

Recovery of phenol from aqueous solution by supported liquid membrane using vegetable oils as liquid membrane

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Abstract

The transport of phenol through a flat sheet supported liquid membrane (SLM) containing vegetable oil as liquid membrane (LM) has been investigated. The permeation of phenol was investigated by varying the experimental conditions like, selection of LM, support material, feed phase pH, stripping solution concentration, stirring speed and different initial concentration of phenol. It has been found that, each LM investigated in the present study shows the effective removal of phenol using polytetrafluoroethylene (PTFE) membrane and PP supported membrane as a solid support. Among the various oils tested, palm oil has chosen to be the best LM with permeability of 8.5×10^{-6} m/s in acidic feed of pH 2.0 with 0.2 M sodium hydroxide as effective stripping agent. After 6 h all the phenol from the feed side gets transported to strip solution with an initial concentration of 100 mg/L. A concentration factor of five has been achieved in the present investigation easily with 0.2 M sodium hydroxide as stripping reagent. After 10 transport studies with one impregnation of LM, the LM showed no significant loss in the transport rate with average permeability of 7.9×10^{-6} m/s with initial concentration 100 mg/L. Further study has also been attempted with cresols to explore the possibility of applying this to industrial wastewater under the optimized conditions for phenol. After 14 h of the transport studies in the phenol–formaldehyde industry wastewater, phenolic concentration in the feed solution was found to be below detectable level (1×10^{-2} mg/L). For wood processing industry wastewater the transport takes place at the initial permeability of 7.1×10^{-5} m/s. Thus it has been demonstrated the use of renewable, cheap, non toxic, naturally occurring vegetable oils as a novel, green liquid membrane for the recovery of phenol from aqueous solution in SLM, which has never been employed before in liquid membrane techniques.

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1. Introduction

Phenol and its derivatives are among the most prevalent forms of chemical pollutants in the industrial wastewater. They are produced from common manufacturing processes including the product of synthetic resins, dyes, pharmaceutical, wood products, paint and antiseptics. Concentration of phenol in wastes of this kind varies in wide range from several ppm to 2–3% [1]. Nowadays, the worldwide production and use of chemical compounds have increased tremendously which find their way into the environment and many of these compounds are biologically non-degradable. Therefore, the major concern is to treat the wastewater before it is discharged into the environment [2]. On the other hand, phenolic compounds are considered to

be the valuable chemicals for industrial processes. Therefore, the innovative method for separation and recovery of phenolic compounds is considered for the removal of unwanted phenol from aqueous wastes. There are many methods available for the removal of phenols from industrial wastewater. However, the liquid membrane processes could be regarded as a successful method for the treatment of wastewater containing organic compounds and metals in comparison with solvent extraction for recovery [3].

After the novel study in LM extraction method by Li [4] during 1968, LM was further investigated by various researchers for the recovery of metal ions [3] and organic compounds [5]. LM processes combine extraction and stripping into one single stage and thus non-equilibrium mass transfer characteristic where the separation is not limited by the conditions of equilibrium [6]. The various configurations of LM such as bulk liquid membrane (BLM), emulsion liquid membrane (ELM), supported liquid membrane (SLM), contained liquid membrane (CLM), elec-

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trostatic pseudo liquid membrane (ESPLIM) were researched for different applications. The various configurations of LM technique have been investigated by number of researchers with a wide variety of applications and their performance has been reviewed recently [3,6]. Among these configurations of LM, SLM system offers the following process advantages: (i) low capital investment and operating cost, (ii) low energy consumption, (iii) minimal loss of extractant, (iv) low LM requirement, and thus less amount of expensive extractants which offer good selectivity and (v) simple to operate and easy to scale up.

