

# Soybean Oil-Based Bulk Liquid Membrane for Simultaneous Extraction and Stripping of Cu(II) from Aqueous Solutions

Siu Hua Chang, Tjoon Tow Teng, and Norli Ismail

**Abstract**— This work aimed to investigate the simultaneous extraction and stripping of Cu(II) from aqueous solutions through a soybean oil-based bulk liquid membrane (BLM). The membrane phase used was soybean oil (diluent) loaded with di-2-ethylhexylphosphoric acid (carrier) and tributylphosphate (phase modifier), whereas the stripping phase was sulphuric acid ( $H_2SO_4$ ) at various concentrations. Effects of stirring condition, strip to feed interface area (S:F) ratio,  $H_2SO_4$  concentration and operating time on Cu(II) extraction and stripping through soybean oil-based BLM were investigated. It was found that stirring affected the extraction process significantly but showed relatively smaller effect on the stripping process. The other parameters such as S:F ratio,  $H_2SO_4$  concentration and operating time, however, were found to control the stripping process more than the extraction process. The highest extraction (98%) and stripping (86%) were achieved by using soybean oil-based BLM with four stirrings for all phases, S:F ratio of 2.5:1 and 3 M  $H_2SO_4$  as the stripping phase within 24 h of operating time. Application of soybean oil-based BLM in real industrial wastewater was also investigated.

**Index Terms**—Bulk liquid membrane, Cu(II), di-2-ethylhexylphosphoric acid, extraction, soybean oil, stripping

## I. INTRODUCTION

Cupric ion (Cu(II)) is the most commonly found copper species in the environment and the most toxic form to living organisms [1]. Various techniques that can be applied to remove and recover Cu(II) from aqueous solutions include chemical precipitation, reverse osmosis, ion exchange, solvent extraction, membrane filtration and adsorption [2]. However, these techniques have their own inherent limitations such as less efficiency, sensitive operating conditions, production of secondary sludge, high capital and operating costs, and further the disposal is a costly affair [3]. Hence, more efficient and cost-effective removal and recovery methods are sought-after to overcome these difficulties.

Recently, liquid membrane has been given a considerable attention by a host of researchers in the removal and recovery of heavy metals from aqueous solutions. Some of the pronounced advantages of liquid membrane over the

traditional separation and solid membrane techniques include the low capital and operating costs, low energy consumption, high concentration factors and high fluxes [4]. However, the conventional organic solvents used in liquid membrane systems are those of petroleum derivatives such as kerosene [4-5], benzene [6], dinitrile [7] and chlorinated organic solvents [8]. These solvents are usually toxic, flammable, volatile, non-biodegradable, non-renewable and expensive. Losses of these solvents into the waterways due to the poor membrane stability [2] would lead to a severe environmental problem to all living things. To overcome this problem, application of greener solvents such as vegetable oil-based organic solvents [9-10] to replace the conventional toxic organic solvents in liquid membrane is indispensable.

Bulk liquid membrane (BLM) is among the simplest system to perform liquid membrane processes. In this work, simultaneous extraction (removal) and stripping (recovery) of Cu(II) from aqueous solutions was conducted with a soybean oil-based BLM. The membrane phase used was composed of soybean oil (diluent), di-2-ethylhexylphosphoric acid (D2EHPA) (carrier) and tributylphosphate (TBP) (phase modifier), whereas the stripping phase was sulphuric acid ( $H_2SO_4$ ) at various concentrations. Effects of stirring condition, strip to feed interface area (S:F) ratio,  $H_2SO_4$  concentration and operating time on Cu(II) extraction and stripping from aqueous solutions through soybean oil-based BLM were investigated, followed by experimentation of this BLM on real industrial wastewater.

## II. MATERIALS AND METHODS

### A. Materials

Soybean oil (Soon Soon Oil Mill Sdn. Bhd., Malaysia), copper sulphate pentahydrate ( $CuSO_4 \cdot 5H_2O$ ), D2EHPA, TBP,  $H_2SO_4$ , acetic acid ( $CH_3COOH$ ), sodium acetate ( $CH_3COONa$ ), sodium hydroxide (NaOH) and sodium sulphate ( $Na_2SO_4$ ) (Merck,  $\geq 99\%$  purity) were used as received.

