Cleaning Disposal of High-Iron Bauxite Residue (Red Mud) Using Hydrochemical Conversion of Goethite to Magnetite

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Abstract

In this paper, the hydro-chemical conversion of goethite to magnetite process for treating high-iron bauxite residue (red mud) was investigated, and the optimum conditions of alumina extraction as well as the enrichment of iron minerals were verified. Results show that the magnetization of Al-goethite in the presence of Fe^{2+} accelerates its conversion to magnetite with the simultaneous Al release from the solid matrix. After ferrous oxide was added directly as $FeSO_4*7H_2O$ at the ferrous sulfate to bauxite residue ratio of 1:1 at 120 °C for 150 min in the alkaline media, the alumina extraction ratio reaches 97.13 % for sand and 89.13 % for bauxite residue and the grade of iron (total iron in the form of iron element) in the residue can be enriched to 69.55 % for sand and 58.31 % for bauxite residue. The obtained iron-rich residue can be used as a pigment-quality magnetite or in the steel industry.

Keywords: Red mud, High-iron, Al-goethite, Conversion, Magnetite.

1. Introduction

The bauxite residue (BR, red mud) production accounted for more than 200 million tonnes per annum [1]. BR is formed during the Bayer process used for alumina production worldwide via the alkaline method of leaching. As a result, BR contains a high amount of caustic alkali which makes this waste highly corrosive. In addition, the concentration of heavy metals after alumina extraction can be doubled in BR. Because its high toxicity and corrosivity, the BR utilization rate is very low, and it is stockpiled in large ponds.

Nevertheless, BR contains a high number of valuable components, such as iron, rare earth elements (REE), vanadium, titanium, etc [2]. The extraction of these elements from BR together with the reduction of its toxicity can be economically and ecologically beneficial. For example, BR produced during the processing of the Fria bauxite deposit in Guinea contains a very high amount of iron: from 40 % of the iron in BR to 55-60 % of the iron in sands formed by the gravity method of separation after digestion of bauxites on the Friguia alumina refinement.

Many methods of iron extraction from BR have been developed to date. These methods can be divided into pyro- and hydrometallurgical. Pyrometallurgical methods include magnetic separation after preliminary reductive roasting, reductive sintering with the different fluxes, and the smelting of BR with a reducing agent to obtain pig iron [3]. The major disadvantage of these methods is the high energy consumption because the temperature of these processes can be as high as 1000-1750 °C.

In the recent work of Li et al. [4,5], and Pasechnik et al. [6], it was shown that hematite from BR can be transformed into magnetite during a hydrothermal reduction in the presence of iron, Fe^{2+}, and OH^- ions (Equation (1)-(3)).

$$Fe + H_2O + OH^- = HFeO_2^- + H_2 \quad (1)$$

$$Fe^{2+} + 3\ OH^- = HFeO_2^- + H_2O \quad (2)$$

$$Fe_2O_3 + HFeO_2^- = Fe_3O_4 + OH^- \quad (3)$$

Furthermore, Zhou et al. [7] showed that the addition of Al during high-temperature digestion of high-iron BR, obtained after digestion of Guinea's high-iron bauxites, not only transforms iron into hematite covered by magnetite but also accelerates Al extraction from Al-goethite. However, high-pressure leaching at a temperature of 270 °C is needed for the formation of the iron-enriched residue with an iron content of 56 %.

In this work, a novel method of atmospheric pressure reduction of Guinea's high-iron BR using $FeSO_4$ was proposed. The optimum conditions of alumina extraction as well as the enrichment of iron minerals were verified. The solid residue was characterized using X-ray diffraction (XRD), SEM-EDS, and spectrophotometry methods.

2. Methods and Materials

The bauxite residue and the sand used in this research were obtained from Friguia alumina refinery in Guinea. The chemical compositions of BR and the sand are shown in Table 1. Other reagents, NaOH and $FeSO_4$*7H_2O were of analytical grade. Sodium alkaline solutions with the Na_2O concentration 330-400 g L^{-1} were prepared by dissolution of NaOH in distilled water.

Table 1. Chemical compositions of bauxite residue and sand from Friguia alumina refinery, Guinea.

Sample	Fe	Si	Ti	Al	Na	O	Other
Bauxite residue	41.7	4.25	4.36	12.34	4.53	30.68	2.14
Sand	56.23	0.77	1.38	5.55	1.26	33.80	1.01

The extraction of Al by NaOH and conversion of goethite to magnetite was carried out in the thermostated 0.5 L stainless steel reactor. The reactor has openings for overhead stirring as well as for temperature control and the recycling of evaporated water through a water-cooled condenser. The stirring speed in all experiments was 300 rpm; the liquid to BR ratio (L:S ratio) was 10; the molar ratio of Fe^{2+} to Fe_2O_3 in BR and sand according to Equation (3) was equal to 1. The BR and sand together with the iron sulphate were added to the solution with the Na_2O concentration from 330 g L^{-1} to 400 g L^{-1} that makes it possible to use atmospheric leaching process even at a temperature 120 °C. Temperature of the leaching was varied from 100 to 120 °C; leaching time – from 1 to 5 h. After leaching, the pulp was filtered; the solid residue was dried at 110 °C for 8 h before analysis using powder X-ray fluorescence spectrometry (XRF) with an Axios MAX spectrometer (Malvern Panalytical Ltd., Almelo, The Netherlands), and X-ray diffraction (XRD) using a Difrei-401 diffractometer (JSC Scientific Instruments, Saint Petersburg, Russia) using a Cr-Kα radiator with 2θ angles ranging from 15 ° to 140 °. The operating mode of the X-ray source was 25 kW/4 mA with 30 min of exposure time. Match 3 software was used to process the diffraction data.

production. The difference in extraction degree and the total iron content in the solid residues obtained from sand and BR can be attributed to the higher amount of hematite and sodalite in BR. Sc acid leaching or lime causticisation can be used to reduce sodalite content in BR before disposal in iron production.

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5. References

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