

# RECOVERY OF RARE EARTH ELEMENTS AND SCANDIUM FROM EUROPEAN DEPOSITS BY SOLVENT EXTRACTION

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Keywords: EURARE, Rare Earths, Scandium, Solvent Extraction

## Abstract

Solvent extraction methods are being developed for the separation and purification of Rare Earth elements (REE) as part of the EC funded EURARE project. Following initial laboratory batch test work, the mission was to construct and operate a flexible solvent extraction purification and separation mini-pilot plant capable of testing the process developed and producing high purity REE products and scandium of high purity. So far, the work performed has resulted in the separation of heavy (HREE), medium (MREE) and light (LREE) Rare Earths elements, and the separation of yttrium from the HREE fraction and Nd from the LREE fraction. Scandium purification will follow using a separate flowsheet.

## Introduction

The Rare Earth Elements are 17 chemically similar metallic elements, including the 15 lanthanides, scandium and yttrium. They occur in a wide range of REE bearing minerals and are mined collectively. Due to their chemical similarities and high chemical activities, REE recovery and separation are technically complicated. REE are usually divided into light REE (LREE; La, Ce, Pr, Nd), medium REE (MREE; Pm, Sm, Eu, Gd, Tb and Dy) and heavy REE (HREE; Ho, Er, Tm, Yb, Lu, and Y). HREE are usually present at lower concentrations than MREE or LREE in REE bearing minerals and are hence more expensive.

Fractional crystallization, ion-exchange techniques and chromatographic methods are used to separate the REE in small amounts. Industrial scale separation is generally achieved using solvent extraction. Solvent extraction is a selective separation procedure for isolating and concentrating substances from aqueous solutions with the aid of an immiscible organic solvent. The procedure has a rapidly growing industrial importance and has been widely adopted for the recovery and separation of base metals and REE. Specific REE compounds (usually oxides) with purities in excess of 99.99% can be produced.

Europe has significant REE resources. Historically, REE were discovered in Scandinavia and today REE deposits in Greenland and Sweden are listed among the most interesting deposits in the world, resources that aim to undermine the Chinese REE monopoly in the coming years. Additionally, REE presence has been reported in by-products from the metallurgical industries. One example is the recovery of the Scandium content in bauxite residues (red mud), emanating from primary aluminium production in Greece.

The EC funded EURARE project therefore aims to set the technological basis for the development of a European REE industry. The reason is to safeguard an uninterrupted supply of REE raw materials and products at a crucial moment for the EU economy industrial sectors

in a sustainable, economically viable and environmentally friendly way. Twenty three academic and industrial partners from 10 European countries participate in this 5 year project.

The MEAB Group has been active in the hydrometallurgical field for more than 50 years. The work has, to a great extent, been focused on the development of processes for the recovery of metals from metal containing solid or liquid waste. However, the recovery of REE from phosphate minerals also has been investigated. MEAB is therefore responsible for developing solvent extraction methods for the RE carbonates produced in the EURARE project.

In this study, MEAB's experimental work for the EURARE project is presented, with a focus on optimising a continuous solvent extraction separation and purification operation for the laboratory demonstration plant design.

### Sources of the Rare Earth Carbonates

In this study, laboratory-scale experiments have been carried out using intermediate Rare Earth carbonates prepared in downstream EURARE operations. The project involves ores from four different European Rare Earth resources:

- Steenstripine from Kvanefjeld deposit in Greenland,
- Eudialyte from Norra Kärr deposit in Sweden,
- Eudialyte from TANBREEZ project (TANBREEZ is an abbreviation of the metals which are planned to be extracted from Eudialyte) in Greenland, and
- Bastnasite from Rødberg ore in Norway.

In addition, the recovery of scandium, yttrium and other REE is also being investigated from a Greek bauxite residue (Red Mud).

### Conversion of REE Containing Ores to REE carbonates

Due to the unique nature of the Kvanefjeld deposit in Greenland, a customised metallurgical flowsheet was developed by the Greenland Minerals and Energy Limited (GMEL) in-house metallurgical team. This selected flowsheet was then tested during the EURARE work program at GTK Mineral Processing in Outokumpu, Finland. The ore was beneficiated using flotation, which increased the total REE concentration to more than 15 % Total Rare Earth Oxides. The following multi-stage circuit consisted of sulfuric acid leaching, uranium solvent extraction, caustic conversion, hydrochloric acid REE re-leaching and production of a mixed high value REE intermediate carbonate using sodium carbonate /1/.

