Transport of Tb$^{3+}$ in Dispersion Supported Liquid Membrane System with Carrier P507

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The Tb$^{3+}$ transport in dispersion supported liquid membrane (DSLM) consisting of polyvinylidene fluoride membrane (PVDF) as the liquid membrane support and dispersion solution including HCl solution as the stripping solution and 2-ethyl hexyl phosphonic acid-mono-2-ethyl hexyl ester (P507) dissolved in kerosene as the membrane solution, has been studied. The effects of pH value, initial concentration of Tb$^{3+}$ and different ionic strength in the feed phase, volume ratio of membrane solution and stripping solution, concentration of HCl solution, concentration of carrier, different stripping agents in the dispersion phase on transport of Tb$^{3+}$ has also been investigated, respectively. As a result, the optimum transport condition of Tb$^{3+}$ was that concentration of HCl solution was 4.0 mol/L, concentration of P507 was 0.10 mol/L, and volume ratio of membrane solution and stripping solution was 1.0 in the dispersion phase, and pH value was 5.2 in the feed phase. Ionic strength had no obvious effect on transport of Tb$^{3+}$. Under the optimum condition studied, when initial concentration of Tb$^{3+}$ was $1.0 \times 10^{-4}$ mol/L, the transport rate of Tb$^{3+}$ was up to 95.2% during the transport time of 95 min. The kinetic equation was developed in terms of the law of mass diffusion and the theory of interface chemistry. The results were in good agreement with the literature data.

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Introduction

Sewages with nonbiodegradable and highly toxic heavy metal ions are generated in electrochemical, hydrometallurgy, and electroplating industry. By way of environmental resources recycling and conservation, the recovery and removal of these heavy metals have become stringent increasingly.1-3 Recently, people pay attention to rare earth metal which is applied in more and more technologies of our production and life. It is also necessary to develop a method for the separation and recovery of rare earth metals. Several conventional methods, such as chemical precipitation,2,3 reverse osmosis,4 adsorption,5 ion exchange,6 solvent extraction7,8 and liquid membrane (LM)9-12 have been developed for these purposes. Among these methods, solvent extraction is the most common method and the liquid membrane is a kind of methods on the basis of solvent extraction.

The main types of liquid membrane systems include emulsion liquid membrane (ELM),13 supported liquid membrane (SLM),14 bulk liquid membrane (BLM), flowing liquid membrane (FLM),15 electrostatic pseudo liquid membrane (EPLM),10 supported emulsion liquid membrane (SELM),16,17 hollow fiber contained liquid membrane (HFCLM),18 and supported liquid membrane with stripping dispersion (SLM-SD).19,20 etc. The potential advantages of LM techniques, over traditional separation techniques and solid membranes techniques, are low capital and operating costs, low energy and extractant consumption, high concentration factors and high fluxes. However, LM techniques have not been adopted for large-scale industrial processes,9,11,12,23-27 primarily due to the lack of longtime stability, hard to operating of the emulsification and de-emulsification steps in ELM and SELM processes, and larger membrane resistance in BLM and HFCLM processes, etc.28

For the purpose of resolving these above difficulties in the conventional LM systems, a new liquid membrane technique, named dispersion supported liquid membrane (DSLM),29 was proposed. The effect of various experimental parameters on the transport of rare earth Tb$^{3+}$ ions was investigated. Although the metal ions transport by BLM containing the same carrier (P507) has been extensively studied, there was little research about it by DSLM. The transport of Tb$^{3+}$...
through a DSLM consisting of polyvinylidene fluoride membrane (PVDF) as the support and dispersion solution concluding HCl solution as the stripping solution and 2-ethyl hexyl phosphonic acid-mono-2-ethyl hexyl ester (P507) dissolved in kerosene as the membrane solution, has been studied. The effects of pH value, initial concentration of Tb$^{3+}$ and different ionic strength in the feed phase, volume ratio of membrane solution and stripping solution, concentration of HCl solution, concentration of P507, and different stripping agents in the dispersion phase on transport of Tb$^{3+}$ have also been investigated, respectively. The comparison with DSLM and conventional SLM was conducted. A kinetic equation for DSLM process derived from the law of mass diffusion and the theory of interface chemistry was also developed.

