Global J. Environ. Sci. Manage. 10(SI): 53-70, 2024

Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

Podcasts

ORIGINAL RESEARCH ARTICLE

Phenol solutions recovery as water pollutants with eugenol cross-linked diallyl phthalate using supported liquid membrane

A.A. Kiswandono*, N. Ningsih, A.V. Sindiani, Rinawati, H.I. Qudus

Department of Chemistry, Faculty of Mathematics and Natural Sciences, University of Lampung, Jl. Prof. Dr. Ir. Sumantri Brojonegoro, Bandar Lampung City, Lampung 35141, Indonesia

ARTICLE INFO

Article History:
Received 24 May 2024
Revised 30 July 2024
Accepted 05 September 2024

Keywords:
Copoly eugenol-diallyl phthalate
Phenol
Supported liquid membrane
Wastewater

ABSTRACT

BACKGROUND AND OBJECTIVES: The swift advancement of the industrial sector raises concerns due to its detrimental impact on the environment, notably in the production of pollutants, such as organic substances like phenol. These compounds are corrosive and toxic to the environment. The study for transport of phenol using copoly eugenol-diallyl phthalate as a carrier based on membrane of polytetrafluoroethylene with supported liquid membrane method was conducted to handle phenol solution. This study seeks to mitigate phenol waste by employing an 8 percent copolymer of eugenol and diallyl phthalate through the supported liquid membrane method. Furthermore, it aims to assess the effectiveness of phenol transport and separation using this membrane technique. The objectives of this study was contributed to the reduction of phenol solution with copoly eugenol diallyl phthalate 8 percent which was utilized from cross linked eugenol using supported liquid membrane method.
METHODS: This study was carried out with several variations, namely source phase power of hydrogen, receiving phase sodium hydroxide concentration, immersion time for supported liquid membrane, carrier concentration and time transport of phenol. This study for membrane evaluation was conducted to use the parameters such as concentration and type of salt, as well as lifetime. Fourier Transform Infrared Spectroscopy was employed to characterize the membrane, assessing its properties before and after the transport process in order to delineate the functional groups associated wit the membrane. Phenol concentration was determined using an ultraviolet-visible spectrophotometer with 4-aminoantipyrine reagent at a maximum wavelength of 455 nanometer.
FINDINGS: The phenol transport test showed that membrane containing copoly eugenol-diallyl phthalate 8 percent was successful in transporting phenol with the conditions such as power of hidrogen of 5.5 in the source phase, 0.25 molar sodium hydroxide concentration for receiving phase, immersion time membrane was 90 minutes, carrier concentration 0.005 molar for 24 hours. The results of the study revealed that portions of the membrane were damaged during the transport process. This conclusion was further validated by the outcomes of the supported liquid membrane technique and the characterization conducted through Fourier transform infrared spectroscopy.
CONCLUSION: The supported liquid membrane containing copoly eugenol diallyl phthalate 8 percent was able to transport phenol even though some membrane components were lost. The presence of 1 molar sodium nitrate salt enhances the durability of the supported liquid membrane, resulting in a lifespan of 15 days, whereas the membrane without the salt addition only lasts for 6 days. This study has significantly enhanced the recovery of phenol solutions, achieving a phenol recovery rate of 87.77 percent, while also successfully prolonging the lifespan of membrane.

DOI: 10.22034/gjesm.2024.10.SI.04

This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

NUMBER OF REFERENCES
53

NUMBER OF FIGURES
8

NUMBER OF TABLES
3

*Corresponding Author:
Email: *agung.abadi@fmipa.unila.ac.id*
Phone: +62813 2912 1722
ORCID: 0000-0002-8145-1959

Note: Discussion period for this manuscript open until November 1, 2024 on GJESM website at the “Show Article”.

INTRODUCTION

The industrial sector did not only make a positive contribution to economic development such as social and technological progress for society, but also has a negative impact in the form of liquid waste. Liquid waste still contains a number of pollutant particles which are dangerous for human health, environmental sustainability and ecosystems (Beulah *et al.,* 2020). Phenol is classified as an organic pollutant that is discharged into the environment, leading to the production of offensive and undesirable odors. Phenol waste in water, even it is lowest concentration and toxic to aquatic organisms such as fish and other marine biota (Alsheri *et al.,* 2017). As an industrial pollutant, phenol is recognized for its corrosive and toxic properties. Its stability renders it a persistent environmental contaminant in industrial waste, highlighting the urgent need for effective solutions to address this issue (Rosly *et al.,* 2018). Phenol pollution in wastewater results in high toxicity which is not good for health and can cause systemic poisoning (Messikh *el al.,* 2017). The efficient processing of phenol waste must reduce the harmful effects caused by phenol waste (Sygoun *et al.,* 2019). As a weak acid, phenol possesses an acid dissociation constant (pKa) of 9.98. The introduction of a strong base like sodium hydroxide (NaOH) facilitates the release of hydrogen ions (H^+), leading to the generation of phenolic ions ($C_6H_5O^-$), which are soluble in aqueous environments. Phenolic water systems can produce unpleasant smeels and be dangerous to humans. Phenol waste is found in several industries such as oil refineries is 6-500 milligram per gram (mg/L), coal processing is 9-6800 mg/L, and petrochemical manufacturing is 2.8-1220 mg/L (Othman *et al.,* 2017). In 2001, overall phenol production was 7.78 x 10^6 tons, 39 percent (%) was the production of bisphenol A., phenolic resin was 27 % (Topkara *et al.,* 2019). Membrane technology, especially in the form of liquid membranes, presents an effective method for minimizing phenol waste or facilitating the recovery of phenol. The supported liquid membrane (SLM) is a liquid membrane technique, an efficient combination method of simultaneous liquid and liquid extraction (Amini *et al.,* 2018). SLM functions as a selective transport technique for a range of compounds, particularly in the context of metal ion transport. Its effectiveness is attributed to the incorporation of a carrier, which enhances the selectivity of the process (Panja *et al.,* 2014). The advantages of the liquid membrane is cost savings high selectivity, efficient separation, and SLM for separation of metal ions. The separation and recovery of metals can greatly benefit from the potential of SLM based on parameters such as metal ion concentration, feed potential of hydrogen (pH), carrier concentration, carrier type, stirring speed, pore size, and receiving phase (Amini *et al.,* 2018). Among various conventional methods, SLM separation technology is recognized as one of the most effective approaches for the recovery of toxic metal ions from a range of sources, including aqueous solutions, hydrocarbons, weak acids and bases, gas mixtures, and biological materials. SLM has process advantages such as low research costs, low energy consumption and easy application (Malik *et al.,* 2011). The SLM technique has demonstrated its effective and broader application (Duan *et al.,*2020), capabilities for the extraction of various aqueous solutions (Pont *et al.,*2018), such as metals Ga(III) from chloride solution (Zhou *et al.,* 2019), carbón dioxide (CO_2) separation from air (Li *et al.,* 2016), and separation of phenol from wastewater (Othman *et al.,* 2017). Kazemi *et al.,*(2013) separated methylane blue dye from textile industry liquid waste using the SLM method with an SLM membrane using mono-(2-ethylhexyl) ester of phosphoric acid (M_2EHPA) and bis-(2-etylhexyl) ester of phosphoric acid (D_2EHPA) as a carrier and vegetable oil as a liquid membrane. The study revealed that the most effective transport of methylene blue dye was achieved with a receiving phase concentration of 0.4 molar (M) acetic acid (CH_3COOH) and a source phase pH of 6 (Reyes *et al.,* 2008). The concentration of phenol, tri-n-octyl phosphine oxide (TOPO) was treated phenol in a ratio of 1:1 with the SLM membrane resulting in 74.3% with 24 hours (h) of the initial phenol in source phase NaOH in receiving phase (Zidi *et al.,* 2011). Phenol transport (PhOH) for SLM using bis(2-ethylhexyl) sulfoxide (BESO), the results obtained were that 91% of PhOH was transported efficiently (Yang *et al.,* 2015). In the context of utilizing SLM for the proficient separation of alkali metal cations, the selectivity of the membrane is primarily determined by the ions' mobility and the variations in energy required for dehydration (Qian *et al.,* 2020). Separation of copper from ammonia solution using SLM containing the carrier N902 extractant (Duan *et al.,* 2020). The SLM process for removing acetic acid from aqueous

