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Research Article

# Effect of Salt on the Stability of PIM Membranes Containing Poly-BADGE Carrier for Phenol Transport

Agung Abadi Kiswandono*, Anisa Rahmawati, Niswah Fadillah, Rinawati Rinawati, Pandri Ferdias, and Herlian Eriska Putra

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**Abstract**

Phenols, which are toxic and have a significant environmental impact, require effective removal methods from various waste sources. One potential solution is the use of polymeric inclusion membrane (PIM) based on Poli-BADGE which is designed to have high stability and resistance to operating conditions. The main problems in membrane development are the decline in stability and transport effectiveness due to damage to the membrane structure, leakage of carrier, and limited membrane lifetime. This study examines the stability and ability of PIM membranes in transporting phenols using 1:1 poly-BADGE as a carrier. This study aims to evaluate the stability of the membrane as well as the ability to transport phenols by varying a number of parameters, such as the type and concentration of salts in the source phase and the receiving phase, as well as the service lifetime of the membrane. The results showed that the optimal stability of the PIM membrane was achieved by the addition of NaCl as a salt in the source phase resulting in phenol transport of 54.53%, better than other salts. The addition of NaCl 0.01 M in both phases was able to transport phenols by 51.17% and 52.97%, respectively. The addition of $KNO_3$ salts in the source phase was proven to extend the lifetime of the membrane by up to 67 days, compared to only 47 days without salt. This research provides an effective solution to improve the efficiency and durability of PIM membranes in overcoming phenol pollution problems, while extending the service lifetime of the membrane through optimizing operational parameters.

**Keywords:** membrane stability, phenol, PIM, Poly-BADGE, salt

## 1. INTRODUCTION

The rapid growth of industrial activities in various sectors, such as petrochemicals [1], coals [2], fuels, lubricants [3], plastics, polymers [4], paints, varnishes [5], pharmaceuticals, and medical waste treatment [6], has had a significant impact on the environment [7][8]. One of the most concerning impacts is water pollution by harmful organic pollutants, such as phenols [9]. Phenol is an aromatic compound that is widely used as raw material in various industrial processes, but its presence in industrial liquid waste is often a serious threat to human health and the environment [10]. As a carcinogenic, corrosive, and toxic compound, phenol can cause a variety of health effects even in low concentrations (5–25 mg/L), including liver damage, blood pressure disorders, and decreased heart function [11]. Therefore, the handling and management of phenol-containing waste is essential to prevent further negative impacts on ecosystems and communities [12].

Various methods have been developed to treat liquid waste containing phenols [13]. Techniques such as adsorption and distillation have shown promising results in lowering phenol levels [14][15]. However, the main obstacles of this method are high operational costs, large energy consumption, and technical complexity that limit large-scale implementation [16][17]. As more cost-effective and environmentally friendly technologies develop, membrane-based separation technology is one of the leading alternatives [18]-[21]. Liquid membrane technology, particularly the supported liquid membrane (SLM) system, has attracted attention as an efficient method for phenol separation [22][23]. By utilizing a porous material that supports the liquid phase, SLM enables the selective transport of phenols through the membrane [12]. However, despite the many advantages of SLM, membrane stability issues remain a major obstacle in its application [24].

To overcome these challenges, polymer inclusion membrane (PIM) technology has been developed. In contrast to SLM, PIM offers better stability by utilizing a base polymer such as polyvinyl chloride (PVC) combined with a plasticizer such as dibenzyl ether to prevent leakage and improve membrane durability [25]. One of the

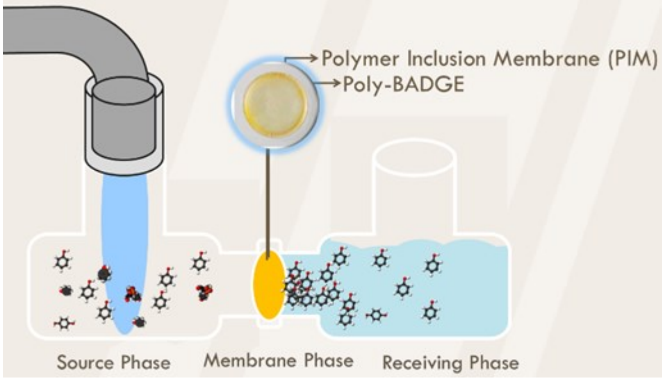

**Figure 1.** A schematic diagram of the experimental setup.

**Figure 2.** The photograph of PIM membrane with 1:1 Poly-BADGE carrier.

key components in PIM is a carrier that allows for selective transport of target compounds, such as phenols. Eugenol, an organic compound with hydroxy, methoxy, and alyl functional groups, is a popular choice as a carrier due to its ability to interact strongly with phenols [11]. Although eugenol and its derivatives, such as polyeugenols, have been used in the development of PIM, the limitations of molecular weight and the number of active sites often reduce their transport efficiency. To overcome this limitation, cross-linking agents such as bisphenol A diglycidyl ether (BADGE) are used to modify the properties of the polymer. BADGEs can increase the molecular weight of polymers and improve interactions with target compounds, thus enabling higher transport efficiency [26].

