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Parameter Optimization of the Separation Process for Hematite and Quartz Mixture Minerals Based on a Cyclone Centrifugal Separator

Yanling Jin [1], Haiyun Xie [1,2,*], Peng Zeng [1], Jialing Chen [1], Luzheng Chen [1,*], Dianwen Liu [1,2] and Rongxin Liu [1]

[1] Faculty of Land Resource Engineering, Kunming University of Science and Technology, Kunming 650093, China
[2] Yunnan Key Laboratory of Green Separation and Enrichment of Strategic Mineral Resources, Kunming 650093, China
* Correspondence: xiehaiyun@kust.edu.cn (H.X.); chluzheng@kust.edu.cn (L.C.)

Abstract: The current centrifugal concentrators do not continuously concentrate heavy minerals of large mass weight—for example, in the processing of iron oxides. A cyclone centrifugal separator is a new type of beneficiation equipment that has been developed on the basis of the principles of centrifugal separation and hydrocyclones. In this study, a cyclone centrifugal separator was used for the beneficiation of a hematite–quartz mixture, and the separation effect under different operating conditions was analyzed. The results showed that various factors, such as the feeding concentration, the feeding pressure, and the number of fluidization holes in the separation cone, had a significant influence on the separation performance of the cyclone centrifugal separator. The single-factor separation test results showed that the appropriate operating conditions were a feeding concentration of 10%, a feeding pressure of 120 kPa, a 40-hole separation cone, a settling port pressure of 70 kPa, and an overflow port pressure of 50 kPa. The results of the open circuit separation test that was designed on the basis of the single-factor experiment showed that the concentrate grade of Fe in the hematite–quartz mixture, with 44.12% Fe, was 54.42% after beneficiation, indicating better beneficiation separation effects. This study provides a new approach for the beneficiation of a large number of difficult-to-select hematite ores in China, and can provide a reference for the further expansion and application of the cyclone centrifugal separator in the field of mineral processing.

Keywords: hematite; Cyclone Centrifugal Separator; separation

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1. Introduction

Iron is a common ferrous metal that has wide application in various fields, including metallurgy, chemical industry, and the manufacture of mechanical equipment [1,2]. Hematite (α-Fe_2O_3), an iron mineral that is widely distributed in nature, is an important raw material for iron smelting. It also has applications as a red pigment [3]. Although China possesses 12% of the world's iron ore reserves, over 20% of these reserves are difficult to separate from hematite ore [4,5]. Hematite is a weakly magnetic oxide mineral that is commonly associated with gangue minerals, such as quartz and aluminosilicate. High-intensity magnetic or roasting-magnetic separation processes and flotation are commonly used to enrich hematite ore. However, the main drawbacks of these methods are their low separation efficiency, their high cost, and their pollution of the environment. Therefore, there is an urgent need to develop a low-cost, highly efficient, and environmentally friendly separation process for hematite ore.

Gravity separation is a clean process that offers advantages such as low energy consumption, environmental friendliness, and low production cost. It has become an important beneficiation method [6–10]. However, existing types of gravity separation equipment, such as spiral separators and shaking tables, are not suitable for hematite ore separation,

due to the small density difference between hematite and gangue minerals. Therefore, there is an increasing need for the development of new equipment and technology for the separation of hematite ore.

Centrifugal concentrators use enhanced gravity to enlarge the density difference between particles, thereby separating heavy and light particles in a fluid. Compared with other gravity separation methods, such as shaking tables and spiral separators, centrifugal separation has significant advantages in terms of processing capacity and separable particle size [11,12]. In particular, centrifugal concentrators can provide considerable centrifugal force that is dozens of times that of gravity, allowing ultrafine mineral particles to be recovered from slimes and tailings. For example, Knelson concentrators, Falcon concentrators, and the SLon centrifugal concentrator have been effectively used to recover fine minerals such as gold, tungsten, native copper, and hematite [13–15]. In the early 1960s, China successfully developed the Yunxi-type centrifugal concentrator, which can selectively enrich fine heavy minerals, for separating fine-grained tin, tungsten, and hematite. However, the discontinuous operation and high mechanical failure rate of this centrifugal concentrator limited its widespread application. Since 2007, the SLon centrifugal concentrator has been developed on the basis of the Yunxi-type centrifugal concentrator and used for the beneficiation of weak magnetic ores such as hematite [5,16], and later for the recovery of ultrafine tungsten and tin values from tailings and slurry [17–19]. Fluidized bed centrifugal separation technology, represented by Knelson and Falcon centrifugal concentrators, has been widely used in the mining industry [20–23], but centrifugal separation has problems, including intermittent tailings discharges and a low processing capacity [24–26].

Therefore, based on the principles of centrifugal separation and hydrocyclone, a cyclone centrifugal separator has been developed. The cyclone centrifugal separator has a simple structure and is easy to operate [27–29]. This article analyzes its main structure and its separation mechanism and discusses the impact of key parameters on its separation performance, using a hematite–quartz mixture as an example and providing a reference for the industrial application of the cyclone centrifugal separator.

2. Materials and Methods

2.1. Materials

The hematite ore sample utilized in this experiment was obtained from Yuxi, Yunnan Province, China. The sample underwent crushing and grinding by a SGF200x75 roller crusher (Nanchang Honghao Laboratory Equipment Co., Ltd., Nanchang, China); it also underwent XRF multi-element analysis. The analysis results are presented in Table 1, and the Fe phase analysis results are shown in Table 2.

Table 1. Major element analysis of hematite ore sample.

Ingredient	Fe	SiO_2	Al_2O_3	CaO	MgO	ZnO
Content/%	58.77	10.63	7.54	3.62	1.23	0.11

Table 2. Fe phase analysis results of hematite ore sample.

Element	Hematite	Magnetite	Limonite	Specularity	Siderite	Pyrite
Content/%	58.81	1.78	1.96	2.34	2.79	1.25
Distribution/%	83.25	2.52	2.77	3.31	3.95	1.77

As shown in Table 1, the iron grade of the hematite ore was 58.77%, with SiO_2 and Al_2O_3 being the main gangue components. Table 2 shows that the main iron mineral in the sample was hematite (83.25%); the other minerals were other iron oxides.

We prepared a synthetic material with an iron grade of 44.12% using the hematite ore sample with an iron content of 58.77% and quartz ore with an SiO_2 content of 95.60% as raw materials.

2.2. Separating Equipment: Cyclone Centrifugal Separator

2.2.1. Operating Principle

The separation test was carried out using a cyclone centrifugal separator. The equipment schematic and a three-dimensional model of the cyclone centrifugal separator are shown in Figure 1. As shown in Figure 1a, the test used some fittings and pressure gauges connected to a semi-industrial continuous centrifugal separator. The equivalent diameters of the feeding ore pipe, the concentrate port, the tailings port, and the water supply pipe were 16 mm, 19 mm, 25 mm, and 16 mm, respectively. Two pressure gauges were installed on the feeding pipe and the settling chamber to measure the feeding pressure and the water supply pressure, respectively. The feeding pressure and the water supply pressure were controlled and adjusted by a frequency converter connected to the feeding pump and the water supply pump. In all tests, the concentrate port and the tailings port were open at fixed values (the equivalent diameters of the concentrate port and the tailings port were 16 mm and 6.3 mm, respectively). The three-dimensional model of the cyclone centrifugal separator is shown in Figure 1b, consisting of three separation rings with a diameter of 100 mm, each of which was uniformly distributed, with 8 fluidization holes with a diameter of 4.5 mm.

