

An Alternative Approach for Production of Non-Metallurgical Grade Aluminium Hydroxide Utilizing Low-Grade Bauxite

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Abstract

The Bayer process is used worldwide for aluminium hydroxide (ATH) production with 95 % used for aluminium production and the remaining 5–6 % used for non-metallurgical applications. The untapped low/inferior-grade bauxite deposits on the western coast of India have an alumina content up to 40 %, and high Fe₂O₃ (40 %), with SiO₂ (2–8 %), CaO (2–4 %) remain unutilized due to their inferior quality and small and pocket deposits. Employing a different route other than the Bayer process, this low-grade bauxite is utilized to produce sodium aluminate liquor using sodium bicarbonate. The reagent is used to digest aluminous compounds in the bauxite at a temperature of 180–200 °C to form an intermediate product. The intermediate product is calcined and washed to extract alumina into a clear sodium aluminate solution which is further processed through CO₂-assisted precipitation with seed to yield non-metallurgical aluminium hydroxide. The developed process offers a viable alternative to the Bayer process for processing low-grade bauxite, benefiting bauxite mine owners and industries producing non-metallurgical alumina.

Keywords: Low-grade bauxite, Sodium bicarbonate route, Sodium aluminate, Non-metallurgical grade ATH.

1. Introduction

The western coast of India in Gujarat state contributes a significant portion to India's bauxite production, with a approximately 8–10 % share in the country's overall bauxite production of 22.7 million tonnes in the year 2024 [1]. However, these deposits remain largely unexplored due to their low alumina content (35–40 %) and high levels of iron oxide (35–40 %), silica (2–8 %), and calcium (2–4 %). As a result, they remain unutilized, contributing to the decline in bauxite exports from the state and possibly not used in the Bayer process for alumina production. To date, most efforts have been focused on the characterization and beneficiation of bauxite. However, this low/inferior grade bauxite can be used to produce aluminium hydroxide (ATH) for non-metallurgical applications.

Non-metallurgical grade ATHs/Specialty-grade aluminium oxides and hydroxides are used in a variety of applications, in chemicals such as PAC (polyaluminium chloride) and alum, including fire-retardant fillers, cosmetics as bulking agent and opacifier, toothpaste, antacids, paints, pigments, printing ink, catalysts (e.g. pseudoboehmite), glass ceramics, refractories, etc. For these specialized uses, specific grades of hydroxides or oxides are required, tailored to each application. Key factors that determine suitability include soda content, particle size, purity, and product brightness [2, 3]. Reduced yields of aluminium hydroxide precipitate from sodium aluminate solutions, along with its slow precipitation kinetics, have led researchers to explore alternative

methods for enhancing recovery and quality particularly when the alumina products are intended for non-smelting applications [4]. In addition to its flame-retardant properties, aluminium hydroxide filler also contributes to a marble-like translucency in cast acrylic. This has led to the development of products marketed as commonly used in applications such as kitchen countertops and bathroom panels. The degree of translucency depends on how closely the refractive indices of aluminium hydroxide (gibbsite) and the polymer match. The aluminium hydroxide can be used as a filler in a polymer matrices [5]. Aluminium hydroxide produced from the Bayer process, is an inorganic mineral product used as a fire retardant filler and is available in large volumes and various particle size distributions with consistent physical and chemical properties [6]. Approximately 95 % of aluminium hydroxide in an alumina refinery is used for the production of smelter-grade alumina while on an average 5–6 % is of non-metallurgical grade in Asian and African countries [7]. In Europe and North America its production has increased up to 20 %.

The European Union (EU) funded ENSUREAL initiative is primarily driven by the need for more environmentally friendly and sustainable methods to process predominantly low-grade bauxite ores. This has led to the exploration of a potential revival of the Pedersen process, which was effectively used between 1928 and 1969 to produce alumina at a plant in Høyanger, Norway, with a capacity of 17 000 t/y. The process effectively addresses all these issues and has the potential to be a zero-waste operation, generating by-products that can be utilized in other industries [8]. The Bayer Process produces aluminium hydroxide with a whiteness of up to 70–75 % which is ground to produce aluminium hydroxide for non-metallurgical applications with a whiteness of up to 85 to 86 %. [9] and the material obtained tends to have larger or irregular particles. Additional grinding or milling can be used to improve particle uniformity and whiteness. Unlike the Bayer process, the approach suggested herein is the production of non-metallurgical ATH through the sodium bicarbonate route which produces aluminium hydroxide with a whiteness of up to 90 % and results in finer and more uniform particles without the need for additional grinding. The process know-how has been developed by exploring low-grade bauxite from the western coast region which presently remains unutilized and unexplored.

