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CHITOSAN-STARCH FORWARD OSMOSIS MEMBRANE FOR DESALINATION OF BRACKISH WATER

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ABSTRACT

The global water scarcity problem has encouraged the development of various technologies to support limited direct access to water in nature. In this research, a chitosan-starch forward osmosis (FO) membrane was prepared from chitosan and starch polymers using glutaraldehyde as a cross-linking agent and glycerol as a plasticizer. The cross-linking reaction was indicated with Fourier Transform-Infrared (FT-IR) spectral analysis and corroborated with a significant increase in the tensile strength. Differential Scanning Calorimetry (DSC) analysis showed an endothermic peak at 135 °C, associated with the presence of water. Meanwhile, an exothermic peak at 320 °C was assigned to the initial thermal degradation of the membrane. The membrane porosity and the swelling degree were revealed to be 54.36% and 78.98%, respectively. FO membrane was applied to purify the brackish water on different osmotic pressure in the draw solution. The draw solution used was 1 M sucrose. High water flux was obtained in the FO process for 1 hour with a flux value of 4 L/m^{2}h and with the rejection value closed to 100%. The quality of water has met the drinking water standards based on the regulation of the Minister of Health of the Republic of Indonesia number 492/MENKES/PER/VI/2010. In conclusion, chitosan-starch forward osmosis membranes can be developed as a way to produce drinking water from brackish water.

Keywords: Forward Osmosis Membrane, Brackish Water Desalination, Cross-link, Chitosan, Starch Sucrose

INTRODUCTION

The survival of humanity depends on the availability of sufficient clean water on Earth. Although the water covers almost the entire earth's surface, one billion people globally cannot access adequate drinking water, and more than 2 billion people suffer from not having access to clean water, specifically drinking water. The availability of clean water must be increased from year to year and into the future to be in line with the growth of the global population. Global climate change, natural disasters, water pollution, and future indicators show increasing scarcity of water worldwide.[1, 2] Besides, some parts of the world prone to natural disasters also face a clean water crisis, especially in the emergency response period after the natural disaster. The clean water availability worsens during an emergency, such as a natural disaster. If the availability of water is very low, then the victims of disasters will suffer various diseases. Disaster relief agencies procure cars equipped with sewage machines that produce clean water. However, they are ineffective in isolated areas due to some constraints including disasters, resource water contamination, and infrastructure damage.[3] The development of alternative water treatment and purification methods is essential especially in emergencies.[4,5] Rapid and sufficient clean water can be obtained through the purification of contaminated water and desalination of brackish water and seawater. A desalination membrane is a well-developed technology that could meet the increasing demand for drinking water.[6,7]

The popular alternative of the desalination membrane method or technology for water purification and seawater desalination is a forward osmosis (FO) membrane. The FO membrane method is a water purification process in which water from a low concentration of the feed solution will move through the semipermeable membrane to the draw solution that has a high concentration.[8,9] The process works based on the osmotic pressure gradient, thus the energy used for water movement can be minimized. The

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forward osmosis membrane method has high practicality owing to the fact that it does not require energy, pressure, pumps, or chemicals. It also effectively removes bacteria and viruses from wastewater. The membrane is hydrophilic, allowing water to pass through, but can exclude all contaminants due to its tiny pore size.[10] One of the most promising applications of the membrane is the proliferation of a waterproof filter module and bag. This FO membrane allows pure water to be prepared from almost any water source, including a very turbid, polluted, or toxic water supply.[11]

The critical innovation of FO membranes is to utilize the difference in potential osmotic pressure induced by a draw solution. The draw solution is a highly concentrated solution that can also function as an additional energy source (e.g. sugar, salt, and electrolytes). Therefore, the FO drinking water product is not only pure water, but also water with sugar or electrolyte content, which is similar to energy drinks. The applications and needs of these FO membranes in the future will increase exponentially and rapidly.

One of the natural polymers that have the potential to be developed as a base material for a forward osmosis membrane is chitosan[6]. Chitosan is used as a base material because it is a natural polymer, making it more environmentally friendly, compared to synthetic polymers. Its advantages include abundant availability, excellent mechanical properties, non-toxicity, hydrophilic nature stem from its many hydroxyl groups, relatively excellent biocompatibility, and possession of active sides. The surface has high hydrophilicity properties, which are essential for improving FO membrane performance and reducing fouling tendencies[12].

Chitosan is one of the most promising natural polymers, widely used in a membrane preparation. Chitosan can be developed for ultrafiltration, reverse osmosis, pervaporation, and other types of membrane applications. Chitosan has been proven to be able to remove various organic and inorganic contaminants from aqueous solutions. This ability is essential for the filtration process. Membranes made from chitosan have been developed for solution filtrations that improve the quality of feed solutions. Therefore, they are suitable for ultrafiltration and reverse osmosis separation techniques. Chitosan can be used either as a single primary material or as a composite in membrane synthesis, where the surface layer of the chitosan membrane is a very selective layer for separation. Characteristics possessed by ~~this~~ chitosan make the biopolymer a promising candidate for the manufacturing of FO membranes. However, the application of pure chitosan membrane still has some disadvantages because it is brittle, rigid, and not resistant to acids, reducing its performance in water purification[13]. These weaknesses can be overcome by several methods, such as the addition of cross-linking agents or polymer blending techniques[14].

The addition of cross-linking agents can increase the stability of the membrane so that it can survive in acidic conditions and not be easily damaged.[15] Cross-linking agents that can be used include glutaraldehyde. Glutaraldehyde was chosen as a cross-linking agent because it has low toxicity and is not carcinogenic, so it is safe to use it as a cross-linking compound.

