Evaluation of Alternative Raw Materials and Processes for Alumina Production

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Abstract

Inclusion of bauxite in EU's latest version of the Critical Raw Materials list is indicative of the importance of primary aluminium as a technological commodity, but also of the inelastic nature of its supply chain, from mine to metal. Central to this supply chain is the dominance of the Bayer Process for alumina production from high quality bauxite. Although there is no doubt of the inherent benefits of the Bayer Process, its complete dependence on the availability of bauxite, along with the persistent challenge of Bauxite Residue handling and reuse, are increasingly becoming obstacles to the transition of the industry in circular, near zero waste modus operandi. Consequently, a diversification of the primary aluminium supply chain with the inclusion of aluminate raw materials besides bauxite is becoming increasingly important. Especially for the case of EU who is a major importer of both bauxite and aluminium. The Laboratory of Metallurgy of NTUA, investing in its decades long experience of in the field of alumina and aluminium metallurgy, has been actively engaged in research projects that evaluate alternative alumina production processes. In the course of these studies several alternative, primary and secondary, raw materials have been investigated in both acid and alkaline process routes. This paper summarizes the most significant results and findings produced in the course of our investigations with aluminosilicate raw materials, aluminate rich tailings from different sources, Ca-rich and Si-rich aluminate slags. Different process routes are investigated for each raw material with ultimate goal of producing several process alternatives for each material and evaluating the best alternatives for further upscaling.

Keywords: Alumina Production, Aluminosilicate raw materials, Aluminate Slags, HCl Process, Alternative Alkaline Process

1. Introduction

Aluminium is a metal of high technological significance. Its unique combination of properties (light weight, electrical conductivity, resistance to corrosion, malleability, excellent thermal properties etc.) and recyclability, elevate it to a superior status among other technological metals, making it virtually indispensable to modern societies. This dependence is reflected on the current global production of primary aluminium which, for 2020, was estimated at just over 65 million tonnes, with China accounting for more than half of this production [1] [2]. Moreover, the projected demand of aluminium is expected to continue its upward trend. In a recent critical review on the demand of major metals [3], based on the median of the 197 data points, obtained by 70 studies, the largest growth rate in demand in 2050, relative to 2010, was estimated for aluminum, with a projected median increase of 215%. Consequently, the production of primary aluminium will remain an issue of immense technological significance for decades to come.

For more than 120 years primary aluminium has been produced by the combination of two industrial processes: (i) the Hall-Héroult electrolytic process for the production of metallic aluminium from alumina dissolved in cryolite bath and (ii) the Bayer Process, for refining bauxite ore to obtain Al_2O_3 of quality suitable for electrolysis (metallurgical grade or MG Al_2O_3) [4]. In other words, the world's primary aluminium is produced almost exclusively by the Hall-Héroult, with the Bayer Process serving as its dominant supplier of metallurgical grade alumina for the Hall-Héroult cells. These extraordinary conditions give rise to a one-of-a-kind value chain, from bauxite to alumina and then to aluminium, with each ring in the chain imposing limitations to the others.

First of all, not all bauxite ores are suitable for treatment by the Bayer process but only those with a high concentration of Al_2O_3 (usually ≈35% - 50%) and sufficiently high mass ratio of alumina to silica (A/S), (usually >9). Consequently, the supply of primary aluminium is directly dependent on the uninterrupted availability of high-quality, low in silica, bauxite. On the other hand, bauxite reserves are unevenly distributed, usually found in areas around the tropics and their control is considered, as "a *sine qua non* for business success" [5].

The near absolute dominance of the Bayer Process and the century long process of accumulating engineering optimizations have created a winner-takes-it-all scenario. Without a doubt, alumina production is up to this point synonymous with the Bayer Process and the treatment of high-quality bauxite. Furthermore, with high purity bauxite reserves estimated in magnitudes that could sustain the demand in the future [1], it appears as though there is no real need for changing the *modus operandi* of the industry. That is true, only if one considers the issue solely on grounds of cost effectiveness which, for the greater part of the 20th century, is where the undisputed benefit of the process lied.

In the beginning of the 21st century, an acute awareness of the inelastic character of the primary aluminium production value chain, as previously described, has arisen. For instance EU is dependent on bauxite imports from areas where political conditions tend to be unstable, such as Guinea and Brazil. Such considerations have urged the EU to include bauxite in its most recent list of Critical Raw Materials [6]. Moreover, owing to its inflexibility, the value chain of primary aluminium production could become susceptible to various forms of political, strategic, or economic manipulations. These factors have also been identified in other economic areas as well, e.g., in Russia [7].

On the environmental front, what has been an enduring thorn on the industry's side is the accumulation of the aluminium depleted residue of the bauxite ore after the Bayer leaching process, termed Bauxite Residue (BR). It is estimated that more than 120 years of bauxite ore treatment by the Bayer Process inherited to the world an estimated 2.7 billion tonnes of BR. This vast repository is ever-growing with a rate of approximately 160 million tonnes per annum [8]. The excessive production volumes of this residue, its mineralogical heterogeneity, both within the residues produced by the same plant and among the residues originating from different bauxite locations, and its alkalinity, are some of the defining features of this material that, on one side have driven research on possible utilization routes for more than 50 years, while, at the same time, are considered the main obstacles for the non-application thereof [9].

Finally, Kaolin B was intensively ground to induce amorphicity to the structure of kaolin. The activated kaolin was then leached in an HCl solution of azeotropic concentration, at 90°C with an optimized stirring rate. The kinetic study results in comparison with the extraction results of the original sample are shown in Figure 9. The potential of the ultra-grinding process is apparent, and research continues toward further optimizations.

4. Conclusion

In this paper, a comprehensive summary was presented of the most important findings of the work performed in the Laboratory of Metallurgy of NTUA in the field of alternative alumina production technologies. Two major sources of alternative raw materials and their various process alternatives were presented: (a) calcium aluminate slags, which could be treated by an alkaline and an acid process route and (b) aluminosilicate materials that are treated by an acid route. Calcium aluminate slags have proved to be versatile materials and are studied in the context of various integrated flowsheets as raw materials for MG grade alumina and high purity alumina production. Challenges of both routes have been identified and the technological maturity of these processes is accelerating towards pilot scale tests. From the various aluminosilicate materials studied up to this point, the most promising appear to SiO_2 rich slags produced by the reductive smelting of BR and kaolin. In the case of kaolin, several process alternatives are being investigated.

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