Analysis of Bauxite Fractions and Synthesis of Stable Sodium Silicate Solution

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Abstract

Caustic soda is a critical reagent in alumina refining, but its reaction with kaolinite in bauxite leads to the formation of sodium silicate, contributing to irreversible caustic losses due to sodalite formation in the Bayer process. To address this issue, this study analyses different bauxite fractions to identify high-silica fractions suitable for silica extraction and stable sodium silicate synthesis. Bauxite samples were fractionated and analysed using X-ray Fluorescence (XRF) to determine the silica-bearing fraction. Dissolution studies were conducted in process liquor to selectively leach kaolinite, while key process parameters—reaction time, temperature, and slurry concentration—were optimized to maximize silica extraction while minimizing gibbsite dissolution. The study establishes a basis for selective silica extraction and stable sodium silicate synthesis. Future research will focus on large-scale implementation and potential applications of the extracted silica in value-added products.

Keywords: Alumina refining, caustic soda consumption, bauxite fractions, silica extraction, sodium silicate synthesis.

1. Introduction

Caustic soda (NaOH) is a crucial component in the Bayer process, the main industrial method to produce alumina from bauxite. Caustic soda reacts with alumina bearing minerals like gibbsite, boehmite, diaspore to produce sodium aluminate. However, caustic also reacts with kaolinitic silica, known as reactive silica, to produce sodium silicate. Although sodium aluminate is the preferred intermediate in the production of alumina, simultaneous production of sodium silicate is undesirable as increases caustic losses and other downstream issues. One of the key problems with sodium silicate is that it can react with dissolved alumina and sodium ions to produce insoluble phases such as sodalite and cancrinite under specific process conditions. These sodium aluminosilicates tend to precipitate on the surface of heat exchangers, causing scaling, inefficiencies in energy, and periodic maintenance shutdowns. More importantly, these reactions cause irreversible caustic soda losses, which have a negative impact on the process economy and raises operating costs.

Earlier research has highlighted the negative effect of reactive silica in high-silica bauxite ores [1]. It is known that the extraction rate of silica and the formation of sodalite greatly depend on the bauxite feedstock mineralogy and particle size. Smaller fractions tend to have higher surface area and can accumulate reactive clay minerals, enhancing undesirable side reactions [2]. Pickering et al [3] have investigated different pre-treatment methods to reduce reactive silica prior to digestion, including selective leach and desilication methods, without much success in retaining caustic efficiency and product quality. In recent years, the alternative solution has been to valorise it, rather than simply remove reactive silica as waste: researchers have sought to extract and convert it to value-added products such as stable sodium silicate solutions. Sodium silicate is used in a variety of industrial applications across detergents, adhesives, refractories, and as a feedstock in the manufacture of silica gel [4]. Yet its synthesis demands strict control of the reaction conditions like temperature, alkali concentration, and the composition of silica-bearing source, to maintain solubility and stability. Smith et al [1] suggested that size fractionation of bauxite particles can determine silica-rich components that are prone to controlled dissolution and conversion into sodium silicate under optimized hydrothermal conditions. Based on this idea, the current research explores the role of bauxite's particle size distribution in the silica behaviour during caustic leaching. It has a two-pronged objective: first to describe and separate high-silica fractions of bauxite liable for the loss of caustic soda during alumina refining, and secondly, to evaluate whether reactive silica can be extracted from such fractions for use in producing stable sodium silicate solutions. This two-way strategy is designed to alleviate the problems with reactive silica in bauxite while providing a promising route for resource valorisation in alumina refineries.

2. Methodology

2.1 Collection of Bauxite Samples

Fine bauxite samples with a particle size below 30 mm were obtained directly from the crusher feed stream of an existing alumina refinery. They are representative of the finely crushed fraction of run-of-mine (ROM) bauxite and are known to be a heterogeneous mixture of mineral phases, including gibbsite and reactive silica-bearing phases like kaolinite. After collection, the samples were air-dried under ambient laboratory temperature (~30 °C) for 48 hours to eliminate surface moisture. To dry completely and avoid agglomeration during further handling, the air-dried samples were additionally oven-dried for 12 hours at 105 °C in a hot-air oven. This procedure provided homogenous moisture content throughout all samples and reduced size classification variability. The dry bauxite was then mechanically sieved with a Ro-Tap sieve shaker (Model RX-29) following ASTM standard D6913. A set of regular stainless-steel sieves with mesh sizes of + 6.3 mm to - 75 µm were employed to separate the sample into well-defined size fractions.

