Journal of Mineral Resources Engineering, 9(4): 115-132, (2024)

Imam Khomeini International University

Vol. 9, No. 4, Winter 2024

نشریه مهندسی منابع معدنی

Journal of Mineral Resources Engineering (JMRE)

Research Paper

A Feasibility Study of Extracting Alumina from Kaolin by Calcination, Dissolution, and Solvent Extraction

Azizi S.[1], Abdollahy M.[2*], Mohseni M.[3]

1- M.Sc, Dept. of Mining Engineering, Tarbiat Modares University, Tehran, Iran
2- Professor, Dept. of Mining Engineering, Tarbiat Modares University, Tehran, Iran
3- Assistant Professor, Dept. of Mining Engineering, Tarbiat Modares University, Tehran, Iran

Received: 12 Aug. 2023 **Accepted: 13 Mar. 2024**

Abstract: This paper studies the extraction of alumina from kaolin through an acidic leaching process. The kaolin sample used in this study was taken from the Zonuz kaolin mine (Iran Porcelain Industries Company) at particle sizes smaller than 150 microns. Calcination of the kaolin sample was conducted at 700 ºC for 2 hours. Aluminum was leached from calcined kaolin with an H_2SO_4 acid solution. Temperature and time of leaching, acid concentration, and liquid-to-solid ratio were investigated as leaching parameters. The optimal leaching conditions were considered at 90 °C, 3 hours duration, 2.5 M acid concentration, 7 ml/g liquid-to-solid ratio, and 600 rpm stirring speed, and under these conditions, aluminum leaching recovery was obtained at 94.87%. To remove the iron impurity that is transferred to the solution during leaching, the pregnant leaching solution was purified. Purification was done by solvent extraction with an organic phase containing D2EHPA as an extractant and oil as a diluent, iron removal was achieved at 88.71%. By precipitating the aluminum hydroxide from a solution of aluminum sulfate with sodium hydroxide followed by calcination of the produced aluminum hydroxide at a temperature of 1200 °C for 2 hours, alumina with a purity of 97% was produced. The total recovery of alumina obtained from the studied kaolin under optimal conditions was 89.46%, which is desirable.

Keywords: Alumina, Kaolin, Calcination, Acidic leaching, Precipitation.

How to cite this article
Azizi, S., Abdollahy, M., and Mohseni, M. (2024). *"A feasibility study of extracting alumina from kaolin by calcination, dissolution, and solvent extraction"*. Journal of Mineral Resources Engineering, 9(4): 115-132.
DOI: 10.30479/jmre.2024.19160.1656

*Corresponding Author Email: *minmabd@modares.ac.ir*

INTRODUCTION

Alumina (Al_2O_3), or aluminum oxide, is the only oxide formed by aluminum metal, and bauxite is sedimentary mineral rich in aluminum, which is considered the main source of alumina [1-3]. In addition to bauxite, there are other minerals rich in aluminum, such as alunite, nepheline syenite, kaolinite, kyanite, andalosite, and sillimanite, which are used to produce aluminum in some countries [4-7]. Kaolin is one of the main groups of clay minerals, and the most important mineral in this group is kaolinite ($Al_2Si_2O_5(OH)_4$) [8]. The methods used to extract alumina from clays are divided into two categories: the acid process and the alkaline process [9-11]. By comparing the acid leaching of calcined kaolin using HNO_3, H_2SO_4, and HCl, Halbert and Huff found that the leaching rate among HNO_3, H_2SO_4, and HCl is the fastest with HCl and the slowest with HNO_3 [12]. By using an acid process with H_2SO_4 or HCl and then precipitation and calcination of the produced aluminum hydroxide, researchers have been able to produce alumina with a purity of over 96%, and their extraction efficiency has been over 90% [13-17]. Researchers have been able to produce alumina with a purity of 98% and a recovery of 85% by using an alkaline process with sodium carbonate solution as a leaching agent and then precipitation and calcination. In extracting aluminum from kaolin by leaching, acids are more effective than bases [9,10,18-20]. Alumina with a grade of 90 to 98% is suitable for all kinds of ceramic products that are used in a wide range of applications [21].

