Continuous Extraction of Europium(III) by Ionic Liquid in the Rotating Disk Column with an Asymmetrical Structure Aimed at the Evaluation of Reactive Mass Transfer

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ABSTRACT: In this study, the features of the solvent extraction technique were investigated to explore the potential of ionic liquid for extracting Eu(III) from aqueous solution. The transport process between the aqueous and organic phase was carried out in the rotating disk column with an asymmetrical structure and a continuous mode of operation. The utilization of Cyphos IL 104 as an ionic liquid in comparison with Cyanex272 extractant was evaluated for the extraction abilities in the recovering of Eu(III) under different conditions, including agitation speed, inlet aqueous, and solvent phase velocities. The degree of extraction and the mass-transfer rate were best when the agitation speed and the superficial velocities of aqueous and solvent phases were adjusted to 690 rpm, 0.831 mm/s, and 1.385 mm/s, respectively. The better efficiency was achieved using the ionic liquid with 0.02 mol/L concentration, 96.52% Eu(III) extraction in comparison to the same condition without the presence of ionic liquids with Cyanex272 (0.5 mol/L, 99.66%). With the analysis of the data, it was noted that the increase in the operating parameters has a positive influence on the holdup, degree of extraction, and mass-transfer rates. The percentage increase equal to 33.57% for overall mass-transfer coefficients was obtained with the increment of mixing in the column. The results showed that the mass transfer is associated with reactive resistance. The previous correlation did not explain the behavior of the system correctly in the reactive mode. Finally, the empirical models using the Sherwood number were developed to correlate the mass-transfer coefficient.

INTRODUCTION
The quest for a circular economy focuses more on the processes of extraction, separation, and recovering rare-earth elements from the primary and secondary sources. 1 The rare-earth elements are acknowledged as supporting materials of modern technology. The demand for the production of these materials has made the efficiency of processes aimed at more attention to producing. 2 In addition to providing high-tech materials, the issue of recovering from used and spent materials is a concern in the future. 3

The fluorescent lamp effluent is known to be a rich source of europium and yttrium. 4 Securing these elements will entail risks in the future. In addition to application in fluorescent lamps, europium is also very effective in producing phosphorus, computer monitors, and televisions. 5 The process of metal production and recovery is accompanied by several steps. It is acknowledged that solvent extraction is a significant part of the process. 6 Due to the importance of solvent extraction in separating europium and its similar ions, numerous studies in the literature have been conducted to investigate the effect of different solvents on the removal of this element. 7−10 Studies by Tunsu and co-workers showed that the separation of yttrium and europium ions could be provided...
The increase in temperature has adverse effects on the separation process, and the high hydrochloric acid concentration (>3 mol/L) is required for the stripping and recovery of these elements. The extraction process is performed with better efficiency with aliphatic solvents compared with the aromatic solvents and alcohols with long branches. Investigation of the modification in the behavior of carboxylic acid with calixarene derivative was investigated in studies by Lu and co-workers. Examination of the conditions in the mass transfer of europium with carboxylic acid diluted with chloroform in a stirred tank showed that the chemical reaction is slow, and the mass-transfer coefficient equal to $3.35 \times 10^{-6} \text{ m/s}$ was obtained.

The application of new and novel solvents for the extraction of europium to raise the degree of extraction is paramount importance, and research is leading to this issue. Applicability of $N,N'$-diethyl-$N,N'$-diphenyl-1,10-phenanthroline-2,9-dicarboxamide in the europium extraction by determination of equilibrium components was investigated in the study of Makrlik and co-workers. Similar results with the introduction of another new reactive agent by the same authors showed that these extractants are suitable acceptors for europium ions and can be used to remove elements from effluents.

The synergistic effect of the extractants helps to increase the transfer of the europium ions from the aqueous phase to the organic phase. The mixtures of hydrogen dicarbollylcobaltate and bis(diphenylphosphino)acetylene dioxide in nitrobenzene, and the combination of furosemide and tribenzylamine in benzyl alcohol, showed the synergistic effects in the Eu(III) extraction. Various cations of copper, cadmium, zinc, and cobalt have no significant interference on the europium extraction with a mixture of two extractants.