A hydrometallurgical flowsheet was developed for the Eudialyte deposits at IME Process Metallurgy and Metal Recycling RWTH Aachen University, Germany in cooperation with MEAB. After beneficiation using magnetic separation techniques, the resulting REE concentrate was treated with concentrated hydrochloric acid in order to stabilize silicon. After dilution with water, the resulting slurry was fed to a two stage neutralisation circuit to remove impurities (mainly Al, Fe, Mn, and Zr). Finally, a mixed high value RE intermediate carbonate was achieved.

Rødberg bastnasite ore of high iron content (78 % Fe<sub>2</sub>O<sub>3</sub>) underwent a reductive iron smelting procedure in a small electric arc furnace, with carbon added as a reducing agent. REE and impurities transferred to the slag and the REE were recovered with good recovery yields by adding sulfuric acid after milling. A direct leaching process was also developed for Rødberg bastnasite ore with a lower Fe content. After grinding and milling, the resulting fine fraction was leached using hydrochloric acid, followed by removal of dissolved iron by solvent extraction. The REE were precipitated from the raffinate using sodium carbonate /2/.

Ionic liquids (ILs) have been identified as greener alternatives to conventional solvents as they are capable of enhancing the yield and selectivity of reactions. Research from National Technical University of Athens (NTUA) in the EURARE project showed that ILs can selectively leach critical metal including REE and scandium from bauxite residue. The functionalized hydrophobic ionic liquid betainium bis(trifluoromethylsulfonyl)imide (HbetTf<sub>2</sub>N) can selectively dissolve a range of metal oxides including REE against iron, aluminum and silicon oxides. REE dissolved in the ionic liquid were then stripped with an acid solution, and the ionic liquid was regenerated for reuse. The stripping process can be performed with any acidic solution; therefore this process can be easily adapted to any technology that is currently available for REE/Sc purification. A scandium-oriented process developed in EURARE resulted in Sc leaching efficiencies of around 45 % and produced acid strip liquor for further treatment of 40 mg/L Sc /3/.

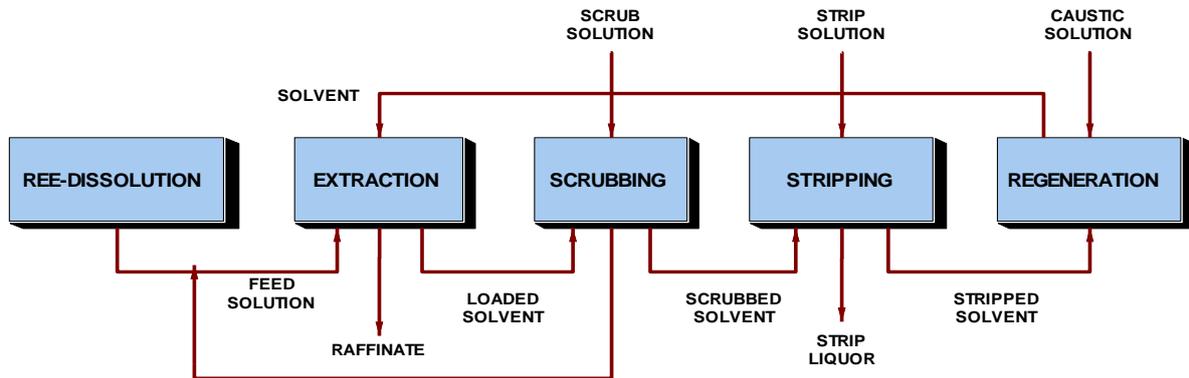
## Methods

### Solvent Extraction - Separation and Purification of REE

MEAB's development of a continuous solvent extraction separation and purification method for a laboratory scale demonstration plant has proceeded as follows:

- Selection of reagents,
- Investigation of solvent extraction parameters (e.g. distribution coefficient, extraction rate, extraction selectivity),
- Determination of scrubbing and stripping liquors and conditions,
- Equilibrium curves for extraction and stripping,
- Flowsheet development,
- Set up of a mixer settler demonstration plant (MSU-0.5), and
- Demonstration plant operation.

Figure 1 shows a general flow sheet of the integrated REE dissolving and solvent extraction process.



**Figure 1. General Process Flow Sheet – REE Separation and Purification by Solvent Extraction**

### Definition of Solvent Extraction Parameters

**Distribution coefficient D:** The distribution coefficient D is defined as the concentration ratio  $C_o/C_a$ , where  $C_o$  represents the concentration of the extracted substance in the organic phase and  $C_a$  represents the concentration in the aqueous phase, at equilibrium. Distribution curves are commonly represented as D (%) versus pH plots or as log D versus pH plots.