Theoretical analysis

DSLM separation process

In this study, DSLM configuration adopted a PVDF as the liquid membrane support. The stripping solution comprises an aqueous phase containing a stripping agent in solvent extraction, while the membrane phase contains extractant in an membrane solvent. The transport process by DSLM includes two steps. Firstly, metal ions contained in the feed phase are passed on one side of the SLM embedded in a microporous support material. In this step the extraction takes place in the interface between feed phase and membrane phase. In the meanwhile, the metal is extracted and the metal-carrier complex diffuses to the other side of the SLM and treated to remove the metal ions by the use of a dispersion phase. In general, the usage of a stirrer can disperse an stripping solution in an membrane solution and form the droplets of the aqueous stripping solution in a continuous organic phase because of the weak surface-active of the extractant. It is called as the dispersion phase. In the experimental process, there is a constant supply of the membrane solution, i.e. the membrane solution of the dispersion phase, contacting the pores of SLM. This constant supply of the membrane solution ensures a stable and continuous operation of the SLM. In this way, the metal-carrier complex could diffuse to the interface between the stripping solution and the membrane solution in pores of SLM. Therefore, the direct contact between the stripping solution and the membrane solution provides efficient mass transfer for stripping. Secondly, once removal of the target species is completed, the stirrer for the stripping dispersion is none worked. The dispersion phase is allowed to suspend, resulting in separating of the dispersion phase into two phases: the membrane phase readily wetting the pores of support and the stripping solution containing concentrated metal ions. The concentrated stripping solution is the product of this process. Figure 1 is a schematic principle of the DSLM process.

Principle and theory of the DSLM process

Figure 2 is the principle of DSLM process, in which concentration change and transport processes are depicted. The co-transport involves various equilibrium reactions, which are described as follows:

(a) Tb$^{3+}$ diffuses from the feed phase to the interface A.

(b) On the feed side interface of the DSLM, the extraction of Tb$^3+$ from feed solution with carrier P507 [can be as (HR)$_2$] in kerosene can be expressed as:30,31

$$\text{Tb}^{3+} + 3(\text{HR})_{2,\text{org}} \rightleftharpoons \frac{k_1}{k_{-1}} \rightleftharpoons \text{TbR}_3(\text{HR})_{3,\text{org}} + 3\text{H}^+ \quad (1)$$

where f and org stand for feed phase and organic phase, respectively; (HR)$_2$ indicates that the P507 in kerosene mainly exists as a dimer; $k_1$ and $k_{-1}$ stand for forward and backward reaction rate constants at the interface between the feed phase and membrane phase.

(c) The metal-complex [TbR$_3$(HR)$_3$] diffuses through the membrane A—B.

(d) At the stripping side interface of the DSLM, the TbR$_3$(HR)$_3$ dissolved in membrane solution and the metal ion Tb$^{3+}$ are stripped by stripping agent. The stripping reaction on the other side of the SLM.
is written as follows:\(^{30,31}\)
\[
\text{Tb}_3\text{R}_3\text{HR}_{3,\text{org}} + 3\text{H}^+ \xrightarrow{k_2} \text{Tb}^{3+} + 3\text{HR}_{2,\text{org}}
\]  
(2)

where \(s\) represents the dispersion phase; \(k_2\) and \(k_2\) stand for forward and backward reaction rate constants at the interface between the membrane phase and dispersion phase.

(c) Carrier P507 returns from B to A. In this mechanism the transport of Tb\(^{3+}\) across DSLM will be described by considering only diffusion coefficient of Tb\(^{3+}\), because the complex reaction between the Tb\(^{3+}\) and P507 at the interfaces is much faster compared to the diffusion in the feed phase and membrane phase.\(^{32-34}\)

To formulate the model, the following assumptions were made:

1. The Tb\(^{3+}\) diffuses in the organic medium only as the TbR\(_3\)(HR)\(_3\) complex.
2. There is no net flow due to convection within the liquid membrane.
3. The metal ions react only with P507 at the membrane interfaces.
4. The P507 monomer and dimer are in equilibrium at all times throughout the organic phase.
5. The solubility of P507 in the aqueous acid solution has been found to be negligible and, therefore, its concentration in the DSLM is assumed to remain constant.\(^{35}\)

