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Research Article

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Molecularly imprinted membrane for transport of urea, creatinine, and vitamin B_{12} as a hemodialysis candidate membrane

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Abstract: High levels of urea and creatinine in the blood are a sign of decreased kidney function. To remove these substances from the blood, hemodialysis which utilizes membranes could be used. In this study, a molecularly imprinted membrane (MIM) was synthesized for the selective transport of urea. The synthesis is initiated with the polymerization of eugenol into polyeugenol and then into polyeugenoxy acetate (PA). The PA is then contacted with urea and then used as the functional polymer in the synthesis of MIM with polysulfone as the membrane base, and polyethylene glycol as the cross-linking agent. The result was later analyzed with FTIR and SEM-EDX. The membrane is then used in the transport of urea, creatinine, and vitamin B₁₂ and then compared with the non-imprinted membrane (NIM) performance. By using UV-Vis spectrophotometry, the results showed that the membrane with 10 h heating variation is able to transport more urea and is more selective than NIM; this proves that the urea template on the MIM enables it to recognize urea molecules better than creatinine and vitamin B₁₂. The order of transport from the best results is urea > creatinine > vitamin B_{12} .

Keywords: polyeugenoxy acetate, urea, molecularly imprinted membrane, selectivity

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1 Introduction

Chronic kidney disease is becoming more common in every part of the world with an estimated prevalence of 5–15% throughout the world [1]. Chronic kidney failure is a progressive and irreversible disorder in the kidney function in which the body's ability to maintain fluid and electrolyte balance and metabolic waste excretion is lost, ultimately leading to uremia (retention of urea and other nitrogenous wastes in the blood) [2]. Renal disease or chronic renal failure is a progressive renal damage which is fatal and characterized by uremia and may lead to complications or even to a kidney transplant [3] if hemodialysis is not carried out.

Hemodialysis utilizes a semipermeable membrane to remove unwanted nitrogenous wastes from the blood. Molecular transport process using a membrane is not only determined by the membrane's pore size but also by the presence of reactive groups on the membrane that activate the interaction between the membrane and the target compound to occur. Furthermore, the membrane used for hemodialysis needs to have high permeability that means it needs to be able to transport metabolite as fast as possible [4].

In this research, we utilize molecularly imprinted membrane (MIM) to transport urea and compare its ability with creatinine and vitamin B_{12} transport. MIM is a membrane that has molecular recognition abilities due to its template that is achieved through cross-linking the functional polymer and the target molecule. The target molecule is later removed from the membrane, forming a cavity with correct shape and orientation of functional groups that serves as the template binding area for selective recognition [5]. Molecular imprinting material has some advantages such as high stability and specificity [6]. Imprinted material has greater flexibility in selecting the appropriate functionalities due to the availability of a large amount of polymerizable compounds [7]. Djunaidi et al. synthesized a molecularly imprinted polymer using

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polyeugenol as the functional polymer to achieve a ureaselective adsorbent [8]. Other previous studies that utilized imprinting method used poly(methyl methacrylate) as the functional polymer to synthesize a non-enzymatic urea sensor, 3,4-ethylenedioxythiophene monomer, for the synthesis of electrochemical urea sensor, and methacrylic acid as the monomer for diisopropylurea recognition [9-11].

One of the potential compounds to be used as the functional polymer in MIM is eugenol-based polymer. Previous research has showed the promising potential of eugenol derivatives such as polyeugenol, polyeugenol sulfonate, and polyeugenoxy acetyl thiophene methanolate for the separation of gold and other metals [12-14]. Eugenol is suitable for the synthesis of a new compound that is more reactive; this is due to the allyl, hydroxyl, and methoxy groups present in eugenol [15,16]. Through the allyl group, eugenol can be polymerized into polyeugenol, while through the hydroxyl group, a carboxylic compound of polyeugenoxy acetate (PA) can be synthesized. PA has an active group of -COOH which can be used as a carrier compound in selective transport [17]. PA will be used as the functional polymer in this research, combined with polysulfone and polyethylene glycol for the synthesis of MIM.

