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RESEARCH ARTICLE

Characteristics and Performance of Polysulfone-Polyvinylpyrrolidone Synthetic Hybrid Membrane in Water Purification System

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ABSTRACT

Clean water is a fundamental need for human. Whether it is used for recreational purposes, food production, domestic use and drinking, safe and readily available water is important for everyone. Water scarcity is very serious and is one of the most extensive problems affecting people throughout the world. In this study, the emphasis is to fabricate polysulfone-polyvinylpyrrolidone hybrid membrane with different polymer formulation to study the characteristics and morphology in determining the optimum formulation of polysulfone-polyvinylpyrrolidone hybrid membrane. In this study, polysulfone and polyvinylpyrrolidone were used as the polymers and 1-Methyl-2-Pyrrolidone was used as the solvent. The optimum formulation is obtained by conducting the test on the membrane; permeate flux test, salt rejection test and tensile test. The resulted optimum polysulfone-polyvinylpyrrolidone hybrid membrane were undergone two more tests which were Scanning Electron Microscopy (SEM) and wastewater quality test. These two tests were conducted to measure its ability to filter the wastewater and the pore size of membrane were captured. The optimum Membrane is sample4 which had the highest value of permeate flux with 33.78 L/m2hr, it had removal percentage of 11.76% for salt rejection, decreased 12.42% in conductivity from 3.3 S/m to 2.89 S/m, and it was able to withstand 48 kN/m2 at strain value of 3.6 m/m. The optimum sample 4 has formed a microfiltration membrane with average 3.23 µm pore size which is successfully filter out particles in the wastewater, where it could remove 44.27% turbidity, 23.08% TSS, 14.29% COD, 4.73% TDS, 4.79% conductivity, 4.34% pH and 13.04% colour.

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Introduction

A United Nations (UN) report has warned there are about 2.1 billion people around the world lack access to safe and readily available water at home[1]. According to the UN Children's Fund (UNICEF) and World Health Organization (WHO) joint report, many healthcare facilities, schools, and homes also lack water and soap for handwashing, exposing all the people, especially young children, at preventable health risks [2].

As a result of unsafe hygiene, sanitation and drinking water, about 842,000 people die from diarrhoea every year which claims the lives of 361,000 children under the age of 5 every year [1][3]. In the coming years, with the globally occurring water scarcity, more water related problems are likely to happen, and in order to overcome this, numerous research to discover new ways to purify water with less energy and lower cost are needed to be developed [4][5]. In the 1960s, membranes have become a feasible medium for the purification of water with high performance of synthetic

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membranes development [6]. Application of membrane for water treatment has improved using more advanced membrane made from new materials and utilized in various arrangements [7][8]. The population of membranes are rising in potable drinking water production from seawater, surface and ground sources, and even in the advanced treatment of desalination and wastewater.

Water also strongly affects energy and food production, industrial output, and the quality of our environment, affecting the economies of both developing and industrialized nations. Due to the thermal resistance, mechanical and chemical limitation, the applied scale is restricted which could cause the most critical problems in membrane application are membrane fouling and flux and selectivity. These need to be improved by implementing extensive efforts. Obstacles need to be eliminated and problems of using membrane need to be reduced, by improving the development of new materials and methods for fabricating and modifying polymeric membrane. Membrane can be classified as biological membrane or synthetic membrane. A biological membrane is a barrier within living things, whereas synthetic membrane is a membrane created synthetically in the industry for separation purposes. This study will focus on the synthetic membrane.

The purpose of this study is to fabricate polysulfone-polyvinylpyrrolidone hybrid membrane with different polymer formulation and to study the characteristics and morphology with different polymer formulation so that the optimum formulation of the hybrid membrane could be determined. In order to satisfy the first objective of this study, the percentage of polymers will be varieties and the percentage of solvent used will remain constant. In this study, polysulfone (PSf) and polyvinylpyrrolidone (PVP) were used as the polymers, while 1-methyl-2-pyrrolidone (NMP) was used as a solvent. The membrane fabrication processes, including the dope solution preparation and casting, were conducted at the Hydrology Laboratory at the School of Civil Engineering, UiTM Shah Alam. Permeate flux test was also conducted in the same Hydrology Laboratory. Scanning Electron Microscopy was conducted at the Faculty of Dentistry, UiTM Sungai Buloh.

Synthetic Membrane

Synthetic membrane can be produced from organic materials such as polymers, as well as inorganic materials such as ceramics [9]. Polymeric membranes are the most common synthetic membranes in the separation industry. Based on the use of synthetic membrane, membrane systems allow the solution concentration and separation at zero thermal damage. Based on the shape and molecular size of particles, it can be separated by using and specially designed semi-permeable and synthetic membranes [9].

Membrane Configuration

Membranes are manufactured in a variety of configurations including flat sheet, tubular, and hollow-fibre shapes all of which has been utilized in various applications in many industries. The ideal membrane configuration depends on several factors such as cost, feed stream component characteristics, production volume and scaling needs.

1. Flat Sheet Membrane

Flat sheet membrane configuration is easy to clean and replace so it can be very useful on a laboratory scale [10][11]. Flat sheet membrane has been used in the membrane distillation (MD) process such as desalination and water treatment [12]. Since most flat sheet membranes used on MD studies have very low thickness, low mechanical strength and low packing density (membrane surface area per module volume) that made the material require stronger support [10][12]. Flat sheet membrane is layered and wrapped around a hollow core along with feed separators and form a spiral-wound membrane.

2. Tubular Membranes

In the 1920s, tubular membranes were available for use in the laboratory and in 1960's, itwas used in industrial applications [13]. Tubular membrane modules have one or more tubes of varying diameter. The tubes are constructed of a microporous substrate material which provides mechanical strength and the membrane is cast on the inside of the tube as a finely porous surface layer.