**Percentage of Extraction P (%):** The percentage extraction P (%) states the percentage of extracted species in relation to its total quantity  $m_o + m_a$ .

$$P (\%) = 100 * m_o / (m_o+m_a)$$

The variable  $m_o$  and  $m_a$  represent the quantities of the species under consideration in the organic and aqueous phases, respectively, after reaching equilibrium.  $m_o$  is only equal to the amount of extracted substance if fresh unloaded reagent has been used in extraction.

**Selectivity S:** The selectivity of a reagent for different groups of REE ( $REE_1$  and  $REE_2$ ) is represented by the separation factors S. This is calculated as quotient of the distribution coefficients D of the groups of REE.

### Laboratory Batch Experiments

Laboratory batch experiments first were carried out using bench-scale laboratory equipment. To investigate the extraction efficiency of heavy REE over medium and light REE, equilibrium tests were carried out at different pH values using the intermediate product from Kvanefjeld. The dissolved RE carbonates contained 32 g/l La, 56 g/l Ce, 6.4g/l Pr, 19 g/l Nd, 2.7 g/l Sm, 0.2 g/l Eu, 1.6 g/l Gd, 1.7 g/l Dy, 0.2 g/l Ho, 0.5 g/l Er, 0.2 g/l Yb and 8.7 g/l Y. Hydrochloric acid and ammonia solutions were used to adjust the feed solution pH as required. Removal of co-extracted REE from a loaded organic solution was performed using dilute HCl. Finally, REE stripping from the loaded organic solution was investigated using concentrated HCl.

In all experiments, the organic solutions were mixed with the aqueous solution for about 15 minutes in stirred beakers under fairly high speed mixing conditions and at different organic to aqueous (org/aq) ratios. After phase separation, the resulting aqueous and organic phases were saved and analysed.

### Advanced Research Equipment – The AKUFVE System

AKUFVE is a worldwide-recognised instrument for rapid and accurate measurement of partition factors in solvent extraction. The instrument is characterised as an idealised, one-stage mixer-(centrifugal) settler unit. It was developed about 40 years ago to improve accuracy and rapidity in the measuring technique of solvent extraction distribution data.

In applied research the AKUFVE instrument considerably reduces the time and labour in the evaluation and optimisation of solvent extraction processes. Its application to basic research has included the determination of distribution and stability constants for various metal complexes, together with enthalpy and entropy values, obtained from temperature dependency measurements and the determination of reaction rates and activation energies. In general, the AKUFVE instrument offers great advantages over more conventional techniques /4/. General equipment set up is shown in the Figure 2 below.

