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Recovery of magnetite from waste ferrous sulfate using polyethylene glycol (PEG) as a dispersant

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Abstract: The effect of PEG dispersant on the magnetic separation of magnetite (Fe₃O₄) synthesized from ferrous sulfate solution via co-precipitation method with calcium hydroxide as the precipitant was investigated. The results indicated that a PEG dispersant could significantly affect Fe₃O₄ recovery. Adding PEG during the preparation of Fe₃O₄ was unfavorable for Fe₃O₄ recovery. When the PEG-6000 concentration was increased from 0 to 8 g/L, the iron grade and median particle size of the Fe₃O₄ product decreased from 65.58% and 2.35 μ m to 57.79% and 1.35 μ m, respectively. However, adding PEG during the wet milling of the mixed product promoted the subsequent recovery of Fe₃O₄. When the amount of PEG-200 increased from 0% to 4% of the powder mass, the grade of iron in the Fe₃O₄ product increased from 65.58% to 68.32%. While the relative molecular mass of PEG at an amount of 4% of the powder mass increased from 200 to 20000, the grade of iron was reduced from 68.32% to 66.70%. **Key words:** ferrous sulfate; Fe₃O₄; PEG; co-precipitation; magnetic separation; wet milling

1 Introduction

Ferrous sulfate (FeSO₄·7H₂O) is a by-product of titanium dioxide manufacture via the sulfate method. In this method, 3-4 t ferrous sulfate is generated to obtain 1 t titanium dioxide. In China, about 98% of the titanium dioxide is manufactured by the sulfate method, thereby yielding more than 7×10^6 t ferrous sulfate waste each year, and the annual growth rate in waste emissions production exceeds 10% as titanium dioxide expands [1,2]. Unfortunately, this waste is less marketable and difficult to be utilized due to its high impurity contents (i.e., Mg, Mn, Ti, Zn and Al) [3], which causes not only severe environmental problems but also the waste of iron resource.

Using ferrous sulfate to produce iron oxides is an effective method for ferrous sulfate re-utilization because of the increasing demand for iron oxides driven by the increasing consumption in industry. Fe_3O_4 , with fascinating properties, including good biocompatibility, high surface area, low toxicity, super-paramagnetism,

and high saturation field [4], has attracted much attention from both academic and industrial interests in many application fields, such as magnetic storage media, solar transformation, catalysis, biological energy and sensing. ferrofluids chemical and environmental remediation [5-9]. In environmental engineering, however, the utilization of Fe₃O₄ particles prepared from reagent-grade chemicals could not be cost-effective in the full-scale process, due to the characteristics of the water or wastewater, such as high flow rate, and the presence of various pollutants and associated high consumption and loss of particles [10]. In this work, we proposed a novel and low cost method to synthesize Fe_3O_4 particles from waste ferrous sulfate.

Numerous methods have been developed for preparing Fe_3O_4 particles, such as co-precipitation [11], microemulsions [12], sol–gel syntheses [13], and hydrothermal or solvothermal process [14]. However, the most common method for producing synthetic Fe_3O_4 particles is the co-precipitation of Fe^{2+}/Fe^{3+} ions (molar ratio 1:2) by sodium hydroxide or ammonia solution [15]. In our approach, Fe_3O_4 was recovered from ferrous

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1466

sulfate solution by co-precipitation and magnetic separation with calcium hydroxide as the precipitant [16,17]. We used lime instead of other alkali reagents due to its availability and low cost. Although caustic soda (NaOH) can be used for the pH adjustment, its price is 5 times higher than that of lime [18].

In the magnetic separation process, the Fe_3O_4 particles tend to heterocoagulate, so a good dispersion is required to improve their separation efficiency. The application of a polymeric dispersant in the magnetic separation of Fe_3O_4 , however, has not drawn considerable attention. Since PEG is a water soluble polymer together with the other properties, such as biocompatibility, low immunogenicity, and ease of use [19], we investigated the effect of a PEG dispersant on the magnetic separation of Fe_3O_4 synthesized from waste ferrous sulfate. The aim of this work is to investigate the effect of adding PEG during the preparation of Fe_3O_4 or during the wet milling of the mixed product on magnetite recovery.