3. Hollow-fibre Membranes

Hollow-fibre modules are usually made up of fifty to five thousand self-supporting, hollow-fibre membrane tubes [14]. It was developed in the 1960's. Among the other available module geometries, hollow-fibre systems are often preferred due to the highest membrane surface areas per unit volume and it is easy be used in flow streams. The main difference between hollow-fibre and tubular membrane is the achievement of the regime of flow on the bore side. In hollow-fibre membrane with internal diameter is less than 1mm, laminar flow can be achieved but turbulence cannot, this limits the mixing at membrane surface. Whereas in tubular membrane with internal diameter greater than 2mm, turbulence can be achieved easily and concentration polarization, fouling and scaling can be reduced.

Membrane Fabrication

In this study, the membrane fabrication method used is phase of inversion. It is a process of controlled polymer transformation from a liquid phase to solid phase. Phase inversion via immersion precipitation is the most widely used membrane preparation method. A porous bulk structure can be obtained by immersion precipitation.

Typically, the formation of membranes made by the immersion precipitation method occurs in less than a few seconds which in a short time scale. Multi-component solutions containing solvents, polymer and sometimes additives are used in the immersion precipitation method to make the most commercial used membranes.

The membranes can be prepared from polymeric materials which are mostly organic compounds. The polymer concentration in the casting solution that can control the membrane's pore size and porosity [15][16]. Even in very small amounts of these solution additives can have a significant effect on the membrane structure, and hence, its separation performance.

1. Polysulfone

Polysulfone (PSf) is part of the thermoplastic polymer family. These polymers are recognized due to the toughness and stability at high temperatures it can possess. It contains the subunit aryl-SO2-aryl, the defining feature of which is the sulfone group. PSfis used in specialty applications and often is a superior replacement for polycarbonates. PSf polymers are rigid, high-strength, and transparent polymers that retaining these properties between -100 and +150 °C. It has very high dimensional stability; the size change when exposed to boiling water generally falls >0.1%. PSf is highly resistant to mineral acids, alkali, and electrolytes, in the pH range from 2 to 13. It is resistant to oxidising agents; therefore, it can be cleaned by bleaches. PSfis also resistant to surfactants and hydrocarbon oils but is not resistant to low-polar organic solvents. and aromatic hydrocarbons. It is also stable in aqueous acids and bases and many nonpolar solvents; however, it is soluble in dichloromethane and methylpyrrolidone[17].

2. Polyvinylpyrrolidone

Polyvinylpyrrolidone (PVP), also commonly called as polyvidone or povidone, is a water-soluble polymer made from the monomer N-vinylpyrrolidone. N-Vinylpyrrolidone (NVP) is an organic compound consisting of a 5-membered lactam linked to a vinyl group. It is a colorless liquid although commercial samples can appear yellowish. To attain a resistance to fouling and high permeation flux, polyvinylpyrrolidone is added with the polysulfone membrane.

3. 1-Methyl-2-Pyrrolidone

1-Methyl-2-Pyrrolidone is a solvent used in a variety of industries and applications. It is especially widely used in fabrication process of polymeric membrane as solvent. N-methyl-2-pyrrolidone (NMP) is widely used as a solvent in polymeric membrane fabrication process, its elimination from the process wastewater (normally at a high concentration > 1000 mg/L) prior to discharge is essential because of the environmental concern.