Metal-complex [TbR\(_3\)(HR)\(_3\)] diffusion through the membrane may be described by Fick's second law:

\[
\frac{\partial C_{\text{R}_{\text{R}}} \text{dl}}{\partial t} = D_c \frac{\partial^2 C_{\text{R}_{\text{R}}} \text{dx}^2}
\]  
(3)

where \(C_{\text{R}_{\text{R}}}\) stands for concentration of the Tb\(^{3+}\)-(P507) complex in the organic solution; \(D_c\) stands for diffusion coefficient of the Tb\(^{3+}\)-(P507) complex; \(x\) stands for distance in the liquid membrane. The boundary conditions can be written as follows:

\[
x = 0, C = C_A
\]  
(4)

\[
x = l, C = C_B
\]  
(5)

\(l\) stands for thickness of the membrane, \(C_A\) and \(C_B\) stand for concentration of Tb\(^{3+}\) in interface A and interface B, respectively.

An assumption was made, in a twinkling of diffusion there is no Tb\(^{3+}\) in membrane, so the initial condition is presented by:

\[
t = 0, C = 0 \ (0 \leq x \leq 1)
\]  
(6)

From Eqs. (4)–(6), according to the solution of equation (3), the follow equation can be obtained:

\[
C = C_A + (C_B - C_A) \frac{x}{l} + \frac{2}{n} \sum_{n=1}^{\infty} \frac{C_B \cos \frac{n\pi x}{l} - C_A}{n} \sin \frac{n\pi x}{l} \exp \left( -\frac{-D_c n^2 \pi^2 t}{l^2} \right)
\]  
(7)

In these conditions the concentration of Tb\(^{3+}\) in the dispersion phase can be assumed to 0 (mean \(C_B = 0\)), so Eq. (7) can be simplified as follows:

\[
C = C_A \left( 1 - \frac{x}{l} \right) + \frac{2}{n} \sum_{n=1}^{\infty} \frac{C_B}{n} \sin \frac{n\pi x}{l} \exp \left( -\frac{-D_c n^2 \pi^2 t}{l^2} \right)
\]  
(8)

Eq. (9) can be integrated from \(t = 0\) to \(t = t_c\), so the follow equation can be obtained:

\[
Q_t = \frac{AD_c C_A l}{l} \left( t_c - \frac{l^2}{6D_c} \right)
\]  
(10)

The distribution ratio \((K_d)\) of metal ion should be considered, so Eq. (12) can be written as follows:

\[
Q_t = \frac{AD_c K_d C_A l}{l} \left( t_c - \frac{l^2}{6D_c} \right)
\]  
(13)

Therefore, it is possible to calculate the equivalent Tb\(^{3+}\)-(P507) concentration for the bulk aqueous free Re\(^{3+}\) in the following manner.

Extraction equilibrium constant:

\[
K_{eq} = [\text{H}^+] [\text{TbR}_3\text{HR}_{3}] / [\text{[HR]}_2]^3
\]  
(14)

So Eq. (13) can be written as follows:
where [Tb$^{3+}$] stands for uncomplexed Tb$^{3+}$ in the bulk aqueous solution; [TbR$_3$(HR)$_3$] stands for Tb$^{3+}$-(P507) concentration in the organic phase in equilibrium with the bulk aqueous phase Tb$^{3+}$ concentration; [(HR)$_2$] stands for P507 dimer concentration in the organic phase.

**Experimental**

**Reagents**

All the reagents such as Tb(CH$_3$COO)$_3$•4H$_2$O, Arsenazo III (C$_{22}$H$_{18}$As$_2$O$_{14}$N$_4$S$_2$), HCl, Na$_2$HPO$_4$, Na$_3$HPO$_4$, CH$_3$COONa, and CH$_3$COOH used in the present work were of analytical grade. 2-Ethyl hexyl phosphonic acid-mono-2-ethyl hexyl ester (P507) is a commercial extractant (purity >95%) and used without any further purification. Kerosene was washed with concentrated sulfuric acid and distilled at 185—225 °C.

**Preparing of solutions**

Tb$^{3+}$ stock solution: a stock solution of Tb$^{3+}$ was prepared by dissolving Tb(CH$_3$COO)$_3$•4H$_2$O in 1 mol•L$^{-1}$ HCl, and analyzed by Arsenazo III (C$_{22}$H$_{18}$As$_2$O$_{14}$N$_4$S$_2$) as the chromogenic agent.