Several authors have reported the separation-concentration of phenol using SLM. Phenol recovery using the SLM technique is based on the solubility difference of the phenol between the aqueous phase and the organic phase. In this technique, the liquid membrane is impregnated in the pore structure of a hydrophobic micro porous polymeric film. Organofunctionalized polydimethylsiloxane membranes were tested for the pervaporative recovery of phenolic compounds from water. Acetate, ethyl ether, dimethylamino and pyridyle functionalities were loaded into the pure polydimethylsiloxane with the functional loading ranging from 10 to 25 mol%. Significant performance was observed with dimethyl amino and ethyl functionalities [7,8]. Liquid membrane based on water–oil emulsification with tributylphosphate was tested for phenol removal from aqueous streams [9]. Hollowfibre supported liquid membranes were used for phenol separation, for example, kerosene and methylisobutylketone were immobilized in the porous wall of two different polypropylene hollow fibres [10,11].

Organic carriers like Aliquat 336 [12], Aliquat 366, Cyanex 921 [6], toxic tri-*n*-octyl amine [13], polyorganosiloxane [14], diglycolamine [15], etc., and solvents like chloroform [16], carbon tetrachloride, dichloromethane, benzene, toluene, pyridine are categorized as hazardous chemicals were commonly used for the separation [3].

Separation of phenol from the wastewater by solvent extraction method has been reported using alcohols, amines and organic acids [17]. In LMs linear monoalkyl cyclohexane [18], *N,N*-di (1-methyl heptyl) acetamide [19], dibenzo-18-crown-6 [20], dodecane [21], trioctylamine [22], *N*-octanoylpyrrolidine [23] have been reported, all of which are synthetic toxic chemicals. The solvents generally used for the liquid membrane processes are typically flammable, volatile, toxic and their use leads to environmental and safety risks. The room temperature ionic liquids (RTILs) are considered as green solvent due to non-flammable and negligible vapour pressure. However, their toxicity data are not available [24]. Nevertheless, the choice of a solvent also depends on economic considerations, which has not been evaluated in laboratory scale studies.

The vegetable oil was considered to be the non-hazardous, cheap chemical, which could be used in SLM, as the novel and greener LM. These vegetable oils are naturally occurring, easily available, non-toxic, low cost and renewable sources. Recently, from our laboratory we have reported the transport of textile dye in vegetable oil based SLM [25]. The present paper presents the experiments performed during the investigation of the efficiency of vegetable oils as LM for the recovery of phenol from aqueous solution. In addition, to the selected objectives the phenol

studies, attempt has also been made for the recovery of phenols from two different industrial effluents and the cresols transport was also studied. The details of the investigation are presented here.

2. Experimental

2.1. Reagents and membranes

Nine types of commercially available vegetable oils purchased from market were used in the present study. The other chemicals used include phenol (Merck, India), cresols (Merck, India), and sodium hydroxide, sulphuric acid obtained from SRL, India. 4-Aminoantipyrine (CDH, India), and potassiumhexacyanoferrate (SD fine chem, India). All the chemicals used were of analytical grade. The phenol–formaldehyde resin manufacturing industry wastewater and the effluent of wood products industry were obtained from industries located in Chennai, India. Hydrophobic polytetrafluoroethylene membranes of 47 mm in diameter with different pore sizes of 0.2 μm (Sartorius, Germany), 0.5 μm (Fluoropore, Bangalore), 1.0 μm plain and polypropylene supported membranes (Pal Gellman, Germany) were used.

The composition of vegetable oil varies according to the origin from which the oil is extracted. The vegetable oil is a complex mixture of chemically distinct components, with fatty acids and di- and triglycerides as major constituents and palmitic acid, lauric, caprylic, capric, erucic acids, etc. as major constituents [26].

2.2. Analytical methods

The concentrations of phenol, *o*-cresol, *m*-cresol were analyzed by 4-aminoantipyrine spectrophotometric method using a spectrophotometer (spectronic 20 Genesys, Germany) at 500 nm as per standard methods [27]. The concentration of *p*-cresol was quantified at a λ_{max} of 292 nm [28]. The pH was measured with WTW pH meter using combined electrode. The viscosity of the vegetable oils was determined using falling sphere viscometer method [29].

