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A Study on Supported Liquid Membrane for Selective Separation of Cr(VI)

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ABSTRACT

A supported liquid membrane (SLM), impregnated with tricaprylmethyl ammonium chloride (Aliquat 336) as a carrier, was investigated for separating and recovering Cr(VI) in aqueous solutions containing Cr(III). It was found that the transport of Cr(VI) through the SLM was dominated by membrane diffusion and that the Aliquat 336 in the SLM played a key role in the selective transport of Cr(VI) while *o*-nitrophenyl octyl ether (NPOE) assisting mobility of the ion–carrier complex in the membrane. The maximum recovery of Cr(VI) in the test solution containing Cr(III) was 93.2% with a permeability of 1.01×10^{-3} cm/s through the SLM made of 0.0735 g poly(vinyl chloride) (PVC), 0.1471 mL NPOE, and 5.43×10^{-5} mol Aliquat 336 for a sheet of 24.6 cm². The permeability

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of Cr(VI) was not influenced by concentrations of Cr(VI) and cationic interferences in the feed solution, except for Cr(III). Selective recovery of Cr(VI) in the presence of anionic interferences and Cr(III) was attained reasonably when the nitrate, nitrite, and Cr(III) concentrations did not exceed tenfold of the Cr(VI) concentration.

Key Words: Supported liquid membrane; Hexachromic ion; Tricaprylmethyl ammonium chloride; Transport mechanism; Selectivity.

INTRODUCTION

Both forms of Cr(III) and Cr(VI) enter the environment from various sources such as effluent discharge from tanning industries, electroplating, oxidative dyeing, chemical industries, steel works, and cooling water towers.^[1] The separation and sequential determination of chromium (Cr) has received considerable attention due to the high toxicity of Cr(VI) and the useful biological activity of Cr(III).^[2]

Liquid membranes have been widely utilized in the recovery of various heavy metals^[3–12] and rare metals.^[13–15] As Cr(VI) is considered to be one of the most poisonous pollutants in wastewater, many studies on the separation and recovery of Cr(VI) from wastewater using liquid membrane processes have been carried out^[16–19] in order to reduce its concentration to <0.05 ppm, the limit recommended by the World Health Organization. Cr(VI) may exist as a variety of species, including $H_2Cr_2O_7$, $Cr_2O_7^{2-}$, H_2CrO_4 , and $HCrO_4^-$, according to the total Cr(VI) concentration and the solution pH.^[20–22] In the recovery and separation of Cr(VI) from aqueous solutions, the mechanism of Cr(VI) transport through a liquid membrane has been investigated by several researchers.^[22,23] However, previous studies described Cr(VI) transport from aqueous solutions through a liquid membrane based on either the Cr(VI) concentration without Cr(III) and other interferences or the total chromium concentration. Even though Djane et al.^[23] reported chromium speciation in Cr(VI) solutions containing Cr(III) using serial supported liquid membrane (SLM), recovery efficiency of Cr(VI) over 40% was not attained. It is necessary to clarify the transport mechanism of Cr(VI) and to accomplish efficient recovery of Cr(VI) in the presence of various interferences containing Cr(III).

SLMs represent one of the feasible types of liquid membranes. Typically, they use porous polymer membranes impregnated with complex carriers to separate feed solution and stripping solution.^[11–13,22,23] However, they have a structural drawback in that the oil phase and the porous membrane phase are separated physically; porous parts are filled with lipophilic matters only



and nonporous parts are not. It is easy to lessen the membrane property. Accordingly, in this study, homogeneous SLMs were prepared using a solvent casing method with plasticized PVC membranes.

Aliquat 336 has been utilized as an effective ion exchanger for both separating and purifying Cr(VI)^[23-25] due to its excellent ion pair-forming stability and low solubility in water. In this study, the mechanism of Cr(VI) transport through an SLM was investigated with Aliquat 336 as the mobile carrier using homogeneous poly(vinyl chloride) (PVC) membrane plasticized by *o*-nitrophenyl octyl ether (NPOE). The permeability of Cr(VI) through the SLM was measured for various Aliquat 336 concentrations in the membrane phases. Further, the effect of the ratio of the Cr(VI) to Cr(III) concentrations on the transport was investigated. A permeation model was proposed to describe the transport of the predominant species, HCrO₄⁻, through the SLM in a HCrO₄⁻/CrO₄²⁻ binary system. The simultaneous counter-transport of chloride ions occurred from the stripping to the feed phase as driving force. The interference of several anions and cations on the recovery of Cr(VI) was also examined to apply the SLM to environmental monitoring system such as sensors.