solutions, utilizing tri-n-octylamine (TOA) as a carrier and sodium hydroxide as the receiving phase (Harruddin *et al.,* 2016). Kazemi *et al.,* (2014), SLM conducted phenol study using SLM 7 hours extraction (feed concentration: 200 mg/L; carrier concentration 40%, feed pH 2, strip phase concentration 1.1 M). The removal of phenols from coal gasification with the SLM method was conducted, and the rate of phenols exceeded 90% after 120 minutes (min.) (Sun *et al.,*2017). A polymer inclusion membrane (PIM) utilizing a combination of cellulose triacetate and cellulose acetate has been shown to achieve a phenol transport efficiency of 95% in the remediation of phenol solution (Benosmane *et al.,* 2018). Saka *et al.,* (2020) conducted synthesis of coply eugenol diallyl phthalate 4% to reduce phenol solution using the PIM method. Ling and Suah (2017), used Polymer Inclusion Method (PIM) method which consists of bis-(2-ethylhexyl) phosphate (B_2EHP) as the carrier, polyvinyl chloride (PVC) as the base polymer, and dioctyl phthalate (DOP) as the plasticizer. The efficiency extraction was more than 98%. Kiswandono *et al.,* (2024), did malachite green (MG) transport using the PIM method which used polyeugenol as a carrier and obtained a transport percentage of 89.09%. Utilizing the liquid membrane approach for the separation of pollutants, bulk liquid membranes (BLM) with nonionic surfactants have demonstrated an extraction rate of 83.4% for phenol removal (Rosly *et al.,* 2018). Emulsion liquid membrane (ELM) containing ionic liquid in tributyl phosphate with a phenol removal percentage of 99.5% (Balasubramanian *et al.,* 2012). Hasanoğlu *et al.,* (2013) was using an emulsion membrane to remove phenol which resulted in 99.4% of phenol could be removed from the water. Within the discipline of membrane science, a critical area of research involves the utilization of membranes to achieve effective ion separation from various solutions, especially in relation to wastewater treatment processes. This research developed cellulose membranes from biomass because cellulose-based membranes are environmentally friendly (Syukri *el al.,* 2024). The separation process using a membrane will be perfect if the mixture move through the membrane faster than other compounds (Benosmane *et al.,* 2018). Othman *et al.,* (2017) carried out phenol recovery from phenol wastewater using a mixture formulated with ionic surfactant liquid emulsion membranes and produced 83% phenol that could be extracted or recovered. Emulsion Ionic Liquid Membrane (EILM) technique was conducted to recovery of Pb(II) metal using nitric acid and Aliquat336 as a carrier and 82.61% of lead ions were extracted by Aliquat 336, according to the results (Mesli *et al.,* 2018). The study employed an ELM technique to eliminate phenol utilizing surfactants, achieving a transportable phenol removal rate of 83.4% (Rosly *et al.,* 2020). Bukhari *et al.,* (2019) carried out optimized phenol recovery from wastewater using an ionic surfactant liquid emulsion membrane and 83% of phenol was successfully extracted. The research used an Emulsion liquid membrane (ELM) to remove phenol with surfactants and obtained results of 83.4% phenol that could be transported (Yildirim *et al.,* 2017). The structural similarity of benzene rings in both polyeugenol and phenol allows for the formation of pi (π) interactions between them. Furthermore, diallyl phthalate (DAF) can function as an effective cross-linking agent for the diene. Crosslinking causes the molecular weight of the resulting polymer to increase because it produces the DAF eugenol copoly. If the molecular weight is greater like active sites (benzene rings and –OH groups) (Kiswandono *et al.,* 2019). The copolymerization of eugenol with diallyl phthalate, known as copoly eugenol diallyl phthalate (Co-EDAF), is projected to augment the active sites present in the polymer, thus improving its efficacy as a carrier in the phenol transport mechanism. Consequently, the present study investigated the treatment of phenolic waste employing Co-EDAF at an 8% concentration through the SLM method, while also assessing the effectiveness of phenol separation achieved by this approach. The findings of Khan *et al*. (2023) further substantiate this claim, demonstrating the use of a carrier to assist in the selection and design of biobased ionic liquids aimed at the separation of formaldehyde. Phenol is a dangerous pollutant that can damage the environment and can harm living organisms, so it is necessary to recover phenol from the environment using the SLM liquid membrane method with Co-EDAF 8% carrier. This study investigates several parameters, namely the potential of hydrogen (pH) in the source phase, the concentration within the receiving phase, the time of immersion, the concentration related to carrier transport time, the characterization of the supported SLM, the effect of different salt types in the source

phase, the influence of optimal salt concentration in the source phase, and the longevity of the system. The aim of this study was contributed to the reduction of phenol solution with Co-EDAF 8% was utilized from cross linked eugenol using SLM method. This SLM method is expected to be an effective method in handling phenol solutions.The target compound was phenol and eugenol cross-linked diallyl phthalate as the carrier both have hydroxyl groups (-OH), so the function of eugenol cross-linked diallyl phthalate can facilitate the transport of phenol as the target from the source phase to the receiving phase. The study significantly contributes to mitigating the effects of phenol waste, a prevalent organic pollutant in aquatic environments. The findings indicate an impressive removal rate of 87.77% of phenolic compounds from contaminated solutions, thereby alleviating environmental pollution. The study has been carried out in the Analytical Chemistry and Instrumentation Laboratory, Department of Chemistry, Faculty and Mathematics and Natural Sciences (FMIPA), University of Lampung and at the UPT Integrated Laboratory and Technology Innovation Center (LTSIT) University of Lampung in 2023 to 2024.

MATERIALS AND METHODS

The main materials were eugenol oil obtained from Ghimas Bologna Company and diallyl phthalate supply from Sigma Aldrich. Other materials were polytetrafluoroethylene membrane (PTFE) with 0.45 micrometer (µm) pore size and 47 millimeter (mm) diameter (Hawach Scientific), phenol (C_6H_5OH) of Nice Chemical, chloroform ($CHCl_3$) of Merck, 4-aminoantipyrine ($C_{11}H_{13}N_3O$) of Sigma Aldrich, potassium ferricyanide [$K_4Fe(CN)_6$], ammonium hydroxide (NH_4OH) of Merck, hydrochloric acid (HCl) of Merck, sodium hydroxide (NaOH) of Merck, sodium sulfate (Na_2SO_4) ACS Grade, dipotassium phosphate (K_2HPO_4) of Merck, monopotassium phosphate (KH_2PO_4) of Aus Chem Source, sodium nitrate ($NaNO_3$) of Merck, sodium chloride (NaCl) of Merck, potassium nitrate (KNO_3) of Merck, and potassium chloride (KCl) of Merck.

Source phase pH

After placing PTFE membrane was in transport pipe (middle of the pipe), 50 milliliters (mL) of 0.1 molar (M) NaOH as receiving phase, and 50 mL of 60 part per million (ppm) phenol, was previously pH-adjusted to 3.5, 4.5, 5.5, 6.5, and 7.5, was added as the source phase. After sealing pipe of transport, a magnetic stirrer was used to homogenize the mixture for nine hours at room temperature. Phenol in both phase (source and receiving phase) was determined maximal wavelength using a ultraviolet visible (UV-Vis) spectrophotometer.

Concentration of receiving phase (NaOH)

The transport pipe was closed and the PTFE membrane was positioned in the center. 50 mL phenol 60 ppm (source phase) with optimal pH and 50 mL of 0.01 molar NaOH were added. The receiving phase consisted of 0.05, 0.1, 0.25, and 0.5 M. The transport pipe was sealed using a magnetic stirrer, which facilitated continuous stirring at ambient temperature for a period of nine hours. Upon the conclusion of the transport, both the source phase and the receiving phase were extracted for analysis. Phenol in both phase (source and receiving phase) was determined maximal wavelength using a UV-Vis spectrophotometer.

Immersion time variation

Various immersion times of one min., thirty min., sixty min., and ninety min., the PTFE membrane was immersed in a solution containing Co-EDAF 8% carrier and placed in the center of the phenol transport pipe. For ideal circumstances, 50 mL phenol 60 ppm (source phase) and 50 mL NaOH (receiving phase) were then added. Once both transport pipes were sealed, a magnetic stirrer was utilized to maintain continuous stirring at room temperature for a total of nine hours. Samples were taken from both the receiving and source phases. Phenol in both phase (source and receiving phase) was determined maximal wavelength UV-Vis spectrophotometer.

Carrier concentration

The optimum immersion, receiving phase concentration, and pH source phase were all considered during the transport process. In the center of the transport pipe was a PTFE membrane with carrier concentrations of 0, 0.005, 0.01, 0.015, and 0.020 M. NaOH 50 mL (receiving phase) and 50 mL phenol 60 ppm (source phase) were then added. The source and receiving phases of the transport pipe were sealed and subjected to continuous stirring at room temperature for a period of nine hours, utilizing

a magnetic stirrer. Samples were taken from both the receiving and source phases. Phenol in both phase (source and receiving phase) was determined maximal wavelength using a UV-Vis spectrophotometer.

Transport time

For ideal conditions, the PTFE membrane (center in transport pipe) and 50 mL NaOH (receiving phase) and 60 ppm phenol 50 mL (surce phase) were added. A magnetic stirrer was employed to seal and agitate the transport pipe for intervals of three, nine, fifteen, twenty-four, and thirty-six hours. Samples were taken from both the receiving and source phases. Phenol in both phase (source and receiving phase) was determined maximal wavelength using a UV-Vis spectrophotometer.

Characterization of SLM PTFE membranes

Fourier transform infrared (FTIR) and scanning electron microscope (SEM) were utilized to analyze the SLM PTFE membrane during the phenol transport optimization technique.

Effect of salt types

After being prepared, the SLM PTFE membrane was weighed before being utilized and put in the center of the transport pipe. During the source and receiving phases, a spin bar was utilized to close and homogenize the transport pipe. The source phase contains variations of the salts NaCl, $NaNO_3$, Na_2SO_4, and KNO_3 at concentrations of 0.01 molar. Samples are collected during the source phase and the receiving phase following the completion of the transportation process. After transport, phenol in both phase (source and receiving phase) was determined maximal wavelength using a UV-Vis spectrophotometer.

Salt $NaNO_3$ concentration

The prepared SLM PTFE membrane is weighed before being used and put in the center of the transport pipe. In the source phase, the optimal salt type $NaNO_3$ was utilized in the closed, homogenized transport pipe. A spin bar magnet was used to transport the salt in changes in concentrations of 0 (control); 0.001; 0.01; 0.1; and 1 M. Following the completion of the transit, samples have been collected at the source and receiving phases. Phenol in both phase (source and receiving phase) was determined maximal wavelength using a UV-Vis spectrophotometer.

