BR07 - Recovery of Scandium, Iron, and Aluminum from Bauxite Residue by Carbothermic Smelting Followed by Acid Baking – Water Leaching

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Abstract

The management of bauxite residue produced in the Bayer process is a major economic and environmental cost associated with the production of alumina from bauxite ore. Conventional disposal of this highly alkaline and mineralogically complex solid byproduct in large dry heaps or tailing ponds is expensive and carries environmental risks. On a positive side, bauxite residue is rich in several valuable metals such as scandium, iron, and aluminum, which can be valorized, bringing value to this byproduct. In this study, an integrated multistep process is developed to extract these valuable metals from a Canadian bauxite residue by employing carbothermic smelting to separate crude metallic iron, followed by acid baking – water leaching to extract scandium and aluminum. To avoid the production of acidic solid waste, the calcium- and silicon-rich leaching residues are thermally desulfated to produce regenerated smelting flux for the smelting step of the process. The use of residue desulfation can potentially enable the recovery of the consumed sulfuric acid by the acid baking step of the process, reducing the overall reagent consumption and increasing process efficiency. This waste valorization process was developed and optimized using design of experiment and response surface methodology techniques alongside morphological and mineralogical characterizations to elucidate the underlying physicochemical mechanisms of the smelting and acid baking – water leaching processes and to demonstrate the feasibility of fully valorizing bauxite residue at the laboratory scale. The results of this study are the first step in utilizing bauxite residue as a low cost, readily available resource for valuable materials, which can help reduce the environmental impact and economic costs of the Bayer process.

Keywords: Bauxite residue, carbothermic smelting, acid baking – water leaching, near-zero-waste process.

1. Introduction

Around the world, there are increasing numbers of studies investigating techniques for the efficient utilization of bauxite residue, which is the solid byproduct of the Bayer process for alumina production from bauxite ore. Because of its high production rate (0.7–2 tonnes per tonne of Al_2O_3 produced, resulting in 150–165 million tonnes produced per year) and large global stockpiles (3–4 billion tonnes), [1–3] as well as problematic physical and chemical properties, in particular high alkalinity and complex mineralogy, the management of bauxite residue presents considerable economic and environmental costs. Currently, less than 3% of the global production of bauxite residue is utilized productively, primarily as an additive for construction materials, with the balance stored in dry heaps and tailing ponds, which can present considerable maintenance costs and potential environmental impacts. [2,4]

On the positive side, bauxite residue holds significant promise as a potential secondary resource of valuable metals because it is enriched in iron, scandium, aluminum, titanium, among others.[5] Bauxite residue is a particularly attractive resource because of its low cost, readily availability globally, and production in facilities that already have industrial infrastructure. Despite several attempts to valorize bauxite residue, typically focussing on direct leaching using mineral acids (hydrochloric, sulfuric, or nitric acid), no large scale approaches have been globally adopted due to the practical challenges of large consumption of concentrated acid solutions, long leaching durations, production of large amounts of acidic wastewater and solid residues, and the difficult separation of co-extracted elements, in particular iron and scandium. [6–9]

Acid baking – water leaching is a process that has previously been developed to address some of the challenges associated with direct acid leaching for the recovery of scandium.[5] In this process, solid bauxite residue is mixed with concentrated (98 wt%) sulfuric acid to neutralize its alkalinity, break down its mineral phases and convert the insoluble minerals to soluble sulfates. The acid–bauxite residue mixture is then baked at 200–400 °C to induce changes in the crystal structures to make them more soluble and achieve a higher extent of sulfate conversion. The resulting acid-baked residue is then leached in water at ambient temperature and pressure to dissolve the soluble sulfate products. This processing approach, which is similar to processes used in the rare earth industry,[10] offers the advantages of reduced acid and water consumption, shorter leaching durations, and reduced waste production.

One of the primary challenges associated with the direct acid baking – water leaching of bauxite residue for the recovery of scandium is the co-extraction of iron during leaching. In bauxite residue, scandium is closely associated with the iron-bearing phases. [5,11] Thus, any technique with high extraction of scandium results in high co-extraction of iron, which requires costly separation steps.[12] One approach for iron separation from bauxite residue is the preemptive removal of iron by carbothermic smelting.[6]

This pyrometallurgical route, adapted from iron and steel production, is based on the high temperature (1400 – 1600 °C) reduction of iron(III) of the bauxite residue, present as Fe_2O_3 and FeO(OH) into crude metallic iron, using carbon typically added as coal, according to reaction 1:

$$Fe_2O_{3(s\ or\ l)} + 1.5\ C_{(s)} \rightarrow 2\ Fe_{(l)} + CO_{2(g)} \quad (1)$$

This smelting approach is promising because liquid metallic iron is immiscible with the molten slag containing other components of the bauxite residue. In this process, fluxing agents are added to control the melt viscosity and to facilitate the phase separation. As a result, the crude iron can be separated as a value-added product for use as a feed for steelmaking, [13,14] while the slag can be treated to recover scandium, aluminum, and other valuable metals.

Previous studies on the recovery of valuable materials from bauxite residue slag have typically utilized direct acid leaching for the extraction step;[13,15] however, similar to the processing of unsmelted bauxite residue, acid baking – water leaching has the potential to achieve more efficient extraction compared with direct acid leaching. Another common shortfall of previous studies on bauxite residue valorization is the production of large amounts of acidic leaching residue, which present an additional environmental challenge and considerable barrier to the adoption of this process.

In this work, an integrated process consisting of carbothermic smelting followed by acid baking – water leaching was developed to extract metallic iron, scandium, and aluminum from a Canadian bauxite residue. The acid baking – water leaching step of this process was optimized to determine the optimum operating conditions for scandium and aluminum extraction, and to gain insight into the physicochemical mechanisms of this process. Moreover, the potential for recycling of leaching residues produced after the water leaching step was investigated by using thermal desulfation to regenerate smelting flux. This investigation integrates with a larger venture

Overall this work supports a larger project to develop an environmentally and economically sustainable process to fully utilize bauxite residue as a resource for several critical materials, while reducing reliance on environmentally-damaging primary mining and reducing the environmental footprint of the Bayer process.

5. References

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