In the process, the aluminous compounds in the bauxite reacts with sodium bicarbonate to form dawsonite ($\text{Na Al}(\text{CO}_3)(\text{OH})_2$). The dawsonite is heated to about 600–700 °C process to decompose it into solid sodium aluminate and carbon dioxide. The resulting sodium aluminate is subsequently extracted in liquid form and utilized in a precipitation process with CO_2 purging to produce aluminium hydroxide of up to 90 % whiteness and fineness of d_{50} size 10–12 μm . This process enables the effective use of inferior or low-grade bauxite, thereby enhancing the potential for bauxite miners and speciality grade alumina producers.

2. Materials and Methods

2.1 Materials

The bauxite was sourced from the Gujarat region in India and chemicals such as sodium carbonate (Qualigens, Thermo Fisher Scientific India) and sodium bicarbonate (Qualigens, Thermo Fisher Scientific India), were used in various experimental steps. The chemical analysis of bauxite was done using wet chemical method and is shown in Table 1. Reactive SiO_2 was determined gravimetrically. Table 2 presents the mineral composition of the bauxite. The analysis was carried out with a PANalytical X'Pert Pro MPD diffractometer (Netherlands), using $\text{Cu K}\alpha$ radiation ($\lambda = 1.541 \text{ \AA}$).

The bauxite is composed of low alumina i.e. 37 % Al_2O_3 , high iron i.e. 36 % Fe_2O_3 and low SiO_2 (2 % silica) as shown in Table 1. The mineralogical composition of bauxite in Table 2 indicates that gibbsite is the predominant mineral in the alumina phase. The iron phase mainly consists of hematite (31 %) and alumogothite (4.82 %). Silica is primarily present as kaolinite (1.63 %),

with a smaller amount of quartz (0.5 %). Titania occurs in the form of anatase (3.0 %), while calcium is present in minor quantities as calcite (0.28 %).

Table 1. Chemical analysis of bauxite.

Constituents	%
Al ₂ O ₃	37.03
Fe ₂ O ₃	36.29
SiO ₂	1.95
TiO ₂	2.98
CaO	0.217
LOI (0–1000 °C)	20.80
Reactive (SiO ₂)	1.38

Table 2. Mineralogy of bauxite.

	Mineralogical Phases	%
Al₂O₃ as	Gibbsite	35.29
	Boehmite	0.42
	Kaolinite	1.38
	Aluminogoethite	0.54
Fe₂O₃ as	Hematite	31.00
	Aluminogoethite	4.82
SiO₂ as	Kaolinite	1.63
	Quartz	0.50
TiO₂ as	Anatase	3.0
CaO as	Calcite	0.28

2.2 Methods

In the process, tested at a lab scale, the bauxite processing undergoes a series of processes such as digestion, calcination, leaching, and precipitation. Bomb Digester of 200 ml capacity (Make: Noble Polymech Corporation, Mumbai, INDIA) and 5 L Autoclave equipment (Make: Amar Equipment Pvt. Ltd., Mumbai) was used to carry out the digestion, leaching and desilication study. Solids and liquor after digestion and leaching test were separated using Centrifuge (Make: REMI KPR-70). Hard drying of the solids was carried out in furnace (Make: Therelex). Water bath (Make: Galaxy scientific eqpts., Dombivali, Mumbai) was used to carry out a precipitation study in a 1 L capacity vessel with CO₂ inlet facility which was locally fabricated.