Tb$^{3+}$ feed solution: a known amount of the Tb$^{3+}$ stock solution was diluted with 0.01 mol•L$^{-1}$ HCl solution to a given extent after adding a calculated amount of CH$_3$COONa and CH$_3$COOH or Na$_2$HPO$_4$ and Na$_3$HPO$_4$.

Arsenazo III (C$_{22}$H$_{18}$As$_2$O$_{14}$N$_4$S$_2$) stock solution: a stock solution of Arsenazo III was prepared by dissolving powder of Arsenazo III in deionized water.

Stripping solution: the required amount of HCl was added to the stripping solution to achieve the desired concentration.

Distilled kerosene: commercial kerosene was washed with concentrated sulfuric acid and distilled at 185—225 °C.

P507 solution: a calculated amount of extractant was diluted with kerosene.

**Experimental procedure and determination**

The measurements of transport rate for the DSLM were performed as follows: the experiments were accomplished at (25±1) °C with a simple diffusion cell. The diffusion cell consisted of two-compartment perspex half-cells. Two half-cells were separated by the membrane. The membrane was impregnated with P507 dissolved in kerosene and clamped between the two half-cells. The effective volume of each one is 80 mL. A microporous PVDF membrane was used as a solid support. It had a 65 µm thick film with a nominal porosity of 75% and a tortuosity of 1.67. The effective area is 12 cm$^2$. The feed phase (60 mL) consisted of Tb$^{3+}$ and buffer solution, and was poured into the perspex half-cell. The mixed dispersion phase consisted of the different volume ratios of the membrane solution containing the carrier P507 and HCl stripping solution was placed into another half-cell. Samples of the feed phase were taken at timed intervals. The stirring of dispersion phase was allowed to stand until phase transport occurred. Then the Tb$^{3+}$ sample from the dispersion phase was collected. Samples containing Tb$^{3+}$ in the feed phase only were analyzed for ion concentration with a UV-1200 spectrophotometer using Arsenazo III as the chromogenic agent (under the detection wave lengths: 653 nm).

**Results and discussion**

**Effect of the volume ratio of membrane solution and stripping solution**

The effect of volume ratio of membrane solution and stripping solution in the dispersion phase on transport of Tb$^{3+}$ is studied. The assumed experimental conditions chosen are in the certain pH value in the feed phase, which is adjusted to 4.0. Initial concentration of Tb$^{3+}$ is 1.0×10$^{-4}$ mol/L in the feed phase, the concentration of HCl solution is 4.0 mol/L and the concentration of P507 is 0.10 mol/L in the dispersion phase. The effect of volume ratio membrane solution and stripping solution in the dispersion phase on transport of Tb$^{3+}$ is shown in Figure 3. The volume ratio is increased from 0.2 to 5.0. It can be seen that the most effective volume ratio is 5.0, which gives a transport rate of Tb$^{3+}$ much higher than 0.2, but a little higher than 2 and 1.0.

![Figure 3](image-url)
tacting between P507 and Tb$^{3+}$ increase. In this way, the mixing between the membrane phase and dispersion phase provides an extra stripping surface and renewal rate of liquid membrane, which leads to extremely stripping rate for the target species from organic phase and life of liquid membrane. Therefore, it enhances the transport rate of Tb$^{3+}$. As far as our researching conditions are concerned, considering saving membrane solution and stripping solution in the dispersion phase during the following experiments.

**Effect of concentration of HCl solution in the dispersion phase**

The stripping reaction in the dispersion phase plays a vital role in the transport of metal ion from the feed phase to the stripping phase. So the effect of the concentration of HCl solution in the dispersion phase on transport rate of Tb$^{3+}$ is studied in this section. All the other parameters, such as pH value, initial concentration of Tb$^{3+}$ in the feed phase, volume ratio and concentration of P507 are adjusted to 4.0, 1.0×$10^{-4}$, 1.0 and 0.10 mol/L, respectively. The effect of concentration of HCl solution in the dispersion phase on transport rate of Tb$^{3+}$ is shown in Figure 4. It indicates that, with the increasing of acid concentration in the dispersion phase, the transport rate of Tb$^{3+}$ increases. It can be seen that the effective concentrations of HCl solution for transport are 5.0 and 4.0 mol/L, which give transport rates of Tb$^{3+}$ to be about 74.8% and 73.5%, respectively. The increasing of concentration of HCl solution from 1.0 to 2.0 mol/L has no significant effect on transport rate of Tb$^{3+}$, and it is less than 55%, because definite are the number of Tb$^{3+}$ complex and the concentration of P507 which transport through the membrane per unit area of the membrane per unit time. However, under the condition of 6.0 mol/L HCl solution, the transport rate is a little lower than 5.0 and 4.0 mol/L, by reason of higher acidity resulting in ionic solvation. Considering controlling acidity as well as increasing transport rate, we choose 4.0 mol/L as the optimum concentration of HCl solution in the dispersion phase during the following experiments.