Methodology

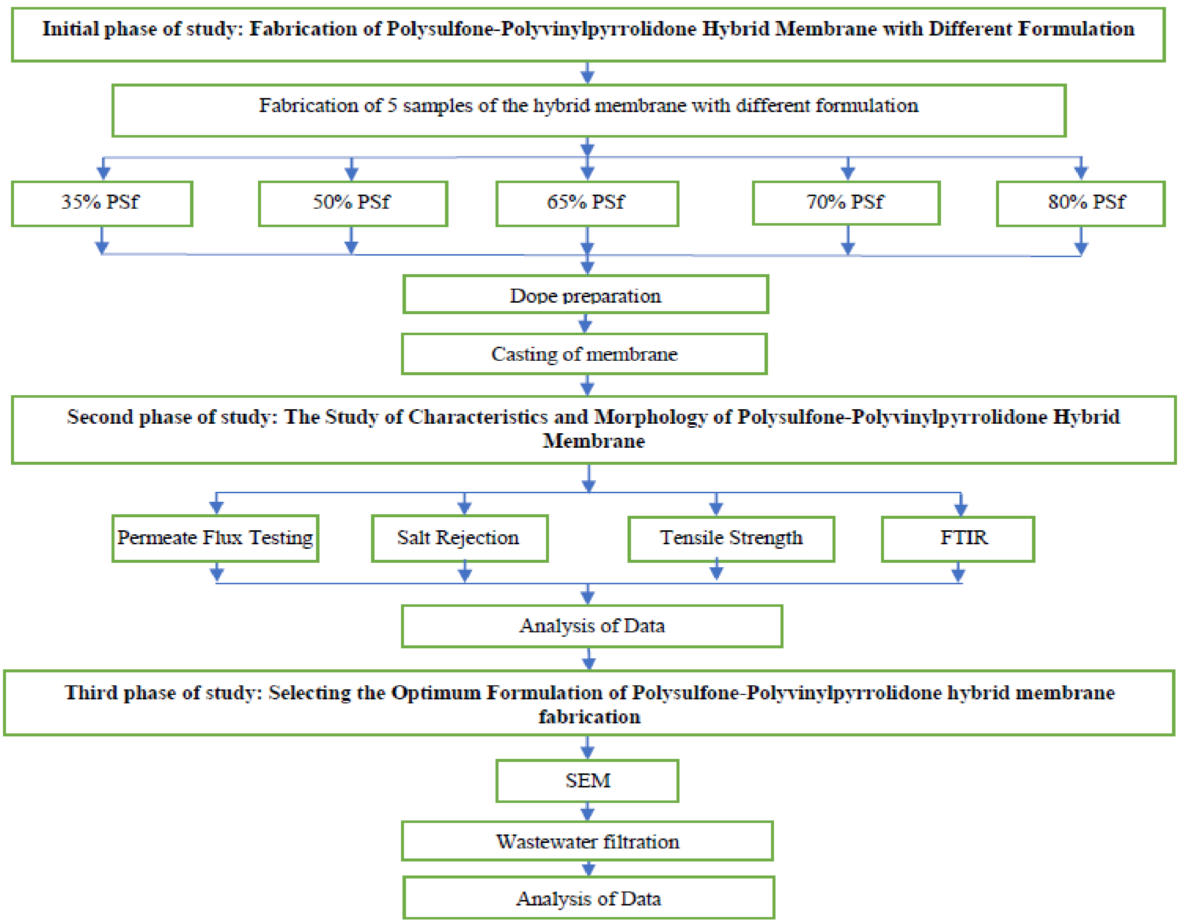

Figure 1. Flow chart of Methodology

There are three phases in this study. The initial phase, Fabrication of Polysulfone-Polyvinylpyrrolidone Hybrid Membrane with Different Formulation for the membrane fabrication, dope preparation and the casting of membrane. The next phase is the Study of Characteristics and Morphology of Polysulfone-Polyvinylpyrrolidone Hybrid Membranes after all tests for the characteristics of the membrane are completed, the tests are permeate flux testing, salt rejection, tensile strength and FTIR. In the final phase, the Optimum Formulation of Polysulfone-Polyvinylpyrrolidone will be selected based on the membrane with the best performance result and was tested for its final ability to filter wastewater and SEM images of the membrane were captured. The flowchart of the method is shown in Figure 1.

Materials and Apparatus

In this study, the materials used for membrane fabrication are polysulfone (PSf), polyvinylpyrrolidone (PVP), and 1-methyl-2-pyrrolidone (NMP). The apparatus used for the fabrication of the membranes are electronic balance (2007 TX/TXB UniBloc Top-Loading Balances), 200ml beakers, hotplate magnetic laboratory stirrer/digital/bench-top (MS7-H550-S) from Dragon Laboratory Instruments, digital overhead mechanical stirrer (WiseStir HT-50DX-SET from Wisd Laboratory Equipment), thermometer, aluminium foil, capped bottles, spirit level, and pneumatic control flat sheet membrane machine. The material used for permeating flux is pure water. The apparatus used are scissors, measuring cylinder, and timer. The materials used for salt rejection are pure water and sodium. The apparatus for salt rejection is electronic balance and all the apparatus used are similar to permeate chloride (NaCl) flux testing. The apparatus for the testing is SensION 7 Benchtop Conductivity Meter, DR 2800 Portable Spectrophotometer from Hach, 2100P Turbidimeter from Hach, SensION 3 Benchtop pH/mV Meter, 110 VAC from Hach.

The apparatus used for SEM are SC7620 Mini Sputter Coater/Glow Discharge System from Quorum Technologies, and TM3000 TableTop Scanning Electron Microscope from Hitachi-High Technologies, the testing was conducted at the Research Lab at the Faculty of Dentistry at UiTM Sungai Buloh. Wastewater was collected from a lake in Shah Alam by using a bucket and a bottle. The apparatus for water quality check is similar to those of permeate flux testing. The apparatus for the testing are SensION 7 Benchtop Conductivity Meter, DR 2800 Portable Spectrophotometer from Hach, 2100P Turbidimeter from Hach, SensION 3 Benchtop pH/mV Meter, 110 VAC from Hach.

Laboratory

The laboratory works include dope preparation, membrane casting, permeate flux test, salt rejection test, SEM, FTIR, water quality test and tensile test.

1. Dope Solution Preparation

Dope solution is prepared by a formulation using the additive, which is polyvinylpyrrolidone that acts as a polymer. In this proses the additive is removed in the formulation, having left with only 95%, the formula is then derived into 100% again, where the NMP is at 81.05% and the polymers at 18.95%. The polymers' percentages vary in this study and are shown in Table1. The compositions of the dope solution formulation are shown in Table 2, the percentage of solvent is remained constant in the formulation.

Table 1. Polymer Percentage in Dope Solution

Membrane Sample	Polysulfone (%)	Polyvinylpyrrolidone (%)
1	35	65
2	50	50
3	65	35
4	70	30
5	80	20

Table 2. Membrane Formulation Material Percentage

Membrane Sample	Polysulfone (%)	Polyvinylpyrrolidone(%)	1-Methyl-2-Pyrrolidone (%)
1	6.635	12.315	81.05
2	9.475	9.475	81.05
3	12.315	6.635	81.05
4	13.265	5.685	81.05
5	15.160	3.790	81.05

2. Casting

After the dope solution has been placed in an ultrasonic water bath for 48 hours and kept for at least 24 hours in the chemical cabinet, the resulted dope solution was taken out for casting. The casting process was performed by the usage of pneumatically controlled flat sheet membrane machine. The machine that has a clean flat glass on it was make sure must be clean and dry before use. The level of the clean flat glass on the machine was arranged to be horizontal by using a spirit level. The casting knife gap was set to 300 μm by adjusting the two micrometric screws at the assembly of casting knife. The dope solution was cast onto the glass plate by pouring some of the solution into the reservoir of the machine and the knife was run through it, producing a clear flat layer of solution. Then, the glass plate was immediately immersed into a clean water bath in room temperature at around 28 °C where the solution turned itself into a flat sheet membrane and then removed from the glass plate. The glass plate was removed and cleaned for reuse and the membrane was kept submerged in a water bath for about 24 hours before air drying it so that the solvent of the membrane is dissolved. The steps were repeated three times for each membrane formulation to get three flat sheet membranes for each dope solution. After 24 hours, the membranes were air dried in the room temperature for another 24 hours before storing them in sealed plastic bags prior to testing.

3. Salt Rejection

The salt used in this study is sodium chloride (NaCl). The concentration of the solution is 2000mg/L. 5L of pure water was used to create the solution. 10g of NaCl was weighted and then mixed with the 5L pure water to create the solution. The mixing was done by using a mechanical mixer to mix the solution homogenously. The salinity, conductivity, and total dissolved solids of the solution were recorded. With the same set up for the permeate flux test, the pure water as the feed has been changed to the NaCl and pure water solution. The permeate was collected to be tested for salinity, conductivity, and total dissolved solids. The steps of filtering were repeated for the other 4 samples of membrane with different formulation.

