Pertraction of neodymium
M. Toure, G. Borda, D. Ode, J. Duhamet, S Pellet-Rostaing

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HAL Id: cea-02492580
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Submitted on 27 Feb 2020

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PERTRACTION OF NEODYMIUM

1,2TOURE Moussa / 1G. BORDA ; 1D. ODE ; 1J. DUHAMET ; 2S. P-ROSTAING

1 CEA, DEN, DTEC, SGCS, F-30207 Bagnols-sur-Cèze, France
2 ICSM, UMR5257, LTSM, F-30207 Bagnols-sur-Cèze
Presence of rare earth elements (REE) in permanent magnets

<table>
<thead>
<tr>
<th>Elements</th>
<th>Nd</th>
<th>Dy</th>
<th>Pr</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>23-25</td>
<td>3.5-5</td>
<td>0.05-5</td>
</tr>
</tbody>
</table>

Others: Gd; Tb

Prakash and al. ERES2014

Volume needed to generate a field of 1000 gauss from 5 mm of a pole of the magnet

NdFeB
Volume = 0.22 cm³

AlNiCo 5-7
Volume = 14 cm³

Source: amold magnetics

Some applications of permanent magnets (NdFeB)

Phones
Loud speakers
Microphones

Wind turbines
generators

The demand for Nd will rise by 700% over the next 25 years.
Why rare earth’s recycling?

**Source**: Report on Critical Raw Materials for the EU (May 2014)

**Targets**: Ores and Waste Electrical and Electronic Equipment (WEEE)
Why rare earth’s recycling?

Global potential of REE recycling from magnets

<table>
<thead>
<tr>
<th>REE application</th>
<th>Estimated REE stocks in 2020 (tons)</th>
<th>Estimated average lifetime (years)</th>
<th>Estimated REE old scrap in 2020 (tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnets</td>
<td>300,000.00</td>
<td>15</td>
<td>20,000.00</td>
</tr>
</tbody>
</table>

Koen and al. JOCP 51(2013) 1-22

Supply security; no thorium issues.
Solvent extraction (SX) for rare earth recycling

**Advantages of solvent extraction**

- Separation of compounds: with similar properties (REE; Ta-Nb),
- High purity of final products: REE (for optical and electronic products).

**Others processes after leaching**

- Selective precipitation/electrodeposition,
- Separation by ion exchange.

**Some of SX process equipments**: Pulsed column; Centrifugal extractors

**Mixer settlers**: principle

Transfer of interest solute from aqueous phase to the solvent by mixing and settling of two phases.

**Drawbacks related with conventional equipments**:

- Impossible to use very emulsive solvents: which extends the time of settling,
- Density difference required for phases separation: Using of diluent which can cause:
  - third phase formation (avoid by adding a modifier in some cases);
  - and a large volume of solvent in the process

Pertraction avoids the settling step and offers the possibility to operate without diluent
Contents

Pertraction: principle - interface stabilisation – advantages(drawbacks)

Solvent L for neodymium’s extraction: selection criteria

Neodymium’s extraction: mechanism

Neodymium’s extraction: temperature effect

Recycle of REE: from magnets

Taylor Dispersion Analysis (TDA): for neodymium’s diffusion coefficient determination in aqueous and solvent L phases

Neodymium’s extraction by pertraction: experiments and mass transfer simulation

General conclusion
Pertraction: principle

- Solvent wets the hydrophobic membrane pores.
- Interface solvent – aqueous phase takes place at the pore mouth of the membrane.
- Mass transfer is governed by:
  - Solute diffusion
  - $\Delta C$ as driving force.
Pertraction: solvent – aqueous interface stabilisation

Critical pressure

For maintain interface immobilized at pore mouth of the membrane:

\[(P_{aq} - P_{org}) < \Delta P_c\]

\[\Delta P_c = (P_{aq} - P_{org}) = \frac{2\sigma \cdot \cos \theta}{R}\]

