Technical and Engineering Insights into Green Iron Production from Bauxite Residue: A Microwave Plant Assembly Process

Marcelo Montini[1], Darllan do Rosario Pinheiro[2], Raphael Vieira da Costa[3], Luis Rodolfo Mariani Bittencourt[4], Lucas Arantes Araújo[5], Amaury Jose Leone Negrao[6], Guilherme Henrique Camello do Nascimento[7] and Izabel Nunes Ivancko[8]

1. Senior Chemical Consultant
2. R&D Specialist
3. Head of Technology

Norsk Hydro Alunorte, Barcarena, Brazil

4. CTO
5. Head of R&D
6. Head of Engineering
7. R&D Coordinator
8. Engineering Specialist

New Wave, Rio de Janeiro, Brazil

Corresponding author: marcelo.montini@hydro.com

https://doi.org/10.71659/icsoba2024-br007

Abstract

Recent advancements in the production of low-carbon iron from bauxite residue have indeed yielded promising results, paving the way for sustainable iron production processes. Bench-scale and pilot-scale studies have underscored the technical and economic viability of this approach to start the microwave plant engineering for a 50 000 tpy bauxite residue capacity. Specifically, the utilization of carbon-capturing sources during growth, such as charcoal and biomass, coupled with microwave energy, has been instrumental in the reduction of iron. Moreover, the use of renewable energy sources to power microwave energy further enhances the sustainability profile of the process. The resulting iron briquette exhibits exceptional metallization, surpassing 90 %, with iron content ranging from 92 % to 95 %, and notably low sulfur and phosphorus levels. These characteristics not only meet but exceed the stringent specifications required for steel production. The reuse of bauxite residue not only minimizes waste but also creates a sustainable and economically feasible product, thus closing the lifecycle loop of alumina production. This innovative approach not only addresses environmental concerns associated with traditional iron production methods and bauxite residue handling but also offers a feasible pathway towards achieving carbon-neutral steel production. Furthermore, the material that remains after the conversion and production of pig iron, having undergone thermal conversion, exhibits interesting characteristics and is under development for use mainly in civil construction, ceramic and steelmaking sector, and other applications with high demand, potentially enabling the utilization of 100 % of the bauxite residue.

Keywords: Bauxite residue, Green iron, Microwave, Circular economy.

1. Introduction

Bauxite residue (BR) is produced as waste in alumina refineries through the Bayer process. This process was developed by Austrian chemist Karl Josef Bayer on August 3, 1888, and remains the primary method for producing alumina from diasporic, boehmitic, and gibbsite bauxite to this day, accounting for up to 90 % to the total production [1]. The bauxite residue processed by this process produce from 0.55 to 2.21 tonnes of bauxite residue per tonne of alumina produced [2] making this residue a concern to disposal due the quantity of waste generated and the hazardous characteristics of this material, the Figure 1 shows the Bayer process and the bauxite residue formation.

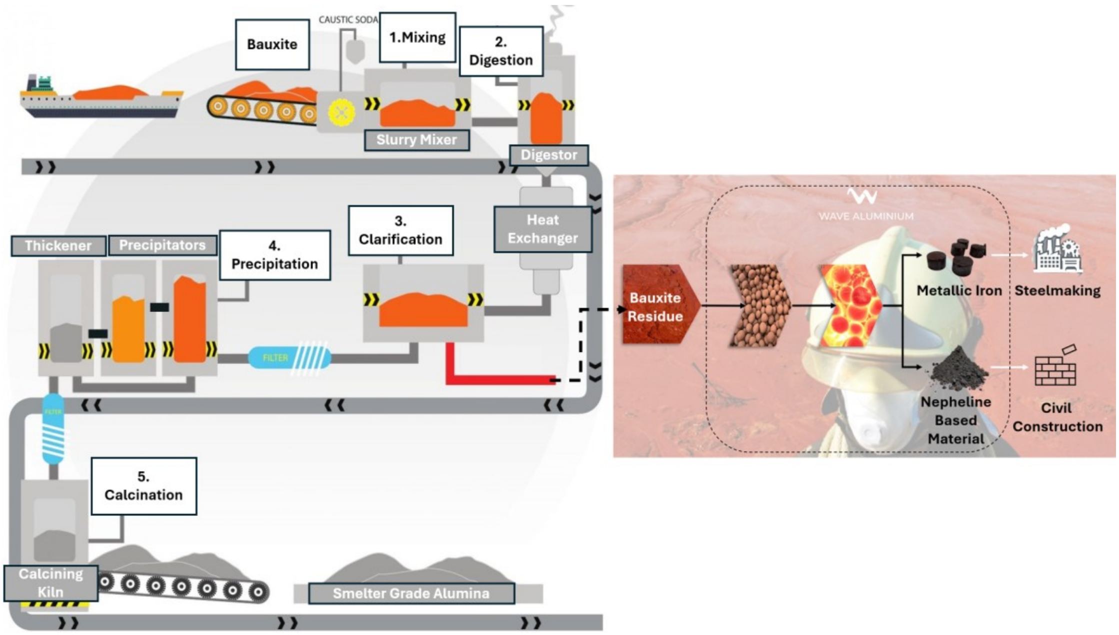

Figure 1. Main unit operations for alumina beneficiation [3] and Wave Aluminium bauxite residue beneficiation.