The application of ionic liquids as diluents in the extraction of europium showed that the transport mechanism in the combination of ionic liquids and the reactive agents is different from conventional systems diluted with a molecular solvent. The homogeneous process of combining ionic liquids in europium extraction showed that an unlimited contact surface between the two phases could be obtained for extraction. This work is associated with high extraction rates and helps as an alternative system in recovering rare-earth elements.

### Table 1. Physical Properties of Two Selected Systems in the Investigation of Europium Extraction

| type | $\rho_c$ (kg/m$^3$) | $\rho_d$ (kg/m$^3$) | $\mu_c$ (kg/m·s) | $\mu_d$ (kg/m·s) | $\sigma$ (N/m) | $D_c$ (m$^2$/s) |
|------|-------------------|-------------------|-----------------|-----------------|------------|-------------|
| system 1: Cyanex272 in organic phase/Eu(III) ions in aqueous solution with pH = 4 | 1003 | 786 | 0.001087 | 0.0013991 | 0.0154 | $1.024 \times 10^{-9}$ |
| system 1: Cyphos IL 104 in organic phase/Eu(III) ions in aqueous solution with pH = 4 | 1003 | 798 | 0.001087 | 0.0014071 | 0.0127 | $1.053 \times 10^{-9}$ |

![Figure 1. Variation in droplet diameter inside column versus operating variables and type of solvent containing ionic liquid and organophosphorus extractant: (a) effect of agitation speed; (b) effect of solvent phase velocity; and (c) effect of aqueous phase velocity.](https://dx.doi.org/10.1021/acsomega.0c01636)
The results of the study of the effects of thiocyanate ionic liquids showed that the europium ions could be separated from the fluorescent lamp waste in four steps with an efficiency of higher than 98%.\textsuperscript{21}

A comparison of the dissolution of carbamoylmethylphosphine oxide in $n$-dodecane and imidazolium ionic liquid showed that the hybrid system with ionic liquid is more desirable for the extraction of europium. Thermal effects occurred with the more exothermic reaction in this system, and a combination of the cation exchange and solvation mechanism is observed in the extraction.\textsuperscript{22} Comparative studies on the extraction of europium(III) with D2EHPA extractant and Cyphos IL 104 as an ionic liquid showed that the ionic liquid capacity in the extraction of Eu(III) is higher than that of the D2EHPA extractant. The ion association mechanism was the result of the interaction between Eu(III) and molecules of ionic liquids. However, the mechanism of cation exchange is predominant in the reaction of these ions with the D2EHPA extractant.\textsuperscript{23} Although the type of extractant has been investigated in the process of europium extraction, few studies have been performed in the kind of applied system to extract these metals. Limited research has been reported by examining the supported liquid membranes\textsuperscript{24−27} and microchannels to intensify the extraction process.\textsuperscript{28−30}

The extraction equipment was a crucial factor in raising the extraction and the mass-transfer rates between two phases.\textsuperscript{31−35} In this study, the rotating disk column with an asymmetrical structure was investigated for europium extraction. The performance of the extractive column under different operating conditions was monitored by changes in the input variables and the composition of organic and aqueous feeds to obtain desirable results in the removal of europium ions in the presence of ionic liquids, which have not been mentioned in the research by others.

\section*{RESULTS AND DISCUSSION}

\textbf{Evaluation of Drop Sizes and Dispersed Phase Holdup.} In this study, the extraction of europium in the reactive conditions was investigated in two separate systems. In the first system, Cyanex272 diluted in kerosene, and in the second system, the ionic liquid Cyphos IL 104 diluted in kerosene were investigated in the experiments for europium extraction from aqueous solution. The physical properties of the two selected systems are presented in Table 1.

The reaction of europium ions with Cyanex272, and Cyphos IL 104 is performed according to the following equations for the transfer of ions from the aqueous phase to the organic phase:\textsuperscript{23,36}

\begin{equation}
\text{Eu}^{3+} + 3(\text{HL})_{2,\text{org}} \rightleftharpoons [\text{Eu(HL)}]_{3,\text{org}} + 3\text{H}^{+} + \text{[HL]}
= \text{Cyanex272}
\end{equation}

\begin{equation}
\text{EuCl}_{3(\text{aq})} + 3[\text{R}_{3}\text{R'}\text{PA}]_{\text{org}} + \text{H}_{\text{aq}}^{+} \rightleftharpoons 3\text{R}_{3}\text{R'}\text{PCl}_{\text{org}} + \text{EuA}_{3(\text{org})} + \text{H}_{\text{aq}}^{+} + [\text{R}_{3}\text{R'}\text{PA}]
= \text{Cyphos IL 104}
\end{equation}

Figure 2. Variation in the holdup of dispersed phase inside column versus operating variables and the type of solvent containing ionic liquid and organophosphorus extractant: (a) effect of agitation speed; (b) effect of solvent phase velocity; and (c) effect of aqueous phase velocity.
The effect of changes in the input factors on the variation of droplet diameter is described in Figure 1.

