International Journal of Mining Science and Technology 24 (2014) 117–121

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

# Preconcentration of rare earth elements from Iranian monazite ore by spiral separator using multi-response optimization method

Khanchi Ali Reza *, Sedighi Hassan, Ansar Sheida, Fasihi Javad

*Nuclear Fuel Cycle Research School, Nuclear Science and Technology Research Institute, AEOI, Tehran 11365-8486, Iran*

ARTICLE INFO

*Article history:*
Received 9 May 2013
Received in revised form 15 June 2013
Accepted 5 July 2013
Available online 6 January 2014

*Keywords:*
Monazite
Taguchi method
Spiral
Preconcentration
Optimization

ABSTRACT

The present work dealt with the preconcentration of rare earth elements in Saghand ore (Yazd province, Iran) which was achieved by Humphrey spiral using orthogonal optimization method after scrubbing the sample at 45% solid pulp density for 30 min. The pulp was diluted and was fed to a Humphrey spiral for upgrading. The process parameters considered were feed size, feed solids and feed rate, and Taguchi's $L_9$ ($3^4$) orthogonal array (OA) was selected for optimization of the process. The results show that the feed rate and feed size were more significant than the other operation parameters of the process. It was also found that under optimal conditions, the concentrate grade of rare earth elements increased from $2860 \times 10^{-6}$ to $6050 \times 10^{-6}$ and recovery reached to 58%.



## 1. Introduction

Over the past few years, there has been a growing demand for rare earth elements (REEs) because of development of their various industrial applications and their potential uses in many advanced materials, such as high-temperature superconductors, high performance magnets, fluorescent materials, magneto optical disks, chemical sensors, and nickel-metal hydride batteries. Monazite (Ce, La, Th, Y) $PO_4$ and bastnasite (Ce, La) $FCO_3$ are two principal commercial ore minerals of REEs in the world [1]. Monazite occurs widespread as a common accessory mineral in pegmatites, granites and gneisses. It frequently occurs as a detrital mineral in placer deposits, principally in river and beach sands. Monazite is associated with other heavy minerals such as ilmenite, magnetite, zircon, and rutile [2–4].

So far, several methods have been used for industrial processing of REEs [2,5]. These methods include combination of gravity, magnetic, and electrostatic techniques along with leaching methods. REEs minerals are separated commercially from associated minerals in placer deposits using a combination of gravity, magnetic, and electrostatic techniques [6]. Flotation is the standard method for recovering rare earth minerals from igneous and hydrothermal deposits, while physical methods, such as gravity and magnetic/electrostatic separation, are currently employed for the treatment of REEs containing placer deposits [7].

Gravity separation techniques are usually the most cost effective beneficiation technology. Importantly, even in instances where complete separation cannot be achieved by gravity techniques, it is often desirable to produce gravity preconcentrate. This preconcentrate product (now with less mass) concentrated or processed by more expensive, perhaps environmentally sensitive, techniques to produce the final desired product [8].

The Humphrey spiral is one of the mineral concentration machines based on gravity separation. The parameters that affect the performance of Humphrey spiral are the feed size, feed solids, feed rate and splitter position [9]. Successful concentration with Humphrey spiral depends on the selection of suitable operating conditions and mineral solids. In mineral processing operations, it is sometimes essential to maximize both grade and recovery simultaneously, because in some mineral concentration plants a 1% or 2% improvement in grade and recovery may be economically remarkable. Therefore, it is important to determine the operating parameters at which the response reaches to high value. In this context, it has been established that the design of experiment using Taguchi method provides efficient and systematic approach to determine the optimum conditions for processes parameters [10,11].

Iran has a complex ore deposit in Saghand (north of Yazd province), which contains about 500 thousand tons of REO reserves with an average concentration of 0.5% REO. The complex ore is of hydrothermal origin and consists of rare earth minerals and ilmenite, hematite, calcite and uranium with thorium. Monazite is the principal source of REEs in Saghand Mine [12].

* Corresponding author. Tel.: +98 21 88221117.
*E-mail address:* akhanchi@aeoi.org.ir (A.R. Khanchi).

2095-2686/$ - see front matter © 2014 Published by Elsevier B.V. on behalf of China University of Mining & Technology.
http://dx.doi.org/10.1016/j.ijmst.2013.12.020

In the present study, an attempt has been made to maximize both grade and recovery simultaneously for the concentration of REEs in Saghand monazite ore. For this purpose, the effect of changing each process parameter involved was investigated by muti-objective optimization technique using Taguchi approach.

## 2. Experimental

The sample was obtained from Saghand ore deposit. The ore samples were ground and gravity separation tests carried out by Humphrey spiral.

### 2.1. Mineral characterization

Tables 1 and 2 show the chemical composition and ICP analysis of the Saghand ore deposit and its distribution of REEs. The X-ray diffraction spectra indicated the presence of ilmenite ($FeTiO_3$), hematite ($Fe_2O_3$), magnetite ($Fe_3O_4$), hornblende, calcite ($CaCO_3$), bastnasite ($LnFCO_3$), monazite (Ce, La, Nd, Th) $PO_4$ whilst optical mineralogical analysis confirmed the presence of hematite, magnetite, hornblende and calcite as the main minerals. The characterization of Saghand ore by optical microscopy was revealed that REEs present in a cementing material with various minerals such as ilmenite and hematite. Therefore, they were concentrated in the coarse fraction in primary comminution.

