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Investigation on purification of α-Fe_2O_3 from zinc smelting iron slag by superconducting HGMS technology

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Abstract

Comprehensive utilization of zinc smelting iron slag not only solves environmental problems but also creates huge economic benefits. This study was conducted on the enrichment and recovery of α-Fe_2O_3 from zinc smelting iron slag by superconducting HGMS technology. Several variables such as slurry flow velocity, slag concentration, magnetic field intensity and the amount of dispersing agent were tested in magnetic separation. In the experiments, obtained optimal magnetic separation parameters were 1.60 T of magnetic flux intensity, 600 mL/min of slurry flow velocity of, 15 g/L of slag concentration of, 0.10 g/L of dispersing agent. Under this condition, the content of α-Fe_2O_3 was increased from 86.22% to 94.39% that can approach the Chinese national standard requirements (A level) of iron oxide red. It was concluded that using superconducting HGMS technology was an effective method for the purification of α-Fe_2O_3 from zinc smelting iron slag.

Keywords : superconducting HGMS, zinc smelting iron slag, α-Fe_2O_3, separation and purification

1. INTRODUCTION

Iron oxide red was the largest color inorganic pigment [1]. The global production of iron oxide red was about 1 million t/a [2], which widely be used in building materials, coatings, inks, rubber, plastics, ceramics and other industrial fields owing to the merits of wide color gamut, inexpensive, non-toxic, weather-resistant and anti-rust. As the most important part of iron oxide red, the magnetism of α-Fe_2O_3 was so weak that cannot be separated and purified by conventional magnetic separation technology.

Iron oxide was the principal constituent in zinc smelting iron slag, which was commonly treated by roasting to get α-Fe_2O_3. Consequently, the extraction of α-Fe_2O_3 from the zinc smelting iron slag can help to protect the environment and achieve economic value. High gradient magnetic separation (HGMS) was a new kind of magnetic separation technology [3] that can be effectively applied to the separation and purification of weak magnetic materials. The HGMS system consists of an array of magnetic matrices and a uniform background magnetic field. The matrices were usually achieved by stainless-steel wools of high magnetic susceptibility [4].

For the recovery of the α-Fe_2O_3, the different magnetism of various constituents of zinc smelting iron slag were the basis for magnetic separation. In the process of magnetic separation, large magnetic particles and weak magnetic small particles were easily separated from less magnetic substances. However, the less magnetic particles would be sucked by the steel wool if the magnetic field large enough, which would cause the decline of α-Fe_2O_3 content in the steel wool. Therefore, suitable magnetic separation parameters had great significance for the actual purification process.

2. EXPERIMENTAL

2.1. The raw materials

The zinc smelting iron slag samples were provided by a zinc smelting plant (Jiyuan, Henan province, China). It was ground to 200 mesh for component testing, and the chemical constituents and mineralogical characteristics were analyzed by a series of detection methods, such as X-ray fluorescence (XRF), and X-ray diffraction (XRD) with Cu-Kα radiation between 10°and 80° (2θ). The XRF analysis results of the tailings samples were presented in Table 1, the phase analysis results of the slag were presented in Fig 1. It was found that the samples had high Fe and S contents from Table 1. According to Fig. 1, Fe_2O_3 was the main phase and other iron-containing minerals include $NaFe_3(SO_4)_2(OH)_6$, $KFe_3(SO_4)_2(OH)_6$, $FeOH(SO_4)_3H_2O$, FeOOH.

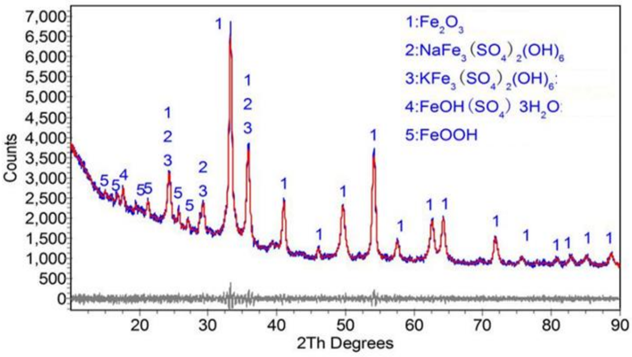

Fig. 1. X-ray diffraction pattern of the raw slags

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TABLE 1
COMPONENT ANALYSIS OF TAILINGS SAMPLES BY XRF (%).

Chemical composition	Fe_2O_3	CaO	SiO_2	SO_3	MnO	ZnO	K_2O	CuO	As_2O_3
Mass fraction （%）	86.220	0.356	0.885	8.773	0.130	3.235	0.247	0.031	0.123

TABLE 2
THE MAIN PARAMETERS OF MAGNET[5].