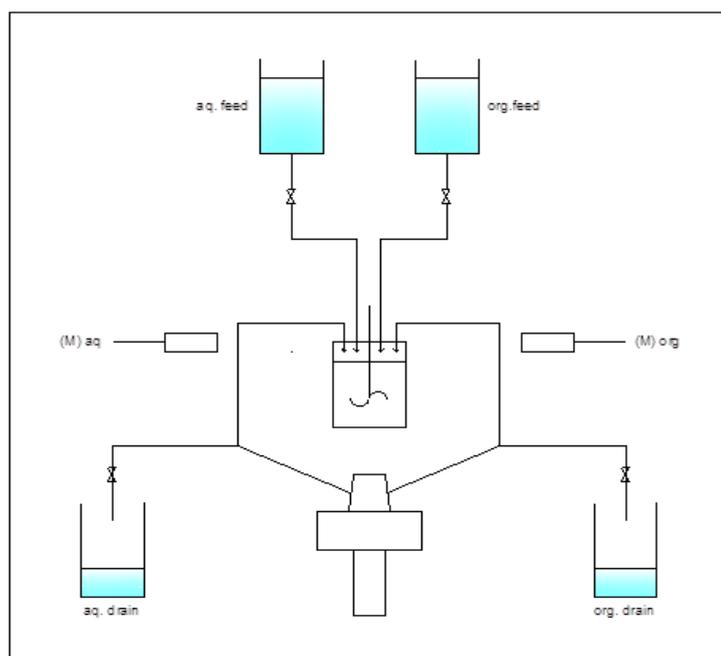


FIGURE 9

**Figure 2. The AKUFVE instrument – Principal of operation**

## Mixer-Settler MSU-0.5 Laboratory Equipment



**Figure 3. MSU-0.5 multi stage laboratory unit for REE separation and purification**

The MSU-0.5 units shown in Figure 3 are compactly designed, self-contained mixer-settler units, built in blocks, one for each function – extraction, scrubbing, stripping, regeneration etc. The blocks include built-in heavier and lighter liquid flow transfers. The mixer includes a top-mounted, variable speed motor with mixing impeller. The stirrer also acts as a pump for the heavier liquid. The settler is equipped with a picket fence for distribution of the mixture and an adjustable interface controller (a jack-leg). The heavier liquid can be recycled. Altogether, the construction eliminates the need for excessive pipelines, bulky framework and unnecessary bench space. The equipment possesses the inherent flexibility needed for rapid evaluation of solvent extraction data. In addition, the experience shows that the mixer-settlers are large enough to provide reliable chemical data and sufficient product solutions for further evaluation. At the same time, the units are small enough to minimize consumption of chemicals, maintenance and operation attendance /5/. The picture shows the mixer-settler (MSU-0.5) set-up used in the experiments.

The construction material in contact with process solutions is PVDF (polyvinylidene fluoride). The complete experimental set-up of the MSU-0.5 equipment includes:

- An flexible number of mixer-settler units arranged in functional blocks with the end supports containing inlets and outlets,
- Mixer motor speed control units one for each mixer, and
- Adjustable flow pumps and support tanks.

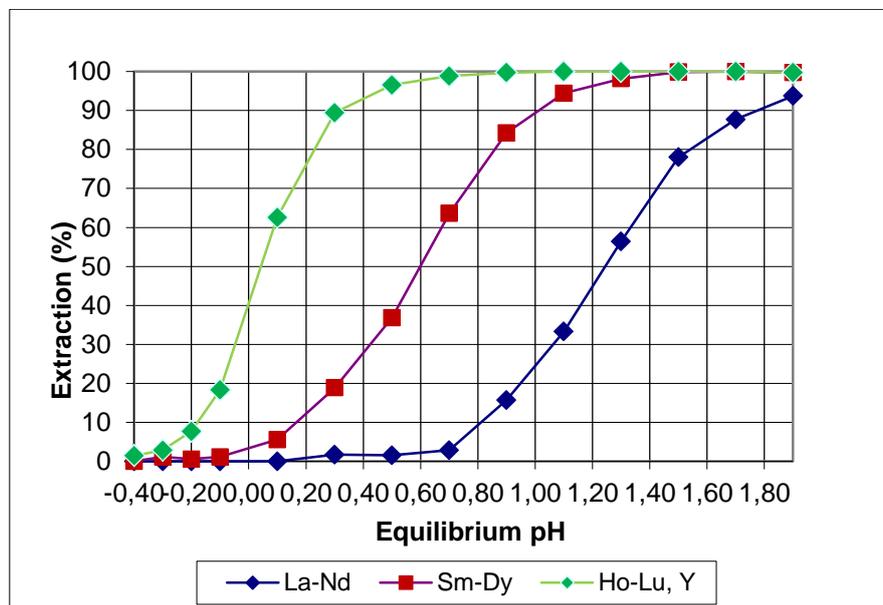
## Batch Solvent Extraction Laboratory Tests

### Reagent Selection

A literature review was conducted [6, 7, 8, 9]. Acidic extractants of organo-phosphorus, carboxylic and sulphonic acids include functional groups. The most commonly used acid organo-phosphorus extractants are divided into phosphoric, phosphonic and phosphinic acids. Generally the extraction of metallic ions followed the cationic-exchange reaction:



Commercially, REE have been extracted from a weak acid solution by di(ethylhexyl)phosphonic acid (Ionquest 801), di(ethylhexyl)phosphoric acid (DEHPA) or blended extractants. The pH isotherms of REE obtained in laboratory experiments carried out for Orbite Aluminae Inc., Canada are shown in Figure 4 [10].



**Figure 4. Extraction of REE in chloride solution with di(ethylhexyl)phosphonic acid (Ionquest 801)**

Based on the literature, MEABs experience and previous experimental test work, di(ethylhexyl)phosphonic acid (Ionquest 801) was chosen as the organic reagent with aliphatic kerosene (Ketrul D85) as the diluent. No modifier was used in these experiments.

### Feed solution (PLS) preparation

The raw material provided from the EURARE test work program was a RE intermediate carbonate with the general composition given in Table 1. The feed stock material did not contain elevated concentrations of naturally occurring uranium and thorium or their daughter products.

**Table 1. Kvanefjeld REE Carbonate, REE composition in g/kg (100 % solids)**

La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Y

133	230	22	74	11	0.8	6.2	<0.1	5.0	0.7	1.8	0.1	0.7	<0.1	34
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The material was dissolved using concentrated HCl (30 to 32 wt.-%) at room temperature. The feed solution composition (PLS) is given in Table 2.

