



## Investigating Phenol Transport Using Copoly(Eugenol–DVB) 8% as a Carrier with the Supported Liquid Membrane Method

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### Abstract

The presence of phenol in water has adverse effects on human health and the environment, as it is a toxic contaminant commonly found in industrial waste. To address this issue, studies were conducted to investigate the transport of phenol using copoly(eugenol–divinyl benzene) (Co-EDVB) 8% as a carrier on polytetrafluoroethylene (PTFE) membranes, employing the Supported Liquid Membrane (SLM) method. Various parameters affecting phenol transport were examined, including the pH of the source phase, concentration in the receiver phase, immersion time, carrier concentration, and transport duration. Co-EDVB 8% was synthesized through copolymerizing eugenol and 8% divinyl benzene, facilitated by the  $\text{BF}_3\text{O}(\text{C}_2\text{H}_5)$  catalyst. The synthesized polymer was characterized using FTIR. The phenol concentration post-transportation was determined spectrophotometrically using a 4-aminoantipyrine reagent, with absorbance measured at  $\lambda = 456 \text{ nm}$ . The findings indicate that under optimal conditions—source phase pH of 5.5, NaOH concentration of 0.1 M, immersion time of 1 hour, carrier concentration of 0.01 M, and a transportation time of 24 hours—the Co-EDVB carrier in the PTFE membrane efficiently transported phenol. Even after 24 hours of the phenol transport process, the percentage of membrane liquid loss (%ML Loss) did not significantly decrease, remaining at 8.35%. This was corroborated by Scanning Electron Microscope (SEM) results and FTIR characterization. In conclusion, the PTFE membrane incorporating 8% Co-EDVB as a carrier exhibits effective phenol transport, achieving a transportation efficiency of 92.10%.

### 1. Introduction

Presently, industrial activities are experiencing rapid growth, resulting in an increased production of industrial waste. Inadequate management of industrial waste can lead to adverse consequences, including environmental pollution, with subsequent implications for human health. The toxic components commonly found in industrial waste predominantly encompass heavy metals and organic compounds. An illustrative instance of a hazardous organic compound originating from industrial waste is phenol [1].

Phenol is categorized as an organic pollutant originating from liquid waste produced by industrial processes, exhibiting a notably high level of toxicity.

Elevated phenol concentrations in water can lead to water pollution, potentially threatening human health [2]. Upon penetration into the human body, phenol has the capability to cause harm to protozoa or blood cells, leading to mobility disorders and contributing to conditions such as brain disorders, venous thrombosis, and neurochemical injuries. Additionally, phenol can induce skin necrosis, and contact with the eyes can result in irritation [3].

The permitted threshold for phenol in industrial wastewater is 500 mg/L, and exceeding this limit complicates the decomposition process [4]. Several methods have been employed to separate and diminish phenol in waste. These approaches include the use of plant biological systems to decrease phenol

concentration in wastewater containing rhodamine B [5], the application of electrocoagulation to reduce phenol levels in wastewater from the songket weaving industry [6], the use of photocatalysis for treating environmental waste in water [1], distillation fractionation in managing pulp industry wastewater [7], and the implementation of the anaerobic activated sludge method for handling pharmaceutical industry waste [8]. Nonetheless, the conventional methods outlined above entail significant costs. Consequently, there is a current focus on developing membrane technology for phenol separation. Membrane technology offers advantages in terms of technical simplicity, minimal energy consumption, and economic considerations [9].

A membrane is a thin layer between two liquid phases. Its function is to act as a barrier against certain species and limit the movement of different species depending on their physical and chemical properties. In other words, membranes play a role in controlling the transfer of substances between two media, maintaining selectivity based on their specific characteristics [10]. The liquid membrane technique can be used as an alternative method for separating phenol because it is susceptible, efficient, and cost-effective. In addition, this technique has a large surface area for mass transfer and allows extraction and stripping to be carried out in just one operation [11]. The liquid membrane method is a combination of liquid-liquid extraction with a reception stage in a continuous process [12, 13, 14].

Selecting the type of membrane to treat liquid phenol waste involves considering various factors, such as the chemical properties of phenol, operational conditions, and waste processing objectives. The liquid membrane was chosen because it has certain characteristics that can effectively overcome the problem of phenol liquid waste pollution. Some advantages of liquid membranes include: (1) liquid membranes can be designed with selective properties towards certain compounds, including phenol, thus enabling the separation of phenol from liquid waste mixtures with a high-efficiency level. (2) phenol tends to be corrosive to several types of materials. Liquid membranes can be designed to resist corrosion caused by phenol, increasing system life and performance. (3) liquid membranes can adapt to variations in waste loads or changing operational conditions. This flexibility increases operational stability and process efficiency. (4) Liquid membranes can be designed to be regenerated, allowing reuse of the membrane after saturation with phenol. This can reduce operational costs and environmental impact. (5) Sometimes, liquid membranes can be designed to produce less waste residue than other waste treatment methods, supporting sustainable principles [11].

One method for treating liquid waste containing phenol is by applying a supported liquid membrane (SLM) [12]. In the SLM method, the organic liquid employed remains immiscible between the source and receiver phases. This technique relies on liquid-liquid distribution under non-equilibrium conditions, wherein organic carrier are housed within a porous polymer membrane. The efficacy of the SLM technique has been substantiated

and is extensively utilized in extracting various aqueous solutions, including metals [15], CO<sub>2</sub> separation from air [16], low acid concentrations [17], and the isolation of phenol from wastewater [18].

The separation of phenol utilizing organic compounds as carrier agents has been explored, including vegetable oil [14], tributyl phosphate [19], and polyorganosiloxane compounds that exhibit reactivity with amine and ether compounds [20]. An alternative carrier derived from natural materials is eugenol. Naturally occurring in clove leaves, eugenol can serve as a viable raw material for synthesizing polyeugenol and its derivatives through cross-linking, owing to the presence of three distinct functional groups: hydroxy, methoxy, and allyl [21].