\(\sigma\) interfacial tension; \(\theta\) wetting angle; \(R\) pores radius

At \(\Delta P \geq \Delta P_c\)
Pertraction: solvent – aqueous interface stabilisation

By hydrostatic pressure

With low pressure drop related to fluid flow \( \sim 75.92 \times 10^{-5} \text{ bar} \)

\[ P_i = \rho_i \times g \times h_i \]

\[ \Delta P = (P_{aq} - P_{org}) \]

\( i = \text{aq or org} \)
Pertraction : advantages / drawbacks

**advantages**

Possibility to use incompatible phases systems with conventional equipments :

- Using very emulsive solvents
- Operating without diluent
- No density difference is required

Settling step is avoid
Simple implementation
Scale up without major difficulty

**Drawbacks**

Reduction of mass transfer related to the presence of the membrane
Fouling problems of the membrane
Solvent for neodymium’s extraction: selection criteria

**Selectivity**

Distribution coefficient ($K_D$)

$$K_D = \frac{[C]_{org}^M}{[C]_{aq}^M}$$

Separation Factor ($SF_{M1/M2}$)

$$SF_{M1/M2} = \frac{K_D(M1)}{K_D(M2)}$$

**Back-extraction; solvent: solubility, flash point and cost.**

**Viscosity**

As low as possible for minimize pressure drop and enhance mass transfer at aqueous and organic interface:

**Fick’s first law**

$$J = -D \nabla c$$

**Stokes-Einstein**

$$D = \frac{k_B T}{R_h 6\pi \eta}$$

$k_B$: Boltzmann constant  
$\eta$: viscosity of solvent  
$R_h$: hydrodynamic radius of solvent complexes

Conditions:
Batch process at $T(°C)$,  
Time, O/A
Neodymium’s extraction : mechanism

The main mechanisms for neodymium extraction

By ion exchange

\[ \text{M}^{m+}_{\text{aq}} + m\text{HL} \leftrightarrow \text{ML}_n + m\text{H}^+_{\text{aq}} \]

By solvation

\[ \text{M}^{m+}_{\text{aq}} + m\text{A}_{\text{aq}}^- + n\text{L} \leftrightarrow \text{ML}_n\text{A}_m \]

Marcus and al. have described the four mechanisms in solvent extraction:

« Ion Exchange and Solvent Extraction of Metal Complexes, Wiley-Interscience, 1969 »
Neodymium’s extraction: mechanism

\[ Nd^{3+} + 3NO_3^- + nL_{\text{free}} \leftrightarrow NdL_n(NO_3)_3 \]

Law of mass action

\[ K_{\text{ex}}^{\text{app}} = \frac{[NdL_n(NO_3)_3]}{[Nd^{3+}] \cdot [NO_3^-]^3 \cdot [L]^n_{\text{free}}} = \frac{K_D}{[NO_3^-]^3 \cdot [L]^n_{\text{free}}} \]

Slope analysis technique

\[ \log K_D = n \cdot \log [L]_{\text{free}} + 3 \cdot \log [NO_3^-] + \log K_{\text{ex}}^{\text{app}} \]

\[ y = A \cdot x + B \]

Experimental conditions

\[ [HNO_3] = 0.1 \text{ M} ; [NaNO}_3] = 2.5 \text{ M} ; [Nd] = 6.10^{-3} \text{ M} ; A/O=1 ; T = 20-22^\circ C \]

\[ \log (K_D) = f(\log[L]_{\text{free}}) \]
Neodymium’s extraction: mechanism

Neodymium’s extraction equilibrium:

\[ \text{Nd}^{3+} + 3\text{NO}_3^- + 3L \leftrightarrow \text{NdL}_3(\text{NO}_3)_3 \]

Confirm by mass spectroscopy (ESI-MS)