EXPERIMENTAL

Materials

The PVC-based SLMs were prepared by modifying the method reported in our previous study.^[26] Aliquat 336 was used as the carrier for the selective separation of Cr(VI), NPOE as a plasticizer to provide mobility for the carrier, and tetrahydrofuran (THF) as the solvent for mixing the membrane materials. K₂Cr₂O₇ and CrCl₃·*x*H₂O were dissolved in deionized water to make the Cr(VI) and Cr(III) solutions. To maintain pH of the test solution during the separation process of Cr(VI), NaCl was employed as a source generating driving force in striping solutions. All the other reagents were of analytical grade. The compositions of the SLM prepared in this study are shown in Table 1.

Cr(VI) Selectivity by Solvent Extraction

A solvent extraction method was employed to determine the distribution coefficients of Cr(VI) and interfering cations and anions. The solvent extraction experiments were carried out under the following conditions. One milliliter NPOE and 1 × 10⁻² M Aliquat 336 were dissolved in 100 mL THF. The oil phase was mixed with an aqueous solution of 100 mL containing Cr(VI) of 1 × 10⁻³ M and each interfering ion of

Table I. SLM compositions used with fixed PVC to *o*-nitrophenyloctyl ether (NPOE) ratio for preparation of a sheet of 24.6 cm².

SLM no.	1	2	3	4	5	6	7	8	9	10
PVC (g)	0.0735	0.0735	0.0735	0.1471	0.1471	0.1471	0.1471	0.2206	0.2206	0.2206
NPOE (mL)	0.1471	0.1471	0.1471	0.2941	0.2941	0.2941	0.2941	0.4412	0.4412	0.4412
Aliquat 336 (mol)	3.66E - 5	5.43E - 5	7.84E - 5	5.43E - 5	1.86E - 4	1.57E - 4	2.18E - 4	1.63E - 4	2.35E - 4	3.26E - 4
Membrane thickness (μm)	46	52	68	79	90	111	120	166	172	180



1×10^{-3} M. The resulting solution was stored at room temperature for 1 day. Samples were taken from the aqueous phase after extraction to measure the concentrations of Cr(VI) and the interfering ions remained. The samples were analyzed for the total chromium and cation interferences using inductively coupled plasma (Thermo Jarrel ash, IRIS/AP, USA) and the Cr(VI) concentration was measured by a UV spectrophotometer (UV mini 1240, Shimatzu, Japan) at a wavelength of 540 nm. The anions were analyzed using ion chromatography (DIONEX, DX-500, USA).

Permeability Measurements

The membrane film was interposed between two Plexiglas compartments of 200 mL each. The effective membrane area exposed to the aqueous phases was 7.07 cm^2 . Both feed and strip solutions were synchronously stirred with magnetic bars at 600 rpm. The initial metal concentrations in the feed solution were 2–20 ppm Cr(VI) and 0–200 ppm Cr(III) and pH was measured to 3.5–5.6. The NaCl concentrations providing the driving force in the strip solution were between 0.1 and 4.7 N (saturation in pure water). In the permeation experiments, the feed solutions contained Cr(VI) and Cr(III) of 2 ppm each, and the strip solution prepared with 1 N NaCl were used as the reference condition (see also Table 2). The permeation experiments were performed at room temperature. Samples were taken periodically and analyzed for the total chromium concentration and for the Cr(VI) concentration after combining with diphenylcarbazide. $\text{CrCl}_3 \cdot x\text{H}_2\text{O}$, FeCl_2 , FeCl_3 , AlCl_3 , MgCl_2 , NiCl_2 , CuCl_2 , and PbCl_2 were used for the interfering cations, and K_2SO_4 , KNO_3 , KNO_2 , and KCl were used for the interfering anions.

Table 2. Composition of the feed and strip solutions used in this study.

	Feed solution	Strip solution
Component of primary ions	$\text{K}_2\text{Cr}_2\text{O}_7$, $\text{CrCl}_3 \cdot x\text{H}_2\text{O}$	0.1–4.7 N NaCl
pH	3.5–5.6	6.7
Concentration of Cr(VI)	2–20 ppm	—
Concentration of Cr(III)	0–1000 ppm	—
Concentration of cationic interferences	2 ppm	—
Concentration of anionic interferences	2–200 ppm	—



