Mineral Evolution and Elemental Migration During Reductive Bayer Digestion of Guinea Bauxite

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https://doi.org/10.71659/icsoba2025-br002

Abstract

Bauxite residue is an alkaline solid waste produced during alumina extraction, characterized by its significant volume and low utilization rate, which poses a serious threat to both the ecological environment and the safety of human lives and property. The reductive Bayer digestion process facilitates the source reduction of bauxite residue, enhancing opportunities for its value-added utilization while simultaneously improving the alumina extraction rate. The TESCAN Integrated Mineral Analyzer (TIMA), a comprehensive mineral analysis system, enables the quantitative assessment of the physical properties and chemical composition of various minerals present in ores. This study utilizes TIMA as the primary tool to characterize the mineral composition and elemental distribution of Guinea high-iron bauxite and reductive Bayer bauxite residue, incorporating analyses of chemical composition, particle size, and mineral phases. In Guinea bauxite, gibbsite predominantly occurs in close association with Al-goethite, while rutile/anatase and ilmenite are distributed stellately within the matrix comprised of gibbsite, Al-goethite, and hematite. Following the reductive Bayer digestion process, Aluminous Goethite is transformed into hematite, while titanium minerals remain diffusely distributed among the iron minerals. Notably, the relative content of titanium in rutile/anatase and ilmenite shifts from 75.31 % and 24.69 to 26.95 % and 73.05 % respectively, compared to the unprocessed bauxite. The Guinea bauxite is notably rich in iron (Fe), vanadium (V), titanium (Ti), and rare earth elements, with vanadium, titanium, and cerium co-enriched in rutile/anatase and ilmenite. Some of the valuable elements maintain their original mineralization during the reductive Bayer digestion process, with their concentrations further enhanced. This study provides essential data on mineral evolution and elemental migration during the reductive Bayer digestion process to the Guinea bauxite.

Key words Guinea bauxite, Bauxite residue, Reductive Bayer digestion, Mineralogy, Critical metals.

1. Introduction

Bauxite residue is a substantial solid waste generated from the alumina production process, characterized by high alkalinity, fine particle size, and a complex mineral composition [1, 2], along with a significant quantity of iron, titanium, and rare earth elements [3–5]. To achieve complete extraction of alumina, the current high-temperature Bayer digestion process typically adds 3 to 10 % lime to eliminate titanium mineral blockages [6]. However, the substantial addition of lime not only increases bauxite residue output but also raises costs and complicates the subsequent utilization of bauxite residue. To address this issue, Wang et al. [7–9] have proposed a reductive Bayer digestion process that mitigates titanium mineral blockages by incorporating a small quantity of additives, thereby increasing the digestion rate of alumina.

Guinea bauxite is a high-iron gibbsitic bauxite ore with proven reserves of 7.4 Gt [10, 11]. It is characterized by a single layer thickness ranging from 3 to 9 meters and is typically found in open, gently undulating upland areas, often covered by shrubby vegetation, making it suitable for open-pit mining [10]. Generally, the alumina content in Guinea bauxite ranges from 40 to 60 % and silica content from 0.5 to 6 %, with concentrated mineral reserves [12, 13]. Notably, more than 10 % of the Al_2O_3 present in the ore exists as insoluble aluminum minerals, such as Al-goethite [2], which results in a lower alumina extraction rate. As the port-based alumina industry continues to expand, Guinea's bauxite imports are on the rise.

To elucidate the mineral composition of Guinea bauxite and bauxite residue, researchers have conducted a series of studies. Moussa et al. [10] performed petrological, mineralogical, and geochemical investigations on bauxite ores from the Kindia region of Guinea. Their findings revealed that the primary components of the ores are gibbsite and Al-goethite, with minor quantities of anatase, rutile, diaspore, and kaolinite, alongside significant enrichments of titanium (Ti), gallium (Ga), chromium (Cr), and heavy rare earth elements. Zainudeen et al. [14] conducted a comparative analysis of the mineralogical and chemical compositions of ores from major bauxite-exporting countries in Africa. The TESCAN Integrated Mineral Analyzer (TIMA) system [15], is capable of quantitatively resolving the mineral embedding forms, as well as analyzing the elemental distribution within both bauxite and bauxite residue [16, 17]. Chen et al. examined the distribution of lithium (Li) in bauxite with TIMA and discovered that it is primarily enriched in clay minerals. Additionally, Luo et al. [18] investigated bauxite in Guizhou Province, China, and found that rare earth elements are predominantly distributed in the form of phosphates within monazite, hematite, and anatase. These studies demonstrate that TIMA not only assesses the physical properties of target minerals but also characterizes valuable metals and their relative concentrations, offering robust support for element extraction.

The application of the reductive Bayer digestion process further enriches the valuable elements in Bauxite residue [19]; however, mineralogical studies of reductive Bayer digestion bauxite residue remain relatively scarce. This study employs the TIMA as the primary research tool to analyze the mineral composition and elemental distribution of Guinea bauxite and reductive Bayer digestion bauxite residue. The research aims to describe the changes in mineral species and elemental distribution resulting from the reductive Bayer digestion process, thereby supplying critical data to facilitate the large-scale economic utilization of bauxite residue.

2. Experimental

2.1 Materials

The Guinea bauxite and bauxite residue utilized in the experiments were sourced from an alumina plant in Shandong. The bauxite ore was crushed using a jaw crusher, while the bauxite residue underwent a washing process with hot water to eliminate any attached alkali. Subsequently, the bauxite residue was dried in preparation for mineralogical characterization.

2.2 Characterization

Mineralogical analyses of the ore and bauxite residue were conducted utilizing a TIMA-X integrated mineral analysis system (Tescan, Czech Republic). Samples were embedded in resin, followed by polishing and carbon spraying. The phase composition was analyzed using a D/Max 2500VB X-ray diffractometer (Rigaku, Japan) with a copper target, scanning at a speed of 8°/min over a range of 5° to 80°. The particle size was assessed using a BT-9300ST laser particle sizer (Dandong Baxter Instrument Co., Ltd., China). Micro-morphological analyses were performed with a Mira3 LMH high- and low-vacuum scanning electron microscope and complemented by a One Max20 X-ray energy spectrometer (Tescan, Czech Republic). The concentrations of major

6. Acknowledgement

This work was financially supported by the National Key Research and Development Program of the Ministry of Science and Technology of China [grant number 2022YFC3900900] and the Key Research and Development Program of Shandong Province [grant number 2024CXGC010317].

7. References

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