4. Tensile Test

To obtain the stress-strain curves, the module of Dynamic Mechanical Analyzer (DMA) from Mettler Toledo (DMA 1). Dynamic mechanical analysis (DMA) determines the force and displacement amplitudes. It is an important technique used to measure the mechanical and viscoelastic properties of materials.Prior to testing, the membrane samples were immersed in a water bath at room temperature for about 24 hours and were cut into a rectangular shape of 6mm by 25mm. The test was performed at room temperature at a rate of 2N/min until the membrane fractured. The results were obtained from the TOLEDO Software in the desktop.

5. Water Quality

After choosing the optimum formulation, the efficiency of the membrane was evaluated by filtering wastewater. Wastewater was collected from a lake in Seksyen 7, Shah Alam, Selangor as shown in Figure 2at the mark 'x'.

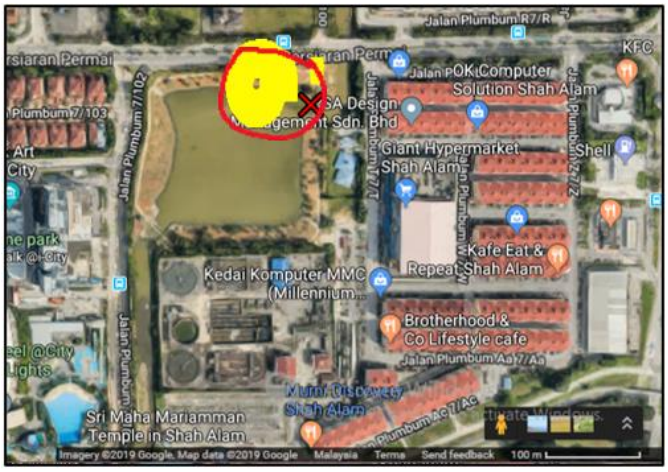

Figure 2. The map of sampling location

Before taking the sample, the bottle needs to be washed 3 to 4 times with water from the same sampling site. The method to collect the water was according to the standard MS ISO 5667-6:2014, "Guidance on sampling of rivers & streams". All the laboratory tests for water quality are according to Water Analysis Handbook | HACH and safety standard operating procedure.

pH

pH level is the acidity or alkalinity level of a water-based solution. The wastewater sample was poured into a beaker. The probe of the SensION 3 Benchtop pH/mV Meter was rinsed with deionized water and then dried with a lint-free cloth. The probe was then put and stirred gently in the sample. The temperature sensor was ensured to be submerged completely. The Read button was pushed and the probe was stirred gently while the display showed "Stabilizing". A lock icon appeared as the probe was stabilized in the sample, the reading for pH was recorded. This was repeated two times for a more reliable reading and the process repeated by replacing the unfiltered wastewater with the wastewater filtered through the membrane for three times.

Turbidity

The sample was poured into a sample cell up to the line which is about 15mL. The cell was then capped and was handled carefully by holding the top to avoid touching the glass surface of the cell. The cell was wiped off with a lint-free cloth to ensure fingerprints and water spots were removed. The turbidity meter was placed on a flat surface and switched on. The sample cell was inserted into the cell compartment of the instrument where the raised orientation mark in front of the cell compartment was aligned with the diamond markand close the lid.

Colour& Total Suspended Solids

The blank sample is used distilled water filled in a cell. The sample cell was then capped and was handled carefully by holding the top to avoid touching the glass surface of the cell. The cell was wiped off with a lint-free cloth to ensure fingerprints and water spots were removed. The sample cell was inserted into the cell compartment with the transparent sides facing the light source, and the lid of the compartment is then closed. The ZERO key was pressed to set the distilled water in the sample cell as blank sample. Then, the blank sample cell was discarded and another cell was filled with the sample from the permeate was placed in the compartment of the spectrophotometer. The READ key was pressed to measure the colour and TSS. Result was recorded and the steps were repeated for all the samples.

Chemical Oxygen Demand

Chemical Oxygen Demand (COD): Chemical oxygen demand is a measure of the capacity of water to consume oxygen during the decomposition of organic matter and the oxidation of inorganic chemicals such as ammonia and nitrite. 2ml of permeate filtered through the membrane samples from were taken and added to low-range (3-50 ppm) vials. The vials were then shaken gently and put into the reactor along with a blank. Distilled water was used as a blank. The reactor was set to 150°C for two hours. After two hours, the vials were left to cool in room temperature. The COD readings were taken by using a spectrophotometer by comparing the permeate with the blank.

Escherichia Coli

The Quanti-Tray Sealer was turned on to allow it to warm up for about 10 minutes. While waiting for the machine to warm up, 100 mL of the water sample obtained from the lake in Shah Alam was poured into a beaker before pouring it into a bottle for a more accurate reading. Afterwards, the 100mL of water sample was poured into a bottle with a cap and was shook vigorously 25 times within 7 seconds.

Then, 1 packet of Colilert reagent was added to the bottle and the bottle was recapped and shook until the reagent appears to be dissolved. The sample was then poured into the tray, with one hand holding the tray with the wells facing the palm of the hand, and the other pouring the sample into the tray. Once the tray with the sample was sealed, the tray was placed in a 35°C ± 0.5°C incubator for 24 hours.

After 24 hours, take the sample out, and then by using a colour comparator, the yellow wells were checked for coliform. To check for E.coli, a UV lamp was used to check for fluorescence appearance. If the wells fluoresce, there is presence of E.coli, and vice versa. All the fluorescing wells were counted. The steps were repeated for the permeate of the wastewater.

Scanning Electron Microscopy

SEM was done at The Faculty of Dentistry at UiTM Sungai Buloh, Selangor. For the cross-section of the membrane, one part of the sample was cut straight in mid-air with a sharp cutter knife. This is to avoid pressure that could distort the morphology of the membrane. The sample was then coated with the SC7620 Mini Sputter Coater/Glow Discharge System from Quorum Technologies.