Item	**Specification**
Central magnetic field strength	5.5T
Room temperature aperture	300mm
Length of magnet (not including iron shield)	1110mm
Height of magnet (not including iron and service tower)	780mm
Working current	150A
Magnets inductance	127H
Energy storage	1.33MJ

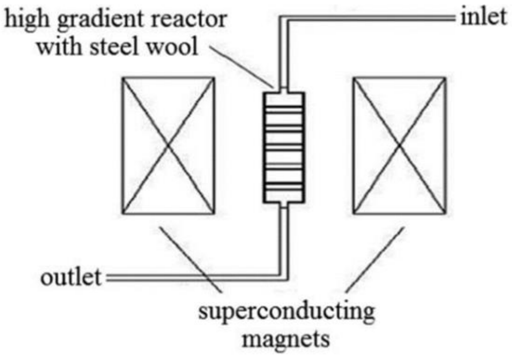

Fig. 2. Schematic diagram of superconducting HGMS

2.2. Separation device and parameters

The device of magnetic separation experiments was made by the Institute of High Energy Physics (IHEP) of Chinese Academy of Sciences (CAS) [6]. Low temperature cooling system provided the necessary environment for superconducting magnet. In order to ensure the entire temperature consistency and stability of superconducting system, superconducting coils were immersed in liquid helium. Low temperature cooling system was designed to be after-condenser mode [7]. The main specification of the magnet were exhibited in Table 2. The schematic diagram of the separators was shown in Fig. 2.

2.3. Ancillary equipment

The auxiliary equipment used included peristaltic pump (WT600-1F/KZ25), analytical balance (AUY220), constant temperature oven (JXX1-277607), X-ray camera (D/MAX-RB), Scanning Electron Microscope (SUPRATM55), constant temperature magnetic stirrer (HJ-3) and so on.

3. RESULTS AND DISSCUSSION

3.1. Effect of magnetic flux intensity on separation efficiency

Magnetic intensity was an important parameter that effect the efficiency of magnetic separation. In this test, different intensities from 0.8 to 2.0 T were attempted with a slag concentration of 20 g/L, dispersing agent 0.15 g/L and a slurry flow velocity of 600 mL/min. The test results were exhibited in Fig. 3.

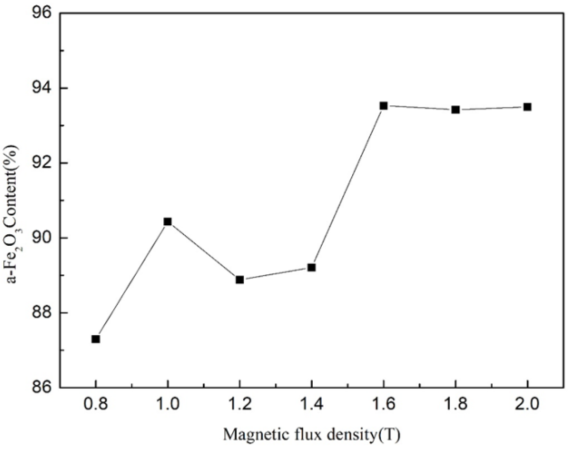

Fig. 3. The effect of magnetic flux density on separation efficiency.

It can be seen from Fig. 3 that magnetic flux density had an appreciable effect on separation efficiency. The α-Fe_2O_3 content of magnetic concentrate firstly increases with the increase of magnetic flux density and reaches the maximum value of 93.53% at the magnetic flux density of 1.6 T, and then drops with its further increase. In the magnetic separation process, weak magnetic particles were mainly affected by magnetic flux density. The content of α-Fe_2O_3 in the steel wool increases with the increase of the magnetic flux intensity. However, further increase of the magnetic flux intensity decrease the α-Fe_2O_3 contents and it is possible by some weak magnetic particles and non-magnetic fine particles would also be adhered by the steel wool, which would affect the α-Fe_2O_3 contents.