ESI-MS: Mass Spectroscopy by Electrospray Ionization

\[ Y = 2.9 \pm 0.1X - 0.77 \pm 0.06 \]
\[ R^2 = 0.99622 \]
Neodymium’s extraction: temperature effect

Experimental conditions
\[ [\text{HNO}_3] = 0.1 \text{ M} ; [\text{NaNO}_3] = 2.5 \text{ M} ; [\text{Nd}] = 6.10^{-3} \text{ M} ; \text{A/O} = 1 \]

\[ K_D = f(T^\circ \text{C}) \]

Exothermique extraction with \( K_D \in [14 - 5] \)
Neodymium’s extraction: temperature effect

Law of mass action

\[ K_{ex}^{app} = \frac{K_D}{[NO_3]^3 \cdot [L]^3} \]

\[ \Rightarrow \ln K_{ex}^{app} = \frac{-\Delta H_{ext}^0}{R} \times \frac{1}{T} + \frac{\Delta S_{ext}^0}{R} + 3\ln[NO_3] + 3\ln[L] \]

Van’t Hoff equation

**Graph:**
- \( Y = 2752 \pm 12 \)X  - 6.59 ± 0.04
- \( R^2 = 0.99997 \)

\[ \Delta H_{ext}^0 = -22.9 \text{ kJ.mol}^{-1} \]
Recycle of REE

Experimental conditions

\[ [\text{HNO}_3] = 0.1 \text{ M} ; \ [\text{NaNO}_3] = [0.5 \text{ – } 3] \text{ M} ; \ A/O=1 \]

<table>
<thead>
<tr>
<th>Elements /g.L(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nd</td>
</tr>
<tr>
<td>----</td>
</tr>
<tr>
<td>0.3</td>
</tr>
</tbody>
</table>

waste model of magnets
Recycle of REE

Distribution coefficients *versus* [NaNO₃]

NO₃⁻ favors extraction of Nd, Pr, Dy and Fe
Solvent L extracts significantly Nd, Pr, Dy with $K_D \in [7 – 12]$
Fe is the main impurity with $K_D < 2.5$
Recycle of REE

Separation factors versus [NaNO₃]

<table>
<thead>
<tr>
<th>[NaNO₃] / mol.L⁻¹</th>
<th>3</th>
<th>[NaNO₃] / mol.L⁻¹</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>SF Nd/Fe</td>
<td>5.44</td>
<td>SF Nd/Pr</td>
<td>1.039</td>
</tr>
<tr>
<td>SF Nd/Ni</td>
<td>116.037</td>
<td>SF Nd/Dy</td>
<td>2.17</td>
</tr>
<tr>
<td>SF Nd/Co</td>
<td>154.03</td>
<td>SF Pr/Dy</td>
<td>2.088</td>
</tr>
<tr>
<td>SF Nd/B</td>
<td>30</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

/selective extraction of REE at NaNO₃ (3M) and possibility to separate them each other at NaNO₃ (0.5M)

REE back-extraction can be made at low acidity.
Recycle of REE

Scheme of process

Co-extraction of REE

HNO₃ + NaNO₃

Aqueous phase (Nd, Pr, Dy, Fe, Co, Ni, B)

Effluents (Fe, Co, Ni, B, NO₃⁻)

Back-extraction REE

Distilled water

Calcination

Dy₂O₃

Pr₂O₃

Nd₂O₃

Solvent traitement

Liquid-liquid extraction equipment with required stages
Taylor Dispersion Analysis (TDA) : for neodymium’s diffusion coefficient determination in aqueous and solvent L phases

\textit{solvent L name is not mentioned here for confidential aspect}

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Collaboration with 3J. CHAMIEH ; 3H. COTTET

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2 ICSM, UMR5257, LTSM, F-30207 Bagnols-sur-Cèze
3 IBMM, UMR 5247-UM2, DSBC, place Eugène Bataillon CC 017, 34095 Montpellier Cedex 5, France
Taylor Dispersion Analysis (TDA)