2.3. Supported liquid membrane cell and transport studies

A microporous hydrophobic PTFE membrane was impregnated with vegetable oil for 12 h. Consequent up on the impregnation, the excess oil was wiped out and then sandwiched between the feed and strip cells as illustrated in Fig. 1. The effective volume of each cell was 130 cm^3 and the contact area was 15.2 cm^2 . A new supporting membrane was used for each experiment. The aqueous phenol and NaOH solutions were used as a feed and strip solutions respectively. The source and stripping phases were stirred at 300 rpm with a magnetic stirrer at $27 \pm 1^\circ\text{C}$ to avoid concentration polarization conditions at the membrane interfaces and in the bulk of the solutions. The transport of phenol from feed phase to the receiving phase was measured by taking samples from the feed and strip solutions at regular time intervals and analyzed for the transport of phenol.

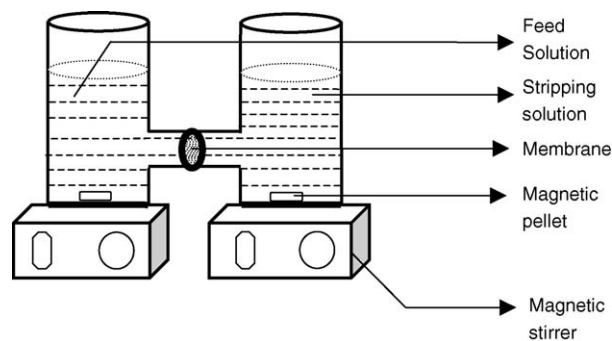


Fig. 1. Schematic representation of SLM (not to scale).

The experiments were carried out in duplicate and the analysis was carried out in triplicate. The results were found to be reproducible within $\pm 4\%$ standard deviation. The phenol transport was calculated by the permeability parameter as described earlier [3].

2.3.1. Permeability (P)

This measure the quantity of a solute transported through a specific area of membrane surface in a given unit of time

$$P \text{ (m/s)} = -\frac{V_f}{At} \ln \frac{[C]_t}{[C]_0} \quad (1)$$

where A is the area of the membrane (m^2), V_f the volume of feed solution (m^3) $[C]_t$ the concentration of phenol at feed phase at time t (mg/L), $[C]_0$ the concentration of phenol at zero time (mg/L) and t is the elapsed time (s).

3. Results and discussion

3.1. Selection of liquid membrane

Generally, oils have the ability to dissolve phenolic substances [30], which are hydrophobic in nature. This phenomenon is called as dissolution and has found a number of practical applications. Taking into account the experimental data on dissolution of phenols and applications of dissolution in technology, the hydrophobic vegetable oils were used for the transport of phenol. Initial studies by solvent extraction of phenol resulted in the formation of emulsion. Hence, all the studies were conducted by

SLM only. Nine types of vegetable oils were tested for their efficiency for the transport of phenol. In order to ensure the effect of oil, a blank experiment was conducted using only plain Teflon membrane. There was no transport of phenol from feed to strip solution without oil in the membrane. The permeability for various vegetable oils for the transport of phenol from feed to strip is presented in Table 1. Among the tested oils, palm oil was found to have more permeability of 8.5×10^{-6} m/s where as the castor oil possessing high viscosity value showed low permeability of 2.4×10^{-6} m/s. From the observation it may conclude that palm oil has higher distribution coefficient than other oils used for the study.