In this study, the brackish water purification process was used to investigate the performance of FO membrane prepared from cross-linked chitosan starch with the addition of glycerol as a plasticizer. Membrane preparation was begun with the preparation of a homogeneous solution with the desired viscosity, followed by molding the polymer solution into a thin layer. Furthermore, the membranes were characterized and applied as a medium for producing ready-to-drink water. This article discusses the performance characteristics of FO membrane and presents data of choice relating to the influence of concentration of draw solution, salt rejection, and the rate of flux of chitosan membrane in brackish water desalination.

EXPERIMENTAL

Materials and Methods

Chitosan with an average degree of acetylation of up to 94 mol % was purchased from a chitosan manufacturer. Acetic acid 1% (Merck) was used as a solvent; meanwhile, dimethylformamide (Fluka) was used as an additive in the casting solution. Sucrose was used to draw solutions. Sodium bisulfite, silver nitrate solution, 50% glutaraldehyde, and glycerol were in pro-analysis grade. The starch was used to prepare the chitosan-starch composite and it was isolated from janeng flour.

Janeng Starch Isolation

Two kg janeng tubers were peeled and washed with distilled water. Next, it was cut into cubes and blended with a solution of sodium bisulfite (1.12 g/L) then added to distilled water. Janeng tubers were then

smoothed and then squeezed and filtered using gauze. The filtrate obtained was allowed to settle for 24 hours to form a precipitate. The precipitate obtained was dissolved again in distilled water and filtered using a Buchner vacuum. Furthermore, the precipitate was washed repeatedly to remove the toxins contained in the sediment by negative testing the filtrate with $AgNO_3$. Then, the precipitate was dried in an oven at 70°C for 24 hours. After that, the dried precipitate was mashed and sieved using a 100 mesh sieve to obtain the starch of janeng. The janeng starch can be applied to make bioplastics[16], food material[17], and bioadsorbent.[18]

Membrane Preparation

The preparation of the cross-linked chitosan-starch membrane was proceeded in accordance with Li et al.[19] As much as 1.5 g of janeng tuber starch flour was dissolved in 100 mL of distilled water. The solution was then stirred at ~~a~~ temperature 75-80°C in a water bath until a gelatinization process occurs, which takes 10-15 minutes. Three g of chitosan was dissolved in 100 ml of 1% (w/v) acetic acid solution. Furthermore, the dissolved chitosan ~~is~~was mixed with a starch solution (2:1) (chitosan-starch) (w/w). The chitosan-starch mixture was stirred at temperature 75-80°C for 10 minutes and cooled at room temperature. Then the glutaraldehyde crosslinking agent was added with a concentration variation of 0.0; 5.6×10^{-6}; 1.1×10^{-5}; 5.6×10^{-5} mol. Glycerol was then added to the mixture. The solution mixture was stirred until homogeneous and molded onto granite with a thickness of 3.5 mm at room temperature. The membrane was left to dry and come off the mold. Finally, the membrane was washed using 1% NaOH and distilled water until neutral. Then the membrane was allowed to dry at room temperature and used for further characterization.

Membrane Characterization

Membrane qualities that were characterized include porosity, swelling degree, mechanical strength, and membrane morphology[20]. Membrane porosity (ε) and the swelling degree (sd) of the membrane were determined based on taking water from the volume of the membrane calibrated in dry and wet conditions. Scanning Electron Microscopy (SEM) characterized the structure and morphology of FO membranes. The cross-section, as well as the upper and lower surfaces of the membrane, was scanned. Tensile strength and elongation testing for membranes refer to the ASTM-D638 method using mechanical test equipment. Membrane testing using Fourier Transform-Infrared (FT-IR) is done by cutting the membrane to a size of 5x5 cm and then characterized using FT-IR Shimadszu Prestige at 4000-500 cm^{-1} wavenumbers. The membrane with a size of 1x1 cm is tested for its thermal resistance by using Differential Scanning Calorimetry (DSC) and Thermogravimetric Analysis (TGA) instruments.

FO Membrane Performance

FO performance of chitosan membranes was investigated employing simple forward osmosis set up the module, as reported in the previous work[21]. The set up forward osmosis experiment is represented in figure 1. On the left side of the module was filled in with brackish water, and the right side was filled with 1 M sucrose as a draw solution. The effective surface area of the membrane acting on the FO process was 9.6 cm^2. The water passing through the semipermeable membrane is due to the concentration difference between the draw and the feed solutions. The amount of water that passes through the membrane to the withdrawal solution is calculated as water flux. The efficiency of FO under various conditions was also tested. The forward osmosis process is carried out with variations of time 1, 2, 4, 6, and 8 hours. Total dissolved solids (TDS), salinity, and pH of brackish water and withdrawal solutions are measured and observed for changes during the FO experiment. The determination of the water flux (Jv, L m^{-2} h^{-1}) was carried out using eqn.-1.

$$J_V = \frac{\Delta V}{A\,\Delta t} \qquad (1)$$

Where, ΔV (L) is the volume of water that passes through the membrane at a certain time, Δt (h) is the duration of the FO test, and A is the effective membrane surface area (m^2). The experiments were carried out at room temperature.

Membrane selectivity is determined by the interaction of the interface with the species that will pass through the membrane, the molecule size, and the membrane pore size. The parameter used in the calculation is the rejection factor (R) which is calculated by the eqn.-2.

