Bauxite Residue Alkali-Magnetization Reduction Roasting Process

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Abstract

High-iron bauxite residue is a secondary metallurgical resource with complex intergrowth of iron and alumina minerals, making it difficult to recover valuable elements through conventional mineral processing. This study investigates the mineral phase transformation and recovery behaviour of iron and alumina from high-iron bauxite residue under different roasting conditions and reagent formulations, using a 'soda-magnetization reduction roasting' process. The test results indicate that increasing the roasting temperature and NaOH dosage promoted the conversion of $Na_{1.75}Al_{1.75}Si_{0.25}O_4$ to $Na_{1.95}Al_{1.95}Si_{0.05}O_4$, thereby enhancing the leaching rate of alumina. However, excessive NaOH and reductant addition led to the transformation of Fe_3O_4 into $NaFe_{0.75}Al_{0.25}O_2$ and FeO, resulting in a significant decrease in iron recovery. Under optimal conditions, the recovery rates of alumina and sodium oxide in the roasted product reached 81.56 and 90.97 %, respectively. The iron concentrate obtained from magnetic separation had a grade exceeding 55 %, an alumina impurity content below 4 %, and an iron recovery rate above 90 %. The comprehensive reduction rate of high-iron bauxite residue reached 93 %.

Keywords: Bauxite residue, Magnetization roasting, Mineral phase transformation, Alumina leaching, Iron recovery.

1. Background

Bauxite residue is a soda-rich solid waste generated during the Bayer process for alumina production. Approximately 0.8–1.5 tonne of bauxite residue are discharged per tonne of alumina produced. As of 2024, China's alumina output reached 85.5 million tonnes, resulting in a bauxite residue production of 115 million tonnes, with total accumulated stockpiles exceeding 1.6 billion tonnes. However, the comprehensive utilization rate of bauxite residue remains only 12 % [1, 2]. Consequently, most bauxite residue is disposed of in solid waste landfills, leading to loss of land resources and the potential for contamination of groundwater and soil. Effective reduction of bauxite residue is urgently needed, yet progress has been hindered by its complex physicochemical properties. Bauxite residue contains valuable resources such as Fe_2O_3, Al_2O_3, SiO_2, TiO_2, Na_2O, and rare metals, making it promising for comprehensive utilization, particularly for its iron and alumina resources [3–5].

The methods for recovering iron and alumina resources from bauxite residue can be classified into physical beneficiation, hydrometallurgy, and pyrometallurgy processes. However, due to the fine particle size and lattice substitution between iron and aluminium oxides, it is difficult to separate valuable elements from bauxite residue using conventional physical methods. Liu et al.

[6] designed a parabolic hydrocyclone to address the issue of low iron recovery efficiency. The results demonstrated that the parabolic hydrocyclone significantly enhanced the concentration of iron minerals, increasing the iron concentrate grade from 26.75 to 36.04 %. However, this method still faces challenges such as low recovery efficiency and poor concentrate quality, failing to fundamentally achieve effective resource recovery. Zhu et al. [7] treated bauxite residue through acid leaching, extraction, polymerization, soda leaching, and aging processes. This process achieved recovery rates of over 96 % for scandium and vanadium, while more than 97 % of iron and alumina were precipitated and recovered in the form of polymers. Additionally, by-products included a titanium-rich residue with a grade of 62 % and white carbon black with a purity of 99.5 %. Although the acid method demonstrates high efficiency in bauxite residue treatment, its complex process flow and potential risks to reactors [8, 9] hinder its large-scale industrial application for bauxite residue solid waste disposal.

Pyrometallurgy is the most promising method for large-scale resource utilization of bauxite residue, which can be divided into reduction smelting and reduction roasting [10–12]. Reduction smelting involves adding reductants and limestone to reduce iron oxides in bauxite residue into molten iron or pig iron while generating highly reactive calcium aluminate residue that enables alumina recovery. Wu et al. [13] utilized a mixture of steel slag, high-iron bauxite, coal fly ash, and bauxite residue to produce pig iron and smelting slag. The slag contained compounds such as $12CaO \cdot 7Al_2O_3$ and $CaO \cdot Al_2O_3$, which could react with sodium carbonate liquor to recover alumina. Although reduction smelting enables comprehensive recovery of valuable metals from bauxite residue, this process typically requires temperatures exceeding 1400 °C, posing challenges such as high energy consumption, excessive reductant usage, and large residue volumes. The reduction roasting can be divided into metallization and magnetization reduction roasting. In metallization reduction roasting, sodium and calcium salts are used as mineralizers to inhibit the formation of intermediate products during iron metallization reactions, while generating soluble sodium aluminate to recover alumina from bauxite residue. Silicon and titanium oxides in the bauxite residue are simultaneously converted into calcium salts to ensure efficient leaching of sodium aluminate. However, this process still requires a reduction sintering temperature of approximately 1200 °C, and its high energy consumption and high residue volume diminish the economic benefits of the process and limit its industrial application. Therefore, the industry has proposed the magnetization roasting process to reduce energy consumption and improve the efficiency of bauxite residue treatment. The principle involves the targeted conversion of hematite and goethite into magnetite, followed by magnetic separation to recover iron concentrate. The aluminium-, silicon-, and titanium-bearing minerals in bauxite residue lack magnetism and can thus be separated and concentrated in the iron-removed tailings. The magnetization roasting process has been widely applied in the removal of impurities and upgrading of low-grade iron resources. However, due to the lattice substitution of iron and aluminium elements in bauxite residue, the iron concentrate derived from bauxite residue through this method often contains high levels of alumina (Al_2O_3) and sodium oxide (Na_2O), making it difficult to be directly used as raw material for blast furnace ironmaking. Additionally, gibbsite and boehmite in bauxite residue are prone to transform into γ-Al_2O_3 during roasting, leading to a decline in digestion efficiency. This complicates the recovery of alumina resources and results in poor economic viability of the process [14, 15].

Based on the advantages and disadvantages of metallization reduction and magnetization roasting, this study proposes a low-temperature reduction roasting process for recovering iron and alumina from bauxite residue, which includes soda-enhanced magnetization roasting, atmospheric soda leaching, and weak magnetic separation. This study is dedicated to significantly reducing bauxite residue volume and efficiently recovering iron and alumina resources from bauxite residue at relatively low temperatures. It investigates the mineral phase transformation behaviour of roasted products under different roasting and batching ratio conditions, while exploring the recovery

(3) Over 92 % of the iron minerals in the roasted product are strongly magnetic magnetite. Among them, $Na_{1.75}Al_{1.75}Si_{0.25}O_4$ and $Na_{1.95}Al_{1.95}Si_{0.05}O_4$ are recovered via atmospheric leaching, achieving a comprehensive reduction rate of bauxite residue exceeding 93 %. The sodium aluminosilicate in the tailings has strong cementitious reactivity and can be used as a raw material for producing geopolymer-based green building materials, thereby enabling the full-scale and efficient utilization of bauxite residue.

5. References

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