METHODS

The sample of kaolin required in this research was prepared from the Zonuz mine located in Marand city in the East Azarbaijan province of Iran. The particle size of the sample was smaller than 150 microns, with D_{80} equal to 63 microns. The main steps used in this research to extract alumina from kaolin are calcination of kaolin, acid leaching of calcined kaolin, followed by filtration, purification (solvent extraction), precipitation, and final calcination. Sulfuric acid 98% (H_2SO_4) was used as a leaching agent, sodium hydroxide (NaOH) as a precipitation agent, and D2EHPA and oil were used as organic phases in the solvent extraction operation.

FINDINGS AND ARGUMENT

According to the chemical analysis, the aluminum grade of the calcined sample was 6.55% on average, and the maximum amount of extractable aluminum was considered equivalent to it. . In XRF analysis, 16.626% by weight of Al_2O_3 was observed, and disturbing chemical compounds of SiO_2 (75.042% by weight) and Fe_2O_3 (0.348% by weight) were detected. The results of XRD analysis also showed that the dominant phases are kaolinite ($Al_2Si_2O_5(OH)_4$) and quartz (SiO_2).

When the uncalcined kaolin sample was leached in a sulfuric acid solution with a concentration of 3 M at a liquid-to-solid ratio of 5 ml/g at a temperature of 90 ºC for 2 hours with a stirring speed of 600 rpm, the percentage of extracted aluminum was only 3%. Therefore, before leaching, kaolin must first be calcined, because calcination converts kaolin to metakaolin ($Al_2Si_2O_7$), which is more reactive and from which aluminum is easily leached. The optimal conditions for kaolin calcination were obtained at 700 °C for 2 hours.

By investigating the effect of different amounts of leaching parameters on aluminum recovery, the optimal conditions of the parameters of the leaching process were obtained as follows: leaching temperature of 90°C, leaching time of 3 hours, acid concentration of 2.5 M, liquid-to-solid ratio of 7 ml/g, and stirring speed of 600 rpm. Under optimal conditions, aluminum recovery was obtained at 94.87%.

A single-step solvent extraction method was used to remove iron in this research. According to the obtained results, the best conditions for carrying out this process are suggested as follows: ambient temperature, ratio of organic phase to aqueous phase 1:1, ratio of constituents of organic phase was 40% D2EHPA and 60% oil, pH=1, and the mixing time of the organic phase with the aqueous phase was 45 minutes. In this condition, by adjusting the pH to 1, 5.695% Al loss and 13.35% Fe removal were achieved, and by performing the solvent extraction process, trace amounts of Al removal and 84.94% Fe removal were achieved. In general, Fe removal was 88.71% under the aformentioned optimal conditions.

The results of precipitation and the investigation of the effect of pH on its recovery showed that by increasing the pH to 7, the recovery of the precipitation process also increases, and by precipitating aluminum sulfate solution with NaOH, aluminum hydroxide is precipitated in the form of gibbsite. Alumina with a purity of 97% was produced by the calcination of aluminum hydroxide precipitate at a temperature of 1200 °C for a duration of 2 hours. The results of the identified phases show that the thermodynamic phase of the produced alumina is α-Al_2O_3.

The recovery of each stage of the leaching, purification, and sedimentation steps was 94.87%, 94.305%, and 99.99%, respectively. From the processing of 100 g of calcined kaolin for the extraction of alumina, with optimal conditions obtained in all process steps, 10.99 g of alumina was produced with a purity of 97% and a total recovery of 89.46%. Therefore, for every 100 g of kaolin, 10 to 11 g of Al_2O_3 are obtained.

CONCLUSIONS

In this research, the extraction of alumina from kaolin with an acid process that includes steps such as calcination of kaolin, acid leaching of calcined kaolin, removal of iron from the leaching solution using the solvent extraction method, precipitation of aluminum from the purified leaching solution with sodium hydroxide, and final calcination. The precipitation of aluminum hydroxide was for the production of aluminaby calcination, and alumina with a purity of 97% and a total recovery of 89.458% was obtained. Therefore, due to the high content of alumina in kaolin, it can be considered an alternative source instead of bauxite for the extraction of alumina.

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