Lifetime

Before being transported, the SLM PTFE membrane was weighed and positioned in the center of the transport pipe. The movement of phenol was executed in an environment characterized by optimal optimization parameters. A spin bar stirrer was utilized to close and define the transport receiving and source phases. Samples have been collected from both the source and receiving phases. After transport, phenol in both phase (source and receiving phase) was determined maximal wavelength using a UV-Vis spectrophotometer. Solution of source phase was utilized to test lifetime in five different ways: without salt (control), 0.01 M NaCl salt, 0.01 M $NaNO_3$ salt, 0.1 M $NaNO_3$ salt, and 1 M $NaNO_3$ salt. By taking a pH reading at the source phase, lifetime was calculated. The rise in pH levels observed in the source phase indicated a potential breach in the SLM membrane. The phenol transport process stopped when the pH reached ±9.0, in the source phase which was measured (Kiswandono *et al.,* 2020).

RESULTS AND DISCUSSION

Source phase pH

A significant factor influencing the diffusion of protons, in the presence of differing concentrations between the source and receiving phases, is attributed to the properties of the membrane. In a source phase had a greater proton concentration than the receiving phase. The pH variation used was 3.5; 4.5; 5.5; 6.5 and 7.5. The findings derived from the investigation into phenol transport revealed a correlation between the percentage concentration of the source phase and the percentage concentration of the receiving phase, which is depicted in Fig. 1. The most effective phenol transport which was an optimum condition was in a source phase pH of 5.5 with a phenol concentration of 44.46% because the driving force became very strong because had different substantial pH between the source and receiving phases, so that the phenol transport process increased. At low pH levels, the protons associated with the –OH group of phenol remain bound to the molecule, preventing their release prior to traversing the membrane phase. This phenomenon results in an increased rate of phenol transport. Under conditions of acidic

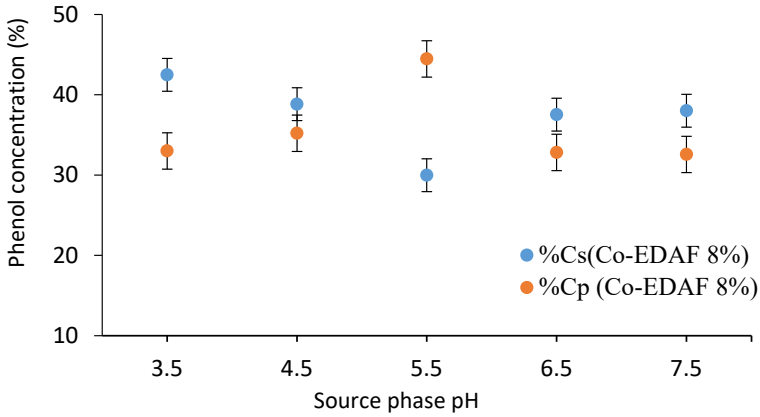


Fig. 1: Percent phenol transported in pH consentration
(Cp : Receiving Phase, Cs : Source phase)

pH, the solubility of phenol in the organic phase is enhanced, resulting in an elevated concentration. In the membrane phase, phenol interacts with carrier molecules through π-π interactions and hydrogen bonds so that phenol will be transported at a higher rate (Fan *et al.,* 2008).

Phenol transport in acidic pH, namely pH 3.5; 4.5; 5.5 caused low efficiency of transport and extraction processes. As the acidity of the source phase rises, a greater proportion of phenol exists in its molecular form, which subsequently hinders the transport of phenol to the receiving phase. Based on Meng *et al.,* (2015), phenol complex after transport was formed through hydrogen bonding. The degree of ionization of phenol became comparatively stronger at higher pH levels (pH>4), which reduced the extent of complexation. The presence of protons in the source phase inhibited the interaction of phenol molecules with the carrier, as the alkaline nature of the receiving phase rendered the transport of phenol ineffective. The highest pH in the source phase of 6.5 and 7.5 of the transported phenol decreased because in these conditions the phenol would be in the form of phenolate so that the hydrogen bonds and π-π interactions between copoly carrier molecule eugenol-diallyl phthalate and phenol on the membrane phase also became weaker. According to Pérez-Silva *et al.* (2018), the investigation into the impact of the feed solution's pH on the transport of phenol indicated a decline in the extraction percentage as pH levels increased, with a notable decrease at pH 11. This observation is largely due to the prevalence of phenolate (charged species) at such high pH.

Concentration of receiving phase (NaOH)

The concentration of NaoH as the receiving phase were carried out at the optimum phenol pH, namely pH 5.5 for 9 hours and in the source phase was phenol 60 ppm. Phenol permeates the membrane phase and is subsequently conveyed to the receiving phase, where it undergoes a reaction with NaOH, resulting in the formation of sodium phenolate. The addition of a stripping agent, NaOH, to the stripping phase serves to obstruct the movement of phenol through the membrane. The stripping agent works to convert phenol into phenolic derivative compounds, specifically sodium phenolates, and traps these compounds in the strip phase, preventing the phenol from returning to the membrane phase (Febriasari *et al.,* 2016). Various concentrations of a strong base (NaOH) were evaluated as stripping solutions to determine the optimal re-extraction conditions for phenol transport (Pérez-Silva *et al.,* 2018). Variations in NaOH concentration used were 0.01; 0.05; 0.1; 0.25 and 0.5 M. The results of phenol transport were in Fig. 2.

Findings from the transport analysis revealed that the ideal concentration was 0.25 M, which resulted in a performance level of 56.30%. The optimum condition at 0.25 M was because this concentration was quite concentrated and had strong basic

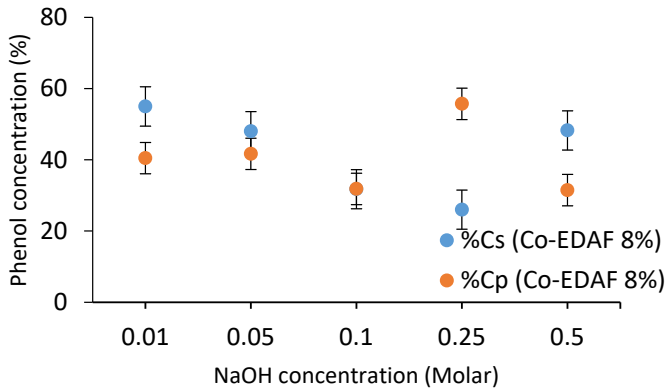


Fig. 2: Percent phenol transported in NaOH concentration
(Cp: Receiving phase, Cs: Source phase)

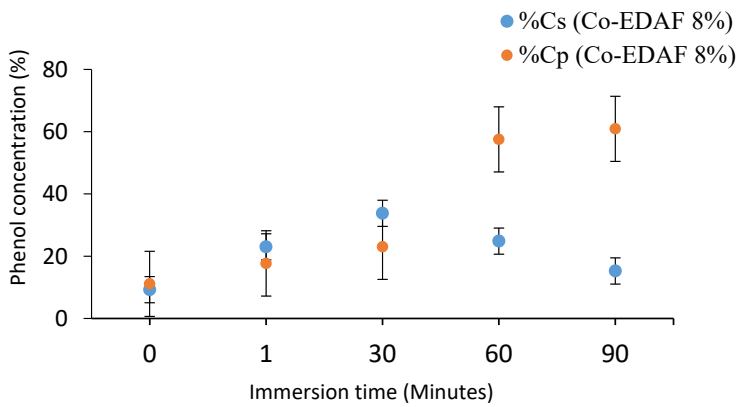


Fig. 3: Effect of immersion time on %phenol transported
(Cp: Receiving phase, Cs: Source phase)

properties so that the process of releasing phenolic ions from membrane phase interface the receiving phase was faster with higher concentration of NaOH so that the transported phenol produced increasing phenolic ions. Phenol transport varies in receiving phase 0.01; 0.05; and 0.1 M produced phenol percentages in the receiving phase of 40.48%, 41.68%, and 43.05%. Analysis of the data reveals that an increase in concentration within the receiving phase corresponded to a higher percentage of successful phenol transport. Nevertheless, once the concentration exceeded 0.25 M, a reduction in the transport percentage was observed. The phenol concentration increases at a concentration of 0.01 until 0.25 M due to the high concentration of NaOH, so the release of phenolic ions at the membrane would be faster.

Immersion time variation

Phenol transport studies with varying immersion times on SLM PTFE membranes were carried out at NaOH concentration receiving phase and the pH optimum source phase. The study employed different durations of immersion, specifically 0 hours (indicating no immersion with the carrier), as well as 1 min., 30 min., 60 min., and 90 min. The findings are illustrated in Fig. 3. Based on Syawaliah *et al.* (2018), modifications were carried out by varying the immersion times to 0, 2, 6, and 24 hours. It was proven that the duration of immersion affects the membrane's characteristics and performance. Prolonged immersion of membranes in the phenol solution resulted in the development of thicker layers and enlarged surface membrane pores.

