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Utilization of Stripping Agents in the Internal Phase for the Removal of Heavy Metal Contaminants Using Emulsion Liquid Membranes

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Abstract: *Heavy metals have a high density, atomic weight, or atomic number. Heavy metals are potentially hazardous to health and the environment and must be separated. Emulsion liquid membrane is a promising technique to remove heavy metal contaminants from industrial and household effluents. Emulsion liquid membrane (ELM) is used to separate heavy metals as it is effective and efficient. ELM involves external, membrane, and internal phases. The internal phase is essential in the separation process as it carries stripping agents to pull metals from the membrane to the internal phase. The choice of stripping agent concentration in the internal phase, such as* HNO_3*,* H_2SO_4*, HCl, NaOH, and* Na_2CO_3*, affects the extraction efficiency in separating heavying metals using ELM. This article evaluates the effect of stripping agent concentration on extraction efficiency.*

Keywords*: heavy metals, emulsion liquid membrane, internal phase, stripping agent.*

INTRODUCTION

Metals are chemical elements that have an excellent ability to conduct heat and electricity. Metal properties are also often characterized by high melting and boiling points (Al-Sagheer et al., 2017). Heavy metals refer to metals with high density and atomic weight (Wu et al., 2018). The presence of these heavy metals, such as As, Pb, Cr, Cd, Zn, Co, Ni, Ag, and U, can be potentially harmful to the environment and human health due to their tendency to bioaccumulate which is challenging to biodegrade naturally in living organisms that can cause various diseases and disorders and are toxic (Al-Sagheer et al., 2017; Sabry et al., 2007). Due to the potential environmental pollution and risks to human life posed by heavy metals, several studies have been conducted to develop methods for separating heavy metals to rid the environment of these substances (Amenaghawon et al., 2022). In addition, the separation process must also be carried out for heavy metals from their primary and secondary sources, namely industrial waste (Kakoi et al., 1996).

Heavy metals are also significantly beneficial and widely used in various everyday applications. Examples include using heavy metals as electrical conductors, cooking utensils, construction materials for roofs and walls, and jewelry making. Heavy metals also serve as raw materials, catalysts, and additives in various industries. For example, Cr(VI) is used as a color pigment in paints, industrial anti-rust coatings, and chemical catalysts (Ayuningtias, 2013; Kurnia et al., 2023).

Several techniques separate heavy metals, including chemical precipitation, ion exchange, liquid-liquid extraction, electrodeposition, and adsorption (Ahmad et al., 2017). The liquid-liquid extraction method is the most common technique for separating heavy metals. It is often used in the industrial field to separate heavy metals because it allows the solvent to extract the desired substance without dissolving other materials. It can separate heavy metals with high selectivity. However, it has the problem of using many chemical solvents that can pollute the environment, and its separation is limited to heavy metals with similar chemical properties (Hachemaoui & Belhamel, 2017; Husnurrofiq et al., 2021). Then, developing an alternative method that is more effective in separating heavy metals, namely Emulsion Liquid Membrane (ELM) (Kiswandono et al., 2016), the ELM method has more significant potential. The liquid membrane emulsion method is a unique method that attracts attention because it has several advantages, namely the simultaneous extraction and stripping process, which makes it more time-efficient(Widianti et al., 2023). In addition, the solvent used can be reused in ELM, thus supporting the principle of green chemistry and producing a high mass transfer rate (Raji et al., 2017). However, the ELM method has the disadvantage that its efficiency limitations vary. This efficiency depends on the surfactant concentration, internal phase concentration, and feed phase pH. Therefore, separating some metals requires optimization (Purnama et al., 2024).

In the separation process of metals such as heavy metals and rare earth metals by the ELM method, metal ions are extracted from the external water phase into the organic membrane phase and then diffused into the internal water phase for simultaneous stripping (Hirai & Orikoshi, 2004). The three phases that significantly affect the successful separation process by the ELM method are the external phase, which contains a collection of metal ions to be separated; the membrane phase, which consists of a mixture of extractants and surfactants in organic solvents; and the internal phase, which consists of stripping agents (Azarang et al., 2019).