TRANSPORT MECHANISM

Permeation Model Through the SLMs Prepared in this Study

In the pH range from 3 to 6 with a low Cr(VI) concentration (i.e., $<1 \times 10^{-3}$ M), the predominant Cr(VI) species are $\text{HCrO}_4^-/\text{CrO}_4^{2-}$. In particular, in the pH range between 3 and 5, HCrO_4^- constitutes more than 96% of the total Cr(VI) (pH range of the test solutions measured in this study was 3.5–5.6). The concentration profiles for the $\text{HCrO}_4^-/\text{CrO}_4^{2-}$ permeating through the SLM are shown in Fig. 1. This permeation model suggested by Huang et al.^[22] was modified to be suited for this study. The transport steps are as follows: (1) $\text{HCrO}_4^-/\text{CrO}_4^{2-}$ in the bulk feed solution diffuses through the aqueous film to the feed–membrane interface; (2) $\text{HCrO}_4^-/\text{CrO}_4^{2-}$ then combines with the Aliquat 336 at the feed–membrane interface; (3) $(\text{Capryl})_3\text{CH}_3\text{N}^+\text{HCrO}_4^-$ and $((\text{Capryl})_3\text{CH}_3\text{N}^+)_2\text{CrO}_4^{2-}$ complexes are formed at the feed–membrane interface and permeate through the membrane phase to the stripping side of the membrane phase; and (4) Cr(VI) ions are extracted by chloride pumping ions on the stripping side.

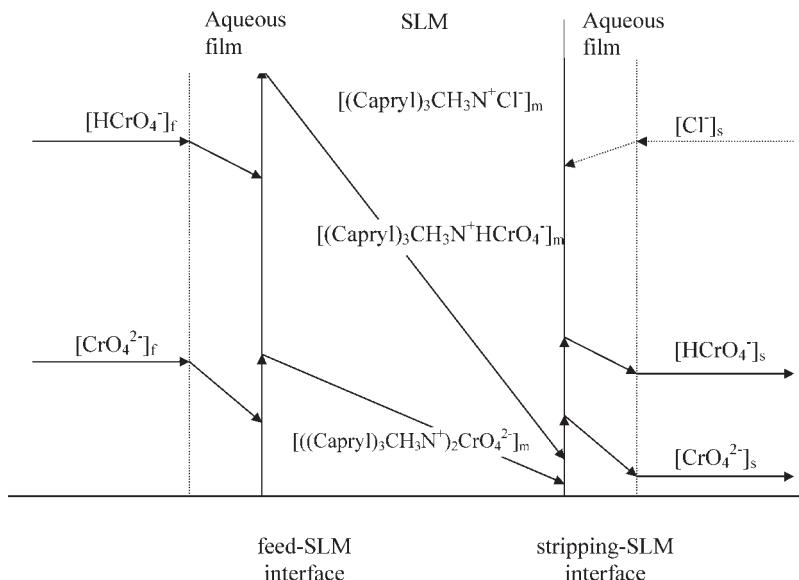


Figure 1. Schematic description of the counter facilitated transport of chromium ion species through a SLM impregnated with Aliquat 336.



If the solubility of the metal ion in the membrane is very low, the concentration of the complex combined with carrier–metal ions determines the ion concentration in this phase. Therefore, the equilibrium constant is equal to the ratio of the distribution coefficients on the feed side. Since the chemical reaction between the metal ion and the carrier is very fast at the aqueous–membrane interface, a local equilibrium is easily attained. At a steady state, $J_{bl} = J_i = J_m$, and the total flux $J = J_{HCrO_4^-} + J_{CrO_4^{2-}}$. Furthermore, if $[HCrO_4^-]_f = x[CrO_4^{2-}]_f$ in the feed phase and $[HCrO_4^-]_m = y[CrO_4^{2-}]_m$ in the membrane, and if the permeation process is dominated by membrane diffusion, then the total flux can be simplified in terms of the predominant species, $HCrO_4^-$, and the permeability, P ,

$$\frac{J}{[HCrO_4^-]_f} = \left(\frac{yD_{m,HCrO_4^-} + D_{m,CrO_4^{2-}}}{yl} \right) k_{d,HCrO_4^-} = P \quad (1)$$

where, D_m is the diffusion coefficient in the membrane and k_d is the distribution coefficient for each species. In addition, if the metal ion concentration in the feed solution is not constant, then the total flux is given by

$$J = -\frac{V}{A} \left(1 + \frac{1}{x} \right) \frac{d[HCrO_4^-]_f}{dt} \quad (2)$$

Combination of Eqs. (1) and (2), and integration with the boundary conditions

$$\begin{aligned} [HCrO_4^-]_f &= [HCrO_4^-]_{f,0} & \text{at } t = 0 \\ [HCrO_4^-]_f &= [HCrO_4^-]_{f,S} & \text{at } t = t \end{aligned}$$

leads to the following equation:

$$\ln \left(\frac{[HCrO_4^-]_{f,S}}{[HCrO_4^-]_{f,0}} \right) = -\frac{A}{V} \frac{1}{(1 + (1/x))} Pt \quad (3)$$

Neglecting $1/x$ at high value x , Eq. (3) can be simplified finally as

$$\ln \left(\frac{[HCrO_4^-]_{f,S}}{[HCrO_4^-]_{f,0}} \right) = -\frac{A}{V} Pt \quad (4)$$

Equation (4) is well known as the general equation in separation processes using liquid membrane. However, it is emphasized that the total transport of Cr(VI) is dominated by the concentration of $HCrO_4^-$ species only, even though the Cr(VI) transport mechanism through the SLM is derived for the $HCrO_4^- / CrO_4^{2-}$ binary system.