In recent years, the application of PIMs has evolved significantly, particularly through the incorporation of advanced carriers to improve selectivity, transport efficiency, and membrane stability. Among these, poly-BADGE has emerged as a promising polymeric carrier due to its unique structural features that allow enhanced interactions with phenolic compounds through hydrogen bonding and π–π interactions. Several studies have highlighted the potential of poly-BADGE in increasing the hydrophobic compatibility between the membrane matrix and target compounds, minimizing carrier loss, and improving mechanical robustness over long-term usage. In particular, the crosslinking ability of BADGE offers a more rigid and interconnected polymeric network within the membrane, which not only improves phenol transport efficiency but also significantly extends the operational lifetime of the membrane. However, despite these advancements, comprehensive studies on the stability of poly-BADGE-based PIM systems under various operational conditions, such as salt effects and long-term exposure, remain limited. Therefore, this research aims to fill that gap by systematically evaluating the effect of salt type and concentration on the structural integrity, transport capacity, and longevity of PIMs containing poly-BADGE as the carrier. This study aims to evaluate the performance of PIM systems containing poly-BADGE 1:1 as carrier in wastewater treatment containing phenol. This research includes analysis of membrane stability, phenol transport efficiency, variety of salt types and concentrations, and membrane lifetime resistance. By understanding these parameters in depth, this study is expected to provide comprehensive insights for the development of PIM technology as an effective and sustainable solution for the management of phenol-containing liquid waste.

## 2. MATERIALS AND METHODS

### 2.1. Materials

The materials used include poly-BADGE 1:1 carrier $(C_{16}H_{18}O_4)_n$ (Sigma-Aldrich), phenol ($C_6H_5OH$, Merck), dibenzyl ether (DBE, $C_{14}H_{14}O$, Sigma-Aldrich), PVC (Aldrich), tetrahydrofuran (THF, Merck), sodium hydroxide (NaOH, Merck), sodium chloride (NaCl, Merck), sodium nitrate ($NaNO_3$, Merck), sodium sulfate ($Na_2SO_4$, Merck), potassium nitrate ($KNO_3$, Merck), chloroform ($CHCl_3$, Sigma-Aldrich), 4-aminoantipyrine ($C_{11}H_{13}N_3O$, Sigma), potassium ferricyanide ($K_3[Fe(CN)_6]$, Merck), hydrochloric acid (HCl, Merck), ammonium hydroxide ($NH_4OH$, Merck), and phosphate buffers (Merck). Distilled water (aquadest) and bidistilled water (aquabides) were prepared in-lab using a GFL distillation unit.

This study used a variety of tools, including a digital analytical balance (Mettler Toledo AB54-S), a membrane mold with a diameter of 3.5 cm, a set of phenol transport tools (consisting of a transport pipe with a diameter of 3.5 cm and a transport board), pH meter, and thickness gauge (Mitutoyo 7301). Phenol concentrations were analyzed using a UV-vis spectrophotometer (Hitachi U-2010). The PIM membrane was characterized using a Fourier transform infrared (FTIR) spectrophotometer (Perkin Elmer 99951) for functional cluster analysis and a scanning electron microscope (SEM) (JSM 6360LA) to observe the surface morphology.

### 2.2. Methods

#### 2.2.1. PIM Membrane Manufacturing

PIM membrane is made in a membrane mold by dissolving the composition of the PIM membrane, namely 0.054 g of poly-BADGE 1:1 carrier, 0.1728 g of polyvinyl chloride as the base polymer, and 0.3132 g of DBE as a plasticizer dissolved in 10 mL of THF solvent [24]. THF serves as a solvent to homogenize membrane components. Once all components have dissolved, the membrane is left

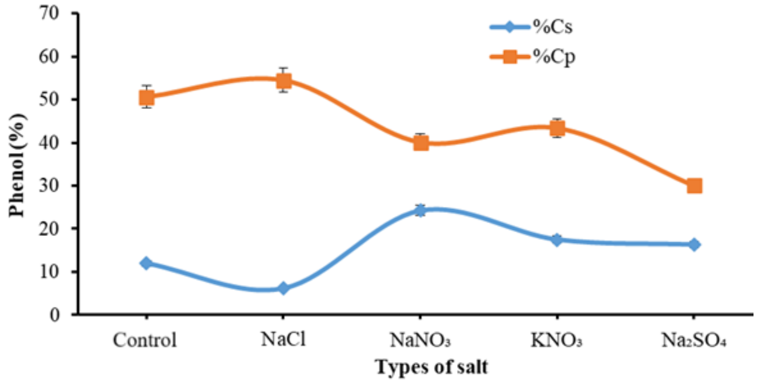

**Figure 3.** The effect of the addition of salt type on phenol concentration in the source phase and the receiving phase.

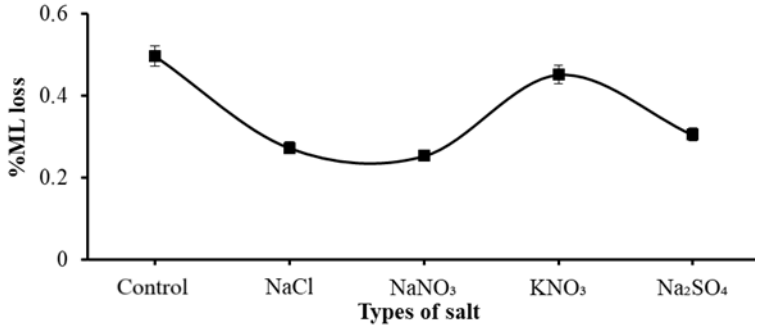

**Figure 4.** Effect of salt type variation on %ML loss.

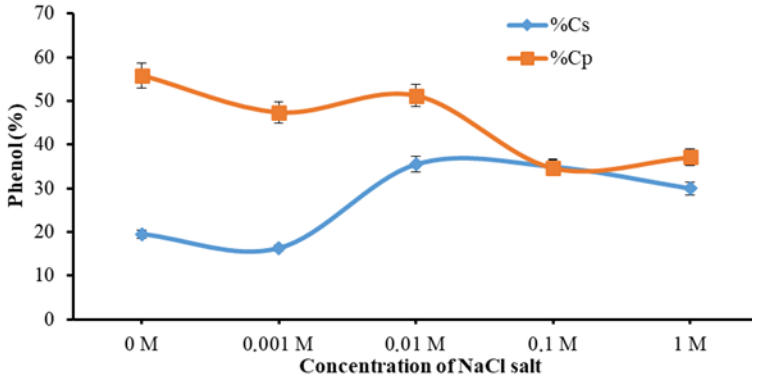

**Figure 5.** Effect of salt concentration in the source phase on phenol concentration in the source phase and receiver phase.