2 Materials and methods

2.1 Materials

Eugenol p.a. (Merck), chloroform p.a. (Merck), BF₃O(C₂H₅)₂ (Sigma Aldrich), diethyl ether p.a. (Merck), anhydrous Na₂SO₄ p.a. (Merck), Aqua demineralized, HCl (Merck), polysulfone $M_{\rm w}$ 35.000 (Sigma Aldrich), methanol p.a. (Merck), 1-methyl-2-pyrolidone (NMP) 99.5% (Sigma Aldrich), NaOH p.a. (Merck), NaHCO₃ (Merck), polyethylene glycol 6000 (Sigma Aldrich), Cl₂CH₂COOH p.a. (Merck), 2,2',azobis(2methylpropionitrile) (AIBN) (Sigma Aldrich), Na₂HPO₄ (Merck), NaH₂PO₄ (Merck), creatinine (Merck), ethanol p.a. (Merck), vitamin B₁₂ (Merck), urea (Merck), picric acid (Merck), and 4-(Dimethyl amino benzaldehyde) (DAB) (Merck) were used in this study. The materials were used as received without further purification step.

2.2 Preparation of phosphate buffer solution (PBS)

PBS of pH 7.4 was made by mixing 29 mL of 0.01 M Na₂HPO₄ with 6.5 mL of 0.02 M NaH₂PO₄ in a 100 mL

volumetric flask. Afterward, pH measurement was carried out using a pH meter to obtain a pH of 7.4.

2.3 Tools and instruments

Laboratory equipment glass (Herma dan Pyrex), reflux, analytic scale (Mettler-200), magnetic stirrer, hot plate, SEM-EDX (Jeol Jsm 6510 La), thickness meter (Digilife), pH meter (HACH E C20), UV-Vis spectrophotometry (LW-V-200-RS), and FT-IR (Shimadzu Prestige 21) were used in this study.

2.4 Synthesis of polyeugenol

Into a three-necked flask, 5.8 g of eugenol (0.035 mol) was added with BF3-diethyl ether catalyst as much as 0.25 mL each hour for the next 4 h while being stirred. The polymerization reaction was done for 12-16 h under room temperature and pressure and then it was stopped by adding 1 mL of methanol. It then turned into a gel form which was later dissolved with chloroform and washed with aquabidest until it reached a neutral pH. The solution was then added with anhydrous Na₂SO₄ and then let to evaporate at room temperature until it hardened. The precipitate formed was weighed and analyzed by FTIR.

2.5 Synthesis of PA

As much as 5 g of polyeugenol (0.03 mol) was added with 17.5 mL of 33% NaOH (0.144 mol) in a three-necked flask. The mixture was then stirred for 30 min and slowly added with 12.5 mL of 50% chloroacetic acid (0.066 mol) while continuously being stirred. With a reflux apparatus, the mixture is heated in a water bath at a temperature of 80-90°C for 2h. Afterward, once the mixture had cooled down, it was acidified with 6 M of HCl until the mixture reached a pH of 1. It was then extracted with each of 50 mL of diethyl ether and 50 mL of sodium bicarbonate (5 wt%, 0.029 mol) three times. The result was acidified again in the same way, then filtered, and dried. The polymer was analyzed with FTIR.

2.6 PA contact with urea

PA was contacted with 1,000 ppm of urea to make a urea mold in the membrane with the weight ratio of PA to urea of 1:20. The contacting process is done through stirring. The PA was added with 1,000 ppm of urea solution and the mixture was stirred for 24 h in a tightly shut container; it was then filtered and dried.