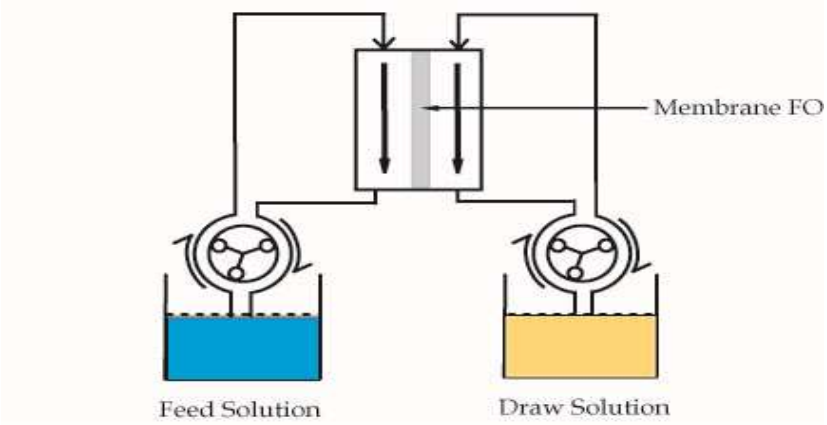

Fig.-1: Illustration of the Process of the Forward Osmosis Experiments.[21]

$$R = 1 - \frac{Cp}{Cf}\, x\, 100\% \qquad (2)$$

Where R = rejection factor coefficient, Cp = concentration of solute in permeate (TDS), and Cf = concentration of solute in feed solution (TDS).

RESULTS AND DISCUSSION

Cross-Linked Chitosan-Starch Membrane

Modification of the chitosan membrane was conducted by the cross-linking reaction of chitosan with the starch and glutaraldehyde as the cross-linking agent. The determination of the concentration of the cross-linking agent was carried out to obtain the optimum mole of the glutaraldehyde (GA) crosslinking agent in the formation of the chitosan-starch membrane. There were four different concentrations of GA added: 0, 5.6×10^{-6}, 1.1×10^{-5}, and 5.6×10^{-5} moles. Four types of membranes were produced: non-crosslinked, and three types of the cross-linked membrane with varying amounts of GA. The visual observation shows that membrane has a more transparent color compared to cross-linked chitosan-starch membranes. The addition of GA affects the color of the produced membrane. The higher the amount of GA added to the membrane mixture, the more yellow the membrane color[19]. All membranes visually have smooth, flat, and robust properties. The results of mechanical properties testing reveal that all type of the membranes have different tensile strengths and elongations.

Membrane Characterization

Mechanical Properties

Figure-1 shows the tensile strength and elongation values of the four types of membranes. The tensile strength values of cross-linked membranes have increased due to the influence of the addition of cross-linking agents when compared with the tensile strength values of the uncross-linked membrane (A1). The number of moles of GA influences the increased tensile strength value of the membrane[19]; the tensile strength value of the membrane increases by increasing the amount of cross-linked agents. However, increasing the tensile strength of membranes is followed by a decrease in membrane elongation due to changes in interactions in the polymer chain. When groups of each cross-linked polymer can cause limited movement, the limitation of this movement can increase tensile strength, but the elongation of the membrane is reduced[22]. Membrane A4 has the best tensile strength value when compared to membranes A2 and A3. The increased tensile strength of the membrane after cross-linking shows that membrane A4 is a membrane that has GA with an optimum amount of 5.6×10^{-5} mol. Increasing the amount of GA above this mole will cause clumping in the polymer solution.

The addition of a plasticizing agent is present on membrane A4, which has the optimum amount of GA, as evidenced by the results of the best tensile strength and elongation of the membrane. The addition of glycerol causes significant changes in the tensile strength and elongation values of membranes A5 and A6. Figure-1 showed that the tensile strength and elongation values of membranes A5 and A6 have increased

when compared to membranes A1; this may be due to the addition of glycerol. Glycerol has a smaller molecular size so that it can enter between polymer chains and affect hydrogen bonds in the chain; disruption of hydrogen bonds in the polymer chain can increase the nature of flexibility in the membrane. The chitosan-starch cross-linked membrane has a tensile strength of 87.63 kgf/mm^2 and elongation equal to 16.08%.