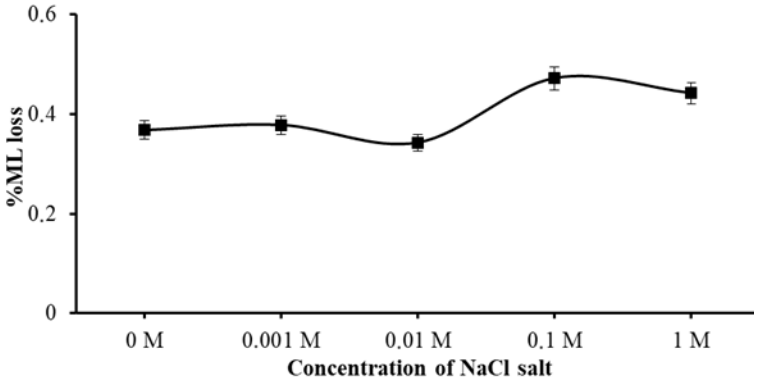

**Figure 6.** The %ML loss variation in salt concentration at the source phase.

for 3 days at room temperature to evaporate the solvent naturally. The PIM membrane formed is characterized by FTIR and SEM.

### *2.2.2. Phenol Transport Procedure*

This study studied the stability and ability of PIM membranes with 1:1 poly-BADGE as a carrier for phenol transport. The PIM membrane stability test includes several variations, namely the type of salt, salt concentration, and lifetime or lifetime of the membrane. To determine the concentration of transported phenol, samples were analyzed using a UV-vis spectrophotometer. In addition, the PIM membrane was characterized by FTIR and SEM to observe structural changes. In each phenol transport procedure, the following steps are performed for each variation of its parameters. The transport pipe is covered with plastic wrap and stirred using a spin bar for 9 h at room temperature. After 9 h, the transport process is stopped, the membrane is removed, and dried for 24 h. The weight of the membrane after the transport is measured. Phenol concentrations in the source phase and receiver phase were analyzed using a UV-Vis spectrophotometer (Hitachi U-2010) at 460 nm [26]. The PIM membranes were characterized using FTIR and SEM to identify functional groups and observe surface morphology before and after phenol transport. The FTIR analysis was conducted in the range of 4000–400 cm$^{-1}$. Membrane samples were analyzed in solid form by an external laboratory using standard operating procedures. The spectrum results were used to identify the characteristic absorption peaks of functional groups present in the PIM membrane, particularly the O–H, C–H, and aromatic ring vibrations. SEM samples were prepared by cutting and mounting the membranes, followed by gold coating prior to imaging. The images were used to observe morphological changes such as pore formation and surface roughness due to phenol transport and salt treatment. Each procedure is followed by these steps to maintain the consistency of the method.

### *2.2.3. Variation of Salt Type in the Source Phase*

To evaluate the effect of salt type on phenol transport, five different salts were used in the source phase: NaCl, $NaNO_3$, $Na_2SO_4$, $KNO_3$, and a control condition without salt. All salts were prepared at a fixed concentration of 0.01 M. The phenol concentration in the source phase was maintained at 60 ppm, while the receiving phase contained 0.1 M NaOH. This setup allowed for a consistent comparison of different anions and cations on phenol transport behavior across the membrane.

### *2.2.4. Variation of Salt Concentration*

To investigate the influence of salt concentration on phenol transport, two sets of experiments were conducted. In the first set, the concentration of NaCl in the source phase was varied at five levels: 0 (control); 0.001; 0.01; 0.1; and 1.0 M. The phenol concentration was maintained at 60 ppm, and the receiving phase used 0.1 M NaOH. In the second set, the concentration of NaCl in the receiving phase was varied at the same range (0; 0.001; 0.01; 0.1; and 1.0 M), while the source phase contained 60 ppm phenol with 0.01 M NaCl. These experiments were designed to examine the role of salt in both the driving and receiving sides of the membrane system.

### *2.2.5. Lifetime*

A PIM membrane with optimal composition and condition is placed between the two phenol transport pipes. In the source phase, 50 mL of phenol solution is filled with 60 ppm pH 5.5 with three variations, (a) no salt (as a control solution); (b) addition of $Na_2SO_4$ salt 0.01 M; and (c) add $KNO_3$ salt 0.01 M. In the receiving phase is filled with 50 mL of 0.1 M NaOH solution. Lifetime is determined by measuring the pH value at the source phase. An increase in pH in the source phase indicates that the PIM membrane has leaked. The pH in the source phase is checked periodically until the pH in the source phase ±9, after which the phenol transport process is stopped [24].

