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# Application of Polymer Inclusion Membrane in the Transport of Malachite Green Dye Using Copolymer(Eugenol-Diallyl Phthalate) 2% as a Carrier

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## Abstract

Malachite green is a compound commonly used as a dye for silk, leather, wool, cotton, and paper. Additionally, malachite green is utilized as a bacterial stain in microscopic analysis of cells and tissues. This study explores the transport of malachite green using the 2% copolymer of eugenol-diallyl phthalate (Co-EDAF) with the Polymer Inclusion Membrane (PIM) method. Several parameters influencing the transport of malachite green were investigated, including the pH of the source phase, $HNO_3$ concentration in the receiving phase, PIM membrane thickness, and transport duration. The PIMs were prepared by dissolving the carrier 2% Co-EDAF, polyvinyl chloride (PVC), and dibenzyl ether (DBE) in tetrahydrofuran (THF). The concentration of malachite green after transport was measured using UV-Vis spectrophotometry at a wavelength of 613 nm. The results showed that the PIM with 2% Co-EDAF effectively transported malachite green with an efficiency of 91.30% under optimal conditions: source phase pH of 9, $HNO_3$ concentration of 0.75 M, PIM membrane thickness at $T_{54}$, and transport duration of 18 hours.

## 1. Introduction

The rapid growth of industrial activities has led to environmental pollution as a side effect. This is due to industrial waste being discharged into the environment with pollutant levels exceeding the permissible limits. One of the causes of environmental pollution is the presence of dye substances in wastewater released into the environment, such as malachite green, a widely used dye in the textile industry. Malachite green is known for its high stability and strong recalcitrance, indicating carcinogenic, mutagenic, and teratogenic properties that can directly damage human living cells [1]. Treatment of dye substances is crucial to address various environmental issues caused by them. The allowable concentration of malachite green in water is 0.01 ppm [2]. Given the potential hazards it poses, wastewater treatment is necessary to reduce the concentration of malachite green compounds.

Conventional dye removal methods such as adsorption, photocatalytic degradation, and chemical oxidation are widely accepted in the treatment of textile industry wastewater due to their ability to be applied on a large scale [3]. However, these methods have drawbacks in terms of relatively high production, operational, and maintenance costs. The separation of malachite green using adsorption techniques with various adsorbents such as zeolite, silica gel, activated carbon, graphite, chitosan, and bentonite is generally cost-inefficient and requires significant amounts of materials and energy inputs [4].

Based on the description above, membrane separation presents a promising alternative for malachite green waste treatment. According to their structure and separation principles, membranes are classified into three types: porous, non-porous, and liquid. Among these, liquid membrane techniques are widely employed for malachite green removal from aquatic environments due to their high diffusivity in liquid media. Liquid membrane systems offer several advantages over conventional separation methods. They enable continuous operation, require lower energy consumption, and can be integrated with other separation processes. Additionally, they operate under mild conditions and allow for the customization of membrane components to meet specific treatment needs [5].

Almeida *et al.* [6] highlight that liquid membranes are more cost-effective than liquid-liquid extraction methods while offering high stability. Liquid membrane separation techniques utilize an effective carrier, are easy to prepare, and exhibit versatility, stability, and favorable chemical and mechanical properties. The liquid membrane transport technique involves three phases: the source phase, which contains the target compound; the membrane phase, which includes the carrier in an organic solvent; and the receiving phase, which acts as the release agent for the carrier compound-complex. The carrier is one of the components in the membrane, allowing the separation process to occur.

One potential carrier for malachite green transport is copolymer (eugenol-diallyl phthalate) (Co-EDAF), a copolymer derived from eugenol. Its copolymerization is expected to enhance the number of active sites on the polymer, improving its efficiency as a carrier in the malachite green transport process. The carrier compound facilitates the target compound through the membrane in the malachite green transport process. A membrane is a layer between two adjacent phases that acts as a selective barrier, capable of regulating the transport of chemical components across the separated sides [7].