2 Experimental

2.1 Materials

Reagent-grade NaOH, CaO, and PEG (Guangdong Xilong Chemical Co., Ltd., China) were used directly without further purification. The dried ferrous sulfate was obtained from Guangdong Hui Yun Titanium Industry Corporation Limited, China. The dried ferrous sulfate sample was further dried in a vacuum atmosphere at 80 °C for 12 h, and then its chemical composition was analyzed by X-ray fluorescence (XRF), as given in Table 1. The sample was composed of O (39.24%), Fe (36.08%), S (22.11%) and other impurities.

 Table 1 Chemical composition of dried ferrous sulfate (mass fraction, %)

0	Fe	S	Mg	Ti	Mn	Zn	Al
39.24	36.08	22.11	1.24	0.89	0.31	0.02	0.02

The ferrous sulfate solution was purified with the addition of NaOH solution to precipitate impurities [16]. The solution pH was adjusted to 3.5-4.0 by 5 mol/L NaOH solution, followed by continuous stirring for 30 min at room temperature. After filtration, the solution was diluted with distilled water. The diluted solution was used as an iron source for the Fe₃O₄ preparation and its composition is given in Table 2.

 Table 2 Chemical composition of purified ferrous sulphate solution (g/L)

Fe	Mg	Ti	Mn	Zn	Al
22.400	0.744	0.012	0.337	0.060	0.031

2.2 Experimental procedures

Fe₃O₄ was prepared from ferrous sulfate solution by co-precipitation method with calcium hydroxide as the precipitant. 4 L of purified ferrous sulfate solution (Table 2) was added to a 5 L, four-necked flask fitted with a reflux condenser and electric heater. Lime milk was obtained by adding distilled water to calcium oxide (CaO) at a liquid-to-solid mass ratio of 3:1 under vigorous stirring. Then, the lime milk with a 1.4:1 molar ratio of CaO/Fe²⁺ was added dropwise to the solution under sufficient stirring. The reactor was heated to 80 °C, and air was bubbled into the solution at $0.6 \text{ m}^3/\text{h}$. When the mole ratio of Fe^{3+}/Fe^{2+} in the reaction solution reached 1.9:1-2.1:1, the reaction was stopped. The obtained mixture of Fe₃O₄ and gypsum (CaSO₄·2H₂O) was then filtrated, dried, and ground for use in subsequent experiment. The wet-milling pretreatment was conducted at room temperature in a ball mill using a slurry with a mixed product-to-water mass ratio of 1:40 and a rotation speed of 130 r/min. The time of milling was 20 min, and the treated mixed product was directly subjected to magnetic separation. Magnetic separation was performed using a low-intensity magnetic separator (CRIMM DC CXGø50, Changsha Research Institute of Mining and Metallurgy Co., Ltd., China), with a working electrical current of 1.75 A. The magnetic fractions were washed, filtered, dried, weighed and subjected to various analyses. Fe₃O₄ can be formed from ferrous salts according to the following reactions [20]:

$aO+H_2O\rightarrow Ca(OH)_2$ (1)
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 $FeSO_4 + Ca(OH)_2 + 2H_2O \rightarrow Fe(OH)_2 + CaSO_4 \cdot 2H_2O$ (2)

 $4Fe(OH)_2 + O_2 + 2H_2O \rightarrow 4Fe(OH)_3 \tag{3}$

$$2Fe(OH)_3 + Fe(OH)_2 \rightarrow Fe_3O_4 + 4H_2O \tag{4}$$

In this work, the effect of PEG dispersant on the magnetic separation of Fe_3O_4 was investigated as follows: 1) During the preparation of Fe_3O_4 , PEG-6000 with a concentration ranging from 0 to 8 g/L was added to the reaction solution; 2) During the wet milling of the mixed product, PEG-200, in amounts ranging from 0% to 16% of the powder mass, was added to the slurry; PEG, with a relative molecular mass ranging from 200 to 20000, was also studied at an amount under 4% of the powder mass.