**Table 2. Feed solution (PLS), Rare Earths composition in g/l**

La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Y
32	56	6.4	19	2.7	0.2	1.6	<0.1	1.7	0.2	0.5	<0.1	0.2	0.02	8.7

### Optimisation of the pH

As shown by Equation 1, the extraction of REE is dependent on the hydrogen ion concentration, i.e. the distribution of a species between aqueous and organic phases depends on the pH in the system. The measurement of pH dependency is usually conducted using an organic to aqueous phase (O/A) ratio of 1.

From the literature review, it was found that the pH for the separation of HREE from MREE and LREE should be between pH 0.1 to pH 0.4. The extraction pH for the separation of MREE from LREE should be around 0.7. The extraction of the REE from chloride media using 40 vol.-% di(ethylhexyl)phosphonic acid was therefore investigated between pH 0.1 to pH 1.0, and the results are shown in Table 3.

**Table 3. Extraction yields P (%)**

pH	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Y
0.1	0.1	0.4	0.7	1.1	4.3	7.3	11	19	36	73	68	75	32	88	52
0.4	0.2	0.4	1.0	1.5	6.0	11	15	20	40	88	75	79	49	95	72
1.0	0.9	6.4	15	20	51	66	66	40	51	89	84	98	98	98	79

The extraction of a narrower range of REE from chloride media using 40 vol.-% di(ethylhexyl)phosphonic acid was investigated further between pH 0.6 to pH 1.1 and the results are shown in the Table 4.

**Table 4. Extraction yields P (%)**

pH	La	Ce	Pr	Nd	Sm	Eu	Gd
0.6	1.5	8.0	8.1	17	53	50	49
0.8	2.7	15	16	31	64	56	53
1.1	3.7	22	22	41	69	57	54

Finally, the extraction of the neodymium from chloride media was investigated using the AKUFVE instrument, shown in Figure 2.

### Separation of Neodymium from the LREE Fraction

Batch extraction equilibrium tests were conducted to investigate the separation of neodymium from the LREE fraction. A synthetic RE chloride solution was prepared containing 23 g/l La, 21 g/l Ce, 2.6 g/l Pr and 9.0 g/l Nd. The extractant concentration was 40 vol.-% di(ethylhexyl)phosphonic acid (Ionquest 801) in aliphatic kerosene (Ketrul D85). No modifier was used in these experiments. During the neodymium extraction the pH was adjusted using HCl and ammonia solution. The results are shown in Table 5.

**Table 5. Neodymium extraction yield P (%)**

pH	Aq/Org	Org.-Nd g/l	Aq.-Nd g/l	D Co/Ca	P %
-	-				
1.3	2.15	6.89	8.20	0.840	9
1.3	1.20	5.24	5.78	0.907	36
1.4	0.68	4.29	2.09	2.053	77
1.2	0.45	2.68	2.48	1.081	72
1.2	0.34	2.02	2.47	0.818	73
1.2	0.28	1.81	1.61	1.124	82

Table 6 below shows the co-extraction of other LREE during the neodymium recovery tests, performed at pH 1.3 and carried out at an O/A ratio of 1.

**Table 6. Composition of the aqueous feed and raffinate during neodymium extraction. Organic solution (40 vol.-% 801 in Kerosene)**

Metal	Aqueous feed g/l	Raffinate g/l	Co-Extraction efficiency %
Lanthanum	23	19.7	14
Cerium	21	16.3	22
Praseodymium	2.6	1.9	27

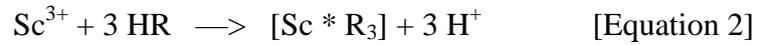
**Table 7. Selectivity data for Neodymium over light REE using 40 vol.-% 801 in Kerosene at pH 1.3**

