowing for improved hardness ion removal. On the other hand, more shear stress and turbulence can aid in removing particles from the membrane surface and minimizing fouling when flow rates are higher.

The removal efficiency of the total suspended solid decreases from 81.25% at 2 LPM to 68.75% at 6 LPM with the increase in supplied flow rate. Turbidity decreases from 2 LPM with a removal efficiency of 70.00% to 6 LPM with a separation efficiency of 60.00%. This phenomenon may be due to several factors, such as concentration polarization and fouling. The feed solution velocity over the membrane surface will be lower at a lower flow rate, which improves suspended particle removal and lower concentration polarization. Increased feed solution velocity across the membrane surface due to higher flow rates might increase concentration polarization and fouling. This may result in suspended particles clogging membrane pores, decreasing the effectiveness of turbidity removal.

Table 4.8: Results of UF Membrane under Different Flow Rate.

Parameter		**2 LPM**		**3 LPM**		**4 LPM**		**5 LPM**		**6 LPM**	
	Initial	**Final**	**Removal Efficiency (%)**	**Final**	**Removal Efficiency (%)**	**Final**	**Removal Efficiency (%)**	**Final**	**Removal Efficiency (%)**	**Final**	**Removal Efficiency (%)**
pH	7.06	7.58	-	7.76	-	7.68	-	7.72	-	7.75	-
COD (mg/L)	54.00	43.67	19.14	30.00	44.44	26.00	51.85	25.67	52.46	24.00	55.56
Colour (ADMI)	19.00	17.00	10.53	18.00	5.26	17.00	10.53	17.00	10.53	17.00	10.53
Colour (Pt-Co)	138.67	7.33	94.71	15.33	88.94	19.67	85.82	19.67	85.82	25.67	81.49
Hardness (mg/L)	44.00	34.00	22.73	38.00	13.64	41.00	6.82	42.00	4.55	42.00	4.55
Total suspended solid (mg/L)	10.67	2.00	81.25	2.00	81.25	2.67	75.00	2.67	75.00	3.33	68.75
Turbidity (NTU)	10.00	3.00	70.00	3.00	70.00	3.67	63.33	3.67	63.33	4.00	60.00

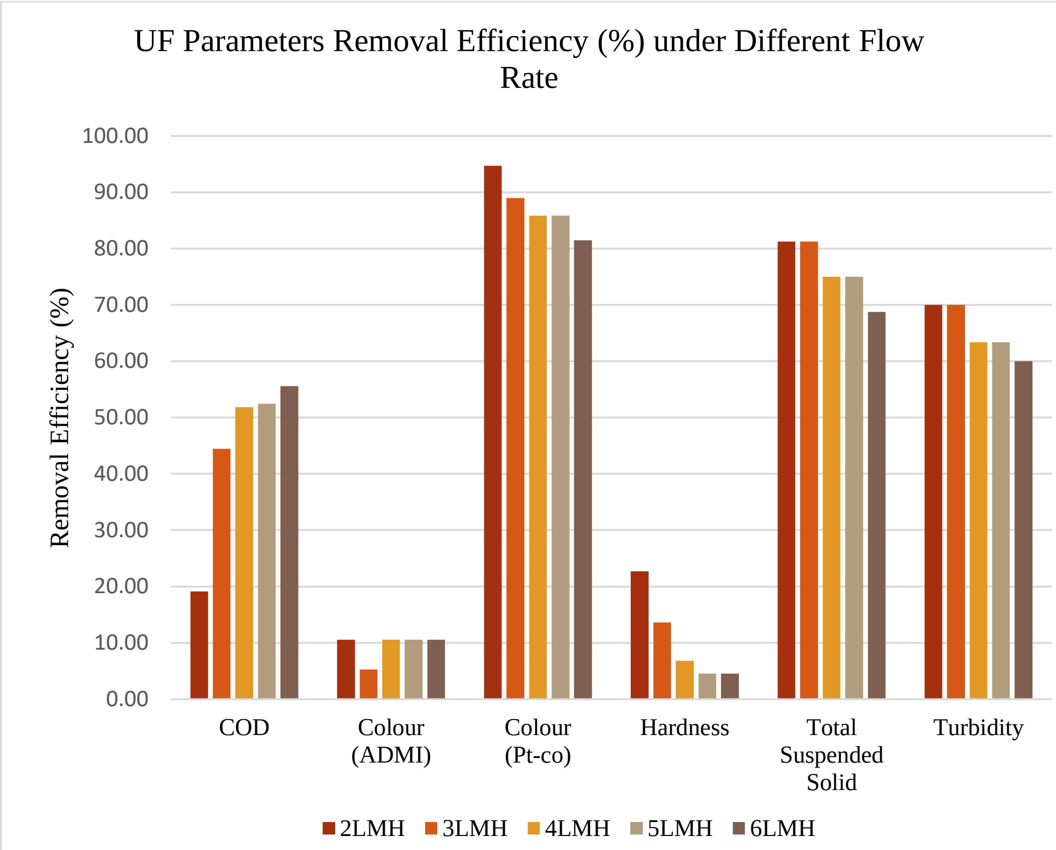

Figure 4.15: Summary of Studied Parameters Removal Efficiency (%) of UF Membrane under Different Flow Rate.

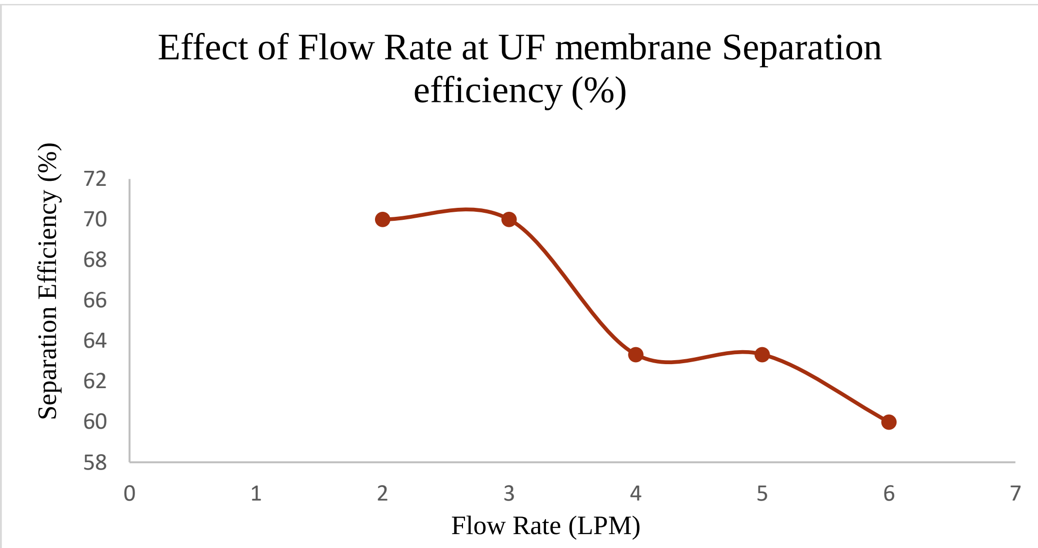

Figure 4.16: Separation Efficiency (%) of UF Membrane under Varies Flow Rate.