After coating, the sample was placed inside the TM3000 TableTop Scanning Electron Microscope (Plate 3.35) from Hitachi-High Technologies which is provided by the Research Lab at the Faculty of Dentistry at UiTM Sungai Buloh. The images are displayed on a desktop on the Hitachi TM3000 software.

Result and Discussion

Five hybrid polymeric membranes were casted with different formulation. The membranes were tested with permeate flux test, salt rejection test, tensile test, FTIR, SEM and water quality.

Permeate Flux Test

Permeate Flux tests have been conducted on the membranes. Table 3below shown that there was a failure in obtaining the result for membrane sample 1. Four sheets of sample 1 were found ripped after attempting the permeate flux test.

Table 3. Permeate flux of membrane samples with different formulation

Sample	Volume (L)	Area (m^2)	Time (hr)	Flux (L/m^2.hr)
1	-	-	-	-
2	0.1	0.0113	0.273	32.42
3	0.1	0.0113	0.277	31.91
4	0.1	0.0113	0.262	33.78
5	0.1	0.0113	0.282	31.38

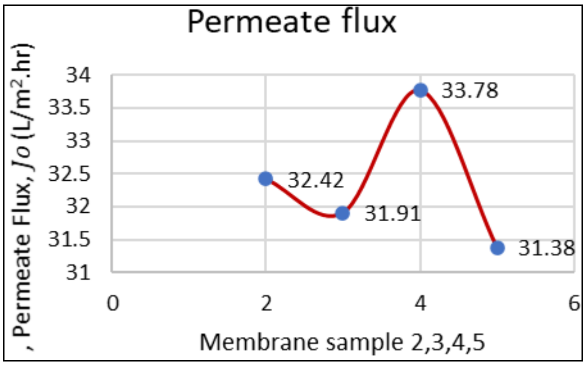

Figure 3. Graph of permeate flux against membrane sample

From the graph in Figure 3 and Table 3, it is apparent that membrane sample 4 has the highest permeate flux with 33.78 L/m^2hr, while membrane sample 5 has the lowest permeate flux of 31.38 L/m^2hr. There is not much difference in the permeate flux results, with only 2.40 L/m^2hr the difference in percentage of the highest and lowest permeate flux is 4.36%. The mean of the permeate flux result is 32.37 L/m^2hr. According to Mansur et al. 2018, the higher the percentage of PVP, and the lower percentage of PSf, the lower the permeate flux is(Mansur et. al., 2018). This would be true according to the trend is declining in the decrement of PSf percentage except for sample 4.

Salt Rejection Test

From Table 4, it is found that all the parameters of the permeate water are lesser than the pure water and salt (NaCl) solution. The conductivity values decrease from 3.3 S/m, salinity from 1.7 PSU and TDS from 1650 ppm.

Table 4. Salt rejection of membrane samples with different formulation

Sample	Conductivity (S/m)	Salinity (PSU)	TDS (ppm)	Salt Rejection %
Pure Water + Salt	3.3	1.7	1650	-
1	-	-	-	-
2	3	1.5	1549	11.76
3	3.13	1.6	1599	5.88
4	2.89	1.5	1499	11.76
5	3.1	1.6	1549	5.88

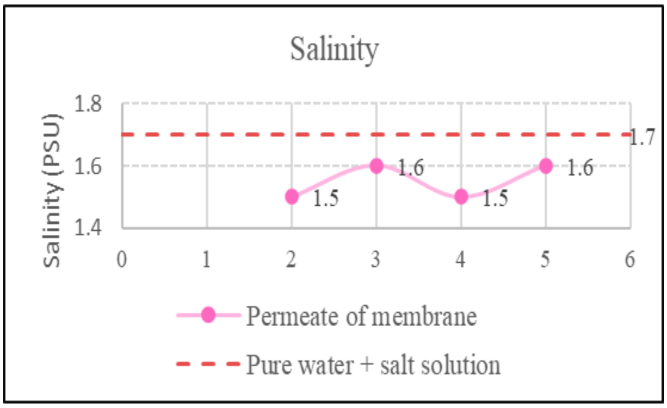

Figure 4. Graph of salinity against membrane permeate

As shown in Figure 4, it is apparent that all the feed permeates that passed through each membrane sample have decreased from the original value of 1.7 PSU. The permeate of the second and fourth membrane sample has the lowest salinity 1.5 PSU, while the permeate of the third and fifth sample both had a salinity value of 1.6 PSU. The equipment only measured up to one decimal place, the membrane permeate might have higher salinity than the other. The graph for percentage of salt rejection is shown in Figure 5, where permeate for sample 2 and 4 has a rejection of 11.76% and sample 3 and 5 have 5.88%. The best formulation to remove salinity is membrane sample 2 and sample 4.

