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INTEGRATED TECHNOLOGY FOR THE RECOVERY OF IRON, SILVER, AND COPPER FROM ZINC PRODUCTION WAELZ CLINKER

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Abstract. This study investigates a technology for recovering valuable components from clinker generated during the Waelz process in zinc production. The clinker was characterized using chemical, mineralogical, and instrumental methods. Microwave thermal treatment was applied to reduce carbon and sulfur contents and improve separation. Magnetic separation was used to obtain an iron-rich concentrate, while the non-magnetic fraction was processed by hydrometallurgical leaching. Silver was leached using the Jinchan reagent and recovered from solution by zinc powder cementation. Copper was subsequently extracted from the residue through sulfuric acid leaching. The results demonstrate the potential for recovery of valuable metals from zinc industry waste.

Keywords: zinc production, Waelz clinker, technogenic waste, microwave roasting, magnetic separation, hydrometallurgical leaching.

INTRODUCTION

The rapid development of the metallurgical industry, the increasing demand for mineral resources, and the growing volume of industrial waste have made the comprehensive processing of technogenic materials an important scientific and technological challenge. Despite advances in existing metallurgical technologies, the efficient recovery of all valuable components from industrial waste remains difficult. In particular, waste generated by non-ferrous metallurgy often contains significant amounts of iron, copper, zinc, gold, silver, and other valuable elements, making its treatment as a secondary mineral resource highly relevant.

One of the important by-products of zinc production is clinker generated during the Waelz process. This material contains valuable metallic components, including iron, copper, and silver. However, the complex mineralogical composition of clinker, the presence of carbon, and the distribution of metals among different mineral phases complicate their effective recovery using conventional processing methods. Therefore, the development of an integrated processing technology that takes into account the chemical and mineralogical characteristics of clinker is essential for improving metal recovery efficiency.

In this regard, the combination of microwave thermal treatment, magnetic separation, and hydrometallurgical leaching represents a promising approach to the comprehensive processing of zinc industry waste. Microwave treatment can facilitate changes in the mineral structure and reduce the carbon and sulfur content, thereby creating more favorable conditions for subsequent separation and leaching operations. Magnetic separation makes it possible to recover an iron-rich fraction, while the non-magnetic fraction can be further processed to extract valuable and non-ferrous metals through selective leaching and cementation processes.

The purpose of this study is to develop and investigate an integrated technology for recovering valuable components from zinc production clinker. Particular attention is given to determining the technological parameters of microwave roasting, magnetic separation, silver leaching using the Jinchan reagent, silver cementation with zinc powder, and copper leaching using sulfuric acid. The proposed approach is aimed at improving the recovery of valuable metals, reducing their losses in technogenic waste, and expanding the possibilities of using industrial residues as secondary mineral raw materials.

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MATERIALS AND METHODS

The material used in this study was clinker generated during the Waelz process at the zinc plant of Almalyk Mining and Metallurgical Complex (AMMC), Uzbekistan. The initial clinker sample had a mass of 200 kg, with a maximum particle size of 30 mm. According to the chemical analysis, the material contained valuable components, including iron, zinc, copper, lead, gold, and silver, as well as carbon and other mineral compounds. The chemical and mineralogical characteristics of the clinker were investigated to determine the distribution of valuable metals and their suitability for further processing.

A combination of chemical, physicochemical, mineralogical, and technological methods was employed. The analytical methods included X-ray diffraction (XRD), scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS), atomic absorption and emission spectrometry, X-ray fluorescence analysis, infrared spectrometry, and granulometric analysis. Thermogravimetric analysis was also used to investigate the thermal behavior of the material. These methods enabled the evaluation of the initial clinker composition and the structural and phase changes occurring during processing.

The experimental procedure consisted of several consecutive stages. First, the clinker was subjected to microwave thermal treatment to reduce its carbon and sulfur content and improve the conditions for subsequent separation processes. The influence of temperature, microwave power, and treatment duration on the properties of the calcined material was investigated. The roasted product was then processed by magnetic separation to obtain an iron-rich magnetic concentrate and a non-magnetic fraction containing the main part of the valuable non-ferrous and precious metals.

The non-magnetic fraction was subjected to hydrometallurgical leaching to recover silver using the Jinchan reagent in the presence of hydrogen peroxide (H_2O_2). The effects of reagent consumption, temperature, pH, solid-to-liquid ratio, and leaching duration on silver extraction were investigated. The silver-containing solution was subsequently treated by cementation using zinc powder. Finally, the solid residue obtained after cementation was leached with sulfuric acid to recover copper. The effects of acid concentration, temperature, solid-to-liquid ratio, and processing time were evaluated.