These are effective factors, such as mixing intensity inside the column and velocities of aqueous and organic phases. The results of this figure showed that the droplet behavior is subject to the interfacial tension, and the decrease of this property with the presence of ionic liquid Cyphos IL 104 is associated with a reduction in droplet size. Therefore, extraction with ionic liquid produces smaller droplets compared to the extraction system with the Cyanex272 extractant. The variation of mixing in the column is accompanied by the phenomenon of breakage and coalescence, and the increase in agitation speed (see in Figure 1a) helps in the production of smaller droplets due to higher breakage rates. The increase in the velocity of the organic phase containing Cyphos IL 104 or Cyanex272 solvent in the column causes an increase in the amount of organic phase value in the constant volume. This enhancement in this value will help the coalescence phenomenon of droplets, causing the size of the larger droplets to increase with an increase in velocity of the organic phase from 0.831 to 1.384 mm/s (see in Figure 1b). The results of the evaluation of the velocity of the aqueous phase containing europium ions from 0.831 to 1.384 mm/s in Figure 1c, showed a limited increase in droplet sizes, and this variation in the velocity did not have a positive effect on the results.

The presence of droplets in the column is directly related to the parameter of dispersed phase holdup. The results of the study about this parameter by examining the changes in the column operating parameters are shown in Figure 2.

As mentioned, higher values for mixing between two phases are associated with the increase in the droplet breakage and the reduction in coalescence speeds. This effect contributes to high values for the holdup of the dispersed phase (see Figure 2a). The interfacial tension between the two phases also helps to increase this parameter in conditions where it is associated with lower values. The result is an increase in the holdup for the second system containing Cyphos IL 104 diluted in kerosene (0.0127 N/m) compared to the first system of Cyanex272 (0.0154 N/m). As shown in Figure 2b, the effect of the increase in the solvent velocity containing the extractant or the ionic liquid (dispersed phase) described that the reasons for the rise in the holdup are the presence of more solvent inside the column. The velocity of the aqueous phase containing europium ions helps to increase the drag forces between the two phases, this effect contributing to the increase in the amount of holdup as shown in Figure 2c.

The interfacial area is calculated as 6 times the amount of holdup divided by the droplet sizes. The simultaneous effect of both parameters can affect the numerical value of the interfacial for mass transfer between two phases (the direct impact of the holdup, and the inverse effect of droplet diameter). The results of the variation in the interfacial area in Figure 3a indicated that the increase in mixing intensity is subject to more holdup and that the inverse effect of diameter led to an increase in the interfacial area. The impact of phase velocity is also dominated by increasing the holdup of dispersed phase over increasing diameter with low percentage values. Therefore, the interfacial area has an upward trend with an increase in these two velocities of phases (see Figure 3b,c).

Evaluation of Mass-Transfer Rates. The mass-transfer conditions inside this column were determined based on the axial dispersion model with the governing equations in ref 37.

Figure 3. Variation in the interfacial area inside column versus operating variables and type of solvent containing ionic liquid and organophosphorus extractant: (a) effect of agitation speed; (b) effect of solvent phase velocity; and (c) effect of aqueous phase velocity.
The equations were solved based on the numerical solutions in Matlab software. The axial dispersion coefficient for the dispersed phase was assumed to be negligible in the selected equations, and this coefficient for the continuous phase was replaced by Kumar and Hartland. The results of the numerical solution of the equations are shown in Figure 4 for the volumetric overall mass-transfer coefficient. The variation of the concentration distribution inside the column for both selective systems is shown in Figures 5−7.

The results in Figure 5 show that the increase in rotor speed results in a decrease in the drop diameter, thus reducing the mass-transfer rate by eliminating internal circulatory and tendency to form rigid droplets. However, the variation in Figure 4a shows that the interfacial area has a positive effect on mass transfer. The higher values for volumetric overall mass-transfer coefficients and the increase in the rate of transfer of europium ions to the organic phase are achieved with the increase in the mixing intensity of the column.

