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Separation of Dissolved Phenolics from Aqueous Waste Stream using Micellar Enhanced Ultrafiltration

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The micellar enhanced ultrafiltration (MEUF) process has been used for the separation of phenol and o-cresol from aqueous solutions at room temperature (30 + 2°C) using a cationic surfactant, cetyltrimethylammonium bromide (CTAB), and polyethersulfone membrane of molecular weight cut-off 10 kDa. The effect of the cross-flow rate, the surfactant to pollutants (S/P) concentration ratio in feed, the variation of pollutants concentration in the feed keeping S/P constant, the presence of Na_2SO_4 and NaCl salts and mixed surfactants on the rejection of each solute and permeate flux have been studied in detail. The % rejection of phenol and o-cresol without using the surfactant observed was 24% and 41% respectively, which was increased to 60% for phenol and 80% for o-cresol at S/P ratio of 8. The effect of salts was also investigated. There was no significant effect of the cross-flow rate on the % rejection of the solutes. The effect of the membrane pore size was also investigated using 1 KDa and 30 KDa PES membranes. Characteristic parameters of MEUF such as the distribution coefficient, micelle loading, and the micelle binding were also estimated.

Keywords CTAB surfactant; micellar enhanced ultrafiltration; o-cresol; permeate flux; phenols

INTRODUCTION

Phenols or phenolics are among the most common water pollutants and constitute the 11th of the 126 chemicals, which have been designated as priority pollutants by USEPA (1). Wastewater containing phenol discharged into the natural environment is difficult to be cleaned by natural degradation. The maximum permissible levels of the total phenolic concentration in a wastewater stream as fixed by environmental agencies such as, USEPA and the Environmental Pollution Act 1986, India, ranges from 1 ppm to 5 ppm depending on the type of industries. Thus, careful treatment of wastewater containing phenol and phenolic compounds is then required before the final discharge to the environment. Various treatment technologies such as adsorption, photo-degradation, coagulation, flocculation, chemical oxidation, and biological process etc. are available for the removal of phenol from the wastewater. However, these techniques have their own disadvantages such as high-energy consumption, high cost, low efficiency, secondary pollution, as well as difficulty of recycling the chemical agent and phenol (2,3).

The membrane process has also been considered to remove some organics pollutants from wastewater. The application of pressure-driven membrane processes for the removal of low molecular weight organic compounds from wastewater has been analyzed in several research publications (4–8). Micellar-Enhanced Ultrafiltration (MEUF) based on the coupling of micellar extraction and ultrafiltration may be a viable alternative technique which is effective and economical for removing organic matters.

The basic principle of the MEUF process is the solubilization of organic solutes in the surfactant's micelle, thereby increasing the size of the solutes to be separated and eventually retained by the ultrafiltration membrane. This technique involves the addition of the surfactant to the contaminated aqueous solution. The surfactants in the aqueous or the organic solution, above critical micelle concentration (CMC) form micelles (9,10). Most of the organic solute molecules are solubilized in the micelles. Micelles being larger in size can be rejected along with the solubilized organic contaminants using a relatively porous membrane at a lower operating pressure. In the MEUF process solubilization of organic solutes in micelles plays an important role that decides the amount of retention of solutes by the membrane (11–14).

MEUF has several characteristics:

(1) due to the membrane polarization effects, a secondary layer of the surfactant in liquid-crystalline form deposits onto the membrane surface
(2) the secondary layer "fouls" the membrane, reducing its permeability;
(3) it enhances the ability of the membrane to reject the target solute (15–17).

In the present study, the mixture of phenol and o-cresol dissolved in an aqueous stream was separated by the MEUF technique using a plate and frame cross flow ultrafiltration

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module. The effect of the important factors like the hydrophobic character of solutes, the cross flow rate, S/P ratio, the variation in feed concentration, the presence of salts in feed solution, and mixed surfactants in terms of retention and flux have been studied in detail. Also, the rejection of solutes and the permeate flux for 1 KDa and 30 KDa PES membrane was studied. It was an additional aim to determine the parameters such as the micelle loading (Lm), the micelle binding constant (Kp), and the distribution coefficient (D) which are typical in colloid and extraction studies.

EXPERIMENTAL

Materials and Reagent

The phenol (M.W. 94), o-cresol (M.W. 108), sodium sulfate (M.W. 142) and sodium chloride (M.W. 58) were procured from S.D. Fine Chem. Ltd., Mumbai, India. Surfactant CTAB (M.W. 364) was obtained from CDH Pvt. Ltd., Mumbai, India. Surfactant sodium dodecyl sulfate (SDS) (M.W. 288), chloroform (M.W. 119), and methanol (M.W. 32) of HPLC grade were obtained from Merck India Pvt. Ltd., Mumbai, India. All the chemicals were over 99% pure and of analytical grade. They were used as received without further purification. Ultra pure deionized (DI) water of conductivity 0.054 μs was used to carry out all the experiments and to prepare the solutions of desired concentration. DI water was prepared by purification of distilled water of conductivity 18 μs using Milli-Q water purifier system.