**Effect of pH in the feed phase**

Based on mechanism of mass transfer process, the concentration difference between feed phase and dispersion phase is the driving power of mass transfer process. So in the feed phase the lower the H$^+$ concentration is, the stronger the driving power of mass transfer process will be. Stronger power will promote the transport rate of Tb$^{3+}$. Equally, the greater the pH value in the feed phase is, the higher the transport rate of Tb$^{3+}$ is. The effect of pH in the feed phase on transport of Tb$^{3+}$ is studied in the pH range of 4.0 to 5.4, which is adjusted with an HAc-NaAc buffer solution. Initial concentration of Tb$^{3+}$ in the feed phase is 1.0×$10^{-4}$ mol/L. Concentration of HCl solution is 4.0 mol/L, volume ratio of membrane solution and stripping solution is 1.0, concentration of P507 is 0.10 mol/L in the dispersion phase. The results are shown in the Figure 5. The transport rate of Tb$^{3+}$ increases when the pH in the feed phase increased from 4.0 to 5.4, and a maximum transport rate observed at pH 5.2 is 95.2% during 95 min. Above the pH of 5.2 in the feed phase, the transport rate of Tb$^{3+}$ decreases to 92.1%. When pH value is greater than 5.4, the feed phase emulsifies, so the transport rate of Tb$^{3+}$ decreases. Against all previous cases, announcement of associated documents put forward the influence of pH on distribution coefficient of extraction process. Because the transport process is mainly governed by the driving power of mass transfer caused by the distribution equilibrium, when the renewal effect of the liquid membrane and the diffusion mobility of Tb$^{3+}$ ions are determined under specific experimental conditions. As far as our researching conditions are concerned, considering saving chemical agents as well as increasing transport rate, we choose 5.2 as the optimum pH condition in the feed phase during the following experiments.
Effect of initial concentration of Tb\(^{3+}\) in the feed phase

Effect of initial concentration of Tb\(^{3+}\) on transport rate of Tb\(^{3+}\) is studied in the Tb\(^{3+}\) concentration range from \(0.5 \times 10^{-4}\) to \(1.5 \times 10^{-4}\) mol/L. The pH value in the feed phase is adjusted to 5.2, volume ratio of membrane solution and stripping solution is adjusted to 1.0, concentration of HCl solution is also adjusted to 4.0 mol/L in the dispersion phase, and concentration of P507 is 0.10 mol/L. The results obtained are presented in Figure 6. With the increasing of initial concentration of Tb\(^{3+}\) in the feed phase from \(0.5 \times 10^{-4}\) to \(1.5 \times 10^{-4}\) mol/L, the transport rate of Tb\(^{3+}\) decreased during the same time. This is because the number of P507 is definite through the membrane when the interface between the feed phase and the membrane phase is definite. That is to say, the number of Tb\(^{3+}\) transported is definite in this transport process. When the Tb\(^{3+}\) concentrations are \(0.8 \times 10^{-4}\), \(1.0 \times 10^{-4}\), \(1.2 \times 10^{-4}\) and \(1.5 \times 10^{-4}\) mol/L, the transport rates are up to 99.2%, 95.2%, 83.7% and 70.6% in 95 min, respectively. Further more, the transport rate is up to 100% in 65 min, when initial concentration of Tb\(^{3+}\) is adjusted to \(0.5 \times 10^{-4}\) mol/L, and after 65 min Tb\(^{3+}\) is hardly determined.