The effects of phase velocities showed incremental effects on the overall mass-transfer rate (Figures 6 and 7).
increase in the volumetric overall mass-transfer coefficient is obtained by applying the interfacial area effect (Figure 4b,c). The dispersed phase changing is more effective than the continuous phase in raising this coefficient due to the presence of more solvent for the reaction and mass transfer. The variation in the type of solvent in the column also indicated that ionic liquid Cyphos IL 104 is more efficient in extracting Eu(III) ions, resulting in more exceptional mass transfer.

**Evaluation of Results in Reactive System.** The reported equations in the previous research of Asadollahzadeh and co-workers were used to evaluate the comparative conditions in the determination of the Sauter mean drop diameter and the holdup of the dispersed phase. These described equations are as follows

\[
d_{12} = 0.089 \left( \frac{N^2 d_{12} \rho}{g \sigma} \right)^{0.015} \left( \frac{\mu^2 \gamma}{\Delta \rho \sigma^4} \right)^{-0.10} \left( 1 + \frac{V_g}{V_d} \right)^{0.10} \left( \frac{V_g}{\sigma d_{12} \rho^2} \right)^{0.25} \left( \frac{h_d d_g}{D_H} \right)^{-0.26} \left( \frac{V_d}{\sigma d_{12} \rho^2} \right)^{-0.07}.
\]

\[
\varphi = 7.22 \left( \frac{N^2 d_{12} \rho}{g \gamma} \right)^{0.41} \left( \frac{\mu}{\mu_d} \right)^{-0.04} \left( 1 + \frac{V_g}{V_d} \right)^{0.64} \left( \frac{\sigma \gamma}{\rho_d V_d^2} \right)^{-0.95}.
\]

These equations were associated with 47.52 and 38.93% errors in the prediction of results for \(d_{12}\) and \(\varphi\), respectively. These errors are related to the type of selected system. The description of these equations is based on physical systems without reaction and is associated with high errors for examining reactive systems.

These authors proposed the below equation for the prediction of the overall mass-transfer coefficient in the asymmetric rotating disk column: \(^{37}\)

\[
Sh_{oc} = -120.72 + 117.01 \times Re^{0.12} (1 - \varphi)
\]

The results of the above equation for the prediction of the overall mass-transfer coefficient are shown in Table 2. The results illustrated that the prediction values are much higher than the experimental values, and the average absolute relative error is above 100%.

The main reason for this significant error is that the overall mass-transfer coefficients in the system with the reaction have small values. This small amount is due to the resistance to the reaction in the system. To investigate the effect of the reactive resistance, the mass-transfer relationship was considered as follows.

\[
\frac{1}{K_{oc}} = \frac{1}{k_d} + \frac{1}{m k_d} + \frac{1}{k_r}
\]

The sum of the effect of dispersed and continuous phase mass-transfer coefficients on the physical systems is defined as follows

\[
\frac{1}{K_{oc, physical}} = \frac{1}{k_d} + \frac{1}{m k_d}
\]

This above value can be calculated based on eq 5 that is defined for the physical system (toluene/acetone/water). Therefore, the value of the reactive coefficient can be determined as follows