Capillary electrophoresis (CE) for TDA

Theory

Taylor – Aris –Golay equation

\[ H = \frac{2D}{u} + \frac{R_c^2 u}{24D} \]

Axial diffusion

\[ H = \frac{I_D \sigma^2}{t^2_R} \]

H: Plate height
\( \sigma^2 \): Variance of the elution profile
\( t_D \): average elution time
\( I_D \): capillary Length to the detector
\( R_c \): capillary radius

Reduced to:

\[ D = \frac{R_c^2}{24 \sigma^2 t_R} \]

Validity:

Satisfied if:

\[ \tau = \frac{D t_R}{R_c^2} \geq 1.25 \]

Satisfied if:

\[ Pe = \frac{R_c u}{D} \geq 40 \]
Taylor Dispersion Analysis (TDA)

Capillary electrophoresis (CE) for TDA

Pump

Capillary e = 400 µm

Polyimide coating

100 µm

C⁴D cell

UV cell

PC

Buffer+solute

Buffer

Theory

Taylor – Aris –Golay equation

\[ H = \frac{2D}{u} + \frac{R_c^2 u}{24D} \]

Axial diffusion

\[ H = \frac{I_D \sigma^2}{t_R^2} \]

\( H \): Plate height

\( \sigma^2 \): Variance of the elution profile

\( u \): linear velocity

\( R_c \): capillary radius

\( l_D \): capillary length to the detector

\( t_D \): average elution time

Reduced to:

\[ D = \frac{R_c^2}{24\sigma^2} t_R \]

Validity:

Satisfied if:

\[ \frac{D t_R}{R_c^2} \geq 1.25 \]

Satisfied if:

\[ Pe = \frac{R_c u}{D} \geq 40 \]

Taylor Dispersion

C (g/L)

t (minutes)
Taylor Dispersion Analysis (TDA)

Capillary electrophoresis (CE) for TDA

Theory

Taylor – Aris – Golay equation

\[ H = \frac{2D}{u} + \frac{R_c^2 u}{24D} \]

Axial diffusion

\[ H = \frac{l_D \sigma^2}{t_R^2} \]

In practice, \( D \) is calculated by fitting the experimental profile with a Gauss error function for determine \( \sigma \) and \( t_R \):

\[ \frac{C}{C_0} = \frac{1}{2} \pm \frac{1}{2 \sqrt{\pi}} \text{erf} \left( \frac{t - t_R}{\sigma \sqrt{2}} \right) \]
Taylor Dispersion Analysis (TDA)

Capillary electrophoresis (CE) for TDA

Theory

Taylor – Aris – Golay equation

\[
H = \frac{2D}{u} + \frac{R_c^2 u}{24D} \quad \Rightarrow \quad H = \frac{l_D \sigma^2}{t_R^2}
\]

- \( H \): Plate height
- \( \sigma^2 \): Variance of the elution profile
- \( t_D \): average elution time
- \( l_D \): capillary Length to the detector
- \( R_c \): capillary radius

Reduced to:

\[
D = \frac{R_c^2}{24 \sigma^2} t_R
\]

Advantages of TDA

Simple ;
Fast ;
Low sample volume (0.7 nL) ;

Validity:

Satisfied if : \( \frac{D t_R}{R_c^2} \geq 1.25 \)

Satisfied if : \( Pe = \frac{R_c u}{D} \geq 40 \)
Taylor Dispersion Analysis (TDA)
Neodymium’s diffusion coefficient in aqueous phase

Validity

\[ \text{Pe} \in [255 - 276] \geq 40 \]
\[ \tau \in [66.2 - 71.9] > 1.25 \]
Taylor Dispersion Analysis (TDA)