4.4.3 Post Water Treatment SEM Analysis

The optimum operating condition for UF membranes will be at a pressure of 6 bar and a flow rate of 3 LPM. The membrane morphology at the optimum operating condition membrane will be evaluated. Figure 4.17 (a) – (c) shows the SEM image of the UF membrane after undergoing the cross-flow filtration process at the optimum condition of 6 bar and 3 LPM in the magnification of 5,000X, 15,000X, and 25,000X, respectively. After the cross-flow ultrafiltration of textile wastewater, the surface image shows that the impurities and particles are retained and trapped in the pores of the membrane. The pores may get blocked due to the accumulation of particles and solutes on the surface of the membrane, which eventually decreases the effective surface area for filtration. The surface of the UF membrane initially appears homogeneously and smoothly (Figure 4.1); however, the surface may become uneven due to the build-up of trapped particles or molecules after cross-flow filtration (Figure 4.17). This is noticeable as a coating of material covering the membrane surface may lead to foulant on the surface. As the UF membrane utilized is PES material, one of the downsides of PES is its hydrophobic nature, which leads to high-fouling membrane for aqueous filtration (Alisa et al., 2012). A membrane can become fouled when trapped particles, colloids, and macromolecules are deposited on the membrane surface or within the pores of the pore wall. The consequent reduction in membrane flux, whether temporary or permanent, is one drawback of fouling.

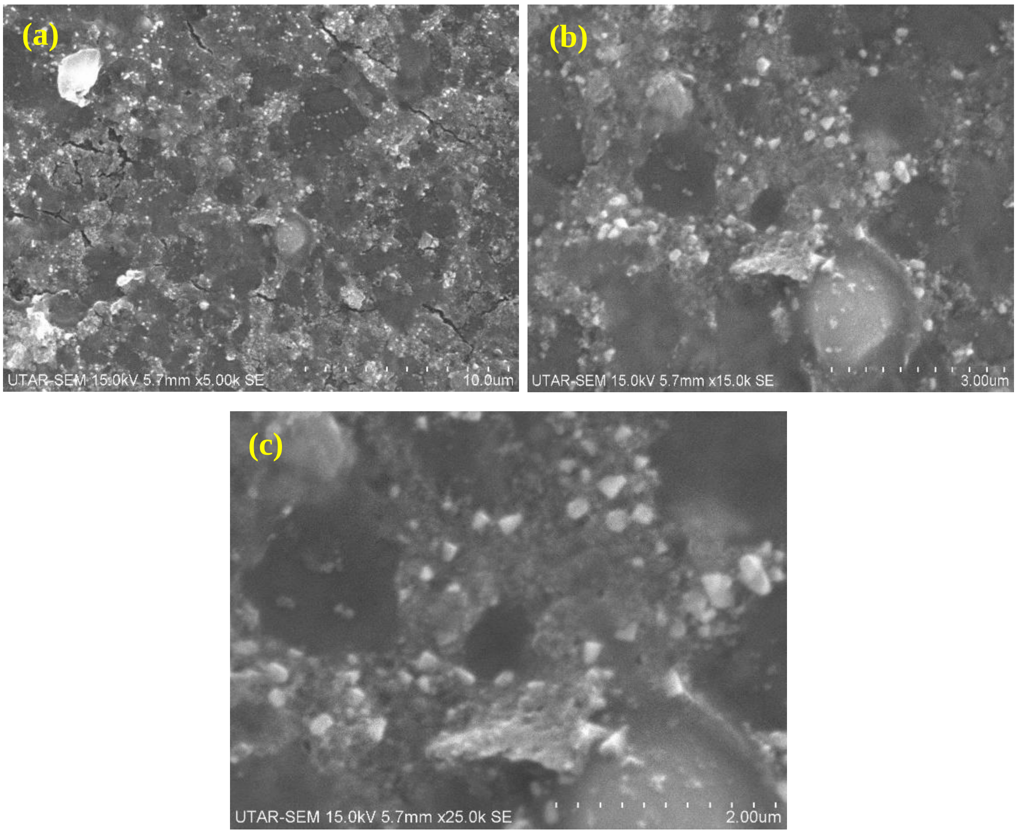

Figure 4.17: SEM Image of (a) Optimum Performance (3 LPM, 6 bar) UF Membrane (5,000X) (b) Optimum Performance (3 LPM, 6 bar) UF Membrane (15,000X) (c) Optimum Performance (3 LPM, 6 bar) UF Membrane (25,000X).

4.5 Performance of MF Membrane in Textile Wastewater

4.5.1 Pressure

The water flux of the MF membrane obtained under various pressure (Figure 4.18). The water flux increases linearly and substantially with increasing pressure. Since the pressure supplied is the driving force of the MF membrane process, steady-state permeate flux is expected to increase as the pressure supplied increases. Moreover, the improved driving force for solvent flux was greater than the membrane fouling resistance (Tomczak and Gryta, 2020).

Table 4.9: Water Flux and Separation Efficiency of MF Membrane under Constant Condition at Varies Pressure.

Parameter	2 bar	4 bar	6 bar	8 bar	10 bar
Water flux ($L/m^2.hr$)	1,046.39	2,205.81	2,652.68	3,571.27	4,238.52
Permeability ($L/m^2.hr.bar$)	523.20	551.45	442.11	446.41	423.85

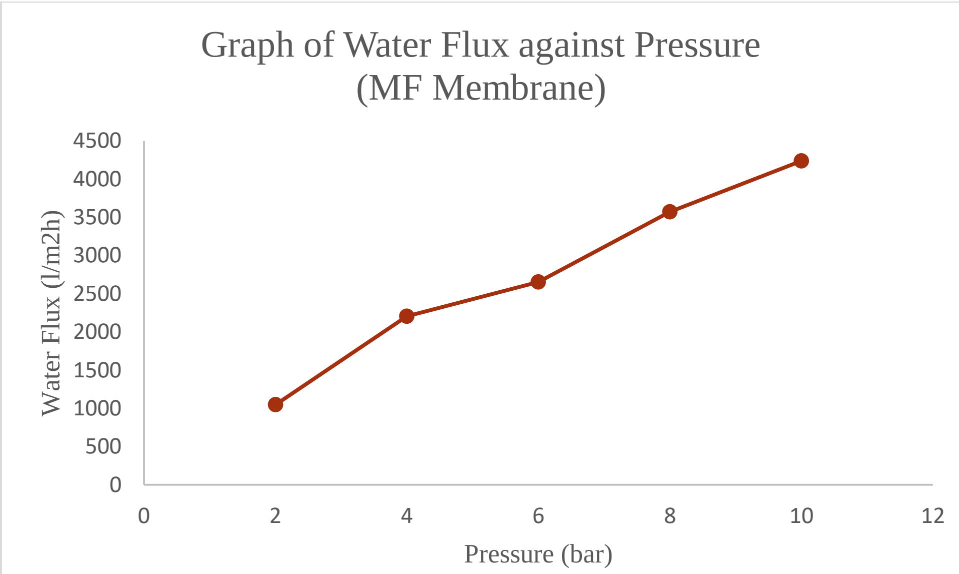

Figure 4.18: Water Flux of MF Membrane under Varies Pressure.

Table 4.10 below summarizes the results of all the studied parameters of cross-flow MF membrane under various pressure, and Figure 4.19 below summarises the removal efficiency of all the studied parameters. The trend of removal efficiency is mostly similar to the UF membrane, as discussed above. Firstly, similar to the UF membrane, the cross-flow filtration will not affect the pH of the sample, and the pH is in the range of 7 to 8. In terms of COD, the removal efficiency decreases as the pressure increases, similar to the UF membrane. The primary method for removing organic matter in MF and UF is sieve retention, in which particles are held on the membrane surface (Guo et al., 2009). Due to the UF membrane lower cut-off than the MF membrane, which was too wide to trap the COD-causing particles, COD was eliminated more with UF than with MF.