### B. Methods

Fig. 1 shows the experimental rigs (Rigs 1, 2 and 3) of soybean oil-based BLM used in this work. They are rectangular glass containers divided into two compartments by a 40 mm-height flat vertical wall. One compartment is filled with an aqueous feed (F) phase while another one with an aqueous strip (S) phase. These aqueous phases are layered with a membrane (M) phase. The flat vertical wall is placed at specific positions so that it gives S:F ratios of 1:1, 2.5:1 and

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1:2.5 to Rigs 1, 2 and 3, respectively. The F phase contained 500 mg/L of initial concentration of Cu(II) which was prepared by dissolving an appropriate amount of CuSO<sub>4</sub>·5H<sub>2</sub>O in 0.1 M acetate buffer solution with pH 4.46 and loaded with 250 mM Na<sub>2</sub>SO<sub>4</sub>, whereas the S phase was H<sub>2</sub>SO<sub>4</sub> at various concentrations (1.5-6.0 M). The M phase, on the other hand, was prepared by mixing soybean oil with 85 mM D2EHPA and 60 mM TBP. Initially, effect of stirring condition on Cu(II) extraction and stripping was investigated using Rig 1 by stirring some or all its phases at 100 rpm (Fig. 2). A blank test where no stirring was applied to any phases was also conducted. The best stirring condition was then used to investigate the effect of S:F ratio on Cu(II) extraction and stripping using Rigs 2 and 3 (Fig. 1). All experiments to investigate the effects of stirring and S:F ratio employed 1.5 M H<sub>2</sub>SO<sub>4</sub> as the S phase and were conducted for 5 hours throughout. Lastly, effects of H<sub>2</sub>SO<sub>4</sub> concentration (1.5, 3, 4, 6 M) and operating time (1, 3, 7, 9, 11 and 24 h) on Cu(II) extraction and stripping were investigated by using the selected rig.

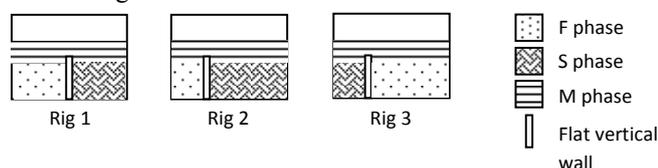


Fig. 1: Experimental rigs of soybean oil-based BLM used in this work

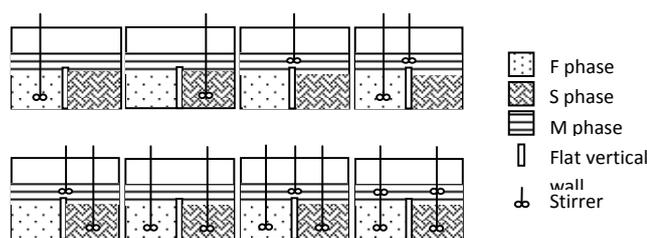


Fig. 2: Different stirring conditions studied with Rig 1

During the course of experiments, samples (0.5 mL) of F and S phases were analyzed for Cu(II) concentration by a flame atomic absorption spectrophotometer (Perkin Elmer, AA-400) after appropriate filtration and dilution. The percentage extraction (%E) of Cu(II) was then calculated according to:

$$\%E = \frac{[Cu]_{o,F} - [Cu]_{f,F}}{[Cu]_{o,F}} \times 100\% \quad (1)$$

where [Cu]<sub>o,F</sub> and [Cu]<sub>f,F</sub> are the initial and final Cu(II) concentrations in the F phase, respectively. The percentage of stripping (%S) of Cu(II) was given by:

$$\%S = \frac{[Cu]_{f,S}}{[Cu]_{o,F} - [Cu]_{f,F}} \times 100\% \quad (2)$$

where [Cu]<sub>f,S</sub> is the final Cu(II) concentration in the S phase. The initial concentration of Cu(II) in both the M and S phase was assumed zero. All experiments were carried out in duplicate or triplicate at room temperature (25°C) and the relative standard deviation between replicate samples within an experiment range was less than 2%.