The experimental results were processed using mathematical and statistical analysis, material balance calculations, and the determination of technological performance indicators. Metal recovery was evaluated based on the distribution of valuable components between the obtained products and solutions. This integrated experimental approach made it possible to assess the effectiveness of microwave treatment, magnetic separation, and hydrometallurgical processing in the comprehensive recovery of valuable components from zinc production clinker.

RESULTS AND DISCUSSION

The experimental results demonstrated that microwave thermal treatment significantly improves the technological properties of clinker generated during the Waelz process. The treatment was conducted to reduce the carbon and sulfur contents and facilitate the subsequent recovery of valuable metals. The results showed that microwave roasting reduced the carbon content by 99% and the sulfur content by 96%. These changes indicate that thermal treatment contributes to the transformation of the clinker structure and creates more favorable conditions for the separation of valuable components. The investigation of roasting duration also showed a gradual decrease in calcine yield: from 87.6% after 15 minutes to 78.6% after 90 minutes. This trend reflects the removal of volatile components and changes in the material during thermal processing.

Following microwave treatment, the roasted clinker was subjected to magnetic separation. The experiments established that a magnetic concentrate containing 90.8% iron could be obtained at a magnetic field current of 2 A. The degree of iron recovery into the magnetic fraction reached 91%. This result confirms the effectiveness of magnetic separation for concentrating iron-bearing components and separating them from the non-magnetic material. The non-magnetic fraction, in which

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the main part of the valuable non-ferrous and precious metals remained, was subsequently directed to hydrometallurgical processing.

Silver recovery from the non-magnetic fraction was investigated using the Jinchan reagent in the presence of hydrogen peroxide. The experimental results showed that increasing the Jinchan consumption improved silver extraction. At a reagent consumption of 20 kg/t, silver extraction reached approximately 90.1%. Further experiments established the following optimal leaching conditions: Jinchan consumption of 20 kg/t, H_2O_2 consumption of 4 ml/L, temperature of 65 °C, pH 11, solid-to-liquid ratio of 1:3, and leaching duration of 1.5 hours. Under these conditions, the silver extraction degree reached 90.82%, according to the dissertation's final results. The findings indicate that reagent consumption and the physicochemical conditions of the leaching process have a substantial influence on silver recovery.

The silver-containing solution obtained after leaching was treated by cementation using zinc powder. The results showed that the efficiency of silver precipitation depended on the pH of the solution and the duration of cementation. At pH 9, the degree of silver cementation reached approximately 96% after 3 minutes and 99% after 5 minutes. This confirms that zinc powder can be effectively used to recover silver from the pregnant leach solution under the investigated conditions.

The solid residue remaining after silver cementation was further processed by sulfuric acid leaching to recover copper. According to the experimental results summarized in the dissertation, the most favorable conditions included an H_2SO_4 concentration of 140 g/L, a temperature of 50 °C, a solid-to-liquid ratio of 1:5, and a leaching duration of 120 minutes. Under these conditions, copper extraction into solution reached 88.8%. The results demonstrate the possibility of recovering copper from the residue after silver extraction and cementation.

Overall, the experimental findings confirm the effectiveness of combining microwave thermal treatment, magnetic separation, and hydrometallurgical processes for the comprehensive treatment of zinc production clinker. The proposed sequence makes it possible to obtain an iron-rich magnetic concentrate, recover silver from the non-magnetic fraction, and subsequently extract copper from the remaining solid residue. Thus, the integrated approach provides a technological basis for recovering valuable components from Waelz clinker and reducing their losses in industrial waste.

CONCLUSION

The results of this study demonstrate the effectiveness of an integrated technology for recovering valuable components from clinker generated during the Waelz process in zinc production. Microwave thermal treatment reduced the carbon content by 99% and sulfur content by 96%, creating favorable conditions for subsequent processing. Magnetic separation at a current of 2 A enabled the production of an iron-rich concentrate containing 90.8% Fe, with an iron recovery degree of 91%. These findings confirm that the combination of microwave treatment and magnetic separation is an effective approach to improving the separation of iron-bearing components from zinc production clinker.

Furthermore, hydrometallurgical processing of the non-magnetic fraction enabled the recovery of silver and copper. Under the established optimal conditions, silver extraction using the Jinchan reagent reached 90.82%, while subsequent cementation with zinc powder at pH 9 achieved approximately 99% silver recovery after 5 minutes. Sulfuric acid leaching of the remaining solid residue resulted in copper extraction of 88.8%. Overall, the proposed technological sequence—microwave roasting, magnetic separation, silver leaching and cementation, followed by copper leaching—provides an effective basis for the comprehensive processing of zinc industry clinker. The findings highlight the potential of utilizing technogenic waste as a secondary source of valuable metals and improving the efficiency of industrial waste treatment.

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