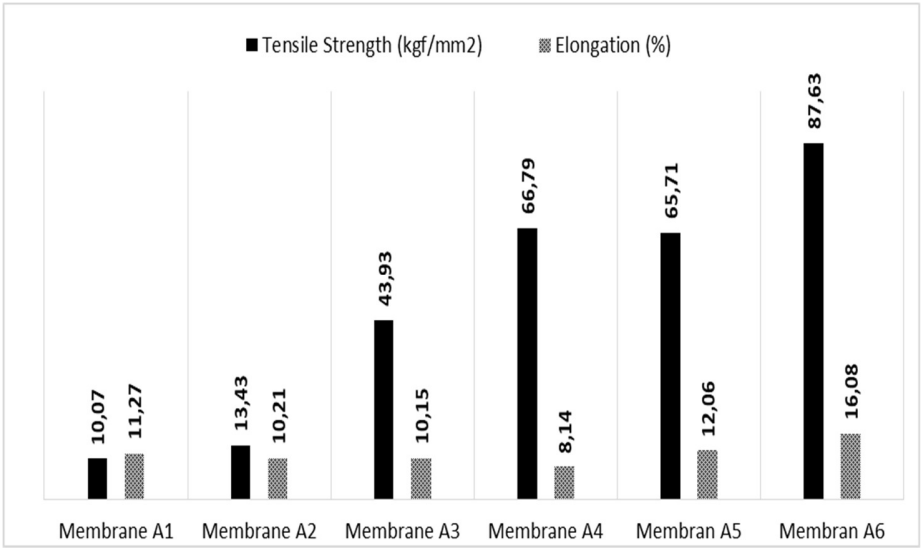

Fig.-1: Mechanical Properties of Membranes A1 (Uncross-linked), A2 (Cross-linked with GA 5.6 × 10^{-6} mol), A3 (Cross-linked with GA 1.1 × 10^{-5} mol), and A4 (Cross-linked with GA 5.6 × 10^{-5} mol), A5 (Uncross-linked plus Glycerol as an Additive), A6 (Cross-linked with Number of GA 5.6 × 10^{-5} mol plus Glycerol as an Additive).

FT-IR Spectra

The results of the characterization of the membranes by FT-IR shown in Fig.-2 inform that there has been a change in the intensity of the spectrum of chitosan, starch, uncross-linked membrane, and cross-linked membrane. Li et al. explained that the decrease in the intensity of the peak indicates that cross-linking had formed between the hydroxyl group and amine from chitosan and the starch hydroxyl group with glutaraldehyde[19]. The peak intensity of the cross-link membrane is reduced when compared to the peak intensity of the uncross-linked membrane, and this is caused by the effect of cross-linking formation on the membrane. The absorption peak at wavenumber 3550-3200 cm^{-1} indicates the presence of stretching -OH groups detected in starch, chitosan, uncross-linked membrane, and cross-linked membrane. The -OH groups on uncross-linked membranes and cross-linked membranes have a stronger intensity, ascribing to the hydrogen bonds in the membrane. The absorption peak at wavenumber 2950-2840 cm^{-1} indicates the presence of the -CH stretching group on chitosan, starch, membrane A5, and membrane A6. The absorption peak at wave number 1690-1640 cm^{-1} indicates the presence of the -C=N stretching group detected on the cross-linked membrane. Then it is known that there is a -NH group at wave number 1650-1580 cm^{-1} found on chitosan and membrane A5, while the peak intensity on membrane cross-linked has been reduced. The absorption peak at wavenumber 1420-1330 cm^{-1} indicates the presence of the bending OH group found in starch, chitosan, membrane A5, and membrane A6. The absorption peak at wavenumber 1210-1000 cm^{-1} indicates the presence of a -CO stretching group found in starch, chitosan, uncross-linked membrane, and cross-linked membrane.

DSC and TGA Thermogram

The thermal analysis used was DSC, which functions to determine the transition phases in the membrane and TGA, which was used to determine the volatilization and decomposition of the membrane. Thermal analysis using DSC-and TGA performed on uncross-linked and cross-linked membranes. Fig.-3 shows the results of DSC-and TGA thermal analysis on both membranes. Fig.-3(a) informs endothermic peak that appear at 119ºC on membrane A5 had shifted to 135ºC on chitosan-starch membrane. Also, an exothermic peak with a temperature of 324ºC on the uncross-linked chitosan-starch membrane was

detected. The exothermic peak also experienced a shift to 320ºC which was also detected on uncross-linked chitosan-starch membrane.

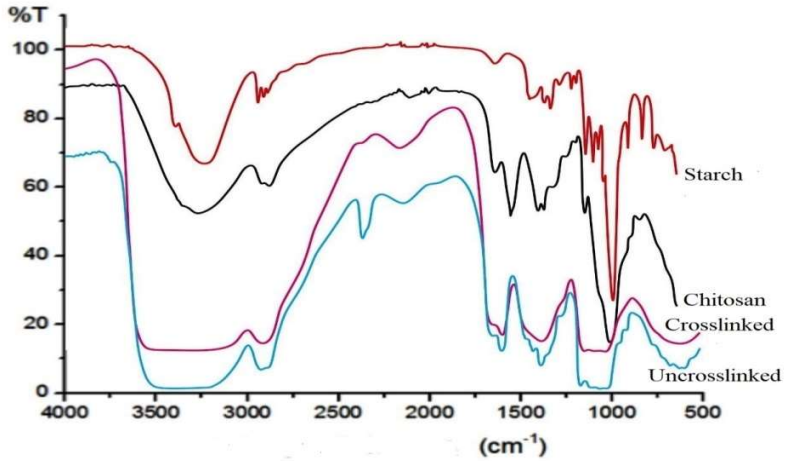

Fig.-2: FT-IR Test Results of Chitosan, Starch, Uncross-linked Chitosan-Starch, and Cross-linked Chitosan Starch Membrane.

The emergence of endothermic peaks in the temperature range 40–150ºC is related to the process of evaporation of water content contained in both membranes and the emergence of exothermic peaks in the temperature range of 280–370ºC shows that both membranes have undergone a decomposition process.[23,24] A shift in the endothermic temperature peaks on the cross-linked membrane indicates a reduction in water content in the cross-linked membrane[19]. This is also supported by the existence of the TGA analysis (right), which informs the occurrence of the evaporation of water that ends until just before the decomposition process occurs at a temperature of 300–320ºC which occurs on membrane A5 and temperatures 289–364ºC are detected on the cross-linked membrane.[25] Membranes using glycerol plasticizers undergo several stages of change, namely at temperatures of 68–145ºC and 290–380ºC, which show the loss of water bonds and decomposition of polymers respectively[26].