### III. RESULTS AND DISCUSSION

#### A. Effect of Stirring Conditions

Fig. 3 shows the %E and %S obtained at different stirring conditions with Rig 1. For cases with no stirring ({1}) and one stirring for the S phase ({3}), the %E achieved is about 30% only. The low %E leads to no stripping observed in these cases. For the rest of the cases ({2}, {4}, {5}, {6}, {7}, {8} and {9}) studied, %E of more than 80% are recorded. This implies that stirring of either the F, M, or all phases inclined to improve the transport of Cu(II) from the F into M phases by minimizing the boundary layers in the aqueous and organic phases [11]. In spite of the great improvement of %E observed in these cases, the corresponding %S achieved are, however, much lower, which are about 10% only. This indicates that the stripping process was not controlled by the hydrodynamic conditions. Nevertheless, it should be noted that stirring of M phase affects the %S appreciably. If the M phase is stirred ({4}, {5}, {6}, {8} and {9}), a substantial amount of Cu(II) is stripped, with %S of about 10%. When the M phase is not stirred ({1}, {2}, {3} and {7}), however, extremely low or zero %S is observed. These findings could be explained by the viscous soybean oil-based organic solvent which was used as the M phase in this work. Apparently, stirring of M phase increased its fluidity and, thus, enhanced the transport of Cu(II) from the M into S phases. The best stirring condition, i.e. four stirrings for all phases ({9}), which achieved %E of over 90% and %S of over 10% was selected for further studies.

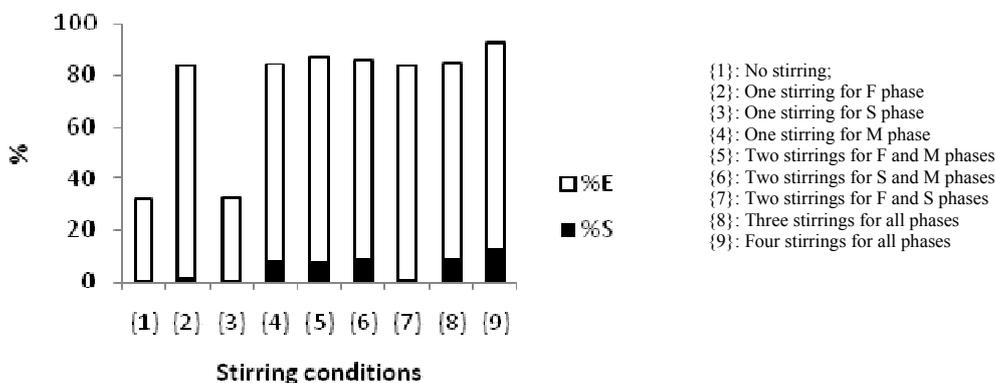


Fig. 3: %E and %S obtained at different stirring conditions using Rig 1

### B. Effect of S: F Ratio

Fig. 4 shows the %E and %S obtained at different S:F ratios with four stirrings for all phases. It is found that %E of more than 90% is achieved by S:F ratios of 1:1 and 2.5:1 while less than 80% is achieved by S:F ratio of 1:2.5. This implies that the bigger S:F ratio (2.5:1) did not affect the %E much compared with 1:1 S:F ratio, but inclined to reduce it when the smaller S:F ratio (1:2.5) was used. The smaller S:F ratio (1:2.5) means a greater volume of F phase and, hence, a lower %E is achieved within the same operating time. On the other hand, the highest %S (~20%) is obtained at S:F ratio of 2.5:1 while the lowest %S (<10%) at S:F ratio of 1:2.5. The higher %S achieved at S:F ratio of 2.5:1 was attributed to the larger M/S interfacial area available for the transport of Cu(II) from the M into S phases. Hence, the S:F ratio of 2.5:1 was selected for further studies.