RESULTS AND DISCUSSION

Cr(VI) Selectivity by Solvent Extraction

The distribution coefficients of the primary and the interfering ions with respect to Aliquat 336 were calculated using the following equation:

$$\text{Distribution coefficient} = \frac{\text{Concentration of the ion extracted into the oil phase}}{\text{Equilibrium concentration of the ion remaining in the aqueous phase}} \quad (5)$$

Typically, a hydrophobic solute has a distribution coefficient >1 with a high mobility in the oil phase while a hydrophilic solute has a distribution coefficient of $\ll 1$. A hydrophilic solute is not easily extracted into the oil phase without an assistant carrier. However, in spite of the hydrophilic properties of Cr(VI), its distribution coefficient was greater than that of the interfering ions, indicating that Aliquat 336 has a higher selectivity for Cr(VI) than the other interfering ions. The results are shown in Table 3.

Table 3. Distribution coefficients of the primary ion and interfering ions for Aliquat 336 by solvent extraction.

Ionic matter	Distribution coefficient	Selectivity ^a of chromate against the interfering ion
Cr(VI)	0.750	1
Cationic interference		
Cr(III)	^b Not detected	—
Fe(III)	Not detected	—
Al(III)	1.25E - 4	6000
Mg(II)	Not detected	—
Ni(II)	Not detected	—
Cu(II)	Not detected	—
Pb(II)	3.24E - 3	231.5
Anionic interference		
Sulfate	Not detected	—
Nitrate	2.70E - 2	27.78
Nitrite	6.40E - 2	11.72
Chloride	1.11E - 3	675.7

^aSelectivity = (distribution coefficient of primary/distribution coefficient of interference).

^b“Not detected” means below the detection limit of the analyzer.



Cr(VI) Transport Through SLMs

Figure 2 shows that the concentration profiles of Cr(VI) and Cr(III) from the experimental results and from the permeation model through the SLM impregnated with the membrane no. 2 in Table 1. The feed solution contained Cr(VI) and Cr(III) of 2 ppm each. A solution of 2 N NaCl was used as a strip solution. The dotted lines in the figure shows the time profiles calculated from Eq. (4) using the permeability values obtained from the experimental results. The result at the feed phase shows that the profile can be estimated reasonably from Eq. (4). Even though the Cr(VI) transport mechanism through the SLM was derived for the $\text{HCrO}_4^-/\text{CrO}_4^{2-}$ binary system, the experimental results revealed that HCrO_4^- species dominated the total transport of Cr(VI). Thus, as described in the permeation model, the concentration of Cr(VI), both $\text{HCrO}_4^-/\text{CrO}_4^{2-}$ can be expressed as the single predominant species, HCrO_4^- . However, the concentration profiles in the stripping phase did not agree well because transport of Cr(III) and Cr(VI) was delayed due to the trapping effect in the membrane.