Membranes

An organic polyethersulfone membrane of molecular weight cut off (MWCO) 10000 (10 KDa), procured from Sartorius India Pvt. Ltd., Mumbai, India was used for all the MEUF experiments without further treatment. The membrane material is relatively hydrophobic in nature and the cross-flow area is $0.02\,m^2$. 1 KDa and 10 KDa membrane used are also of the same characteristics and material.

Experimental Setup

A rectangular cross-flow cell, made of stainless steel is used for all experiments procured from Sartorius India Pvt. Ltd., India. A schematic of the experimental set up is shown in Fig. 1. The length of the membrane cassette is 0.21 m and the width is 0.057 m. The cross-flow cell is provided with a reservoir of 500 ml volume as a feed tank. The micellar solution was placed in this reservoir. A peristaltic pump is used to feed this solution across the membrane. The retentate stream is recycled to the feed tank continuously throughout the experiment. The permeate stream is also recycled to maintain a constant concentration in the feed tank.

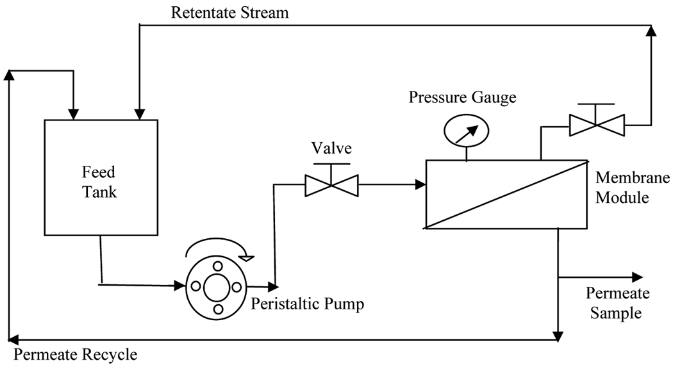


FIG. 1. Schematic of cross flow experimental set up.

Procedure

For experiments, an aqueous solution of 250 ml volume of equimolar concentration of phenol and o-cresol was prepared and then the CTAB surfactant is added in proportion to it and this feed solution is then taken for cross-flow ultrafiltration. Before ultrafiltration of the feed solution the membrane was continuously washed with DI water for about an hour and the DI water flux was measured and then the actual feed solution was passed through the membrane. During the ultrafiltration run, the permeate samples were taken after each interval of 15 min and the permeate fluxes in these intervals were also measured simultaneously. The duration of the cross-flow ultrafiltration was 1 hr and 15 min. After finishing the ultrafiltration of the feed solution, a back wash was given to the membrane with DI water for about 30 min to clean the membrane and then again the DI water flux was measured to check the membrane fouling.

All the experiments were carried out at room temperature (30 ± 2°C) and at constant Trans Membrane Pressure (TMP) of 85 kPa. The % rejection of the organic pollutants and the permeate flux were calculated as given below:

$$\%\ \text{Rejection} = \left(1 - \frac{C_p}{C_R}\right) \times 100 \qquad (1)$$

Where, C_P and C_R represent the concentration of the pollutants in the permeate and the retentate respectively.

$$\text{Permeate Flux} = \left(\frac{V_p}{(t) \times (A_M)}\right) \quad (\text{L/m}^2\text{hr}) \qquad (2)$$

Where, V_P, t, and A_M represent the permeate volume in L, time in hr and membrane area in m^2 respectively.

Analysis

Concentrations of phenol and o-cresol in the permeate stream were determined by using HPLC (KNAUER) ODS C18 5 μm (250 × 4 mm) reverse phase column with

UV detector at $\lambda_{max} = 270\,nm$. The mobile phase used was methanol/water (60:40 on v/v basis) at a flow rate of 0.8 ml/min, whereas, the concentration of phenol and o-cresol in the retentate stream were determined by the material balance across membrane. The concentration of the CTAB surfactant in the permeate was determined by a two-phase titration method using SDS as a titrant and methylene blue used as an indicator.

RESULTS AND DISCUSSIONS

Ultrafiltration in the Absence of Surfactant

Variation in % rejection of phenol and o-cresol and permeate flux without using the surfactant is shown in Fig. 2. It can be observed from the figure that the % rejection decreases with time. This may be attributed to the fact that as filtration progresses, more pollutants will be deposited on the membrane surface leading to an increase in the membrane surface concentration (concentration polarization). This results in an increase in the convective transport of the solutes to the permeate side and thereby increasing the permeate concentration and subsequently, decreasing the retention with time. The average % rejection for phenol and o-cresol was 24% and 41% respectively. This value is well above the expectation. This may be attributed to hydrophobic interaction between the membrane material and the solutes with slightly similar structures. Hydrophobic interaction can be described as "like attracts like." Hydrophobicity of the membrane media is usually characterized by the water contact angle. The greater the contact angle, the more hydrophobic is the membrane medium. The water contact angle for polyethersulfone membrane is 65° and is relatively hydrophobic in nature (18). Hydrophobic attraction results from the van der Waals force between molecules. It is estimated that the van der Waals energy per CH_2 group is approximately 2.5 kJ/mol (19). For example, in case of a 12-C organic segment, the van der Waals cohesive energy is approximately 30 kJ/mol, which exceeds the electrostatic repulsion energy from the dissociation of one charge group. Therefore, the phenol and o-cresol might have got attracted to the membrane in accordance with there hydrophobic character, resulting in some rejection even without using a surfactant. It can be observed that the permeate flux during ultrafiltration remains almost more or less constant indicating that the gel layer formation is not significant and there is no blockage of the membrane pores.

