A Sustainable and Profitable Bauxite Residues Valorization Process

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Abstract

Globally, the production of alumina generates about 175 million tonnes of bauxite residues (BR) per year, containing valuable metals such as Sc and REE, that are currently accumulating in storage ponds. With the lack of storage space, stricter environmental regulations, and the surge in REE demand, the need for a sustainable approach to valorize these residues, while minimizing waste volume is imminent. The avenue of BR valorization has been explored for decades but no approach has been successfully commercialized yet. Many routes have been studied and proposed but they either lack economic viability, and or do not reduce the waste volume sufficiently to make them attractive. In other words, environmental impacts are shifted towards effluents or other harder-to-manage waste.

A successful approach should reduce the waste volume significantly by recovering the value of both bulk (Fe, Al) and critical (Sc/REE) constituents. So called “zero-waste” approach to the BR valorization has been proposed to recover multiple compounds and to minimize waste volume and get the most value out. Main proposed processes are based on direct acid leaching and/or iron smelting, each facing limitations and serious technical challenges yet to be addressed. Direct leaching with acids creates large effluents and is expensive owed to low selectivity and extensive separation steps. Iron smelting presents technical challenges related to sodium and aluminium content in BR.

This paper provides an overview of the BR valorization approaches. Focus is placed on the proposed process by Innord Inc. which targets the recovery of bulk metals (Fe, Al) and generating valuable metal concentrate (Sc/REE), maximizing volume reduction (+70 %) and improving the process economy by producing several low value marketable by-products. Other objectives of the development are having limited number of steps, major regent recycling avoiding any regular effluent as much as feasible. The process steps consist of alkalinity and DSP removal, iron conversion and separation, and Sc/REE concentrate and reagent recycling.

Keywords: Zero-waste, Rare-earth elements, Valorization, Sustainable, Bauxite Residues.

1. Introduction

In the context of the fight against climate change, the demand for light metals such as aluminium is increasing, especially for the manufacturing of vehicles with lower fuel consumption. While this will result in decreasing greenhouse gas (GHG) emissions, aluminium production creates large amounts of waste. Bauxite residue, also known as red mud, is a major waste resulting from the alumina extraction from bauxite, mainly via the Bayer process. It is a mineralogically complex mixture composed of undigested solids from the high-pressure bauxite digestion in a hot caustic soda (NaOH) solution and precipitated aluminosilicates (a.k.a. desilication product or DSP). Up to 2 tonnes of bauxite residue are produced per tonne of alumina. BR is usually found in the form of slurry containing a variable percentage of solid residue from the process, typically between 20 and 40 wt. %.

Large spaces are required for BR stockpiling, and the extension of storage facilities necessitate periodic capital investments and permitting. In general, environmental issues associated with bauxite residue storage and disposal include its high pH (11-14), the potential for alkali (Na, K) and ecotoxic (V, Al) metals seepage into groundwater, instability of storage and the impact of alkaline airborne dust on plant life.

The annual production of alumina in 2020 was over 133 million tonnes resulting in the generation of about 175 million tonnes of BR [1]. Currently, about 97 % of this production is stockpiled, leading to over 4 billion tonnes accumulated globally to date [2]. The global volume of the stored BR is expected to double in the next decade if the rate of utilization remains the same [3].
Moreover, BR is rich in iron (Fe), aluminium (Al), titanium (Ti), as well as strategic and/or critical metals such as vanadium (V), scandium (Sc) and other rare-earth elements (REE) that are discarded during stockpiling. Assuming a 100 USD/t of BR metal value, $17.5 billion worth of material is being stockpiled annually. Valorizing BR is therefore an opportunity for the alumina refineries to achieve their waste reduction targets and take advantage of the metal value of BR.

The typical composition of BR (dry basis) is given in Table 1 below.

Table 1. Composition of dry BR (oxide basis) [4].

Oxide	**Fe_2O_3**	**Al_2O_3**	**Na_2O**	**CaO**	**TiO_2**	**SiO_2**	**V_2O_5**	**Sc***	**La***	**Ce***	**LOI**
wt. % or ppm*	30-60	10-20	6-12	2-5	5-10	5-15	0.1-0.15	21-54	20-147	30-285	5-15

A typical mineralogy of BR is given in Table 2 below. Some variations in the composition are expected, depending on the type of bauxite treated at the alumina refinery.

Table 2. Mineralogy of BR feed (adapted from [4]).