3.2. Selection of support material

The use of hydrophobic membrane as a support in membrane extraction processes gives rise to lower mass transfer resistance than hydrophilic membranes [3]. Yang reported that the PTFE membranes are much more robust and significantly have long durability [6]. Four types of commercially available hydrophobic PTFE membranes with pore size ranging from 0.2 to 1.0 μm were tested for the impregnation of palm oil. The results are presented in Table 2. The permeability for the four hydrophobic membranes were compared in the present study and the one with the 0.2 μm pore size presented the lowest permeability of 5.7×10^{-6} m/s and the one with pore size of 0.5 and 1.0 μm membrane possessed the highest permeability. Polypropylene (PP) supported 1.0 μm PTFE showed lower permeability compared to the plain PTFE membrane, this could be attributed due to the resistance to mass transfer by PP support and difference in the porosity of the membranes used. Further experiments were conducted with 0.5 μm membrane only.

3.3. Effect of feed phase pH

The initial pH value of the aqueous solution substantially influences the process of phenol transport. The result proved that the efficiency decreased with increase in the pH of the feed phase beyond pH 2.0. Therefore, a feed pH of 2 was maintained throughout the study, in order to ensure the existence of phenol in molecular state, which is essential for the transport of phenol. It is to be noted that, only the un-dissociated phenol

Table 1
Effect of vegetable oil on the transport of phenol in SLM

S. No.	Name of the vegetable oil used	Viscosity (Pa s)	Permeability ($\times 10^{-6}$ m/s)
1	Plain membrane	–	0.0
2	Castor oil	0.590 ± 1.32	2.4 ± 1.93
3	Coconut oil (refined)	0.040 ± 2.11	6.3 ± 2.34
4	Coconut oil (unrefined)	0.050 ± 2.76	6.4 ± 1.96
5	Gingely oil	0.096 ± 3.14	8.1 ± 0.96
6	Groundnut oil	0.092 ± 4.14	8.2 ± 1.92
7	Mustard oil	0.090 ± 2.18	7.9 ± 1.84
8	Olive oil	0.090 ± 3.12	7.8 ± 3.14
9	Palm oil	0.106 ± 3.10	8.5 ± 2.54
10	Sunflower oil	0.070 ± 2.45	6.8 ± 3.14

Conditions: initial phenol concentration, 100 mg/L; pH of feed, 2.0; membrane, 0.5 μm ; time, 240 min; strip solution, 0.5 M NaOH.

Table 2
Selection of support material for the recovery of phenol

S. No.	Membrane	Pore size (μm)	Thickness (μm)	Porosity (%)	Permeability $\times 10^{-6}$ (m/s)
1	Teflon with polypropylene support	1.0	15	70	6.3 ± 3.14
2	Teflon plain	1.0	10	85	8.7 ± 2.89
3	Teflon plain	0.5	18	85	8.5 ± 3.22
4	Teflon plain	0.2	27	70	5.7 ± 4.19

Conditions: initial phenol concentration, 100 mg/L; pH of feed, 2.0; liquid membrane, palm oil; strip solution, 0.5 M NaOH; stirring speed, 300 rpm; time of experiment, 240 min.

existing in aqueous solution is soluble in oil (pK_a of phenol is 10.00).

The amount of phenol and dissociated phenol at different pH values were already reported [18] and it was recommended to adjust the initial pH to less than 4 in order to obtain an efficient phenol removal as this was said to keep the phenol in the molecular state. Paulo and Jorge [31] reported the recovery of phenol from phenolic resin plant effluent by ELM at pH 4.6. Li et al. [23] reported pH 2–9 was found suitable for the phenols dissociation. According to these results, the feed condition should be in acidic. In SLM studies, proton leakage to other compartment was observed [5]. But, in the present study using vegetable oil, there was no such effect. This may be due to nature and viscosity of oil that provides stability to SLM.