Ultrafiltration in the Presence of Surfactant

Variation in % rejection of phenol and o-cresol and permeate flux using surfactant is shown in Fig. 3. It can be observed from the figure that the % rejections for phenol and o-cresol are 55% and 75% respectively indicating significant enhancement in the separation efficiency of ultrafiltration in the presence of the surfactant. But, it is found that the extent of rejection for phenol is less compared to that of o-cresol. This may be due to the effective solubilization of o-cresol by CTAB micelles than that of phenol, probably because o-cresol is somewhat more hydrophobic than phenol. The extent of solubilization of pollutants in surfactants micelle can be characterized by some physical properties like the solubility of pollutants in water, the dipole moment, and the octanol-water partition coefficient (log K_{OW}) (20). More correctly, the hydrophobicity of the solute can be characterized by its octanol-water partition coefficient (21). As per the solubilization of organic pollutants in micelles defined by Mcbain, the solubility of the pollutants in water also plays an important role in deciding otherwise insoluble material that causes the solubilization of pollutants in micelle.

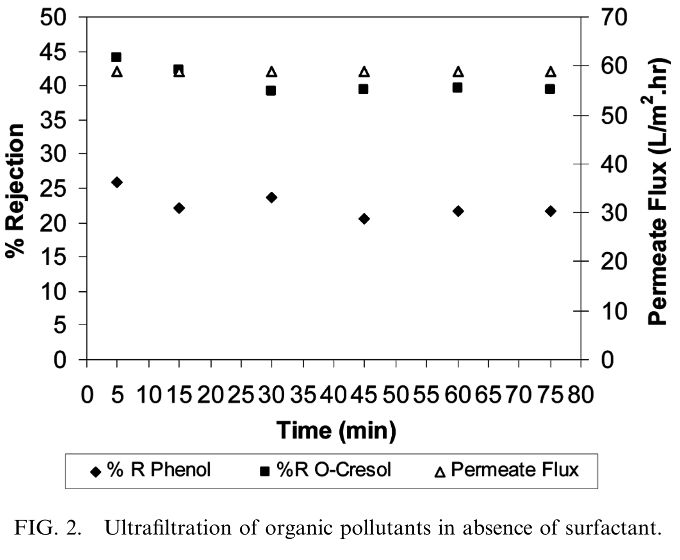


FIG. 2. Ultrafiltration of organic pollutants in absence of surfactant.

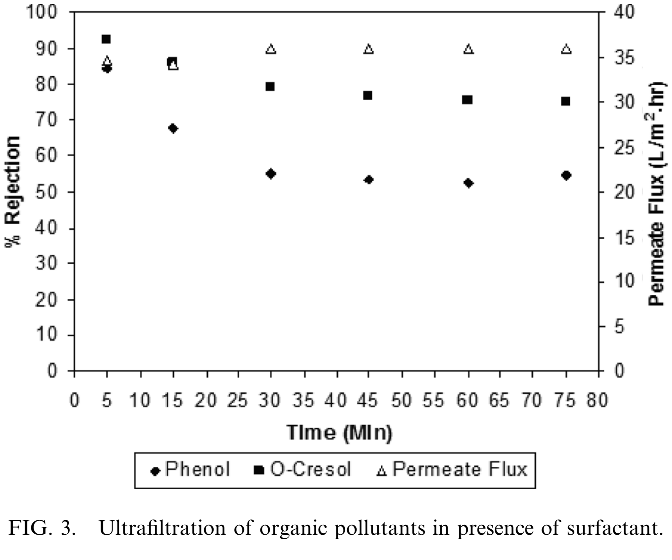


FIG. 3. Ultrafiltration of organic pollutants in presence of surfactant.

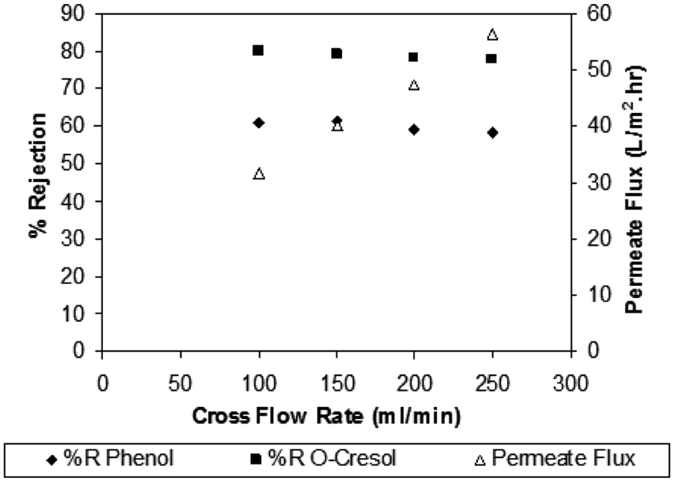


FIG. 4. Effect of cross flow rate.

