Original Research Article

AusIMM THE MINERALS INSTITUTE

I·M3 Institute of Materials, Minerals & Mining

Mineral Processing and Extractive Metallurgy
1–11

DOI: 10.1177/25726641251362948
journals.sagepub.com/home/mpe

Sage

Optimisation of rare earth element extraction from apatite ore: case study of Qarabag mica mine

Ataallah Bahrami[1], Sarina Ahadi[1], Fatemeh Kazemi[2], Mohammad Raouf Hosseini[3,4] and Yousef Ghorbani[5]

Abstract

The increasing demand for rare earth elements (REEs) arises from technological advancements and the global shift towards renewable energy sources. This underscores the need to develop efficient extraction methods from various mineral sources, such as apatite. REEs, along with other essential raw materials and energy metals, are crucial for sustainable energy technologies, including wind turbines, electric vehicles, and solar panels. Enhancing extraction processes is vital for reliably and responsibly meeting this growing demand, ensuring a stable supply for the transition to green energy. This study focuses on identifying the optimal extraction conditions for REEs from apatite ore obtained from the Qarabag mica mine in northwest Iran. The apatite sample contained 3665 g/t of light REEs and 531 g/t of heavy REEs. Leaching tests were conducted on finely crushed apatite ore ($d_{90} = 75$ µm) using sulphuric, hydrochloric, and nitric acids at various concentrations. Additionally, the effects of pre-treatment methods, including calcination and mechanical activation, on apatite leaching were examined. Mechanical activation of apatite ore followed by leaching with 30% nitric acid at 20°C for 1 h proved to be the most effective method for REE dissolution. Under these conditions, the leachate contained 748 mg/L of light REEs and 123 mg/L of heavy REEs, with recovery rates of approximately 68% and 77%, respectively. Subsequent solvent extraction tests, conducted at pH 2.5–3 using a combination of D2EHPA and kerosene, yielded an organic phase containing 739 mg/L of both light and heavy REEs, corresponding to an extraction efficiency of about 97%. This study demonstrates the feasibility of the efficient extraction of both light and heavy REEs from apatite ore, providing valuable insights into optimising extraction processes to meet the growing demand for these critical elements in sustainable energy technologies.

Keywords

Apatite, flotation, leaching, REEs, solvent extraction

Received: 20 November 2024; accepted: 11 July 2025

Introduction

Rare earth elements (REEs), known for their unique structural, physical, and chemical properties, such as magnetic, luminescent, and catalytic characteristics, are becoming increasingly essential in various critical industrial sectors, including healthcare, defence, communication technologies, and sustainable energy. The demand for REEs has surged dramatically due to technological advancements and the global transition towards renewable energy sources. They play a crucial role in manufacturing key components for green technologies, such as wind turbines, electric vehicles, and solar panels.[1–5] According to the U.S. Department of Energy, between 2015 and 2025, the heavy REE dysprosium (Dy) is the most critical REE for the deployment of clean energy technologies.

Although REEs are relatively abundant in Earth's crust, they rarely occur in concentrated forms, making their extraction both technologically and economically challenging. In rock-forming minerals, REEs are typically present as trivalent cations in carbonates, oxides, phosphates, and silicates. Currently, nearly 200 minerals containing more than 0.01% REEs have been identified. The primary mineral sources of REEs and their classifications

[1]Department of Mining Engineering, Faculty of Engineering, Urmia University, Urmia, Iran
[2]Department of Mining Engineering, Faculty of Engineering, University of Kashan, Kashan, Iran
[3]Department of Mining Engineering, Isfahan University of Technology, Isfahan, Iran
[4]Centre of Health and Life Science, Coventry University, Coventry, UK
[5]School of Chemistry, University of Lincoln, Lincoln, Lincolnshire, UK

Corresponding author:
Mohammad Raouf Hosseini, Department of Mining Engineering, Isfahan University of Technology, Isfahan 8415683111, Iran; Centre of Health and Life Science, Coventry University, Coventry, UK.
Email: ae3661@coventry.ac.uk