Effect of different stripping agents on transport of Tb\(^{3+}\)

The stripping agent at the membrane-dispersion side plays a vital role in transport of metal ions from feed phase to stripping phase. So the effects of different stripping agents in the dispersion phase on transport of Tb\(^{3+}\) are studied. All the other parameters, such as pH value, initial concentration of Tb\(^{3+}\) in the feed phase, volume ratio of membrane solution and stripping solution and concentration of P507 in the dispersion phase are adjusted to 5.2, \(1.0 \times 10^{-4}\), 1.0 and 0.10 mol/L, respectively. The effect of different stripping agents in the dispersion phase on the transport rate of Tb\(^{3+}\) is shown in Figure 7. Using hydrochloric acid (HCl), sulfate acid (H\(_2\)SO\(_4\)) and nitric acid (HNO\(_3\)) as the stripping agent respectively under the same acidity condition, it was found that hydrochloric acid is the most efficient stripping agent in this investigation. Under the conditions of hydrochloric acid solution, sulfate acid solution and nitric acid solution, the transport rate of Tb\(^{3+}\) is 95.2%, 91.4% and 81.8%, respectively. Choosing hydrochloric acid as the stripping agent, the transport rate of Tb\(^{3+}\) can be more efficient, so hydrochloric acid can be used as the optimum stripping agent during the following experiment.

Effect of concentration of P507 on transport of Tb\(^{3+}\)

Concentration of P507 in the membrane phase and dispersion phase also plays a significant role in transport of Tb\(^{3+}\). Effect of concentration of P507 on transport rate of Tb\(^{3+}\) is studied in the P507 concentration range from 0.036 to 0.23 mol/L. The pH value is adjusted to 5.2, initial concentration of Tb\(^{3+}\) is \(1.0 \times 10^{-4}\) mol/L in the feed phase, volume ratio of membrane solution and stripping solution is adjusted to 1.0 and concentration of HCl solution is also adjusted to 4.0 mol/L in the dispersion phase. The results are shown in the Figure 8. With the increasing of concentration of carrier in the membrane phase from 0.036 to 0.23 mol/L, the transport rate of Tb\(^{3+}\) increases, however, when concentration of P507 increases from 0.10 to 0.23 mol/L, the increasing of transport rate of Tb\(^{3+}\) is not obvious. Within this concentration range of P507 from 0.036 to 0.23 mol/L in the dispersion phase, the availability of P507 at the feed-membrane-dispersion interfaces increases with the increasing of concentration of carrier. The chemical equilibrium moved towards left. Similarly, when concentration of P507 became low, the balance shifts to the right. The increasing of concentration of P507 to a significant extent, the transport rate of Tb\(^{3+}\) will no longer increase with time. When the concentrations of P507 are 0.10, 0.16 and 0.23 mol/L, the transport rates are 95.2%, 96.6% and 97.1%, respectively. The concentration of P507 is proportionate with Tb\(^{3+}\) concentration in membrane phase. When the concentration of P507 in the
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**Effect of concentration of P507 on transport of Tb\(^{3+}\)**

The number of P507 used to transport Tb\(^{3+}\) is decreased when the feed phase on transport rate of Tb\(^{3+}\) only at the aqueous-DSLM interfaces.

Conclusions

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- Optimum transport condition of Tb\(^{3+}\) in the DSLM system is that the concentration of HCl solution was 4.0 mol/L, volume ratio of membrane solution and stripping solution was 1.0, the concentration of P507 was 0.10 mol/L in the dispersion phase, pH value was 5.2 in the feed phase. When initial concentration of Tb\(^{3+}\) was 1.0x10\(^{-4}\) mol/L, the transport effect of Tb\(^{3+}\) was very obvious in the optimum condition and the transport rate of Tb\(^{3+}\) was up to 95.2\% during the transport time of 95 min.

A transient model was developed which considers the reaction between the Tb\(^{3+}\) and the extractant P507 only at the aqueous-DSLM interfaces.

The results of Tb\(^{3+}\) extraction with respect to time produced by the kinetic research and equations coincide well with those obtained by experimentation. The application of this model to the extraction of other rare earth species is possible as long as the equilibrium and transport characteristics, such as the nature and diffusivities of the complexes formed in the organic phase, are known. In the future, the same methodology will be applied to systems which contain different rare earth species.

**References**

5. Ludek, J.; Wei, Y. Z.; Mikio, K. J. Rare Earths 2006, 24, 385.

![Figure 8](Image) Effect of concentration of P507 on transport of Tb\(^{3+}\).

![Figure 9](Image) Effect of ionic strengths on transport of Tb\(^{3+}\).
28 Ren, Z. Q.; Zhang, W. D.; Liu, Y. M.; Dai, Y. A.; Cui, C. H.