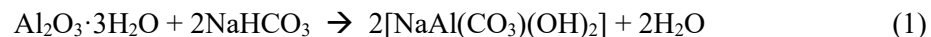
During the digestion stage, an intermediate compound known as sodium dawsonite is formed through the reaction between aluminium hydroxide present as gibbsite and boehmite in bauxite and sodium bicarbonate. Key parameters such as temperature, reaction time, bauxite quantity, solid-to-liquid ratio, and the amounts of sodium bicarbonate and sodium carbonate were systematically optimized. During this step, the percentage of sodium (Na) conversion into solid dawsonite was determined. The resulting solid compound was characterized using X-ray diffraction (XRD). The calcination process was conducted to convert sodium dawsonite into sodium aluminate with liberation of CO₂. The process was optimized for both time and temperature. Scanning electron microscopy (SEM) was performed on the solids both after digestion, calcination and product ATH using a JEOL JSM-IT300 instrument to observe its surface morphology. The particle size distribution of the aluminium hydroxide was carried out using a Particle size analyzer (Micromeritics, Satun Digitizer 5205, USA). The whiteness of the

aluminum hydroxide was analyzed using an Optics Technology Whiteness Meter (Make: Optics Technology, Delhi, India).

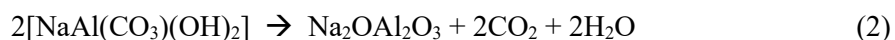
Subsequent leaching, which included desilication to lower the silica content, was carried out by optimizing parameters like temperature and time. Following leaching, the resulting clear sodium aluminate solution was subjected to the precipitation steps to obtain aluminium hydroxide. Purging of carbon dioxide was done during precipitation to obtain aluminium hydroxide.

Various reactions taking place in the process are as follows and Figure 1 illustrates the process flowsheet.

Digestion:



Calcination:



Leaching:

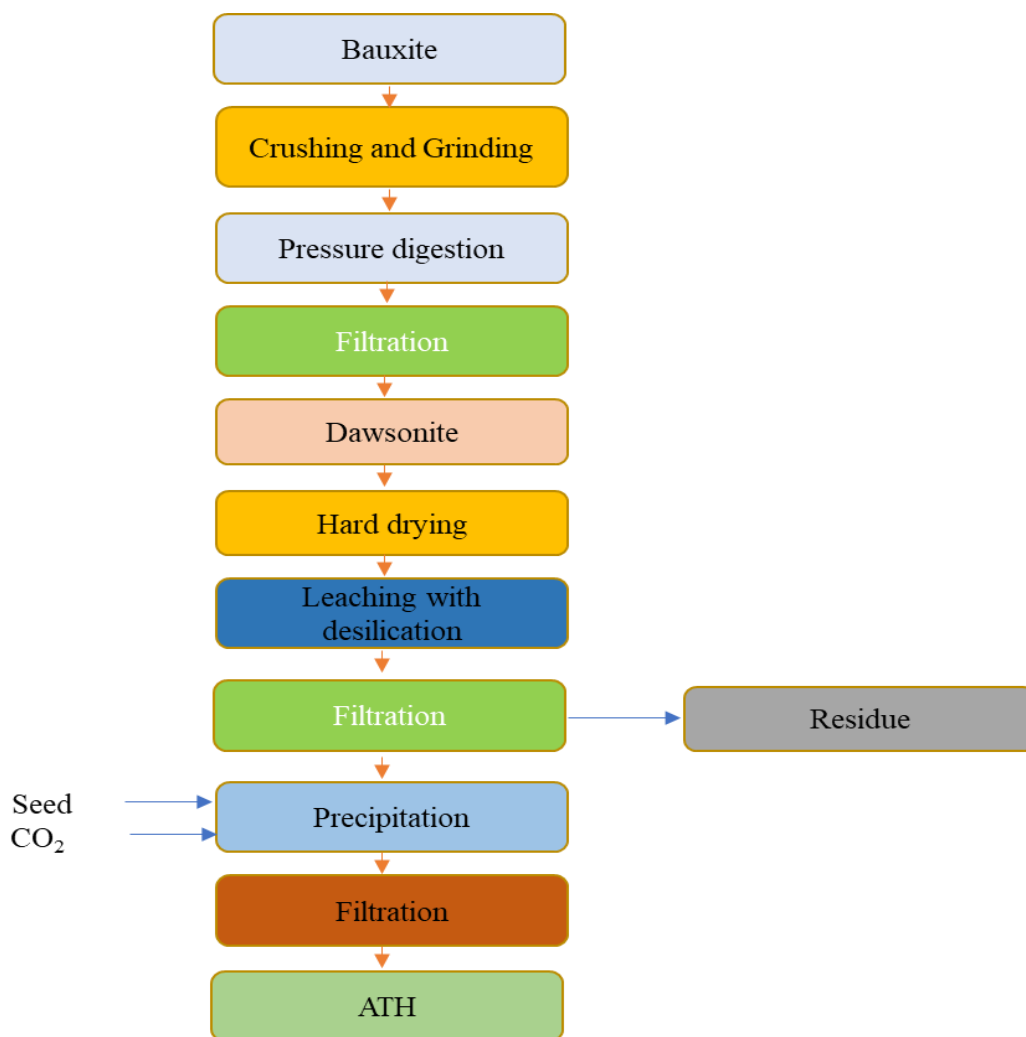


Figure 1. Process flowsheet for non-metallurgical grade aluminium hydroxide (ATH) from low-grade bauxite.

3. Results and Discussion

3.1 Digestion

According to reaction (1), aluminium hydroxides within the bauxite react with sodium bicarbonate to produce sodium dawsonite and water [10]. The digestion process was conducted using sodium bicarbonate (NaHCO_3) concentrations and sodium carbonate (Na_2CO_3) concentrations up to 170 g/L. The reactions were carried out at temperatures between 180 and 200 °C for durations ranging from 1 to 1.5 h. A maximum Na conversion of approximately 85 to 86 % was achieved in sodium dawsonite. Sodium carbonate does not directly take part in the primary reaction; however, it acts as a reaction medium to regulate the pH of the solution. By maintaining an appropriate pH level, sodium carbonate favours the formation of dawsonite over competing reactions. Its presence also enhances the reactivity of aluminium hydroxide (ATH), thereby supporting the formation of dawsonite with a better sodium conversion. The sodium conversion percentage in the dawsonite was the deciding factor for calculating the efficiency of the digestion reaction. The solid product was identified as dawsonite and was characterized using XRD and scanning electron microscopy (SEM). The SEM images revealed needle-like structures in the solid dawsonite after digestion, which is consistent with observations reported in the literature [11]. Figure 2 represents the SEM images of solid dawsonite obtained after digestion.

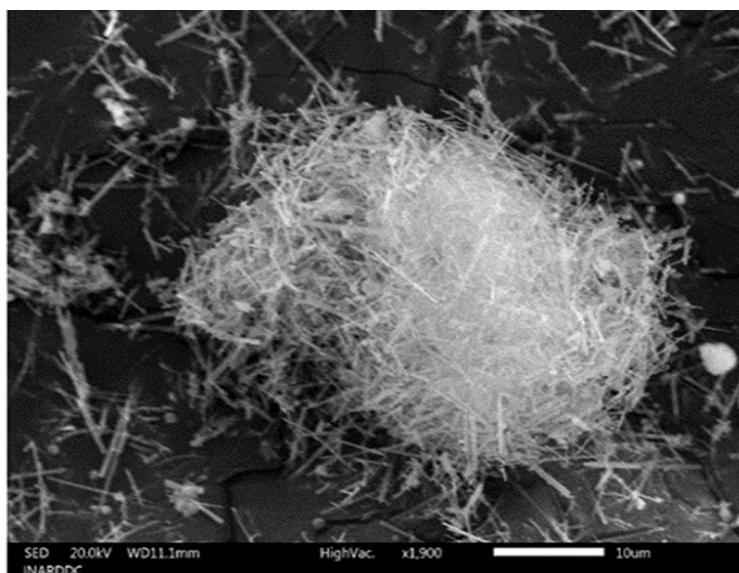


Figure 2. SEM photograph of solid sodium dawsonite.