According to Fig. 3, the percentage of phenol

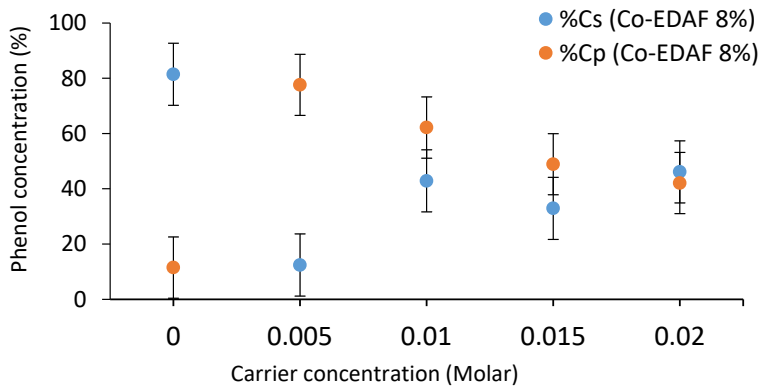


Fig. 4: Effect of carrier concentration on %phenol transported
(Cp: Receivings phase, Cs: Source phase)

concentration effectively transported to the receiving phase increased with increasing membrane immersion time. The most favorable conditions for phenol transport were determined to be a soaking time of 90 min., achieving a rate of 60.94%. Additionally, the length of immersion plays a crucial role in influencing the thickness of the layer. As the immersion time in the solution increases, the membrane surface becomes denser with carriers (Syawaliah *et al.,* 2018). Soaking times < 90 min. resulted in smaller results, namely at 1 min., 30 minutes and 60 minutes of soaking respectively 17.70%, 23.05% and 57.53%. The observed phenomenon can be attributed to the reduced soaking duration, which resulted in the PTFE membrane pores not being entirely saturated with the carrier. In contrast, at a soaking time of 0 minutes, where no carrier was present, the transport of phenol was minimal, recorded at only 11.12%. This showed without any interaction between carrier and phenol, it was difficult for phenol to be transported to receiving phase. The retention of phenol in the membrane phase was influenced by a reduction in the number of carriers present, which complicated the transport process of phenol. This scarcity of carriers led to less than ideal interactions with phenol.

Carrier Concentration

The experiment on phenol transport with varying carrier concentrations was conducted with optimal parameters, including a source phase pH of 5.5, 0.25 M NaOH in the receiving phase, and an immersion time of 90 min. Carrier concentration such as 0 (without carrier); 0.005; 0.01; 0.15 and 0.02 M. A support is essential for the liquid membrane to effectively position the carrier between the feed and receiving solutions. This support must be a hydrophobic, porous material with high chemical resistance to the organic solvents used. The results of phenol transport with varying concentrations of the copoly diallyl phthalate (Co-EDAF) 8% carrier could be seen in Fig. 4. The carrier content in the membrane significantly influences analyte extraction. To improve the conditions for preparation, particularly in relation to carriers like cyanex 923, additional investigation is necessary (Pérez-Silva *et al.,* 2018).

As depicted in Fig. 4, there was a notable rise in carrier concentration, yet the volume of phenol that migrated to the receiving phase was limited. The transport percentage of phenol was 11.48% without a carrier, meaning only a small fraction of phenol was transported because there were no hydrogen bonds or π-π interactions between the carrier and phenol in the membrane phase. The highest phenol transport of 77.63% was obtained with a carrier concentration of 0.005 M. The amount of phenol transported is affected by the carrier concentration present in the membrane phase. Elevating the concentration of carriers in this phase accelerates the formation of phenol complexes, which in turn leads to an increase in the transported phenol (Zidi *et al.,* 2011). An increase in carrier concentration to 0.01; 0.015; and 0.020 M is inversely proportional to the amount of phenol transported to receiving phase. The data indicated that as the concentration of the carrier applied during the immersion process rose, there was a corresponding decline in the amount of phenol that

was successfully transported.

Transport time

The length of the transport time was linked to the amount of time phenol was in the source phase and the carrier was in contact with the membrane. The interaction of phenol with membrane carriers is characterized by the establishment of hydrogen bonds alongside π-π interactions. An extended transport duration correlates with a heightened interaction strength between phenol and the carrier embedded in the membrane. The transport time was varied at 3, 9, 12, 24 and 36 hours using optimum conditions previously obtained using Co-EDAF 8% as a carrier in the SLM membrane. The transport time results was in Fig. 5.

As depicted in Fig. 5, the most effective transport time was determined to be 24 hours, resulting in the transportation of 87.77% of the phenol concentration. The data indicated that the amount of phenol transported to the receiving phase had increased from 0-24 hours. The rationale behind this was the anticipated increase in the volume of phenol being transported. When it was a longer transport time, between phenol (source phase), membrane and NaOH (receiving phase) which was transported into the receiving phase. When transport lasts for 24 hours, the ligand begin to saturate and the amount of phenol transported begin to reach its maximum. The transport time of 36 hours marked a considerable shift in the volume of phenol transported. Extending the transport duration could prove ineffective, given that the quantity of phenol transported was comparatively minimal. With an increase in transport time, the phenol concentration gradient between the source and receiving phases decreased. This reduction in the concentration gradient of the phenol solution leads to a diminished driving force for the movement of phenol from the source to the receiving phase, thereby slowing the transport rate. This was proven by a decreasing percentage of phenol transported during the 36 hours transport time, was 60.87%. The limited number of carriers for optimal interaction with phenol, and there may have been competition for interaction with the carrier, while Phenol was trapped in the membrane and not effectively transported to the receiving phase (Kiswandono *et al.,* 2024).

Characterization of SLM PTFE membranes

The membrane underwent FTIR analysis both before and after the modification to investigate modifications in its chemical structure, particularly the introduction of new functional groups (Tran *et al.,* 2021). FTIR was employed to characterize the SLM PTFE membrane, specifically to ascertain the existence of the hydroxyl (-OH) functional group, which is essential for facilitating the transport process. The results of FTIR characterization could be seen in Fig. 6, explained that the spectra from the analysis of the carrier used was Co-EDAF 8%. The IR spectra obtained before the phenol transport represent the analysis of the PTFE membrane that had previously integrated the carrier. Conversely, the IR spectra obtained after the phenol transport illustrate the analysis of the PTFE membrane that contained the carrier subsequent to its use in phenol transport. Based on Xu *et al.,* (2019), FTIR spectroscopy was used to analyze the surface chemistry of the TODGA-SLM. Each spectrum was recorded in the range of 400

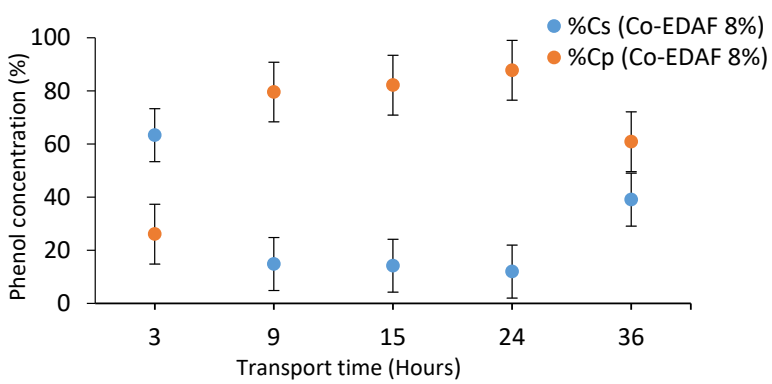


Fig. 5: Percent phenol transported for time
(Cp: Receiving phase, Cs: Source phase)

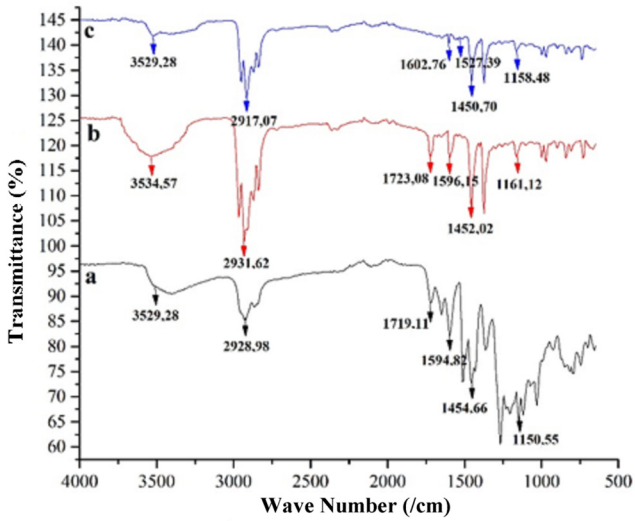


Fig. 6. FTIR characterization results (a) Co-EDAF 8% carrier; (b) Before transport of SLM; (c) After phenol of SLM at 24 hours transport time

Table 1: Functional group comparison resulting from IR PTFE membrane cointained Co-EDAF 8% before and after transport with time transport was 24 hours

Functional group	Wave number per centimeter (/cm)		
	Co-EDAF carrier	Before transport	After tranport
C-H stretching (alkyl)	2928.98	2931.62	2917.07
C-H bending	1454.66	1452.02	1450.70
C=O stretching (carbonyl)	1719.11	1723.08	-
C=C *stretching* (aromatic)	1594.82	1596.15	1527.39
C-O stretching	1150.55	1161.12	1158.48
O-H stretching	3529.28	3534.57	3529.28

to 4000/cm. No significant differences were observed in the FTIR spectra on either side of the TODGA-SLM. Table 1 provides a representation of the functional groups identified on the membrane.