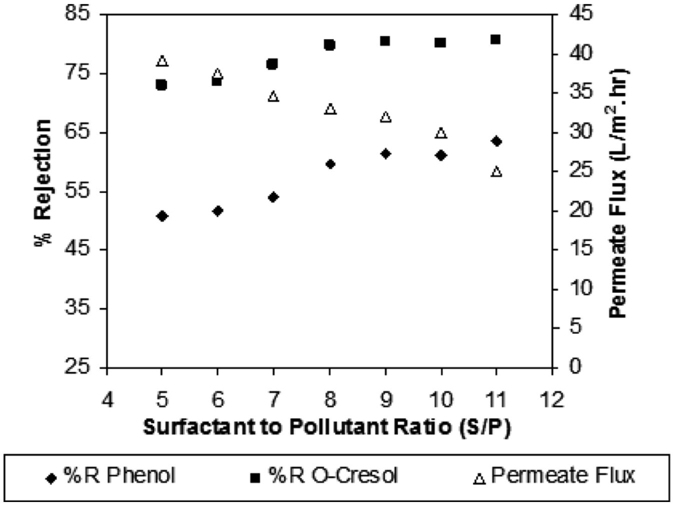


FIG. 5. Effect of surfactant to pollutants ratio (S/P ratio).

The permeate flux is almost constant throughout the experiment and the value of the flux is $35\,\mathrm{L/m^2\,hr}$, which is lower than the value of the flux in the absence of surfactant ($60\,\mathrm{L/m^2\,hr}$) because colloidal micelles are kept in suspension in the flowing feed stream (13).

Effect of Cross-Flow Rate

The effect of the cross-flow rate on the rejection of organic pollutants and permeate flux is presented in Fig. 4. It may be observed from the figure that the rejection of both the solutes remain almost unchanged with the cross-flow rate which means the extent of solubilization of organic pollutants in micellar aggregates is independent of the cross-flow rate. The increase in flux value with the cross-flow rate may be attributed to the fact that the resistance offered by the deposited layer of the micellar aggregates on membrane surface is slightly lowered with the increase in cross-flow velocity. This is in agreement with Purkait et al. (22). The flow rate was optimized at 100 ml/min by considering the required cost for pumping and to avoid the high pressure across the membrane.

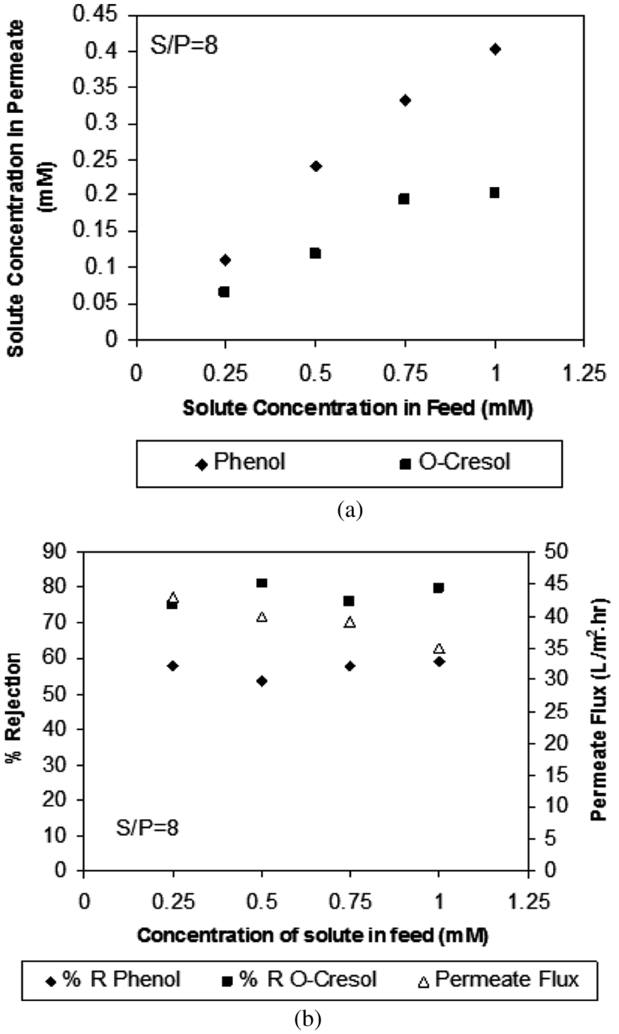
Effect of Surfactant to Pollutants Ratio (S/P Ratio)