### *2.2.6. Experimental Setup*

A schematic diagram of the experimental setup is shown in Figure 1. The phenol transport system consists of a two-compartment cell, each containing 50 mL of solution. The source phase contains 60

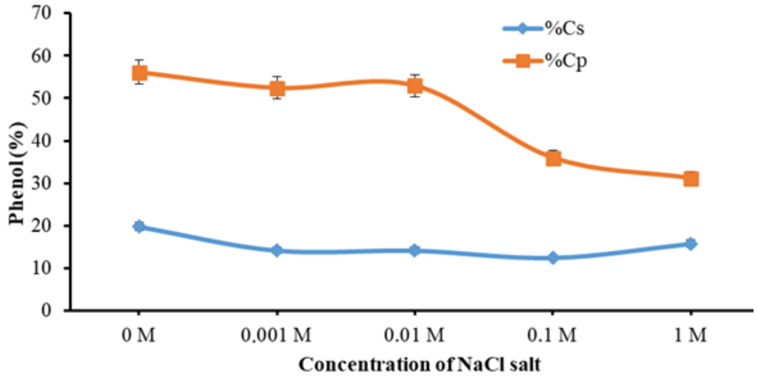

**Figure 7.** Effect of salt concentration in the receiving phase on phenol concentration in the source phase and the receiving phase.

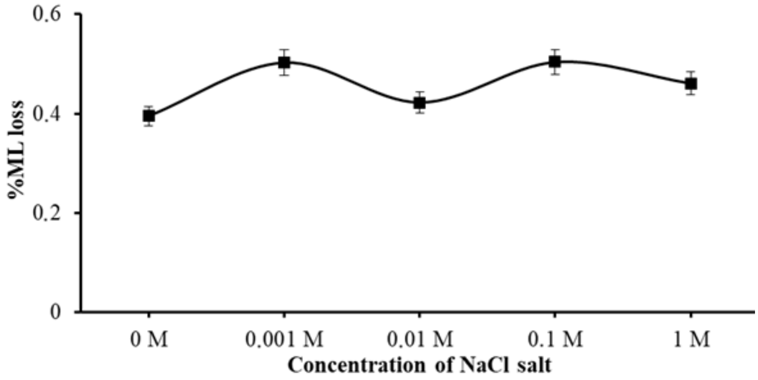

**Figure 8.** The %ML loss variation in salt concentration in the receiving phase.

**Table 1.** Measurement of pH at the source phase as a lifetime parameter.

| Day | pH of Phenols in the Source Phase | | |
|---|---|---|---|
| | Control | $Na_2SO_4$ | $KNO_3$ |
| 1 | 5.51 | 5.51 | 5.51 |
| 3 | 5.74 | 5.70 | 5.62 |
| 6 | 5.88 | 5.83 | 5.75 |
| 9 | 6.25 | 6.07 | 5.90 |
| 16 | 6.96 | 6.65 | 6.42 |
| 23 | 7.63 | 6.82 | 6.66 |
| 30 | 7.92 | 7.45 | 6.91 |
| 37 | 8.57 | 7.89 | 7.13 |
| 44 | 8.91 | 8.54 | 7.35 |
| 47 | 9.18 | 8.76 | 7.88 |
| 50 | - | 8.95 | 8.20 |
| 54 | - | 9.16 | 8.42 |
| 63 | - | - | 8.96 |
| 67 | - | - | 9.18 |

ppm phenol with various types or concentrations of salts, while the receiving phase contains 0.1 M NaOH or other test conditions. The compartments are separated by a PIM membrane containing a 1:1 poly-BADGE carrier compound tightly sandwiched between them. The experiments were carried out at room temperature (~25 °C), and samples were taken from the source and receiving phases periodically for phenol concentration analysis using UV-Vis spectrophotometry.

## 3. RESULTS AND DISCUSSIONS

The overall mechanism of phenol separation through the PIM membrane used in this study is illustrated schematically in Figure 1. The setup demonstrates the role of the membrane in facilitating selective transport of phenol molecules from the source phase to the receiving phase, driven by concentration gradients and the chemical interaction between phenol and the poly-BADGE carrier. The following discussion elaborates on how different factors, including salt type, salt concentration, and membrane composition, influence the stability and transport behavior in the system.

### *3.1. PIM Membrane*

The successfully created PIM membrane is then used for phenol transport. The membrane produced in this study is transparent yellow with an average weight of 0.4485 g, and has an average thickness of 0.33 mm. The membrane obtained can be seen in Figure 2.

### *3.2. Types of Salt in the Source Phase*

The addition of salt to the phase of the source containing the phenol solution can improve the stability of the PIM membrane [27]. The salt added to the source phase is expected to reduce the rate of leakage in the membrane. The rate of leakage in the membrane can be affected by the type and concentration of salts in the source phase. A salt can be said to be optimal when it is able to produce the largest %Cp with the smallest %ML loss, it can be said that the PIM membrane has shown its stability [24][28]. The addition of salt in the source phase with various types of salt aims to determine the effect of salt on the percentage of phenol transport yield, shown in Figure 3.

Figure 3 shows that the addition of salt in the source phase has an effect on the yield of the percentage of phenol transported to the receiving phase. Based on the graph, the addition of NaCl salts in the source phase produced the largest %Cp compared to the addition of other types of salts, which was 54.53%. This is due to the salting-out effect that can affect the percentage of phenol transported to the receiving phase. The salting-out effect affects the decrease in phenol solubility, so that the phenol will be difficult to transport to the receiving phase [29]-[31]. This effect is consistent with previous findings that increased ionic strength can reduce solubility of hydrophobic organic compounds due to dehydration of the solute molecules [27]. In addition to affecting the percentage of phenol transported to the receiving phase, the addition of salt can also affect the loss of membrane components (%ML loss). The magnitude of %ML loss from the variation in salt type in the source phase can be seen in Figure 4.

