Recovery of Rare Earth Elements and Refractory Metals from Bauxite Residue

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Abstract

To move towards a sustainable future and building a circular economy, there is a push towards waste valorization. Bauxite residue is the by-product of the Bayer process for alumina production. It contains considerable amounts of rare earth elements (REEs) and refractory metals, some of which are considered critical materials; to the point initiatives have begun to mine them from secondary sources, such as landfilled industrial process residues. Here, we develop a novel pyro-hydrometallurgical process called acid-baking water-leaching to extract REEs and refractory metals from bauxite residue. In this process, bauxite residue is mixed with concentrated sulfuric acid, baked at 200 – 400 °C, and leached in water at ambient conditions. Compared with conventional hydrometallurgical processes, the developed process offers the advantages of less acid consumption, less wastewater generation, and fast kinetics. This process is a promising technique as the first step of a potential near-zero-waste integrated process for the sustainable valorization of bauxite residue.

Keywords: Rare earth elements, refractory metals, acid baking water leaching, waste valorization

1. Introduction

In recent years, there has been an increasing push to minimize the environmental impact of industrial activities by the sustainable sourcing of raw materials, in particular by sourcing these materials from secondary or tertiary resources – in other words, from materials that are commonly considered to be waste, either industrial or post-consumer. One such secondary resource is bauxite residue, also referred-to as "Red Mud", the solid side-product of Al_2O_3 production in the Bayer process.

Bauxite residue is produced worldwide at an estimated annual rate of 150 million tonnes. Considering the Bayer process has been employed industrially for over one hundred years, such an annual production rate results in a worldwide stockpile of approximately three billion tonnes [1 – 2]. Bauxite residue is a mineralogically complex product, containing iron (Fe) and aluminum (Al) oxides and hydroxides, and various calcium (Ca), titanium (Ti), and Al silicates [3] – the exact composition and production rate is a function of the characteristics of the starting bauxite ore, and the various Bayer process parameters [4].

Despite several initiatives to put this material to practical use, particularly as a component of cement in the construction industry, the global valorization rate of bauxite residue is low, approximately 3 % [1]. It has previously been shown that the Bayer process acts to concentrate various valuable minor elements found in the starting bauxite ore, in particular scandium, rare earth elements (REEs) [5] and refractory metals (such as titanium and niobium) [3], as such, bauxite residue represents a readily-available low-cost source of these materials.

Scandium (Sc) is a high-value ($ 4600/kg Sc_2O_3) metal, which is used to create high-strength lightweight aluminum and magnesium alloys, and is used in solid oxide fuel cells [6]. REEs, in particular yttrium (Y), cerium (Ce), lanthanum (La), samarium (Sm), and neodymium (Nd), are critical materials, which play crucial roles in several modern and green technologies, such as hybrid/electric vehicles, wind turbines, photonics equipment, and electronics [7 – 8]. Refractory metals, such as titanium (Ti), niobium (Nb), zirconium (Zr), and hafnium (Hf) are important for the aerospace, nuclear, and electronics industries because of their heat-, corrosion-, and wear-resistance properties [9 – 10] – the demand for Ti and Nb in particular is rapidly increasing worldwide.

Several efforts have been reported to extract valuable materials, mainly Sc and REEs, from bauxite residue via hydrometallurgical or pyrometallurgical methods. Direct acid leaching has traditionally dominated the literature on the subject; however, other methods have been reported, such as alkaline leaching, alkaline roasting, smelting, ionic liquid leaching, and bioleaching [11 – 14]. Despite its operational simplicity and the maturity of the technique, acid leaching possesses several limitations, such as moderate Sc extraction, elevated consumption of acids, water, and organic solvents, poor selectivity against Fe, the major leachate contaminant, the formation of silica gel, which interferes with downstream processing, and a high rate of hazardous waste production [15 – 16].

Recently, work has been carried-out to develop an alternative hybrid pyro-hydro-metallurgical extraction process based on Acid-Baking Water-Leaching (ABWL) or Acid-Roasting Water-Leaching (ARWL), sometimes referred-to as sulfation roasting. These techniques both involve mixing the bauxite residue with concentrated sulfuric acid to sulfate the component minerals, then heat-treating the acid-solids mixture to accelerate the reaction, before finally leaching the heat-treated material in water at ambient conditions. ABWL and ARWL differ primarily in the temperature used for the heat treatment step – ABWL involves treatment at low temperatures (200 – 400 °C), while ARWL uses higher temperatures (> 700 °C) [17 – 18]. In the past, this relatively uncommon technique has primarily been applied to REE ores, although some studies have been reported, which have applied ABWL to secondary/tertiary resources, such as end-of-life catalysts, NiMH batteries, and NdFeB magnets [19 – 22].

Previously, ARWL has been demonstrated as a promising technique for the recovery of Sc and REEs from bauxite residue, as the high-temperature roasting step can be used to selectively decompose the contaminant $Fe_2(SO_4)_3$ into water-insoluble Fe_2O_3, because it has a lower thermal stability than REE-sulfates, allowing for high REE recoveries with minimal co-extraction of undesirable matrix species, mainly Fe and Al; however, processes employing this technique have the disadvantages of requiring elevated processing temperatures (> 700 °C) and unfavorably slow leaching kinetics [23 – 24]. In contrast to ARWL, ABWL relies on considerably lower processing temperatures, thus reducing process complexity and energy costs, and allows for considerably faster leaching. This technique has not been extensively studied in the application of bauxite residue processing.

We have developed an ABWL process to extract REEs, Sc, and refractory metals from bauxite residue, in an effort to develop a larger near-zero-waste process to fully valorize bauxite residue, by using it as a feedstock for the recovery of various valuable materials.

2. Experimental Methods – The ABWL Process

ABWL is a hybrid pyro-hydro-metallurgical process, which involves three primary steps:

1. Feed preparation
2. Acid baking (dry digestion + heat treatment)
3. Water leaching

5. References

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