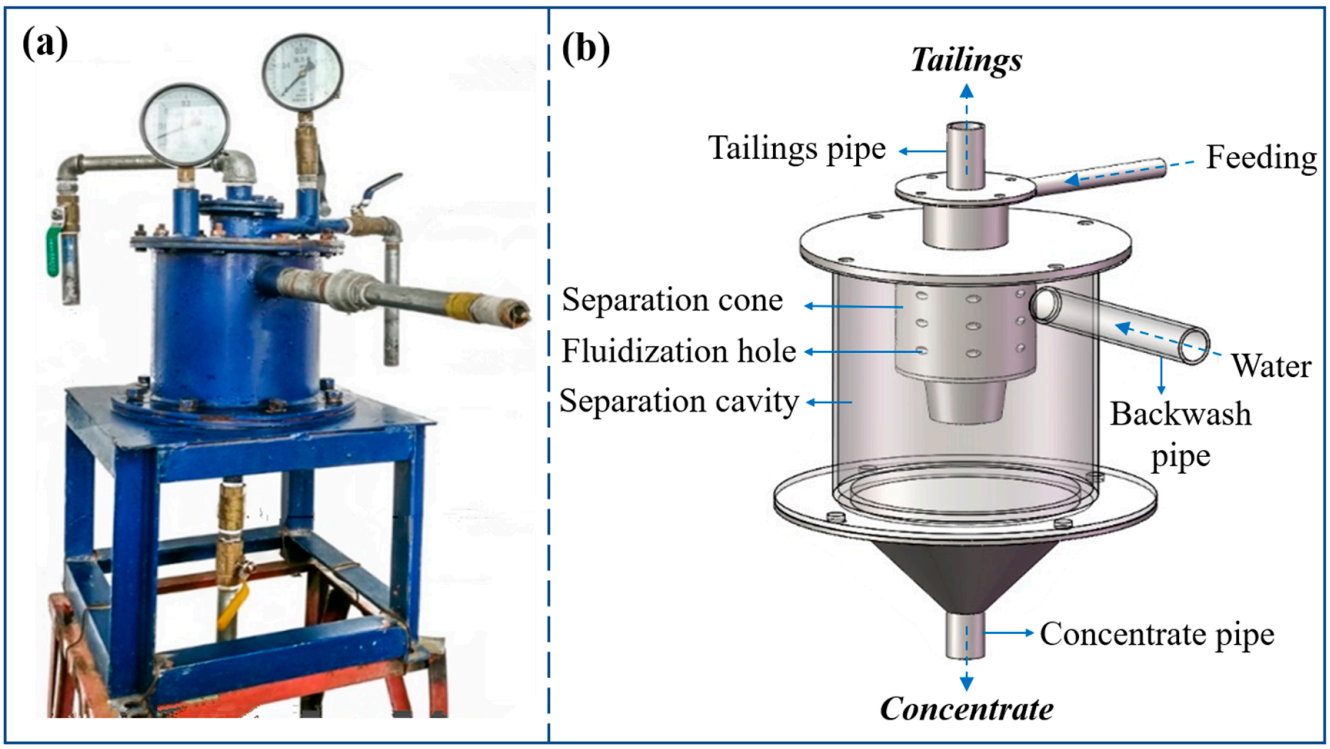


Figure 1. Equipment diagram (**a**) and three-dimensional model (**b**) of cyclone centrifugal separator.

The working principle was as follows: at the beginning of the separating operation, the mixture was injected from the feeding port into the water-filled equipment at a high speed. By adjusting the pressure of the settling chamber and the feeding pipe to obtain effective separation, the radial settling of the ore was stronger than natural settling. The ore particles were pre-settled and separated in the cyclonic column, then continued to separate in the separating cone. Under the combined action of centrifugal force and gravity, the high density coarse minerals were uniformly thrown toward the inner wall of the separating cone, overcoming the resistance of the flushing water and entering the settling chamber through the fluidization holes. The concentrate was collected by a static distributor and discharged from the concentrate pipe. Low-density and fine-particle minerals entered

the tailings pipe under the action of the fluid axial force and gravity, and were finally discharged as tailings by high-speed rotation.

2.2.2. Mechanism for Separation of Mineral Particles

After the particles entered the separation chamber of the cyclone centrifugal separator, they were subjected to a variety of forces, including gravity, centrifugal force, fluid friction resistance, recoil water resistance, and centrifugal buoyancy [28]. The force analysis is shown in Figure 2.