SEM Characterization

The chitosan membrane was through several stages: polymer dissolution, solvent evaporation of the molding solution, and solidification. The chitosan-starch membrane morphology can be observed from SEM characterization of the top layer, the bottom layer, and cross-sectional surfaces the membrane, as shown in Fig.-4. It revealed that the membrane has an asymmetric structure that is a different structure between a dense selective layer on the top and a more open structure on the bottom surfaces. It appears that the top surface is denser, while the bottom surface is a coarse texture with 250x magnification. The membrane has an overall thickness of about 55µm.

In membrane cross-section with 1500x magnification, the membrane structure has a well-connected structure, without the presence of no macro void. For application purposes, the preferred membrane for FO is a dense membrane type. According to Yang et al.[27], chitosan concentration of over 2% is preferred to compose a casting solution of the membranes. The depletion of the water flux rate of the membrane occurs when the casting solution concentrations increase. The increase of chitosan concentration in casting solution resulted in a higher degree of crystallinity and a relatively void-free membrane. The intensely cross-linked polymer chains lead to the small size or the absence of free salt; thus, salt ions were not able to pass through. The chitosan membrane is suitable for water desalination. How et al. suggested that a thin dense selective layer without any loose fabric support layer is required for an ideal FO membrane[28]. The membrane possesses an asymmetric structure with 54.36% porosity and 78.98% swelling degree.

FO Membrane Performance Evaluation

In the FO process, the feed and the withdrawal solutions flowed into the FO module at a flow rate of 23 ml/min using a peristaltic pump (Watson Marlow). The difference in osmotic pressure between the two solutions becomes the driving force for transferring water from brackish water to the withdrawal solution

across the chitosan-starch membrane. As expected, the operation of the FO process at higher draw solution concentrations results in an increase in permeate flux due to a higher osmotic gradient that pushes water flux across the membrane more. According to Phuntsho et al. [29], the osmotic difference of the draw solution and the feed solution is generated by the higher osmotic pressure in the draw solution, thus forming a high osmotic pressure which enables the water to be drawn into the draw solution.

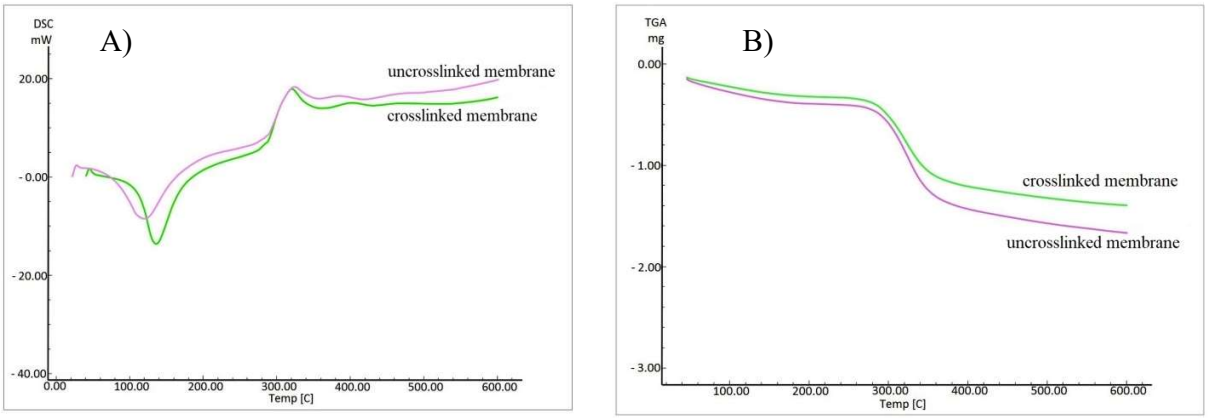

Fig.-3: DSC (a) and TGA (b) Analysis of Uncross-linked Membrane Chitosan-starch and Cross-linked Chitosan-starch Membrane.