Enhancing the binding efficiency between the target compound and polyeugenol derivative compounds is achievable through addition polymerization, with vinyl compounds presenting an alternative approach [22]. Divinyl benzene (DVB), a diene compound capable of undergoing addition polymerization, is frequently employed in the plastics industry for cross-linking, material modification processes, and facilitating copolymerization. The reactive double bonds in DVB interact with those in eugenol, instigating copolymerization and consequently elevating the molecular weight of the resultant polymer [23].

Therefore, this study investigates the transport of phenol utilizing the copoly (eugenol-divinyl benzene) 8% as a carrier, employing a porous polymer membrane made of polytetrafluoroethylene (PTFE) through SLM method. Utilizing the Co-EDVB carrier is anticipated to enhance the selectivity and efficiency of phenol transport. The primary focus of this research is the application of the Co-EDVB carrier within the SLM method for treating liquid waste containing phenol. The distinctive aspect of this study lies in implementing the Co-EDVB carrier, which has the potential to elevate both the selectivity and efficiency of phenol transport. This research significantly contributes to advancing our comprehension of the prospective application of Co-EDVB carrier in phenol processing through the SLM method, presenting new opportunities and potential improvements over previous studies that utilized SLM for similar purposes [24].

## 2. Experimental

### 2.1. Tools and Materials

The phenol transport process was conducted using a set of transport devices comprising two identical compartments, each with a capacity of 50 mL, positioned on either side of the SLM membrane. The pH of both the source and receiver phases was determined using a benchtop pH meter, specifically the Orion Star™ A211 by ThermoFisher Scientific™ (Benchtop pH Meter, Ottawa, ON, Canada). The quantification of phenol in the source and receiver phases was performed using a UV-Vis Spectrophotometer 772 from Shanghai, China.

Analytical grade materials from the supplier Merck, without additional purification, were utilized in this research. These materials include phenol (C<sub>6</sub>H<sub>5</sub>OH) for

preparing phenol solutions, potassium hexacyanoferrate (II) trihydrate  $K_4[Fe(CN)_6] \cdot 3H_2O$ , sodium hydroxide (NaOH), hydrochloric acid (HCl), 4-amino antipyrine, ammonium hydroxide ( $NH_4OH$ ), and phosphate buffer ( $K_2HPO_4$ ,  $KH_2PO_4$ ). Copoly(eugenol–divinyl benzene) 8% was used as a carrier, and aquabides were used to prepare all solutions. A polytetrafluoroethylene (PTFE) membrane, with a 47 mm diameter and a pore size of 0.5  $\mu m$ , served as the SLM membrane. The solvent used for preparing the SLM membrane and carrier was chloroform ( $CHCl_3$ ) from Merck.

## 2.2. Procedures

The research encompassed three principal stages: the fabrication of Supported Liquid Membrane (SLM) membranes, the transport of phenol utilizing SLM membranes, and the characterization of the SLM membranes. The impact of carrier concentration and immersion time of the SLM membrane in the carrier solution was conducted to enhance the stability of the SLM.

The SLM membrane was characterized using FTIR (Fourier Transform Infrared; Agilent Technology; Santa Clara, California, USA) type Cary 630 and SEM (Scanning Electron Microscope) (JSM-6360LA, Tokyo, Japan). In this research, the author opted not to perform the FTIR and SEM characterization of the SLM membrane directly. Instead, an alternative approach was chosen, utilizing laboratory services provided by the UPT Integrated Laboratory and Technology Innovation Center – Universitas Lampung. This decision was made to ensure a thorough analysis of the membrane's properties.

### 2.2.1. SLM Membrane Immersion

The polytetrafluoroethylene (PTFE) membrane, with a 47 mm diameter, served as the polymer membrane support for preparing the SLM. Each membrane pore possessed a size of 0.5 microns, and the effective surface area of the membrane in contact with the source and receiver phases was 4.91  $cm^2$ . The supporting polymer was initially immersed in distilled water for two hours and subsequently dried with paper towels to initiate SLM membrane preparation. This process induced membrane swelling, enlarging the pores and facilitating the entry and occupation of the carrier, thereby aiding in the penetration of the carrier.

The preparation of the eugenol–DVB copoly, employed as a carrier in SLM membrane preparation, followed the method by Kiswandono *et al.* [25] [26]. The polymer support was soaked in a 10 mL chloroform solution containing copoly(eugenol–DVB) 8% with a concentration of 0.01 M for one hour. The membrane was removed from the solution and allowed to dry naturally for approximately 10 minutes. The resulting membrane, a Supported Liquid Membrane (SLM), comprised a polymer support with the carrier contained within its pores. SEM and FTIR characterization techniques were employed to further assess the initial properties of the SLM membrane both before and after phenol transport.

### 2.2.2. Optimization of Phenol Transport

The transport experiments were conducted within a transport cell featuring an effective surface area of 4.91  $cm^2$ , comprising two identical compartments, each holding 50 mL of the source or receiver phase, with the SLM membrane acting as a separator. Throughout the nine-hour experiment at room temperature, continuous stirring of the source and receiver phases was maintained using a magnetic stirrer. Following the methodology outlined in previous studies [27, 28], phenol concentration in both the source and receiver phases was measured at predetermined time intervals through a UV-Vis spectrophotometer, with readings taken at the maximum wavelength of 456 nm.

The determination of the maximum wavelength of phenol in this study relied on the UV-Vis spectrophotometry method. Following the mixing of phenol with a solution of 4-aminoantipyrine and potassium ferricyanide, a complex compound was formed, exhibiting maximum absorbance at a specific wavelength. Subsequently, the phenol solution was extracted using chloroform, and the absorbance of the chloroform solution extract was measured with a UV-Vis spectrophotometer within the wavelength range of 370–600 nm. The wavelength at which the absorbance reached its peak value was identified as the maximum wavelength of phenol. This method allows for the measurement of absorbance at various wavelengths, enabling the determination of the point where phenol exhibits the highest absorbance, indicative of its maximum wavelength (National Standardization Agency SNI 06-6989.21-2004).