The removal efficiency of colour in ADMI does not have a trend, this may be due to the initial colour in ADMI being relatively low. Therefore, MF cross-flow filtration does not bring a major effect in removing colour in ADMI. On the other hand, the removal efficiency of colour in Pt-co increases from 2 bar to 6 bar and decreases from 6 bar to 10 bar. The highest removal efficiency of colour (Pt-co) is highest at 6 bar with 89.90%. Moreover, the removal efficiency of hardness is relatively low, where the highest is at 18.18% for both 2 bar and 8 bar and the lowest is at 2.27% for 6 bar. This shows that MF cross-flow filtration does not significant in removing hardness, and the pressure change may not affect the trend of the harness removal.

The removal efficiency of total suspended solids increases from 2 bar to 4 bar and decreases gradually from 4 bar to 10 bar, with the highest removal efficiency of 78.13% at 4 bar. Besides, the removal efficiency of turbidity constantly increases from 2 bar to 6 bar and maintains and drops slightly from 8 bar to 10 bar with the highest removal efficiency of 70% at 6 to 8 bar. The overall performance of the MF membrane is lower than the UF membrane. This can be due to the organic colloids, polysaccharides, and proteins being totally maintained by UF membranes and partially by MF membranes (Laabs et al., 2006).

A similar phenomenon was observed in the UF membrane was discussed in the previous section, with the removal efficiency trend of colour (Pt-co), total suspended solids, and turbidity, concentration polarization may occur at around 8 bar to 10 bar as the removal efficiency decreases above this supplied pressure. As mentioned above, it may be due to concentration polarization and the shear stress applied. In short, 6 bar will be the optimum supplied pressure with a constant flow rate supplied of 6 LPM for cross-flow MF membrane as it brings the best overall performance.

Table 4.10: Results of MF Membrane under Different Pressure.

Parameter		2 bar		4 bar		6 bar		8 bar		10 bar	
	Initial	Final	Removal Efficiency (%)	Final	Removal Efficiency (%)	Final	Removal Efficiency (%)	Final	Removal Efficiency (%)	Final	Removal Efficiency (%)
pH	7.06	7.44	-	7.76	-	7.78	-	7.72	-	7.75	-
COD (mg/L)	54.00	29.67	45.06	33.00	38.89	35.00	35.19	48.00	11.11	50.00	7.41
Colour (ADMI)	19.00	17.00	10.53	18.00	5.26	19.00	0.00	17.00	10.53	19.00	0.00
Colour (Pt-Co)	138.67	98.67	28.85	15.00	89.18	14.00	89.90	20.67	85.10	37.33	73.08
Hardness (mg/L)	44.00	36.00	18.18	38.00	13.64	43.00	2.27	36.00	18.18	40.00	9.09
Total Suspended Solid (mg/L)	10.67	6.33	40.63	2.00	81.25	2.33	78.13	3.67	65.63	4.33	59.38
Turbidity (NTU)	10.00	4.33	56.67	3.33	66.67	3.00	70.00	3.00	70.00	3.33	66.67

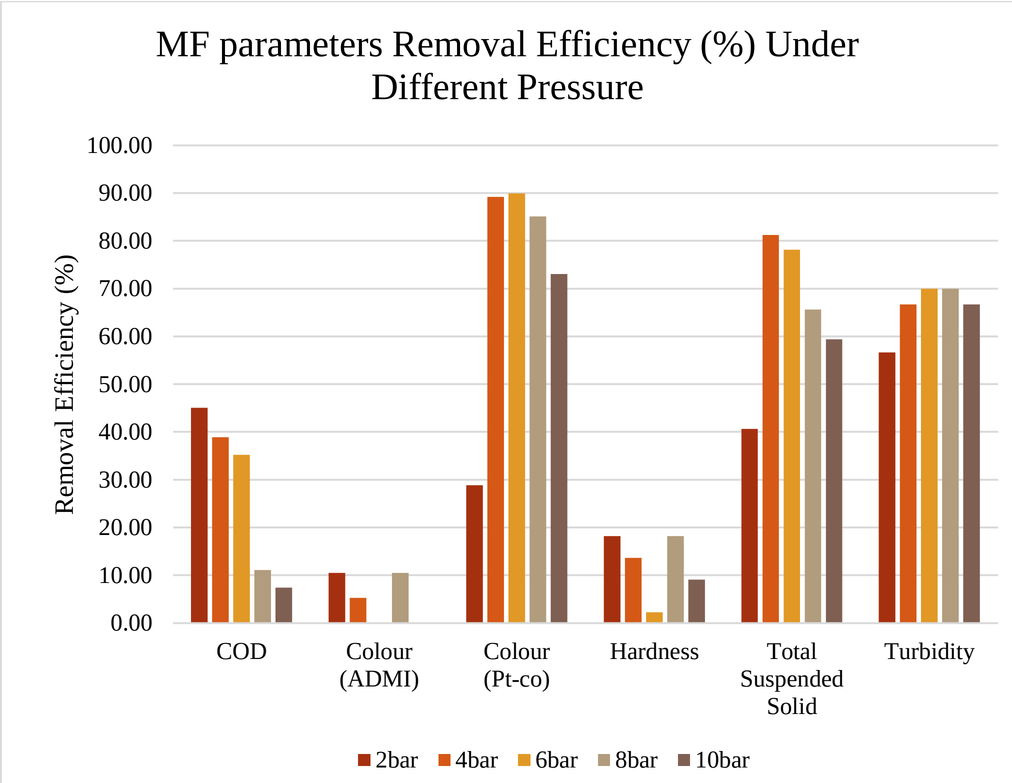

Figure 4.19: Summary of Studied Parameters Removal Efficiency (%) of MF Membrane.

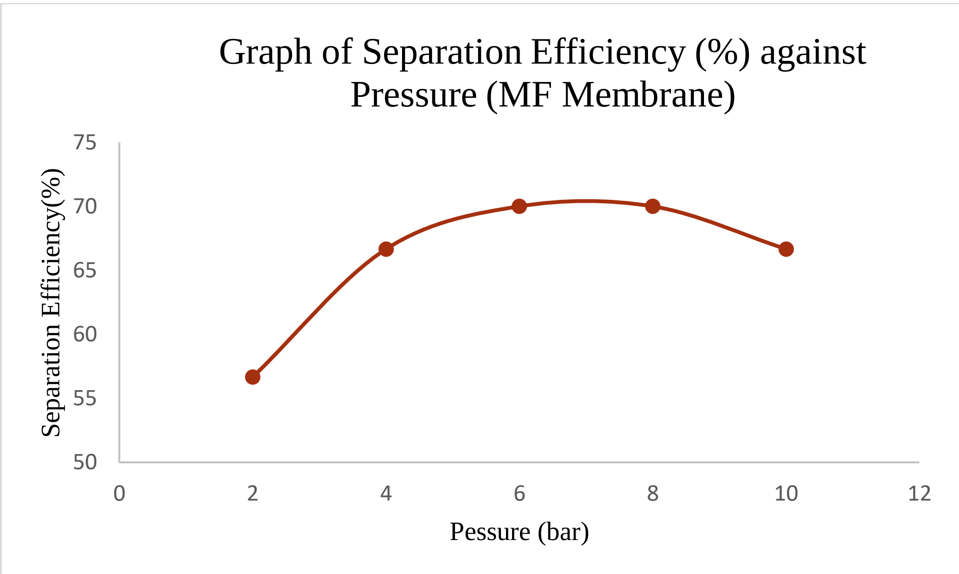

Figure 4.20: Separation Efficiency (%) of MF Membrane under Varies Pressure.