3.4. Effect of stripping reagent concentration

The strength of the receiving phase for the transport of phenol could have a significant effect on the permeability. If the phenol molecule in the membrane phase is not completely stripped, the membrane phase becomes saturated with the LM and the permeation rate may therefore decrease [20]. At the membrane strip solution interface, the phenol gets in to the strip solution and converted into phenolate ion and back transport is controlled. The stripping efficiency of sodium hydroxide was studied in the range of 0.1–1.0 M concentration. The pH of the aqueous feed phase was 2.0 with initial concentration of 100 mg/L and palm oil was used as the LM. After 4 h of transport studies 65% of phenols were transported to the strip phase. The rate of phenol transfer is obviously independent of the concentration of sodium hydroxide with in the range studied. It has been reported that the percentage of molecular phenol reaches nearly zero beyond the pH of 12 [32]. Maw-Ling Wang and Kwan-Hua Hu [22] observed similar results for the transport of phenol by trioctylamine sulphate salts in a SLM. Further study was conducted using 0.2 M NaOH as stripping reagent to ensure all phenol present in the ionised form to avoid back transport of phenol.

3.5. Effect of stirring speed

The effect of stirring speed in the feed phase and the receiving phase was studied in order to obtain uniform mixing so as to minimize the thickness of aqueous boundary layer for an effective permeation [33]. In the present work, the aqueous solutions stirring were carried out in the range of 200–700 rpm. The permeation of phenol increased from 200 to 300 rpm beyond which

no appreciable increase was observed in transport rate up to 500 rpm indicating that the thickness of the diffusion layer in the feed phase has reached its maximum value [3]. Above 500 rpm the permeability showed slight decrease in phenol transport. This indicated that the aqueous boundary layer thickness diminished with increasing stirring speed and that the boundary layer was minimum in the range of 300–500 rpm. Further, a slight decrease in transport rate above 600 rpm could be due to high turbulence caused by stirring, resulting in displacement of LM from the membrane pores [3]. Thus a stirring speed of 400 rpm was maintained throughout the succeeding investigation. Zha et al. [5] reported 330 rpm for the phenol separation using SLM.

3.6. Effect of initial concentration of phenol

The effect of initial phenol concentration in the feed phase on the process efficiency was studied in the range of 100–1500 mg/L. The effect of initial concentration of phenol in the aqueous feed solution on the transport rate is given in Fig. 2. The percentage of phenol transport through the SLM is decreased with increase in initial concentration of phenol in the aqueous feed solution, whereas the absolute concentration in the strip side increases with increase in initial concentration with respect to time. This indicates that, a large initial concentration of phenol in the aqueous feed phase lead to a large molecular gradient across the membrane. Beyond 1250 mg/L transport rate becomes constant, probably due to lower effective area for the transport, maximizing the contact area between the aqueous phase and the organic membrane phase can enhance the separation efficiency. Secondly, the decrease in rate of transport may

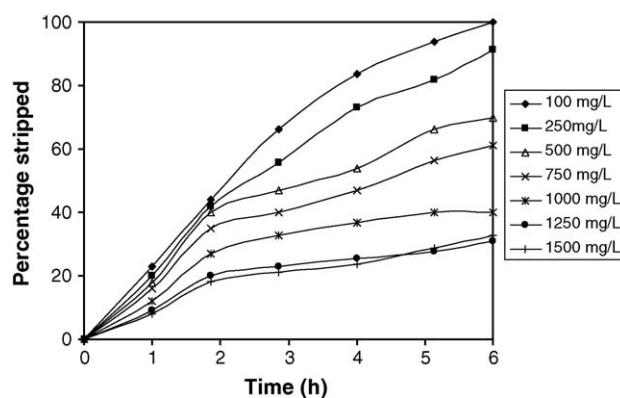


Fig. 2. Effect of initial concentration of phenol in the aqueous feed solution. Conditions: membrane, 0.5 μm ; liquid membrane, palm oil; feed solution pH 2.0; strip solution, 0.2 M NaOH; time of experiment, 240 min.

be due to maximization which occurs as a result of saturation of membrane pores with phenol molecules and build up of the layer on the membrane interface, enhancing the retention of the separating constituent on the entry side and thus causing the transport rate to be constant [33,34]. Therefore, a higher transport rate of phenol was obtained when using a higher initial concentration of phenol in the aqueous phase.