| system | \(N\) (rpm) | \(V_g\) (mm/s) | \(V_d\) (mm/s) | \(K_{oc\ experimental}\) (m/s) | \(K_{oc\ calculated}\) (m/s) | \(\Delta \rho\) (physical) | \(\Delta \rho\) (chemical) |
|--------|-------------|----------------|----------------|-------------------------------|-------------------------------|---------------------------|-------------------------|
| Eu(III) extraction with Cyanex 272 in the organic phase | 150 | 0.831 | 0.831 | 1.98 \times 10^{-5} | 1.29 \times 10^{-4} | 15.33 | 84.67 |
| | 330 | 0.831 | 0.831 | 1.83 \times 10^{-5} | 1.11 \times 10^{-4} | 16.31 | 83.69 |
| | 510 | 0.831 | 0.831 | 1.77 \times 10^{-5} | 7.18 \times 10^{-5} | 24.67 | 75.33 |
| | 690 | 0.831 | 0.831 | 1.63 \times 10^{-5} | 4.43 \times 10^{-5} | 36.81 | 63.19 |
| | 330 | 1.108 | 0.831 | 2.21 \times 10^{-5} | 1.03 \times 10^{-4} | 21.42 | 78.58 |
| | 330 | 1.385 | 0.831 | 2.27 \times 10^{-5} | 9.29 \times 10^{-5} | 24.22 | 75.58 |
| | 510 | 1.108 | 0.831 | 1.86 \times 10^{-5} | 6.87 \times 10^{-5} | 27.06 | 72.94 |
| | 510 | 1.385 | 0.831 | 1.93 \times 10^{-5} | 6.36 \times 10^{-5} | 30.35 | 69.65 |
| | 330 | 0.831 | 1.108 | 1.87 \times 10^{-5} | 9.85 \times 10^{-5} | 18.97 | 81.03 |
| | 330 | 0.831 | 1.385 | 1.94 \times 10^{-5} | 9.06 \times 10^{-5} | 21.40 | 78.60 |
| | 510 | 0.831 | 1.108 | 1.82 \times 10^{-5} | 6.69 \times 10^{-5} | 27.18 | 72.82 |
| | 510 | 0.831 | 1.385 | 1.87 \times 10^{-5} | 6.11 \times 10^{-5} | 30.61 | 69.39 |
| | 150 | 0.831 | 0.831 | 2.06 \times 10^{-5} | 1.19 \times 10^{-4} | 17.24 | 82.76 |
| | 330 | 0.831 | 0.831 | 1.88 \times 10^{-5} | 9.99 \times 10^{-5} | 18.81 | 81.19 |
| | 510 | 0.831 | 0.831 | 1.81 \times 10^{-5} | 5.62 \times 10^{-5} | 32.20 | 67.80 |
| | 690 | 0.831 | 0.831 | 1.69 \times 10^{-5} | 2.94 \times 10^{-5} | 37.56 | 42.44 |
| | 330 | 1.108 | 0.831 | 2.23 \times 10^{-5} | 9.49 \times 10^{-5} | 23.48 | 76.52 |
| | 330 | 1.385 | 0.831 | 2.29 \times 10^{-5} | 8.75 \times 10^{-5} | 26.16 | 73.84 |
| | 510 | 1.108 | 0.831 | 1.91 \times 10^{-5} | 5.91 \times 10^{-5} | 32.35 | 67.65 |
| | 510 | 1.385 | 0.831 | 1.96 \times 10^{-5} | 5.54 \times 10^{-5} | 35.36 | 64.64 |
| | 330 | 0.831 | 1.108 | 1.91 \times 10^{-5} | 9.29 \times 10^{-5} | 20.56 | 79.44 |
| | 330 | 0.831 | 1.385 | 1.97 \times 10^{-5} | 8.77 \times 10^{-5} | 22.46 | 77.54 |
| | 510 | 0.831 | 1.108 | 1.89 \times 10^{-5} | 5.35 \times 10^{-5} | 35.34 | 64.66 |
| | 510 | 0.831 | 1.385 | 1.94 \times 10^{-5} | 5.19 \times 10^{-5} | 37.36 | 62.64 |
\[
\frac{1}{K_{\text{oc,chemical}}} = \frac{1}{K_{\text{oc,physical}}} + \frac{1}{k_r}
\]

Equation 9 expresses the amount of reactive resistance to mass transfer as below
\[
\Delta_s = \frac{\Delta_r}{\Delta + \Delta_s + \Delta}; \quad \Delta_r = \frac{1}{k_r}
\]

The results in Table 2 show that the average values of the reactive resistance for europium extraction with 0.5 mol/L Cyanex272 in kerosene and 0.02 mol/L Cyphos IL 104 diluted in kerosene are equal to 76.5 and 70.3%, respectively. The modification of eq 5 by considering the results of the europium extraction with the two investigated systems is obtained as follows
\[
Sh_{bic} = 2.127 + 25.65 \times Re^{0.365}(1 - \varphi)
\]

This equation with the AARE values equal to 4.18% indicated that the proposed correlation is more accurate for describing the mass transfer in the europium extraction from the aqueous phase to the organic phase containing ionic liquid or organophosphorus solvents.