Various variables influencing phenol transport through SLM membranes were systematically investigated to determine optimal conditions. The variables considered encompassed the pH of the source phase, the concentration of NaOH in the receiving phase, the immersion time of the SLM membrane, the concentration of the carrier, and the duration of the transport process. The pH was adjusted to 3.5, 4.5, 5.5, 6.5, and 7.5 to assess the impact of phenol pH on the source phase during transport. Meanwhile, the concentration of NaOH in the receiving phase was maintained at a constant 0.1 M. The effect of NaOH concentration in the receiving phase was studied by varying it between 0.01, 0.05, 0.1, 0.25, and 0.5 M, with the phenol pH in the source phase set at the optimum level.

The immersion time of the SLM membrane was explored by varying it for 0, 30, 60, and 90 minutes in a chloroform solution containing copoly(eugenol–DVB) 8% as the carrier. The resulting SLM membrane's capacity to transport phenol under optimum conditions was evaluated for each immersion time. The effect of carrier concentration was examined by altering its concentration in chloroform at 0, 0.005, 0.01, 0.015, and 0.020 M. The resulting SLM's ability to transport phenol under optimum conditions for each concentration of the carrier was also assessed.

The source and receiver phases were stirred continuously for 9 hours to facilitate phenol transport.

The optimum transport time was obtained by setting and varying the transport time at 3, 6, 9, 12, 15, 18, 21, 24 and 27 hours. A UV-Vis spectrophotometer set at a maximum wavelength of 456 nm was used to measure the phenol concentration in the source and receiver phases.

### 3. Results and Discussion

#### 3.1. Phenol Transport Optimization

##### 3.1.1. Effect of Phenol pH on the Source Phase

Determining the optimum pH of phenol in the source phase plays a crucial role in enhancing the efficiency of the phenol transport process. One of the main reasons is the influence of phenol activity in the system. Identifying optimal pH conditions involves pinpointing the point at which phenol achieves peak activity or optimal chemical stability, thereby improving the overall efficiency of phenol transport. Moreover, pH significantly influences the sustainability of chemical reactions during the phenol transport process. Determining the optimum pH guides reaction conditions, ensuring the process' continuity with high efficiency.

Another critical consideration is the selectivity of the membrane or liquid membrane employed. Early pH adjustment facilitates the selection or adjustment of membrane conditions to enhance selectivity towards phenol. Furthermore, determining the optimum pH offers preventive advantages against potential environmental pollution resulting from uncontrolled phenol during transport. Finally, optimal pH determination aids in managing or controlling the formation of related compounds or byproducts with varying stability or properties at a specific pH. In summary, establishing the optimum pH in the source phase provides a solid foundation for initiating the phenol transport process under optimal conditions, ultimately elevating the efficiency and success of the entire process.

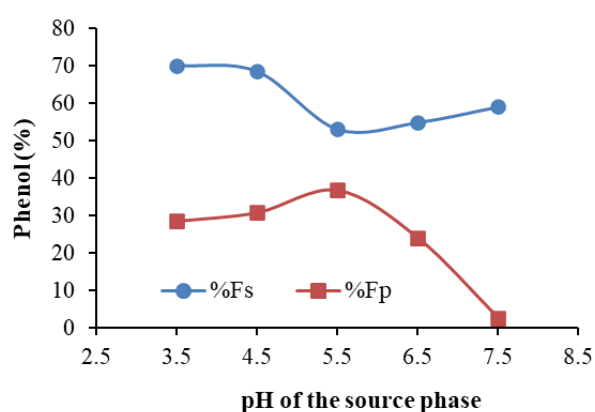


Figure 1. Effect of phenol pH on the percentage of phenol transported

The results of research regarding the effect of phenol pH in the source phase on phenol transport can be seen in Figure 1, which shows the relationship between the percentage of phenol concentration in the source phase (%Fs) and the percentage of phenol concentration in the receiving phase (%Fp).

The graphical representation shows that the optimal phenol transport occurs at pH 5.5, with a transported phenol concentration of 22 ppm, equivalent to 36.82%. This phenomenon can be attributed to the molecular form of phenol at this pH, enhancing its solubility in the organic phase. Consequently, there is an augmentation of  $\pi$ - $\pi$  interactions and hydrogen bonds between phenol and the carrier in the membrane phase. This molecular state at pH 5.5 contributes to an accelerated phenol transport rate [29].

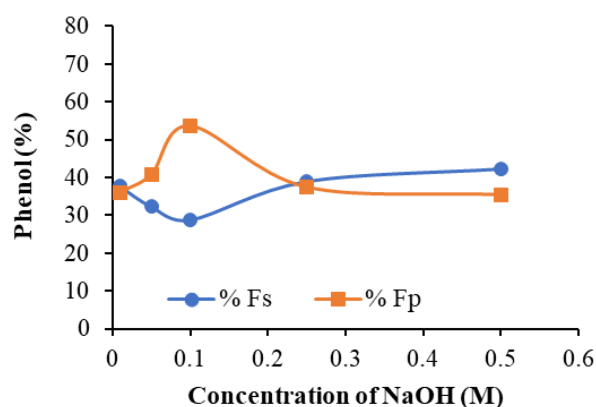
For source phase pH values below 5.5, specifically at 3.5 and 4.5, the transported phenol concentrations are notably lower at 28.56% and 30.87%, respectively. This reduction in transported phenol concentrations is attributed to the heightened acidity levels. In environments with increased acidity, a greater abundance of free protons is prone to being transported towards the alkaline receiving phase. These free protons can also protonate the membrane, creating a barrier that hinders effective interaction between phenol molecules and carrier molecules. As a result, the transport of phenol becomes inefficient under these conditions.