The broad band in the FTIR spectra with a maximum located near 3500 per centimeter (/cm) can be attributed to hydroxyl stretching in organic compounds (Martínez *et al.,* 2023)**.** A wave number of 3529.28/cm was identified, associated with the stretching absorption of the hydroxyl (-OH) group. This wave number exhibited a pronounced decline in intensity, characteristic of the -OH group, thereby implying a decrease in the quantity of hydroxyl groups present. It indicated that hydrogen bonds have occurred between phenol and the carrier molecule during phenol transport. At the wave number 1594.82/cm, C=C stretching (aromatic) absorption occurs, where phi-phi (π-π) interactions occur, indicating a shift in the wave number after transport. This indicated that there was a benzene ring between π-π interaction in a carrier molecule copoly(eugenol-DAF) and phenol during phenol transport.

Effect of salt types

In source phase, salt was added with a concentration of 0.01 M. The types of salt used in this research were control (without salt), Sodium nitrate ($NaNO_3$), Sodium chloride (NaCl), Sodium sulfate (Na_2SO_4), and Potassium nitrate (KNO_3).Based on Luo and Wan, (2011) as the salt concentration increased, the solute-to-pore size ratio decreased, while the ratio of effective membrane thickness to porosity increased. This implies that the role of salt may encompass a decrease in the size of solutes, an enlargement of the membrane pore size, and an improvement in the effective thickness of the membrane. The effect

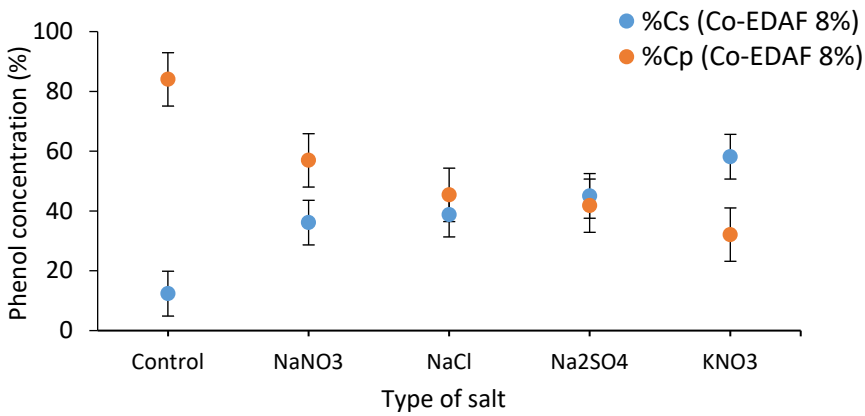


Fig. 7. Effect of salt type
(Cs: Source phase, Cp: Receiving phase)

of introducing various salt types to the source phase on the percentage of phenol transport is depicted in Fig. 7. According to the results (Fig. 7), the type of salt present in the source phase impacted phenol transport for 24 hours, with the phenol at pH 5.5, 90 min., for immersion time, NaOH concentration 0.25 M, and Co-EDAF carrier 8% concentration was 0.01 M. The highest concentration of phenol transported to receiving phase was in control solution which only contained phenol solution without adding salt to the source phase, namely 85.39%.

When the halogenic anion (X) of the salt dissolves in water, hydrogen bonds form between the solvating water molecules and the salt's anion. Vibrational relaxation of the O-H-X system occurs as the O-H group rotates. This rotation breaks the O-H-X hydrogen bond and forms a new O-H-O hydrogen bond with a neighboring water molecule (Kudasheva *et al.*, 2018). The presence of salt in the KNO_3 source phase is associated with a marked decrease in the transport of phenol to the receiving phase, achieving a minimum transport rate of 32.10%. Meanwhile, $NaNO_3$ salt was added in source phase resulted in a good percentage of phenol concentration in receiving phase, namely 56.96%. The lowest number of sodium cation (Na^+) ions will be difficult to bind to the active site (–OH) in the Co-EDAF 8% carrier, so that the interaction of phenol with the carrier was effective in the transport process. Addition of NaCl and Na_2SO_4 salts resulted in phenol transport percentages of 45.42% and 41.80% respectively. The concentration of cations in the phenol solution is directly proportional to the cation content of the salt added. However, when the salt ion concentration in the source phase is elevated, the transport yield decreases, primarily due to the interference caused by the surplus of ions during the phenol transport mechanism. The difference in transport results because NaCl salt was more ionic than $NaNO_3$. Ionic strength greatly influenced the results of phenol transport. The more ionic the salt, it will interfere with phenol transport from source phase to recipient phase. Addition of KNO_3 salt produced lower percentage of phenol compared to the addition of other salts due to the salting-out process. Salting-out was a condition that reduces the solubility of the main substance in a solvent due to salt addition. KNO_3 salt was presence in source phase would interfere with the formation of hydrogen bonds between Co-EDAF 8% and phenol, so that the carrier couldn't facilitate phnenol solution from source phase to receiving phase. Razi and Saien, (2019) investigated the effects of salts with mass fractions of 0.005 and 0.020 in aqueous solutions, demonstrating a marked improvement in the extraction of phenol when compared to systems devoid of salt. The results showed that the presence of salts caused the solute separation factor to reach (46.29% and 95.81%) with NaCl, (63.52% and 165.19%) with Na_2SO_4, and (86.39% and 238.55%) with $MgSO_4$, corresponding to the low and high salt concentrations used. The salting-out effect followed the order $MgSO_4$ more than (>) Na_2SO_4 > NaCl. Alkhudhiri and Hidal, (2017) studied the effects of high concentrations of four salts and three different PTFE membrane pore sizes on

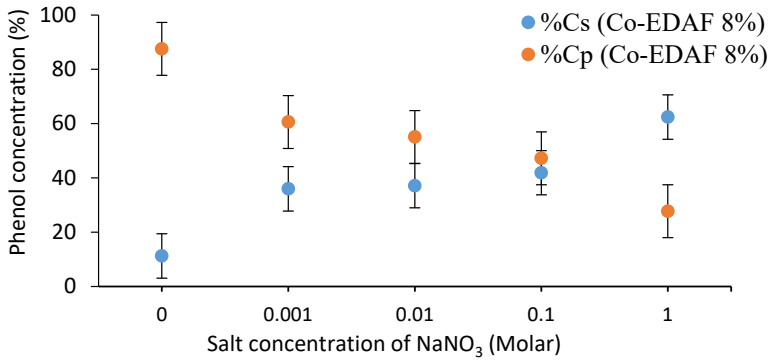


Fig. 8: Effect of salt concentration
(Cp: Receiving phase, Cs: Source phase)

Table 2: pH measurements on SLM membrane lifetime

	pH				
Days	Without salt	NaCl 0.01M	$NaNO_3$ 0.01M	$NaNO_3$ 0.1M	$NaNO_3$ 1M
1	5.14	7.38	7.05	6.26	6.20
3	7.11	7.90	8.59	7.90	6.26
6	9.52	8.08	8.69	8.08	7.95
9	-	9.77	8.86	8.59	8.00
12	-	-	9.07	8.97	8.49
15	-	-	-	9.33	8.54

permeate flux and salt rejection (SR) using an AGMD system. The study showed a significant increase in flux by 39.6% and 56.9% for a maximum NaCl feed concentration of 180,000 mg/L.

Salt $NaNO_3$ concentration

$NaNO_3$ salt concentration was increased by adding $NaNO_3$ salt to source phase, which contained phenol solution 60 ppm then $NaNO_3$ salt concentration was added with 0; 0.001; 0.01; 0.1 and 1 M. The phenol transport process was carried out for 6 hours under pH 5.5 for phenol, NaOH concentration of 0.1 M, 60 min., immersion time and Co-EDAF 8% 0 .01 M. Fig. 8 demonstrates how the addition of varying concentrations of $NaNO_3$ salt and modifications in the source phase influence the percentage of phenol that is transported to the receiving phase.

The introduction of a high concentration of sodium salt into the aqueous phase leads to a reduction in the activity coefficient of water molecules. This alteration subsequently results in an increase in the activity coefficient of the metals, thereby facilitating their transport across the membrane. Membrane pores without the use of salt leak more quickly and the pH in the source phase becomes alkaline more quickly (Zante *et al.,* 2020). The result was showed in Fig. 8 that the highest phenol percentage concentration was efficiently transported to the receiving phase, namely in the control solution or source phase with the addition of 0 M $NaNO_3$ salt, namely 87.55%. Salt concentration was more than 0.1 M, the phenol transported to the receiving phase decreased drastically. $NaNO_3$ was a salt with high solubility, meaning that $NaNO_3$ and phenol can bind water. An increase in the concentration of $NaNO_3$ correlates with a heightened ionic strength of the solution, thereby enhancing the salt's capacity to associate with water molecules. This phenomenon results in a reduction in the solubility of both phenol and NaOH in aqueous environments. This decreased in phenol solubility reduces the ability of the membrane to transport phenol from source to receiving phase. $NaNO_3$ salt addition in the source phase causes Na^+ ions from $NaNO_3$ to bind with -O- to the Co-EDAF carrier in the membrane so that hydrogen bonds occur in phenol and the active side of the carrier will decrease, causing the percentage of phenol transported decreased. According to

Table 3: comparison of phenol transport results with the SLM method

Seperation	Phenol for recovery (%)	Sources
Reducing phenol solutions using the SLM method with a crosslinked agent, namely copoly eugenol divinyl benzene10% (Co-DVB 10%)	91.59	Kiswandono *et al.,* 2024
SLM for the efficient recovery of phenolic compounds, including vanillin and catechol.	76.8	Pavón *et al.,* 2021
Effect and optimization parameters of phenol removal in liquid membrane process	83	Duan *et al.,* 2020
The removal of phenols from coal gasification with the SLM	90	Sun *et al.,*2017
The removal of phenol from aqueous solutions using supported liquid membranes with ionic liquid (IL) as the carrier solvent.	75.63	Duan *et al.,* 2015
SLM phenol study wastewater treatment using Tributyl phosphate and sesame oil	93.14	Kazemi *et al.,* 2014

Kabbani *et al*. (2021), enhancing the ionic strength of the feed solution leads to a diminished effective charge density of the membrane, which permits an increased flow of cations to the permeate side. A charge imbalance is generated, necessitating the movement of anions across the membrane to uphold the solution's electroneutrality, which in turn fosters competition among the anions.