2.7 Synthesis of MIM and non-imprinted membrane (NIM)

The MIM was synthesized by mixing 3.749 g of polysulfone (0.008 mol), 0.8333 g of PA-urea (0.005 mol), 0.8333 g of PEG (0.046 mol), and 0.249 mL of AIBN (0.00027 mol), diluted with 12 mL of NMP (0.00012 mol). Then their treatment was varied by only mixing without heat (MIM-0) and refluxed for 5 (MIM-5) and 10 h (MIM-10) at a temperature of 80–90°C. Afterward, once the mixture had cooled down and was free of air bubble, the membrane was casted on a glass surface and immediately submerged into aquabidest. NIM (NIM-0, NIM-5, and NIM-10) was also synthesized by the same method but using the PA that has not been contacted with urea and then later used for comparison.

2.8 Urea transport

The transport was done by placing the membrane in a diffusion cell with 50 mL of PBS as the receiving phase (RP) and 50 mL of 300 ppm urea diluted in PBS of pH 7.4 as the feed phase (FP). The diffusion cell setup is described in Figure 1. Sampling was done every 2 h for 8 h by taking 2 mL solution of each phase. Then the concentration of samples from both the phases was measured by UV-Vis spectrophotometry at the wavelength of 430 nm to measure the urea concentration by complexing the sample with DAB.

2.9 Determination of urea, creatinine, and vitamin B₁₂ transport percentage

Using UV-Vis spectrophotometer, a standard reference of urea concentration ranging from 0–400 ppm in multiples of 50 ppm was measured. The resulting equation is as follows:

$$y = 0.0026x - 0.0246. \tag{1}$$

Then the concentration of each transported urea samples measured by the UV method was referred to

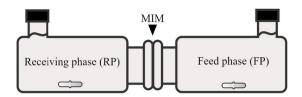


Figure 1: Illustration of the diffusion cell apparatus.

the equation of the standard, and then the transport percentage of the FP and the RP was calculated as follows:

FP transport (%)
$$= \frac{\text{Initial urea concentration in FP}}{\text{Urea concentration in FP at } n \text{ hour}}, \quad (2)$$

$$\times 100 \%$$

RP transport (%) $= \frac{\text{Initial urea concentration in the FP}}{\text{Urea concentration in RP at } n \text{ hour}} \times 100\%,$ (3)

where n is the time of the samples taken. The same method is also used to calculate creatinine and vitamin B_{12} transport percentage. Creatinine concentration used for the standard reference is 0–30 ppm with multiples of 5 ppm with the resulting equation:

$$y = 0.0475x - 0.0102$$
. (4)

While the concentration used to make the vitamin B_{12} standard is 0–50 ppm in 5 ppm multiples with the resulting equation:

$$y = 0.0159x - 0.0057. \tag{5}$$

2.10 Membrane selectivity toward urea, creatinine, and vitamin B₁₂

Transports of 100 ppm of urea, 25 ppm of creatinine, and 20 ppm of vitamin B_{12} were conducted, and the results were then compared to determine the selectivity. Sampling and measurement were done in the same way by taking 2 mL of solution from each phase every 2 h for 8 h. The creatinine was complexed with picric acid before measuring with UV-Vis. Creatinine was measured at the wavelength of 486 nm, while vitamin B_{12} was measured at the wavelength of 361 nm.

Ethical approval: The conducted research is not related to either human or animal abuse.

3 Results and discussions

3.1 Synthesis of polyeugenol and PA

The polyeugenol synthesis showed a yield of 5.67 g (97.89%). The polymerization consists of three stages. The first is the initiation stage where the eugenol will go through an addition reaction due to the protons (H⁺) from BF₃-diethyl ether catalyst which follows Markovnikov's law. Afterward is the propagation stage in which the covalent bonds between the cation chains and the eugenol monomers are formed. This process continues until a long polymer chain is obtained. Intermolecular rearrangement of the carbonium ion also occurs at this stage. The last stage is the termination stage, in which the cationic polymerization reaction between the monomer and the catalyst takes place until all the monomers are used up. Then methanol was added to stop the polymerization by binding the carbonium ion to its anion partner, the CH₃⁰⁻ group from methanol. The mechanism reaction is shown in Figure 2.