Neodymium’s diffusion coefficient in aqueous phase

$D_{Nd} \in [5.99 - 5.52] \times 10^{-10} \text{ m}^2\text{s}^{-1}$

with RSD < 3 %

Same order of magnitude as the one calculated with Nernst–Einstein equation

$D_0 = 6.16 \times 10^{-10} \text{ m}^2\text{s}^{-1}$ (with conductivity of Nd $\sigma = 69.4 \, \mu\text{S}\cdot\text{cm}^{-1}$)
Taylor Dispersion Analysis (TDA)

Neodymium’s diffusion coefficient in solvent L phase

Validity

\[ \text{Pe} = 1910 \geq 40 \]
\[ \tau = 9.58 \geq 1.25 \]
Taylor Dispersion Analysis (TDA)
Neodymium’s diffusion coefficient in solvent L phase

at 1 g.L\(^{-1}\) with UV-Vis and C\(^4\)D detectors

<table>
<thead>
<tr>
<th>D / 10(^{-10}) m(^2).s(^{-1})</th>
<th>C(^4)D</th>
<th>UV-Vis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.33</td>
<td>1.41</td>
<td></td>
</tr>
</tbody>
</table>

with UV-Vis detector

<table>
<thead>
<tr>
<th>[Nd] / g.L(^{-1})</th>
<th>D / 10(^{-10}) m(^2).s(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.13</td>
</tr>
<tr>
<td>8</td>
<td>0.88</td>
</tr>
<tr>
<td>21</td>
<td>0.41</td>
</tr>
</tbody>
</table>
Neodymium’s extraction by pertraction

with solvent L which name is not mentioned here for confidential aspect
### Pertraction : experimental module

**Hollow fiber : hydrophobic polypropylene membrane**

<table>
<thead>
<tr>
<th>property</th>
<th>value</th>
<th>unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (L)</td>
<td>0.25</td>
<td>m</td>
</tr>
<tr>
<td>Internal radius ($R_{int}$)</td>
<td>$0.9 \times 10^{-3}$</td>
<td>m</td>
</tr>
<tr>
<td>Thickness ($e$)</td>
<td>$0.4 \times 10^{-3}$</td>
<td>m</td>
</tr>
<tr>
<td>Tortuosity ($\tau$)</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Volume</td>
<td>$0.635 \times 10^{-6}$</td>
<td>m$^3$</td>
</tr>
<tr>
<td>Interfacial area</td>
<td>$1.148 \times 10^{-3}$</td>
<td>m$^2$</td>
</tr>
<tr>
<td>Interfacial volumic area</td>
<td>230</td>
<td>m$^2$.m$^{-3}$</td>
</tr>
<tr>
<td>Porosity ($\varepsilon$)</td>
<td>80</td>
<td>%</td>
</tr>
<tr>
<td>Pore radius ($R_p$)</td>
<td>100</td>
<td>nm</td>
</tr>
</tbody>
</table>

From Alting (France)

Hollow fiber : hydrophobic polypropylene membrane

0.26 (m)
Pertraction: experimental module

Glass potting around the fiber

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length ($L_p$)</td>
<td>0.26</td>
<td>m</td>
</tr>
<tr>
<td>Internal radius ($R_{intp}$)</td>
<td>2.5 x 10^{-3}</td>
<td>m</td>
</tr>
<tr>
<td>Volume</td>
<td>4.984 x 10^{-6}</td>
<td>m(^3)</td>
</tr>
</tbody>
</table>

Low interfaciale volumic area 230 m\(^2\).m\(^{-3}\)
Pertraction: experimental set-up

Co-current contact – recycle mode

- Pressure gauge
- Teflon tube $\Phi_{int} = 0.3\,\text{mm}$
- Peristaltic pump
- Hollow fiber module
- Rotary piston pump
- Charge Reservoir
- Solvent Reservoir
Pertraction: experimental conditions

Hollow fiber module

Reynolds number and pressure drop

\[ \Delta P = 0.07 \text{ bar} \]