The separation of malachite green using liquid membranes is based on the difference in the solubility of malachite green in the solution and organic phases. This aligns with the definition of a liquid membrane as a thin liquid layer that is semipermeable and separates two liquid phases or two gas phases. The separation mechanism in liquid membranes is not governed by the membrane itself but rather by the specific properties of the carrier molecules. These carrier compounds remain within the membrane and can move if dissolved in the liquid phase [8]. One effective type of liquid membrane for separating malachite green is the Polymer Inclusion Membrane (PIM) method.

PIMs are fabricated by combining a carrier compound, a plasticizer, and a base polymer in a solution, which is then cast into a mold to form a thin, stable, and flexible film [1]. PIMs are known for their enhanced stability, primarily due to two factors: the base polymer (e.g., polyvinyl chloride, PVC) helps prevent leakage of the carrier compound, while the plasticizer contributes to the overall stability of the membrane system. Among the key advantages of PIMs are their ease of operation, reduced chemical usage, and the ability to create flexible and highly selective membranes, enabling efficient separation processes.

Therefore, this study focuses on optimizing and evaluating the transport capabilities of malachite green by investigating key parameters such as pH variations, concentration levels, and membrane durability, including factors like membrane thickness and transport time. Additionally, the study explores the competitive transport of malachite green in synthetic wastewater using a PIM incorporated with a 2% Co-EDAF as the carrier compound.

## 2. Experimental

### 2.1. Materials and Instrument

The materials used in this study included malachite green, 2% Co-EDAF (0.054 g), double-distilled water, distilled water, polyvinyl chloride (PVC) (0.1728 g), dibenzyl ether (DBE) (0.3132 g), tetrahydrofuran (THF) (10 mL), and nitric acid ($HNO_3$) (1 M). The instruments utilized in this research were a Scanning Electron Microscopy-Energy Dispersive X-ray (SEM-EDX; ZEISS EVO MA 10), a Fourier Transform Infrared (FT-IR; spectrometer Cary 630), and a UV-Vis Spectrophotometer (Shimadzu 1800).

### 2.2. Preparation of Polymer Inclusion Membrane (PIM)

PIMs were cast with total weights of 0.27 g, 0.54 g, and 1.08 g in a mold equipped with a magnetic stirrer, as detailed in Table 1. The membrane components consisted of 2% Co-EDAF as the carrier, PVC as the base polymer, and DBE as the plasticizer. For each PIM, 10 milliliters of THF were used as a solvent to homogenize the mixture within the mold. After casting, the membranes were left to sit for three days to allow the solvent to evaporate naturally.

After the PIMs were prepared, they were first weighed before being used in the malachite green transport process, which was conducted in a chamber. The source phase consisted of a 25 ppm malachite green solution, while the receiving phase contained $HNO_3$, which acted as a binding agent. Membranes, both before and after the transport process, were analyzed using FT-IR spectroscopy and SEM.

### 2.3. Malachite Green pH Variation in Source Phase

PIMs, with standard thickness, pre-cast, and containing the carrier, were placed at the center of a transport pipe. Then, 50 mL of 1 M $HNO_3$ was added as the receiving phase, and 50 mL of 25 ppm malachite green was added as the source phase. The pH of the source phase was adjusted to 5.0, 6.0, 7.0, 8.0, and 9.0. The transport pipe was sealed and stirred continuously for 12 hours using a magnetic stirrer. After stirring, 5 mL samples were taken from both the source and receiving phases. The concentration of malachite green in both phases was analyzed using a UV-Vis spectrophotometer at the maximum wavelength.