The resulting polyeugenol was analyzed by FTIR and then compared with eugenol as shown in Figure 3. According to the data, an absorption band in the 995 and 913 cm⁻¹ region which belongs to a vinyl group was found in eugenol but not in polyeugenol. This may indicate that polymerization has occurred.

NMR characterization of eugenol and polyeugenol could also be used to prove the polymerization. In previous research, it was found that there was a chemical shift at 4.75-5.2 ppm that appeared as a doublet in the eugenol spectra which indicates the =CH $_2$ groups. While it was not seen in the polyeugenol spectra, there is a chemical shift at 2.4-3.0 ppm indicating the presence of -CH $_2$ groups in the polymer and the spectrum at 0.7-1.5 ppm indicating the three hydrogen atoms of methyl groups in the polymer backbone. This strengthens the indication that polymerization has happened [18].

The synthesis of polyeugenoxy acetic acid begins with the addition of NaOH and chloroacetic acid to the polyeugenol. Polyeugenol will react with NaOH to form polyeugenolate salt through its hydroxy group. The proton from the hydroxyl group (–OH) on the polyeugenol is easily released because the anion is stabilized by the presence of a benzene ring resonance. So, the addition of base in the form of excess NaOH is carried out so that a lot of salt is produced and the results are maximum. Na-polyeugenol salt is formed by the reaction of chloroacetic acid to form polyeugenoxy acetic acid.

Then the results obtained were purified by extraction using diethyl ether. The function of purification using

Figure 2: Reaction mechanism of eugenol polymerization.

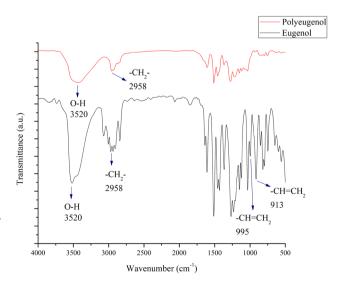


Figure 3: Comparison of FTIR result between eugenol and polyeugenol.

diethyl ether is to remove impurities that are polar. After that, extraction is carried out using sodium carbonate which aims to remove impurities that are non-polar. Next the solution was added with 6 M HCl until pH 1 was obtained and the solution was decanted. The filtrate is then dried at room temperature and the results are then weighed. PA synthesis resulted in a 6.5 g (96.04%) yield with the degree of acetylation of 38.47%. The reaction of PA synthesis is shown in Figure 4.

Eugenol, like most essential oils derived from a plant, is sensitive to heat, highly volatile, and not soluble in water [19]. Polymerizing, synthesizing the derivative, and incorporating it with a cross-linking agent will result in a more stable material. MIM is known to have multiple advantages such as high stability, high affinity, and selectivity toward template molecule [20].

Figure 5 shows the FTIR analysis result of PA compared with polyeugenol, which shows an absorbance band at the range of 3,450 cm⁻¹ indicating hydroxyl group and at 2,960 cm⁻¹ region indicating saturated carbonyl group (Csp²-H). The absorption band of acid carbonyl group (C=O) was identified at the 1,740 cm⁻¹ region, while the acid (C-O) bond was identified at 1,150 cm⁻¹. From these data, it could be concluded that polyeugenoxy acetic acid has been successfully synthesized.

3.2 PA contacting with urea

The synthesized polyeugenol was contacted with urea to create a urea template in the MIM. To calculate the

Figure 4: Reaction mechanism of PA synthesis.

