Value-added Alumina Product from Low-grade Feedstock: From Concept to Test Work and Beyond

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https://doi.org/10.71659/icsoba2025-aa051

Abstract

Currently, the Bayer process is the predominant technology used to produce smelter grade alumina. Due to the dwindling supply of high-grade bauxite, coupled with the challenges of processing red mud generated by the energy intensive Bayer process, there is an interest in exploring options of alumina extraction from "low-grade" mineral resources. The Thor Polymetallic Black Shale deposit is a sizeable low-grade aluminium deposit, located in Tisdale, Saskatchewan, which is under development by the Canadian Energy Metals Corp. (CEM). Hatch has developed a preliminary flowsheet to process the Black Shale deposit to produce value-added alumina products. The flowsheet comprises acidic leaching, hydrometallurgical purification and recovery, and pyrometallurgical upgrading. This paper presents results from a related, iterative, proof-of-concept bench-scale test-work program, conducted at the Saskatchewan Research Council (SRC) in 2024. CEM commissioned a second, larger-scale, semi-continuous pilot program which is currently underway at SRC.

Keywords: Black Shale, Aluminium Chloride Hexahydrate (ACH), Smelter Grade Alumina (SGA), Chemical Grade Alumina (CGA), High Purity Alumina (HPA).

1. Background and Motivation for Study

Currently, the energy-intensive Bayer process is the predominant method for the production of Smelter Grade Alumina (SGA). The process involves leaching of bauxite in an alkaline solution at elevated temperatures and high pressure, followed by precipitation of gibbsite which is then calcined to produce alumina. The Bayer processing typically requires that the bauxite Al_2O_3 to SiO_2 mass ratio is greater than 8 (Jiang et al., 2012) – this necessitates the use of high-grade bauxite. The global reserves of high-quality bauxite are in decline; thus, the development of flowsheet concepts that are alternative to the classical Bayer process is of interest (Cheng et al., 2012, Kyriakogona et al., 2017), which has led to extensive research since the 1940's.

Alternative paths to produce alumina as described in the literature include the processing of clay-based feedstock with hydrochloric acid (Hoffman et al., 1946). Hoffman and co-workers showed that roasting of an aluminous (kaolinitic) clay at 700 °C, followed by leaching of the calcined product with hydrochloric acid led to the efficient separation of siliceous impurities from solution. The resulting solution was then crystallized in the presence of gaseous hydrogen chloride (HCl) to form an "intermediary" Aluminium Chloride Hexahydrate (ACH) product, which upon further calcination, formed alumina.

In the 1970s and 1980s, the US Bureau of Mines conducted independent bench-scale and mini-plant scale research to improve processing methods for a kaolin-based feedstock and obtained preliminary data for the subsequent design of a 25-tonne-per-day alumina pilot plant. The flowsheet comprised hydrochloric acid leaching, and gas sparging crystallization technology (Maysilles et al., 1982). The work demonstrated the technical feasibility of ACH production which was partially compliant with purity criteria for Smelter Grade Alumina, though the study did not examine the calcination of the ACH product.

Advanced Energy Minerals Inc. produces value added alumina products using the patented Chlorine Leach Crystallization Purification (CLCP) process. The Cap-Chat plant in Quebec is a full-scale plant that produces specialty alumina products including 3N and 5N high-purity alumina (HPA) from an aluminium tri-hydrate (ATH) feed.

Anorthosite (a rock type primarily comprised of feldspar) is another feedstock that has been researched as a source of alumina, primarily through processing by the lime-soda-sinter process and the melt-quench technologies routes. The former process involves sintering anorthosite with soda ash and limestone followed by leaching, desilication, and precipitation prior to alumina recovery as a tri-hydroxide (Brown et al., 1947). Calcination of the hydroxide product is expected to yield alumina The latter process involves arc melting of anorthosite at 1650 °C followed by rapid cooling to form an amorphous product that is amenable to leaching (Leitch et al., 1965). Acid leaching of anorthosite has been previously tested using a lixiviant composed of hydrochloric acid (HCl) and fluorides and has shown promise as a potentially viable process route (Bremner et al., 1982).

A common, and important feature of hydrochloric acid processes is the regeneration of the lixiviant for re-use; thereby, reducing processing costs (Demopoulos et al., 2008). This typically involves pyrohydrolysis of aluminium chloride hexahydrate (ACH), and in some cases iron chloride ($FeCl_3$), to regenerate the HCl, which is captured, condensed and recycled back to the process. A further advantage of processes using hydrochloric acid is the ability to achieve effective silica separation during leaching (Wu et al., 2014, Zhang et al., 1950).

2. Introduction

In the present study we establish an experimental basis for a hydrochloric acid-based technology, to valorise a low-grade "black shale" type of feedstock from Tisdale, Saskatchewan, for the production of Chemical Grade Alumina and High Purity Alumina.