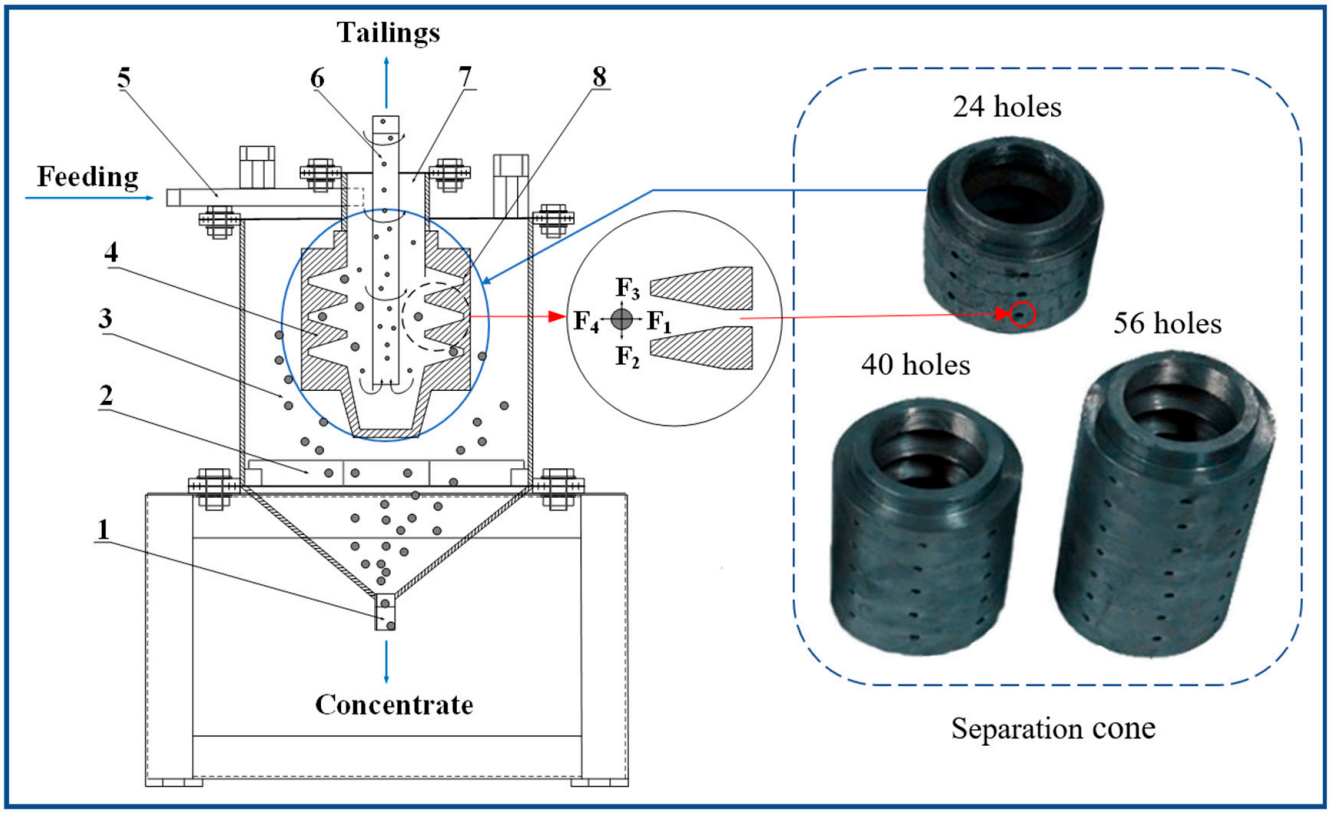


Figure 2. Schematic diagram of cyclone centrifugal separator separation process and force analysis of particles. (1—concentrate pipe, 2—static flow divider, 3—mineral collector, 4—separation cone, 5—tangential feeding pipe, 6—tailings pipe, 7—cyclone column, 8—fluidization hole).

The main forces acting on the particles inside the equipment were as follows:

(1) Centrifugal force: the centrifugal force acting on a particle of diameter d and density ρ_m entering the separating chamber and moving towards the vicinity of the fluidization hole, calculated as follows:

$$\mathrm{F}_1 = \frac{\pi \rho_m d^3 v_t^2}{6r} \quad (1)$$

where F_1 is the centrifugal force; ρ_m is the density of the mineral; d is the diameter of the particle; v_t is the tangential velocity of the fluid; and r is the radius of the particle when it rotates.

Centrifugal force is the primary fluid force experienced by mineral particles in a cyclone centrifugal separator. Sufficient centrifugal strength is the foundation for expanding the differences in the sedimentation speeds of minerals with different densities, leading to the selective separation of different minerals.

(2) Fluid friction resistance: the direction of this resistance points to the center of the equipment, in contrast to the centrifugal force, and balances the centrifugal force that is

experienced by the particles. According to Stoke's formula, the fluid resistance of particles can be calculated using Equation (2):

$$F_2 = 3\pi d(v_m - v_r)\mu \quad (2)$$

where F_2 is the frictional resistance of the mineral; d is the diameter of the particles; v_m is the radial sedimentation velocity of the particles; v_r is the radial velocity of the fluid; and μ is the dynamic viscosity coefficient of the fluid.

(3) Centrifugal buoyancy: this force is the opposite of the centrifugal force experienced by a particle and balances that force. The direction of centrifugal buoyancy points to the center of the equipment. Its effect can be calculated using Equation (3).

$$F_3 = \frac{\pi v_t^2 \rho d^3}{6r} \quad (3)$$

where F_3 is the centrifugal buoyancy; v_t is the tangential velocity of the fluid; ρ is the density of the fluid; and r is the radius of a particle when it rotates.

(4) Resistance of backwash water on mineral particles: by restricting the action area of backwash water near the fluidization hole and under suitable conditions, it is possible to prevent light-density and fine-grained materials from entering the settling chamber, thereby improving the concentrate grade. The recoil water resistance experienced by particles can be calculated using Equation (4).

$$F_4 = \rho A v^2 \quad (4)$$

where F_4 is the recoil water resistance; ρ is the density of fluid; A is the orthogonal projection area of mineral particles; and v is the recoil water velocity.

The forces experienced by the mineral particles were mainly centrifugal force, fluid resistance, centrifugal buoyancy, and recoil water resistance. The positive direction was defined as the outward direction along the radius and the force analysis of the spherical mineral particles at the fluidized hole was established as set out below.

The criterion for particles passing through a fluidization hole was a force analysis of particles in a fluidized hole, as follows:

$$F = F_1 - F_2 - F_3 - F_4 \quad (5)$$

When $F > 0$, the particles entered the sedimentation tank through a fluidization hole. When $F < 0$, the particles could not be discharged through fluidization pores and overflowed.

2.3. Methods

2.3.1. Main-Factor Separation Test of the Cyclone Centrifugal Separator

The influence of six factors on the separation performance was considered in the single-factor separation test. The six factors were particle size, the feeding concentration, the feeding pressure, the number of fluidization holes, the settling port pressure, and the overflow port pressure. The hematite–quartz mixture was added into a stirring tank, then pumped to the cyclone centrifugal separator concentrator for separation; its volume flow rate was regulative with a frequency converter. Under controlled conditions, such as the feeding pressure and the water inlet pressures, the hematite and quartz particles in the mixture were discharged as concentrate and tailings, respectively. After separation, the concentrate and tailings were filtered, dried, weighed, and analyzed. Concentrate grade and iron recovery were used to evaluate the separation performance of the concentrator.

The testing process is shown in Figure 3. In order to measure and control the pressure of the critical parts of the equipment, a Y-100 pressure gauge (Hangzhou Fuyang Hongsheng Instrument Factory) and a ball valve (Shanghai Qiaoshi Valve Manufacturing Co., Ltd., shanghai, China) were installed at the feeding inlet, the overflow outlet, the backwash water inlet, and the sediment outlet and matched with separation cones of three different-sized orifices.