Lifetime

Enhanced stability is indicative of a prolonged operational duration, a characteristic that is highly sought after in practical applications. Most investigators utilize mass flux measurements, and a portion additionally examines selectivity as parameters to gauge the stability of SLM (Saik Su *et al.,* 2022). The lifetime measurement aimed to evaluate the stability of SLM membrane with or without presence of salt. This could be determined by increasing the pH. The stability of the SLM membrane was tested under various conditions and varying salt concentrations, namely without the addition of salt and with the addition of NaCl salt 0.01 M, $NaNO_3$ salt 0.01M, $NaNO_3$ 0.1 M, and $NaNO_3$ 1 M. The findings demonstrate that the type of salt used led to an increased transfer of phenol into the receiving phase, surpassing that of other salts. Table 2 illustrates the correlation between the pH levels of the source phase and the durability of the membrane.

Table 2 showed the lifetime of the SLM membrane that lifetime of the membrane increased to 15 days due to the addition of 1 M $NaNO_3$ salt. The addition of salt had an effect on the %ML Loss because it can decrease the amount of organic phase loss from the membrane thereby increasing membrane lifetime and membrane durability. The transport mechanism involving salt and phenol incorporates water, leading to precipitation and consequently initiating a salting-out phenomenon. Salting-out was a purification method that takes advantage of reduced solubility for certain molecules in solutions that had higher ionic strength. As a consequence, the leakage of the membrane could be mitigated, thereby prolonging its operational life. In the absence of salt, the membrane's longevity is characterized by the absence of sediment accumulation, ensuring that the pores remain unobstructed. Conditions without the addition of salt or the addition of salt at a low concentration, emulsions would easily form, causing the SLM membrane to be unstable. In addition, the increased concentration of $NaNO_3$ added, it was hard to form an emulsion, SLM membrane will be stable. Ragaller *et al.,* (2024), investigated the lifetime sensitivity of the membrane tension probe Flipper in these environments. The application of fluorescence lifetime imaging microscopy (FLIM) to model and biological membranes demonstrated that all probes could identify different membrane phases through their lifetimes. Nonetheless, these probes displayed differing sensitivities to the various biophysical characteristics of the membranes. Finally, this study can recover phenol solution using the SLM method with 8% Co-EDAF carrier, obtaining succesful phenol recovery of 87.77%, as it is referres to the Table 3.

CONCLUSION

The current study concentrated on the reclamation of phenolic solutions, which pose significant risks if

disposed of as waste. The treatment methodology employs a liquid membrane utilizing the SLM technique. Dialyl phthalate as cross linked with a concentration of 8%. Eugenol cross-linked diallyl phthalate as the carrier both have hydroxyl groups (-OH), so the function of eugenol cross-linked diallyl phthalate can facilitate the transport of phenol as the target from the source phase to the receiving phase. The present study investigates multiple variables, such as pH, concentration, time, and the efficacy of the PIM membrane in the transport of phenolic substances. The parameters determined under ideal conditions will be utilized to inform additional testing undertaken in this study. The analysis of test parameters revealed a range of phenol pH values from 3.5 to 7.5, with the optimal pH determined to be 5.5, which produced a result of 44.46%. Furthermore, the concentration of phenol was assessed by varying the NaOH concentration, where the optimal result was recorded at a NaOH concentration of 0.25 M, yielding a concentration of 56.30%. The study examined the immersion time of the SLM PTFE membrane, with various soaking durations tested. The best result was obtained after 90 min., of soaking, leading to transport efficiency of 60.94%, soaking time was longer for the pores of the SLM PTFE membrane to contain carrier Co-EDAF 8% has a lot of -OH active sites so that phenol can be transported to the receiving phase. The concentration Co-EDAF carrier parameter, with optimal conditions found at a 0.05 M concentration, resulting in a transport efficiency of 77.63%. The phenomenon of phenol being released into the receiving phase is linked to the presence of hydrogen bonds or π-π interactions that facilitate this transfer. Variations in transport time were tested, with the optimal transport time of 24 hours achieving an efficiency of 87.77%. This indicateed Co-EDAF 8% effectively driving force phenol towards the receiving phase, aligning with transport time. Upon identifying the optimal conditions, FTIR characterization was carried out on the SLM PTFE membrane to examine the alterations in -OH groups that took place prior to and following the transport. The FTIR analysis showed wave number of 3529.28/cm before transport and a reduction after transport. This change implies that the leaching of -OH groups took place throughout the transport process, with the -OH groups being dissolved as phenol migrated from the source to receiving phase. An evaluation of the membrane durability test was carried out using the parameters of salt type, salt concentration and lifetime of the SLM PTFE membrane. By varying type of salt, $NaNO_3$ was identified as the optimal salt, was 0.01 M concentration with 56.96% phenol transport. The utilization of this specific salt serves to assess the loss of components within the membrane, with the expectation that the incorporation of salt would bolster the stability of the SLM PTFE throughout the duration of transport. The optimum type of salt was $NaNO_3$ salt, this was because this salt had good ionic strength compared to other salts. Subsequently, the ideal form of $NaNO_3$ salt was determined by adjusting its concentration. The optimal concentration identified was 0 M $NaNO_3$ salt, corresponding to 87.55%. This phenomenon can be attributed to the high solubility of $NaNO_3$, which, when combined with phenol, enhances its capacity to bind water. An increase in the concentration of NaNO3 salt resulted in a greater ability to attract water molecules. This happened because ionic of $NaNO_3$ was very high. The final membrane stability parameter was lifetime where this parameter aimed to evaluate the stability of SLM membrane with or without the presence of salt. $NaNO_3$ 1 M salt was added (source phase) for phenol transport made membrane lifetime longer, 15 days compared to without the addition of salt as well as $NaNO_3$ 0.01 M, $NaNO_3$ 0.1 M and NaCl salts with a lifetime of less than 15 days. Stability of the SLM membrane had been tested in various conditions with the lifetime capability of the SLM membrane and can be used repeatedly for 15 days. This study has supported several parameters for successful recovery of phenol solutions using the SLM method supported by Co-EDAF 8% as a carrier. The findings of this study have advanced efforts to mitigate the environmental risks associated with phenol. The methodology adopted is ecologically sound, requiring only a limited quantity of carriers, being economically viable, and characterized by its simplicity in execution.

AUTHOR CONTRIBTIONS

A.A. Kiswandono as the corresponding author was responsible for designing the study, conceptualizing research methods, discussing and executing the research, writing original paper and preparing the manuscript. N. Ningsih was responsible for conducting literature reviews, writing original paper, conducting research experiments, carrying out UV-

Vis analysis also FTIR characterization of samples. A.V. Sindiani was responsible for writing the manuscript, processing research data for UV-Vis data and FTIR data, interpreting the results, and prepared tables and figures. Rinawati was responsible for supervising the experiment and evaluating the data. H.I. Qudus is responsible for manuscript review and manuscript revision.

ACKNOWLEDGEMENT

The study experiment was conducted in Analytical Chemistry and Instrumentation Laboratory and the UPT Integrated Laboratory and Technology Innovation Center (LTSIT) University of Lampung by the team from Membrane Research Department of Chemistry, Faculty of Mathematics and Natural Sciences. The data analysis and preparation of the manuscript was funded by the Ministry of Education, Culture, Research and Technology of Indonesia HETI Project with the [10602/UN26/KS.00.00/2023] commencing on October 16, 2023.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

OPEN ACCESS

©2024 The author(s). This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third-party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit: http://creativecommons.org/licenses/by/4.0/.

PUBLISHER'S NOTE

GJESM Publisher remains neutral with regard to jurisdictional claims with regard to published maps and institutional affiliations.