As we can see from the Fig. 4, steel wool adsorp more larger particles from the slurry, while some small particles of weak magnetic would get together to form some new larger weak magnetic particles by magnetic flocculation, which could also be adsorbed by steel wools. In the magnetic field, particles were under a three-way competition:

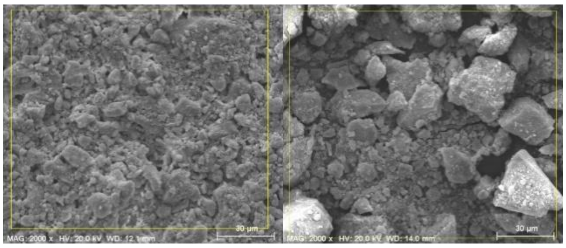

Fig. 4. The original slag(left) and steel wool adsorption(right).

magnetic force, gravitational and interparticle force [8]. The most essential factor that influences the magnetic efficiency is the magnetic susceptibility of particles [9]. The magnetic force (F_M) can be calculated by (1):

$$F_M = V\frac{\chi}{\mu_0}B\frac{dB}{dx} \tag{1}$$

Where χ is the magnetic susceptibility of particles, μ_0 is the permeability in vacuum, V is the particle volume, B is the magnetic flux density, and dB/dx is the magnetic flux density gradient.

It could be seen that large particles were easier to be captured than small at the same condition. Therefore, at the appropriate magnetic field strength, steel wools adsorbed more large particles and some fine particles that come together, as shown in Fig. 4 (right).

3.2. Effect of slurry flow velocity on separation efficiency

The effects of slurry flow velocity (ranging from 300 to 900 mL/min) on separation efficiency were investigated with the magnetic flux density of 1.6 T, dispersing agent of 0.15 g/L and a slag concentration of 20 g/L.

Fig. 5 illustrates the relationship between the α-Fe_2O_3 and a slurry flow velocity. It was found that the α-Fe_2O_3 content firstly elevate slowly with the increase of slurry flow velocity until it reaches 600 mL/min, and then it descends sharply with the further increase of slurry flow velocity. Hence, the optimal value for slurry flow velocity was selected at 600 mL/min. It was due to the residence time of the slag slurry in the magnetic separation device. It may be due to the magnetic force exerted by the α-Fe_2O_3 particles in the slurry suspension is less than the fluid resistance of the particles at this time, so the particles cannot be caught by steel wool, which led to the content of α-Fe_2O_3 decline.

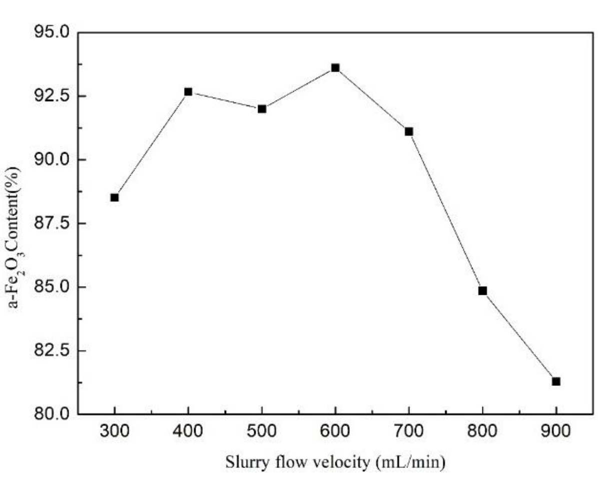

Fig. 5. The effect of slurry flow velocity on separation efficiency.

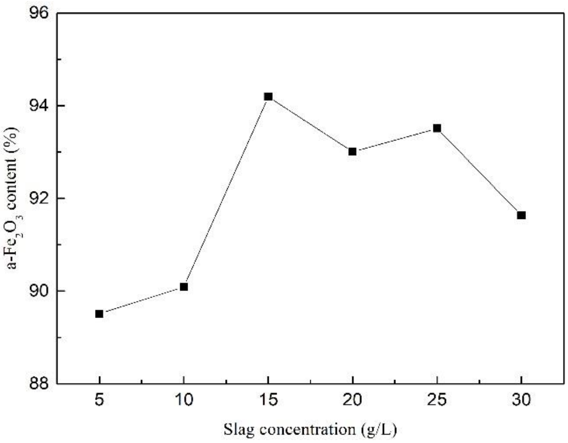

Fig. 6. The effect of slag concentration on separation efficiency.

3.3. Effect of slag concentration on separation efficiency

Besides the slurry velocity and magnetic flux density, the slag concentration also could have a great influence on the separation efficiency. Fig. 6 shows the relationship of the contents of α-Fe_2O_3 and slag concentration when magnetic flux density was 1.6 T and slurry flow velocity was 600 mL/min.