### 2.2. Apparatus

Spiral Test Assembly from Sepor Company was used for preconcentration. The technical information of spiral is as follow: carbon steel sump (378.5 L), tubular steel framework, cast iron centrifugal pump, two isolating flow control valves, piping, and 3 HP motor. The concentrations of REEs in the aqueous phase were determined by the ICP. Fig. 1 shows the experimental setup.

### 2.3. Methods

The experiments were carried out by a Humphrey spiral. The ore sample used for tests was taken from the region of Saghand in Yazd. The sample was ground using a jaw crusher and a rod mill. The batch spiral tests were conducted using the experimental setup, as shown in Fig. 1. As can be seen Fig. 1, the setup consisted of a laboratory scale spiral unit, a feed slurry tank with a stirrer, a pump for supplying feed to the spiral at a consistent rate and sample containers for collecting the concentrate and tailings. To obtain the required feed solids, measured quantities of the dry ore and water were mixed in the slurry tank. A pump was used to feed the slurry to the spiral at various flow rates while the spiral was in operation. After collection of the concentrate stream, it was filtered, dried and weighed for analysis of grade and recovery. For each sample, 3 g was dissolved in 15 mL of the hydrochloric acid and then heated at 105 °C for 2 h. After dissolution, the solution was analyzed by inductively coupled plasma (ICP) technique.

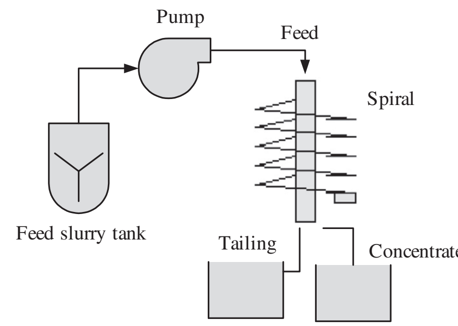


**Fig. 1.** Experimental setup.

### 2.4. Specification of Taguchi method

The aim of Taguchi method is to find out the optimal and robust process characteristic that has a minimized sensitivity to noises. It is a type of fractional factorial design which uses an orthogonal array to study the influence of factors with only a small number of experiments. Taguchi method is based on several steps including identification of the quality characteristics and selection of design parameters, determination of the number of factor levels, selection of the appropriate orthogonal array, execution of the experiments based on the arrangement of the orthogonal array, evaluation of the results using signal-to-noise (SN) ratios, ANOVA, selection of the optimum levels of factors, verification of the optimum process parameters through the confirmation experiment and calculation of the confidence interval [13,14].

**Table 1**
Main chemical composition of the Saghand ore.

| Element (%) | Size fraction (μm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | +425 | −425 + 250 | −250 + 180 | −180 + 150 | −150 + 125 | −125 + 90 | −90 + 75 | −75 + 38 |
| $Na_2O$ | 0.99 | 1.11 | 1.08 | 1.09 | 1.00 | 1.01 | 1.15 | 0.87 |
| MgO | 6.72 | 6.56 | 6.93 | 6.99 | 6.91 | 6.98 | 6.99 | 6.60 |
| $Al_2O_3$ | 6.37 | 6.05 | 5.77 | 5.46 | 5.78 | 5.64 | 6.06 | 6.04 |
| $SiO_2$ | 54.97 | 52.56 | 53.42 | 53.12 | 53.63 | 53.37 | 53.16 | 53.90 |
| $P_2O_5$ | 0.36 | 0.35 | 0.45 | 0.26 | 0.52 | 0.34 | 0.61 | 0.61 |
| $SO_3$ | 0.61 | 1.27 | 0.64 | 0.73 | 0.65 | 0.72 | 0.68 | 0.56 |
| $K_2O$ | 0.27 | 0.20 | 0.22 | 0.21 | 0.23 | 0.23 | 0.26 | 0.33 |
| CaO | 12.93 | 13.65 | 14.24 | 14.62 | 14.59 | 14.51 | 14.58 | 14.36 |
| $TiO_2$ | 2.36 | 2.83 | 2.50 | 2.62 | 2.34 | 2.50 | 1.91 | 1.76 |
| $Cr_2O_3$ | 0.18 | 0.19 | 0.19 | 0.19 | 0.17 | 0.17 | 0.15 | 0.14 |
| MnO | 0.40 | 0.39 | 0.39 | 0.39 | 0.38 | 0.36 | 0.41 | 0.48 |
| $Fe_2O_3$ | 8.14 | 8.70 | 8.20 | 8.54 | 8.22 | 8.33 | 8.19 | 8.64 |

**Table 2**
Partitioning of rare earths in the Saghand ore.

| Element | Ce | La | Nd | Pr | Sm | Gd | Eu | Tb | Ho | Er | Tm | Yb | Lu | Y | Dy |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Content ($10^{-6}$) | 710 | 812 | 144 | 53 | 5 | 70 | 7 | 9 | 5 | 82 | 15 | 103 | 10 | 750 | 85 |