3.7. Feed to strip ratio

In order to increase the concentration in the strip solution, the same strip solution was reused with series of feed solution. Under optimum conditions, on continuous repetition of the procedure up to five operations the average permeability of 6.8×10^{-6} m/s showed no considerable drop in the transport rate. A concentration factor of five can be achieved easily. It shows that the used LM has efficiency of 'uphill transport' and achieving a concentration factor greater than 5.

3.8. Reuse of supported liquid membrane

Stability of PTFE-palm oil system was studied in terms of longtime experimental runs under the optimum conditions. Stability of the SLM was quite remarkable when 10 consecutive experiments were performed without re-impregnation of the same membrane. The permeability remained constant with an average result of 7.9×10^{-6} m/s. This clearly indicates that the palm oil carrier has formed a stable SLM with the PTFE membrane. Jaber et al. [35] studied the phenol transport efficiency over a time period of 2 weeks in SLM. The concentrations of phenol permeated at the steady state were about 100, 80 and 70% of the initial phenol concentration for the freshly prepared membrane and the after 1-week intervals, respectively.

3.9. Transport kinetics

The concentration time profile of phenol transport was studied over a time period of 6 h under optimum conditions. Fig. 3 shows the concentration profile of phenol in the feed and strip solution as a function of time through the SLM. The system had the mass transfer coefficient (k) of 1.0×10^{-4} m/s which was

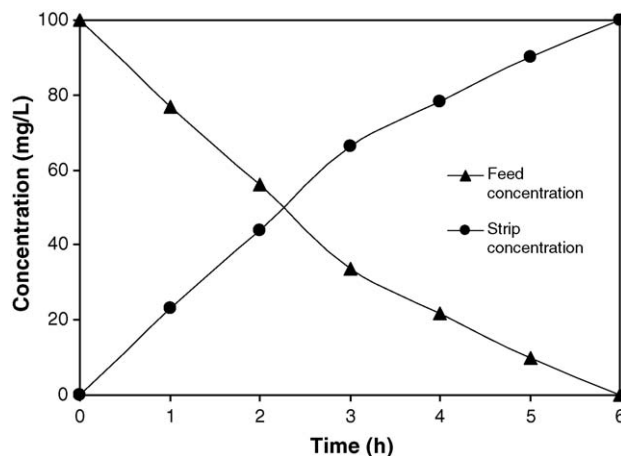


Fig. 3. Concentration profile of phenol in feed and strip phase in a SLM. Conditions: initial phenol concentration, 100 mg/L; membrane, 0.5 μ m; liquid membrane, palm oil; feed solution pH 2.0; strip solution, 0.2 M NaOH; time of experiment, 360 min.

calculated from Eq. (2) [6], assuming that the transport followed first order kinetics.

$$\ln \frac{C_t}{C_i} = - \left(\frac{A k}{V} \right) t \quad (2)$$

where, C_i is the initial phenol concentration, C_t is the concentration of phenol as a function of time t , V is the volume of the source solution and A is the membrane area. The comparison between vegetable oils and toxic carriers with regard to mass transfer coefficient for phenol transport is presented in Table 3. For all the transport studies shown (Table 3) NaOH was used as the stripping reagent. Permeation in carrier-mediated systems like trioctylamine, amberlite LA 2 and cyanex 923 dissolved in kerosene [36] transports through a cellgard membrane was low. Trioctyl amine dissolved in kerosene through a PVDF membrane was also lower. Methyl isobutyl ketone dissolved in kerosene [11] in a hollow fiber supported liquid membrane was (HFSLM) also comparatively low. The mass transfer coefficient (k) for SLM using palm oil (present study) was comparatively higher but lower than *n*-decanol impregnated in a celgard 2500 (PP) membrane. Transfer of phenol through SLM containing palm oil is physical dissolution of phenol in oil. The over-

Table 3
Comparison among vegetable oils and toxic chemicals with regard to mass transfer rate for phenol in SLM