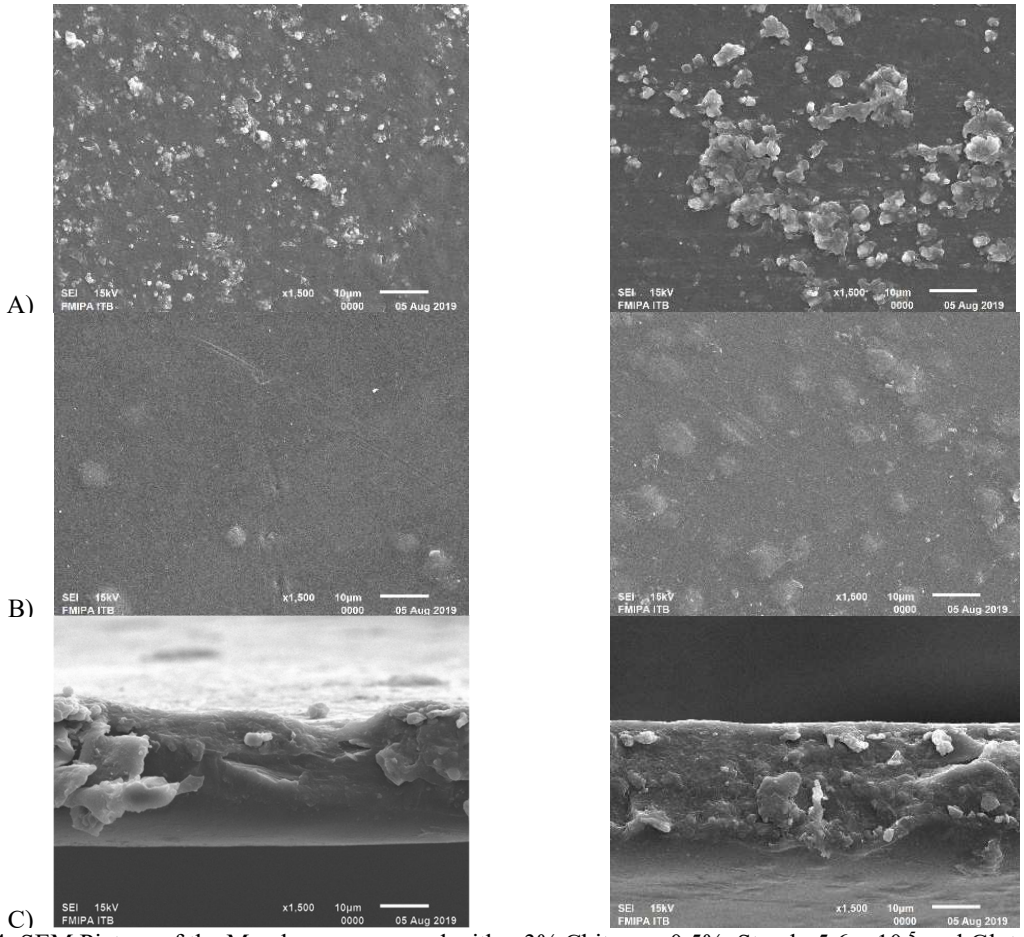

Fig.-4: SEM Picture of the Membranes prepared with a 3% Chitosan, 0.5% Starch, 5.6×10^{-5} mol Glutaraldehyde and 0.4% Glycerol; (A) Top Layer Chitosan (B) Bottom Layer (C) Cross section. Left is Uncross-linked Chitosan-starch Membrane, and right is Cross-linked Chitosan-starch Membrane.

The chitosan-starch membrane used in this study has moderate water flux characteristics. Further optimization in the composition and manufacturing procedures membrane preparation allows for improved membrane performance.

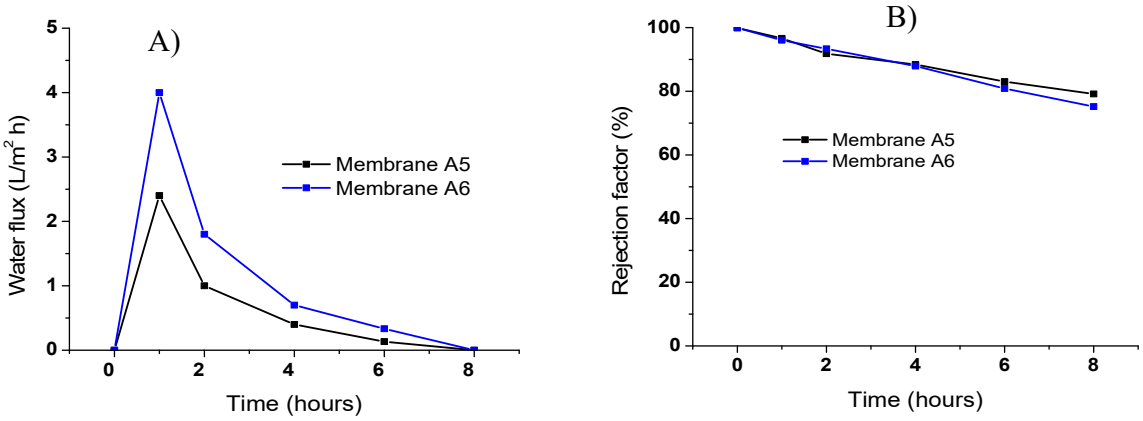

Fig.-5: A Comparison of Water Permeates Flux (a) and Rejection Factors (b) with Brackish Water as Feed and Sucrose as Draw Solutions. Experiments were carried out at Room Temperature of 27 ± 1˚C and Volumetric Cross-flow Rates of 23 ml/min with Active Membrane Layers Facing Draw Solution (Membrane A5 is Uncross-linked Chitosan-starch and Membrane A6 is Cross-linked Chitosan-starch membrane).

Figure-5 informs that the highest value of flux is obtained from membrane A6 during the processing time of 1 hour, and after one hour the water flux shows a decrease and reaches a minimum value at eight hours. Therefore, membrane A5 also shows the state of the highest flux value equal to membrane A6 at one hour operating time and the water flux after one hour shows a decrease with increasing time. the flux value decreases with increasing operating time. However, between the two membranes, the best flux value was obtained on the A6 membrane with a value of 4 L/m^2 hours, while the A5 membrane flux value was only 2.4 L/m^2 hours for 1 hour of operation. The membrane porosities can affect the value of the water flux; the more pores contained in the membrane will further increase the flux value. However, there is also a decrease in the water flux during FO process due to concentration polarization and membrane fouling[30]. A decrease in water flux can also be contributed to by dilution of the draw solution during the FO process where the osmotic pressure drops gradually.

Both membrane A5 and A6 show a high rejection value during the FO process and slightly decrease with increasing operating time, and the rejection value between the two membranes look fairly similar. The rejection value shows the membrane's ability to separate components from the feed stream. A decrease in rejection value shows that the longer the operating time, the lower the rejection value; this is likely due to the increased operating time, the more particles that are dissolved freely through the membrane.