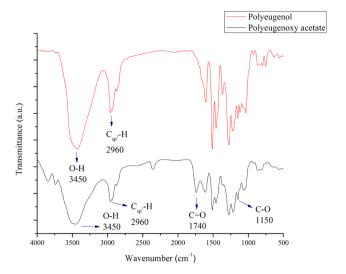


Figure 5: Polyeugenol and PA FTIR comparison.

contacted urea percentage in the polymer, UV-Vis spectrophotometry analysis was used to analyze the urea concentration before and after the contacting process. The concentration of urea used for the contacting step is 1,000 ppm. This concentration is used to optimize the amount of urea contacted with the polymer, while keeping the concentration of urea to be not too high so that it could be analyzed using UV-Vis spectroscopy. The result showed that 23.54% of urea was adsorbed by the PA. The amount of urea that interacts with the polymer is one of the important things that will determine the performance of the membrane when used for transport applications. In the contacting stage, there can be two types of interactions between the polymer and the template. The first type is called a self-assembling approach which is similar to the biological recognition systems that use non-covalent forces such as hydrogen bonds, Van der Waals forces, ionic or hydrophobic interactions, and metal coordination [21]. The second is a preorganized approach which uses reversible covalent bonds. This type of approach tends to produce homogeneous binding sites and reduce non-specific sites. However, it is necessary to break the covalent bonds to remove the template from the polymer matrix [22]. The approximate hydrogen bond between polygenoxy acetic acid and urea is depicted in Figure 6.

3.3 Analysis of MIM and NIM

Two types of membranes were synthesized, the MIM and NIM. The variations carried out in this research were the

Figure 6: Approximation of bond between polyeugenoxy acetic acid and urea.

variation in reflux time of 5 and 10 h at a temperature of 80-90°C and without the use of reflux and only stirring using a stirrer for 10 h at room temperature. The mixture turned into a blackish brown solution which was then cast to form a membrane and allowed to soak in aquabidest for 24 h.

The urea will be released from the membrane when it is being soaked in aquabidest leaving a cavity of size, shape, and structure similar to that of urea, thus creating an MIM. To confirm this, we analyze the urea contacted PA (PA-Urea) sample and the MIM-10 sample. In the result shown in Figure 7, the green box area is the absorption area of urea N-H bending. It is detected in the wavenumber of 1,627 cm⁻¹ in the PA-Urea spectra but it is not shown in the MIM-10 spectra, which indicates that the urea has indeed been released and no longer contained in the membrane, forming a template in the MIM. The N-H bending spectra of urea detected in this research correspond with other previous studies [23,24].

Analysis using SEM-EDX was carried out to determine the surface morphology of the membrane and to determine the elemental content in the membrane. Figures 8 and 9 show the surface and pore morphology of the MIM and NIM at 5,000× magnification, respectively.

Based on the surface morphology of the MIM in Figure 8, it is seen that heating affects the membrane pores. Heating will decrease the pore size of the membrane, but as heating time increases, the pore size of the

membrane will also increase. Some parts of the membrane seem to have impurity in the surface of the pores that looks like some cluster. However, the transport process was done using the membrane part that seems to have the least defect from the rest, so the quality of the transport should not be much affected by it. The pore sizes of the MIM and NIM are measured using ImageJ software and the generated results are shown in Table 1. The EDX analysis results in Table 2 indicate that there are

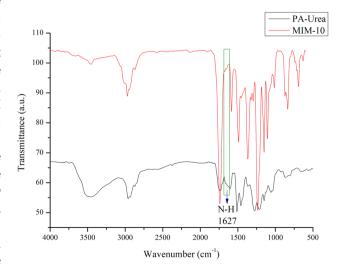
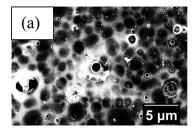
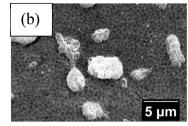


Figure 7: FTIR spectra comparison of PA-Urea and MIM-10 highlighting the N-H urea absorbance area.





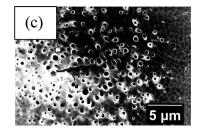
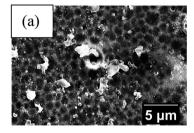
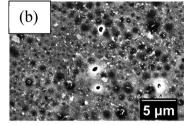


Figure 8: SEM analysis results of (a) MIM-0, (b) MIM-5, and (c) MIM-10 surface morphology.