Nd/La	Nd/Ce	Nd/Pr	Nd/(La-Pr)
20	3.3	1.5	1.0

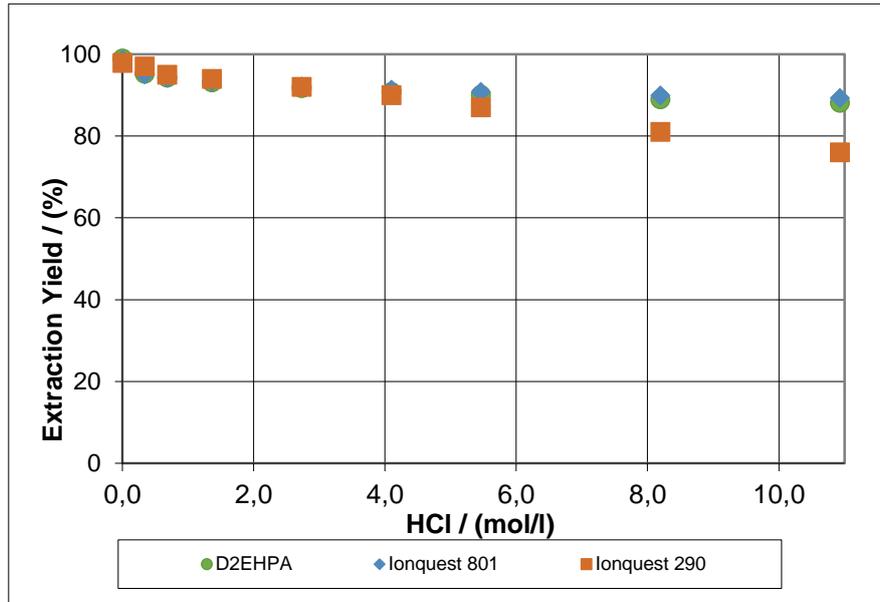
Therefore, to separate the light Rare Earth elements in a fraction containing La-Pr and Nd the extraction pH should be adjusted to around 1.3.

### Separation of Scandium from hydrochloric acid solution

Organo-phosphorus acids are the most investigated cationic exchange extractants and they form a complex with scandium in the cationic-exchange reaction shown in equation 2.



A synthetic Sc chloride solution was prepared containing 100 mg/l Sc. Three different extractants were investigated at a concentration of 5 vol.-% diluted in aliphatic kerosene (D85). No modifier was used in these experiments. As shown in Figure 5, scandium was extracted efficiently almost irrespective of the HCl concentration or extractant used.



**Figure 5. Extraction of Sc in chloride solution with di(ethylhexyl)phosphoric acid (DEHPA), di(ethylhexyl)phosphonic acid (Ionquest 801) and di(ethylhexyl)phosphinic acid (Ionquest 290)**

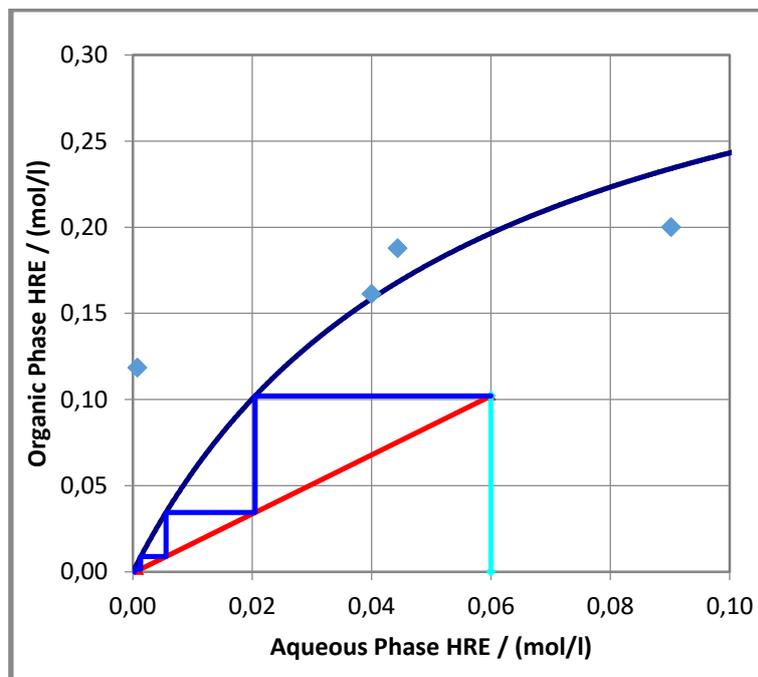
## Demonstration Scale

### Heavy Rare Earth Separation

To confirm the laboratory batch results, a mixer-settler demonstration plant was operated in a continuous mode. The equipment used for the tests are MSU-0.5 mixer-settler units in PVDF for all other functions. The mixer motor is regulated by frequency inverter and the dimensions are:

- Active mixer volume: 0.12 l
- Active settler volume: 0.48 l
- Active settler loading surface: 0.006 m<sup>2</sup>
- Total capacity (aq+org+rec) at 1.5 m/h surface loading: 10 l/h

A modified McCabe-Thiele construction based on the batch experiment equilibrium data (Figure 5) was used to determinate the number of mixer settler stages required in the demonstration plant.