The internal phase is essential in the separation process because its presence acts as a medium that carries the stripping agent. The stripping agent is responsible for pulling heavy metals from the membrane phase and precipitating them in the internal phase because it has a high affinity for the heavy metals to be separated. With the reaction mechanism, the first metal ions react with protons or hydroxides from the stripping agent, and then metal ions form complexes with the stripping agent. They result in the separation of heavy metals (Djunaidi & Haris, 2003). Some substances commonly used as stripping agents in ELM include hydrochloric acid (HCl), sulfuric acid (H2SO4), nitric acid (HNO3), sodium hydroxide (NaOH), sodium carbonate (Na2CO3) (Ahmad et al., 2019). Therefore, this review article discusses the effect of concentration and stripping agent on the internal phase, which is an essential factor in separating heavy metals using the emulsion liquid membrane (ELM) method.

RESULTS AND DISCUSSION

The role of stripping agent and internal phase concentration on emulsion liquid membrane

The internal phase in ELM plays a crucial role in the extraction or separation process. In the internal phase, compounds that have been separated from the external phase enter the internal phase through the membrane (Purwani et al., 2013). In the internal phase, stripping agents with chemical properties can interact with the extractant in the emulsion.

This interaction helps form heavy compounds or reactions with the substance to be extracted and allows it to be transported with the extractant more efficiently and effectively (Hamzah et al. 2015).

A factor affecting the nature and composition of the internal phase in ELM is its concentration. Increasing the concentration of the internal phase to a certain point will increase the extraction and stripping of a metal. However, the concentration of the internal phase is increased further. In that case, it can result in membrane swelling, decrease its stability, and cause surfactants to dissolve on the surface of the internal phase membrane (Davoodi-Nasab et al., 2018a; Shokri et al., 2020). This happens because as the concentration of the internal phase increases, the membrane layer enclosing the internal phase granules becomes thinner. As a result, the emulsion becomes more prone to breakage during the stirring process in extraction (Aprilya et al., 2021). If the concentration of the internal phase is too low, the stripping agent may not be effective in attracting or separating the metal from the membrane phase (Gheorghe et al., 2008). The metal separation process in the membrane interface phase and internal phase is that metal ions will be trapped efficiently in the internal phase and release their bonds with the transport ligand if the concentration of hydrogen ions in the internal phase is high enough. This high concentration of hydrogen ions will push the equilibrium to release metal ions. The higher the concentration of hydrogen ions in the internal phase, the more effectively the metal ions are trapped in it (Hamzah et al., 2012; Hamzah et al., 2015). As for the stripping agent introduced into the internal phase, depending on the solute to be extracted, acidic or basic stripping agents can be used as a stripping phase in the ELM process (Yang et al., 2007).

Nitric Acid (HNO_3)

Nitric acid (HNO_3) is a corrosive liquid substance in the form of a clear, colorless liquid that is a strong acid. HNO_3 is commonly used in industrial applications, such as manufacturing fertilizers, explosives, and organic chemical products (Septiani et al., 2018). Nitric acid is often used as a stripping agent in the ELM method in metal extraction processes because heavy metal ions can form complexes with acids, becoming metal nitrate. Nitric acid can be used with a concentration that is not too high because it has strong oxidizing properties that can disrupt the stability of the emulsion and cause swelling (Meilinda, Noviyanti, et al. 2021). Nitric acid reacts with target components to form more soluble compounds in water. It also separates desired metals from solutions or other mixtures (Setyani et al., 2016). Several studies have been conducted on separating heavy metals using HNO_3 as a stripping agent in the internal phase with the ELM method. Based on research from Rizka et al., the separation of lead (II) metal using solution in a concentration of 3 M in the internal phase obtained an extraction efficiency of 97.95% (Setyani et al., 2016).

Then, in the research of (Hamzah et al., 2015), HNO_3 was used as a stripping agent in the internal phase in the separation of lead (II) ions with variations of 1 M, 2 M, 3 M, and 4 M.