**Table 1**. Comparison of the weight ratio of membrane components (10:32:58)

| Membrane | Co-EDAF (g) | PVC (g) | DBE (g) | Total weight (g) |
|---|---|---|---|---|
| $T_{27}$ | 0.0270 | 0.0864 | 0.1556 | 0.2700 |
| $T_{54}$ | 0.0540 | 0.1728 | 0.3132 | 0.5400 |
| $T_{108}$ | 0.1080 | 0.3456 | 0.6264 | 1.0800 |

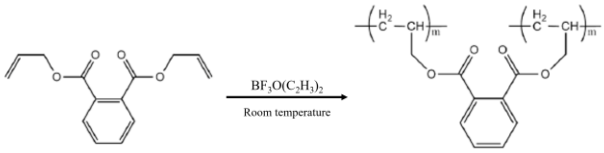

**Figure 1**. The polymerization reaction of DAF [9]

### 2.4. Variation of $HNO_3$ Concentration in the Receiving Phase

The PIMs, with standard thickness and containing the carrier compound, were placed in the center of a transport pipe. Then, 50 mL of $HNO_3$ was added as the receiving phase, and 50 mL of 25 ppm malachite green at the optimum pH was added as the source phase. The concentration of $HNO_3$ in the receiving phase was varied to 0.50, 0.75, 1.00, 1.25, and 1.50 M. The transport pipe was sealed and stirred for 12 hours using a magnetic stirrer. After stirring, 5 mL samples were taken from both the source and receiving phases. The concentration of malachite green in both phases was analyzed using a UV-Vis spectrophotometer at the maximum wavelength.

### 2.5. Membrane Thickness Variation

PIMs with varying thicknesses of thin ($T_{27}$), standard ($T_{54}$), and thick ($T_{108}$) that had been cast and contained the carrier were placed in the center of a transport pipe. Then, 50 mL of $HNO_3$ at optimum concentration was added as the receiving phase, and 50 mL of 25 ppm malachite green at optimum pH was added as the source phase. The transport pipe was sealed and stirred for 12 hours using a magnetic stirrer. After stirring, 5 mL samples were taken from both the source and receiving phases. The concentration of malachite green in both phases is analyzed using a UV-Vis spectrophotometer at the maximum wavelength.

### 2.6. Transport Time Variation

The PIMs, with optimal thickness and pre-cast containing the carrier compound, were placed in the center of a transport pipe. Then, 50 mL of $HNO_3$ at optimum concentration was added as the receiving phase, and 50 mL of 25 ppm malachite green at optimum pH was added as the source phase. The transport pipe was sealed and stirred for varying durations of 6, 9, 12, 16, 18, and 24 hours using a magnetic stirrer. After stirring, 5 mL samples were taken from both the source and receiving phases. The concentration of malachite green in both phases was analyzed using a UV-Vis spectrophotometer at the maximum wavelength.

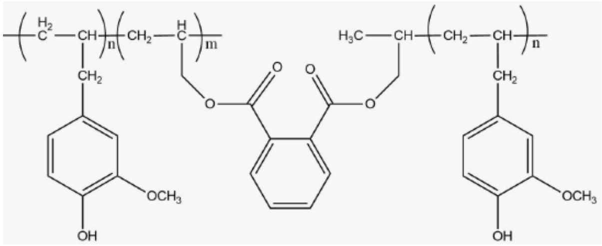

**Figure 2**. Prediction of the structure of cross-linked polyeugenol derivatives using DAF [9]

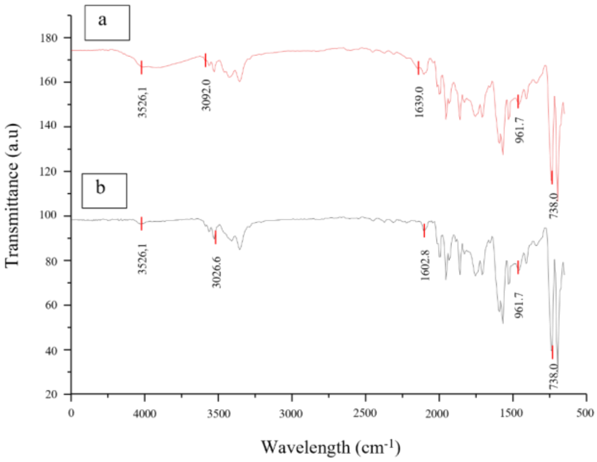

**Figure 3**. FTIR spectra of PIMs: a) before and b) after malachite green transport (transport time: 18 hours)

## 3. Results and Discussion

### 3.1. Membrane Characterization

Co-EDAF is a modified result of the eugenol compound through the copolymerization process, where diene monomer is added as a cross-linking agent. The diene compound often used in this context is diallyl phthalate (DAF). The double bond in diene compounds is very reactive, allowing the synthesis process to be done easily at room temperature only with the help of a weak acid catalyst. Polymerization of the diene compound occurs in the allyl group, as shown in Figure 1.