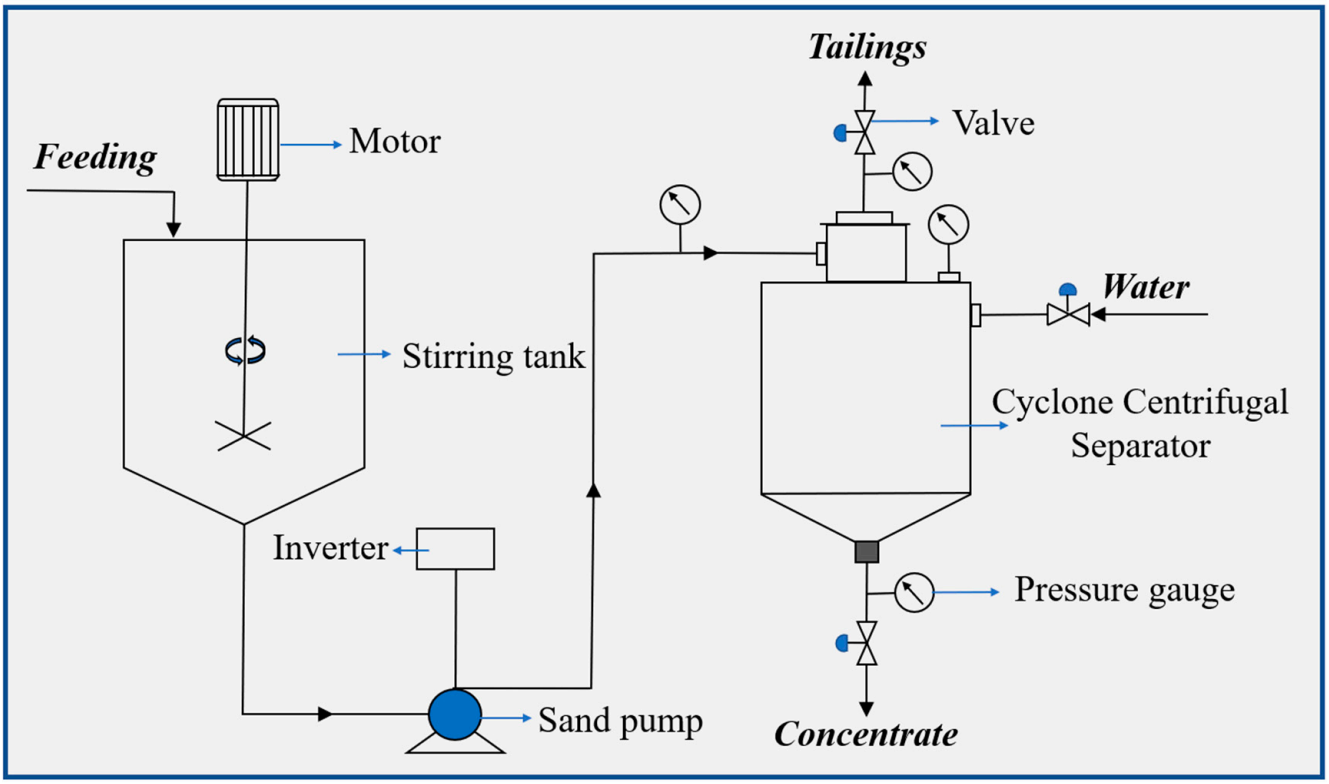


Figure 3. Experimental schematic diagram of cyclone centrifugal separation.

2.3.2. Open-Circuit Separation Test of Hematite–Quartz Mixture

The results of single-factor mineral separation tests showed that a higher concentrate grade can be obtained with a single separation and that the recovery rate is within a controllable range. The optimal level of each factor was also determined. To investigate whether the grade and recovery of concentrate could be further improved under the optimum conditions of various factors, an open-circuit separation test was designed. The experiment consisted of a rougher once, cleaner once, and two-stage scavenger, as shown in Figure 4. Each test involved feeding 600 g of ore with the following operating conditions: a 10% ore feeding concentration, a 120 kPa ore feeding pressure, a 50 kPa sand settling port pressure, a 50 kPa overflow port pressure, and 40 fluidization holes. The test involved a mixture of hematite and quartz with a particle size of −0.71~+0.25 mm and an iron grade of 44.12%. After each test, the concentrate was filtered, washed, and dried to calculate the iron grade and recovery rate.

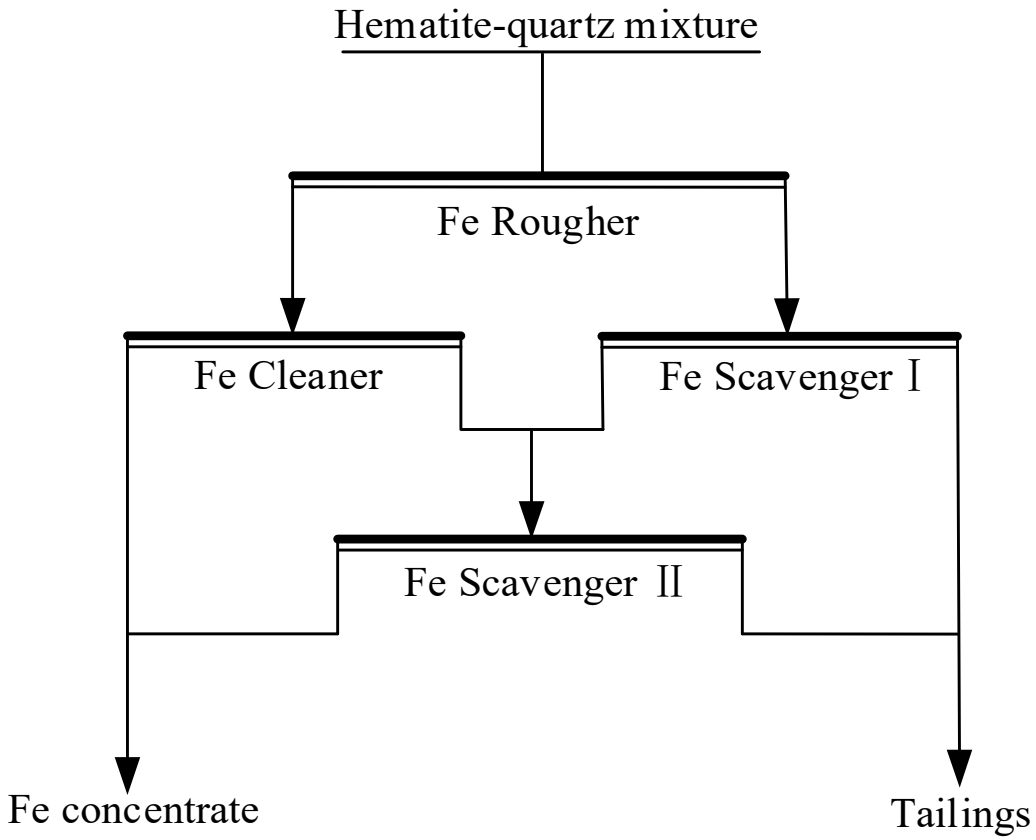


Figure 4. Flow chart open circuit separation test of hematite–quartz mixture based on cyclone centrifugal separator.

3. Results and Discussion

3.1. Effect of Particle Size of Hematite-Quartz Mixture on Separation Test

In order to determine the optimal particle size for the separation test, an experiment was designed using a mixture of 44.12% Fe. The operating conditions were set as follows: a feeding concentration of 10%, a feeding pressure of 100 kPa, 40 fluidization holes, a sand settling port pressure of 70 kPa, an overflow port pressure of 50 kPa, and an overflow pipe insertion depth of 9 cm. The independent variable factor was the particle size, and tests were conducted on four particle sizes: −1~+0.71 mm, −0.71~+0.25 mm, −0.25~+0.1 mm, and −0.1~+0.045 mm, with the sand settling sample being the concentrate. The experimental results are shown in Figure 5.