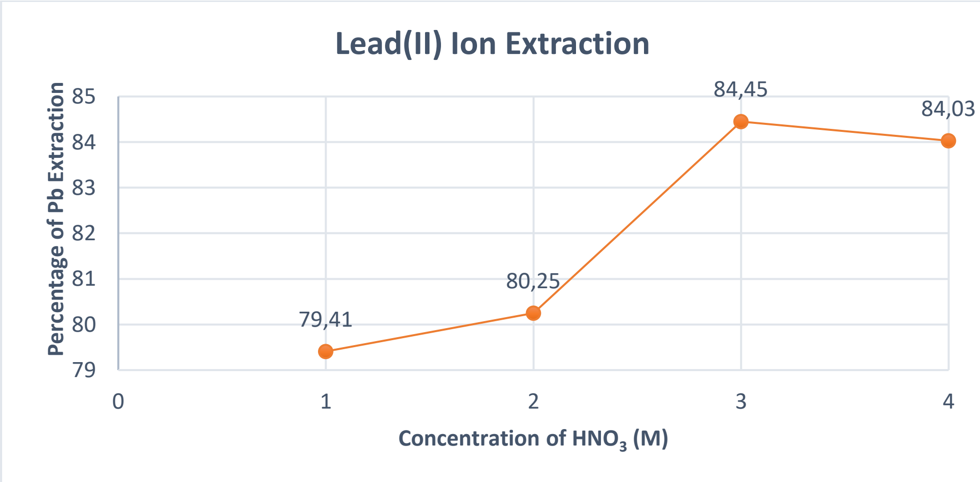

Figure 1. Effect of HNO_3 concentration in internal phase on percent extraction of lead (II) metal ions (Hamzah, Astuti, and Rabiah 2015).

Based on Figure 1, it can be seen that the percentage extraction of lead (II) metal ions reached the maximum value at 3 M HNO_3 concentration compared to other concentrations. The graph shows that the percentage extraction of lead (II) ions increased from 1 M to 3 M HNO_3 concentration, but at 4 M concentration, the percentage extraction remained relatively stable. This observed difference in extraction percentage could be due to increased hydrogen ion concentration in the higher internal phase as the HNO_3 concentration increases. This makes breaking ligand-heavy bonds more efficient due to greater hydrogen ion concentration. The optimum percent extraction of lead (II) ions was obtained at a concentration of 3 M HNO_3 with a percent extraction of 84.45% (Hamzah et al., 2015).

Furthermore, in the research of (Raji et al., 2017), HNO_3 was also used as a stripping agent in the internal phase to separate Dysprosium (III) metal ions by ELM. The concentration of HNO_3 in the internal water phase varied from 0.25 M to 4 M. There was an increase in Dy(III) extraction efficiency from 87% to 99.6% when the HNO_3 concentration increased from 0.25 M to 1 M. However, a further increase in nitric acid concentration up to 4 M led to a decrease in the permeation rate of Dy(III). This was caused by membrane swelling. The swelling comes from the difference in ionic strength between the external and internal phases, reducing the extraction rate. Thus, 1 M was used as the optimum concentration in the internal phase, and the percent extraction of Dy(III) ions was 99.6% (Raji et al., 2017).

Furthermore, research by (Handias et al., 2021) also used HNO_3 as a stripping agent in separating rare earth metals gadolinium. The concentration of HNO_3 used is 0.5 or 2.5 M. The concentration of HNO_3 that affects the swelling ratio response and creaming rate is 0.5 M. So, the efficiency of gadolinium (III) ion extraction is 72.48% with an optimum concentration of 3 M (Meilinda, Bahti, et al. 2021).

Sulfuric Acid (H_2SO_4)

Sulfuric acid, with the chemical formula H_2SO_4, is a strong acid often used in various industrial applications. Sulfuric acid is also a colorless liquid and has hazardous, corrosive properties (Gilson 2020). Many studies have examined using sulfuric acid as a stripping agent in ELMs, especially in heavy metal separation. Sulfuric acid has the potential to be part of the internal phase in ELMs due to its water solubility and ability to form heavy bonds with the compounds to be extracted. Sulfuric acid can also adjust the pH of the internal phase, which can affect the effectiveness of extracting the targeted compounds (Basuki and Sudibyo 2017).