In addition to having an –OH group, Co-EDAF has a benzene structure that allows $\pi$-$\pi$* interactions with the aromatic benzene ring in malachite green. $\pi$-$\pi$* interactions are interactions formed from two or more benzene rings. In the malachite green transport process, the interactions in the polyeugenol and malachite green transport process are hydrogen bonds and $\pi$ bonds [10].

The transport mechanism of malachite green with Co-EDAF membrane is predicted to occur through hydrogen bonds and $\pi$-$\pi$* interactions between malachite green and Co-EDAF (Figure 2). In addition, the reaction of malachite green with $HNO_3$ in the receiving phase causes the malachite green anion to be unable to return to the hydrophobic membrane or the source phase. Transport on the membrane occurs if the malachite green component is undissociated in the source phase and as a malachite green ion in the receiving phase. In this condition, the pH of the source affects the transport process [10]. SEM and FTIR analyses are conducted on the membrane before and after transport under optimal conditions. Figure 3 shows the FTIR analysis results for the membrane before and after transport.

The observed decrease in intensity of the -OH group (Figure 3b) indicates that one of the membrane components, specifically the carrier compound, has diminished. This suggests that the -OH groups in the carrier compound have undergone leaching. The detailed functional groups and their intensities can be found in Table 2.

**Table 2**. Comparison of PIM Co-EDAF functional groups before and after transport

| Functional group | Wavelength ($cm^{-1}$) | |
|---|---|---|
| | Before transport | After transport |
| -OH | 3451 | 3451 |
| Stretch $Csp^3$-H ($-CH_3$) | 3092 | 3092 |
| The aromatic ring (C=C) | 1639 | 1639 |
| Vinyl ($CH_2$=CH-) | 907 | 906 |
| The aromatic ring (C-H) | 695 | 695 |

According to Zhao *et al.* [11], using membranes for transport can lead to leaching of the membrane components. Components that may leach from the membrane include the carrier compound, the base polymer, and the plasticizer. Thus, the active sites of the carrier compound within the membrane are not lost during the transport process; instead, leaching occurs from other membrane components. This indicates that the 2% Co-EDAF membrane is effective and selective for transporting malachite green. This is supported by the morphological characterization results of the PIMs using SEM before and after transport, which achieved optimal conditions.

The active group lost during the transport process is part of the membrane components. The effectiveness of transport has been stated in the receiving phase as the performance of the membrane. The percentage of malachite green transport is stated with optimum conditions, and this is linear with the membrane liquid loss value (including the active group of the carrier).

Figure 4 shows the morphological structure of the PIMs with a 2% Co-EDAF carrier before and after transport. The membrane before transport shows smooth pores with a varying yet nearly uniform size. In contrast, the membrane, after transport, exhibits numerous and larger cavities or pores. The formation of these cavities indicates that the membrane has undergone leaching or the release of components during the transport process.

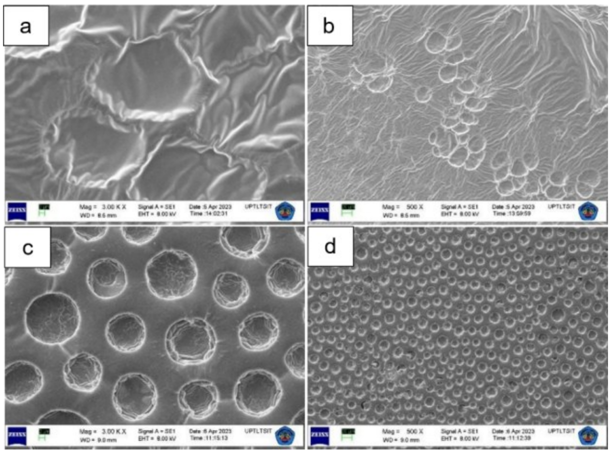

**Figure 4**. Surface morphology of PIMs before transport at (a) 3000× and (b) 500× magnification, and after transport at (c) 3000× and (d) 500× magnification