ABBREVIATIONS

>	More than
π-π	Phi-phi
%	Percent
%Cs	Percent of source phase
%Cp	Percent of receiving phase
B_2EHP	Bis-(2-ethylhexyl) phosphate
BESO	Bis(2-ethylhexyl) sulfoxide
BLM	Bulk liquid membrane
CH_3COOH	Acetic acid
C_6H_5OH	Phenol
$C_{11}H_{13}N_3O$	4-aminoantipyrine
$CHCl_3$	Chloroform
/cm	Per centimeter
CO_2	Carbón dioxide
Co-EDAF	Copoly eugenol dialyl phtalate
Co-DVB	Copoly eugenol divnyl benzene
D_2EHPA	Bis-(2-etylhexyl) ester of phosphoric acid
DOP	Dioctyl phthalate
ELM	Emulsion liquid membrane
FTIR	Fourier transform infrared
HCl	Hydrochloric acid
h	Hour
KCl	Potassium chloride
KH_2PO_4	Monopotassium phosphate
K_2HPO_4	Dipotassium phosphate
KNO_3	Potassium nitrate
$K_4Fe(CN)_6$	Potassium ferricyanide
M	Molar
M_2EHPA	Mono-(2-ethylhexyl) ester of phosphoric acid
MG	Malachite green
mg/L	Milligrams per liter
mL	Mililiter

ML Loss	Membran liquid loss
µm	Micrometer
mm	Millimeter
Min.	Minute
Na^+	Sodium cation
NaCl	Sodium chloride
NaOH	Sodium hydroxide
$NaNO_3$	Sodium nitrate
Na_2SO_4	Sodium sulfate
NH_4OH	Ammonium hydroxide
nm	Nanometer
Na_2SO_4	Sodium sulfate
OH	Hydroxyl
pH	Potential of hydrogen
PhOH	Phenol
pKa	Acid dissociation constant
PIM	Polymer inclusión membrane
ppm	Part per million
PVC	Polyvinyl chloride
SEM	Scanning electron microscope
SLM	Supported Liquid Membrane
TOA	Tri-n-octylamine
UV-Vis	Ultraviolet Visible

REFERENCES

Alkhudhiri, A.; Hilal, N., (2017). Air gap membrane distillation: A detailed study of high saline solution. Desalination. 403: 179–186 **(7 pages).**

Alshehri, M.; Saad, Mu.; Naushad, A.; Tansir, A.; Zeid; Aldalbahi, A., (2014). Synthesis, characterization of curcumin based ecofriendly antimicrobial bio-adsorbent for the removal of phenol from aqueous medium. Chem. Eng. J., 254: 181–189 **(9 pages).**

Amini, M.; Rahbar-Kelishami, A.; Alipour, M.; Vahidi, O., (2018). Supported liquid membrane in metal ion separation: An overview. J. Memb., 4(3): 121–135 **(15 pages).**

Balasubramanian, A.; Venkatesan, S., (2012). Removal of phenolic compounds from aqueous solutions by emulsion liquid membrane containing ionic liquid $[BMIM]^+[PF_6]^-$ in tributyl phosphate, Desalination. 289: 27-34 **(8 pages)**.

Benosmane, N.; Boutemeur, B.; Hamdi, S.M.; Hamdi, M., (2018). Removal of phenol from aqueous solution using polymer inclusion membrane based on mixture of CTA and CA. Appl. Water Sci., 8(1) : 17 **(11 pages)**.

Beulah, S.; Muthukumaran, K., (2020). Methodologies of removal of dyes from wastewater: a review. Int. Res. J. Pure Appl. Chem., 21(11): 68-78 **(11 pages)**.

Bukhari.; Muhammad, J.; Norela; Norasikin, O., (2019). Effect and optimization parameters of phenol removal in emulsion liquid membrane process via fractional-factorial design, Chem. Eng. Res. Desalination., 145: 268–278 **(10 pages)**.

Duan, H.; Liu, H.; Hu, C.; Cheng, W.; Wang, X., (2020). Facilitated recovery of copper from ammoniacal solution by supported liquid membrane following multiple cooperative effects. Chem Pap., 74: 3335–3345 **(10 pages)**.

Fan, J.; Fan, Y.; Pei, Y.; Wu, K.; Wang, J.; Fan. M., (2008). Solvent extraction of selected endocrine-disrupting phenols using ionic liquids. Sep. Purif. Technol., 61: 324-331 **(7 pages)**.

Febriasari, A.; Siswanta, D.; Kiswandono, A.A.; Aprilita, N.H., (2016). Evaluation of phenol transport using polymer inclusion membrane (PIM) with polyeugenol as a carrier. J. Rek. Kim. Ling., 11(2): 99–105 **(6 pages).**

Harruddin, N.; Saufia, S.M.; Faizal, C.K.M.; Mohammad, A.W., (2016). Evaluation of different polymeric membrane support for acetic acid removal by supported liquid membrane process. J. Tech. Sci. Eng., 78(12): 13–18 **(6 pages)**.

Hasanoğlu, A., (2013). Removal of phenol from wastewaters using membrane contactors: comparative experimental analysis of emulsion pertraction. Desalination. 309: 171-180 **(9 pages)**.

Huma, W. K.; Amal A.M.; Mansoor. U.l.; Hasan. S.; Berihun, M. N.; Mohd, K. K.; Kashif, K.; Hesam, K.; Mohammad, Y., (2023). Exploring ionic liquids for formaldehyde separation via computational cosmo-rs screening. Chem. Eng. Res. Des. 196: 588-598 **(10 pages).**

Kabbani, H. M.; Al-Hindi, M.; Ayoub, G. M.; Ahmad, M., (2021). The effects of salt concentration on the rejection of pharmaceutically active compounds by nanofiltration membranes. J. Sustainable Dev. Energy Water Environ. Syst., 9(3): 1-16 (**16 pages).**

Kazemi, P.; Mohammad, P.; Alireza, B.; Toraj, M.; Bakhtiari, O., (2013). Pertraction of methylene blue using a mixture of $d_2$ehpa/$m_2$ehpa and sesame oil as a liquid membrane. Chemical., 67 (7): 722–729 **(7 pages)**.

Kazemi, P.; Peydayesh, M.; Bandegi, A.; Mohammadi, T.; Bakhtiari, O., (2014). Stability and extraction study of phenolic wastewater treatment by supported liquid membrane using tributyl phosphate and sesame oil as liquid membrane. Chem. Eng. Res. Desalination., *92*(2): 375-383 **(8 pages)**.

Kiswandono, A.A.; Annur, V.S.; Rizqohayyu, K.K.; Maulana, B. R.; Bagus, K.; Rinawati; Herlian, E.P., (2024). Transport of malachite green using the polyeugenol-based polymer inclusion membrane (pim) method. J. Memb. Sci. Res., 10(1): 1–5 **(5 pages)**.

Kiswandono, A.A., Rinawati, R.; Agustina, W.; Hadi, N.; Nurhasanah, N.; Rahmawati, A.; Nitti, F.; Lusiana, R.A., (2024). Transport of phenol using a supported liquid membrane containing eugenol cross-linked by diallyl phthalate or divinyl benzene as a carrier. J. Memb. Sci. Res.10(3): 1–8 **(8 pages)**.

Kudasheva, A.; Liu, Y. J.; and Ito, A., (2018). Aqueous salt solution liquid membranes, supported by nanoparticles, for water extraction from the atmosphere via air dehumidification. J. Chem. Technol. Biotechnol., 93(10): 2851–2859 **(8 pages).**

Li, J.; Zhao. T.; Sui, G.; Jia, S., (2016). CO_2 Separation from air using microporous polyvinylidene fluoride-supported triethylene glycol/alkanolamine liquid membranes. Mater. Express. 6(2): 183–190 **(7 pages)**.

Ling, Y.; Suah, F., (2017). Extraction of malachite green from wastewater by using polymer inclusion membrane. J. Environ.

Chem. Eng., 5(1): 785-794 **(9 pages)**.

Luo, J., and Wan, Y., (2011). Effect of highly concentrated salt on retention of organic solutes by nanofiltration polymeric membranes. J. Membr. Sci., 372(2): 145–153 **(8 pages).**

Malik, M.A.; Mohd, A.H.; Firdosa, N., (2011). Ionic liquids in supported liquid membrane technology, Chem. Eng. J., 171(1): 242–254 **(12 pages)**.

Martínez, P.A.; Rodríguez, M. E.; de Gyves, J., (2023). MID-FTIR-PLS Chemometric Analysis of Cr(VI) from Aqueous Solutions Using a Polymer Inclusion Membrane-Based Sensor. Memb., 13(8): 1-21 **(21 pages).**

Meng, X.; Gao, C.; Wang, L.; Wang, X.; Tang, W.; and Chen, H., (2015). Transport of phenol through polymer inclusion membrane with N,N-di(1-methylheptyl) acetamide as carriers from aqueous solution. J. Memb. Sci., 493: 615–621 **(6 pages).**

Mesli, M.; Belkhouche, N. E., (2018). Emulsion ionic liquid membrane for recovery process of lead. Comparative study of experimental and response surface design, Chem. Eng. Res. Desalination. 129: 160–169 **(9 pages)**.

Messikh, N.; Bousba, S.; Bougdah, N., (2017). The use of a multilayer perceptron (MLP) for modelling the phenol removal by emulsion liquid membrane. J. Environ. Chem. Eng., 5(4): 3483–3489 **(6 pages)**.

Othman, N.; Noah, N.F.M.; Shu, L.Y.; Ooi, Z.Y.; Jusoh, N.; Idroas, M.; Goto, M., (2017). Easy removing of phenol from wastewater using vegetable oil-based organic solvent in emulsion liquid membrane process. Chin. J. Chem. Eng., 25(1): 45–52 **(8 pages).**

Panja, S.; Ruhela, R.; Das, A.; Tripathi, S. C.; Singh, A. K.; Gandhi, P. M.; Hubli, R.C., (2014). Carrier mediated transport of Pd(ii) from nitric acid medium using dithiodiglycolamide (dtdga) across a supported liquid membrane (SLM). J. Membr. Sci., 449: 67–73 **(8 pages).**

Pavón, S.; Blaesing, L.; Jahn, A.; Aubel, I.; Bertau, M., (2021). Liquid membranes for efficient recovery of phenolic compounds such as vanillin and catechol. Membranes. 11(1): 1–17 **(17 pages).**

Pavón, S.; Fortuny, A.; Coll, M.T.; Bertau, M.; Sastre, A.M., (2020). Permeability dependencies on the carrier concentration and membrane viscosity for Y(III) and Eu(III) transport by using liquid membranes. Sep. Purif. Technol., 239: 1-10 **(10 pages).**

Pérez-Silva, I.; Galán-Vidal, C.A.; Ramírez-Silva, M.T.; Álvarez Romero, G.A.; Páez-Hernández, M.E., (2018). Evaluation of activated composite membranes for the facilitated transport of phenol. E-Polymers, 18(4): 313–319 **(6 pages).**

Pilli, S. R.; Banerjee, T.; Mohanty, K., (2015). Performance of different ionic liquids to remove phenol from aqueous solutions using supported liquid membrane. Desalin. Water Treat., 54(11): 3062–3072 **(10 pages).**

Pont, N.; Salvadó, V.; Fontàs, C., (2018). Applicability of a supported liquid membrane in the enrichment and determination of cadmium from complex aqueous samples. Membranes., 8(2): 21-32 **(11 pages)**.