The effect of surfactant concentration (from 10 mM to 22 mM) in the feed, while maintaining constant concentration of phenol and o-cresol (1 mM each) in the feed is shown in Fig. 5. The data for the S/P ratio for a given surfactant and pollutants could be useful for scale up of the process. All the data presented here are at 85 kPa TMP and at the cross-flow rate of 100 ml/min. It can be observed from the figure that the rejection of phenol and o-cresol increases with the CTAB concentration upto S/P equal to 8 and remains almost constant after the S/P ratio goes beyond 8. This may be attributed to the fact that at higher concentrations, spherical micelles convert to ellipsoidal, rodlike, or other non-spherical forms, in which the surfactant head groups are packed more tightly than at low concentrations and ordinarily, the transition from spheres to rodlike micelles will cause a decrease in the tendency of phenols, aliphatic alcohols, and any other organic solutes to solubilize, for a given total number of surfactant molecules (23,24). It can also be observed from the figure that the permeate flux decreases with feed CTAB concentration. This trend may be explained by the increase in resistance against the solvent flux due to micellar aggregates, which are deposited on the membrane surface. Thus, the S/P ratio 8 can be considered as an optimum one at which maximum rejections of phenol and o-cresol observed were 60% and 80% respectively. Even at this ratio the value of the permeate flux is also desirable.

Effect of Variation of Pollutant Concentration in Feed by Maintaining S/P Ratio Constant at 8

The effect of variation of pollutants (phenol and o-cresol) concentration in feed by maintaining the S/P ratio constant at 8 on permeate concentration and rejection is as presented in Figs. 6a and 6b respectively. The concentration of both the phenol and o-cresol in feed was varied from 0.25 mM to 1 mM and the concentration of the CTAB surfactant was varied from 4 mM to 16 mM in order to keep the S/P ratio constant at 8. It can be observed from Fig. 6a that the permeate concentration increases with the feed concentration, thus, the lower is the concentration of pollutant in feed, the obtained permeate would have the low concentration of pollutant, indicating that MEUF is suitable for very low concentration and thus may be used as a secondary or tertiary treatment process in the existing wastewater treatment plant.

Figure 6b represents the variation of % rejection and permeate flux with feed concentration. The rejection of pollutants is almost constant. The decreasing trend of the



(a)

(b)

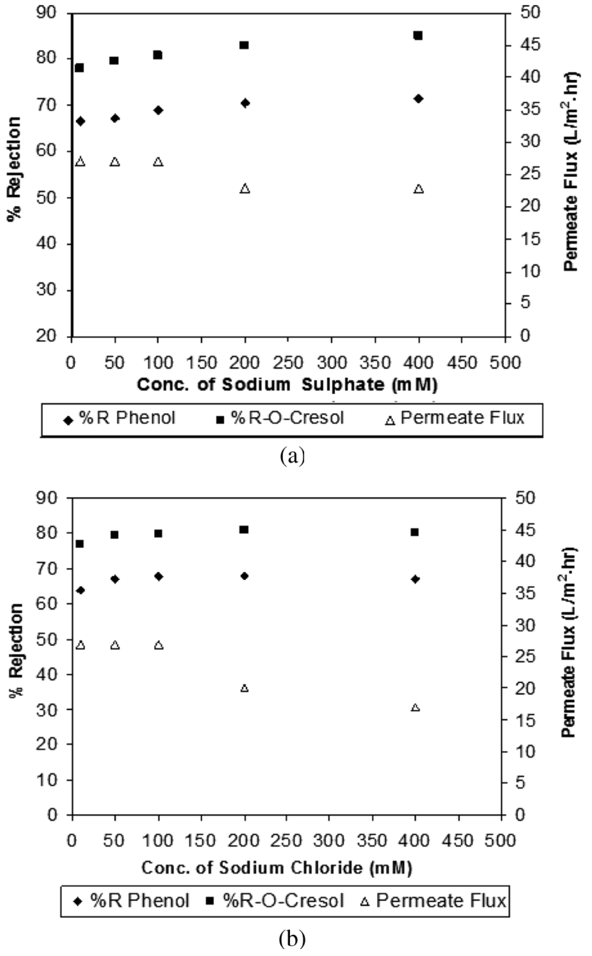
FIG. 6. (a) Effect of variation of pollutant concentration on permeate concentration; (b) Effect of variation of pollutant concentration on % rejection and permeate flux.

permeate flux is due to an increasing concentration of surfactant aggregates at the membrane surface resulting in to concentration polarization offering resistance to ultrafiltration.

Effect of Salts in Feed Solution

Most of the studies published to date were focused on ideal solutions without or with small amounts of salts. However, industrial streams to be treated usually contain various quantities of salt, which may affect the properties of the micellar solutions, possibly involving changes in the micelle structure and changes in viscosity. The micellar solution is then affected and the flux of the permeate decreases. The effect depends both on the salts and on the surfactant. Solutions of some surfactants are strongly affected by the content of salts.