The procedure used to recover Fe_3O_4 from ferrous sulfate is shown in Fig. 1.

2.3 Analysis

The samples were analyzed to examine the ferrous and ferric iron contents according to GB/T 1863–2008 (Chinese National Standard). The contents of trace elements in sample were determined by inductively coupled plasma optical emission spectrometry (ICP-OES, iCAP 7000 SERIES, Thermo Scientific) after the total dissolution of samples. Phase analysis of the products was conducted by a Rigaku D/max-TTR III X-ray diffractometer (XRD) with Cu K_a radiation (λ = 1.54056 Å, voltage of 40 kV, and current of 250 mA) and at the scanning rate of 10 (°)/min from 10° to 70°. To identify the functional groups present in the product, Fourier transform infrared (FT-IR) spectrometer (WQF-510A, Beijing Beifen-Ruili Analytical Instrument (Group) Co., Ltd., China) was used to record the spectrum from 400 to 4000 cm⁻¹. The raw material sample was measured by X-ray fluorescence (XRF) with a Bruker S4 Pioneer system equipped with two X-ray detectors. Surface morphology of the samples was observed by using a FEI Quanta 200 scanning electron microscope (SEM), coupled with an energy dispersive X-ray spectroscope (EDS). Laser particle size analyzer (LS-pop(6), Zhuhai OMEC Instrument Co., Ltd., China) was used to analyze the size distribution of samples. Magnetic properties of the samples were measured with a vibrating sample magnetometer (VSM, Quantum Design) at room temperature.

After the experiment, the recovery rate of iron in the Fe_3O_4 product (*R*) was calculated based on the mass of iron in the raw material (the purified ferrous sulfate solution) and defined as follows:

$$R = m_1 / m \times 100\%$$
 (5)

where m_1 is the mass of iron in the Fe₃O₄ product and *m* is the mass of iron in the raw material.

The grade of iron in the Fe_3O_4 product (*G*) was calculated based on the mass of the Fe_3O_4 product and defined as follows:

$$G=m_1/m_2 \times 100\%$$
 (6)

where m_2 is the mass of the Fe₃O₄ product.

3 Results and discussion

3.1 Characterization of Fe₃O₄ product without adding PEG

In this work, a mixed product was first prepared from ferrous sulfate solution by co-precipitation with calcium hydroxide as the precipitant. Figure 2(a) shows the XRD pattern of the mixed product. XRD analysis indicated that Fe₃O₄ (JCPDS, No. 19–0629) and CaSO₄·2H₂O (JCPDS, No. 33–0311) were the major components. The SEM image of the mixed product is shown in Fig. 2(b). From Fig. 2(b), two distinct phases (zones *A* and *B*) were observed: the phase in zone *A* was irregularly shaped plates, while fine phase in zone *B* were apt to aggregate. The subsequent EDS analysis proved that the two phases were CaSO₄·2H₂O (zone *A*) and Fe₃O₄ (zone *B*), which is in agreement with the above XRD results.

After the co-precipitation stage, Fe_3O_4 was obtained from the mixed product with wet milling prior to the magnetic separation. The grade of iron in the mixed product without adding PEG was determined by titration to be 20.55%, while that in the Fe_3O_4 product was



Fig. 1 Flow sheet of Fe_3O_4 recovery from ferrous sulfate



Fig. 2 XRD pattern (a) and SEM image (b) of mixed product without adding PEG

65.58%. The XRD pattern and SEM image of the Fe₃O₄ product are shown in Figs. 3(a) and (b), respectively. Figures 3(a) and (b) show that a highly crystallized Fe₃O₄ product with a nearly spherical shape was obtained. However, a peak attributable to calcite (CaCO₃) emerged in the product, as shown in Fig. 3(a). The reaction to form CaCO₃ can be expressed by the following reaction equation:

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \tag{7}$$

In subsequent experiments, the PEG dispersant was added before the magnetic separation to decrease the content of calcite in the Fe_3O_4 product.