In the alumina production process, the main unit operations can be seen in Figure 1. The bauxite is received at the plant, crushed, and ground to an appropriate particle size to optimize aluminium extraction. After this step, it is mixed with sodium hydroxide and digested in digesters, producing sodium aluminate and bauxite residue. These are separated in settlers, where the bauxite residue is thickened, filtered using a filter press to reduce moisture, and sent to the solid waste disposal area. The sodium aluminate-rich liquor is then sent to clarifiers and precipitators, where aluminium hydroxide seed is added to precipitate aluminium hydroxide. This precipitate is then filtered and calcined in rotary kilns to produce calcined alumina, which can be used in the chemical industry for refractory production or as smelting grade alumina (SGA) to produce metallic aluminium [4]. Due to the characteristics of this process, the ore used, and the volume generated, bauxite residue has properties that make it difficult to manage. These include the need for large disposal areas, fine particle size (with most of the mass being below 20 micrometers), high pH (around 12 due to the use of sodium hydroxide in the process), and the presence in trace concentration of certain heavy metals and naturally occurring radioactive elements such as lead, mercury, uranium, and thorium [5]. The process developed by Wave Aluminium aims to remove iron from this residue and generate a co-product suitable for use in civil construction by utilizing microwave energy in beneficiation.

According to the database of the International Aluminium Institute (IAI), if no action is taken to consume bauxite residue, the accumulated amount by 2050 will be approximately 9 billion tonnes, Figure 2 [6].

4. Conclusions

Wave Aluminium's process for demonstration plant assembly has been validated with operational parameters were demonstrated at scale-up for the main Unit Operations. Below are the main conclusions:

Utilizing microwave energy and charcoal has been technically feasible for reducing the iron oxides present in bauxite residue and subsequently separating the metallic iron, thereby generating a product with significant demand.

The use of electrical energy and charcoal results in lower emissions compared to conventional processes for producing iron. Life cycle analysis studies are underway to validate the extent of emission reduction, along with instrumentation at the outputs of the demonstration plant to monitor and control these gases.

The non-magnetic material rich in nepheline and fly ash (from combustion) represents a potential co-product that could find application in the construction industry, which also consumes large volumes.

The conducted tests have provided documentation to reach TRL 5 maturity level and establish parameters for the engineering of the demonstration plant.

5. References

1. Guo-tao Zhou et al., Toward sustainable green alumina production: a critical review on process discharge reduction from gibbsitic bauxite and large-scale applications of red mud, *Journal of Environmental Chemical Engineering*, Volume 11, No. 2, (2023), 109433.
2. Adela Svobodova-Sedlackova et al., Mapping the research landscape of bauxite by-products (red mud): An evolutionary perspective from 1995 to 2022, *Heliyon*, Volume 10, No. 3, (2024), e24943, https://doi.org/10.1016/j.heliyon.2024.e24943.
3. PT Cita Mineral Investindo Tbk, *Jakarta*, (2021) https://www.citamineral.com/investor/reports (Accessed on 01/08/2024).
4. Fathi Habashi, A hundred years of the Bayer process for alumina production. In: D. Donaldson and B. E. Raahauge (eds) *Essential readings in light metals*. Springer, Cham, 2016.
5. Huang Lingxiang et al., Research progress on comprehensive utilization of red mud, *Journal of Physics: Conference Series,* Vol. 2009, No. 1, (2021), 012021, https://doi.org/10.1088/1742-6596/2009/1/012021.
6. International Aluminium Institute, *Sustainable bauxite residue management guidance* (2022), https://international-aluminium.org/resource/sustainable-bauxite-mining-guidelines-second-edition-2022-2/ (Accessed on 01/08/2024)
7. Council of the EU, Press release 30 June 2023 https://www.consilium.europa.eu/en/press/press-releases/2023/06/30/critical-raw-material-act-council-adopts-negotiating-position/ (Accessed on 01/08/2024).
8. International Aluminium Institute, *Bauxite residue: an introduction factsheet*, https://international-aluminium.org/resource/bauxite-residue-an-introduction-factsheet/ (Accessed on 01/08/2024)
9. Ken Evans, The history, challenges, and new developments in the management and use of bauxite residue, *Journal of Sustainable Metallurgy,* Vol. 2, No. 4, (2016), 316–331.
10. Tomoko Radomirovic et al., Crystallization of sodalite particles under Bayer-type conditions, *Hydrometallurgy*, Vol. 137, (2013), 84–91.

11. V P Gridasov et al., Behavior of alkalis in blast furnaces, *Metallurgist,* Vol. 59, No. 9-10, (2016), 761–765.
12. Matic Jovičević-Klug et al., Green steel from red mud through climate-neutral hydrogen plasma reduction, *Nature,* Vol. 625, No. 7996, (2024), 703–709.
13. Angel Lopez, *Demonstration of BR microwave roasting in prototype furnace*, (2023), https://cordis.europa.eu/project/id/776469/results (Accessed on 01/08/2024).
14. Lena Mazeina and Alexandra Navrotsky, Surface enthalpy of goethite, *Clays and Clay Minerals,* Vol. 53, No. 2, (2005), 113–122.
15. Gabriel Plascencia and David Jaramillo, *Basic thermochemistry in materials processing,* 1st edition, Springer, Mexico City, 2016.
16. Wolfram Research, *ChemicalData, Wolfram Language function*, (2007), https://reference.wolfram.com/language/ref/ChemicalData.html (updated 2016) (Accessed on 01/08/2024).
17. Dawei Yu et al., TG/DTA study on the carbon monoxide and graphite thermal reduction of a high-grade iron nickel oxide residue with the presence of siliceous gangue, *Thermochimica Acta*, Vol. 575, (2014), 1–11.
18. Jacob Hunt et al., Microwave-specific enhancement of the carbon–carbon dioxide (Boudouard) reaction, *The Journal of Physical Chemistry C* 2013 Vol. 117, No. 51, (2013), 26871-26880.
19. John C. Mankins. *Technology readiness levels. A White Paper*, NASA, Washington, DC, 1995.