4.5.2 Flow Rate

The effect of flow rate (2 LPM, 3 LPM, 4 LPM, 5 LPM, and 6 LPM) on MF membrane was studied. Notably, the enhancement in water flux increased slightly and was not that significant from 2,906.68 L/m^{2}hr to 2,923.98 L/m^{2}hr when the flow rate increased from 2 to 3 LPM (Figure 4.21). Then, the water flux enhanced dramatically from 3 LPM to 5 LPM and slower down from 5 to 6 LPM. Jana et al. (2017) also reported the similar findings where the flux rises as cross-flow velocity rises due to increased turbulence, which prevents particles from attaching to the membrane surface, reducing fouling and raising permeate flux. Additionally, at larger pore sizes, MF offers greater effectiveness in terms of water permeability and fouling mitigation (Nasir et al., 2022).

Table 4.11: Water Flux and Separation Efficiency of MF Membrane under Constant Condition at Varies Flow Rate.

Parameter	2 LPM	3 LPM	4 LPM	5 LPM	6 LPM
Water flux (L/m2.hr)	2,906.68	2,923.98	3,138.28	3,341.69	3,393.46
Permeability (L/m2.hr.bar)	484.45	487.33	523.05	556.95	565.58

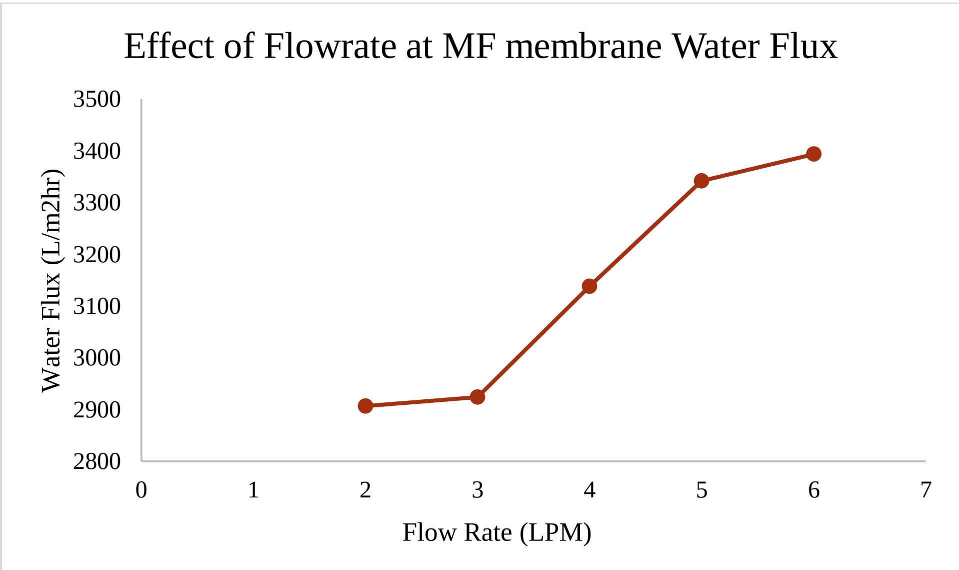

Figure 4.21: Effect of Flow Rate Supplied on MF Membrane Affects the Water Flux.

Firstly, similar to the UF membrane, COD removal efficiency generally increases with the flow rate increase, with a removal efficiency of 13.58% at 2LPM to 33.33% at 6 LPM (Figure 4.22). The theory for this increasing trend may be caused by decreased concentration polarization and increased cross-flow velocity. The fine fibers and other floating materials that the membrane has cleared appear to be adsorbing the detergents, oils, and other compounds present in the effluent (Manouchehri and Kargari, 2017).

Furthermore, the colour in ADMI has no removal efficiency by undergoing MF cross-flow with various flow rate. While removal efficiency of colour in Pt-co increases slightly from 65.14 to 69.95% when increasing the flow rate from 2 to 5 LPM. Then, removal efficiency drop from 69.95 to 55.29% when the flow rate increases from 5 to 6 LPM. These results demonstrate that increasing the flow rate can improve the efficiency of colour removal slightly by raising shear stress and lowering fouling. Yet, in other circumstances, exceeding a specific flow rate beyond a certain point may result in a loss in colour removal effectiveness because colorants are not completely removed, or the membrane becomes fouled. Besides, regarding hardness, the removal efficiency was in the range of 4.55 to 22.73%. However, no noticeable trend was observed between the operating condition and removal efficiency.

The efficiency of the membrane for total suspended solid reduction was in the range of 78.13 to 62.50%, where removal efficiency decreased from 78.13 to 62.50% when the flow rate increased from 2 to 5 LPM. Then, a sudden increase in removal efficiency to 68.78% at 6 LPM. On the other hand, the removal efficiency of turbidity decreased from 66.67 to 56.67% when the flow rate increased from 2 to 6 LPM. Increasing the flow rate can reduce TSS and turbidity removal effectiveness because the feed solution is in contact with the membrane surface for a shorter period, and the filtration duration will be decreased. Moreover, turbidity is often related to suspended particles in the inlet solution. An increase in flow rate can enhance the removal of larger suspended particles by stimulating higher shear forces, but it can also promote concentration polarization, which lowers filtration effectiveness. Therefore, it is possible that the accumulation of smaller suspended particles causes turbidity removal efficiency to decline with increasing flow rate.

Table 4.12: Results of MF Membrane under Different Flow Rate.

Parameter		**2 LPM**		**3 LPM**		**4 LPM**		**5 LPM**		**6 LPM**	
	Initial	**Final**	**Removal Efficiency (%)**	**Final**	**Removal Efficiency (%)**	**Final**	**Removal Efficiency (%)**	**Final**	**Removal Efficiency (%)**	**Final**	**Removal Efficiency (%)**
pH	7.06	7.77	-	7.49	-	7.55	-	7.64	-	7.72	-
COD (mg/L)	54.00	46.67	13.58	43.67	19.13	39	27.78	37.67	30.24	36.00	33.33
Colour (ADMI)	19.00	19.00	0.00	19.00	0.00	19	0.00	19.00	0.00	19.00	0.00
Colour (Pt-Co)	138.67	48.33	65.14	44.00	68.27	42.00	69.71	41.67	69.95	62.00	55.29
Hardness (mg/L)	44.00	42.00	4.55	42.00	4.55	34.00	22.73	36.00	18.18	40.00	9.09
Total Suspended Solid (mg/L)	10.67	2.33	78.13	2.67	74.97	3.67	65.63	4.00	62.50	3.00	68.78
Turbidity (NTU)	10.00	3.33	66.67	3.33	66.67	3.67	63.33	4.33	56.67	4.33	56.67