Based on the %ML loss graph in Figure 4, it shows that without the addition of salt in the source phase can lead to a large %ML loss. Based on the data on the variation of this type of salt, it can be concluded that the addition of NaCl salt in the source phase is able to increase the stability of the PIM membrane. This is evidenced by the largest % Cp among other types of salt with a lower %ML loss compared to $NaNO_3$, $KNO_3$, and $Na_2SO_4$ salts. This is in agreement with studies showing that ionic additives can influence membrane leaching through modulation of osmotic pressure and interfacial tension [32]-[34]. The differences in the performance of each salt in stabilizing the PIM membrane and enhancing phenol transport can be attributed to the nature of the ions involved—particularly the cation/anion characteristics and their hydration properties. NaCl, which exhibited the highest %Cp and lowest %ML loss, contains $Na^+$ and $Cl^-$ ions with relatively small ionic radii and moderate hydration enthalpy. These properties enable better ionic interaction balance without disrupting the membrane structure.

Conversely, salts containing multivalent ions or ions with larger ionic radii may influence membrane performance differently. For instance, sulfate anions ($SO_4^{2-}$) may form stronger hydration

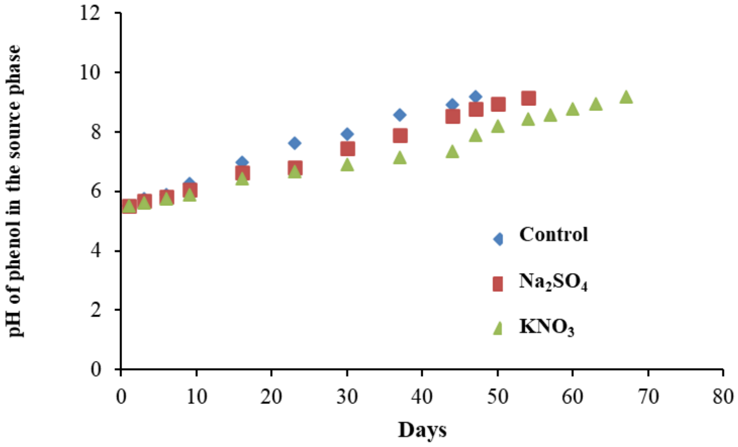

**Figure 9.** The measured pH at the source phase as a lifetime parameter.

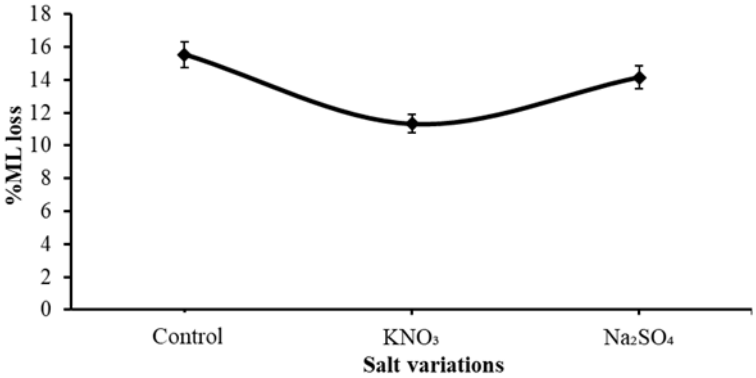

**Figure 10.** The %ML loss lifetime graph.

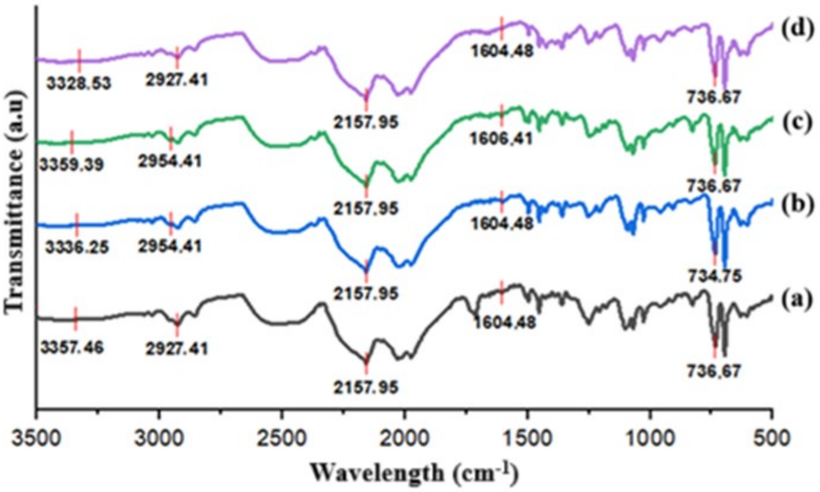

**Figure 11.** FTIR spectra of PIM membrane (a) prior to transport, (b) after lifetime transport without the addition of salt, (c) after lifetime transport with the addition of $Na_2SO_4$ salts, and (d) after lifetime transport with the addition of $KNO_3$ salts.

shells and affect osmotic pressure across the membrane, potentially influencing the leaching rate of membrane components. Similarly, nitrate anions ($NO_3^-$) with delocalized electron structures may interact differently with the membrane matrix and the carrier. The oxidation state of the ions also plays a role. Monovalent cations such as $Na^+$ and $K^+$ tend to exert weaker electrostatic interactions with the membrane compared to potential Lewis acid cations such as $Al^{3+}$ or $Fe^{3+}$. The use of salts containing such trivalent cations may provide additional coordination interactions with the O–H groups in poly-BADGE or phenol, potentially improving selectivity or transport rates through Lewis acid-base complexation mechanisms [35]. However, the strong interaction of Lewis acid salts with membrane components may also alter the membrane integrity or cause precipitation effects. Therefore, while this study focused on monovalent salts to maintain membrane stability and avoid unwanted side reactions, future studies are encouraged to explore the role of Lewis acid salts and multivalent ions in modulating membrane structure and phenol transport behavior.