Method	Liquid membrane	Membrane	Mass transfer coefficient, k (m/s)	References
SLM	<i>n</i> -Decanol	Celgard 2500 (PP)	1.2×10^{-3}	[5]
SLM	Aliquat 336	PTFE	1.7×10^{-6}	[20]
	Dibenso-18-crown-6	PTFE	1.5×10^{-6}	[20]
SLM	Trioctylamine + kerosene	PVDF	3.3×10^{-6}	[22]
HFSLM	Methyl isobutyl ketone + kerosene	Accurel 2.6 (PP)	1.7×10^{-6}	[11]
		Accurel 1.00 (PP)	2.5×10^{-6}	[11]
		Cellgard X-20	6.5×10^{-6}	[11]
HFSLM	Trioctylamine + kerosene	Celgard	6.5×10^{-7}	[36]
	AmberliteLA2 + kerosene	Celgard	4.2×10^{-7}	[36]
	Cyanex 923 + kerosene	Celgard	7.3×10^{-7}	[36]
SLM	Palm oil	PTFE	1.0×10^{-4}	Present work

HFSLM: hollow fiber supported liquid membrane; PVDF: polyvinylidene fluoride; PP: polypropylene.

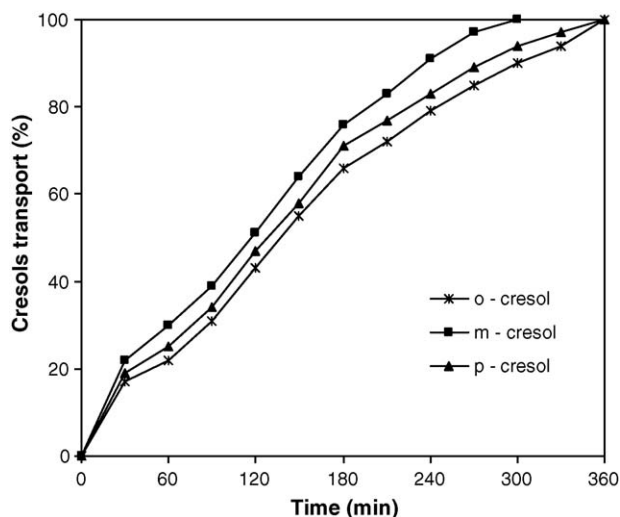


Fig. 4. The transport efficiency for cresols separation in SLM. Conditions: membrane, 0.5 μm ; liquid membrane, palm oil; feed solution pH 2.0; strip solution, 0.2M NaOH; initial concentration, 100 mg/L; time of experiment, 360 min.

all transport process in the SLM is controlled by diffusion in the microporous membrane, membrane thickness, specific area, porosity, etc. However, some authors have reported that the aqueous boundary layer diffusion and membrane diffusion were the simultaneous controlling factors in SLM. Increase in the membrane area conducive to increase the transfer rate [37]. From the above results, it is confirmed that under the optimum conditions, almost all phenol was transported from the feed phase into the receiving phase in about 6 h at an initial concentration of 100 mg/L.

4. Testing with cresols

The transport of cresols (*ortho*, *meta*, *para*) using SLM was studied under the optimized conditions for phenol using 100 mg/L of cresols. The results are shown in Fig. 4. From the figure it is observed that *m*-cresol was completely transported in 5 h where as *o*-cresol and *p*-cresol were transported up to 90 and 95% only. The acidity of the cresols can be measured by their dissociation constants; *m*-cresol is the most acidic phenol with $\text{p}K_{\text{a}} = 10.09$ and can be easily extracted. On the other hand, *o*-cresol and *p*-cresol have a $\text{p}K_{\text{a}}$ value of 10.29 and 10.26, respectively. The selected phenolics (cresols) used in this study are relatively weak acids; which may be the cause for the

