Evaluation of Alternative Raw Materials and Processes for Alumina Production

Michail Vafeias¹, Amalia Bempelou ², Eirini Georgala ³, Maria Bagani⁴, Maria Georgia Tsaousi⁵, Aikaterini Toli⁶, Danai Marinos⁷, Efthymios Balomenos⁸ and Dimitrios Panias⁹

8. Senior Consultant, Research and Sustainable Development, MYTILINEOS SA-Metallurgy Business Unit, Alumina and Aluminium plant, St Nikolas, Greece

Corresponding author: michalisvafeias@mail.ntua.gr

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 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 Al₂O₃ of quality suitable for electrolysis (metallurgical grade or MG Al₂O₃) [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 Al₂O₃ (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 SiO₂ 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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5. References