As seen from Fig. 6, the slag concentration had considerable effect on separation efficiency. When the concentration was about 15g/L, the experimental results were the best. The slag concentration was an important factor because it affects production efficiency in practical production. The optimal value for slag concentration was selected at 15 g/L. The separation efficiency mainly depends on the magnetic force (F_M) and fluid force (F_D). The F_D of particles can be calculated by (2) [10]:

$$F_D = 6\pi\eta r_p\left(V_f - V_p\right) \tag{2}$$

where η is the rate of viscosity, r_p is the radius of particle, V_f is the slurry flow velocity, and V_p is the particle velocity.

From the (2), we can know that the magnetic particles would be separated from non-magnetic particles when $F_M > F_D$. F_D increase with the slag concentration increase. Therefore, the separation efficiency would decline when the condition is $F_M < F_D$. Otherwise, the increased slurry flow velocity could strengthen the hydrodynamic viscous resistance, which might result in the increase of F_D and the decrease of resultant force acting on the magnetic particles. As a result, those weakly magnetic α-Fe_2O_3 failing to be captured by the steel wools, accordingly, the yield of α-Fe_2O_3 is decreased. It confirmed that overly increases in slag concentration and slurry flow velocity all decrease the amount of α-Fe_2O_3 captured by steel wools.

3.4. Effect of dispersing agent on separation efficiency

To investigate the effects of dispersing agent on separation efficiency, the dispersing agent was changed from 0 to 0.5 g/L, with other parameters keeping constant,

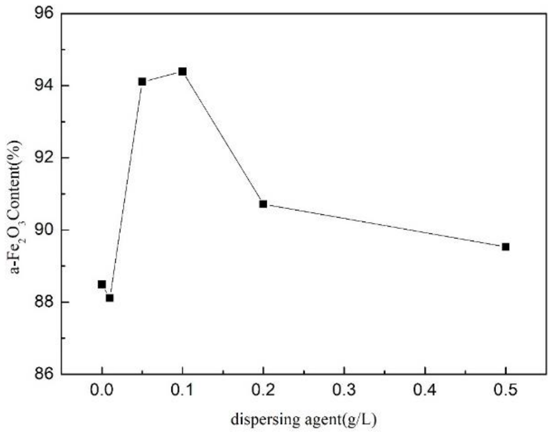

Fig. 7. The effect of dispersing agent on separation efficiency.

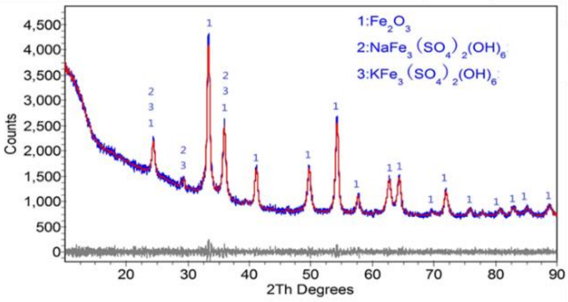

Fig. 8. X-ray diffraction pattern of the products after purification.

i.e. a magnetic flux density of 1.6 T, a slurry flow velocity of 600 mL/min and a slag concentration of 15 g/L.

As Fig.7 shows, the α-Fe_2O_3 content of magnetic concentrate reaches the maximum value of 94.39% at the dispersing agent of 0.1 g/L. It was can confirmed that add dispersants could improve the separation efficiency, but the amount of dispersant was not the more the better, too little dispersing agent would have ineffective on the progress of separation, but the amount of dispersing agent be used too much, all the particles in the suspension may be dispersed, and some non-ferrous magnetic particles also be adsorbed by steel wools, which would affect the separation efficiency. The phase analysis results of the products after purification are presented in Fig. 8, α-Fe_2O_3 was the main phase and other iron-containing minerals include $NaFe_3(SO_4)_2(OH)_6$, $KFe_3(SO_4)_2(OH)_6$. The α-Fe_2O_3 content of magnetic concentrate reaches the maximum value of 94.39%, which can approach the national standard requirements (A level) of iron oxide red.

4. CONCLUSIONS

HGMS was an effective way to purify α-Fe_2O_3 from zinc smelting iron slag. Based on the experiments and analyses, the magnetic flux density, slurry velocity and slag concentration as well as the amount of dispersing agent had great influence on separation efficiency.

In summary, the α-Fe_2O_3 in zinc smelting iron slag can be efficiently recovered under the appropriate parameters, i.e., a magnetic flux density of 1.6 T, a slurry velocity of 600 g/L, a slag concentration of 15 g/L and a dispersing agent of 0.1 g/L. The maximum content of α-Fe_2O_3 was increased from 86.22% to 94.39%, which can approach the Chinese national standard requirements (A level) of iron oxide red. It can be widely used in the pigment industry in the future.

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