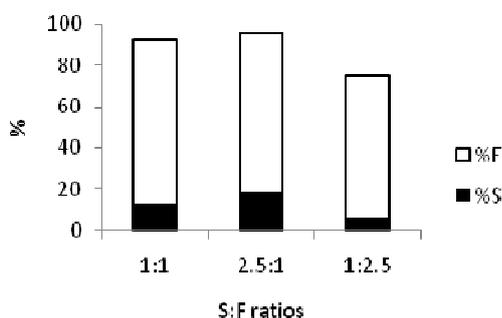


Fig. 4: %E and %S obtained at different S:F ratios

### C. Effect of H<sub>2</sub>SO<sub>4</sub> Concentration

The strength of S phase, which varies with its concentration, is one of the important factors that determine the transport efficiency of metal ions through a liquid membrane. If metal complexes in the M phase are not stripped completely, the M phase would become saturated and this decreases the transport rate of metal ions through the liquid membrane [11]. Fig. 5 shows the %E and %S obtained by using different concentrations of H<sub>2</sub>SO<sub>4</sub> as the S phase. In general, the %E of about or more than 90% are achieved throughout all the different H<sub>2</sub>SO<sub>4</sub> concentrations studied. The %S, on the other hand, presents a maximum where it increases from 1.5 to 3 M and then decreases thereafter. This indicates that the extraction process was not, but the stripping process was, controlled by the concentration of H<sub>2</sub>SO<sub>4</sub> in the S phase. The presence of H<sub>2</sub>SO<sub>4</sub> aids in the stripping of Cu(II) by a cation exchange process between its protons from the S phase and Cu(II) from the M phase [12]. Hence, the rise of %S from 1.5 to 3 M H<sub>2</sub>SO<sub>4</sub> concentrations was deduced from the increase of proton in the S phase for Cu(II) stripping. The reduction of %S beyond 3 M H<sub>2</sub>SO<sub>4</sub>, on the other hand, could be caused by the saturation of driving force for diffusion through soybean oil-based BLM due to the increase of proton at the M/S interface [11]. The maximum %S of approximately 30% was achieved at 3 M H<sub>2</sub>SO<sub>4</sub> and, thus, was used as the S phase for further studies.

### D. Effect of Operating Time

Fig. 6 shows the %E and %S obtained at different operating times. It is found that more than 70% of Cu(II) is extracted in the first hour and this increases to over 90% in 5 h. A slow increment of %E is observed thereafter until it reaches about 98% in 24 hours. Cu(II) stripping, on the other hand, proceeds at a much slower rate than the extraction process. In

the first hour, only about 10% of Cu(II) is stripped. This is followed by a steady increment of about 10% of stripping in the subsequent time intervals up to 7 hours. The %S continues to increase from then on until it reaches 86% in 24 h. Since the stripping process happened at a much slower rate than the extraction process, a substantial amount of Cu(II) was accumulated in the M phase. The slow stripping rate could be deduced from the long transportation path [13] and the high viscous M phase used that may encumber the transport of Cu(II) through soybean oil-based BLM [14]. Given the trend of graph (Fig. 6) obtained, it is predicted that the %S will continue to increase beyond 24 h.

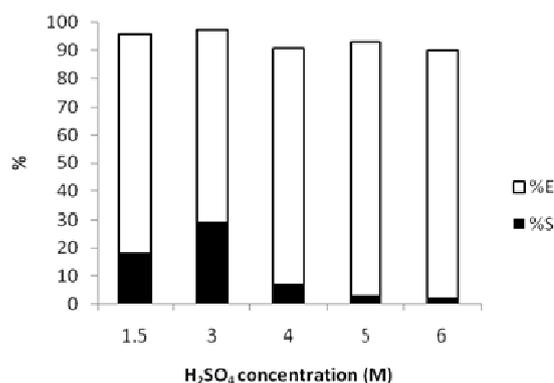


Fig. 5: %E and %S obtained by using different H<sub>2</sub>SO<sub>4</sub> concentrations as the S phase

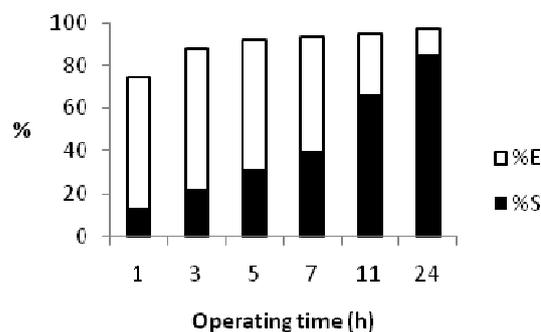


Fig. 6: %E and %S obtained at different operating times

### E. Application of Soybean Oil-Based BLM in Real Industrial Wastewater

To study the application of soybean oil-based BLM in real industrial wastewater, an influent wastewater sample collected from a local copper plating factory was used as the F phase and its characteristics before and after treatment are given in Table 1. The corresponding Standard B discharge limits, as well as the characteristics of S phase (3 M H<sub>2</sub>SO<sub>4</sub>) of soybean oil-based BLM at the end of the process are also presented.