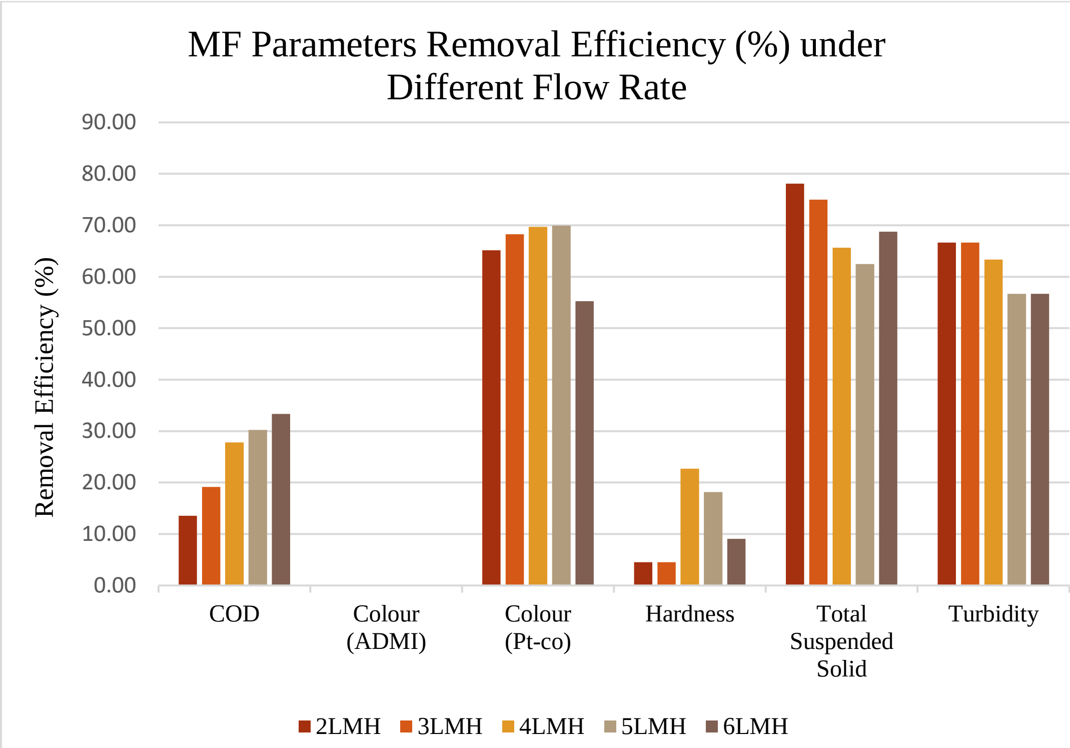

Figure 4.22: Summary of Studied Parameters Removal Efficiency (%) of MF Membrane under Different Flow Rate.

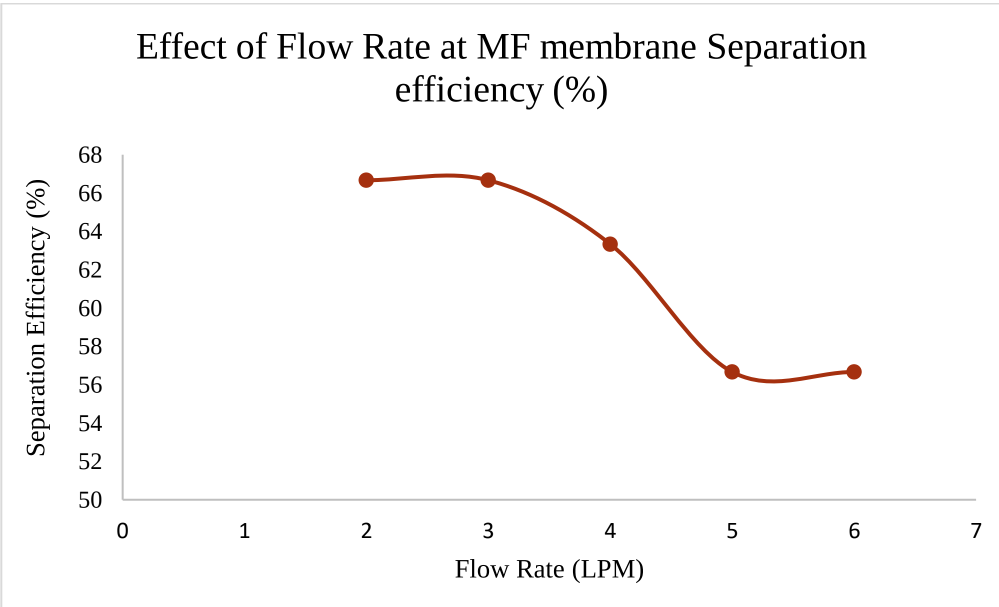

Figure 4.23: Separation Efficiency (%) of MF Membrane under Varies Flow Rate.

4.5.3 Post Water Treatment SEM Analysis

Figure 4.24 (a) – (c) exhibits the SEM image of the MF membrane after undergoing the filtration process at the optimum condition of 3 LPM and 6 bar in the magnification of 700X, 2,500X, and 5,000X, respectively. Besides, it is also noticeable that compared with the UF membrane of Figure 4.17, more impurities retain on the UF membrane than the MF membrane due to the pore size of the membrane that allows it to retain more impurities, hence, improving the water quality. Besides, it appears in Figure 4.24 (a) – (c) that minor ruptures and tears are noticeable on the MF membrane, which can result from the build-up of material on the membrane surface that cause physical harm and damage to the membrane. In addition, the SEM image that shows the accumulations of particles on the surface of the MF membrane can also form a cake layer, which can cause filtration more difficult.

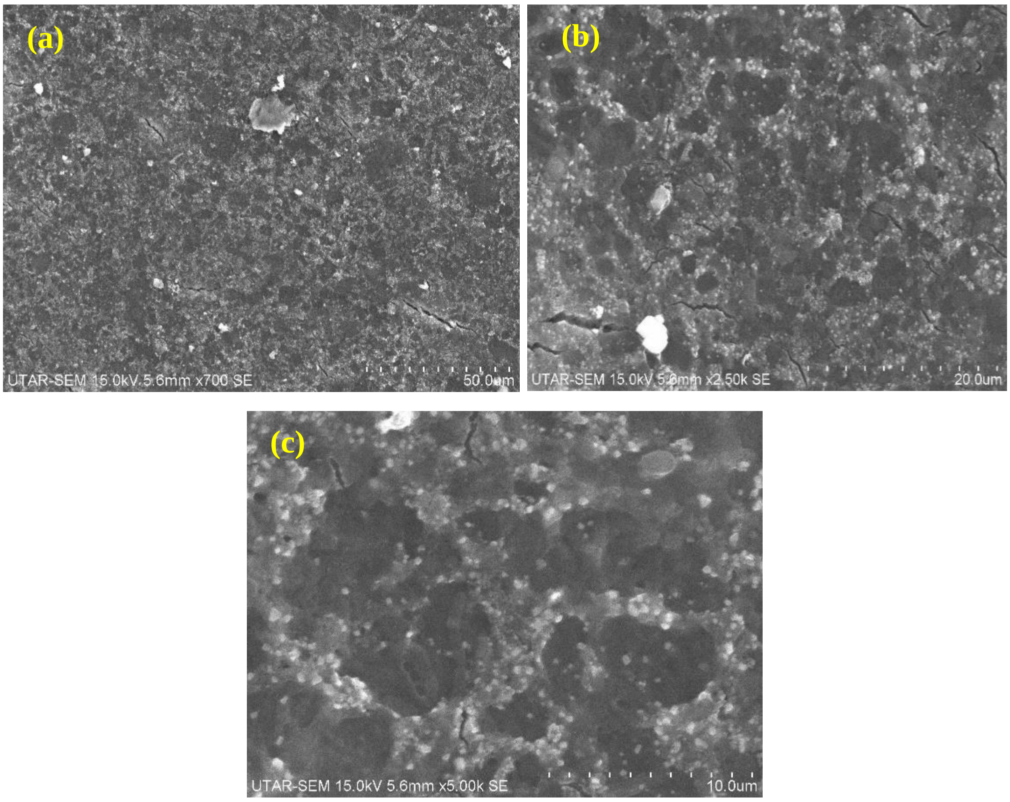

Figure 4.24: SEM Image of (a) Optimum Performance (3 LPM, 6 bar) MF Membrane (700X) (b) Optimum Performance (3 LPM, 6 bar) MF Membrane (2,500X) (c) Optimum Performance (3 LPM, 6 bar) MF Membrane (5,000X).