The effect of sodium sulfate and sodium chloride on % rejection of pollutants and permeate flux is as shown in Figs. 7a and 7b respectively. The concentration of salts in the feed solution was varied from 10 mM to 400 mM. It can be observed from the figures that the rejection of phenol and o-cresol increases gradually with the addition of salt. This is due to the fact that the addition of salt has a great influence on the solubility of an organic compound in an aqueous solution, showing the "Salting in" and "Salting out" effect with an increase or a decrease in solubility respectively. Generally, the salting out effect is observed in case of phenols dissolved in aqueous solutions (25,26) which can be explained by a deficit of water molecules around the organic molecules, caused by the ionic species of salt. The water molecule cages the salt ions and hence encourages the migration of the organic molecules towards the organic phase. In this way the organic pollutant approaches towards the surfactant micelles and get solubilized within micelles. This implies that the solubility of both the pollutants in the aqueous phase decreases and approaches to a character of otherwise insoluble



(a)

(b)

FIG. 7. (a) Effect of sodium sulphate on rejection and permeate flux; (b) Effect of sodium chloride on rejection and permeate flux.

material which always tend to solubilize more effectively in micelles, thereby giving more rejection in the presence of salts.

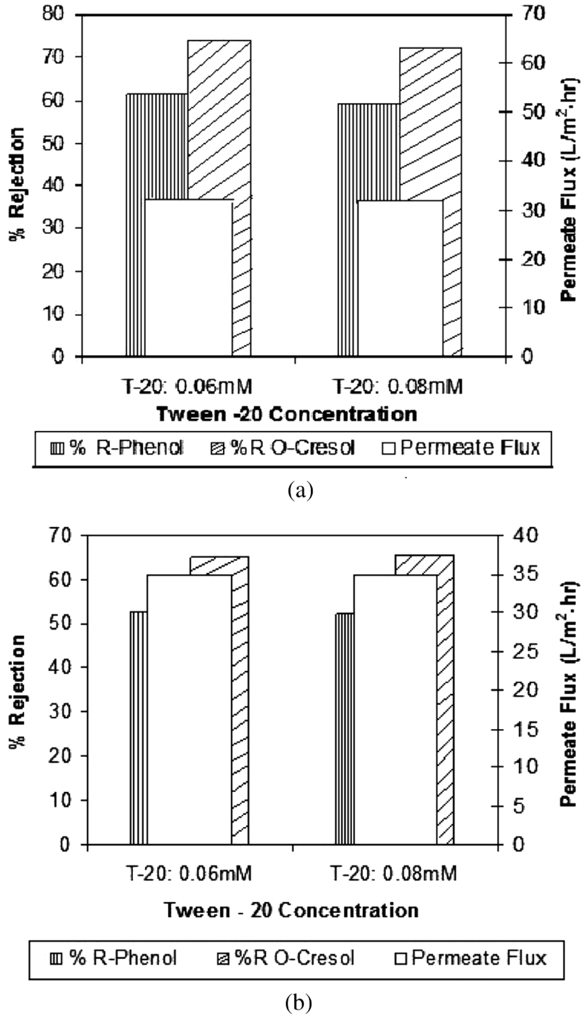
This can also be interpreted in another way. With the addition of salts the CMC of ionic surfactant decreases, presumably because the screening action of simple electrolytes lowers the repulsive forces between the polar head groups of the surfactant monomer and less electrical work is required in micelle formation thereby lowering the CMC of the surfactant (27). Thus the micelle size increases with an increased quantity of salt resulting in the reduction in CMC of the surfactant and increasing the micelle size which is eventually retained by the membrane effectively, giving more rejection.

From both the Figs. 7a and 7b it can be observed that the value of the permeate flux decreases when the salt concentration reaches beyond 100 mM which can be attributed to the fact that the gel layer formation is significant after this concentration, that offers resistance to the flow of the solvent across the membrane.

Effect of Mixed Surfactants

A mixed surfactant study was carried out using Tween-20 (T-20) as a non-ionic surfactant and CTAB as an ionic surfactant. The CMC of T-20 obtained by conductivity measurements was 0.06 mM. The CMC of the mixture of CTAB and T-20 was also determined for different concentrations of T-20 by conductivity measurements. It was found that the CMC of the mixed surfactant decreases with increase in concentration of T-20. Thus the CMC of the mixture of 0.04 mM T-20 and CTAB is 0.6 mM, the CMC of the mixture of 0.06 mM T-20 and CTAB is 0.5 mM, and the CMC of the mixture of 0.08 mM T-20 and CTAB is 0.3 mM respectively. Thus, from the observed reduction in CMC of CTAB in the presence of T-20, it was planned to conduct the experiments in two parts. The first part was to study the rejection and permeate flux using T-20 concentration equal to 0.06 mM and 0.08 mM and adding 15.94 mM and 15.92 mM of CTAB respectively so as to maintain the S/P ratio at 8. In the second part the S/P ratio was not maintained at constant values, instead of that the CTAB concentration used was equal to 18 times of its lowered value of CMC due to the presence of T-20 in solution.