### *3.3. NaCl Salt Concentration in the Source Phase*

Variations in the concentration of NaCl salts in the source phase in the transport process were used to determine the stability of the PIM membrane. The effect of the addition of NaCl salts with varying concentrations in the source phase on the percentage of phenols successfully transported to the receiving phase can be seen in Figure 5. The lower the NaCl concentration added, the higher the percentage of phenols transported to the receiving phase. Concentrations of NaCl salts that are too large or concentrated can increase the salting-out effect, so that it can cause a decrease in %Cp. NaCl salt concentration of 0.01 M has the highest %Cp of 51.17% compared to other NaCl salt concentrations in the source phase.

NaCl salts that have too concentrated concentrations have a higher number of $Na^+$ cation levels, the more the amount of $Na^+$ cation levels can interfere with the phenol transport process, because the $Na^+$ cation levels will interact with the carrier and inhibit the phenol to be transported to the receiving phase [27]. Too high a concentration of NaCl salts in the source phase will interfere with the formation of hydrogen bonds between O–H phenol and poly-BADGE 1:1, because too many $Na^+$ cations will enter the membrane and bind to –O$^-$ in the carrier. The greater concentration of NaCl will cause the decreasing active group O–H in the carrier so that the phenol transport decreases. The effect of salt concentration in the source phase on % ML loss is shown in Figure 6.

This hypothesis is supported by the FTIR analysis, where a noticeable decrease in the O–H stretching intensity was observed after phenol transport using high concentrations of NaCl. This suggests possible interaction or disruption of hydrogen bonding sites between O–H groups of the poly-BADGE carrier and phenol. Moreover, previous studies have reported that the presence of excess alkali metal cations (such as $Na^+$) can weaken hydrogen bonding by forming electrostatic interactions with lone pairs on oxygen atoms, which can inhibit hydrogen bond formation or shift equilibria [27][29]. These observations support our explanation that excessive $Na^+$ may compete with phenol in interacting with the O–H group of the carrier, thereby decreasing the efficiency of phenol transport. The greater the concentration of salts added in the source phase will result in a greater percentage of membrane components being lost [36]. This indicates that the addition of NaCl salts with a concentration of 0.01 M will cause the percentage of membrane loss to be low. The membrane is more stable when producing the highest %Cp but with a small %ML loss. Therefore, based on the data obtained in the study, it can be concluded that the addition of 0.01 M NaCl salt in the source phase is able to increase the stability of the PIM membrane. This is evidenced by the largest %Cp among other types of salt and lower %ML loss.

### 3.4. NaCl Salt Concentration in the Receiver Phase

Similar to the previous variation, the variation in the concentration of NaCl salts in the receiving phase in the transport process is used to determine the stability of the PIM membrane. The effect of the addition of NaCl salts with varying concentrations in the receiver phase on the percentage of phenols successfully transported to the receiver phase can be seen in Figure 7. The lower the concentration of NaCl added in the receiving phase, the higher the percentage of phenols transported to the receiving phase. Concentrations of NaCl salts that are too large or concentrated can increase the salting-out effect, which can lead to a decrease in the resulting %Cp [29]. This occurs because too much $Na^+$ cation level at a concentrated concentration of NaCl salts will interfere with the phenol transport process [27]. The concentration of NaCl salt 0.01 M had the highest %Cp of 52.97% compared to other NaCl salt concentrations in the receiving phase.

The addition of NaCl salts in the receiving phase in phenol transport has an effect on the percentage of transport yield. The results showed that the greater the concentration of NaCl added to the receiver phase, the lower the transport yield. The addition of salt in the receiving phase will prevent the phenol from being transported to the receiving phase, as the $Na^+$ ions of the NaCl salt can reduce the solubility of NaOH. The $Na^+$ ions that function to convert phenols into phenols will be further reduced so that the concentration of NaCl salts added in the receiving phase will affect the percentage of membrane loss (%ML loss). The effect of salt concentration on the receiver phase on %ML loss can be shown through Figure 8. The addition of NaCl salts with a concentration of 0.01 M in the receiver phase will cause the percentage of membrane loss to be low. Based on the data obtained from the study, it can be concluded that the addition of 0.01 M NaCl salt in the receiving phase is able to increase the stability of the PIM membrane. This is evidenced by the largest %Cp among other types of salt and lower %ML loss.

### 3.5. Lifetime

The lifetime measurement of the membrane aims to test the durability of the PIM membrane with and without the addition of salt in the source phase. The salts added to the source phase are $Na_2SO_4$ and $KNO_3$ with a concentration of 0.01 M. The

**Table 2.** Functional groups of PIM membrane before and after phenol transport.

| Function Groups | Wavenumber ($cm^{-1}$) | | | |
|---|---|---|---|---|
| | a | b | c | d |
| Stretching of group O-H | 3357.46 | 3336.25 | 3359.39 | 3328.53 |
| Stretching of group $Csp^3$-H | 2927.41 | 2954.41 | 2954.41 | 2927.41 |
| Stretching of group C≡C | 2157.95 | 2157.95 | 2157.95 | 2157.95 |
| Aromatic ring (C=C) | 1604.48 | 1604.48 | 1604.48 | 1606.41 |
| Aromatic ring (C-H) | 736.67 | 734.75 | 736.67 | 736.67 |