Figure 5 shows that under the given operating conditions, the overall concentrate grade first increased, then decreased, with decreasing feeding particle size. The peak concentrate grade was generally achieved at the −0.71~+0.25 mm particle size. The recovery rate fluctuated overall with changes in particle size, but the peak value was achieved at the −0.71 + 0.25 mm particle size. Based on the above data and analysis, we concluded that particle size has a significant impact on both the concentrate grade and the recovery rate. To minimize the impact of other variables on separation efficiency, subsequent separation experiments were carried out using the −0.71~+0.25 mm particle size.

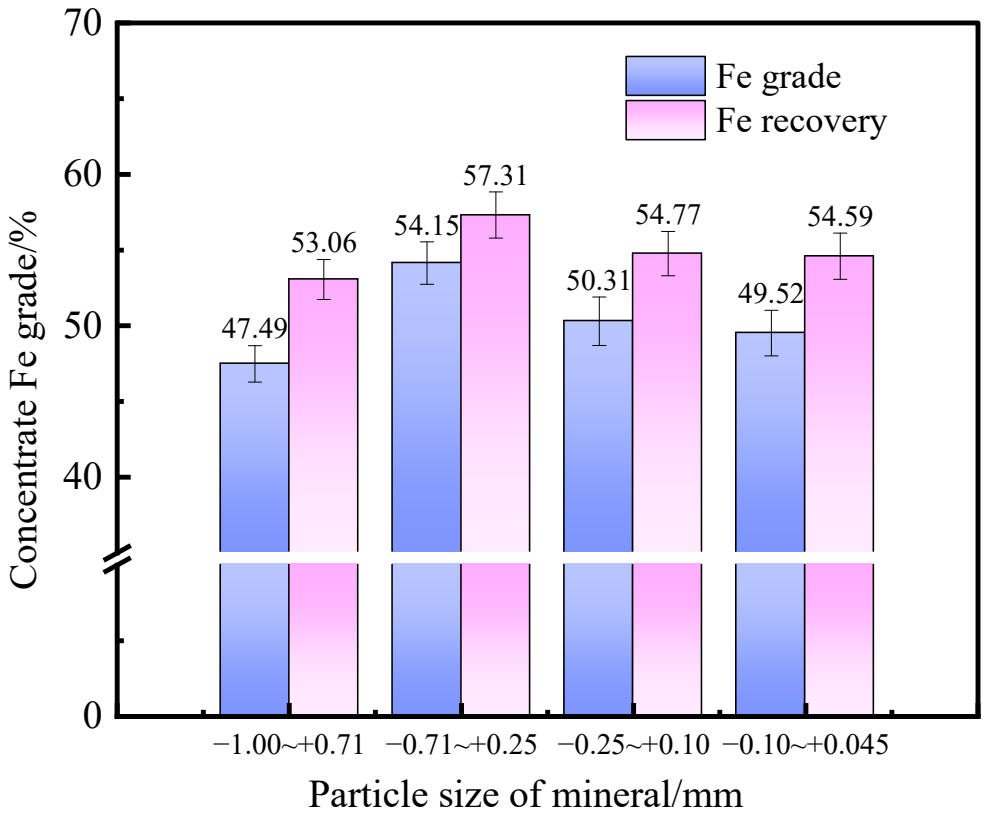


Figure 5. Effect of raw ore size on separation effect.

3.2. Main Influence Factors of the Cyclone Centrifugal Separator for the Hematite–Quartz Mixture

As discussed in this section, a cyclone centrifugal separation test was carried out to investigate the main influencing factors for the separation of a hematite–quartz mixture. The feeding concentration, the feeding pressure, the number of fluidization holes, the settling port pressure, and the overflow port pressure were selected as the variables for this test, with the fixed operating conditions being a hematite–quartz mixture with a grain size of −0.71~+0.25 mm and an Fe grade of 44.12%.

3.2.1. Effect of Feeding Concentration

The solid concentration in feeding presented another important factor in determining the separation performance of the cyclone centrifugal separator concentrator, because it determines the settling pattern of particles in the concentrating rings of a separation cylinder. In this section, We investigated the effect of the feeding concentration on the performance of the cyclone centrifugal separation of hematite. The experiment was conducted using a 40-hole separation cone with a sand discharge pressure of 70 kPa and an overflow pressure of 50 kPa. The feeding pressure was set at 100 kPa, and the feeding concentration was varied at 5%, 10%, 15%, 20%, and 25%. The sand fraction from the separation was collected as the concentrate. Other experimental conditions were as described in Section 3.1. The results of the experiment are presented in Figure 6.

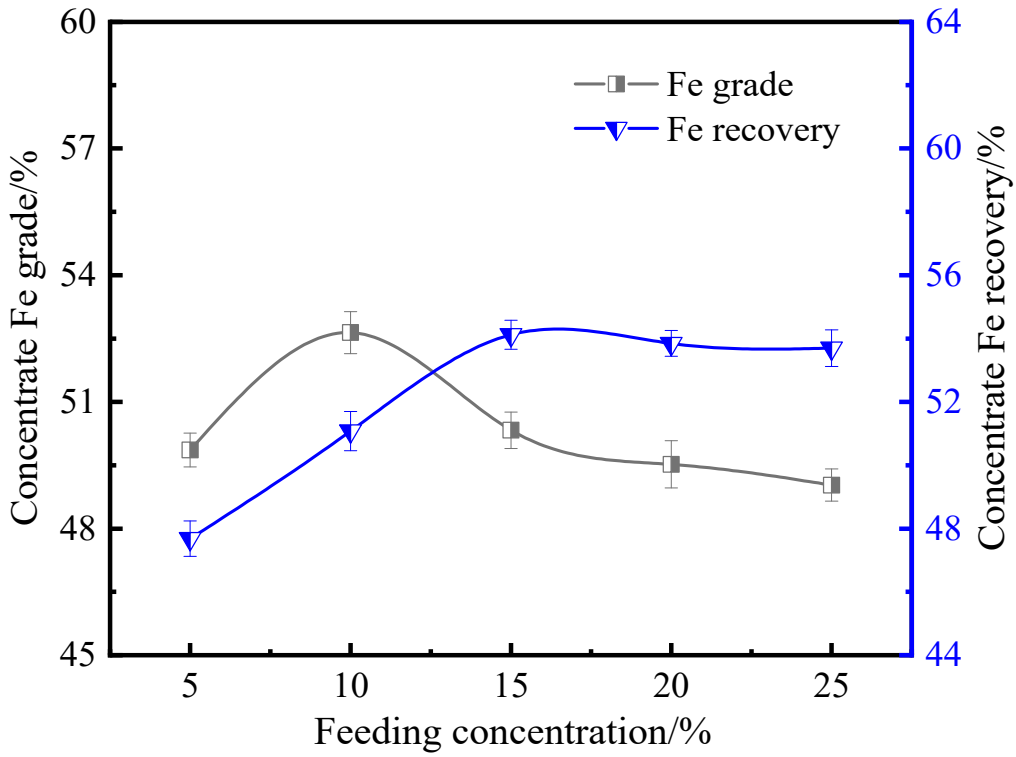


Figure 6. The influence of feeding concentration on separation efficiency.