**Table 3**. Results of %removal of pH variation of malachite green source phase

| pH malachite green | %removal |
|---|---|
| 5 | 56.46 |
| 6 | 58.84 |
| 7 | 66.08 |
| 8 | 69.09 |
| 9 | 76.33 |

According to Zhao *et al.* [11], using membranes for transport can lead to leaching of membrane components. This leaching causes the PIMs' surface to become porous. The components that may leach include the carrier compound, the base polymer, or the plasticizer. This observation is further supported by the weight difference of the membrane before and after transport, measured by weighing. This weight difference is called liquid membrane loss.

### 3.2. Malachite Green Transport with pH Variation in Source Phase

Malachite green, the receiving phase ($HNO_3$), and the membrane phase containing the 2% Co-EDAF carrier. The percentage concentration of malachite green in the membrane phase that is subsequently transported to the receiving phase is expressed as %removal, while the concentration in the source phase is expressed as %Cs. Each solution from the source and receiving phases is calculated based on the change in the amount of malachite green transported through the membrane.

The effect of pH on the malachite green solution in the source phase on the transport of malachite green is studied at pH levels 5, 6, 7, 8, and 9. pH is a critical factor in this study because it serves as an indicator that can influence diffusion through the membrane due to the concentration gradient of protons between the source and receiving phases. The results regarding the impact of source phase pH on the transport of malachite green are shown in Figure 5.

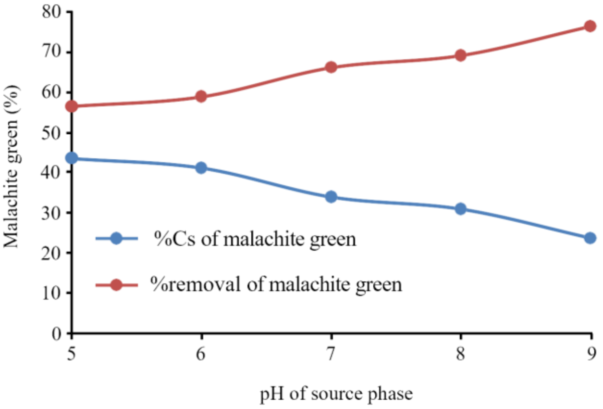

**Figure 5**. The effect of pH of malachite green in the source phase on the concentration of transported malachite green (%Cs: source phase, %removal: concentration of malachite green in the membrane phase and the receiving phase)

Based on the graph in Figure 5, there is a change in the amount of malachite green transported with varying pH levels, and the 2% Co-EDAF liquid membrane effectively transports malachite green. The results of the %removal for different pH variations of malachite green can be seen in Table 3.

Table 3 shows that the efficiency of the malachite green transport process reaches optimal conditions at a pH of 9. This is because malachite green at pH 9 tends to be in its molecular form, which allows for more hydrogen bonding. Additionally, the tendency for the target compound to be more soluble in the organic phase enhances $\pi$-$\pi$ interactions and hydrogen bonding between malachite green and the carrier compound in the membrane phase. This increased interaction results in more transported malachite green [12].

According to Elma [13], the efficiency and separation process is low at pH levels 5 and 6 in the source phase. Transport becomes efficient when the solute (malachite green) is extracted in a state above acidic pH. In this study, the %removal at pH 5 and 6 are 56.46% and 58.84%, respectively. This is because, at more acidic pH levels, the number of protons increases, which hinders the malachite green molecules due to free protons that tend to be transported toward the basic receiving phase. The excess protons in the source phase tend to protonate the membrane, making the interaction between malachite green and the carrier molecules less effective. This results in competition among malachite green molecules for interaction with the carrier, leading to less transported malachite green [12].