4.6 Comparison of UF and MF Membrane

4.6.1 Comparison of Effect of Pressure on UF and MF Membrane

The water flux increases with increased pressure for both UF and MF membranes, as observed in Figure 4.25. This trend was due to the water flux of the MF membrane being more significant than the UF membrane due to its larger pore size that allows more water to pass through. This study discovered that raising transmembrane pressure had no negative effects on the water flux. Kim et at. (1997) reported similar findings from their pilot test, which demonstrated that the permeate flux increased linearly with transmembrane pressure, indicating that the membrane process was still occurring within the pressure-controlled zone. Therefore, if more transmembrane pressure was required, it could be added without having a negative impact on the flux performance.

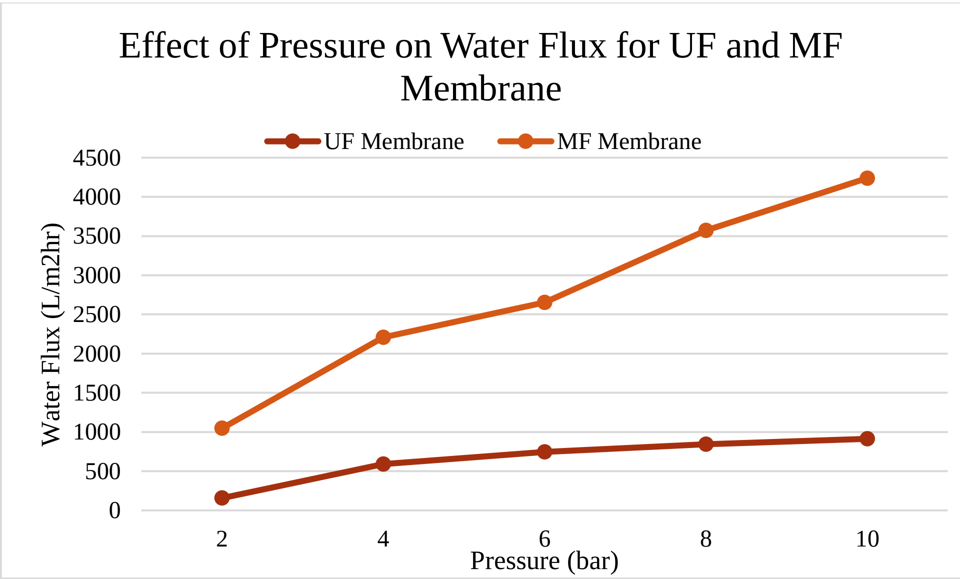

Figure 4.25: Graph of Water Flux against Pressure for both UF and MF Membrane.

In short, the best overall performance pressure for UF and MF membranes is 6 bar with a constant flow rate of 6 LPM. Figure 4.26 compares the removal efficiency (%) of UF and MF membranes with all the studied parameters under the best performance pressure of 6 bar and a constant flow rate of 6 LPM. The findings from Figure 4.26 suggested that the UF membrane performs better and has better overall removal efficiency than the MF membrane. However, the removal efficiency between them is not significant and minor. For example, the difference in removal efficiency between UF and MF membrane in terms of Colour (Pt-co) is 3.85%, total suspended solid is 0.31%, and turbidity is 1.00%. This may be due to the good quality MF membrane that contains generally efficient removal efficiency.

Furthermore, the results demonstrate that UF and MF membranes have good removal efficiency for Colour (Pt-co), total suspended solids, and turbidity. While both membranes do not bring significant effects in removing COD, Colour (ADMI), and hardness. Membrane techniques are increasingly utilized to remove microorganisms, particulates, bacteria, and naturally occurring organic material from water since these contaminants can improve the colour, odour, and taste of the water as well as react with disinfectants to produce by-products of disinfection (National Drinking Water Clearing House, 1999).

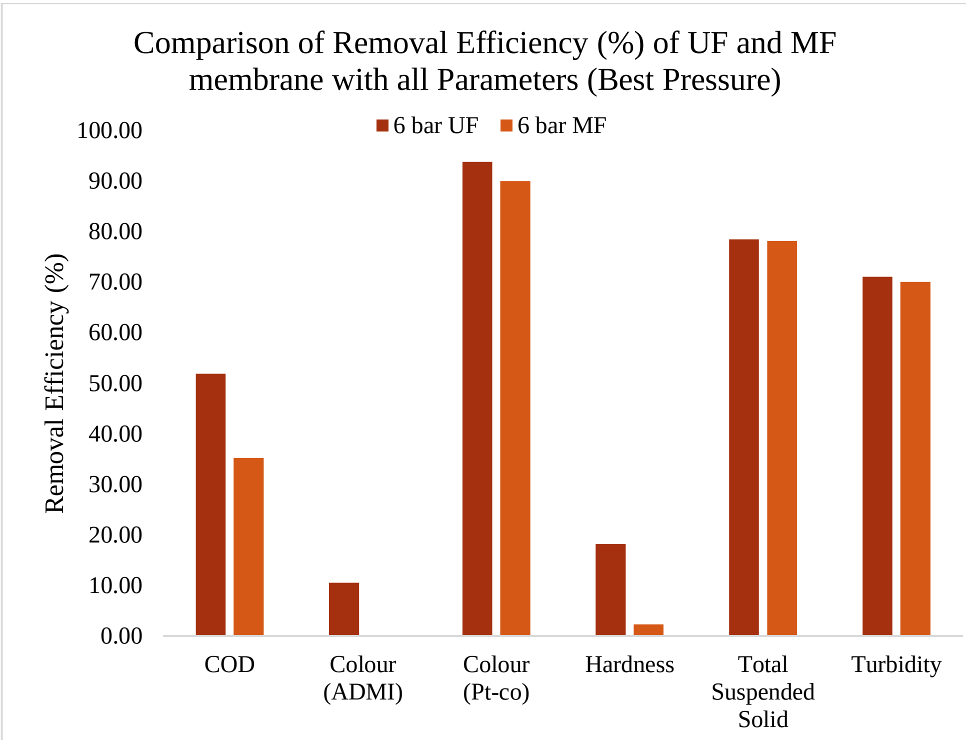

Figure 4.26: Comparison of Removal Efficiency (%) of UF and MF Membrane with all Studied Parameters under the Best Performance Pressure.

4.6.2 Comparison of Effect of Flow Rate on UF and MF Membrane

The water flux of the MF membrane is larger than the UF membrane due to the larger pore size of the MF membrane, where both membranes generally increase with increasing flow rate (Figure 4.27). However, a slight flow rate drop from 5 to 6 LPM of the UF membrane occurs, and it is probably due to the concentration polarization phenomena occurring in this membrane.