As shown in Figure 6, this cyclone centrifugal separator allowed a relatively wide feeding concentration, as a result of the diluting and loosening effect of the fluidizing water in the concentrating rings. When the feed concentration was at low levels, the particles settled freely under the action of centrifugal force and fluid resistance. With an increase in the slurry concentration, the particles collided with each other, hindering the settling in the limited concentrating rings; consequently, the settling route of the particles was disturbed, resulting in reduced separation selectivity and iron recovery. As shown in Figure 6, the concentrate grade and the iron recovery both slightly decreased, while the feed solid concentration increased from 15% to around 25%. Obviously, this drop resulted from the transformation of the settling mode from free settling to hindered settling. The results indicated that the suitable solid concentration for this hematite–quartz mixture should be lower than 15%.

As shown in Figure 6, under the given operating conditions, with the increase in the feeding concentration, the concentrate grade initially increased and then slowly decreased overall, with the maximum concentrate grade obtained at a feeding concentration of 10%. The overall recovery increased with an increasing feeding concentration, and the magnitude of the change was larger at feeding concentrations of 5–10%. Under the same feeding concentration, a significant increase in concentrate grade could be achieved after one separation. Under the given operating conditions, the optimal feeding concentration of 10% was recommended for the experiment.

3.2.2. Effect of Feeding Pressure

The feed pressure determines the revolving velocity of slurry in the separation cylinder of the cyclone centrifugal separator and, thus, the intensity of the centrifugal force acting on the particles. As discussed in this section, we investigated the effect of feed pressure on the spiral centrifugal beneficiation of hematite. The experiment was conducted with an underflow pressure of 70 kPa and an overflow pressure of 50 kPa, using a 40-hole separation cone. The feeding concentration was set to 10% and the feeding pressure was varied at 80 kPa, 100 kPa, 120 kPa, 140 kPa, and 160 kPa. The concentrate was collected as

the underflow product and other experimental conditions were as described in Section 3.1. The results are shown in Figure 7.

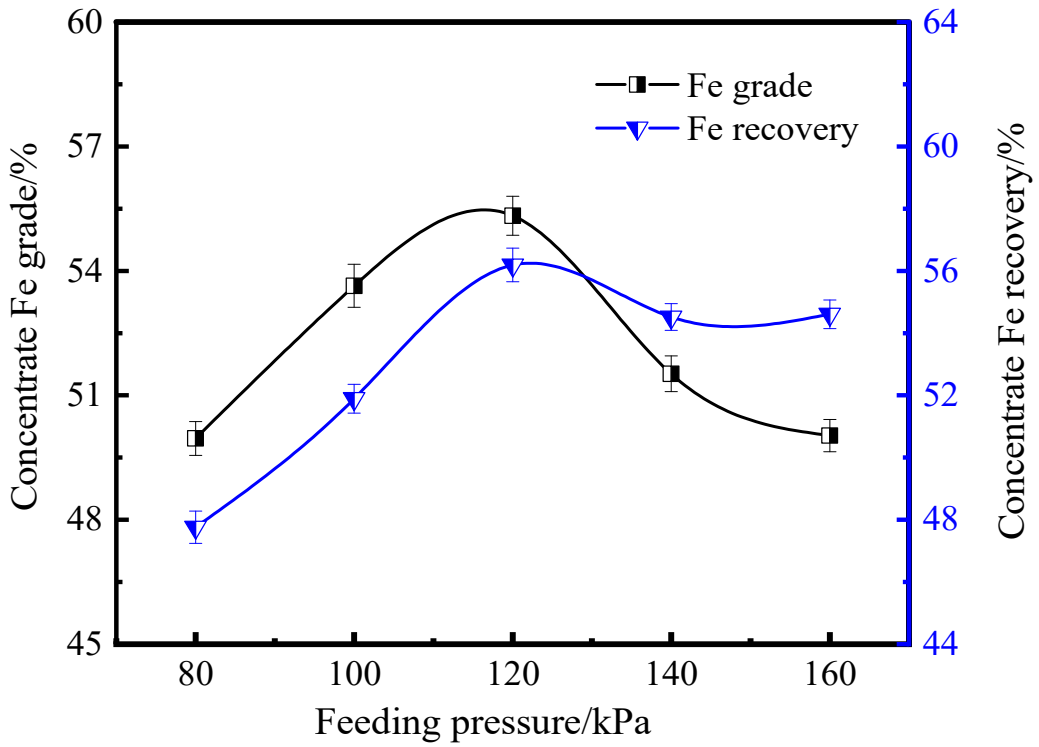


Figure 7. The influence of feeding pressure on the separation effect.

As shown in Figure 7, the separation results were generally consistent with the theoretical analysis. Increasing the feeding pressure improved the centrifugal force on the particles, thus improving the separation for hematite. The iron recovery was greatly improved with an increase in the feeding pressure, but the concentrate grade was reduced, due to the fact that more and more fine hematite proceeded through the fluidization holes as they overcame the water resistance from the fluidization holes. Meanwhile, as the feed pressure increased, more and more coarse light quartz particles proceeded through the holes, reducing the concentrate grade. Therefore, it was clear that a narrow-sized feeding is a key factor in achieving a high separation selectivity with the cyclone centrifugal separator, and a sufficiently high feeding pressure produces a high recovery for heavy particles.

As shown in Figure 7, the Fe grade of concentrate initially increased, then slowly decreased, with the increase in the ore feeding pressure. The maximum grade was achieved when the feeding pressure was 120 kPa. The recovery rate generally increased with the increase in the feeding pressure, and the variation was smaller when the feeding pressure was between 100 kPa and 140 kPa. Therefore, the optimal feeding pressure for this test was determined to be 120 kPa.

3.2.3. Effect of Fluidization Hole Number

It can be seen from Figures 1 and 2 that the separation cylinder is the dominant component of the cyclone centrifugal separator. As discussed in this section, we investigated the effect of the number of fluidization holes on the centrifugal separation performance of hematite. The experiment was conducted with a feeding pressure of 100 kPa, under a sand discharge pressure of 50 kPa and a feeding concentration of 15%. The overflow pressure was set at 50 kPa and the number of fluidization holes was varied as 24, 40, and 56. The sand product was collected as the concentrate. Other experimental conditions were as described in Section 3.1, and the results are shown in Figure 8.