**Figure 5. Extraction of HREE with 40 Vol.-% Ionquest 801 in D85. Aqueous solution: 0.06 mol/ HREE, 0.02 mol/l MREE and 0.05 mol/l LREE, initial pH 1.1**

The mixer settler demonstration plant was operated according the following set-up of MSU stages.

Process Flow	Vol. Flow		Conc.
	l/h		mol/l
Feed Solution (PLS)	12	$C_F = C_{R,a}$	0,06

<b>Raffinate</b>		$C_R = C_{R,\omega}$	<b>0,001</b>
<b>Solvent solution</b>	<b>7</b>	$C_S = C_{E,\alpha}$	<b>0,001</b>
<b>Solvent from Extraction</b>		$C_E = C_{E,\omega}$	<b>0,102</b>
Slope operating line	$\text{tg } \alpha$		1,71
Volume ratio of solvent (O/A)	$v$		0,58
Critical conc. loaded organic	$C_{E\omega,\text{crit}}$	g/l	0,20
Critical slope operating line	$\text{tg } \alpha_{\text{crit}}$		3,31
Min. volume flow pure solvent	$V_{S,\text{min}}$	l/h	3,0
Min. ratio of solvent	$v_{\text{min}}$		0,30
<b>Number of theoret. Stages</b>	<b>NTS</b>		<b>4</b>

The prepared PLS was introduced into the extraction circuit for heavy REE separation. More than 95 % of the heavy REE and yttrium are counter-currently extracted in 4 stages with an organic solution containing 40 vol.-% Ionquest 801 dissolved in aliphatic kerosene (D85) at room temperature. The extraction was operated at pH 0.4 without pH control at organic to aqueous ratio of 1.0 to 0.8. Co-extracted light REE and medium REE accumulated in the organic phase to a concentration of about 0.01 mol/l.

The loaded organic solution was then scrubbed in 6 stages using a counter-current of weak hydrochloric acid at high organic to aqueous phase ratio. More than 99 % of the co-extracted medium REE and light REE were removed.

The resulting organic solution, containing only heavy REE and yttrium was fed to the stripping circuit. Here, heavy REE and yttrium were counter-currently stripped in 5+1 stages with strong HCl. Finally, the stripped organic solution was returned to the extraction circuit for conditioning using alkali.

**Table 8. Composition of the aqueous feed and raffinate during heavy RE extraction of Kvanefjeld demo testing. Organic solution (40 vol.-% 801 in Kerosene)**

Metal	Aqueous feed	Raffinate	Extraction efficiency
	g/l	g/l	%
Dysprosium	0.73	0.020	98
Holmium	0.07	0.006	92
Erbium	0.24	0.019	92
Ytterbium	0.12	0.001	99
Yttrium	4.40	0.008	>99
HRE (Dy - Yb, Y)			96

The composition of resulting strip solution, containing the heavy REE is shown in Table 9.

**Table 9. Strip solution, heavy REE composition in g/l**

La	Ce	Pr	Nd	Sm	Eu	Gd	Dy	Ho	Er	Yb	Y
<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	4.5	0.9	2.2	0.7	38

The composition of resulting raffinate, containing the medium REE and light REE is shown in Table 10.

**Table 10. Raffinate from heavy REE separation, composition in g/l**

La	Ce	Pr	Nd	Sm	Eu	Gd	Dy	Ho	Er	Yb	Y
15.2	25.6	5.9	8.7	0.8	0.07	0.04	0.02	0.006	0.030	0.001	0.008

### Medium Rare Earth Separation

The raffinate containing MREE and LREE (Table 8) was fed to the MREE separation circuit as follows:

Alkali was added to pH of around 2.0. The prepared PLS was then introduced into the extraction circuit for medium REE separation. More than 90 % of the medium REE was counter-currently extracted in 6 stages with an organic solution containing 40 vol.-% Ionquest 801 dissolved in aliphatic kerosene (D85) at room temperature. To minimize the co-extraction of lanthanum and cerium, the extraction was operated at pH 0.7 without further pH control at organic to aqueous ratio of 1.5:1. Co-extracted light REE accumulated in the organic phase to about 0.05 mol/l.

The loaded organic solution was then scrubbed counter-currently in 6 stages with dilute HCl at a high organic to aqueous phase ratio. More than 90 % of the co-extracted light REE were scrubbed.

The resulting organic solution, containing only medium REE was fed to the stripping circuit. Here, the remaining dysprosium and other MREE were counter-currently stripped in 5 stages

with strong HCl. Finally, the stripped organic solution was returned to the extraction circuit for conditioning using alkali.