Figures 8a and 8b represent the rejection and permeate flux for the mixed surfactant when the S/P ratio was maintained at 8 and when the CTAB concentration was 18 times of its lowered value of CMC respectively. It can be observed from Fig. 8a, that the rejection values for phenol and o-cresols are unchanged and are almost similar to values when only the CTAB surfactant was used. Even, when the CTAB concentration was18 times of its lowered CMC, the rejection values for both phenol and o-cresol were dropped to 52% and 65% respectively as shown in Fig. 8b. This indicates that the use of mixed surfactants does not enhance the rejection of organic solutes.



(a)

(b)

FIG. 8. (a) Effect of mixed surfactant (when S/P maintained at 8); (b) Effect of mixed surfactant (18 times of lowered CMC of CTAB).

However, it is not recommended to use a high concentration of nonionic surfactant because they are of high molecular weight and the cost of the surfactant is based on molecular weight, therefore would not be cost-effective and even they are having less solubilizing capacity for organics (4).

Figure 8a shows less permeate flux than in Fig. 8b as in the first case in order to maintain S/P at 8, the amount of the surfactant added is more which may result in gel layer formation giving low values of the permeate flux.

Rejection and Permeate Flux Study for Different Molecular Weight Cut off Membranes

Figure 9 shows the permeate flux and rejection for phenol and o-cresol for different molecular weight cut off

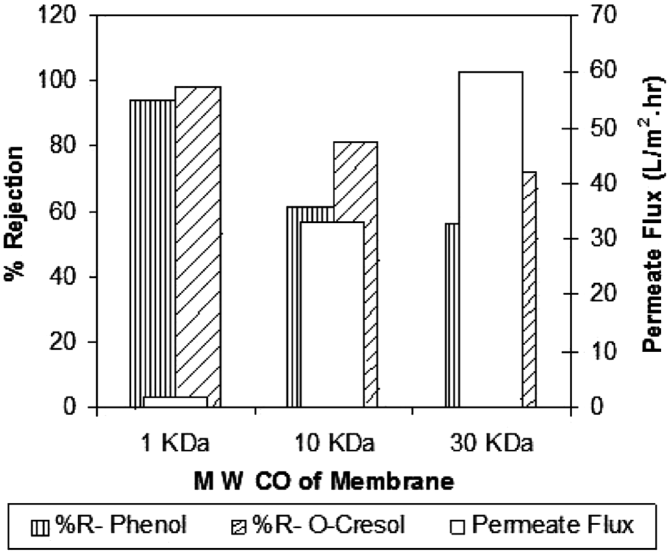


FIG. 9. Rejection and permeate flux study for different molecular weight cut off membrane.

(MWCO) membrane viz. 1 KDa, 10 KDa, and 30 KDa respectively. It is observed that the % rejection of phenol as well as o-cresol gradually decreases with increase in MWCO of membrane whereas the value of the permeate flux increases with MWCO of membrane. The % rejection and permeate flux in case of 10 KDa membrane observed are more satisfactory because the rejection and permeate flux are balanced and good enough compared with 1 KDa and 30 KDa membranes. So, while choosing the membrane cut off one should also consider the optimum value found for the permeate flux and rejection.

Evaluation of MEUF

The performance of MEUF can also be judged from the micelle loading, the micelle binding constant, and the distribution coefficient of solutes in the micellar phase and aqueous phase (23).

The ultrafiltration experiments were used to estimate the value of these constants. The loading of micelles with solutes defined by the following equation:

$$\mathrm{L_M} = \left(\frac{[P]_R - [P]_P}{[S]_R - CMC}\right) \qquad \text{(mol/mol)} \qquad (3)$$

Where, [P] and [S] represent the pollutant concentration and surfactant concentration respectively, whereas suffix R and P represents the retentate and permeate streams respectively.

The loading depends upon the concentration of solutes in the feed $[P]_F$, as shown in Tables 1 and 2. The micelle loading values are almost constant throughout the range of feed concentration, because the surfactant added in the feed was in proportion to the organics concentration in the feed so as to maintain the constant S/P ratio which was optimized at 8, thus these constant values of micelle loading indicate the correctness of the ultrafiltration experiments and of the analytical procedure.

Micelles of surfactants are dynamic aggregates and they are in equilibrium with the individual surfactant molecules, passing through the pores of a membrane. The residence time and micelle lifetime, which characterize an exchange of one surfactant molecule between the micelle and the bulk and the micelle breakdown are very low, i.e., of the order of μs and ms, respectively, although it is impossible to give general values, because these characteristic times depend significantly upon the surfactant type and alkyl chain length. According to the reported results that in one run the permeate concentration of pollutants was constant, and that micelles did not leak, the equilibrium between the solutes in both pseudophases at any time of ultrafiltration could be assumed.