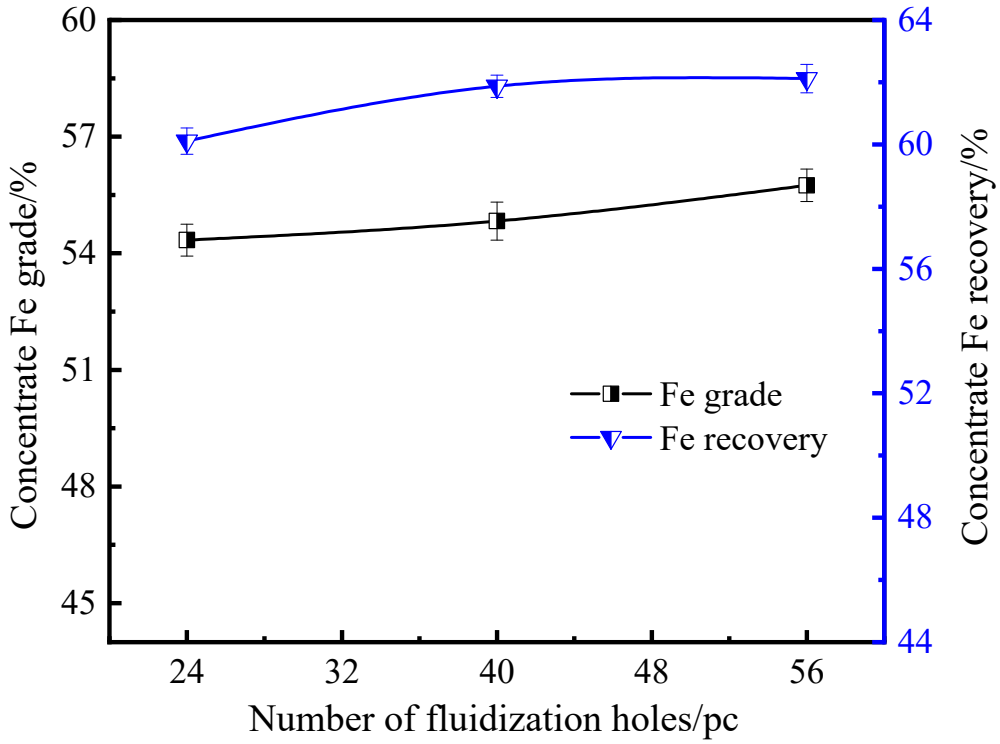


Figure 8. The influence of fluidization hole number on the separation effect.

As shown in Figure 8, for a given feed pressure, the concentrate grade and the iron recovery improved, while the number of rings increased from 3 to 5 to 7. The number of concentrating rings had a significant influence on the cyclone centrifugal separator performance, as it determined the capability of heavy particles to go through the fluidizing holes. As the number of rings increased downward in the separation cylinder, the centrifugal force resulting from the spiraling slurry in the downward rings weakened, and the resistance from the water inlet pressure increasingly exceeded the centrifugal force acting on the particles. Meanwhile, as the number of concentrating rings increased and the centrifugal force acting onto heavy particles continued to decrease, only high-grade hematite particles were able to go through the fluidization holes. As can be seen from Figure 8, there was a small overall increase in concentrate Fe grade as the number of fluidization holes increased relative to the confidence interval. However, the recovery rate remained unchanged with the increase in the fluidization hole numbers. Therefore, under the given operating conditions, the optimal number of fluidization holes was selected as 40.

3.2.4. Effect of Settling Port Pressure

This section investigates the effect of underflow pressure on the performance of the magnetite ore hydrocyclone separation. The experimental conditions included an settling pressure of 120 kPa, an overflow pressure of 50 kPa, a 40-hole hydrocyclone, a feeding concentration of 15%, and underflow pressures of 10 kPa, 30 kPa, 50 kPa, 70 kPa, and 90 kPa. The collected underflow sample was the concentrate. The experimental results are presented in Figure 9.

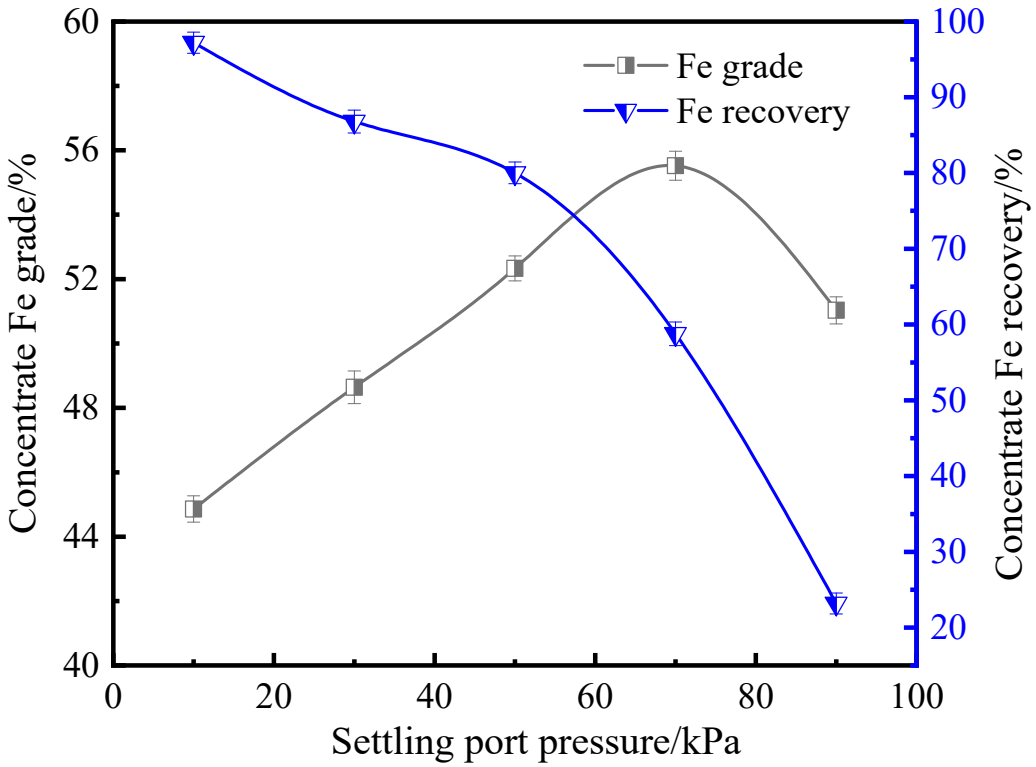


Figure 9. Effect of settling port pressure on separation effect.

As shown in in Figure 9, under the given operating conditions, the overall concentrate grade first increased, then slowly decreased, with the increase of the underflow pressure, and the highest grade was achieved at an underflow pressure of 70 kPa. Recovery generally decreased with an increase in the underflow pressure, and the magnitude of the change was significant at underflow pressures between 50 kPa and 90 kPa. Under the same underflow pressure, a single separation could significantly increase the grade. Based on the data analysis, it can be concluded that the underflow pressure has a relatively small effect on the concentrate grade overall, but a significant effect on the recovery, which shows a negative correlation trend. This is because when the underflow pressure is too low, the slurry is discharged mainly from the underflow outlet, resulting in high recovery, but when the underflow pressure is too high, the slurry is discharged mainly from the overflow outlet, resulting in low recovery. Both situations render the separation meaningless. The overall recovery had a significant difference when the underflow pressure reached 70 kPa. Both excessively high and low underflow pressures failed to achieve the expected separation effect. Therefore, the optimal underflow pressure for this experiment was determined to be 70 kPa.