The pH of the phenol in the source phase plays a crucial role in influencing phenol extraction. The efficiency of phenol transport experiences a notable decrease as the pH of the source phase increases. As illustrated in Figure 1, there is a decline in the yield of phenol transport from 36.82% at pH 5.5 to 24.11% at pH 6.5, with further decreases at pH 7.5 (2.82%). This decrease can be attributed to the elevated alkalinity level of the source phase pH. As the pH increases, the phenol tends to dissociate into phenolic ions, making it more prone to dissolution in water. Consequently, the interaction between the -OH group in phenol and copoly(eugenol-DVB) 8% is reduced, leading to decreased phenol transport efficiency [30].

In a pH below 7, phenol remains neutral, facilitating the extraction process [29, 31, 32]. The ease of separating phenol from the source phase into the organic phase, up to a pH of less than 8, is contingent upon the acidity level. However, exceeding pH 8, extraction efficiency decreases due to the heightened dissociation of phenol into phenolate ions. Within a pH range exceeding 8, the phenolic concentration in the solution experiences an increase. This relationship is inversely proportional to the phenolic concentration, which decreases when the pH surpasses 8 [30].

##### 3.1.2. Effect of NaOH Concentration on the Receiving Phase

Phenol undergoes diffusion through the membrane phase and subsequently permeates the receiving phase, where it reacts with NaOH to transform into sodium phenolate. The employed phenol concentration is 60 ppm, and the source phase operates at the optimum pH, while the receiving phase contains dilute NaOH. This configuration ensures the conversion of phenol to phenolate, retaining it in the receiving phase to prevent diffusion back into the membrane phase.



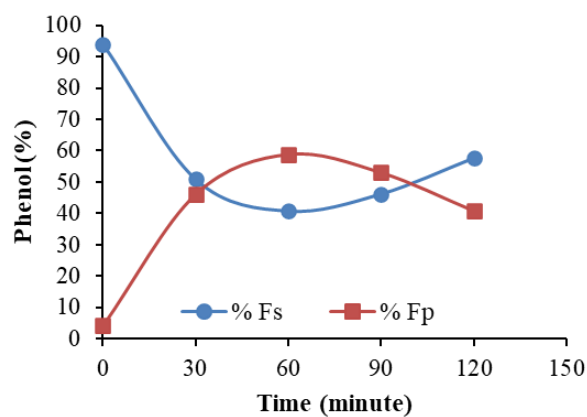
**Figure 2.** Effect of NaOH concentration on the percentage of phenol transported

It is important to note that sodium phenolate formed in the receiving phase does not revert to the membrane phase, as it is insoluble in the membrane phase [33]. Figure 2 illustrates the results obtained from the phenol transport process. The findings indicate that the phenol transported concentration increases with higher NaOH concentrations. The optimal concentration for phenol transport is determined to be 0.1 M, resulting in a transported phenol concentration of 32.15 ppm, equivalent to 53.58%. This enhancement in the transported phenol concentration from 0.01 M to 0.1 M is attributed to the elevated NaOH concentration. The higher concentration of NaOH accelerates the release of phenolic ions at the membrane interface, facilitating a more rapid conversion of phenol into phenolic ions [34].

The heightened permeation of phenol molecules within the 0.01–0.1 M NaOH concentration range can be attributed to the increased diffusion of the SLM due to enhanced complexing at the membrane interface. Consequently, when the NaOH concentration surpasses 0.1 M, the concentration of free phenol molecules at the interface of the receiving phase membrane becomes nearly negligible. The receiving phase solution predominantly contains phenolate ions. This shift results in a reduction of phenol molecules transported to the receiving phase [35]. Furthermore, an increase in NaOH concentration leads to the dissolution of active sites in the membrane phase into the receiving phase. Consequently, the limited availability of active sites in the receiving phase contributes to a reduction in phenol transport [36].

### 3.1.3. Influence of Immersion Time on the SLM Membrane

Transport studies of phenol were conducted on SLM membranes, varying immersion times under optimal pH and NaOH concentrations. Figure 3 illustrates the research findings pertaining to the impact of prolonged immersion times on phenol transport in SLM membranes.



**Figure 3.** Effect of SLM membrane immersion time on the percentage of phenol transported

The results of phenol transport are depicted in Figure 3, specifically highlighting the relationship between %Fs (percentage of phenol transported through the SLM membrane) and %Fp (percentage of phenol present in the permeate). Optimal conditions for phenol transport were observed at a soaking time of 60 minutes, yielding 35.26 ppm or 58.76%. The figure illustrates that the phenol transport process produces smaller results for immersion periods of less than 60 minutes. This can be attributed to the incomplete filling of SLM membrane pores with carrier, particularly evident at 0 minutes of immersion (without carrier compounds), where transported phenol reaches 2.48 ppm, equivalent to 4.14%. This underscores the challenge of phenol transport without interactions with carrier, hindering its efficient transfer to the receiving phase.

### 3.1.4. Effect of Carrier Concentration

Phenol transport with varying concentrations of carrier was carried out under optimum pH conditions, NaOH concentration, and immersion time. The results can be seen in Figure 4. The optimal phenol transport at 35.58 ppm was achieved at a carrier concentration of 0.01 M, equivalent to 59.29%. The concentration of carrier in the membrane phase plays a crucial role in influencing the amount of phenol transported. Elevating the concentration of carrier in the membrane phase will enhance the availability and formation of complex phenol species. This, in turn, facilitates phenol extraction into the receiving phase, thereby augmenting the overall phenol transport [19].

Phenol transport using an SLM membrane without a carrier compound yielded a transport percentage of 4.14%. This outcome suggests that, in the absence of a carrier on the SLM membrane, only a minimal amount of phenol was extracted due to the lack of  $\pi$ - $\pi$  interactions and hydrogen bonds between phenol and the compound. The carriers integrated into the membrane play a vital role in facilitating the transport process. In contrast, at a carrier concentration of 0.01 M, phenol transport exhibited an increase.