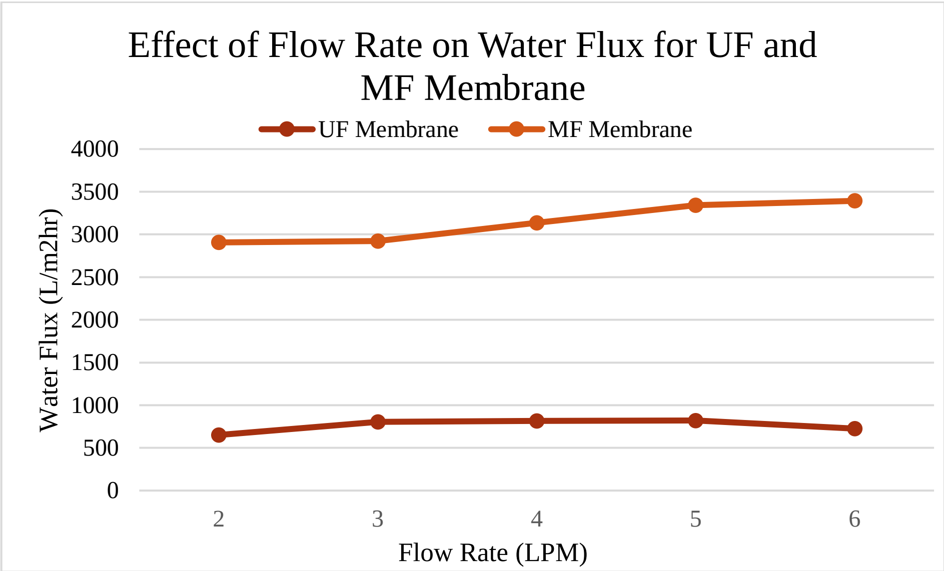

Figure 4.27: Graph of Water Flux against Flow Rate for both UF and MF Membrane.

The removal efficiency of both UF and MF membrane with all studied parameters at the optimum condition of 3 LPM and 6 bar (Figure 4.28). These results confirm that the UF membrane performs better than the MF membrane in all aspects, as the removal efficiency of the UF membrane is higher than the MF membrane for all the parameters studied. In detail, the cross-flow membrane filtration process has high removal efficiency for colour in Pt-co, total suspended solids, and turbidity. At the same time, the removal efficiency of COD is moderate. On the other hand, this mechanism is ineffective in removing colour in ADMI and hardness.

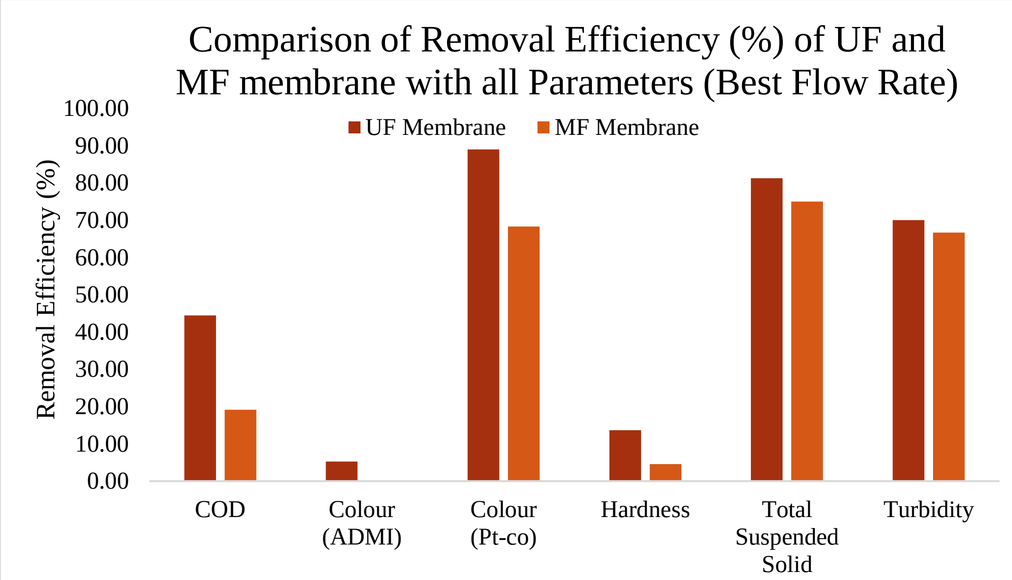

Figure 4.28: Comparison of Removal Efficiency (%) of UF and MF Membrane with All Studied Parameters under the Best Performance Flow Rate.

4.6.3 Comparison of Complete Studied Parameter for UF and MF Membrane

Table 4.13 displays the parameters studied before and after cross-flow filtration using the optimum operating conditions for UF and MF membranes. The results indicate that the filtration process has a significant impact on total suspended solids, turbidity, and colour in Pt-co, as the membranes have a high particle removal efficiency. All parameters obtained after filtration have met the recycling standards, suggesting that UF and MF membranes can be used to recycle the effluent back into the process. Moreover, Table 4.13 lists several recycling limits for textile wastewater. The quality of the treated wastewater after the optimum operating condition of both UF and MF membranes met all reuse criteria specified in Table 4.13 for the three journal articles reviewed. However, according to Guyer et al. (2016) and Hoehn (1998), the pH range for reuse limits should be between 6.5-7.5. The water quality of cross-flow UF membrane slightly exceeded the recycling limit at an optimum operating condition of 7.76. Based on Marina et al. (2022), heavy metals such as chromium, zinc, iron, mercury, and lead are the main elements that pose a risk to the environment in textile effluent. Chromic acid is a weak acid, and iron is quite acidic, making ultrafiltration an effective and affordable technology for removing heavy metals from industrial wastewater compared to conventional and microfiltration technology (Brady and Jaferey, 2003). Therefore, these results confirm that UF membrane has a slightly higher pH than MF membrane, as acidic substances are removed more efficiently by UF membrane. In conclusion, the results indicate that cross-flow filtration using UF and MF membranes can recycle effluent back into the process while meeting the recycling standards.

Table 4.13: Summarised the Complete Studied Parameters Before and After the Optimum Parameter of UF and MF Membrane.

Parameter	Raw	Sand Filtration	UF Membrane (3LPM, 6bar)	MF Membrane (3LPM, 6bar)	Recycle Limit		
Reference					Guyer et al. (2016)	Li and Zhao (1999)	Hoehn (1998)
pH	6.77	7.06	7.76	7.49	6.5-7.5	6.5-8.0	6.5-7.5
Temperature (°C)	24.90	25.00	25.20	25.20	-	-	-
Conductivity (µs/cm)	1194.00	1181.33	1124.00	1145.67	1000-2000 µs/cm	8-2200 µs/cm	-
Dissolved oxygen (%)	2.84	7.43	8.17	8.06	-	-	-
BOD_5	-	-	-	-	-	-	-
COD (mg/L)	94.00	54.00	30.00	43.67	60mg/L	0-160mg/L	<50
Total nitrogen (ppm)	12.30	7.40	7.40	8.00	-	-	-
Ammoniacal nitrogen (ppm)	0.00	0.00	0.03	0.04	-	-	-
Nitrate (ppm)	0.99	0.18	0.32	0.33	-	-	-
Total Suspended Solid (mg/L)	44.00	10.67	2.00	2.67	10 mg/L	0-50mg/L	<500
Total Dissolved Solid (mg/L)	1242.00	1230.00	1207.00	1208.00	-	-	-
Turbidity (NTU)	45.67	10.00	3.00	3.33	-	-	-
Colour (ADMI)	20.00	19.00	18.00	19.00	-	-	-
Colour (Pt-co)	339.00	138.67	15.33	44.00	Colourless	-	-
Zinc (mg/L)	<0.0002	<0.0002	<0.0002	<0.0002	-	-	-