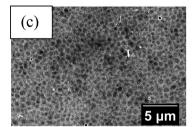


Figure 9: SEM analysis result of (a) NIM-0, (b) NIM-5, and (c) NIM-10 surface morphology.

no nitrogen (N) from urea contained in the sample of the membranes. NIM was synthesized using PA that was not contacted with urea but the MIM used the PA that has been contacted with urea. The lack of nitrogen in the EDX analysis of all the MIM samples indicates that the urea has been released from the MIM when it was soaked with aquabidest, supposedly leaving a urea cavity in the MIM that will later serve as the template that could recognize urea.

In the NIM variation, analysis was carried out using FTIR to determine the effect of heating on the membrane functional groups. The results of FTIR analysis on NIM-0, NIM-5, and NIM-10 are shown in Figure 10. It can be seen in the OH absorption region in the range 3,450–3,460 cm⁻¹ that NIM-0 (without heating) has the greatest OH intensity, followed by NIM-10 and NIM-5. The strengthening of the OH group intensity will show the attenuation of the C–O group detected in the 1106.5 cm⁻¹ absorption area. The strongest C–O group intensity is in NIM-5,

Table 1: Pore size measurement result of all membrane variation

Sample	Average pore size (µm)		
MIM-0	1.087 ± 0.328		
MIM-5	0.373 ± 0.063		
MIM-10	0.530 ± 0.096		
NIM-0	0.867 ± 0.154		
NIM-5	0.746 ± 0.178		
NIM-10	1.134 ± 0.268		

followed by NIM-10 and NIM-0 in the absorption area $1,080-1,130~\text{cm}^{-1}$.

3.4 Urea transport test with heating time variations in the membrane

The variation in the membrane without heating results in a membrane with perforated part when viewed under light. When a leak test is carried out, the membrane without heating leaks. Based on previous FTIR results, membranes without heating had the strongest O–H absorption compared to membranes with heating for 5 and 10 h. So, it can be concluded that less of O–H indicates the ability of the membrane to be leakage free. If transport using a membrane without heating (MIM-0) that leaks is carried out, the transport results obtained may be invalid because it is possible that the urea will escape and does not represent the transport ability and selectivity of the membrane itself.

Table 2: Elemental analysis result by EDX on all membrane variations

Element	NIM- 0 (%)	NIM- 5 (%)	NIM- 10 (%)	MIM- 0 (%)	MIM- 5 (%)	MIM- 10 (%)
С	77.26	76.47	75.70	76.89	75.36	76.13
0	18.32	18.95	19.53	17.70	19.71	19.50
S	4.42	3.93	4.26	4.45	4.36	3.62

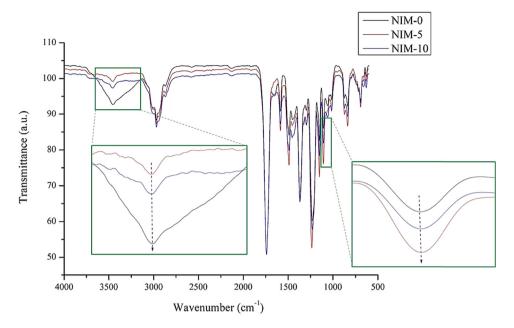


Figure 10: FTIR graph on the absorption of C-O and O-H groups in the NIM variation.

Therefore, the transport test for urea was carried out using a membrane with a heating variation in 5 and 10 h (MIM-5 and MIM-10).

The setup used for the transport process is a diffusion cell that consists of the FP and the RP. The FP contains the solution with the compound that has to be transported, in this case urea diluted by PBS, while the RP only consists of PBS. The MIM is put in-between the FP and the RP, and with concentration difference as the driving force, urea will be transported to the RP. The results of 300 ppm urea transport using NIM and MIM variations are shown in Figure 11.