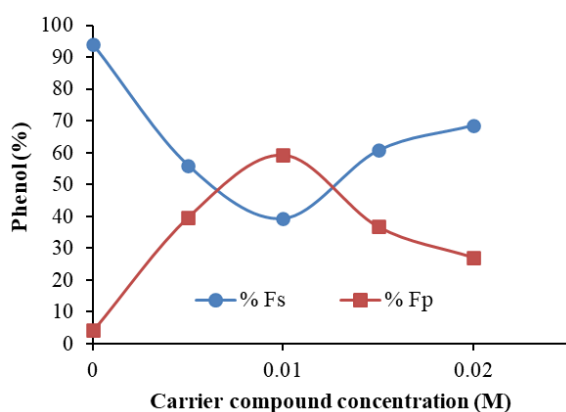


Figure 4. Effect of carrier concentration on the percentage of phenol transported

This elevation is attributed to the heightened benzene ring concentration, resulting in increased hydrogen bonds and interactions formed between phenol and copoly(eugenol-DVB) 8%. Consequently, a greater number of phenol complexes were formed in the membrane phase, leading to an enhanced phenol transport [36, 37, 38]. Nevertheless, at higher concentrations of the carrier, specifically at 0.02 M and 0.025 M, there was a decrease in phenol transport into the receiving phase. This decline can be attributed to the heightened viscosity of the organic solution in the membrane phase resulting from an increased concentration of copoly(eugenol-DVB) 8%. This elevation in viscosity contributes to an augmented resistance of the liquid membrane, impeding the diffusion of phenol complexes.

Consequently, the effective diffusivity of this species experiences a significant decrease, wherein the heightened concentration of copoly(eugenol-DVB) 8% fails to compensate for the concurrent increase in solution viscosity [38]. Additionally, the reduction in phenol transport may also be attributed to the consistent immersion time for carrier with varying concentrations, which may not adequately fill the membrane pore facilities. As a result, the efficacy of phenol extraction diminishes.

### 3.1.5. Effect of Phenol Transport Time

Time is an essential variable in phenol transport. The capacity and ability of the membrane to extract phenol are also determined by the length of transport time. Good membrane performance is indicated by a short transport time with decreasing phenol concentration in the source

Table 1. Comparison of functional groups of copoly(eugenol-DVB) 8% as a carrier, SLM membrane before and after transport phenol

Copoly (Eugenol-DVB) 8%	Wavenumber		Functional groups
	Membrane before transport	Membrane after transport	
797.7	752.9	805.1	Substituted aromatics
1028.7	1028.7	969.1	Stretching ether group (-COC-)
1595.3	1595.3	1595.3	Stretching aromatic C=C group
2929.7	2922.2	2914.8	Stretching Csp <sup>3</sup> -H
3503.7	3436.6	3503.7	Stretching-OH group

phase accompanied by increasing phenol in the receiving phase [39]. The phenol transport results obtained can be seen in Figure 5.

In Figure 5, the optimum transport time is 24 hours with a transported phenol concentration of 55.26 ppm, equivalent to 92.10%. A notable trend observed in Figure 5 indicates a continuous decrease in the percentage of phenol transferred (%Fs) with prolonged transport time. Concurrently, the percentage of phenol present in the receiving phase (%Fp) demonstrates an increase. This phenomenon can be attributed to the prolonged contact between phenol and the carrier as the transport time extends. Consequently, the extended contact duration accelerates the release of phenol ions into the receiving phase, contributing to the observed increase in %Fp [36].

In a prior investigation by Muktiarti [40] employing the PIM method with copoly(eugenol-DVB) 8% as a carrier, the transportation efficiency of phenol reached 70.2% over a 72-hour period. In contrast, in the current study utilizing the SLM method, phenol exhibited a transport efficiency of 92% within a significantly shorter duration of 24 hours. This discrepancy suggests that the SLM method proves to be more effective for phenol transport when employing copoly(eugenol-DVB) 8% as a carrier.

## 3.2. SLM Membrane Characterization

### 3.2.1. Fourier Transform Infrared Spectroscopy (FTIR)

FTIR characterization aims to determine the functional groups contained in the SLM membrane before and after transport phenol. The results of FTIR characterization can be seen in Figure 6.

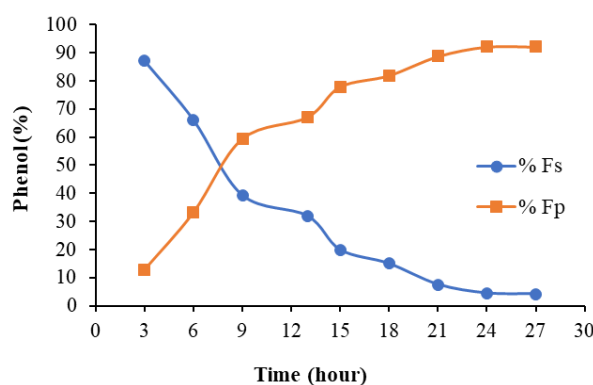
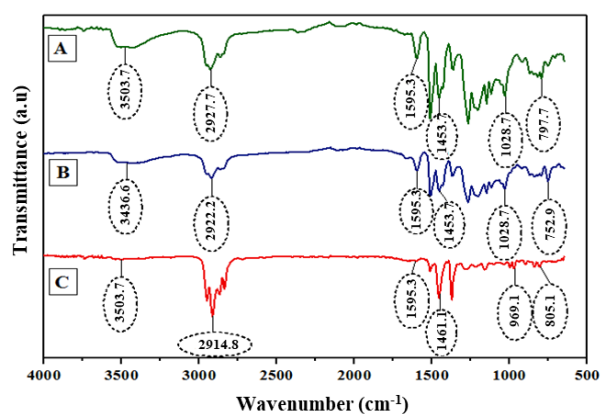