3.2 Calcination

According to reaction 2, solid sodium dawsonite is subjected to calcination to produce solid sodium aluminate, with CO_2 and H_2O being released during the process. The thermal decomposition of dawsonite proceeds via a two-step mechanism. In the first stage, between 300 to 375 °C, dawsonite begins to decompose, releasing water molecules (H_2O). In the second stage, carbon dioxide (CO_2) gradually evolved over a temperature range of 360 °C to 650 °C, leading to the formation of crystalline sodium aluminate (NaAlO_2) as the final solid product. Based on this thermal behaviour, a calcination temperature in the range of 600–700 °C was selected for further study to ensure complete decomposition and formation of the desired sodium aluminate phase. Calcination was carried out at temperatures ranging from 700 to 900 °C and time between 1 to 2 hours. Figure 3 represents the SEM micrographs of sodium aluminate obtained after the calcination process. Additionally, this step reduces the organics in the solids as they volatilize during the process and a clear sodium aluminate liquor is produced during leaching.

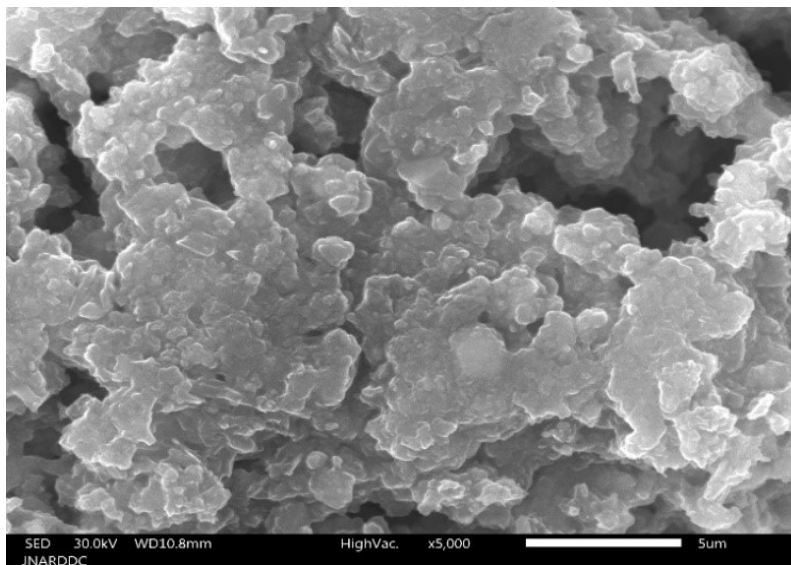


Figure 3. SEM of solid sodium aluminate at 700 °C calcination temperature at 5000× magnification (white bar indicates 5 μm).

3.3 Leaching with Desilication

According to reaction 3, the calcined solid sodium aluminate is leached with water to obtain sodium aluminate in its liquid form. Sodium aluminate from the solids is dissolved in water to produce a clear supersaturated sodium aluminate solution for precipitation. This dissolution process occurs in leaching, commonly used to extract sodium aluminate from a solid. Leaching with desilication was performed by varying the temperature between 105 °C to 120 °C, with desilication times ranging from 1 to 6 hours to reduce the silica content in the liquor using NaOH solution of low concentration. An extraction efficiency of 92–93 % is achieved with a $\text{Na}_2\text{O}_{\text{caustic}}$ concentration of 123 g/L and an Al_2O_3 concentration of 135 g/L in the liquor. The silica concentration in the liquor decreased to 1.11 g/L, which is within the acceptable limit for use in precipitation. The reduced silica content in the liquor is due to the extended desilication time and the formation of sodalite during the process. The residue obtained after leaching has a high iron content up to 70–72 %, 6–8 % Al_2O_3 , 6–8% TiO_2 , 3–5 % Na_2O , 3–5 % SiO_2 . The extraction efficiency of alumina is up to 92 %.