Research from the cobalt (II) ion extraction journal (Gasser et al., 2008) found that the concentration of sulfuric acid for cobalt extraction that gave the lowest breaking effect on emulsion stability was 0.5 M. This is because when the concentration of H2SO4increases, the emulsion stability decreases and can cause leakage of the internal phase and the external phase. This is because when the concentration of H_2SO_4 increases, emulsion stability decreases and can cause leakage of the internal phase to the external phase. This may be due to the reaction between H_2SO_4 and surfactant, which reduces the surfactant's properties, eventually destabilizing the emulsion. The extraction efficiency result of cobalt (II) ion separation was 95% (Gasser et al., 2008).

Furthermore, the research journal (Sabry et al., 2007) mentioned removing lead (II) ions from aqueous solutions. H_2SO_4 was used as a stripping agent in the internal phase. The results showed that when the concentration of sulfuric acid increased from 0.25 to 1 M, the stability of the emulsion would increase, but conversely decreased when the acid concentration was increased gradually from 1 M to 3 M. This may be due to the reaction of the acid with the surfactant which resulted in the loss of some of its surfactant properties. This may be due to the reaction of the acid with the surfactant, which may result in partial loss of its surfactant properties.

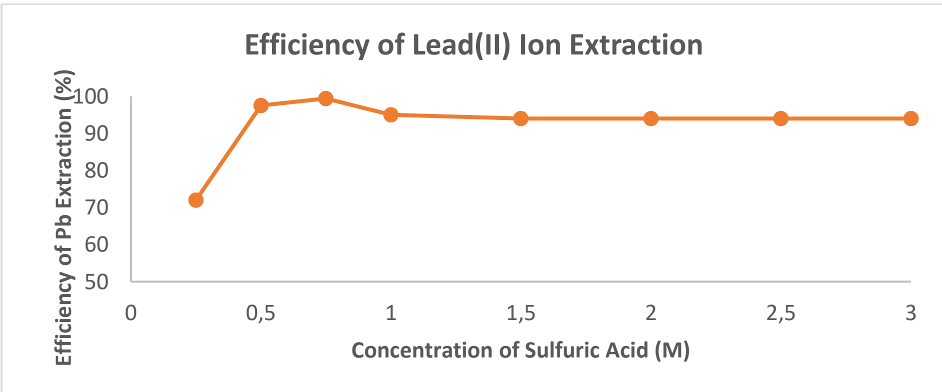

Figure 2. Effect of sulfuric acid concentration in the internal phase on lead (II) removal efficiency (Sabry et al. 2007).

Figure 2 shows the effect of sulfuric acid concentration in the internal phase on lead (II) removal efficiency. The removal efficiency increases sharply with the increase in concentration of H_2SO_4 in the internal phase from 0.25 to 0.5 M, and then the increase is also seen gradually from 0.5 to 1 M concentration. This is due to the increased capacity of the receiving phase. However, for sulfuric acid concentrations greater than 1 M, the emulsion swells due to osmosis, which causes dilution of the internal phase and causes the stripping process to be less effective. So, it was concluded that 1 M H_2SO_4 achieved the highest lead ion removal efficiency of 99.4% (Sabry et al., 2007).

The following research journal (Ma et al., 2018) separates nickel metal (Ni) from ELM. H_2SO_4 was used as a stripping agent in the internal phase at an optimum concentration of 0.5 M. Nickel ion extraction results exceeding 99% can be achieved (Ma et al., 2018).

In the following research journal by (Ahmed et al., 2018), H_2SO_4 was used as a stripping agent at concentrations from 0.2 to 0.5 M to separate lead (II) ions. The results are shown in the graph below.