Qian, Z.; Miedemab, H.; Sahinc, S.; Smet, Sudhölter, E.J.R., (2020). Separation of alkali metal cations by a supported liquid membrane (SLM) operating under electro dialysis (ED) conditions. Desalination., 495: 114631-114647 **(16 pages)**.

Ragaller, F.; Sjule, E.; Urem, Y.B.; Schlegel, J.; El, R.; Urbancic, D.; Urbancic, I;, Blom, H.; Sezgin, E., (2024). Quantifying Fluorescence Lifetime Responsiveness of Environment-Sensitive Probes for Membrane Fluidity Measurements. J. Phys. Chem. B, 128(9): 2154–2167 **(13 pages).**

Razi, A.M.; Saien, J., (2019). Salt effects on liquid-liquid equilibria of water + phenol + (Propan-2-yl) benzene + salts systems. J. Chem. Eng. Data. 64(6): 2414–2422 **(8 pages).**

Reyes, A.J.A.; Gonzalez, M.P.; Navarro, R.; Saucedo, T.I.; Avila-Rodriguez. M., (2008). Supported liquid membranes (SLM) for recovery of bismuth from aqueous solutions. J. Memb. Sci., 310: 13–19 **(6 pages)**.

Rosly, M.B.; Jusoh, N.; Othman, N.; Rahman, H.; Sulaiman, R. N. R.; Noah, N.F.M., (2020). Stability of emulsion liquid membrane using bifunctional diluent and blended nonionic surfactant for phenol removal. Chem. Eng. Process., 148: 107790-107803 **(13 pages)**.

Rosly, N.; Othman; Rahman, H.A., (2018). Liquid membrane component selection for removal of phenol from simulated aqueous waste solution. Malay. J. Anal. Sci., 22(4): 702 – 714 **(12 pages)**.

Saik Su, G.; Morad, N.; Ismail, N.; Rafatullah, M., (2022). Developments in supported liquid membranes for treatment of metal-bearing wastewater. Sep. Purif. Rev., 51(1): 38–56 **(18 pages).**

Saka, C.; Kiswandono, A. A.; Hadi, S., (2020). Synthesis of polymer inclusion membranes based on PVC containing copoly-EDVB 4% as a carrier for removal of phenol solutions, Poll. Res., 39(4): 1009-1016 **(7 pages)**.

Sun, H.; Yao, J.; Li, D.; Li, Q.; Liu, B.; Liu, S.; Cong, H.; Sjak, V.; Feng, C., (2017). Removal Of Phenols From Coal Gasification Wastewater Through Polypropylene Hollow Fiber Supported Liquid Membrane, Chem. Eng. Res. Desalination., 123, 277-283 **(6 pages)**.

Syawaliah, S.; Arahman, N.; Riza, M.; Mulyati, S., (2018). The influences of polydopamine immersion time on characteristics and performance of polyvinylidene fluoride ultrafiltration membrane. MATEC Web of Conference. 197: 1-6 **(6 pages).**

Sygoun, V.; Pantziaros, A.G.; Lakovides; Sfetsa, I.C.; Bogdou, E.; Christoforou, P.I.; Paraskeva, C.A., (2019). Treatment of two-phase olive mill wastewater and recovery of phenolic compounds using membrane technology. Membranes., 9(27): 1-16 **(16 pages)**.

Syukri, H.S.; Kurniawan, F.; Hari, P.D.; Fiana, R.M.; Rini. (2024). Bacterial reduction in river water using nanocellulose membrane from pineapple biomass with ferrous-ferric oxide reinforcement. Global J. Environ. Sci., 10(2): 643–656 **(13 pages)**.

Tran, T.T.V.; Nguyen, C.H.; Lin, W. C.; Juang, R.S., (2021). Improved stability of a supported liquid membrane process via hydrophobic modification of PVDF support by plasma activation and chemical vapor deposition. Sep. Purif. Technol., 277: 1-13 **(13 pages).**

Topkara, D.; Tutkun, O.; Izakov, J.; Shaykieva, N. (2019). Phenol recovery and removal from aqueous solutions by emulsion liquid membranes. MANAS J. Eng., 7(2): 68–73 **(6 pages)**.

Xu, D.; Shah, Z.; Sun, G.; Peng, X.; Cui, Y., (2019). Recovery of rare earths from phosphate ores through supported liquid membrane using N,N,N′,N′-tetraoctyl diglycol amide. Miner. Eng., 139: 1-8 **(8 pages).**

Yang, X.; Duan, H.; Shi, D.; Yang, R.; Wang, S.; Guo, H., (2015). Facilitated transport of phenol through supported liquid membrane containing bis(2-ethylhexyl) sulfoxide (BESO) as the carrier, Chem. Eng. Process. Process Intensif., 93: 79–86 **(7**

pages).

Yildirim, M.; Sumnu, G.; Sahin, S., (2017). The effects of emulsifier type, phase ratio, and homogenization methods on stability of the double emulsion, J. Dispersion Sci. Technol., 38(6): 807–814 **(7 pages)**.

Zhou, H.; Zhang, X.; Lv, T.; Guo, Q.; Wang, L., (2019). Comparative study of solvent extraction and supported liquid membrane for the extraction of gallium (III) from chloride solution using organophosphorus acids as extractants, Sep. Sci. Technol., 3012-3027 **(15 pages)**.

Zidi, C.; Tayeb, R.; Dhahbi, M., (2011). Extraction of phenol from aqueous solutions by means of supported liquid membrane (MLS) containing tri-n-octyl phosphine oxide (TOPO), J. Hazard. Mater., 194: 62–68 **(6 pages)**.

AUTHOR (S) BIOSKETCHES

Agung. A.K., Dr., Assistant Professor, Department of Chemistry, Faculty of Mathematics and Natural Sciences, University of Lampung, Jl. Prof. Dr. Ir. Sumantri Brojonegoro No.1, Bandar Lampung City, Lampung 35141, Indonesia.
- Email: *agung.abadi@fmipa.unila.ac.id*
- ORCID: 0000-0002-8145-1959
- Web of Science ResearcherID: NA
- Scopus Author ID: 55532426900
- Homepage: https://kimia.fmipa.unila.ac.id/

Nurhudawati, N., M.Si., Research Assistant, Department of Chemistry, Faculty of Mathematics and Natural Sciences, University of Lampung, Jl. Prof. Dr. Ir. Sumantri Brojonegoro No.1, Bandar Lampung City, Lampung 35141, Indonesia.
- Email: *nurhudawati15@gmail.com*
- ORCID: 0000-0002-3024-5645
- Web of Science ResearcherID: NA
- Scopus Author ID: -
- Homepage: https://kimia.fmipa.unila.ac.id/

Annur, V.S., S.Si., Research Assistant, Department of Chemistry, Faculty of Mathematics and Natural Sciences, University of Lampung, Jl. Prof. Dr. Ir. Sumantri Brojonegoro No.1, Bandar Lampung City, Lampung 35141, Indonesia.
- Email: *sindiannur7@gmail.com*
- ORCID: 0009-0006-1656-9578
- Web of Science ResearcherID: NA
- Scopus Author ID: 58802912900
- Homepage: https://kimia.fmipa.unila.ac.id/

Rinawati, Ph.D., Assistant Professor, Department of Chemistry, Faculty of Mathematics and Natural Sciences, University of Lampung, Jl. Prof. Dr. Ir. Sumantri Brojonegoro No.1, Bandar Lampung City, Lampung 35141, Indonesia.
- Email: *rinawati@fmipa.unila.ac.id*
- ORCID: 0000-0002-8145-1959
- Web of Science ResearcherID: NA
- Scopus Author ID: 55155732500
- Homepage: https://kimia.fmipa.unila.ac.id/

Qudus, H.I., Dr., Professor, Department of Chemistry, Faculty of Mathematics and Natural Sciences, University of Lampung, Jl. Prof. Dr. Ir. Sumantri Brojonegoro No.1, Bandar Lampung City, Lampung 35141, Indonesia.
- Email: *hardoko.insan@fmipa.unila.ac.id*
- ORCID: 0000-0003-3317-6806
- Web of Science ResearcherID: NA
- Scopus Author ID: 57131159900
- Homepage: https://kimia.fmipa.unila.ac.id/

HOW TO CITE THIS ARTICLE

Agung, A.K.; Nurhudawati, N., Annur, V.S.; Rinawati ; Qudus, H.I., (2024). Phenol solutions recovery as water pollutants with eugenol cross-linked diallyl phthalate using supported liquid membrane. Global J. Environ. Sci. Manage., 10(SI): 53-70.

DOI: 10.22034/gjesm.2024.10.SI.04

URL: https://www.gjesm.net/article_715544.html