The same pattern occurs at pH 7 and 8. At these pH levels, the amount of malachite green transported into the receiving phase also increases, but the %removal is not as high as at pH 9, which is the optimum value for this variation. According to Iqbal and Datta [14], neutral and slightly basic pH conditions in the source phase result in optimal transport. On the other hand, acidic pH levels lead to reduced efficiency in malachite green transport. Research by Ling and Mohd Suah [1] indicates that the optimal pH for removing malachite green from dye waste is between pH 7-9, and excessively high pH (>9) can affect the efficiency of malachite green removal in aquatic environments. Removal of the dye increases with higher pH values in the source phase. This can be attributed to the fact that at higher pH levels, dye solubility decreases, and hydroxyl (-OH) group dissociation occurs, leading to reduced dye intensity.

### 3.3. Transport of Malachite Green with Variation of $HNO_3$ Concentration in the Receiving Phase

This research examines the concentration of the receiving phase as a factor affecting the transport of malachite green through the membrane phase. Malachite green is transported to the receiving phase due to the driving force created by the concentration difference between the receiving and source phases. The receiving phase solution acts as a solvent for the target compound. One of the variables to consider in the study of malachite green transport is the concentration of the receiving phase. In this study, the receiving phase used is $HNO_3$. The variations in $HNO_3$ concentration tested are 0.50, 0.75, 1.0, 1.25, and 1.5 M. Transport is carried out at the optimum pH of the source phase, which is pH 9.

Based on the results, the transport of malachite green reaches its optimum state at an $HNO_3$ concentration of 0.75 M with a %removal of 81.62%. The effect of $HNO_3$ concentration on the transport of malachite green is shown in Figure 6. Based on the graph in Figure 6, this study shows the effect of $HNO_3$ concentration in the receiving phase on the percentage of malachite green transported. The results of the %removal at different concentrations of the receiving phase are presented in Table 4.

Table 4 shows that the results exhibit both increases and decreases. The optimum condition is achieved at an $HNO_3$ concentration of 0.75 M. The %removal increases within the concentration range of $HNO_3$ from 0.5 to 0.75 M, whereas it decreases at concentrations of 1 to 1.5 M. This is due to the dissociation of $HNO_3$ in the receiving phase into its ions, namely nitrate ions ($NO_3^-$) and hydronium ions ($H_3O^+$), which affect the transport of malachite green. Additionally, concentrations not at the optimum level may lead to the leaching of active sites on the membrane, resulting in limited active sites. Higher $HNO_3$ concentrations make it more difficult for the target compound to be transported to the receiving phase due to the increased acidity, which results in the release of the target compound being less effective compared to the nitrate and hydronium ions present in the receiving phase.

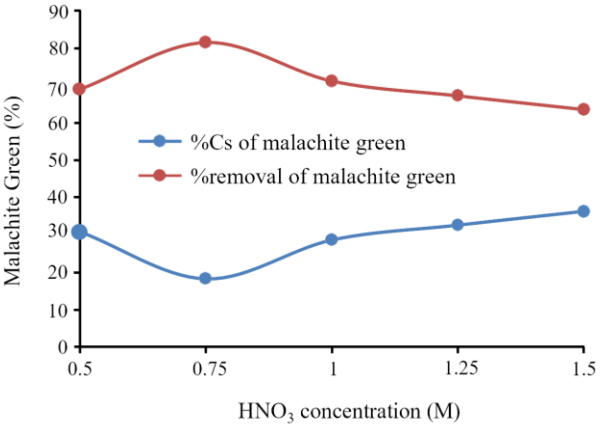

**Figure 6**. The effect of $HNO_3$ concentration in the receiving phase on the concentration of transported malachite green (%Cs: malachite green concentration in the source phase, %removal: malachite green concentration in the membrane phase and receiving phase)

**Table 4**. Results of %removal of variation in the concentration of the $HNO_3$ receiving phase

| $HNO_3$ concentration (M) | %Removal of malachite green |
|---|---|
| 0.50 | 69.09 |
| 0.75 | 81.62 |
| 1 | 71.27 |
| 1.25 | 67.32 |
| 1.50 | 63.65 |

### 3.4. Malachite Green Transport with Variation of PIM Membrane

In this study, the thickness of a membrane is influenced by several factors, one of which is the variation in the total weight of the components forming the membrane, leading to differences in the membrane thickness.