Table 4.13 (Continued)

Parameter	Raw	Sand Filtration	UF Membrane (3LPM, 6bar)	MF Membrane (3LPM, 6bar)	Recycle Limit	Parameter	Raw
Reference					**Guyer et al. (2016)**	**Li and Zhao (1999)**	**Hoehn (1998)**
Copper (mg/L)	0.17	0.12	0.19	0.19	-	-	-
Iron (mg/L)	-0.13	-0.04	-0.14	-0.12	-	0-0.3mg/L	0.1mg/L
Hardness (mg/L)	46.00	44.00	38.00	42.00	-	0-100mg $CaCO_2$/L	90mg/CaCO2/L

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this study, the textile industrial wastewater was prepared and underwent pre-treatment of sand filtration, followed by cross-flow UF and MF membranes respectively with a set of pressure and flow rate to determine the water flux obtained and removal efficiency. The characteristic of both membranes was characterized by using SEM. SEM depicted that both UF and MF membranes have an asymmetric structure. A dense sponge-type structure top layer and a porous sublayer with a finger-like structure were shown in both membranes.

The effect of different parameters for UF membrane of UE050 and the MF membrane of ME010 such as the supplied pressure (2, 4, 6, 8, 10 bar), and supplied flow rate (2, 3, 4, 5, 6 LPM) for cross-flow filtration of textile industrial wastewater were investigated to identify the optimum condition. The overall optimum conditions for the treatment of textile wastewater for cross-flow UF filtration will be at a pressure of 6 bar and flow rate of 3 LPM, while the overall optimum conditions with cross-flow MF filtration is same with UF membrane of 6 bar and 3 LPM. However, in detail, UF membranes result in better overall removal efficiency and performance than MF membranes.

Besides, compared with several recycle limit obtained from Journal Article, all the studied parameters listed in the Environmental Quality (Industrial Effluent) Regulations 2009, Standard B requirement is generally within the recycle limit for both UF and MF membrane under optimum operating condition which prove that recycle of the textile industrial wastewater back to the process can be carried out.

5.2 Recommendations for Future Work

Firstly, the recommendations that were available for this study involved, other than SEM, the characteristic of the membrane can also be characterized by EDX to have a more detailed identification of components retained on both membranes after the cross-flow filtration process.

In addition, more parameters can be studied such as concentration of impurities, pH of solution, and fouling problem. Fouling is an essential problem and concept in the membrane filtration mechanism which can affect the performance of the membrane. The theory of fouling is complicated and needs to be investigated in a relatively long period of time which can be one of the recommendations for future study.

The entire project was carried out in accordance with the specified field of inquiry. Nonetheless, the project's exploration was restricted by the time available. In short, the following are the summarised recommendations that are made to improve future works:

(i) Several different manipulated variables such as pH, the concentration of textile wastewater, and temperature could be varied to determine the optimum condition for the most efficient and cost-effective situation to treat the textile industrial wastewater.

(ii) The effect of fouling can be focused with longer monitoring time and observe the unwanted fouling formation and avoid it to achieve a better cross-flow filtration treatment.

(iii) Different types of membranes and different materials of the membranes can be used to test the cross-flow filtration method in treating industrial textile wastewater.

(iv) More membrane characteristic testing such as EDX, UV Spectrophotometer, and high-resolution transmission electron microscopy (HRTEM) can be carried out for a better understanding of the membrane structure and characteristic before and after cross flow filtration.

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APPENDICES

Appendix A: Notice of Abstract Acceptance for CENVIRON

Kok Chung Chong <chongkc@utar.edu.my>

Your Abstract Submission for CENVIRON-2023
1 message

Morressier Team <discover@morressier.com> Tue, Apr 4, 2023 at 11:29 AM
To: chongkc@utar.edu.my

Morressier

Dear Chong Kok Chung,

Thank you for your abstract submission to 'CENVIRON-2023'.

This message is to inform you that your Submission 'Effect of Flowrate and Pressure on the Crossflow Filtration in Textile Wastewater Treatment by Commercial UF Membrane' has been accepted as an oral presentation. You can log in to your account and view your submitted Abstract under 'My Submissions'.

Should you have any questions or concerns, please don't hesitate to let us know. Reach us by email at support@morressier.com or through the "Get help" option in your personal menu.

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10961 Berlin

Figure A-1: Notice of Abstract Acceptance for CENVIRON.

Appendix B: Abstract Accepted for CENVIRON

Effect of Flowrate and Pressure on the Crossflow Filtration in Textile Wastewater Treatment by Commercial UF Membrane

See Yi Chan[1], Kok Chung Chong[1,2,*], Woon Chan Chong[1,2,], Soon Onn Lai[1,2,], Yean Ling Pang[1,2,], Shee Keat Mah[1,2,]

[1]Department of Chemical Engineering, Lee Kong Chian Faculty of Engineering and Science, Universiti Tunku Abdul Rahman (UTAR), Jalan Sungai Long, Kajang 43000, Selangor, Malaysia.

[2]Centre for Photonics and Advanced Materials Research, Universiti Tunku Abdul Rahman, Kajang 43000, Malaysia.

Abstract. Textile industries are one of the greatest wastewater producers as they require a significant amount of water to be used in the dyeing and finishing processes of textile manufacturing. The number of unit operations in the technological process, the product range, the bath ratio, the mass of fiber in relation to the bath volume, and the finishing machine are some variables that will affect water consumption in the textile industry. As a result, generally, a typical textile plant may consume a volume of water between 100,000 and 300,000 m^3 annually. As textiles address a substantial portion of human requirements, it is predicted that by 2050, there will be 160 million metric tonnes, three times as much clothing as there is today. Membrane technology in wastewater treatment is a recent interest arising technique and garnering the industrial application's interest, owing to its ease of setup and low energy requirement. Crossflow membrane filtration is commonly used in the industry, attributed to its tangential flow across the membrane mechanism, leading to low fouling. This study investigated the textile wastewater's effluents using crossflow ultrafiltration (UF) membrane filtration. The effect of the operating parameter in terms of pressure and flowrate of the crossflow system were performed to evaluate its permeate flux performance. The study's outcome reveals pressure increases from 2 bar to 4 bar, the water flux enhances dramatically from 156.26 L/m^2hr to 591.98 L/m^2hr, and the water flux further increases constantly from 4 bar to 10 bar. On the other hand, the flowrate positively affects the permeate flux, where the flux was enhanced from 651.01 L/m^2hr to 726.08 L/m^2hr when adjusting the flow rate from 2 LPM to 6 LPM. The quality of the permeate was also examined, and it was found to adhere to the standard prescribed by the Department of Environmental, Malaysia. The results from this study suggested that crossflow membrane filtration system could be commercially feasible due to its permeate flux performance and superior permeate quality.

Keywords: Wastewater Treatment, Crossflow, Membrane, Textile, Ultrafiltration

Figure B-1: Abstract Accepted for CENVIRON.