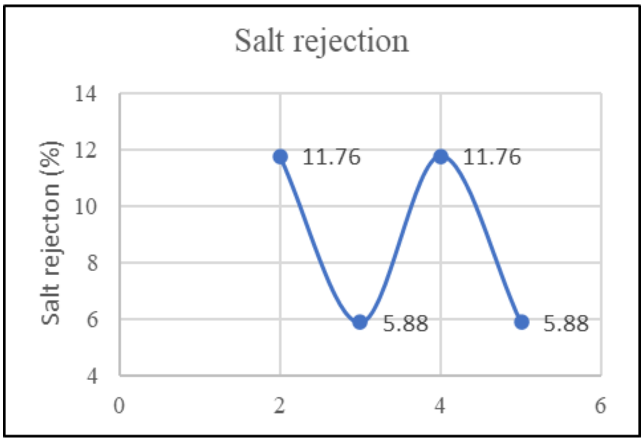

Figure 5. Graph of salt rejection against membrane

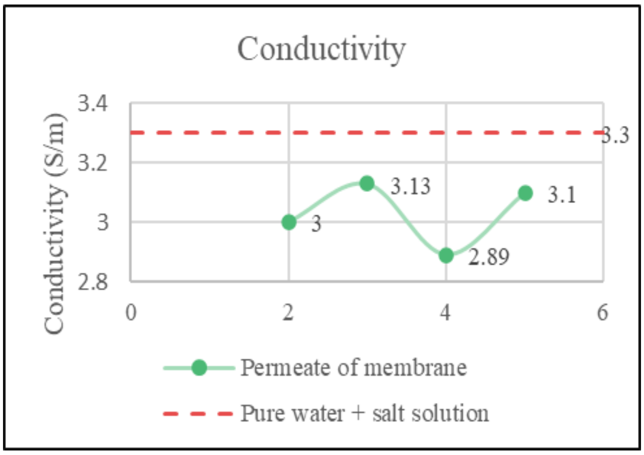

Figure 6. Graph of conductivity against membrane sample permeate

According to Figure 6, it can be seen that all the permeates that passed through each membrane sample have decreased from the original value of 3.3 S/m. The permeate of membrane sample 4 has the lowest conductivity of 2.89 S/m. The formulation of membrane sample 4 is the best formulation to reduce the conductivity of the solution.

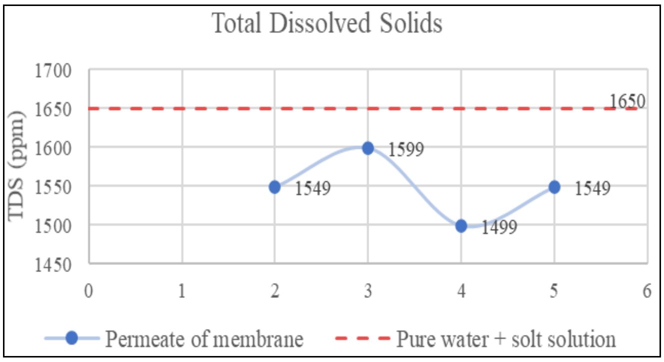

Figure 7. Graph of TDS against membrane permeate

The feed permeates that passed through each membrane sample have their TDS values decreased from 1650ppm as shown in Figure 7. The permeate of membrane sample 4 has the lowest TDS with 1499. The formulation of membrane sample 4 is the best formulation to reduce the total dissolved solids of the solution. In a study by Mansur et al., (2018), the higher the PSf, the higher the salt rejection[18]. However, the results in salinity do not differ much. Samples 2 and 4 share the same salt rejection, and salinity. Sample 2 had a 50-50 percentage of PSf and PVP, while sample 4 had 70% PSf and 30% PVP. Comparing samples 2 and 4, it is true for the conductivity, where sample 4 had decreased in conductivity by 12.42% while sample 2 only had 9.09% decrease in conductivity.

Tensile Test

Tensile stress–strain tests is conducted by dynamic mechanical analysis (DMA) on all five samples of the membrane and the results are shown in Figure 8.

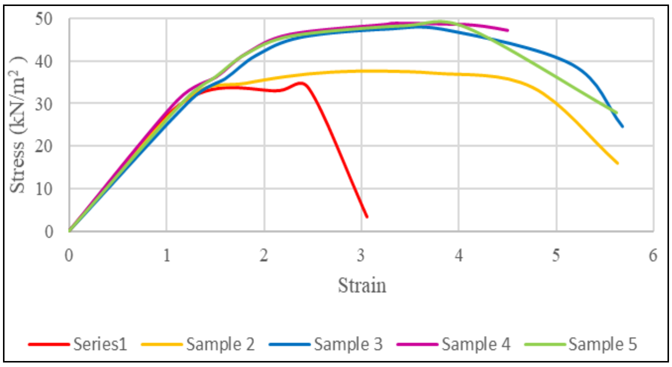

Figure 8. Graph of stress against strain of the membrane samples

As observed, sample 1 shows the lowest maximum stress value among all of the samples with reading of 34 kN/m^2 at strain value of 2.4 m/m but has a maximum strain value of 3.06 m/m which is the lowest among the others. Sample 2 on the other hand, the stress value increases until it reaches its maximum value of 37.5 kN/m^2 at strain value 3. Its maximum strain value reaches up to 5.63 m/m. Whereas, sample 3 has a maximum stress value of 48 kN/m^2 at strain value of 3.6. The maximum strain value sample 3 can get to be up to 5.68 m/m which is the highest strain value among the samples. Sample 4 shows it can serve a maximum stress of 48.3 kN/m^2. However, although it can provide higher stress value compare to sample 1, 2 and 3, it has the lowest value of maximum strain compare to the others with reading of 4.5 m/m. Finally, sample 5 has the highest maximum stress value with reading of 49 kN/m^2 at strain value of 3.8 m/m. The maximum strain value sample 5is 5.62 m/m.

All the samples show a similar pattern in stress-strain relationship graph. The patterns show that the membrane samples have only on elastic region. As the tensile stress increases to a maximum value, after a certain amount of time the membrane started to lose its elasticity. The stress on the membrane sample started to decrease until it finally fractured and failed. This shows that the membrane is not brittle nor ductile. Even though after reaching its maximum stress, it is still able to sustain loading before it breaks.

Water Quality

From the two tests: Permeate Flux Test and Salt Rejection Test, the formulation of membrane sample 4 is chosen as the optimum sample. In this section, the selected membrane is evaluated by the performance of it in wastewater filtration. The results are compared with the National Water Quality Standards for Malaysia of water Class IIB where the water uses are shown in Table 5.