Each sieving procedure involved continuous shaking and tapping for 15 minutes to induce uniform stratification and reduce clogging. Following sieving, the retained material on each mesh was collected with care, weighed, and kept in labelled airtight containers for examination. The obtained size fractions were measured for their mass distribution, and representative samples from each size class were taken for subsequent chemical and mineralogical analysis and for silica extraction experiments.

2.2 Elemental Analysis

All the bauxite size fractions that were sieved, were analysed for chemical composition to find the distribution of major oxides, specifically the content of alumina (Al_2O_3) and silica (SiO_2). For the solids analysis, X-ray Fluorescence (XRF) spectroscopy was performed on a PANalytical Axios Max sequential wavelength-dispersive XRF spectrometer. Before the analysis, representative sub-samples from each size fraction were ground finely to a particle size of < 75 µm using an agate pestle and mortar for homogeneity and improvement in analytical precision. Around 5 g of ground sample was subsequently mixed with an appropriate binder (e.g., boric acid) and pressed into a pellet form using a hydraulic press at a force of 20 t to create stable and smooth analytical discs. The calibration of the XRF analyser was accomplished with certified reference materials (CRMs) for bauxite and laterite ore to provide quantitative precision in the elemental determination. Every pellet was scanned in triplicates to validate repeatability and minimize instrumental error. The acquired spectra were reduced using the instrument software to determine the concentration of major oxides, such as Al_2O_3, SiO_2, Fe_2O_3, TiO_2, and other trace

Table 3. Change in Silica concentration with feed solids variation.

Time, h	50 g/L	100 g/L	200 g/L
0	621.4	698.6	621.4
3	1532.1	2586.4	3456.4
4	1725.0	2925.0	2582.1
5	1881.4	3002.1	1480.7

4. Conclusions

This research identifies the -500 µm bauxite fraction as the ideal for silica recovery, with better dissolution properties. The optimum dissolution conditions were determined at 70 °C, 100 g/L slurry, and 5 hours residence time, defining an accurate processing window for maximum silica recovery. Under this optimum temperature of 70 °C, thermal energy input adequately overcomes the activation energy barriers for silica dissolution without inducing competing reactions or accelerated precipitation processes seen at elevated temperatures. The 100 g/L slurry concentration is an optimal balance between low solids loading (50 g/L) that provides too little silica mobilization and high concentration (200 g/L) that speeds dissolution at first but then fosters fast precipitation, most probably as a result of greater nucleation sites and localized supersaturation conditions. The 5 hours residence time corresponds to maximum silica concentration values (averaging around 3010 mg/L within experimental sets), above which decreasing returns are realized as precipitation mechanisms take control of system dynamics.

These rigorously optimized parameters allow effective silica recovery for stable sodium silicate production, aiding in less caustic soda loss in follow-up Bayer process operations and providing potential paths for value-added silica products for applications as adsorbents, catalysts, and advanced ceramic materials. Systematic determination of these conditions offers both basic understanding of silica dissolution kinetics from aluminosilicate matrices and operating instructions for industrial utilization of selective recovery of silica from bauxite resources.

5. References

1. P. Smith, The processing of high silica bauxites — Review of existing and potential processes, *Hydrometallurgy*, 2009, 98(1–2), 162–176. https://doi.org/10.1016/j.hydromet.2009.04.015
2. S. Wang et al., Silica gel free region and rare earth metal extraction correlations in reprocessing bauxite residue, *Minerals Engineering*, 199, 2023, 108115. https://doi.org/10.1016/j.mineng.2023.108115
3. R. A. Pickering et al., An investigation into the characteristics of reactive silicon pools of coastal marine sediments, *Continental Shelf Research*, 268, 2023, 105126. https://doi.org/10.1016/j.csr.2023.105126
4. I. Hamidu et al., Synthesis of silica and silicon from rice husk feedstock: A review, Heliyon, 11(4), 2025, e42491. https://doi.org/10.1016/j.heliyon.2025.e42491