3.2.5. Effect of Overflow Port Pressure

As discussed in this section, we investigated the effect of overflow pressure on the performance of the cyclonic centrifugal separation of hematite. The experimental conditions were as follows: the feed pressure was set at 100 kPa, the underflow pressure was set at 70 kPa, a 40-hole fluidization hole separation cone was used, the feeding concentration was set at 15%, and the overflow pressure was varied from 10 kPa to 90 kPa in increments of 20 kPa for the experimental study. The underflow sample was the concentrate of hematite, and the other experimental conditions were as described in Section 3.1. The experimental results are shown in Figure 10.

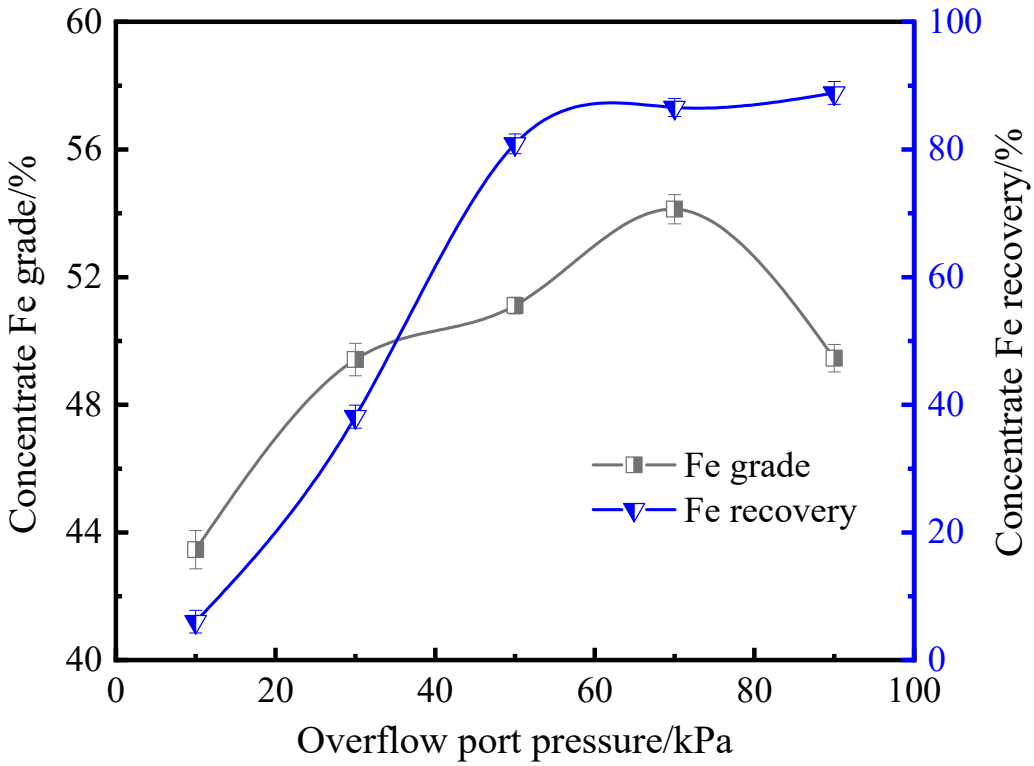


Figure 10. Effect of overflow pressure on separation effect.

As shown in Figure 10, under the given operating conditions, the overall concentrate grade first increased, then slowly decreased with the increase in overflow pressure. The concentrate grade reached the maximum when the overflow pressure qA 70 kPa. The recovery rate generally increased with the increase in the overflow pressure, and the change amplitude was relatively large when the overflow pressure was between 10 kPa and 70 kPa. Based on the above data analysis, we concluded that the overflow pressure had a relatively small impact on the concentrate grade overall, but had a significant impact on the recovery rate, and the impact was positively correlated. This is because when the overflow pressure is too low, the slurry is basically discharged from the overflow port, resulting in a higher recovery rate, while when the overflow pressure is too high, the slurry is discharged from the sand settling port, resulting in a lower recovery rate. Both situations render the separation meaningless. The overall recovery rate had a large difference when the overflow pressure was between 50 kPa and 70 kPa. The optimal overflow pressure determined in this experiment was 50 kPa.

3.3. Cyclone Centrifugal Separation Orthogonal Test Analysis

The results of the single-factor separation test showed that the iron ore could achieve a high grade and a controllable recovery rate through a single separation. In order to further improve the concentrate grade and recovery rate, an open-circuit separation test was designed [28]. The experimental process is shown in Figure 4. Each test used 600 g of feeding (Fe 44.12%), with operating conditions set as follows: a feeding concentration of 10%, a feeding pressure of 120 kPa, an underflow pressure of 50 kPa, an overflow pressure of 50 kPa, and 40 fluidizing holes. The separation test was conducted under the most suitable conditions identified in the single-factor separation test, and the results are shown in Table 3.

Table 3. Test result table of separation open-circuit test.

Products	Grad/%		Recovery/%	
	Single	Accumulation	Single	Single
Concentrate	54.42	-	37.83	-
Intermediate I	48.05	54.55	18.11	37.83
Intermediate II	46.17	52.34	22.08	55.94
Tailings	29.57	50.50	21.98	78.02
Total	44.12	44.23	100.00	100.00

As shown in the experimental results in Table 3, after the open-circuit beneficiation operation, the highest grade of Fe content in the 44.12% iron ore reached 54.42%. The overall recovery rate of concentrate was higher than that of the second intermediate product or the first intermediate product, indicating that there were still many useful minerals to be enriched in the second intermediate product. Meanwhile, the cumulative recovery rate of the concentrate indicated that the total grade of concentrate could be improved by about 20%.

4. Conclusions

(1) The cyclone centrifugal separator is a novel type of separation equipment that combines centrifugal separation and hydrocyclone principles. Its unique compound force field efficiently separates high-density coarse particles and low-density fine particles.

(2) The feeding concentration, the feeding pressure, the number of fluidization holes in the separation cone, the settling port pressure, and the overflow port pressure all have an impact on the separation performance of the cyclone centrifugal separator. The appropriate feeding pressure is the key to building a strong centrifugal separation force field, while the overflow port pressure plays an important role in controlling the overflow discharge rate. The suitable underflow port pressure can achieve the continuous discharge of high-density materials and avoid or reduce pressure loss inside the equipment.

(3) The most suitable parameters for the influencing factors were determined to be a feeding concentration of 10%, a feeding pressure of 120 kPa, a 40-hole separation cone, a settling port pressure of 70 kPa, and an overflow port pressure of 50 kPa, resulting in good separation performance. The research results provide a basis for the efficient separation of a large amount of refractory hematite in China, and provide a new method and approach for the further application of the cyclone centrifugal separator in the separation of other minerals.

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