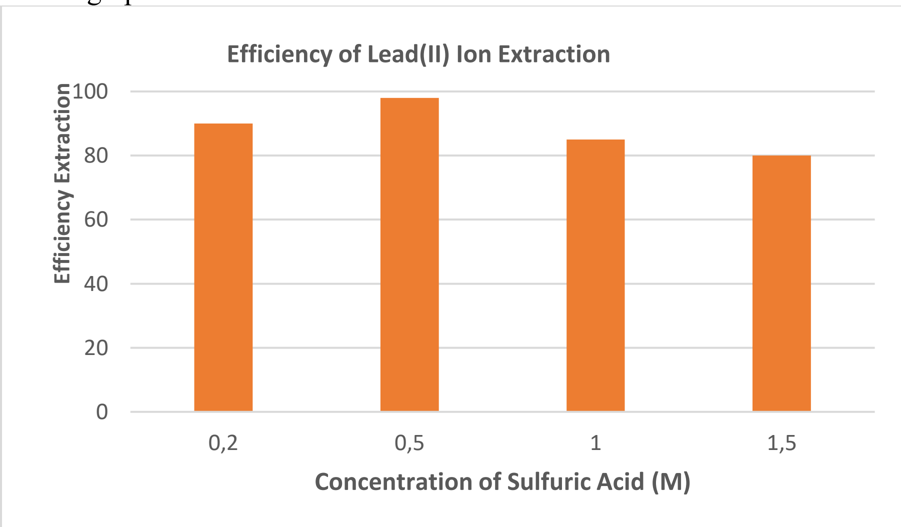

Figure 3. The percentage removal of lead(II) from the H_2SO_4 stripping solution (Mohammed, Selman, and Abukhanafer 2018).

As shown in Figure 3, the percentage of lead removal from the stripping solution first rose and then fell as the concentration of H_2SO_4 increased. Therefore, the extraction efficiency increased as the concentration of H_2SO_4 in the stripping solution increased from 0.2 to 0.5 M. However, it caused the membrane stability to decrease, and there was a decrease in extraction percentage as the H2SO4concentration increased above 0.5 M. At levels above 0.5 M H_2SO_4, the surfactant reacts with H_2SO_4, thus decreasing surfactant activity and affecting membrane stability. It was found that the highest extraction percentage and the lowest emulsion breakage percentage were achieved using 0.5 M H_2SO_4 with an extraction efficiency of 98% (Mohammed et al., 2018).

Hydrochloric Acid (HCl)

Hydrochloric acid is an aqueous solution of gaseous hydrogen chloride known as a strong acid. In addition, HCl has uses in separation techniques, such as the emulsion liquid membrane (ELM) method for separating unique compounds. The existence of HCl provides extensive benefits in everyday life, such as in the steel industry, chemical industry, food industry, and as a cleaning agent in households. Hydrochloric acid (HCl) can act as a stripping agent in the internal phase of the ELM method due to its water-solubility and ability to form heavy bonds with specific compounds such as heavy metals and rare earth metals (Gheorghe et al., 2008).

In the research (Zaheri & Davarkhah, 2017) in the Journal of Uranium (IV) metal separation, HCl solution was selected as a stripping agent in the internal phase with concentrations from 0.05 to 1 M. Then, in the experimental results to optimize the selected factors, the HCl concentration in the stripping phase was selected to be 0.1 M. The high HCl concentration may cause membrane swelling due to the high osmotic pressure gradient between the external and internal phases. The uranium (IV) removal efficiency reached 99.82% (Zaheri & Davarkhah, 2017).

(Sujatha et al. 2022) HCl was also used as a stripping agent in the internal phase to separate cadmium metal ions using the green emulsion liquid membrane (GELM) method. The concentration range used was 0.5-1.5 M, and the cadmium extraction efficiency value obtained was achieved at an internal phase concentration of 0.93 M. However, for concentrations above 0.93 M, the cadmium extraction efficiency was higher. However, for concentrations above 0.93 M, the stripping efficiency decreased due to swelling of the emulsion globules. Membrane swelling and internal phase leakage occur due to increased ionic strength between the internal and external phases. Therefore, the internal phase concentration of 0.93 M was selected as the optimum condition for cadmium extraction in the GELM process. With an extraction efficiency of 97.40% (Sujatha et al., 2022).

Furthermore, according to the latest research by (Admawi et al., 2023), HCl is also used as an internal phase-stripping agent in separating cadmium (II) metal ions. This study investigated the effect of the internal phase concentration from 0.05 to 0.5 M HCl.