According to the observed results of the experiments, the permeate concentration of the pollutants remained almost constant after certain time during ultrafiltration for the given concentration of the surfactant and the pollutants. Thus, by assuming there was no micelles leak, it could be said that there exists the equilibrium between the solutes in both pseudophases at any time of ultrafiltration and this can be confirmed by the estimation of the

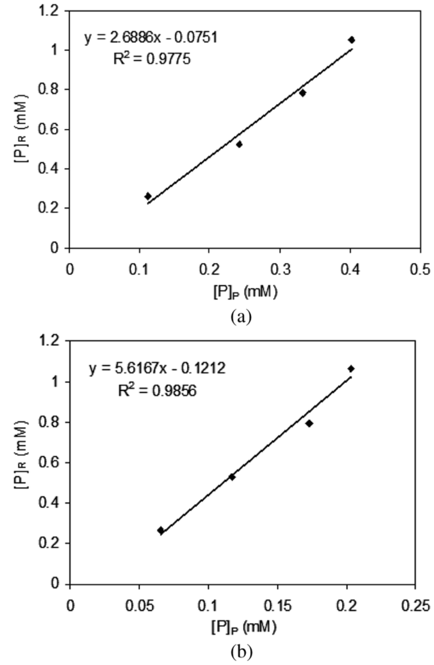
TABLE 1
Distribution coefficient, loading of micelles and micellar binding constant for phenol based feed concentration

	Pollutant concentration			Surfactant concentration					
Sr. no.	Feed (mM)	Retentate (mM)	Permeate (mM)	Feed (mM)	Retentate (mM)	Permeate (mM)	Distribution coefficient (D)	Loading of micelles (Lm)	Micellar binding constant (Kp)
1	0.25	0.26	0.11	4	4.25	1.90	2.35	0.04	0.40
2	0.50	0.52	0.24	8	8.63	2.28	2.15	0.03	0.15
3	0.75	0.78	0.33	12	13.06	2.46	2.36	0.03	0.11
4	1.00	1.05	0.40	16	17.47	2.70	2.62	0.04	0.09

TABLE 2
Distribution coefficient, loading of micelles and micellar binding constant for o-cresol based feed concentration

	Pollutant concentration			Surfactant concentration					
Sr. no.	Feed (mM)	Retentate (mM)	Permeate (mM)	Feed (mM)	Retentate (mM)	Permeate (mM)	Distribution coefficient (D)	Loading of micelles (Lm)	Micellar binding constant (Kp)
1	0.25	0.26	0.06	4	4.25	1.90	4.01	0.06	0.9
2	0.50	0.53	0.11	8	8.63	2.28	4.53	0.05	0.46
3	0.75	0.79	0.17	12	13.06	2.46	4.60	0.04	0.261
4	1.00	1.06	0.2	16	17.47	2.70	5.23	0.05	0.26

distribution coefficient. Linear straight relationships defined as the ratio of pollutant concentrations in the retentate and the permeate were obtained for both the pollutants phenol and o-cresol as presented in Figs. 10a and 10b respectively. A typical relationship for the ultrafiltration of phenol and o-cresol in CTAB solution through the PES membrane was as: $[P]_R = 2.68[P]_P - 0.07$, $R^2 = 0.98$ and $[P]_R = 5.61\ [P]_P - 0.12$, $R^2 = 0.99$ for phenol and o-cresol respectively, where R^2 denotes the determination coefficient, proving the statistical validity of the equation. Thus, the slopes give the distribution coefficients. However, the distribution coefficient values were also calculated by taking the ratio of the organic concentration in retentate to that in permeate as tabulated in Tables 1 and 2.



(a)
(b)

FIG. 10. (a) Distribution of phenol between retentate and permeate streams; (b) Distribution of o-cresol between retentate and permeate streams.

The ultrafiltration data also enabled to estimate the micellar binding constant which is given as,

$$K_P = \left(\frac{[P]_M}{[P]_W \times [S]}\right) \quad (\text{mole}^{-1}) \qquad (4)$$

Where, the subscripts M and W denote the micellar and aqueous pseudophases, respectively, [P] represents the pollutant concentration and [S] is the concentration of the surfactant which contributes to the surfactant pseudophase.

The values of the micellar binding constant tabulated in Tables 1 and 2 for phenol and o-cresol respectively, indicates that the micellar binding depends on the feed concentration and the type of the organic pollutant.

CONCLUSION

There is only marginal % rejection observed in case of ultrafiltration of pollutants without using a surfactant, whereas a significant enhancement in % rejection of phenol and o-cresol i.e., 55% and 75% respectively with the use of a surfactant. The cross-flow rate does not affect the solubilization of the solutes and eventually the rejection of the solutes but affects the permeate flux. For the maximum retention of the solute, the surfactant to solute (S/P) ratio should be maintained at 8, at which the flux is also optimum and observed rejections are 60% and 80% phenol and o-cresol respectively. The MEUF process can be used very effectively and suitably for the separation of trace concentrations of organic pollutants. Salts present in wastewater do not lower the performance of MEUF, despite the fact that more rejections of solutes are observed because of increase in solubilization of solutes in micelle due to the salting out effect. No enhancement in the rejection of organic solutes was observed using mixed surfactants. The smaller the pore size the greater is the rejection but one has to compromise with the lower value of the permeate flux and high TMP. The values of loading of micelles, micellar binding, and distribution coefficient confirms the effectiveness of MEUF for wastewater treatment. To comply with the environmental norms, a multistage ultrafiltration would be suggested from the present study.

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