The PIMs were prepared in three thickness variations: $T_{27}$, $T_{54}$, and $T1_{08}$, with total weights of 0.27, 0.54, and 1.08 g, respectively. It is anticipated that as the amount of carrier compound (with -OH groups), the base polymer (PVC), and the plasticizer (DBE) increases in the membrane, the transport process will become more effective. In this stage, the transport of malachite green through each thickness variation of the PIM was conducted based on the previously determined optimum source phase pH and the optimum $HNO_3$ concentration in the receiving phase. The results regarding the effect of membrane thickness are shown in Figure 7. Based on the graph in Figure 7, the results of membrane thickness variations show an increase and decrease in %removal. The results of membrane thickness variations can be seen in Table 5.

Table 5 shows that the most optimum %removal of malachite green transport occurs with membrane thickness variation at $T_{54}$, with a transported malachite green percentage of 84.13%. This result is due to the effective interaction between malachite green molecules and the carrier compound. Additionally, for membrane thickness variations $T_{27}$ and $T_{108}$, the transported malachite green percentages are 66.31% and 79.59%, respectively.

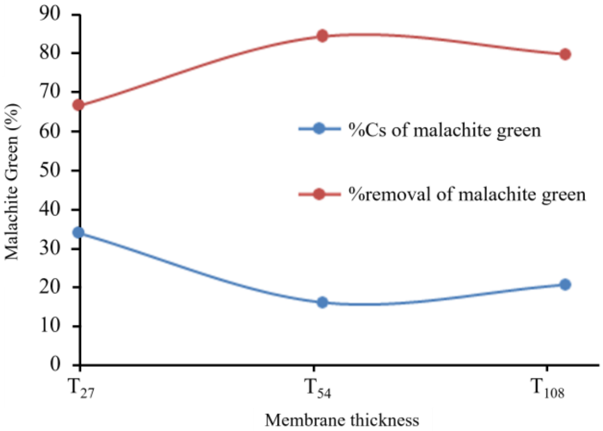

**Figure 7**. Effect of PIM membrane thickness on the transported malachite green concentration (%Cs: malachite green concentration in the source phase, %removal: malachite green concentration in the membrane phase and the receiving phase)

**Table 5**. Results of %removal of membrane thickness variation

| Membrane thickness | %Removal of malachite green |
|---|---|
| $T_{27}$ | 66.31 |
| $T_{54}$ | 84.13 |
| $T_{108}$ | 79.59 |

Optimal malachite green transport is achieved when the interaction between malachite green molecules and the carrier is maximized, and the membrane thickness is neither too thick nor too thin, which allows for relatively fast transport. Very thin membranes can lead to less optimal malachite green transport due to the limited number of carriers, which may cause competition between malachite green molecules and the carrier to be less effective. Conversely, membranes that are too thick can also result in less optimal malachite green transport due to the high amount of plasticizer added, which can obstruct the transport process and lead to a lower amount of malachite green being transported to the receiving phase.

Plasticizers in membranes serve to form or solidify the membrane. Using a smaller amount of plasticizer decreases the viscosity of the membrane. This means that a smaller amount of plasticizer results in lower viscosity, whereas a larger amount increases the viscosity [15]. A large amount of plasticizer can cause the membrane's pores to become covered, thus obstructing the diffusion of malachite green through the membrane. Consequently, the transport percentage decreases as the viscosity of the plasticizer increases [16]. This study uses DBE as a plasticizer to cover the membrane's pores, seeping to the membrane's surface and hindering the interaction between malachite green and the active Co-EDAF groups.

### 3.5. Malachite Green Transport with Variation of Transport Time

This study investigates the transport of malachite green with variations in transport time. The variations in contact time were conducted at the optimum pH of the source phase, optimum $HNO_3$ concentration, and optimum membrane thickness.