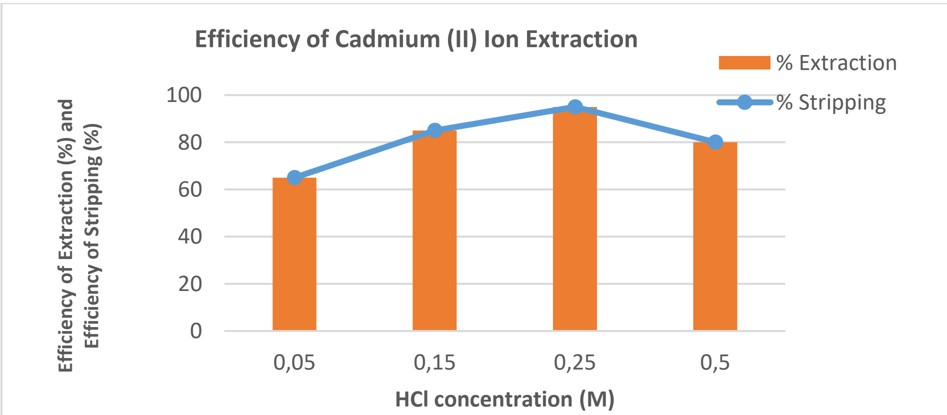

Figure 4. Effect of HCl concentration on extraction efficiency and stripping efficiency (Admawi and Mohammed 2023).

Based on Figure 4 above, with the increase of HCl concentration from 0.05 to 0.25 M, the extraction efficiency increased from 66.42% to 95.16%, and the stripping efficiency also increased from 62.67% to 94.98% due to the increase of receiving phase capacity. It was also found that the viscosity of the emulsion improved with an increase in the amount of HCl in the internal phase. However, increasing the HCl concentration beyond 0.25 M resulted in an increase in drop size and a decrease in extraction from 95.16% to 79.39% and stripping efficiency from 94.98% to 77.41% (Admawi & Mohammed, 2023).

Research by (Davoodi et al., 2018) conducted the separation of rare earth metals gadolinium (III). Stripping agent HCl is used as the internal phase, and the optimum concentration used in the separation is 0.5 M HCl with an extraction efficiency of 67.45% (Davoodi-Nasab et al., 2018b).

Furthermore, research by (Zhang et al., 2016) separated rare earth oxides using HCl as an internal phase. Concentration variations from 2-12 M were used. There was an increase in extraction efficiency when the concentration increased from 2 M to 6 M, namely 90.85% to 93.51%. However, there was a decrease in extraction efficiency when the HCl concentration passed 6 M, from 93.51% to 88.84%. This is due to high HCl concentrations, which makes the ELM system unstable and causes the organic phase to separate from the internal phase during the experimental process. So, the optimum concentration for separating rare earth metals is 6 M, with an extraction efficiency of 93.51% (Zhang et al., 2016).

Sodium Hydroxide (NaOH)

Sodium hydroxide is an inorganic white solid with a strong base. Its composition comprises sodium cations (Na^+) and hydroxide anions (OH^-). NaOH is corrosive and hygroscopic (quickly absorbs water). The solubility of NaOH in water is high. NaOH is often used in various industries, such as pulp and paper making, textiles, detergents, soaps, and other sectors. NaOH is often used as a stripping agent in the internal phase of ELMs despite its alkaline nature. This is because it helps control pH and can react with the metal to be separated. NaOH is essential in ELM to ensure optimal conditions for separating specific compounds (Kiswandono, 2014). Researchers have widely used NaOH as a stripping agent in the internal phase, which results in high separation efficiency.

In the research of (Kumar et al., 2019), the separation of chromium (VI) metal ions was based on a green emulsion liquid membrane (GELM), using NaOH as a stripping agent. NaOH concentration varied from 0.1 to 0.5 M to get the optimum value. As the internal phase concentration increased, the Cr(VI) extraction efficiency of GELM tended to increase. The extraction rate increased when the concentration of the stripping phase increased by 0.1-0.25 M. When the NaOH concentration was increased beyond 0.25 M, the extraction efficiency decreased. This is due to the reaction between NaOH and surfactants resulting in a decrease in the stabilizing properties of the emulsifying agent, consequently leading to poor dynamic instability of the GELM. The poor dynamic instability affects the decrease in extraction efficiency. Thus, the maximum extraction efficiency was obtained for (97±1.46%) Cr (VI) at 0.25 M NaOH concentration (Kumar et al., 2019).

