Suspension Magnetization Roasting with Low-Intensity Magnetic Separation Process for Iron Recovery from Red Mud

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Abstract

In order to solve the problems of poor quality and low yield of iron concentrate from direct magnetic separation of high-iron red mud, a technology of "suspension magnetization roasting combined with low-intensity magnetic separation " was developed. The effects of magnetization roasting temperature, magnetization roasting time, CO concentration, grinding fineness and low intensity magnetic separation field strength were studied. The raw high-iron red mud, with a total iron (TFe) content of 43.51 %, yielded an iron concentrate of 67.69 % with a TFe grade of 56.21 % under optimal conditions, alongside tailings with a 22.51 % yield and 24.26 % TFe grade. X-ray diffraction (XRD) and chemical phase analyses confirmed that weakly magnetic hematite and limonite were selectively reduced to strongly magnetic magnetite during roasting, while aluminum-bearing phases (diaspore, gibbsite, boehmite) dehydrated into Al_2O_3, and gangue minerals (quartz, rutile) remained stable. This process enhanced the magnetic contrast, enabling efficient separation and high-value utilization of red mud.

Keywords: High-iron red mud, Suspension magnetization roasting, Mineral phase reconstruction, Low-intensity magnetic separation, Iron ore concentrate

1. Introduction

Red mud, a byproduct of alumina production, presents significant disposal challenges due to its high alkalinity, fine particle size, and complex mineralogy. In China, approximately 107 Mt were generated in 2023, contributing to a stockpile exceeding 1.6 Gt [1–3]. Rich in valuable metals such as iron, titanium, lithium, gallium, and rare earth elements, red mud represents both an environmental liability and an underutilized resource [4, 5]. However, its comprehensive utilization rate in China was only 9.80 % in 2023, well below the 60 % target outlined in the National Development and Reform Commission's "Guiding Opinions on the Comprehensive Utilization of Bulk Solid Waste in the 14th Five-Year Plan" document. The steel industry is an important industry in the national economy. China has abundant reserves of iron ore resources, but the endowment is poor. Most of them belong to low-grade complex and difficult to select ores, which are difficult to meet the needs of China's steel industry and social development. As a result, the import volume of iron ore in China has been increasing year by year. In 2023, the import volume of iron ores will be 1.16 Gt, and the external dependence will exceed 80 % [6, 7]. Therefore, the recovery of iron minerals from red mud can not only achieve the goal of reduction on the environmental remediation cost of red mud, but also increase the added value of red mud solid waste. Apart from that, iron concentrate can also provide raw materials for regional steel enterprises, meeting the national strategic needs of ecological civilization construction and ensuring the safe supply of iron resources, which is of great significance.

This study introduces a "suspension magnetization roasting combined with low-intensity magnetic separation" process to recover iron from high-iron red mud, investigating its effects on mineral phase reconstruction and separation efficiency to support industrial-scale application.

2. Study on the Properties of Red Mud

2.1 Composition Analysis of Red Mud

Multi-element and phase composition analyses were conducted on low-temperature dissolved red mud derived from imported bauxite at an alumina plant in Henan Province. These analyses aimed to guide the subsequent separation and enrichment of valuable minerals. The analysis results of the X-ray Fluorescence Spectrometer (XRD) and X-ray Diffusion (XRF) are shown in Table 1 and Table 2, respectively.

Table 1. Multi-element analysis results of red mud (%).

Element	Al_2O_3	SiO_2	Fe_2O_3	TFe	TiO_2	K_2O	Na_2O	CaO	MgO	Cr_2O_3
Content	13.48	3.55	62.15	43.51	3.79	0.17	1.22	3.1	0.19	0.19
Element	P	S	Loss on Ignition							
Content	0.077	0.049	9.96							

Table 2. Phase composition analysis results of red mud (%).

Phase	Limonite	Hematite	Perovskite	Diaspore	Quartz	Rutile	Boehmite
Content	34.51	35.50	3.07	2.03	1.70	2.13	3.08
Phase	Gibbsite	Calcite	Sodium-silicon residue		Hydrated garnet		
Content	5.11	1.63	6.85		2.08		

According to the analysis results of Table 1, the main valuable metal element of red mud is iron, and its TFe grade is 43.51 %, which belongs to high iron red mud; the amount of Al_2O_3, SiO_2 and TiO_2 is 13.48 %, 3.55 % and 3.79 %, respectively. The amount of harmful elements sulphur and phosphorus is low, 0.077 % and 0.049 % respectively. It can be seen from the phase analysis results in Table 2 that the valuable element iron in the high-iron red mud is mainly in the form of hematite (limonite), and the red mud also contains sodium silicon slag, hydrated garnet, gibbsite, diaspore, calcite, rutile, perovskite, quartz, and other gangue minerals. Among them, the useful mineral limonite accounts for 49.29 %. Because the magnetism of limonite is weaker than that of hematite, it is more difficult to recover iron-bearing minerals by direct magnetic separation.

2.2 Red Mud Particle Size Analysis

The high-iron red mud samples were analysed by laser particle size analyser. The particle size distribution of high-iron red mud is shown in Fig.1 and Table 3. According to the analysis results of Figure. 1 and Table 3, it can be seen that the particle size distribution of high-iron red mud is bimodal, and the particle size distribution is wide. The volume of -30 μm particle size distribution accounts for 37.71 %, and -10 μm accounts for 20.50 %. There are more fine-grained distribution and a certain amount of coarse-grained distribution, +150 μm accounts for 19.29 %. It can be seen that the fluidization velocity of gas needs to be controlled to avoid the loss of fine particles in the process of suspension magnetization roasting.

4. Conclusion

In this paper, "Suspension Magnetization Roasting and Low-Intensity Magnetic Separation" technology was applied to recover iron-bearing minerals from high-iron red mud, and the effect of suspension magnetization roasting on the phase reconstruction of iron minerals in high-iron red mud was studied. The key findings of this study are summarized as follows:

1. The study on the properties of high-iron red mud shows that the amount of TFe in the original red mud is 43.51 %. The valuable element iron is mainly red (brown) iron ore, and its distribution rate reaches 97.63 %. The high-iron red mud also contains sodium silicon slag, hydro garnet, gibbsite, diaspore, calcite, rutile, perovskite, and quartz.

2. The high-iron red mud with a TFe grade of 43.51 % was subjected to suspension magnetization roasting process combined with low-intensity magnetic separation under the conditions of roasting fluidization speed of 0.3 m/s, magnetization roasting temperature of 800 °C, roasting time of 2.0 min, CO concentration of 15 %, a grinding fineness of 72 % passing 0.023 mm, and low-intensity magnetic separation field of 0.25 T. The iron tailings for preparing cement with a yield of 67.69 %, a TFe grade of 56.21 %, a recovery rate of 87.45 %, a yield of 22.51 %, and a TFe grade of 24.26 % were obtained, which realized the high-value comprehensive utilization of red mud.

3. It was found that the weak magnetic hematite (limonite) iron ore was directionally converted into strong magnetic magnetite during the suspension magnetization roasting process of red mud. Some gibbsite, and boehmite were dehydrated and converted into Al_3O_2, while the gangue minerals such as quartz, rutile, perovskite, and sodium silicon slag did not change. The specific magnetization coefficient gap between iron minerals and gangue minerals was expanded, which laid a foundation for the recovery of high-grade iron concentrate from roasted red mud by weak magnetic separation.

5. References

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