As the transport time increases, the interaction between malachite green and the carrier compound in the membrane is expected to improve. Enhanced interaction between malachite green and the carrier compound should increase the concentration of malachite green transported to the receiving phase. The transport of malachite green was carried out with varying times of 6, 9, 12, 18, and 24 hours using 2% Co-EDAF as the carrier compound in the preparation of PIMs. The results of the malachite green transport with varying transport times are shown in Figure 8. The research results in Figure 8 indicate an increase in %removal in the receiving phase between 6 and 18 hours. However, a decrease is observed at 24 hours. The results obtained from this variation can be seen in Table 6.

**Table 6**. Result of %removal of transport time variation

| Transport time (hour) | %Removal of malachite green |
|---|---|
| 6 | 50.76 |
| 9 | 71.44 |
| 12 | 87.93 |
| 18 | 91.30 |
| 24 | 60.86 |

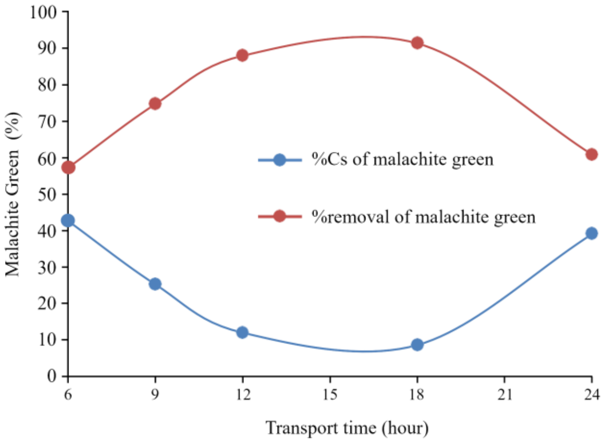

**Figure 8**. Effect of time variation on the concentration of transported malachite green (%Cs: malachite green concentration in the source phase, %removal: malachite green concentration in the membrane phase and the receiving phase)

Table 6 shows that the optimum result for varying transport times occurs at 18 hours, with %removal of 91.30%. The transport of malachite green increases with longer transport times. This is because longer transport times allow for more extended interaction between malachite green and the carrier compound in the membrane. Prolonged interaction between malachite green and the membrane results in a faster release of malachite green ions into the receiving phase [17]. Table 6 also shows that with a 6-hour transport time, 50.76% of malachite green is transported. A shorter transport time results in less malachite green being transported. At 9 hours, 71.44% of malachite green is transported, increasing with longer transport times until the optimum transport time is reached.

The transport of malachite green increases with extended transport time. However, this trend does not hold for transport times exceeding 18 hours, such as 24 hours. Table 6 shows that the transported malachite green at 24 hours decreases to 60.86%. This decrease is due to the $HNO_3$ in the receiving phase becoming saturated or binding a significant amount of malachite green ions, thus unable to bind more. According to Purwasih [18], the concentration gradient of malachite green between the source phase and the receiving phase diminishes with increasing transport time. A smaller concentration gradient results in a weaker driving force for transferring malachite green from the source phase to the receiving phase, causing a slower transport rate.

The membrane used in the malachite green transport process may experience leaching or loss of some of its components. According to Soo *et al.* [19], as transport time increases, the interfacial tension and contact angle decrease due to contamination at the membrane-water interface and the degradation of chelating agents, among other factors. The lost membrane components may include DBE, PVC, or the carrier compound. This loss of membrane components, referred to as liquid membrane loss, is detailed in Appendix 6. Several researchers have reported that the loss of membrane components is a primary cause of instability in the transport process using liquid membranes [9, 10, 20].

## 4. Conclusion

The optimal conditions for malachite green transport are achieved with a source phase pH of 9, an optimum receiving phase $HNO_3$ concentration of 0.75 M, and a membrane thickness of $T_{54}$ (normal thickness) during an 18-hour transport time. Under these conditions, the percentage of malachite green transported from the membrane phase to the receiving phase (%removal) is 91.30%.

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