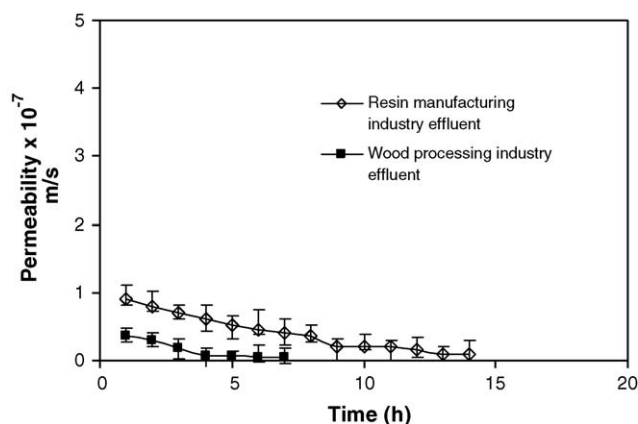


Fig. 5. The transport rate for the phenolic compounds separation in real wastewaters. Conditions: membrane, 0.5 μm ; liquid membrane, palm oil; feed solution pH 2.0; strip solution, 0.2M NaOH; time of experiment, 900 min.

slight deviation from the phenol results. Similar results were also reported for the extraction of phenolics from Eucalyptus wood tar oil by liquid–liquid extraction at a pH of 11–12 [38].

5. Application to real industrial wastewater

The effectiveness of the developed SLM method was tested by treating the wastewater from phenol–formaldehyde resin manufacturing industry and wood products manufacturing industry. The wastewater released during the washing of vessels were collected and characterized. The results are furnished in Table 4. The results show that the phenol–formaldehyde resin manufacturing effluent contained higher concentration of phenol (of about 1550 mg/L) when compared to wood products manufacturing industry (210 mg/L). The pH of the effluents was 5.8 and 7.5, respectively.

The transport rate for the phenolic compounds separation in real wastewaters is shown in Fig. 5. The transport of phenolic compounds from the phenol formaldehyde wastewater occurred at an initial permeability of 2.1×10^{-8} m/s. Phenol gets transported into the stripping solution with the increase in time. Hence, higher phenolic concentration in the feed phase leads to large quantity of phenol molecules transported to the strip phase. After 14 h of the transport studies in the phenol–formaldehyde industry wastewater, phenolic concentration in the feed solution was found to be below detectable level (1×10^{-2} mg/L). For wood processing industry wastewater the transport takes place

Table 4
Characteristics of industrial wastewaters

S. No.	Parameter	Phenol formaldehyde resin manufacturing	Wood products manufacturing
1	pH	5.8	7.5
2	Conductivity ($\mu\text{S}/\text{cm}$)	1026	355
3	Total solids (mg/L)	1350	430
4	Chloride (mg/L)	80	32
5	Sulphate (mg/L)	60	48
6	Sodium (mg/L)	48	44
7	Phenolics (as phenol) (mg/L)	1550	210
8	COD (mg/L)	3690	520

at the initial permeability of 7.1×10^{-5} m/s. After 7 h all the phenol in the feed side was transported to the strip side. Thus the treated wastewater found to meet the Indian pollution control board discharge standard of 1.0 mg/L.

6. Conclusions

As demonstrated, the long-term greener approach for the recovery of phenol using vegetable oils as a suitable LM has been identified in the present study. The study reveals that the optimum pH for the transport of phenol is 2.0 with 0.2 M NaOH as the stripping reagent. A concentration factor of five can be achieved easily with 0.2 M sodium hydroxide as stripping agent. After 10 transport studies with one impregnation, the LM showed no significant loss in the transport rate. This shows that palm oil has formed a stable SLM in the PTFE membrane. The SLM method applied for the removal and recovery of cresols from aqueous solutions was found to be satisfactory.

The developed SLM has been applied to effluents containing phenolics. Thus, this technology seems to have a promising future in the treatment of aqueous effluents containing phenols, allowing their recovery.

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