According to a mineral resource estimate (NI 43-101 Technical report, Thor project-2024 Stantec Consulting, January 15, 2025), the "black shale" deposit, also known as the "Thor" deposit, spans 987 square miles. To date, exploration and evaluation of a portion of the deposit representing approximately 22% of the deposit surface area has identified an estimated resource of approximately 43 billion tonnes (measured and indicated, ore basis). Accordingly, the resource has been estimated to contain approximately 6 billion tonnes of contained alumina equivalent. A photo of "black shale" core samples located at the CEM warehouse in Saskatoon, Saskatchewan is shown in Figure 1. Composites generated from core samples were used in test-work described herein.

The mineral resource estimate established an average stripping ratio of 0.3 waste tonnes per tonne of resource and potentially all resource is surface mineable. Furthermore, the mineral resource estimate reports that the "black shale" deposit includes additional metallization of high value elements such as V, Sc and other REE (rare earth elements). Future study may evaluate whether this additional metallisation can be exploited to improve project viability. At the time of writing this manuscript, the Thor processing flowsheet design has been updated to accommodate the production of a mixed oxide product which would include scandium oxide, vanadium oxide, and rare earth oxides (discussion of same is outside the scope of this technical summary).

The data from the test-work has provided the design criteria for a semi-continuous pilot operation initiated in 2025 at the SRC. Data from the pilot would be used to further process development and ultimately provide design criteria for a commercial demonstration plant in 2026.

6. Acknowledgements

The authors wish to acknowledge the Canadian Energy Metals management team (Christopher Hopkins, Director and CEO and President; Gary Billingsley, Director and Chief Operating Officer; and David Dukes, Resource Exploitation Manager) for their support as well as their very insightful comments and feedback on this paper and many topics, for reviewing this manuscript and for their insightful and critical feedback that helped improving the manuscript.

The authors wish to acknowledge the assistance of the Saskatchewan Research Council (SRC) team (in particular, Baodong Zhao, Manager and Supervisor of Mineral processing; Thi Thu Doan Nguyen, Technologist) for their diligent and timely completion of laboratory tests involving leaching, solvent extraction, and crystallization.

The authors wish to acknowledge the assistance of the Process Research Ortech team (in particular, Jonathan Chen, CEO; and Sahil Kumar, Chief Metallurgist) for their diligent and timely completion of laboratory tests involving calcination.

7. References

1. Brown et al., Recovery of Alumina from Wyoming Anorthosite by the Lime-Soda-Sinter Process. Bu Mines RI 4132, 1947, 127 pp.
2. Bremner et al. Aluminum extraction from Anorthosite by leaching with hydrochloric acid and Fluoride. Report of Investigations, Bu mines.
3. Fc Cheng et al., Aluminum Leaching from Calcined Coal Waste Using Hydrochloric Acid Solution, *Mineral Processing and Extractive Metallurgy Review*, 2012, 33, 391-403. http://dx.doi.org/10.1080/08827508.2011.601700
4. Damtoft et al., Sustainable Development and Climate Change Initiatives, *Concrete Research*, Vol.38, 2008, 115-127.
5. Demopoulos et al. New Technologies for HCL Regeneration in Chloride Hydrometallurgy. Worl Metall.-ERZMETALL. 2008, 61, 89-98.
6. Hoffman et al. Development of a hydrochloric acid process for the production of alumina from clay, 1946.
7. Ya Xiong Jiang et al., A Novel Technology of Study of Separation of Silicon from a High Silicon Bauxite by Direct Flotation, *Advanced Materials Research*, 2012, Vols. 524-527, 924-929. https://doi.org/10.4028/www.scientific.net/AMR.524-527.924
8. Kyriakogona et al. A Comparative Study of Hydrometallurgical Processes, *Proceedings of the Third World Congress on Mechanical, Chemical, and Materials Engineering* (MCM'17), Rome, Italy, 2017.
9. Leitch et al. Extraction of Alumina by leaching Melted and Quenched Anorthosite in Sulfuric Acid. Bu Mines RI 6744, 1965, 32pp.
10. Maysilles et al. Aluminum Chloride Hexahydrate Crystallization by HCl Gas Sparging. 1982.
11. Mohamed et. Al. Cost-Effective and Green Additives of Pozzolanic Material Derived from Waste of Alum Sludge for Successful Replacement of Portland Cement. Sci Reports 12, 20794 (2022).
12. Loveday et al., Technical Report-Thor Project-Tisdale, Saskatchewan, 2024.
13. M. Schneider et al., Sustainable Cement Production - Present and Future, *Cement and Concrete Research*, Vol. 41, No. 7, 2011, 642-650.

14. Scrivener et al., Eco-efficient cements: Potential economically viable solutions for a low-CO_2 cement based materials industry, *Cement and Concrete Research*, Vol.114, 2018, 2-26.
15. Yusheng Wu, Laishi Li and Mingchun Li, Effect of Pressure on Alumina Extraction from Low-Grade Bauxite by Acid-Leaching Method. *Light Metals* 2014, 121-123. http://doi.org/10.1007/978-3-319-48144-9_21
16. Zhang Lei, Wang Hao and Li Yu, Research on the extract Al_2O_3 from coal gangue, *Advanced Materials Research*, 2012, Vols. 524-527, 1947-1950 https://doi.org/10.4028/www.scientific.net/AMR.524-527.1947