In a subsequent study (Khadivi & Javanbakht, 2020), NaOH was also used as a stripping agent in the internal phase to separate lead (II) metal ions. Three concentration variations of 0.001, 0.01, and 0.1 M of sodium hydroxide were used to show the effect of the internal phase on the extraction results. In the experimental results, with a concentration of 0.1 M sodium hydroxide, the extraction efficiency of lead (II) ions was 95%, which became the optimum concentration in this study (Khadivi & Javanbakht, 2020).

In the following study by (Lakhe et al., 2021), lead (II) metal ions were separated using ELM. NaOH was used as a stripping agent in the internal phase with varying concentrations of 0.1 M, 0.3 M, and 1.0 M, showing extraction efficiencies of 100%, 100%, and 71.32% of Pb(II) ions, respectively. Further increase in concentration increased the difference in electrolyte concentration between the internal and external phases. This led to osmotic pressure between the phases, thus causing swelling and breakage of the emulsion, resulting in a decrease in the removal/extraction efficiency of Pb(II) ions (Lakhe et al., 2021).

Sodium Carbonate (Na_2CO_3)

Sodium carbonate (Na_2CO_3) is an inorganic chemical compound that is the neutral salt of carbonic acid and is often known as soda ash. This compound has a variety of industrial uses, such as in the manufacture of glass, soap, detergents, paper, textiles, metallurgy, and ceramics (A. et al., 2019). Sodium carbonate (Na_2CO_3) is also used as an internal phase in the emulsion liquid membrane (ELM) because sodium carbonate has carbonate ions (CO_3^{2-}) that can coordinate with heavy metal ions. This coordination heavy is stable and does not decompose quickly. In addition, because it is a weak base, sodium carbonate also can neutralize acids resulting from the reaction of heavy metals with water. This has a vital role in preventing corrosion of the membrane. Sodium carbonate is also readily available, cheap, and environmentally friendly (A. et al., 2019; Al-Mashhadani & Al-Rawi, 2020).

In the research of (Anarakdim et al., 2021), the separation of Cr (VI) metal ions by ELM using Na_2CO_3 as a stripping agent in the internal phase was carried out. The effect of Na_2CO_3 concentration as a stripping solution on Cr (VI) extraction efficiency was also investigated in the range of 0.1 M to 1 M. The extraction efficiency increased with the concentration of the stripping solution from 0.1 to 0.5 M because, at higher concentrations of Na_2CO_3, the extraction capacity increased due to its ability to form Na-Cr. However, for higher concentrations, namely at a concentration of 1 M, the extraction efficiency decreased because the emulsion became unstable due to the interaction of the stripping solution with surfactants. In addition, the pH difference between the internal and feed phases induces significant osmotic pressure, affecting the emulsion's swelling, resulting in emulsion breakage and reducing extraction efficiency (Kumbasar & Tutkun, 2008; Mortaheb et al., 2009). So, the maximum extraction efficiency of Cr (VI) occurs at a concentration of 0.5 M Na_2CO_3 with a result of 99.5% (Anarakdim et al., 2021).

In the following study by (Kulkarni et al., 2009), uranium metal ions were separated using ELM. Na_2CO_3 was chosen as a stripping agent in the internal phase because the utilization of Na_2CO_3 can be significant in the process of extracting uranium from ore due to the formation of a water-soluble sodium uranyl tricarbonate compound, $Na_4UO_2(CO_3)^3$. This compound is different from most other heavy metal carbonates. The mechanism of the Na_2CO_3 stripping reaction on amine salts is shown in the equation below.

$$(R_3NH)_4UO_2(SO_4)_3(org) + 7Na_2CO_3 \rightleftharpoons Na_4UO_2(CO_3)_3 + 3Na_2SO_4 + 4NaHCO_3 + R_3N(org)$$

Reaction mechanism of Na_2CO_3 on amine salts
(Kulkarni, Mukhopadhyay, and Ghosh 2009).