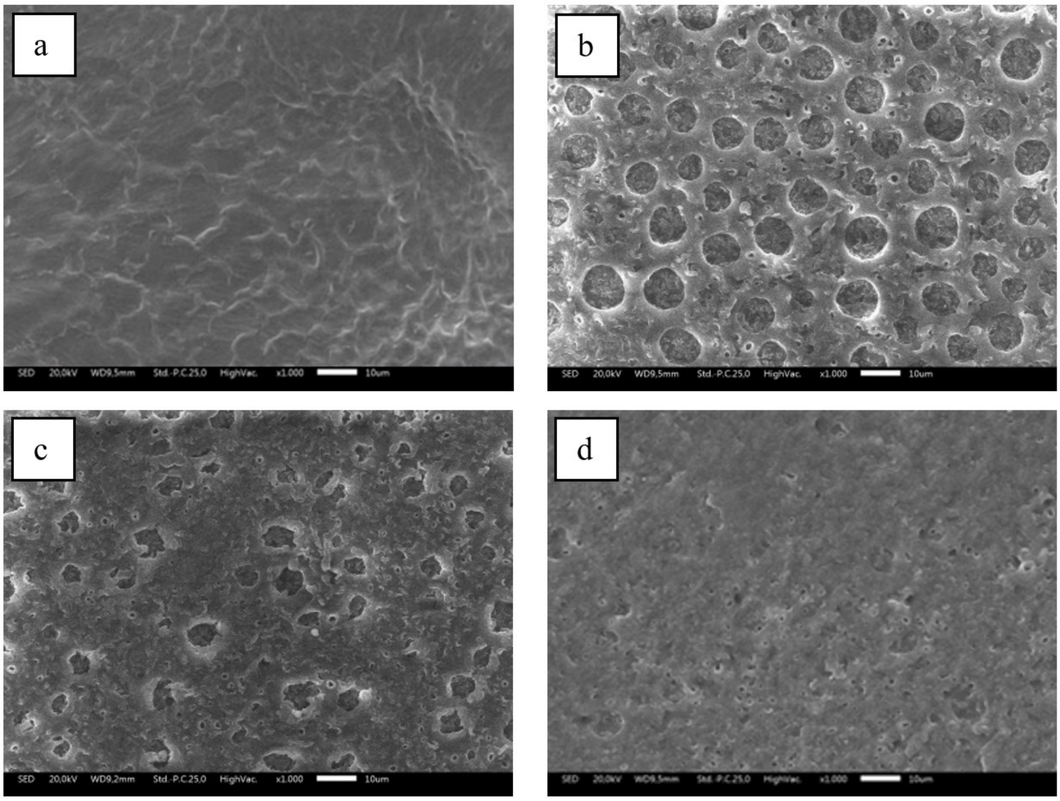

**Figure 12.** Comparison of the results of SEM characterization of PIM membrane (a) before transport, (b) after a lifetime of unsalted transport, (c) after lifetime transport with 0.01 M $Na_2SO_4$ salt, and (d) after lifetime transport with $KNO_3$ salt 0.01 M.

resistance parameter of the PIM membrane to a leak is characterized by an increase in the pH value in the source phase. The pH of the phenol solution in the source phase that rises to close to pH ±9 assumes that the PIM membrane has leaked, so that in that condition the lifetime transport process can be stopped and the length of the transport time is recorded and compared with other lifetime results. The results of the phenol pH measurement in the source phase without salt (control) and with the addition of salt, can be seen in Table 1.

Table 1 shows that on the 47th day the pH of the phenol solution without the addition of salt (control) has reached 9, which means that the membrane has leaked. Lifetime phenol transport with salt addition has a lower source phase pH compared to the pH of the control solution without salt addition. The presence of salt addition in the source phase can increase the lifetime of the membrane and prevent leakage originating from the receiving phase solution. Because the salt in the source phase will experience precipitation due to salting-out, as a result of which membrane leakage can be slowed down so that it can increase the lifetime of the membrane. Meanwhile, in membranes that do not use salt, no deposits are formed so that the membrane pores are not covered by sediment. These pores result in membranes that do not use salts leaking faster and pH in the source phase being more quickly alkaline [37]. These pores are also a factor in increasing the rate of membrane leakage so that the lifetime of the membrane is shorter.

Based on Table 1, membranes containing $KNO_3$ salts have a longer lifetime of 67 days compared to $Na_2SO_4$ salts and in the absence of salt. The longer the transport time, the greater the pH value in the source phase and the longer the transport time will affect the stability and durability of the membrane. This is in accordance with the theory, namely that the membrane is said to be stable if it has a long lifetime and is said to have experienced leakage or instability when the pH in the source phase reaches ±9. The relationship between the pH of the source phase and the age of the membrane is shown in Figure 9. In the source phase without the addition of salts, it can be seen that the pH increase is greater than that of the source phase containing salts, meaning that the addition of these salts in the source phase makes the PIM membrane more stable [32]. The addition of salt in the source phase will also affect the amount of %ML loss because it can reduce the loss of components from the membrane so that it can increase the lifetime of the membrane and the durability of the membrane. The effect of salt addition in the source phase on lifetime on % ML loss value can be seen in Figure 10. Without the addition of salt, more membrane components are lost compared to the addition of salt. Missing membrane components can come from carrier. This increase in membrane lifetime is suspected to be due to a reduction in %ML loss in the membrane, namely the addition of salt in the source phase will reduce the loss of components in the membrane so that the %ML loss becomes small, as a result of which the stability and lifetime of the membrane are increased.