<table>
<thead>
<tr>
<th></th>
<th>Reynolds number</th>
<th>Pressure drop (bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>aqueous</td>
<td>50</td>
<td>75.92 \times 10^{-5}</td>
</tr>
<tr>
<td>solvent</td>
<td>5</td>
<td>0.029 \times 10^{-5}</td>
</tr>
</tbody>
</table>

Charge: HNO₃ + NaNO₃ + Nd
Vol = 22 mL

Solvent (L)
Volume = 20.7 mL

40 mL.h⁻¹
Pertraction: experimental conditions

Residence time

<table>
<thead>
<tr>
<th>Residence time (minutes)</th>
<th>Aqueous Reservoir</th>
<th>Solvent Reservoir</th>
</tr>
</thead>
<tbody>
<tr>
<td>33.02</td>
<td>31.1</td>
<td></td>
</tr>
<tr>
<td>fibre</td>
<td>calandre</td>
<td></td>
</tr>
<tr>
<td>0.95</td>
<td>7.48</td>
<td></td>
</tr>
</tbody>
</table>

\[ \Delta P = 0.07 \text{ bar} \]

Equilibrium reaction:

\[ \text{Nd}^{3+} + 3\text{NO}_3^- + 3L \leftrightarrow \text{NdL}_3(\text{NO}_3)_3 \]

Sample (200 µL) at regular time intervals

Charge HNO₃ + NaNO₃ + Nd Vol = 22 mL

40 mL·h⁻¹

40 mL·h⁻¹

Hollow fiber module

Solvent (L) Volume = 20.7 mL
Pertraction: experimental results

Aqueous samples are analysed by ICP-OES to estimate the concentration of Nd ions. Their concentration in solvent L phase is determined by mass balance described below:

\[
V_{aq} \cdot X_e + V_{org} \cdot Y_e = V_{org} \cdot Y_1 + V_{aq} \cdot X_1
\]

\[
V_{aq} \cdot X_e - \sum V_{pe} \cdot X_{n-1} = V_{org} \cdot Y_n + [V_{aq} - (n-1) \cdot V_{pe}] \cdot X_n
\]

V: volume of phases (mL), org (solvent L) and aq (aqueous) ;
Vpe: volume of each aliquot (mL) ;
X: concentration of Nd ions in aqueous phase (g.L\(^{-1}\)), inlet (e) and n for the others aliquots
Y: concentration of Nd ions in solvent L phase (g.L\(^{-1}\)), inlet (e) and n for the others aliquots.
Pertraction: experimental results

Nd concentration profile in aqueous and organic phases versus time:

Equilibrium is reached after 2500 minutes (42h) with $K_D$(Nd) = 16.1 ± 0.1
Pertraction: mass transfer simulation

### Continuity equation:

\[
\frac{\partial C_i}{\partial t} + \nabla \cdot (-D_i \nabla C_i + C_i V_i) = 0
\]

**Assumptions:**

Uniform pore size and fiber porosity throughout the fiber length
Pertraction: mass transfer simulation

Continuity equation:
\[ \frac{\partial C_i}{\partial t} + \nabla \cdot (- D_i \nabla C_i + C_i V_i) = 0 \]

Assumptions:
- Uniform pore size and fiber porosity throughout the fiber length
- Laminar flow with parabolic velocity profile in two phases in the contactor
- Solute is transported by diffusion and convection in the two phases:
  \[ \frac{\partial C_i}{\partial t} + \nabla \cdot (- D_i \nabla C_i + C_i V_i) = 0 \]
- Diffusion is the only transport mechanism in the membrane:
  \[ \frac{\partial C_i}{\partial t} + \nabla \cdot (- D_i \nabla C_i) = 0 \]
Complexing reaction occurs at the interface aqueous-membrane

\[ \text{Nd}^{3+} + 3\text{NO}_3^- + 3L \leftrightarrow \text{NdL}_3(\text{NO}_3)_3 \]