Figure 5. Effect of transport time on the percentage of phenol transported



**Figure 6.** Comparison of FTIR spectra of (A) copoly(eugenol-DVB) 8% as a carrier, (B) SLM membrane before transport, and (C) SLM membrane after transport phenol

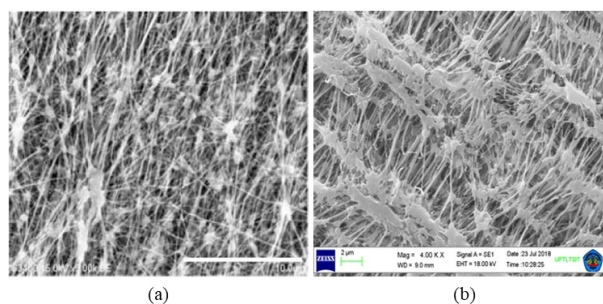
From Figure 6, it can be seen that the carrier copoly(eugenol-DVB) 8% has successfully entered the membrane pores. This can be seen from the comparison of spectra (a) and (b), which have relatively the same spectral shape. The wavenumbers recorded in the spectra resulting from FTIR characterization identify the functional groups of the carrier or the absorption of the carrier as one of the components that make up the membrane. Infrared spectroscopy records the presence of identical groups in the polymer, resulting in spectra that primarily differ in peak intensity (area) and wavelength shift (Table 1).

After utilizing the membrane for phenol transport, the intensity at the specified wave number remains perceptible, albeit at a reduced level. In Figure 6(c), the spectrum displays a similar absorption band as observed in Figure 6(b), yet with a distinct intensity. The diminished intensity at the wavenumber  $3503.7\text{ cm}^{-1}$ , indicative of the  $-\text{OH}$  group, suggests a reduction in the presence of this group. This reduction signifies an interaction between the active site and the carrier on the membrane during the transport process. Since phenol and the carrier possess an  $-\text{OH}$  group, their interactions may form hydrogen bonds within the  $-\text{OH}$  group.

Moreover, the intensity decrease of the  $-\text{OH}$  group can also be attributed to the partial loss of active sites in copoly(eugenol-DVB) 8% during the transport process. Consequently, the  $-\text{OH}$  peak on the membrane becomes nearly imperceptible. The loss of some active sites on the membrane post-transport is further evident in the SEM characterization results of the PTFE membrane (Figure 7).

### 3.2.2. Scanning Electron Microscopy (SEM)

The SLM membrane that had been used under optimum conditions was characterized using SEM, aiming to see the morphology of the membrane before and after transport. A comparative analysis was performed between the membrane after transport phenol, which retained carrier, and the SLM membrane before transport, guided by the precedent set in the research conducted by Nittami *et al.* [41].



**Figure 7.** SEM images of SLM membrane (a) before and (b) after transport phenol

The SEM characterization outcomes are illustrated in Figure 7, shedding light on the structural changes and morphology of the membrane at different stages of the experimental process. In Figure 7, the SLM membrane exhibits elongated nodes interconnected by network fibers resembling a spider web. A noticeable difference is observed between the SLM membrane before and after transport phenol specifically, there is a thickening and an enlargement of the connecting fibers and their surface. This alteration suggests that the aquabides and chloroform solvent containing the copoly(eugenol-DVB) 8% as a carrier effectively wet the membrane surface, leading to membrane swelling. Figure 7(b) further demonstrates that, despite the membrane's use in phenol transport, the connecting fibers remain swollen, indicating the successful entry of the copoly(eugenol-DVB) 8% as a carrier into the membrane pores before transport. Post-transport, the carrier persists within the membrane pores, albeit in relatively diminished amounts.

## 4. Conclusion

The efficacy of the SLM membrane, incorporating a PTFE-supporting polymer and the copoly(eugenol-DVB) 8% as a carrier, has been successfully demonstrated for the transport of phenol using the SLM method. Optimal conditions for the PTFE membrane in phenol transport were determined at a phenol pH of 5.5, a stripping concentration of 0.1 M, a membrane immersion time of 1 hour, a carrier concentration of 0.01 M, and a transport duration of 24 hours. Notably, the copoly(eugenol-DVB) 8% as a carrier within the membrane phase exhibited the capability to transport 92% of phenol under these optimum conditions.

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## References

- [1] Slamet Slamet, R. Arbianti, Daryanto Daryanto, Simultaneous Treatment of Organic (Phenol) and Heavy Metal ( $\text{Cr}^{6+}$  or  $\text{Pt}^{4+}$ ) Wastes over  $\text{TiO}_2$ ,  $\text{ZnO-TiO}_2$  and  $\text{CdS-TiO}_2$  Photocatalysts, *Makara Journal of Technology*, 9, 2, (2005), 66–71 <https://doi.org/10.7454/mst.v9i2.363>