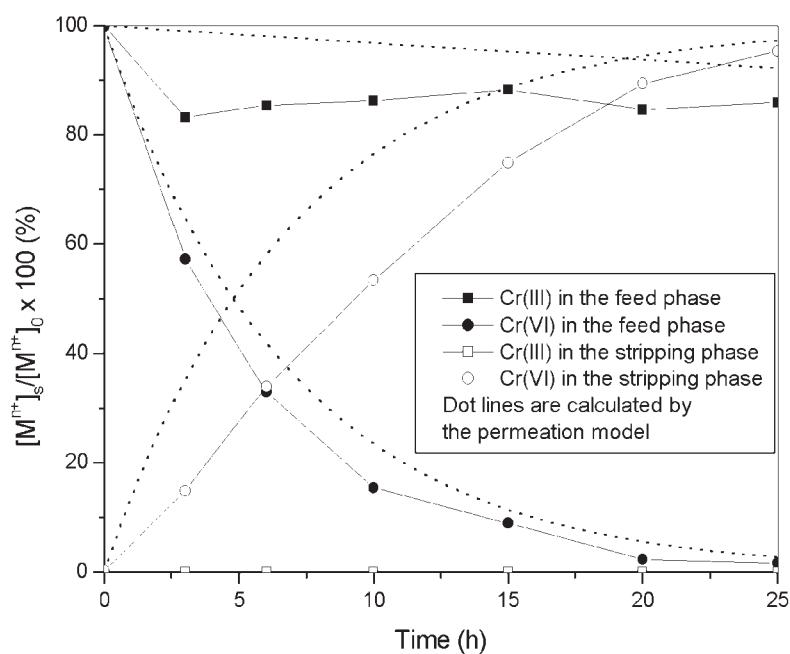


Figure 2. Concentration profile of Cr(III) and Cr(VI) from the experiment and the permeation model: the SLM was impregnated with Aliquat 336; feed solution: Cr(VI) and Cr(III) of 2 ppm each; strip solution: 2 N NaCl.



Effects of the Aliquat 336 Concentration

Figure 3 shows the effects of the carrier concentration on the permeability of Cr(VI) and Cr(III), and the recovery ratio of Cr(VI). As the Aliquat 336 concentration increased, the permeability of Cr(VI) increased gradually while the permeability of Cr(III) decreased. This result suggests that Aliquat 336 has a high selectivity for Cr(VI) while it rejects Cr(III) (i.e., the fraction of the Cr(VI)-carrier complex increased proportionally with increasing Aliquat 336 concentration in the membrane). However, the Cr(VI) recovery ratio decreased rapidly as the Aliquat 336 concentration increased. It is believed that the increasing amount of complex reduces the Cr(VI) stripping rate because the higher Aliquat 336 concentration forms a stronger complex between Aliquat 336 and Cr(VI). Consequently, the most suitable Aliquat 336 concentration for the recovery of Cr(VI) was found to be approximately 5.43×10^{-5} mol in a SLM with 0.0735 g PVC/0.1471 mL NPOE for a sheet of 24.6 cm². Therefore, the membrane no. 2 in Table 1 was used in the following experiments.

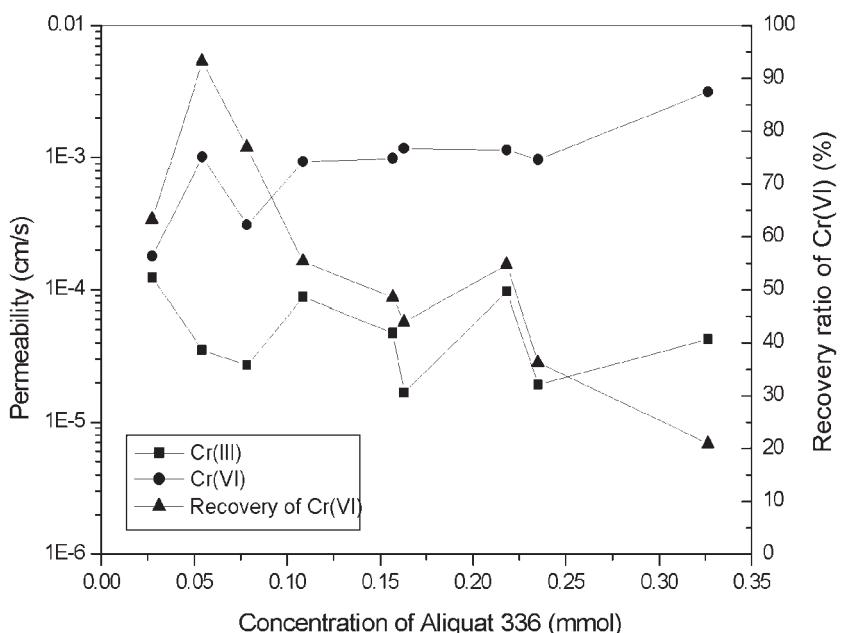


Figure 3. Permeability and recovery ratio of Cr(VI) as a function of the Aliquat 336 concentration. The SLMs were prepared with 0.0735 g PVC/0.1471 mL NPOE; feed solution: Cr(VI) and Cr(III) of 2 ppm each; strip solution: 2 N NaCl.



Effects of the Membrane Thickness

Usually, the membrane thickness does not have a direct influence on reaction-controlling facilitated transport of ions in liquid membranes. In this study, however, the effect of the membrane thickness should not be ignored because the process is dominated by the membrane diffusion as suggested in the permeation model. Also, the effect of the SLM thickness is important to predict the Cr(VI) recovery in the permeate side. The effects of the membrane thickness were examined and the results are presented in Table 4. The results show that the permeability of Cr(VI) ions was nearby constant irrespective of the membrane thickness. This result implies that the permeation process through the SLM is dominated by membrane diffusion. As expected, the Cr(VI) recovery in the stripping phase decreased as the membrane thickness increased because as the volume within the membrane became greater, more carrier–Cr(VI) complexes remained within the membrane. Therefore, the bound Cr(VI) was not fully recovered.