Fig. 3 XRD pattern (a) and SEM image (b) of Fe_3O_4 product without adding PEG

3.2 Adding PEG during preparation of Fe₃O₄

3.2.1 Influence of concentration of PEG on magnetic separation of Fe_3O_4

To investigate the influence of the PEG dispersant on the magnetic separation of Fe_3O_4 , a series of experiments were performed with the PEG-6000 concentrations ranging from 0 to 8 g/L. PEG-6000 was added to the reaction solution before the co-precipitation stage, and the effects of PEG-6000 concentration on the grade and recovery rate of iron in the Fe_3O_4 product are shown in Fig. 4. It is revealed that both the grade and recovery rate of iron decreased rapidly with the increase of PEG-6000 concentration. When the PEG-6000 concentration fluctuated from 0 to 8 g/L, the grade and recovery rate of iron decreased from 65.58% to 57.79% and from 80.35% to 27.20%, respectively. These results indicate that the addition of the PEG dispersant during the preparation of Fe_3O_4 was not conducive to Fe_3O_4 recovery.



Fig. 4 Effects of PEG-6000 concentration on grade and recovery rate of iron in Fe_3O_4 product

It has been proposed that Fe_3O_4 is formed by air-oxidation of $Fe(OH)_2$ via dissolution and recrystallization [21]. PEG, as a crystalline water-soluble polymer, can greatly increase the viscosity of the solution system, which restrains the hydrated iron and ferrous ions migrating from the solution to the surface of the Fe₃O₄ crystal nucleus. Hence, the size of the Fe₃O₄ particle is not too large because of the growth-restraint of the Fe₃O₄ microcrystals [4,22]. This inhibition is proportional to the concentration of PEG in the reaction system. The particle size distributions of the Fe₃O₄ products are presented in Fig. 5. As shown, the size of the Fe₃O₄ particles decreased gradually with an increase in the PEG-6000 concentration, and the median particle sizes of the Fe₃O₄ particles obtained at 0, 2, 4 and 8 g/L



Fig. 5 Size distributions of Fe₃O₄ products obtained at different PEG-6000 concentrations

1468

PEG-6000 were 2.35, 1.80, 1.66 and 1.35 µm, respectively.

In this work, Fe₃O₄ was obtained from the mixed product by magnetic separation. However, magnetic, gravity and hydrodynamic drag forces are the major forces that govern the overall behavior of mineral particles in a magnetic separator [23]. While magnetic forces attract magnetic particles, gravity and drag forces work against magnetic forces. Particle size of minerals has a pronounced influence on the magnitude of these forces. It has been reported that the hydrodynamic drag forces are dominant for fine particles, the gravitational forces are dominant for the coarse particles, and the magnetic forces are dominant for particles in the intermediate size range [24]. Thus, adding PEG dispersant during the preparation of Fe₃O₄ would be unfavorable for Fe₃O₄ recovery because of the size reduction of the Fe₃O₄ particles.

3.2.2 XRD patterns and FT-IR spectra

Figure 6(a) gives the XRD patterns of the Fe_3O_4 products obtained at different PEG-6000 concentrations. All the XRD patterns were in good agreement with the standard pattern for Fe_3O_4 . These peaks were very intensive, indicating a high crystallinity. However, a peak attributable to CaCO₃ emerged in all the XRD patterns.