In Figure 11, the transport of 300 ppm of urea is shown to be the most optimum using the MIM-10 variation which shows a 21.13% decrease in urea in the FP, while the RP shows a 17.91% of urea increment. The concentration lost from the FP and gained in the RP could be different due to urea entrapment in the membrane.

Another transport test using 500 ppm of urea was carried out for 48 h to determine the membrane transport performance when the transport time was increased. The membrane used in this test was the MIM-10 which showed the optimal results when transporting 300 ppm of urea. The results showed that at 48 h, the membrane was able to transport 50.42% of 500 ppm of urea in terms of the FP. Meanwhile, the RP showed that the amount of urea transported was 49.06%. The longer the transport time, the lower the amount of urea being transported. The driving force on this transport is the difference in concentration between the FP and the RP, and at the 48th hour it

is no longer possible to transport because the concentration between the FP and the RP is balanced. The result is shown in Figure 12.

3.5 Urea, creatinine, and vitamin B_{12} transport and selectivity test

For the selectivity test, MIM-10 was used as it is the membrane that showed the best ability in transporting 300 ppm of urea. The membranes are used for the transport of 100 ppm urea, 25 ppm creatinine, and 20 ppm vitamin B_{12} , and from these data, the selectivity of the membrane towards urea is calculated. These specific concentrations were chosen as it is the concentration that gives the highest precision in the UV method, which is in the range of 0.2–0.8 [25]. More than 20 ppm creatinine

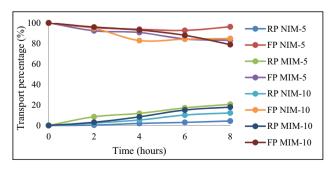


Figure 11: The result of 300 ppm urea transport using variations in MIM and NIM.

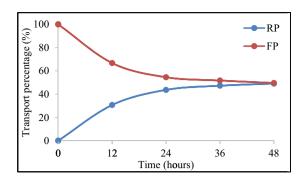


Figure 12: The result of 500 ppm urea transport for 48 h using MIM-10.

would give an absorbance value over 1, while urea concentration of 50 ppm and under would have absorbance value of less than 0.2.

Transport of urea, creatinine, and vitamin B_{12} aims to prove the urea template in the membrane and its ability in transporting urea compared to other substances. The approximate reaction between polysulfone, PEG, and PA-Urea is depicted in Figure 13.

In this test, urea transport was carried out with a concentration of 100 ppm. This time for urea transport, the urea concentration was lowered to obtain better transport results. Evidently, by using a lower concentration of urea, the percentage of urea that was successfully transported when viewed from the FP was 28.89% for MIM and 5.31% for NIM. Meanwhile, when viewed from the RP, the urea transported was 28.09% for MIM and 14.61% for NIM. The results of urea transport using the MIM were better than those obtained using the NIM, indicating that the urea template on the MIM was properly formed so that it was able to recognize urea and transport it more optimally. From the various concentrations of urea used in the transport process, it can be concluded that the

best transport result was achieved by the 100 ppm concentration. The results of 100 ppm urea transport with MIM-10 and NIM-10 are shown in Figure 14.

For the creatinine transport, the NIM was able to transport 4.47% of creatinine, while the MIM was able to transport 23.62% of creatinine when viewed from the FP. While from the RP, NIM was able to transport 3.46% of creatinine and MIM was able to transport 13.44% of creatinine. This shows that the membrane's ability to transport creatinine is not optimal when compared to urea transport. The results of creatinine transport using the 10 h NIM and MIM membranes are shown in Figure 15.

While for the vitamin B_{12} , in terms of the FP, vitamin B_{12} transport using the NIM-10 was able to transport 9.38% of vitamin B_{12} , while the MIM-10 was only able to transport 6.28% of vitamin B_{12} . When viewed from the RP, NIM-10 is able to transport 5.37% of vitamin B_{12} while MIM is able to transport 9.86% of vitamin B_{12} . This shows that the MIM-10 and NIM-10 membranes are less capable of transporting vitamin B_{12} . The results of vitamin B_{12} transport using the NIM-10 and MIM-10 membranes are shown in Figure 16.