Table 5. Water Class IIB and The Uses

Class	The Uses
Class IIA	Water Supply II
	Fishery II
	Recreational use body contact

Table 6. Wastewater quality parameters of wastewater unfiltered and filtered through the selected membrane

Parameters	Unit	NWQSM	Unfiltered	Filtered	Percentage of removal %
pH	-	6-9	7.14	7.45	4.34
Colour	Pt/Co	150	529	460	13.04
Conductivity	S/m	1000	160.8	153.1	4.79
Salinity	PSU	1	0.1	0.1	0.00
TDS	mg/L	1000	80.4	76.6	4.73
TSS	mg/L	50	91	70	23.08
Turbidity	NTU	50	131	73	44.27
COD	mg/L	25	21	18	14.29
E.coli	cfu/100mL	5000	>2419.6	>2419.6	-

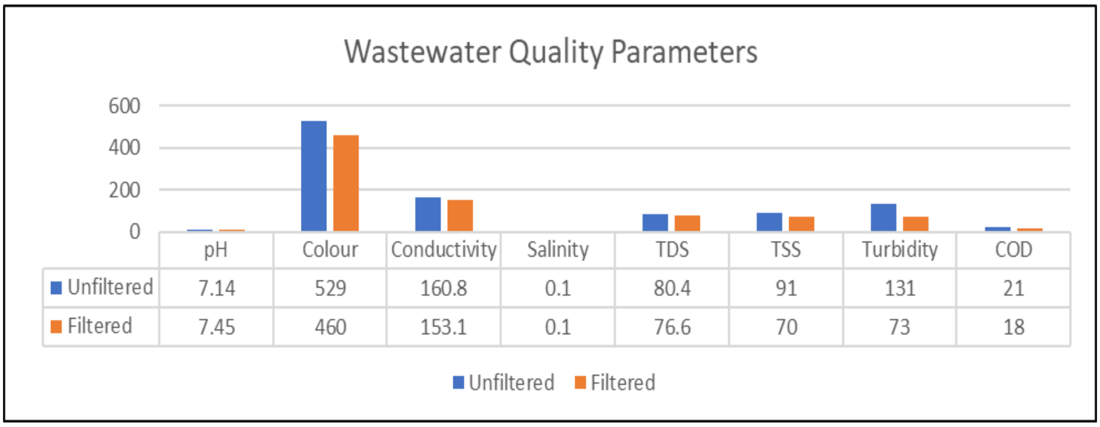

Figure 9. Wastewater quality parameters of wastewater unfiltered and filtered through the selected membrane

From Table 6 and Figure 9, it is shown that the membrane sample can treat waster water. The pH value of unfiltered is 7.14 and the pH value of the filtered wastewater is 7.45. The increase in pH indicates that the water, after being filtered becomes more basic. The colour had cleared a little bit from 529 Pt/Co to 460 Pt/Co.

The zero change in salinity (0.1 PSU) might not be accurate due to the decimal place. Since salinity is directly related to conductivity, it can be assumed that the permeate filtered through the membrane sample has lower salinity since the conductivity has reduced from 260.8 to 153.1 S/m. Same goes to TDS, it is related to the conductivity. The membrane managed to remove only 4.96% of TDS from 80.4 to 76.6 mg/L. The slight difference in readings for conductivity and TDS may be because a microfiltration membrane cannot remove dissolved solids as successfully as for ultrafiltration process[13]. On the parameter TDS, conductivity and salinity are all within the safe range for Class IIA of the NWQSM. The turbidity has decreased 44.27% from 131 to 73 NTU through the membrane. However, the turbidity values recorded for both unfiltered and filtered wastewater samples were higher than the NWQSM for Class IIA. The TSS has decreased 23.08% from 91 to 70 mg/L. The overall quality of the wastewater both unfiltered and filtered were found to be unsafe for drinking purposes due to the presence of E.coli in the water samples taken (>2419.6 cfu/100mL).

Scanning Electron Microscopy

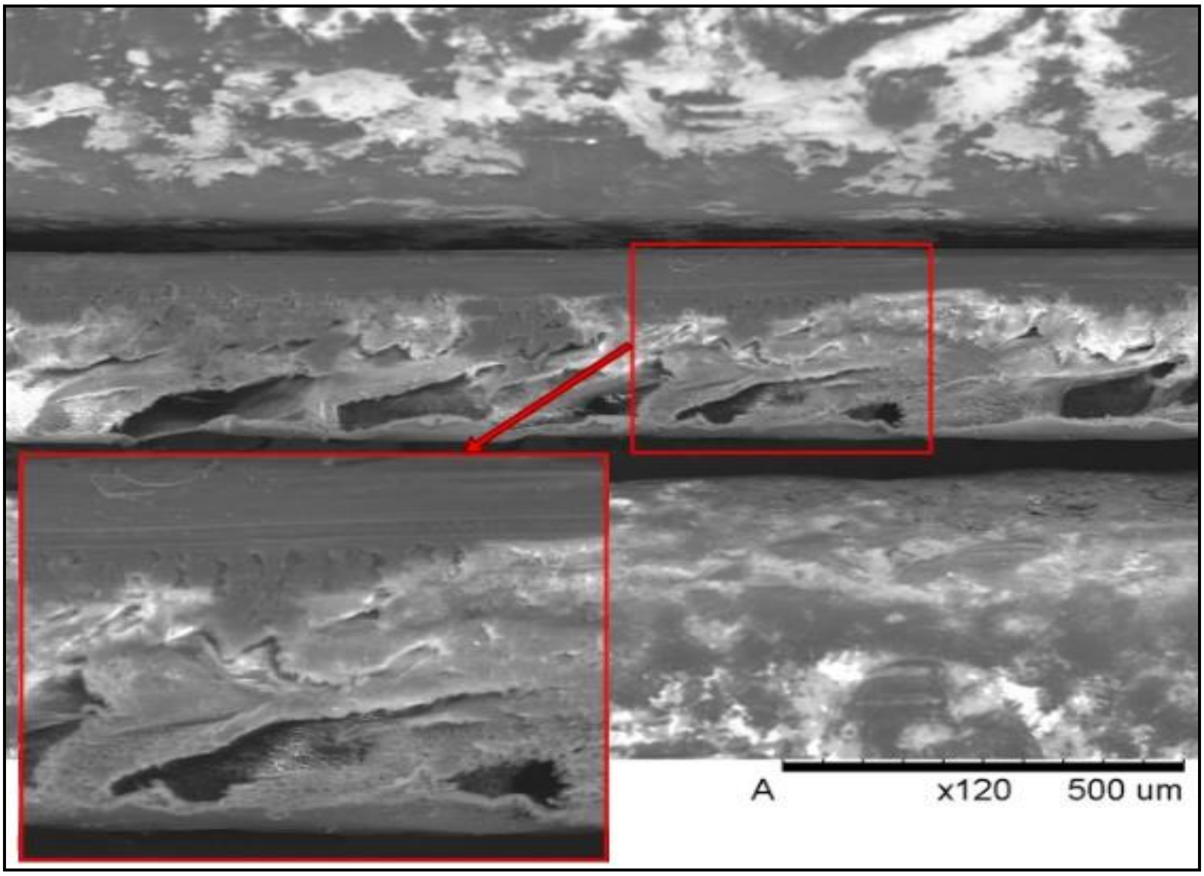

Figure 10. Cross section of membrane with 120 magnification

Figure 10 shows the cross section of the membrane with 120 magnification. It can be seen that the membrane is an asymmetric porous membrane. It has pores at a slightly-angled tear drop shape. This integrally skinned membrane has a non-porous skin layer where the top part of the membrane is dense compared to the microporous support at the bottom part which can be seen clearly in Figure 11.