Water Product Quality

The standard parameters of drinking water quality used to check water quality are total dissolved solids (TDS), salinity, and pH. The results of the brackish water quality test used as they feed on the FO test show that the brackish water quality does not meet the drinking water quality requirements. The results analysis of the total dissolved solids and salinity are far above the drinking water quality standard following the Republic of Indonesia health minister regulation No. 492/Menkes/Per/IV/2010 regarding drinking water quality requirements. Brackish water contains total soluble solids of 1,295 ppm and brackish water salinity 9.1 ppt. High TDS and salinity indicate that brackish water contains relatively high salinity (NaCl), while the pH of the water was meet to the standard quality.

Figure-6 shows a decrease in the water salinity of the feed solution and a relative increase of salinity for the draw solution on membrane A5 and A6. The salinity value of the feed solution using the A5 membrane before the FO process was 9.3 ppt and after 8 hours decreased to 7.5 ppt. By using the A6 membrane, the initial feed solution was 9.3 and decreased to 6.7 ppt 8 hours after the FO process took

place. Also, the salinity value in the draw solution before the FO process took place using the A5 membrane was 0 ppt and increased to 1.5 ppt 8 hours after the FO process. The membrane A6 had a salinity value of 0 ppt before the FO process took place and increased by 1.6 ppt 8 hours after the FO process.

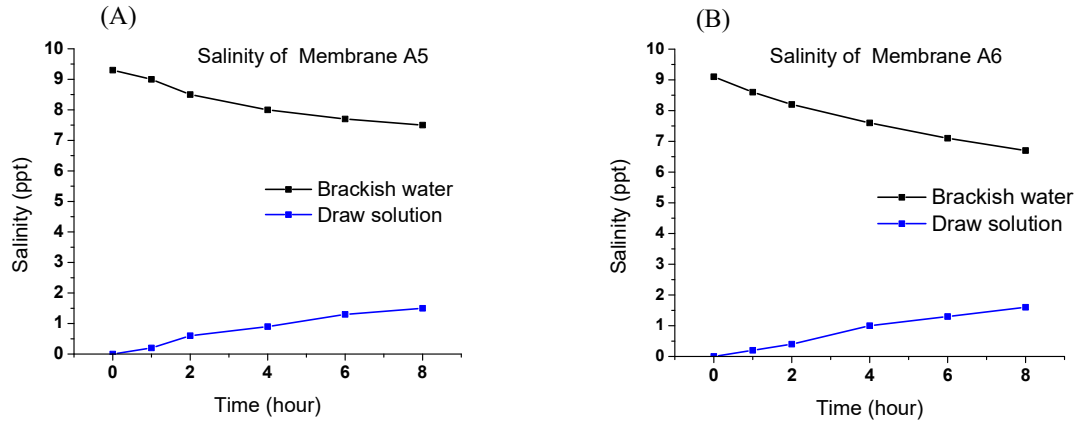

Fig.-6: Comparison of Brackish Water Salinity as Feed and Sucrose as Draw Solutions. Experiments were carried out at Room Temperature of 27 ± 1˚C and Volumetric Cross-flow Rates of 23 ml/min with Active Membrane Layers Facing Draw Solution (Membrane A5 is Uncross-linked Chitosan-starch (a) and Membrane A6 is a Cross-linked Chitosan-starch Membrane (b)).

The salinity of the draw solution using membranes A5 and A6 1 hour after the FO process was 0.2 ppt. This value indicates that the water produced is classified as freshwater and meets the quality standard. Based on the results obtained from the best flux, the salinity value of the water produced in the draw solution using membranes A5 and A6 met the standard; therefore, it can be ensured that the membrane can be appropriately used in the brackish water purification process.

The TDS analysis of the feed solution decreased with the increased contact time, and the results of the TDS analysis of the draw solution increased with the increase in contact time, as illustrated in Fig.-7. The TDS value of the feed solution before the FO process started was 1295 mg/l and then it decreased to 1,026 mg/l 8 hours after the FO process took place. The TDS value of the draw solution before and after the FO process was 1 and 214 mg/l, respectively. However, the TDS value of the draw solution before and 1 hour after passing through the FO process using membranes A5 and A6 was 42 and 47 mg/l, respectively. The TDS values indicated no significant difference between using membrane A5 and A6. It can be concluded that both membranes can be used in the brackish water purification process and produce similar results. Besides, the results of TDS values obtained have passed the quality standard that is permitted by the Ministry of Health: 492/Menkes /Per/IV/2010, which is equal to 500 mg/l.

The change in pH during the FO process from brackish water as feed and sucrose as the draw solution is illustrated in Fig.-8. The results of the analysis of the pH of the feed solution and the draw solution using the membrane A5 and A6 have slightly increased with increasing operating time. The initial pH value of brackish water using membrane A5 before the FO process occurred was 8.07 and increased to 8.62 after 8 hours. The initial pH of the draw solution was 7.5 and then increased to 8.5 after 8 hours FO process. This trend was also observed during the FO process using A6 membranes. The brackish water pH before the FO process with membranes A6 was 7.95 and increased to 8.83 after 8 hours. Similarly, the pH results in the draw solution increased from 7.62 to 8.45 after 8 hours. The pH of the draw solution at the highest flux during the FO process for membranes A5 and A6 was 7.6 and 7.8, respectively. This neutral pH is following the regulation of the Minister of Health of the Republic of Indonesia Number 492/MENKES/PER/VI/2010 for drinking water quality.