Based on the results of creatinine and vitamin B_{12} transport, it shows that the MIM membrane is more capable of transporting urea than creatinine and vitamin B_{12} . This could be due to the molecular size of urea, creatinine, and vitamin B_{12} . Urea has a size of 60 Da, creatinine has a size of 113 Da [26], and vitamin B_{12} has a size of 8.5 Å or 1.35 kDa [27]. The size of vitamin B_{12} is much larger than the size of urea so that the transport ability of the MIM membrane in the transport of vitamin B_{12} is not as good as the transport of urea as well as creatinine.

Based on the selectivity graph of urea and vitamin B_{12} in Figure 17, it shows that the MIM has a greater selectivity value than the NIM. This means that the MIM with

$$\begin{bmatrix} CH_3 & CH_3$$

Figure 13: Estimated formation of a urea template on the MIM membrane.

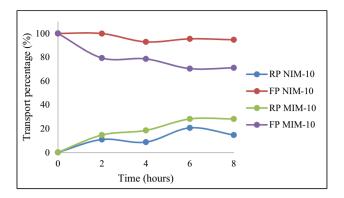


Figure 14: Percentage of 100 ppm urea transport using MIM-10 and NIM-10.

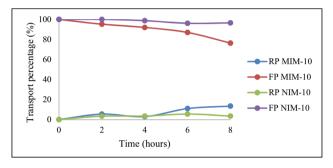


Figure 15: Percentage of 25 ppm creatinine transport using MIM-10 and NIM-10.

urea template is better in transporting urea than vitamin B_{12} . This also proves the presence of urea template on the MIM which makes the MIM more selective toward urea and less capable of transporting vitamin B_{12} . Meanwhile, the NIM, which does not have a urea template, has a lower selectivity value because the NIM is not able to recognize urea properly.

The regeneration of the membrane happens in the transport process during the release of target molecule

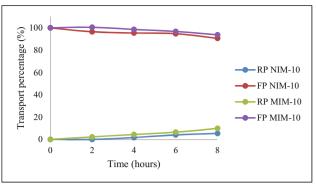
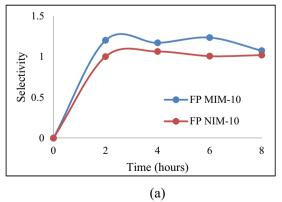


Figure 16: Percentage of 20 ppm vitamin B_{12} transport using MIM-10 and NIM-10.

from the FP to the RP, so it will happen continuously as long as there is a driving force which is the concentration difference between the FP and RP. The reusability of the imprinted membranes is not yet tested on this research and will be an interesting insight to be added in future studies, but as long as the regeneration is proper, the reusability is hoped to be dependable as supported by the low amount of trapped molecule in the membrane when comparing the difference in the transport data between the FP and the RP.

4 Conclusion

Polyeugenol and PA have been successfully synthesized with a yield of 97.89 and 96.04%, respectively. The synthesized MIM is proven to transport urea better than the NIM due to the urea template in the MIM. In an 8-h span, the best urea transport result was shown by MIM-10 variation that was synthesized by heating for 10 h, which



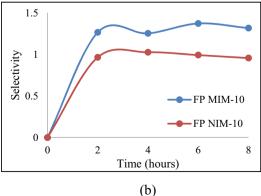


Figure 17: MIM-10 and NIM-10 selectivity for the transport of urea toward (a) creatinine and (b) vitamin B₁₂.

transported 28.89% of 100 ppm urea, while the NIM-10 transported only 5.31%. However, the transport that was conducted for 48 h showed that the MIM-10 could transport 50.42% of 500 ppm urea. MIM-10 selectivity toward urea and against creatinine and vitamin B_{12} showed a higher value than the NIM selectivity. The result proves the presence of the urea template in the MIM. The order of MIM selectivity from the best results was urea > creatinine > vitamin B_{12} .

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