**Table 11. Composition of the aqueous feed and raffinate during medium Rare Earth extraction of Kvanefjeld demo testing. Organic solution (40 vol.-% 801 in Kerosene)**

Metal	Aqueous feed	Raffinate	Extraction efficiency
	g/l	g/l	%
<b>Samarium</b>	0.80	0.010	90
<b>Europium</b>	0.07	0.011	95
<b>Gadolinium</b>	0.40	<0.002	>99
<b>Dysprosium</b>	0.02	<0.002	>99
<b>MREE (Sm-Dy)</b>			96

The composition of resulting strip solution, containing the medium REE is shown in Table 12.

**Table 12. Strip solution, medium REE composition in g/l**

La	Ce	Pr	Nd	Sm	Eu	Gd	Dy	Ho	Er	Yb	Y
<0.05	0.5	0.6	5.0	7.1	0.7	4.0	0.2	<0.01	<0.01	<0.01	<0.01

The composition of resulting raffinate, containing the medium REE and light REE is shown in Table 13.

**Table 13. Raffinate from medium REE separation, composition in g/l**

La	Ce	Pr	Nd	Sm	Eu	Gd	Dy	Ho	Er	Yb	Y
15.0	24.9	5.5	8.3	0.010	<0.005	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001

## Summary

The recovery of heavy REE (and yttrium) and medium REE from the resulting heavy Rare Earths raffinate from a Kvanefjeld Rare Earths carbonate feed stock was investigated by MEAB. A liquid sample was prepared by dissolution the Kvanefjeld intermediate Rare Earth carbonates using hydrochloric acid. The resulting composition of the prepared test solution was analysed and is shown in Table 2.

pH isotherms, selectivity data as well as McCabe Thiele constructions based on equilibrium curves were obtained using a 40 Vol.-% Ionquest 801 (di(ethylhexyl)phosphonic acid) in Ketrul D85 by using our AKUVFE laboratory set-up. Continuous extraction demonstration tests showed that almost all heavy and medium REE were extracted in a multi stage mixer settler arrangement. Finally, the separation and purification parameter for neodymium were investigated using a synthetic solution, containing light Rare Earths elements.

The proposed separation and purification process starts with recovery of HREE (Dy-Yb, Y) from MREE (Sm-Gd, Dy) and LREE (La-Nd). The following three main process sections, based on laboratory development and on our MSU-0.5 mixer settler operation were proposed:

- **Section 1: HREE Separation.** Extraction of HREE from LREE and MREE by solvent extraction using di(ethylhexyl)phosphonic acid (Ionquest 801) in kerosene (D85),
- **Section 2: MREE+LREE Removal.** Scrubbing of LREE and MREE from the organic solvent by using 1.5 mol/l HCl at high O/A phase ratio, and
- **Section 3: HREE Recovery.** Stripping of HREE from the resulting organic solution in section 2 by solvent extraction using 4 to 5 mol/l HCl. Precipitation of the resulting HREE from the strip solution as carbonates.

The recovery of MREE (Sm-Gd, Dy) from LREE (La-Nd) resulted in the following separation procedure, based on laboratory development and on our MSU-0.5 mixer settler operation were proposed:

- **Section 1: MREE Separation.** Extraction of MREE from LREE by solvent extraction using di(ethylhexyl)phosphonic acid (Ionquest 801) in kerosene (D85),
- **Section 2: LREE Removal.** Scrubbing of LREE from the organic solvent by using 1 mol/l HCl at high O/A phase ratio, and
- **Section 3: MREE Recovery.** Stripping of MREE from the resulting organic solution in section 2 by solvent extraction using 3 to 4 mol/l HCl.

The resulting MREE raffinate will be further treated the separate praseodymium and neodymium from lanthanum and cerium.

## Conclusions

Our experimental findings with laboratory and bench scale demonstration tests using our mixer-settler MSU-0.5 equipment resulted in a better understanding of the separation and purification of REE generated from European deposits. An application of Rare Earths separation and purification that now has gained great interest in the metallurgical processing industry is solvent extraction. The process is carried out by occurring acidic extractants of organo-phosphorus including functional groups.

We also have shown the application of the solvent extraction procedure for the separation and purification of Rare Earths elements with the aim to improve of the metal product quality.

## Acknowledgements

This work was carried out within the frame of EURARE (The European project contract 309373). The authors acknowledge the financial support given to this project by the European Commission under the Sevens Framework Programme for Research and Development. We also wish to thank our various partners in the project for providing us with real samples. The provision of Ionquest 801 by Solvay Rhodia Group is also acknowledged.

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