Effects of the NaCl Concentrations in the Stripping Phase

As shown in Fig. 4, the permeability of Cr(VI) was unaffected by the concentration of NaCl, which was used to facilitate the counter-transport of chromate. The results suggest that Cr(VI) permeation is independent of the concentration of NaCl in the range of 0.1–4.7 N. It is believed that the permeation process is not controlled by aqueous film diffusion of the stripping phase. The extent of Cr(VI) recovery increased rapidly with the increasing concentration of NaCl in a strip solution. However, the tendency of the Cr(VI) recovery ratio decreased for concentrations of NaCl greater than 2 N due to the leaching out of Aliquat 336 with the sodium ions, which was caused by the high osmotic pressure (over 40 kgf/cm³) generated in the

Table 4. Permeability and recovery ratio of Cr(VI) as a function of the membrane thickness relative to the PVC content.

Membrane thickness (μm)	Permeability (cm/s)		Recovery ratio of Cr(VI) (%)
	Cr(III)	Cr(VI)	
52	3.51E-5	1.01E-3	93.2
68	7.70E-6	8.55E-4	86.9
79	3.18E-6	7.79E-4	83.2

Note: Feed solution: Cr(VI) and Cr(III) of 2 ppm each; strip solution: 2 N NaCl.



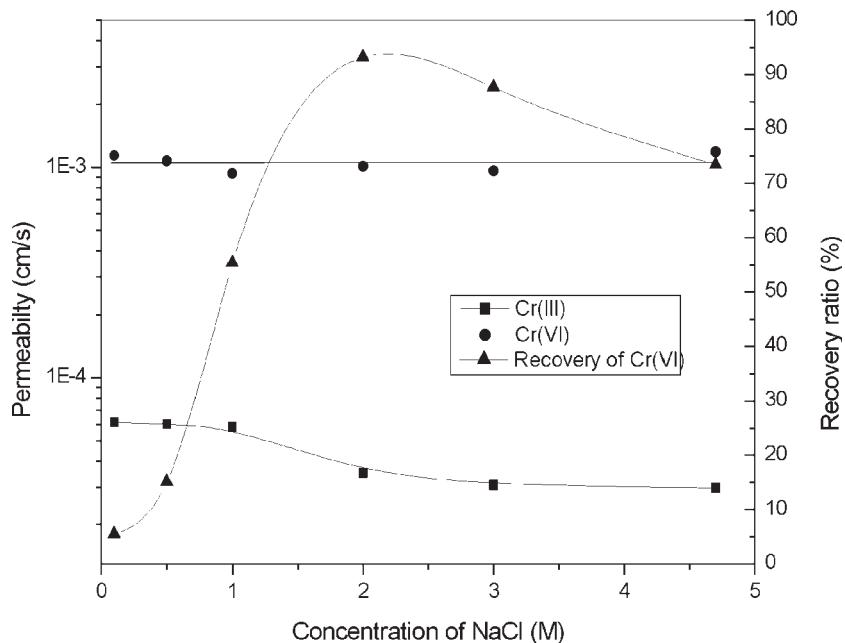


Figure 4. Permeability and recovery ratio of Cr(VI) as a function of the NaCl concentration in the strip solutions with the SLM No. 2; feed solution: Cr(VI) and Cr(III) of 2 ppm each.

SLM. Therefore, the optimal NaCl concentration for Cr(VI) recovery is approximately 2 N, where a recovery of 93.2% was attained.

Effects of the Cr(VI) Concentration in a Feed Solution

If the permeation process is controlled by the diffusion of Cr(VI) ions in the aqueous film, a higher permeability of Cr(VI) should be obtained from the concentration gradient established with a high Cr(VI) concentration in the aqueous feed phase. Unexpectedly, the permeability of Cr(VI) was nearby constant regardless of its concentration in the feed phase as shown in Table 5. This is attributed to the fact that the resistance of Cr(VI) diffusion in the feed solution was not significant under the condition investigated in this study. It is thought that the permeation process is governed by membrane diffusion in addition to the equilibrium distribution at the feed-membrane interface. To determine the rate controlling step for Cr(VI) transport through



Table 5. Effect of the Cr(VI) concentration in a feed solution on its permeability through the SLM No. 2.