### *3.6. Characterization of PIM Membranes Using FTIR and SEM*

FTIR characterization aims to determine the functional groups contained in the PIM membrane. Meanwhile, the characterization using SEM aims to see the morphology of the PIM membrane before and after transport. To evaluate the structural integrity and stability of the PIM membranes, both FTIR and SEM analyses were conducted before and after the phenol transport process. These characterizations are essential to observe any chemical or morphological changes resulting from membrane usage. FTIR characterization was carried out on PIM membrane before transport, PIM membrane after lifetime transport without the addition of salt, PIM membrane after lifetime transport with the addition of $Na_2SO_4$ salt, and PIM membrane after lifetime transport with the addition of $KNO_3$ salt. The results of FTIR characterization can be seen in Figure 11.

The characterization results show that the PIM membrane containing the 1:1 poly-BADGE carrier before and after transport relatively does not experience wave shift. Figure 11 shows that the PIM membrane after transport still has the same functional group as the PIM membrane before transport. Therefore, characterization can be carried out by paying attention to changes in intensity in the FTIR spectrum obtained. It can be seen that the PIM spectrum after transport has relatively the same absorption as the PIM spectrum before transport but has different intensities. The decrease in intensity in the wavenumber of 3343 $cm^{-1}$, which is a characteristic of the O–H group, indicates a decrease in the O–H group. The complete functional group and intensity can be seen in Table 2.

The wavenumber is the identification of the functional group of the carrier or absorption belonging to the carrier as one of the components that make up the PIM membrane. After the PIM membrane is used for phenol transport, the intensity at this wave number is still visible but with a different intensity. The decrease in intensity in the FTIR results before and after transport showed that there was an active side of the membrane that was missing or leaching. Comparison of the five FTIR spectra shows that the peak of the O–H group decreases on the PIM membrane after transport. Reduced O–H absorption indicates that the O–H group present in the membrane is leaching towards the receptor phase. This indicates that there is an interaction between the carrier and the active side of the membrane during the transport process. Phenol and poly-BADGE 1:1 are two compounds that both have an O–H group so that it is possible to interact in the form of hydrogen bonds between the these groups.

One of the causes of instability in the membrane is the size of the pores that are too wide. The comparison of pores on the PIM membrane before and after phenol transport can be used as a parameter for the success of phenol transport. Figure 11 shows the SEM results between the membrane before transport, after lifetime transport without salt (control) and after lifetime transport with the addition of $Na_2SO_4$ and $KNO_3$ salts at $10^3$ times magnification. Figure 12 shows the morphology of the membrane before transport, it can be seen that the membrane surface is still covered by the plasticizer as the liquid medium. In the surface morphology of the PIM membrane after lifetime transport without salt, wide pores can be seen on the PIM membrane. The PIM membrane after lifetime transport has an uneven surface and there are pores. The pores seen on the surface of the membrane after lifetime transport are caused by the presence of membrane components that are missing (leaching) during the transport process and this can indicate that a leak has occurred so that the pores on the membrane are enlarged and visible if the membrane has leaked.

Figures 12(c) and 12(d) show that, some areas on the membrane surface are covered with sediment particles on the PIM membrane that uses salt in the source phase solution, revealing some of the membrane pores are covered by sediment. This deposition is possible due to the influence of salting -out. As a result, membrane leakage can be slowed down so that it can increase the lifetime of the membrane, while in membranes that do not use salt (Figure 12(b)), it can be seen that the membrane pores are more obvious than in Figures 12(c) and 12 (d). These pores are what result in why membranes without the use of salt leak faster and pH in the source phase is faster alkaline. These pores are also a factor in increasing the rate of membrane leakage so that the lifetime of the membrane is lower.

## 4. CONCLUSIONS

Based on the results of the research that has been carried out, several important conclusions were obtained related to the performance of PIM membranes with 1:1 poly-BADGE carrier in phenol transport. These membranes show good performance in phenol transport processes, with optimal stability achieved at the use of NaCl salt addition in the source phase and receiver phase proven to improve the stability of PIM membranes by reducing the percentage of membrane mass loss. The addition of $KNO_3$ salt during the phenol transport process also has a positive effect on the lifetime of the membrane, which can last up to 67 days, longer than the addition of $Na_2SO_4$ salt or without the addition of salt. These results demonstrate the great potential of PIM membranes with 1:1 poly-BADGE carrier in efficient and sustainable phenol transport applications.

## AUTHOR INFORMATION

### Corresponding Author

**Agung Abadi Kiswandono** — Department of Chemistry, University of Lampung, Bandar Lampung-35145 (Indonesia);
orcid.org/0000-0002-8145-1959
Email: agung.abadi@fmipa.unila.ac.id

### Authors

**Anisa Rahmawati** — Department of Chemistry, University of Lampung, Bandar Lampung-35145 (Indonesia);
orcid.org/0000-0003-2226-9521
**Niswah Fadillah** — Department of Chemistry, University of Lampung, Bandar Lampung-35145 (Indonesia);
orcid.org/0009-0001-1990-315X
**Rinawati Rinawati** — Department of Chemistry, University of Lampung, Bandar Lampung-35145 (Indonesia);
orcid.org/0000-0002-4245-1729
**Pandri Ferdias** — Department of Mathematics, University of Lampung, Bandar Lampung-35145 (Indonesia);
orcid.org/0000-0002-1628-5886
**Herlian Eriska Putra** — Research Center for Environmental and Clean Technology, National Research and Innovation Agency (BRIN), Bandung-40135 (Indonesia);
orcid.org/0000-0001-9659-0938

### Author Contributions

Conceptualization, methodology, investigation, writing–original draft: A. A. K., and N. F. Resources, writing, editing: A. R., H. E. P., and P. F. Review & supervision: R. R.

### Conflicts of Interest

The authors declare no conflict of interest.

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