In general, the chitosan-starch membrane can function well to filter and separate brackish water from salt and dissolved ions. The salinity parameter indicates that the salt present in brackish water is relatively not migrated to the withdrawal solution. The change in conductivity of the draw solution is caused by the displacement of a limited amount of solute into the draw solution. This displacement is thought to occur

due to the heterogeneous membrane pore size. Likewise, the pH of water and TDS of the withdrawal solution show values that meet the parameters of drinking water quality. The relatively good performance of chitosan-starch membranes is supported by the relatively high mechanical properties of the membrane, which are expected to be used for a long time, which can be regenerated and reused.

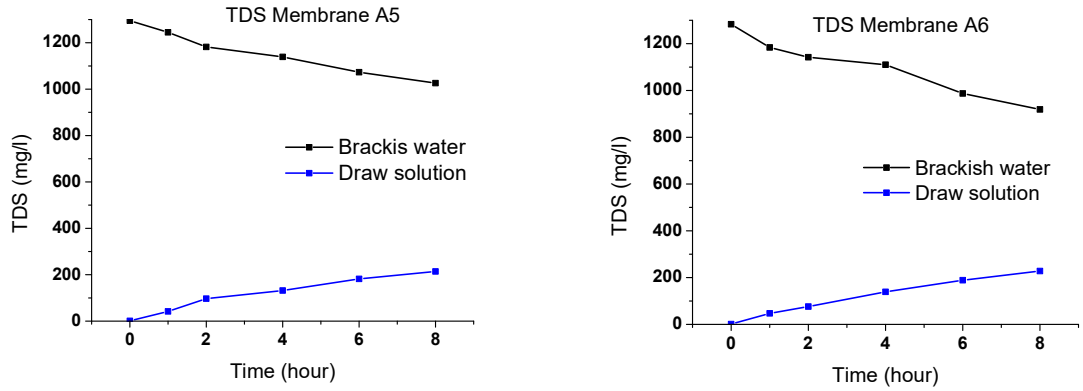

Fig.-7: Comparison of TDS with Brackish Water as Feed and Sucrose as Draw Solutions. Experiments were carried out at Room Temperature of 27 ± 1˚C and Volumetric Cross-flow Rates of 23 ml/min with Active Membrane Layers Facing Draw Solution.

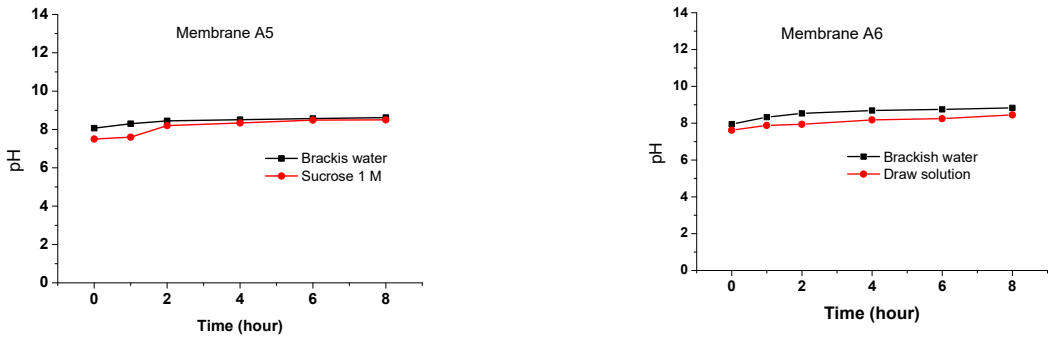

Fig.-8: Comparison of pH between Brackish Water as Feed and Sucrose as Draw Solutions. Experiments were carried out at Room Temperature of 27 ± 1˚C and Volumetric Cross-flow Rates of 23 ml/min with Active Membrane Layers Facing Draw Solution.

CONCLUSION

Chitosan-starch Forward osmosis (FO) membranes were prepared for the desalination of brackish water and successfully filtered it for drinking purposes. The FO membranes ~~are~~ were fabricated from chitosan and starch polymers using glutaraldehyde as a cross-linking agent and glycerol as a plasticizer. The cross-linking reaction ~~is~~ was confirmed with FT-IR spectra and a significant increase in the tensile strength of the cross-linked membrane. The membranes have characteristics as an asymmetric membrane and have a tensile strength of 87.63 kgf/mm^2 and elongation equal to 16.08%. Excellent product water quality was obtained and has met the drinking water quality of the Indonesian government. Chitosan-starch-based forward osmosis membranes can emerge as a way to produce drinking water from brackish water.

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ABBREVIATIONS

FO	Forward Osmosis
GA	Glutaraldehyde

FTIR	Fourier Transform-Infrared
DSC	Differential Scanning Calorimetry
TGA	Thermogravimetric Analysis (TGA
SEM	Scanning Electron Microscope
TDS	Total Dissolved Solid
pH	Potential of Hidrogen
ppt	Part per trillion
ppm	Part per million
J_V	Water flux (Jv, L m^{-2} h^{-1})
ΔV	The volume of water that passes through the membrane at a certain time (L)
Δt	The duration of the FO test (h)
A	The effective membrane surface area (m^2)
R	Rejection factor coefficient
Cp	Concentration of solute in permeate (TDS)
Cf	concentration of solute in feed solution (TDS)
A1	Uncross-linked
A2	Cross-linked with GA (5.6 × 10-6 mol)
A3	Cross-linked with GA (1.1 × 10-5 mol)
A4	Cross-linked with GA (5.6 × 10-5 mol)
A5	Uncross-linked and glycerol as an additive
A6	Cross-linked with GA (5.6 × 10-5 mol) and glycerol as an Additive

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[RJC-5664/2020]