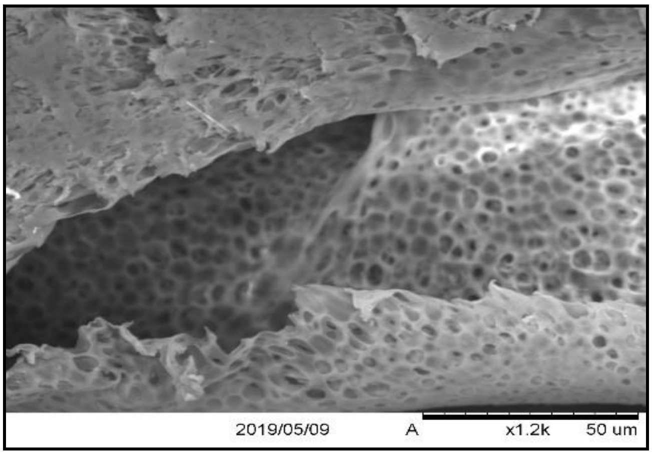

Figure 11. Cross section of membrane with 1200 magnification

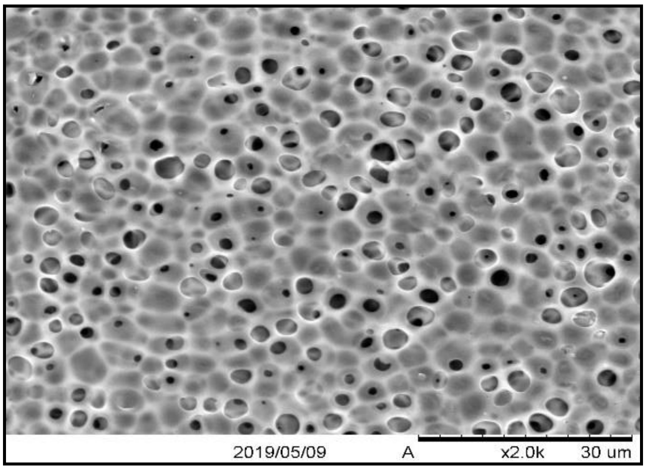

Figure 12. Plan view of the membrane with 2000 magnification

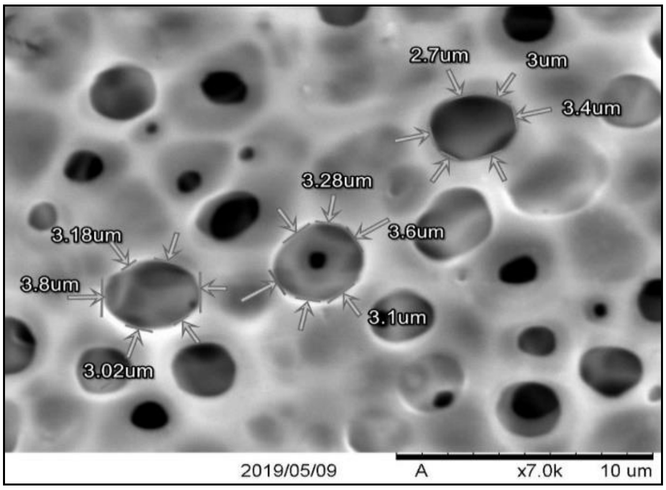

Figure 13. Membrane with 7000 magnification

Figure 11 and 12 shows the plan view of the membrane where it is apparent that the surface of the membrane has well distributed pores of uniform sizes. The average pore size in Figure 13 is 3.23 µm. The membrane can be classified as microporous membrane which is a membrane for microfiltration.

Conclusion

In this study, the first objective was achieved by formulating the polymers; polysulfone (PSf) and polyvinylpyrrolidone (PVP) to form 5 samples of synthetic hybrid membranes along with 1-Methyl-2-Pyrrolidone (NMP) as the solvent. The formulations of the polymer were 35% PSf with 65% PVP, 50% PSf, and 50% PVP, 65% PSf and 35% PVP, 70% PSf and 30% PVP, 80% PSf and 20% PVP.

The second objective was achieved by studying characteristics and performance of the membrane samples by conducting permeate flux test, salt rejection test, and tensile test. Membrane sample 4 shown the best results comparing to other membrane samples. Membrane sample 4 had the highest value of permeate flux with 33.78 L/m^{2}hr, it had removal percentage of 11.76% for salt rejection, decreased 12.42% in conductivity from 3.3 S/m to 2.89 S/m, and it was able to withstand 48 kN/m^2 at strain value of 3.6 m/m. Finally, the third objective which was to determine the optimum formulation of PSf-PVP synthetic hybrid membrane, was achieved after conducting tests for the second objective, a membrane sample was selected to be the best, which was membrane sample 4. Two more tests have been conducted which were SEM and water quality test for the selected membrane.

The membrane sample 4 selected as the membrane with optimum formulation has formed a microfiltration membrane with average 3.23 µm pore size which is suitable to filter out particles in the wastewater, where it could remove 44.27% turbidity, 23.08% TSS, 14.29% COD, 4.73% TDS, 4.79% conductivity, 4.34% pH and 13.04% colour. The membrane requires further research so that the performance can be improved in the future.

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