Fig. 6 XRD patterns (a) and FT-IR spectra (b) of Fe_3O_4 products obtained at different PEG-6000 concentrations

More intense diffraction peaks indicate more extensive crystallization of the particles [25]. Figure 6(a) shows that the peak intensity of Fe_3O_4 decreased with the increase of PEG-6000 concentration, indicating that the obtained product contained less Fe_3O_4 phase with a lower degree of crystallization. These results are consistent with the results shown in Fig. 4.

The FT-IR spectra of the Fe₃O₄ products obtained at different PEG-6000 concentrations are shown in Fig. 6(b). All the products showed characteristic absorption bands at wave numbers around 579, 876, and 1429 cm⁻¹. The IR bands at 577–579 cm⁻¹ could be indexed as the Fe—O bond of Fe₃O₄ [26,27], whereas the IR bands at 876 cm⁻¹ and 1429–1436 cm⁻¹ could be assigned to the bending vibrations of the CO_3^{2-} group in the calcite structure [28,29]. These results are in agreement with the above XRD analysis.

3.3 Adding PEG during wet milling of mixed product

3.3.1 Influence of amount of PEG on magnetic separation of Fe_3O_4

Generally, in many industries handling fine powders, small quantities of dispersants can remarkably improve the grinding efficiency, so they have been widely used in ultrafine wet grinding processes [30]. In this work, Fe₃O₄ was recovered from the mixed product by wet milling prior to magnetic separation, and the PEG dispersant was added to the mixed product slurry at the beginning of the milling process. To study the effect of the amount of PEG on the magnetic separation of Fe₃O₄, a series of experiments were performed with the amount of PEG-200 ranging from 0% to 16% of the powder mass. Figure 7 shows the effects of the PEG-200 amount on the grade and recovery rate of iron in the Fe₃O₄ product. It can be seen that both the grade and recovery rate increased significantly with the amount of PEG-200 ranging from 0% to 4% and achieved their maximum (68.32% and 83.14%) at 4%. A slight downward trend



Fig. 7 Effects of PEG-200 amount on grade and recovery rate of iron in Fe_3O_4 product

was observed with a further increase of the PEG-200 amount. It is clearly demonstrated by the obtained results that adding the PEG dispersant during the wet milling of the mixed product was favorable for Fe_3O_4 recovery and the optimal amount of PEG-200 was 4% of the powder mass.

In the magnetic separation process, fine particles are attracted to each another by van der Waals attractive forces to form aggregates or flocs; hence, a good dispersion is required to improve the separation efficiency [31]. However, by the addition of a small amount of a water-soluble surface-active polymer, it is possible to change the nature of the interparticle forces to be entirely repulsive. The fine particles will therefore not flocculate, but remain as discrete entities [32,33]. For small PEG dosages, the newly-created fracture surface generated in the mixed product grinding process could not adsorb enough PEG to form a stable dispersion system. However, when an excessive amount of PEG was used, it led to the polymer bridging among the particles [34], which had an adverse effect on the stability of the mixed product slurry. Therefore, the optimal PEG-200 dosage for further experiments was chosen to be 4% of the powder mass. A potential mechanism of the PEG-200 dispersant action in milling prior to the magnetic separation process is schematized in Fig. 8.

The particle size distributions of the Fe₃O₄ products obtained at different PEG-200 amounts are shown in Fig. 9. The size distributions of the Fe₃O₄ particles were self-similar, and the median particle sizes of Fe₃O₄ particles obtained at 0%, 2%, 4%, and 16% PEG-200 were 2.35, 2.35, 2.48 and 2.42 μ m, respectively. It can be inferred that the addition of the PEG dispersant during the milling process could not change the particle size of the Fe_3O_4 product. This is because the shape of the powders is determined by the grinding mechanisms operating in the mill, but the grinding mechanisms cannot be altered by the presence of dispersants [35].