The reaction mechanism indicates that H+ ions are transported along with uranyl sulfate into the membrane. As a result, both related transport reaction mechanisms are involved in forming sodium uranyl tricarbonate inside the emulsion globule. Sodium uranyl tricarbonate is a heavy molecule of simple ions, so the stripping reaction maintains a zero concentration of uranyl ions inside the stripping phase. Thus, a high uranyl concentration gradient can be maintained continuously throughout the liquid membrane, preventing equilibrium limitation. The optimum concentration of Na_2SO_4 used was 0.75 M, with an extraction efficiency of more than 90% (Kulkarni et al., 2009).

In the following study by (El Sayed, 2003), uranium metal was separated using Na2CO2 as a stripping agent in the internal phase. Na_2CO_3 concentration variations were used by researchers, namely 0.5 M, 1.0 M, and 2.0 M., and the results showed that by using 1 M ammonium carbonate as an internal stripping phase, it was found that the extraction yield was similar to 0.5 M Na_2CO_3 which was 95% (El Sayed, 2003).

Table 1. Types of stripping agents and the optimum concentrations in the internal phase used for heavy metal separation using ELM.

Metals	Stripping agent	Internal phase concentration	Extraction efficiency (%)	References
Pb (II)	HNO_3	3 M	97,95%	(Setyani et al. 2016)
Pb (II)	HNO_3	3 M	84,45%	(Hamzah, Astuti, and Rabiah 2015)
Dy (III)	HNO_3	1 M	99,6%	(Raji et al. 2017)
Gd (III)	HNO_3	0.5 M	72,48%	(Meilinda, Bahti, et al. 2021)
Co (II)	H_2SO_4	0,5 M	95%	(Gasser et al. 2008)
Pb (II)	H_2SO_4	1 M	99,4%	(Sabry et al. 2007)
Ni	H_2SO_4	0,5 M	99%	(Ma et al. 2018)
Pb (II)	H_2SO_4	0,5 M	98%	(Mohammed et al., 2018)
U (IV)	HCl	0,1 M	99,82%	(Zaheri and Davarkhah 2017)
Cd	HCl	0,93 M	97,40%	(Sujatha et al. 2022)
Cd (II)	HCl	0,25 M	95.16%	(Admawi and Mohammed, 2023)
Gd (III)	HCl	0.5 M	67,45%	(Davoodi-Nasab et al. 2018b)
Rare earth	HCl	6 M	93.51%	(ZHANG et al. 2016)
Cr (VI)	NaOH	0,25 M	97%	(Kumar et al. 2019)
Pb (II)	NaOH	0,1 M	95%	(Khadivi and Javanbakht 2020)
Pb (II)	NaOH	0,1 M	100%	(Lakhe et al. 2021)
Cr (VI)	Na_2CO_3	0,5 M	99,5%	(Anarakdim et al. 2021)
U	Na_2CO_3	0,75 M	90%	(Kulkarni et al. 2009)
U	Na_2CO_3	0,5 M	95%	(El Sayed 2003)

CONCLUSIONS

Heavy metals are toxic and can pose risks to the environment and health. Therefore, heavy metals must be separated from their primary and secondary sources to reduce their harmful environmental and human health effects. Emulsion liquid membrane is a promising technique to remove heavy metal contaminants from industrial and household effluents. The ELM method, efficient due to simultaneous extraction and stripping processes, utilizes an internal phase to carry the stripping agent, which is crucial for metal separation. Increasing stripping agent concentration enhances extraction efficiency, but excessive concentrations may lead to membrane swelling. Therefore, optimal internal phase concentrations, such as 0.5 M, 1 M, and 3 M for HNO_3, yield high extraction efficiencies of 99.6%—similarly, 0.5 M and 1 M concentrations of H_2SO_4 result in 99.4% efficiency. For HCl, concentrations of 0.1 M, 0.25 M, 0.5 M, 0.93 M, and 6 M achieve 99.82% efficiency. NaOH at 0.1 M and 0.25 M yields 100% efficiency, while

Na_2CO_3 at 0.5 M and 0.75 M achieves 99.5%. These optimized concentrations make HNO_3, H_2SO_4, HCl, NaOH, and Na_2CO_3 suitable for separating heavy metals through the ELM method.

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