- [2] Mamay Maslahat, Mediagmi Paramitha, Supriyono Eko Wardoyo, Modification of palm oil empty fruit bunches biosorbent using egg shells for phenol sorption, *Journal of Lignocellulose Technology*, 1, 1, (2017), 43–50
- [3] Amardi Suprasetyo, Pirim Setiarso, Penentuan Kadar Fenol pada Air Sungai Secara *Cyclic Stripping Voltammetry* dengan Menggunakan Elektroda Pasta Karbon Termodifikasi Zeolit, *Prosiding Seminar Kimia dan Pembelajarannya*, Surabaya, 2016
- [4] George Tchobanoglous, Franklin L. Burton, H. David Stensel, *Wastewater engineering: treatment and reuse*, Metcalf & Eddy Inc., New York, 2004,
- [5] Sri Dian Meita Sari, Wayan Budiarsa Suyasa, I Gede Mahardika, Pemanfaatan Biosistem Tanaman Untuk Menurunkan Kadar Fenol, Amonia, Ion Klorida, dan COD dari Proses Biodegradasi Air Limbah yang Mengandung Rhodamin B, *ECOTROPHIC: Jurnal Ilmu Lingkungan (Journal of Environmental Science)*, 10, 1, (2016), 1–8  
<https://doi.org/10.24843/EJES.2016.v10.i01.p01>
- [6] Atikah Atikah, Penurunan Kadar Fenol dalam Limbah Cair Industri Tenun Songket dengan Proses Elektrokoagulasi, *Jurnal Redoks*, 1, 2, (2018), 6–15  
<https://doi.org/10.31851/redoks.v1i2.2024>
- [7] R. Sudradjat, Aldi P. Johor Ning, Pemisahan Senyawa Fenol dari Limbah Cair Industri Pulp (*Black Liquor*) dengan Cara Fraksinasi - Distilasi, *Jurnal Penelitian Hasil Hutan*, 11, 1, (1993), 12–20
- [8] Sukma Budi Ariyani, Decreased Levels of Fenol in the Case of Traditional Herb Industry Using Anaerobic Activated Sludge Method, *Biopropal Industri*, 2, 2, (2011),
- [9] Abdelaziz Gherrou, Hacène Kerdjoudj, Raffaele Molinari, Enrico Drioli, Modelization of the transport of silver and copper in acidic thiourea medium through a supported liquid membrane, *Desalination*, 139, 1, (2001), 317–325  
[https://doi.org/10.1016/S0011-9164\(01\)00325-3](https://doi.org/10.1016/S0011-9164(01)00325-3)
- [10] Heru Pratomo, Pembuatan dan Karakterisasi Membran Komposit Polisulfon Selulosa Asetat Untuk Proses Ultrafiltrasi, *Jurnal Pendidikan Matematika dan Sains*, 3, (2003), 168–173
- [11] F. Valenzuela, C. Salinas, C. Basualto, J Sapag-Hagar, C. Tapia, Influence of Nonionic Surfactant Compound on Coupled Transport of Copper (II) Through a Liquid Membrane, *Journal of the Chilean Chemical Society*, 48, (2003), 79–84  
<http://dx.doi.org/10.4067/S0717-97072003000100014>
- [12] N. M. Kocherginsky, Qian Yang, Lalitha Seelam, Recent advances in supported liquid membrane technology, *Separation and Purification Technology*, 53, 2, (2007), 171–177  
<https://doi.org/10.1016/j.seppur.2006.06.022>
- [13] X. J. Yang, A. G. Fane, K. Soldenhoff, Comparison of Liquid Membrane Processes for Metal Separations: Permeability, Stability, and Selectivity, *Industrial & Engineering Chemistry Research*, 42, 2, (2003), 392–403  
<https://doi.org/10.1021/ie011044z>
- [14] P. Venkateswaran, K. Palanivelu, Recovery of phenol from aqueous solution by supported liquid membrane using vegetable oils as liquid membrane, *Journal of Hazardous Materials*, 131, 1, (2006), 146–152  
<https://doi.org/10.1016/j.jhazmat.2005.09.025>
- [15] R. Anupama, K. Palanivelu, Removal and recovery of lead from aqueous solution using supported liquid membrane, *Indian Journal of Chemical Technology*, 12, (2005), 436–440
- [16] Jinlong Li, Tingting Zhao, Guozhe Sui, Shuaiqiang Jia, CO<sub>2</sub> separation from air using microporous polyvinylidene fluoride-supported triethylene glycol/alkanolamine liquid membranes, *Materials Express*, 6, 2, (2016), 183–190  
<https://doi.org/10.1166/mex.2016.1291>
- [17] Janani Narayanan, K. Palanivelu, Recovery of acetic acid by supported liquid membrane using vegetable oils as liquid membrane, *Indian Journal of Chemical Technology*, 15, (2008), 266–270
- [18] Norasikin Othman, Ling Chui Heng, Norul Fatiha Mohamed Noah, Ooi Zing Yi, Norela Jusoh, Nur Alina Nasruddin, Noraâ€™aini Ali, Sofiah Hamzah, Removal of Phenol from Wastewater by Supported Liquid Membrane Process, *Jurnal Teknologi*, 74, 7, (2015), 10.11113/jt.v74.4709
- [19] Chiraz Zidi, Rafik Tayeb, Mourad Ben Sik Ali, Mahmoud Dhahbi, Liquid–liquid extraction and transport across supported liquid membrane of phenol using tributyl phosphate, *Journal of Membrane Science*, 360, 1–2, (2010), 334–340  
<https://doi.org/10.1016/j.memsci.2010.05.027>
- [20] A. M. Y. Jaber, S. A. Ali, G. O. Yahaya, Studies on phenol permeation through supported liquid membranes containing functionalized polyorganosiloxanes, *Journal of Membrane Science*, 250, 1, (2005), 85–94  
<https://doi.org/10.1016/j.memsci.2004.10.019>
- [21] Sangayu Mustikarini, Sintesis ionofor 5' -kloro-2, 4, 2'-trihidroksiazobenzena dan studi impregnasi resin kopoli (eugenol-dvb) dengan ionofor, Kimia, Universitas Sebelas Maret, Surakarta, 2007
- [22] Malcolm P. Stevens, *Kimia Polimer*, Dua ed., Pradnya Paramita, Jakarta, 2001,
- [23] Desi Suci Handayani, Triana Kusumaningsih, Maria Yuli, Sintesis kopoli (eugenol-DVB) sulfonat dari eugenol komponen utama minyak cengkeh (*Syzygium aromaticum*), *Biofarmasi*, 2, 2, (2004), 53–57
- [24] Yingjie Qin, Joaquim M. S. Cabral, Comparison between supported gas membrane process and supported liquid membrane process for the separation of NH<sub>3</sub> from aqueous media containing NH<sub>3</sub> and CO<sub>2</sub>, *Journal of Chemical Technology & Biotechnology*, 67, 4, (1996), 323–328
- [25] Agung Abadi Kiswandono, Mudasir, D. Siswanta, Nurul Hidayat Aprilita, Sri Juari Santosa, Sutopo Hadi, Synthesis and characterization of co-edaf and its application test as a carrier membrane for phenol transport using polymer inclusion membrane (PIM), *Research Journal of Chemistry and Environment*, 23, 5, (2019), 1–9
- [26] Agung Abadi Kiswandono, Dwi Siswanta, Nurul Hidayat Aprilita, Sri Juari Santosa, Transport of Phenol Through Inclusion Polymer Membrane (PIM) Using Copoly(Eugenol-Dvb) as Membrane Carriers, *Indonesian Journal of Chemistry*, 12, 2, (2012), 8  
<https://doi.org/10.22146/ijc.21348>