Mineral	**Chemical formula**	**Typical range wt. %**
hematite	α-Fe_2O_3	7-29 %
Goethite	α -FeOOH	7-24 %
Boehmite	AlOOH	1-10 %
Aluminated goethite	$Al_xFe_{1-x}OOH$; x=0…1	10 %-40 %
Quartz	SiO_2	0-2 %
Rutile/Anatase	TiO_2	0-5 %
Bayer sodalite (DSP)	$Na_8[Al_6Si_6O_{24}][(Y)]\cdot xH_2O$; Y= $2Cl^-$, $2OH^-$, CO_3^{2-}	2-24 %
Cancrinite	$Na_6[Al_6Si_6O_{24}]_2CaCO_3$	0-51 %
Tricalcium aluminate	$3CaO\cdot Al_2O_3\cdot xH_2O$	0-5 %
unknown	V_2O_5	<1 %
unknown	REE (Sc, Ce, La…)	0-400 ppm

The avenue of BR valorization has been investigated for decades and to this day there is no implemented large-scale process that can extract these metals and effectively reduce waste volume. Moreover, the project feasibility might not be assessed based on the price of the pure metal oxides, unless all the purification steps toward the market specification are included in the process, or conservative discounts are applied. Besides, the environmental impacts of an

Innord has proposed a process in an attempt to address most of these challenges by obtaining multiple product streams:

- Iron and aluminium products
- Strategic metal concentrates (Sc/REE, Ti)
- other by-products

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6. References

1. World-aluminium,https://www.world-aluminium.org/statistics/alumina-production/ (accessed on 18 July 2022)
2. Ken Evans, The history, challenges, and new developments in the management and use of bauxite residue., *Journal of Sustainable Metallurgy*, 2016, vol. 2(4), 316-331.
3. International Aluminium Institute, Sustainable Bauxite Residue Management Guidance, 2021
4. K. Binnemans, P. t. Jones, B. Blanpain, T. Van Gerven and Y. Pontikes, Towards zero-waste valorization of rare-earth-containing industrial process residues: a critical review, *Journal of Cleaner Production*, 2015, 17-38.
5. R. M. Rivera, B. Ulenaers, G. Ounoughene, K. Binnemans and T. Van Gerven, Extraction of rare earth from bauxite residue (red mud) by dry digestion followed by water leaching, *Minerals Engineering*, 2018, vol. 119, 82-92,
6. B. Terry, The acid decomposition of silicate minerals part I. Reactivities and modes of dissolution of silicates, *Hydrometallurgy*, 1983, Vol 10-2, 135-150
7. J. Anawati and G. Azimi, Recovery of scandium from Canadian bauxite residue utilizing acid baking followed by water leaching, *Waste Management*, 2019, vol. 95, 549-559
8. Queneau, P. B., & Berthold, C. E. Silica in hydrometallurgy: an overview. *Canadian Metallurgical Quarterly*, 1986, 25(3), 201-209.
9. S.A. Gennadievich, K.A. Borisovich and P. A. Vladimirovich, Production of scandium-containing concentrate and further extraction of high-purity scandium oxide from the same, *US Patent 11, 021, 773 B2*, filed May 4, 2017, granted June 1, 2021
10. C. Borra, B. Blanpain, Y. Pontikes, K. Binnemans and T. Van Gerven, Recovery of Rare Earth and Other Valuable Metals from Bauxite Residue (Red Mud): A Review, 2016, *Journal of Sustainable Metallurgy*, vol. 2, no., 365-386.
11. Y. Liu and R. Naidu, "Hidden values in Bauxite residue (red mud): Recovery of metals, *Waste Management*, 2014 vol. 34, no. 12, pp. 2662-2673.
12. M. Archambo and S. Kawatra, Red Mud: Fundamentals and new Avenues for Utilization, *Mineral Processing and Extractive Metallurgy Review*, 2020.
13. Kaußen, F. M., & Friedrich, B. Methods for alkaline recovery of aluminium from bauxite residue. *Journal of Sustainable metallurgy*, 2016, 2(4), 353-364.
14. L. Wang, N. Sun, H. Tang and W. Sun, A Review on Comprehensive Utilization of Red Mud and Prospects Analysis, *Minerals*, 2019, 9(6), 362-371.
15. Joyce, P. James, and Anna Björklund., Using life cycle thinking to assess the sustainability benefits of complex valorization pathways for bauxite residue, *Journal of Sustainable Metallurgy*, 2019, 5(1), 69-84.
16. Borra, C. R., Blanpain, B., Pontikes, Y., Binnemans, K., & Van Gerven, T., Comparative analysis of processes for recovery of rare earths from bauxite residue, *Journal of Metallurgy*, 2016, 68(11), 2958-2962.

17. R. Boudreault, J. Fournier, D. Primeau and M. M. Labrecque Gilbert, Processes for treating red mud, *US Patent 9, 556, 500 B2,* filed April 15, 2015, granted July 2
18. https://www.chemanalyst.com/Pricing/Pricingoverview (Accessed January 2022)
19. Hydro Québec, GHG emissions and Hydro Québec electricity, Hydro Québec, [Online]. https://www.hydroquebec.com/sustainable-development/specialized-documentation/ghg-emissions.html, (accessed on January 2022)
20. City of Winnipeg - Water and waste department, Emission factors in kg CO_2-equivalent per unit - Appendix H - WSTP South End Plant Process Selection report, July 2011. [Online]. Available: https://winnipeg.ca/finance/findata/matmgt/documents/2012/682-2012/682-2012_Appendix_H-WSTP_South_End_Plant_Process_Selection_Report/Appendix%207.pdf. (Accessed January 2022).