Before treatment, the F phase (wastewater sample) was a clear solution in light blue, with all its parameters exceeding the Standard B discharge limits and, thus, could not be discharged directly into the waterways. After treatment, it turned into a clear and colourless solution, with its pH increased to 4.46 as a result of constant pH adjustment with 1 M NaOH throughout the experiment. It was found that all metal ions, except for Cr(VI), were extracted and stripped substantially (> 80 %) through soybean oil-based BLM, with Cu(II) being extracted (97.61 %) and stripped (84.84 %) the most among all metal ions. Akin to Cu(II), Zn(II) and Cd(II) existed as positively charged ions in the F phase.

TABLE 1: CHARACTERISTICS OF F (BEFORE AND AFTER TREATMENT) AND S (AT THE END OF THE PROCESS) PHASES OF SOYBEAN OIL-BASED BLM IN THE TREATMENT OF REAL INDUSTRIAL WASTEWATER

Parameters	Unit	F phase (wastewater sample)		Standard B discharge limits [15]	S phase (3 M H <sub>2</sub> SO <sub>4</sub> ) at the end of process
		Before treatment	After Treatment		
Appearance	-	Clear solution	Clear Solution	-	Clear solution
Apparent colour	-	Light blue	Colourless	-	Colourless
pH	-	4.2	4.46	5.5-9.0	-
Cu(II)	mg/L	124.5	2.98 (97.61 %E)	1.0	103.1 (84.84 %S)
Zn(II)	mg/L	10.5	0.455 (95.67 %E)	2.0	8.26 (82.23 %S)
Cd(II)	mg/L	5.4	0.993 (81.61 %E)	0.02	3.53 (80.10 %S)
Cr(VI)	mg/L	3.86	3.83 (0.78 %E)	0.05	0 (0 %S)

Consequently, they were attracted to the deprotonated D2EHPA (carrier) in the M phase which was negatively charged and could be stripped from the M phase by the acidic S phase. This finding is consistent with the high extraction and stripping of Cu(II) achieved with the prepared aqueous F phase in Section D at 24 h of operating time, as well as with those of Zn(II) and Cd(II) attained in similar liquid membrane systems as reported in the literatures [16-17]. The low extraction (0.78 %) of Cr(VI) obtained, on the other hand, was attributed to the poor extractability of D2EHPA and TBP in the M phase for chromate ion (HCrO<sub>4</sub><sup>-</sup>), which was the ionic form of Cr(VI) present in the F phase under the experimental conditions studied [18-19]. This agrees well with the previous works which reported the inability of D2EHPA to extract chromate ion from aqueous solutions due to their same charges that inclined to repel each other [20], as well as the poor extractability of TBP for chromate ion at pH > 2 [21]. The low extraction of Cr(VI) led to no stripping of Cr(VI) into the S phase at the end of the process. This implies that Cu(II), as well as other metal ions like Zn(II) and Cd(II), could be separated selectively from Cr(VI) by using the soybean oil-based BLM used in this work. The treated F phase, however, still did not meet the Standard B discharged limits and required further treatment prior to discharge.

#### IV. CONCLUSION

Investigation of the effects of various parameters such as stirring, strip to feed interface area ratio, H<sub>2</sub>SO<sub>4</sub> concentration and operating time revealed that they were influential to the extraction and stripping processes of Cu(II) through soybean oil-based BLM. The extraction process was improved by stirring of either the feed, membrane, or all phases, while the stripping was enhanced by stirring of the membrane phase, applying a high strip to feed interface area ratio (2.5:1), using a moderately high concentration (3 M) of H<sub>2</sub>SO<sub>4</sub> as the stripping phase, and by running the process for an extended period of time (24 h). It was found that high extraction (98%) and stripping (86%) of Cu(II) could be achieved by using soybean oil-based BLM with four stirrings for all phases, S:F ratio of 2.5:1, and 3 M H<sub>2</sub>SO<sub>4</sub> as the stripping phase, as well as that operates for 24 h. It was found that simultaneous Cu(II) extraction and stripping through soybean oil-based BLM was not affected by various inorganic ions present in the real industrial wastewater.

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