Concentration of Cr(VI) (ppm)	Permeability (cm/s)
2	1.01E - 3
5	7.92E - 4
10	8.13E - 4
20	5.74E - 4

Note: Strip solution: 2 N NaCl.

the SLM, the interfacial kinetics were investigated using a cell with constant interfacial area (7.07 cm^2). When the experiment was performed with 2 ppm Cr(VI) using the optimized SLM, the permeability of Cr(VI) was $1.01 \times 10^{-3} \text{ cm/s}$. In another experiment performed with 20 ppm Cr(VI) using the optimized SLM, the permeability of Cr(VI) was found to be $5.74 \times 10^{-4} \text{ cm/s}$. These results show that resistance for the Cr(VI) transport increased due to the use of a microporous membrane impregnated with Cr(VI)-carrier complexes. It also suggests that the resistance of the interfacial chemical reaction may be neglected compared to that of membrane diffusion, because the permeation process is governed primarily by membrane diffusion.

Effects of the Cr(III)-Cr(VI) Concentration Ratio

The effects of the Cr(III)-Cr(VI) concentration ratio on the permeability and recovery ratio of Cr(VI) were presented in Table 6. Since Cr(III) species are present as positive ions in the aqueous solutions, they do not directly form

Table 6. Effect of the concentration ratio of Cr(III)/Cr(VI) on the permeability and recovery ratio of Cr(VI) through the SLM No. 2.

Concentration ratio of Cr(III)/Cr(VI)	Permeability of Cr(VI) (cm/s)	Recovery ratio of Cr(VI) (%)
0.1	9.91E - 04	95.36
1	8.54E - 04	93.685
10	7.47E - 04	91.176
50	7.42E - 04	83.121
500	6.45E - 04	75.758

Note: Strip solution: 2 N NaCl.



complexes with Aliquat 336 that has a positively charged functional group. However, high Cr(III) concentrations may interrupt Cr(VI) transport because Cr(III) ions can adsorb on the feed–membrane surface via interactions between the ions and the molecules on the surface organized within NPOE and PVC. Cr(VI) recovery decreased gradually with the increasing Cr(III) to Cr(VI) ratio, while the permeability of Cr(VI) through the SLMs decreased slightly.

Effects of Interfering Ions

Cr(VI) is a strong oxidant and may be reduced to Cr(III) through chemical reactions with compounds in the aqueous solution. Shendrikar and West^[27] found that Cr(VI) was rarely reduced to Cr(III) in a neutral solution. Jong and Brinkman^[20] reported that Cr(VI) is gradually reduced to Cr(III) in acidic solutions and the reduction rate is dependent on the compositions of those solutions. Figure 5 shows the effects of interfering cations present in the feed solution on the permeability and recovery of Cr(VI). Most cations, other than Pb(II) and Fe(II), did not significantly affect the selective separation of Cr(VI). The permeability of Cr(VI) did not change significantly and the Cr(VI) recovery ratios were over 90%. However, the permeability and recovery ratio of Cr(VI)

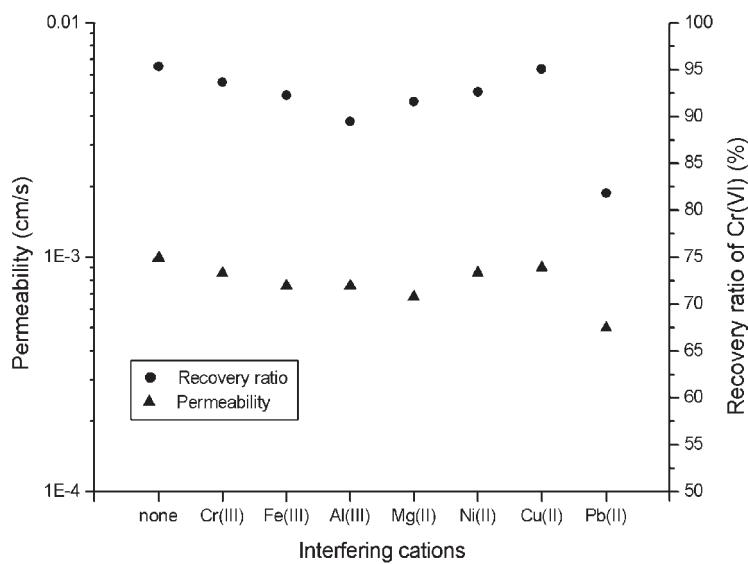
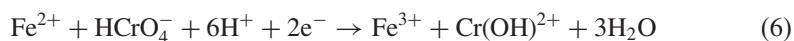


Figure 5. Effect of cationic interferences in a feed solution on the permeability and recovery ratio of Cr(VI) through the SLM No. 2; strip solution: 2 N NaCl.



