Current Prospects and Status of Research on the Recovery of Scandium from Bauxite Residue

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Abstract

Whilst scandium resources are abundant in China, it is invariably found in nature in complex mineralogical forms, making its separation and extraction difficult and complicated. During the refining of bauxite, over 98 % of scandium is concentrated in the bauxite residue, making bauxite residue a major source of scandium. The main focus has been on developing leaching methods for bauxite residue and techniques for recovering scandium from it, in particular solvent extraction and ion exchange. This article reviews the current status of scandium recovery and aims to develop a new, simpler process for extracting scandium, providing technical support for the efficient separation of scandium in bauxite residue.

Keywords: Scandium, Bauxite residue, Acid leaching method, Solvent extraction method, Ion exchange method.

1. Introduction

Bauxite residue, frequently called red mud, is an alkaline slurry residue produced during the production process to make aluminium hydroxide which is subsequently converted to aluminium oxide [1]. Approximately 1–2.5 t of bauxite residue are produced for every tonne of alumina. In the past decade, China's alumina industry has experienced rapid development. In 2023, China produced 107 million tonnes of bauxite residue, with a comprehensive utilization of 10.5 million tonnes, a utilization rate of only 9.8 %.

During the Bayer process, the bauxite residue is typically separated from the liquor by thickeners, washers or filtration [2]. However, bauxite residue itself possesses characteristics such as a large specific surface area, ultra-fine particle size distribution, strong water absorption capacity, and long-lasting alkalinity [3]. As a result, dealing with bauxite residue is more complicated. The treatment and effective utilization of bauxite residue presents significant challenges for the alumina industry in various countries. Due to the unique physical and chemical properties of bauxite residue, there have been numerous studies on recycling and utilizing of bauxite residue as a secondary resource. This includes using it as a building material or recovering other metal elements such as iron, titanium and rare earth elements such as scandium. Simply using bauxite residue as a building material may lead to the wastage of precious metal resources. Therefore, from a perspective of sustainable resource development, recycling valuable metals from bauxite residue is a feasible and environmentally friendly approach.

Scandium is a rare metal with a wide range of applications in industries such as electronics, optics, transportation, and the production of advanced materials [4, 5]. However, due to its rare and trace distribution in natural minerals, extracting scandium directly from ores containing is difficult. As a result, scandium is primarily recovered as a by-product from tailings, waste residue, and waste liquid in the production process of metals like aluminium, titanium, nickel, tungsten, tantalum, uranium, niobium, and rare earth [6]. Because of its huge reserves, bauxite residue can be considered as an important potential source of scandium [7].

This article reviews recent research progress on the recovery of scandium from bauxite residue both domestically and internationally. The main methods discussed include the use of acid leaching to extract scandium from bauxite residue, as well as solvent extraction and ion exchange adsorption to recover scandium from the leaching solution. The goal of this article is to identify a simple new process for scandium extraction, providing technical guidance for the efficient separation of scandium from bauxite residue.

2. Acid Leaching Method for Leaching Scandium from Bauxite Residue

Metallic species in bauxite residue mainly exist in the form of metal oxides, which react with acids to generate soluble metal cations and enter into solution. In order to improve the recovery rate of scandium and other rare earth metals, an acid leaching method is usually used to dissolve bauxite residue.

Diana et al. [8] extracted Sc (III) from solid bauxite residue using three acids (HCl、HNO_3 and H_2SO_4) at different concentrations (10 %, 20 %, and 30 % respectively). By changing experimental parameters such as the solid-liquid ratio, initial acid concentration, contact time, and temperature, the optimal experimental plan was designed, and the extraction kinetics of Sc (III) with acid were evaluated using first-order and second-order kinetic models, including kinetic parameters, rate constants, saturation concentration, and activation energy. In addition, the study also outlined the mass transfer mechanisms involved in the Sc (III) acid extraction process. Based on the research results, it is possible to design, optimize, and control large-scale bauxite residue recovery processes from a theoretical calculation perspective, saving experimental time and improving efficiency.

Zhou et al. [9] proposed a new method for selective leaching of scandium and iron from bauxite residue, using EDTA (ethylenediamine tetraacetic acid) as a complexing agent to redistribute the types of scandium and iron ions in the leaching process, greatly improving the selectivity of scandium over iron. The optimal process parameters are leaching agent ($HCl+H_2O$) volume of 40 mL for 10 g of bauxite residue and 2 g of EDTA, hydrochloric acid dosage is 40 % of the theoretical (stoichiometric) value, at a temperature of 70 °C with a reaction time of 4 h. Under optimal conditions, the leaching efficiencies of scandium and iron are 79.6 % and 6.12 %, respectively, and the leaching rate ratio of Sc/Fe reaches 13.0, which is twice the leaching rate ratio of Sc/Fe without the addition of EDTA. This method not only reduces acid consumption, but also greatly improves the Sc/Fe leaching rate ratio, making subsequent separation of iron and scandium easier. In addition, this work provides another method for recovering and separating valuable metals from solid waste.

Wang et al. [10] used HCl as a leaching agent to recover scandium from bauxite residue and found that the most important factor affecting the extraction rate of scandium was the liquid solid ratio (L/S). At the same time, the concentration of HCl also has a significant impact on the extraction rate of iron. At a HCl concentration of 6 mol/L and under the conditions of an L/S ratio of 5, temperature of 60 °C, and reaction time of 1 h, the leaching efficiency of scandium can reach over 85 %. In addition, according to the experimental research, the estimated consumption of hydrochloric acid per kilogram of bauxite residue is about 21.2 mol. The experimental results described above were used to optimize the subsequent leaching work.

Borra et al. [11] conducted a series of leaching experiments on MYTILINEOS bauxite residue, studying the leaching of rare earth elements from bauxite residue by inorganic and organic acids

At present, solvent extraction is still a common method to extract scandium from acid leaching solution, which has the advantages of large processing capacity and simple operation. The ion exchange method has the advantages of being a simpler process, creates low environmental pollution, and is more cost advantageous when the scandium concentration in the recovered solution is low.

In order to achieve environmentally friendly processes with a high scandium recovery rate and low cost, it is necessary to further optimize the selective leaching of scandium to reduce mineral acid consumption and pollution and to develop new solvent extraction systems and ion exchange adsorption materials with high selectivity and recognition for scandium. In addition, from the perspective of zero emissions and full utilization of bauxite residue, the slag extracted from scandium can be further used for the preparation of building materials and ceramics.

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6. References

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