- [27] Jian-Mei Li, Xiang-Guang Meng, Chang-Wei Hu, Juan Du, Adsorption of phenol, p-chlorophenol and p-nitrophenol onto functional chitosan, *Bioresource Technology*, 100, 3, (2009), 1168–1173  
<https://doi.org/10.1016/j.biortech.2008.09.015>
- [28] Ana R. Sousa, Maria A. Trancoso, Validation of an environmental friendly segmented flow method for the determination of phenol index in waters as alternative to the conventional one, *Talanta*, 79, 3, (2009), 796–803  
<https://doi.org/10.1016/j.talanta.2009.05.009>
- [29] Jing Fan, Yunchang Fan, Yuanchao Pei, Kun Wu, Jianji Wang, Maohong Fan, Solvent extraction of selected endocrine-disrupting phenols using ionic liquids, *Separation and Purification Technology*, 61, 3, (2008), 324–331  
<https://doi.org/10.1016/j.seppur.2007.11.005>
- [30] M. Teresa A. Reis, Ondina M. F. de Freitas, M. Rosinda C. Ismael, Jorge M. R. Carvalho, Recovery of phenol from aqueous solutions using liquid membranes with Cyanex 923, *Journal of Membrane Science*, 305, 1, (2007), 313–324  
<https://doi.org/10.1016/j.memsci.2007.08.016>
- [31] Yonggyun Park, A. H. P. Skelland, Larry J. Forney, Jae-Hong Kim, Removal of phenol and substituted phenols by newly developed emulsion liquid membrane process, *Water Research*, 40, 9, (2006), 1763–1772  
<https://doi.org/10.1016/j.watres.2006.03.005>
- [32] Colin F. Poole, Salwa K. Poole, Extraction of organic compounds with room temperature ionic liquids, *Journal of Chromatography A*, 1217, 16, (2010), 2268–2286  
<https://doi.org/10.1016/j.chroma.2009.09.011>
- [33] Xiangjun Yang, Hengpan Duan, Deqiang Shi, Ruisi Yang, Shixiong Wang, Hong Guo, Facilitated transport of phenol through supported liquid membrane containing bis(2-ethylhexyl) sulfoxide (BESO) as the carrier, *Chemical Engineering and Processing: Process Intensification*, 93, (2015), 79–86  
<https://doi.org/10.1016/j.cep.2015.05.003>
- [34] Ratih Purwasih, Studi Transpor Fenol Menggunakan Polymer Inclusion Membrane (PIM) dengan Molekul Pembawa Kopoli (Eugenol-Dialil Ftalat); Study of Phenol Transport Using Polymer Inclusion Membrane (PIM) with Poly(Eugenol-Co-Diallyl Phthalate) as Carrier Molecules, Universitas Gadjah Mada, 2013
- [35] F. F. Zha, A. G. Fane, C. J. D. Fell, Phenol Removal by Supported Liquid Membranes, *Separation Science and Technology*, 29, 17, (1994), 2317–2343  
<https://doi.org/10.1080/01496399408003181>
- [36] Agung Abadi Kiswandono, Dwi Siswanta, Nurul Aprilita Hidayat, Sri Santosa Juari, Takashi Hayashita, The Capability of Copoly(Eugenol-Divinylbenzene) as a Carrier For Phenol Transport with Polymer Inclusion Membrane (PIM), *Journal of Environmentally Friendly Processes*, 2, 2, (2014), 57–68  
<http://dx.doi.org/10.13140/RG.2.1.1857.0961>
- [37] Kabita Chakrabarty, Prabirkumar Saha, Alope Kumar Ghoshal, Separation of mercury from its aqueous solution through supported liquid membrane using environmentally benign diluent, *Journal of Membrane Science*, 350, 1, (2010), 395–401  
<https://doi.org/10.1016/j.memsci.2010.01.016>
- [38] P. Venkateswaran, A. Navaneetha Gopalakrishnan, K. Palanivelu, Di(2-ethylhexyl)phosphoric acid-coconut oil supported liquid membrane for the separation of copper ions from copper plating wastewater, *Journal of Environmental Sciences*, 19, 12, (2007), 1446–1453  
[https://doi.org/10.1016/S1001-0742\(07\)60236-8](https://doi.org/10.1016/S1001-0742(07)60236-8)
- [39] Ayu Hindayani, Recovery Fenol Menggunakan Polimer Polieugenol Tersambung Silang Bisphenol A Diglycidyl Ether (Badge) Sebagai Carrier dalam Membran Cair Berpendukung (Supported Liquid Membranes, SLM) Berbasis PVC, Chemistry Department, Universitas Gadjah Mada, Yogyakarta, 2011
- [40] Nurtina Muktiarti, Transport of Phenol Through a PVC-Based Supported Liquid Membrane Containing Poly(Eugenol-Co-Divinyl Benzene) as a Molecular Carrier, Universitas Gadjah Mada, 2011
- [41] Tadashi Nittami, Tetsuo Hitomi, Kanji Matsumoto, Kazuho Nakamura, Takaharu Ikeda, Yoshihiro Setoguchi, Manabu Motoori, Comparison of Polytetrafluoroethylene Flat-Sheet Membranes with Different Pore Sizes in Application to Submerged Membrane Bioreactor, *Membranes*, 2, 2, (2012), 228–236