The results of the study in this equation in the prediction of the mass-transfer coefficient of the continuous phase based on the Sherwood number is shown in Figure 8. This equation with conditions were investigated in a pilot-scale rotating column with an asymmetric structure on the rotation system’s internal components. Evaluation of the system based on the mass-transfer coefficient of the axial dispersion model showed that the reactive mass transfer inside the column is associated with a reactive resistance. This resistance with an average percent of 73% reduces the mass-transfer rates in the column. The variation in surface tension, holdup, and droplet diameter affects the interfacial area, and increasing this parameter helps that the overall coefficients have an increasing trend in the column. The variation in the interfacial area by examining the type of solvent inlet to the column showed that ionic liquids are more efficient in extraction by enhancing mass-transfer coefficients. Therefore, a reactive system using environmentally friendly solvents is recommended for removing of rare-earth elements such as europium from the leaching solution of primary or secondary sources.

### EXPERIMENTAL SECTION

**Chemical Agents.** In this study, bis(2,4,4-trimethylpentyl) phosphinic acid/Cyanex272 and ionic liquid trihexyl(tetradecyl)phosphonium bis(2,4,4-trimethylpentyl) phosphinate/Cyphos IL 104 were purchased from Aldrich company. Two types of organic feed were provided for the dispersed phase. The first feed was prepared from the dissolution of Cyanex272 with a concentration of 0.5 mol/L in kerosene, and the second feed was obtained from the dissolution of an ionic liquid solution with the concentration of 0.02 mol/L in kerosene. The aqueous feed was prepared by the dissolution of the europium nitrate salt, 300 mg/L (from Middle East Ferro Alloy Company) in the distilled water with the pH value equal to 4. The concentration of the organic phase and the pH value was 330 mg/L and pH 7.5, respectively. The increment in the intensity with increasing rotor speed helps to enhance the higher values for the degree of extraction. Also, the variation in the two phases’ velocities has a positive effect, but their impact is far less than the mixing effect. The transfer of ions to the organic phase by the two solvents illustrated that the ionic liquid showed higher performance in the extraction process, and the evaluation of a system with an ionic liquid is more favorable than the presence of organophosphorus solvent in the organic phase.

### CONCLUSIONS

In this study, the extraction of europium from aqueous solution to organic phase was investigated by the presence of two systems, one containing Cyanex272 and the other containing Cyphos IL 104 ionic liquid. The extraction
studies to maximize the extraction efficiency (higher than 99.9%).

**Experimental Setup.** The extraction process was investigated with and without ionic liquid in the rotating disk column with an asymmetrical structure. The demonstration of the system structure and the relationship between its components is described in Figure 9. The column was built based on the working condition in continuous mode.

The height and diameter of the active section were 1430 and 113 mm, respectively, and 36 central disks were installed inside the column. The contact and transport sections in the column are separated by an asymmetric structure from the vertical stator baffle. The disk impellers at the center of each contact chamber cause the mechanical mixing of both phases. The position of the interface between both phases is controlled by installing an optical sensor at the end of the column. The countercurrent flow between the two phases is adjusted in the column. The steady-state conditions are obtained in the column after three times of the column’s active volume for the passing of inlet phases. A series of initial tests were performed to determine the operating conditions of the column, and after determining the flooding point, the experiments were performed so that they were far from the flooding point and in stable conditions. In the steady-state process, the droplet size is determined by the technique of shooting (20 photos in each run) and converting drop photos to the actual size in Digimizer software, thus obtaining the Sauter mean drop diameter \(d_{32}\) by data analysis from pictures. The concentration of europium ions is measured throughout the column with sampling valves and transmitted to the ICP instrument. The degree of extraction is determined by dividing the rate of transfer into the organic phase relative to the initial value in the aqueous phase. Finally, all connections of the flow and agitated system are disconnected and dispersed phase holdup \(\phi\) is measured by the shutdown technique and the accumulation of drops at the end of the column. The interfacial area \(a\) in the extraction process is described by the following equation

\[
a = \frac{6\phi}{d_{32}}
\]  

(11)

The distribution ratio is equal to the concentration of ions in the organic phase to the aqueous phase, which is obtained as follows

\[
D_{Eu} = \frac{[Eu^{3+}]_{org, after extraction}}{[Eu^{3+}]_{aq, after extraction}}
\]  

(12)

The following equations can calculate the degree of extraction

\[
\%E = \frac{[D]_{Eu}}{[D]_{Eu} + \left(\frac{V_{aq}}{V_{org}}\right)} \times 100
\]  

(13)
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Notes
The authors declare no competing financial interest.

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