This chemical reaction is defined by a kinetic with flux expression:

\[ \varphi (\text{mol.m}^{-2}.\text{s}^{-1}) = k_v \cdot \left( \left[ \text{Nd}^{3+} \right]_{aq} - \frac{[\text{NdL}_3(\text{NO}_3)_3]}{K_{ex} \cdot [\text{NO}_3]^3 \cdot [L]^3} \right) \frac{\partial [\text{Nd}^{3+}]_{aq}}{\partial r} \bigg|_{r = r_{int}} \]

The model is solved by scilab 5.5.1 and is just optimised by one parameter $k_v$ (m.s^{-1}) for best fitting experimental results.
Simulation and prediction of Nd concentration in aqueous and solvent L phases

Pertraction: mass transfer simulation

Neodymium’s diffusion coefficient in solvent L and aqueous phases is determined experimentally by TDA

<table>
<thead>
<tr>
<th>Geometric characteristics</th>
<th>Process variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{\text{int}}$</td>
<td>0.9. $10^{-3}$ m</td>
</tr>
<tr>
<td>$R_{\text{intp}}$</td>
<td>2.5. $10^{-3}$ m</td>
</tr>
<tr>
<td>$e$</td>
<td>0.4. $10^{-3}$ m</td>
</tr>
<tr>
<td>$L$</td>
<td>0.25 m</td>
</tr>
<tr>
<td>$\varepsilon$</td>
<td>80</td>
</tr>
<tr>
<td>$\tau$</td>
<td>2</td>
</tr>
</tbody>
</table>

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_{\text{ex}}$</td>
<td>9.3210^{-3}</td>
</tr>
<tr>
<td>$D_{\text{aq}}$</td>
<td>6.16 . $10^{-10}$ m$^2$.s$^{-1}$</td>
</tr>
<tr>
<td>$D_{\text{org}}$</td>
<td>1.29 . $10^{-10}$ m$^2$.s$^{-1}$</td>
</tr>
<tr>
<td>$A$</td>
<td>40 mL.h$^{-1}$</td>
</tr>
<tr>
<td>$O$</td>
<td>40 mL.h$^{-1}$</td>
</tr>
<tr>
<td>[solvent]</td>
<td>-</td>
</tr>
</tbody>
</table>
Simulation results were in good agreement with the experimental data for a value of \( k_v = 5 \times 10^{-7} \) m.s\(^{-1}\) which validated the model assumptions. This value of \( k_v \) is maintained for predict the influence of geometric characteristics and process variables.
General conclusion

Possibility to use solvent L to selectively extract REE and separate them each other from magnets waste in nitric media;

Neodymium’s extraction mechanism:
\[ \text{Nd}^{3+} + 3\text{NO}_3^- + 3L \leftrightarrow \text{NdL}_3(\text{NO}_3)_3 \]

Exothermic reaction with \( \Delta H^0_{\text{ext}} = -22.9 \text{ kJ.mol}^{-1} \)

Taylor Dispersion analysis for determine Nd diffusion coefficient in aqueous and organic phases with RSD\( \leq 3\% \) : simple method fast and few sample volume needed (0,7 nL);

Installation and implementation of pertraction module for Nd extraction with hydrophobic polypropylene membrane which has low interfacial volumic area 230 m\(^2\).m\(^{-3}\);

Mass transfer simulation results were in good agreement with the experimental data for a value of \( k_v = 5.10^{-7} \text{ m.s}^{-1} \) which validated the model assumptions. The value of optimise \( k_v \) is maintained for predict the influence of geometric characteristics and process variables.

Experimental determination of \( k_v \) by Rotative Membrane Cell (RSD) method
Thank to

H. Cottet ; J. Chamieh ; F. Gandi ; G. Arrachart ; S. Dourdain ; V. Dubois ; T. Chave; T. Davin ; N. Zorz ; L. Berthon ; D. Maurel ; O. Miolan ; K. Mandrick