The XRD patterns of the Fe₃O₄ products obtained at different PEG-200 amounts are given in Fig. 10. All the XRD patterns had obvious diffraction peaks and matched well with the reflections of the standard Fe₃O₄. CaCO₃ was only observed when the PEG-200 amount was 0%. This result indicates that it was not easy to obtain a pure-phase product without adding the PEG dispersant, which is consistent with the results shown in Fig. 7. Figure 11 gives the FT-IR spectra of the Fe₃O₄ products obtained at different PEG-200 amounts. All the products exhibited an absorption peak at around 577 cm⁻¹, corresponding to the Fe-O bond in Fe₃O₄. Notably, the product obtained at 0% PEG-200 exhibited absorption peaks at 876 cm⁻¹ and 1436 cm⁻¹, which were attributed to the CO_3^{2-} group in CaCO₃. These results are in agreement with the above XRD results.

The chemical composition of the Fe₃O₄ products obtained at different PEG-200 amounts was determined by titration and ICP-OES, and the results are presented in Table 3. It is shown that the product obtained by adding PEG contained higher concentrations of Fe, Ti, and Mn compared with the product obtained without adding PEG, whereas the product obtained by adding PEG contained less Ca, S and Mg, and the content of Ca was notably reduced from 2.01% to 0.81%. The results well accord with the previous results shown in Figs. 7 and 10. Therefore, it can be concluded that the effective magnetic separation of Fe₃O₄ can be realized by adding PEG dispersant during the wet milling of the mixed product, through a substantial reduction of the content of calcite in the Fe₃O₄ product.



Fig. 8 Schematic diagram of changes of potential in milling prior to magnetic separation process using PEG-200 as dispersant



Fig. 9 Size distributions of Fe₃O₄ products obtained at different PEG-200 amounts



Fig. 10 XRD patterns of Fe₃O₄ products obtained at different PEG-200 amounts



Fig. 11 FT-IR spectra of Fe_3O_4 products obtained at different PEG-200 amounts

3.3.2 Influence of relative molecular mass of PEG on magnetic separation of Fe₃O₄

To illustrate the influence of the relative molecular mass of the PEG dispersant on the magnetic separation

of Fe₃O₄, a series of experiments were performed with the relative molecular mass of PEG ranging from 200 to 20000. Figure 12 shows the grade and recovery rate of iron in the Fe₃O₄ product obtained at different PEG relative molecular masses. It is shown that by increasing the relative molecular mass from 200 to 20000, the grade of iron was gradually reduced from 68.32% to 66.70% while the recovery rate of iron increased from 83.14% to 85.01%. These results indicate that the increase in the PEG relative molecular mass led to a reduction in the efficiency of the magnetic separation. REN et al [36] and YANG et al [37] reported that polymers with larger relative molecular masses can form a better conjunction with Fe₃O₄ particles, leading to well-enwrapped large particles, which results in the remarkable decrease of the magnetic property. Hence, the increase of the PEG relative molecular mass resulted in a poor magnetic separation probably because of a reduction in the magnetic property of the Fe₃O₄ particles.

Table 3 Chemical compositions of Fe_3O_4 products obtained at different PEG-200 amounts (mass fraction, %)



Fig. 12 Effects of PEG relative molecular mass on grade and recovery rate of iron in Fe_3O_4 product

3.4 Magnetic properties

The magnetic properties of the Fe₃O₄ products obtained without and with the PEG dispersant were measured at room temperature, and the magnetic hysteresis (*M*–*H*) loops are presented in Fig. 13. It is shown that the Fe₃O₄ product obtained without adding PEG exhibited the highest magnetization saturation (M_s) of 79.963×10⁻³ A·m²/g, a coercivity value (H_c) of 5878.44 A/m, and a remanence value (M_r) of 8.8972×10⁻³ A·m²/g (Fig. 13(a)). While adding PEG