3.4 Precipitation

Precipitation of the clear sodium aluminate liquor obtained after leaching is carried out by seeding the solution with a seed charge of approximately 200 g/L of a milled aluminium hydroxide with a d_{50} of approximately 20 μm (procured from an industry in India). During the process, CO_2 was purged into the liquor at a flow rate of 0.5 to 0.75 L/min. to maintain a pH between 9 and 10. The liquor analysis after precipitation ranged between Al_2O_3 : 5 to 10 g/L, SiO_2 : 0.25 to 0.30 g/L, Na_2CO_3 : 190 to 200 g/L, NaHCO_3 : 60 to 70 g/L. The resulting hydrate product was then evaluated against the target parameters. The precipitated hydrate has characteristics as shown in Table 4. The table shows that SiO_2 is quite low in the product hydrate with a slightly high Fe_2O_3 content, which could be attributed to the elevated iron concentration in the bauxite (36 %), whiteness is up to 90 % which is due to the volatilization of organics in the calcination step. Figure 4 represents the SEM image of the product showing the hexagonal structure of particles. The particle size distribution is relatively fine, with a d_{50} of 10–12 μm. The product hydrate has a fine size as compared to seed due to the generation of secondary nuclei caused by instantaneous purging of CO_2 in a supersaturated solution. The overall product characteristics show that it well

suited for non-metallurgical uses such as in polymers, and coatings and as a flame-retardant filler in some important applications.

Table 4. Properties of product ATH.

Al ₂ O ₃ , %	65.00-66.00
Fe ₂ O ₃ , %	0.015-0.024
SiO ₂ , %	0.005-0.009
Na ₂ O, %	0.23-0.24
Particle size, μm	d ₁₀ : 2-3 d ₅₀ : 10-12 d ₉₀ : 32-33
Whiteness, %	up to 90

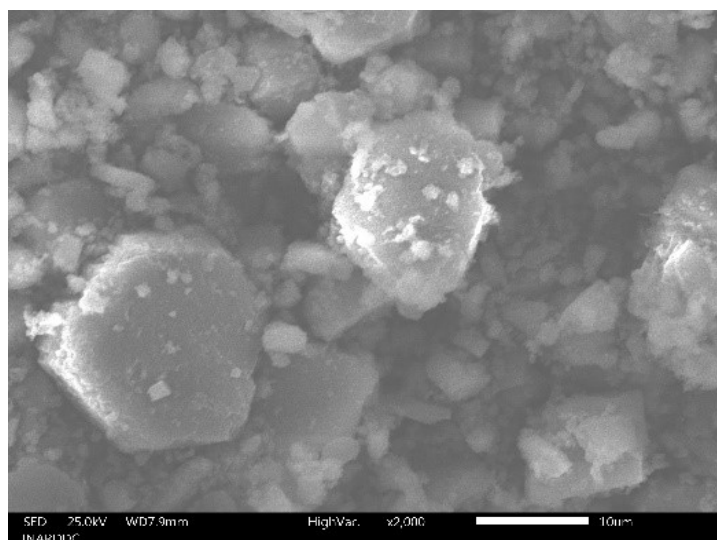


Figure 4. SEM photograph of product ATH at 2000 magnification (white bar indicates 10 μm).

4. Conclusions

The sodium bicarbonate route described is a novel approach for processing the currently under-utilized low-grade bauxite from the western coast of India (Gujarat) for the manufacture of high-quality speciality aluminium hydroxide.

The route involves reacting sodium bicarbonate with bauxite in an autoclave at a temperature between 180 °C to 200 °C, calcining the digested bauxite at a temperature of approximately 700 °C, leaching the solid residue to obtain clear sodium aluminate liquor and finally precipitating fine aluminium hydroxide by purging with CO₂.

The bauxite requirement is nearly 3.5–3.7 tonne per tonne of alumina production as compared to 2.5–3.0 tonnes of bauxite per tonne of alumina production (depending on the quality of the bauxite) for the conventional Bayer process. However, the process produces relatively fine particle size of aluminium hydroxide (d₅₀ from 10 to 12 μm) and a whiteness up to 90%. Meanwhile, grinding would be required to produce the same grade if using aluminium hydroxide from a conventional Bayer process route as well as involving more process steps. The results presented are based on laboratory-scale studies. Therefore pilot scale work using the appropriately sized ball mill, digester, filter, washing tank, calciner, precipitator, and dryer are required to determine the energy consumption and other key factors to assess the viability of the route.

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