decreased in the tests with Pb(II). The Pb(II) species influences Cr(VI) transport by combining with CrO_4^{2-} to form PbCrO_4 . Furthermore, for Fe(II), Cr(VI) recovery in the presence of Fe(II) in synthetic solutions may be difficult because Cr(VI) is readily reduced to Cr(III) by Fe(II) oxidation to Fe(III), e.g.:



The effect of anionic interferences is presented in Fig. 6. The selective recovery of Cr(VI) in the presence of the interfering anions decreased when the concentrations of nitrite and nitrate concentrations were tenfold greater than Cr(VI). In addition, for all the anions, the permeabilities and selective recoveries of Cr(VI) were significantly lower when the anion concentrations were 100-fold higher than that of Cr(VI). It is explained that the stability of the SLM is significantly lower at the feed-membrane interface due to leaching-out of lipophilic materials (i.e., NPOE, Aliquat 336, and the ion-carrier complex), caused by the driving force to pump the ions from the stripping phase. In particular, it is thought that chloride ions used as the pumping ion from the stripping phase, act as an interfering ion during the selective transport because

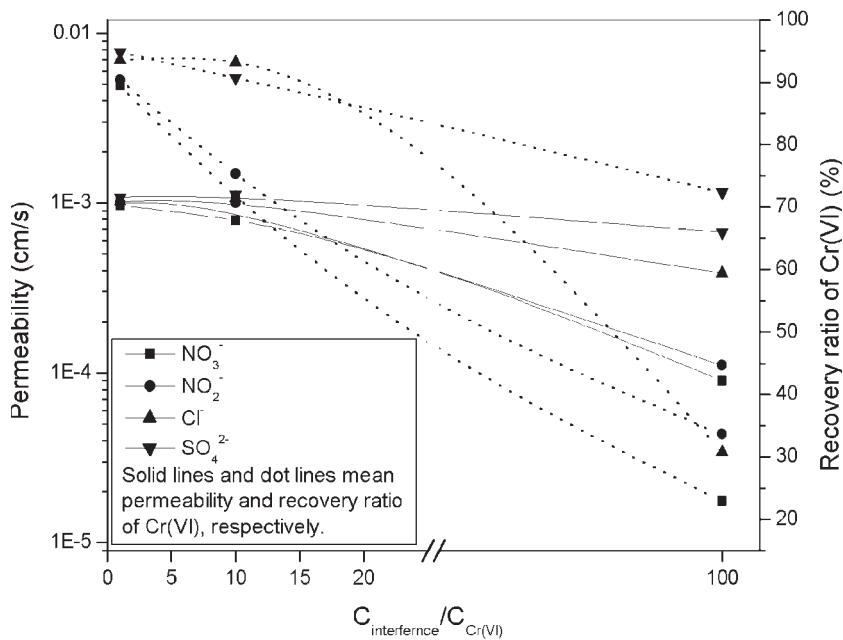


Figure 6. Effect of the interfering anions at various concentration ratios on the permeability and recovery ratio of Cr(VI) through the SLM No. 2; strip solution: 2 N NaCl.



they compete with Cr(VI) to form complexes with Aliquat 336. Therefore, the high concentrations of chloride ion may disturb the selective transport of Cr(VI) (i.e., HCrO_4^-). Of Cr(VI) species, HCrO_4^- is more selective than CrO_4^{2-} since monovalent ions cause more significant interference. It is found that the Cr(VI) recovery was attained reasonably when the concentrations of the interfering anions did not exceed tenfold of the Cr(VI) concentration.

CONCLUSIONS

In this work, selective separation and recovery of Cr(VI) were investigated in simulated waste solutions, pH 3.5–5.6, containing Cr(III). Even though Cr(VI) transport mechanism through the SLM was derived by assuming a $\text{HCrO}_4^-/\text{CrO}_4^{2-}$ binary system, it was empirically proved that HCrO_4^- species dominated the total transport of Cr(VI). It was also found that the permeation process, using the SLMs prepared in this work, was controlled by membrane diffusion. The permeability of Cr(VI) was unaffected by the concentration of NaCl, while the Cr(VI) recovery ratio decreased for concentrations of NaCl greater than 2 N. Permeability of Cr(VI) was not affected by concentrations of Cr(VI) and cationic interferences in the feed solution, except for Cr(III). For anionic interferences and Cr(III), selective recovery of Cr(VI) was attained when their concentrations were below a tenfold of Cr(VI). The maximum recovery of Cr(VI) using the optimized SLM with Aliquat 336 was 93.2% in a test solution containing interferences.

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