during the preparation of Fe₃O₄, the $M_{\rm s}$ and $M_{\rm r}$ for the Fe_3O_4 product decreased to 58.796×10^{-3} and 7.7917×10^{-3} A·m²/g, respectively, but the H_c increased to 6527.60 A/m (Fig. 13(b)). These observations are consistent with the results in Figs. 5 and 6. It is well known that the decrease in the particle size can lead to an increasing surface-to-volume ratio, which in turn increases the surface spin disorder and consequently results in a reduction in the saturation magnetization [38]. The reduction in the overall magnetic phase concentration or poor crystallization may also affect the magnetic behavior of the as-synthesized powder by reducing the saturation magnetization and slightly increasing the coercive force [39,40]. However, when adding PEG during the wet milling of the mixed product, $M_{\rm s}$ for the Fe₃O₄ product increased to 83.656×10^{-3} A·m²/g, which is not far from the theoretical value of bare Fe₃O₄ (~90×10⁻³ A·m²/g) [41], and H_c decreased to 5729.28 A/m (Fig. 13(c)). This result indicates that the obtained Fe₃O₄ product possessed stronger magnetic properties after adding the PEG dispersant during the wet milling of the mixed product.



Fig. 13 Magnetization versus magnetic field curves of Fe_3O_4 products obtained without adding PEG (a), with adding PEG-6000 (4 g/L) during preparation of Fe_3O_4 (b) and with adding PEG-200 (4% of powder mass) during wet milling of mixed product (c)

4 Conclusions

1) The effect of PEG dispersant on the magnetic separation of Fe_3O_4 synthesized from a ferrous sulfate solution via co-precipitation with calcium hydroxide as the precipitant was investigated. The results indicated that the PEG dispersant had a significant influence on Fe_3O_4 recovery. When PEG was added during the preparation of Fe_3O_4 with PEG-6000 concentration increasing from 0 to 8 g/L, the grade of iron in the Fe_3O_4 product decreased from 65.58% to 57.79%. This result could be explained by the size reduction of the Fe_3O_4

particles, which was unfavorable for the magnetic separation of Fe_3O_4 .

2) When PEG was added during the wet milling of the mixed product and the PEG-200 amount was increased from 0% to 4% of the powder mass, the grade of iron in the Fe₃O₄ product increased from 65.58% to 68.32%. The addition of PEG in the milling process made it possible to change the nature of the interparticle forces to be entirely repulsive, which caused an increase in the efficiency of the subsequent magnetic separation. While the relative molecular mass of PEG at an amount of 4% of the powder mass increased from 200 to 20000, the grade of iron was reduced from 68.32% to 66.70%. Polymers with larger molecular mass can give rise to improved conjunction to Fe₃O₄ particles and lead to a more remarkable decrease of the magnetic property, which results in a poor magnetic separation. In addition, the obtained Fe₃O₄ product possessed stronger magnetic properties after adding the PEG dispersant during the wet milling of the mixed product.

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以 PEG 为分散剂从废绿矾中回收 Fe₃O₄

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摘 要: 以 CaOH 为沉淀剂通过共沉淀从绿矾溶液中回收 Fe₃O₄,研究分散剂 PEG 对 Fe₃O₄磁分离的影响。结果 表明,分散剂 PEG 对 Fe₃O₄的回收有显著影响。在 Fe₃O₄制备过程中添加 PEG 不利于 Fe₃O₄ 的回收。当 PEG-6000 浓度从 0 增加到 8 g/L 时, Fe₃O₄产品的铁品位从 65.58%降至 57.79%,中值粒径从 2.35 μm 降至 1.35 μm。然而, 在混合产物的湿磨过程中添加 PEG 可促进随后的 Fe₃O₄ 回收。当 PEG-200 用量从粉末质量的 0%增加到 4%时, Fe₃O₄产物中铁的品位从 65.58% 升高到 68.32%。当 PEG-200 用量为 4%时,改变 PEG 相对分子质量从 200 增加 到 20000, Fe₃O₄产物中铁品位从 68.32%降至 66.70%。 **关键词:** 绿矾; Fe₃O₄; PEG; 共沉淀; 磁分离; 湿磨

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