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Development of an open-gradient magnetic separator in the aerodynamic field

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Abstract: Open-gradient magnetic separator in the aerodynamic field named an Aerodynamic Open Gradient Magnetic Separator (AOGMS) was developed for recovering magnetite under the dry condition. In this paper, the principle of AOGMS is discussed, and a continuous lab-scale AOGMS was tested to separate magnetite particles from a material with the particle size of minus 3mm and inadequate liberation degree. The effect of key variables such as magnetic field intensity, the flow rate of air, and the rotation speed of the roller on the separation performance was investigated. The results suggest that the magnetic field intensity and the airflow rate both have the most significant influences on the performance. Under the condition of the magnetic intensity field 1250Gs on roller surface, an increase in the airflow rate can significantly improve concentrate grade with only a slight change of Fe recovery due to enhance the removal of the quartz and mica containing SiO_2 andAl_2O_3. AOGMS process could provide the appropriate competitiveness in the dry separation process, thus, the locked particles and fine non-magnetic particles can be discarded efficiently. This also shows that reasonable matching multiple force fields can effectively strengthen the separation efficiency of complex iron ore.

Keywords: magnetic separator, aerodynamic field, drag force

1. Introduction

Magnetic separation system under wet process is used conventionally, however, it has several shortcomings such as (1) necessity of drying treatment after separation, (2) necessity of preventing leakage of liquid materials and (3) difficulty of running the system in the cold region (Chen et al.,2012). Magnetic drum separator is widely used in industry for magnetite concentration (Tripathy et al., 2013; Tripathy et al., 2014). It can upgrade magnetite concentrate or obtain pre-concentration by discarding coarse gangues. However, SiO_2 and Al_2O_3 grade in the concentrate or pre-concentrate efficiency is still hard to be satisfied enough, which causes a high energy consumption in mineral processing and melting (Mishima et al.,2004; Li et al.,2007). It has been accepted that the silica and aluminum contamination is attributed to the entrainment of silicate or aluminosilicate minerals and locked particles into magnetite coagulates. This is supposed to be caused by the cohesive force between the particles of silicate and magnetite particles (Chen et al.,2009; Garcia-Martinez et al.,2015; Garcia-Martinez et al., 2011).

At present, measures are being adopted to against magnetic agglomeration in order to improve the traditional magnetic separator (Ku et al.,2014), and the development of a new magnetic separator to enhance concentrate grade is underway. For instance, alternately arranged N-S magnets, or ultrasonic waves (Stener et al., 2014) are adopted by the magnetic drum separator to prohibit magnetic agglomeration, a magnetic agglomeration gravity separator with the intermittent magnetic field is designed to concentrate magnetic particles (Dimova et al., 2014). To improve the recovery of magnetic particles, a pulsating field is used by a column magnetic separator to control magnetic agglomeration

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(Zhao et al., 2013). In a magnetic field screening separator, magnetite particles aggregate in a low-intensity magnetic field and are then separated from individual gangue mineral particles (Zheng et al., 2015). A rotating magnetic field separator utilizes the instantaneous reverse property of the magnetic field to disperse magnetic agglomeration (Ku et al.,2015).

In this paper, we developed an Open Aerodynamic Gradient Magnetic Separator (AOGMS) under the dry process. The entrainment of fine non-magnetic particles into magnetite coagulates and material deposition will be decreased because airflow in the direction perpendicular to the roller surface can disperse the materials and enhance the difference between magnetite and gangue particles. The principle of AOGMS is theoretically discussed, and a continuous lab-scale AOGMS was tested on materials with minus 3mm, to study the effects of key variables such as magnetic field intensity, the flow rate of air, and rotation speed. Besides, the separation results were compared with the Open Gradient Magnetic Separator without the aerodynamic field.

2. Description of AOGMS

2.1. AOGMS and it's working procedure

A continuous lab-scale AOGMS as shown in Fig.1 was designed and constructed. Its main components are a magnetic system, a separation roller and an external compressor for supplying air passing through the separating roller made of a stainless 600-mesh filter, an aerodynamic field is built up in the magnetic field of AOGMS. Magnetite particles are attracted onto the surface of the roller, while non-magnetic particles move downward to get a non-magnetic product, under the combined actions of magnetic force, centrifugal force, aerodynamic force, and gravity.

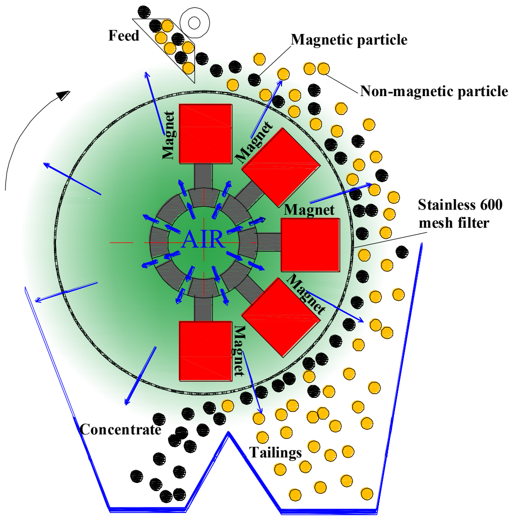


Fig. 1. Equipment in the aerodynamic field for the magnetic separation in dry process

In the AOGMS separation process, the aerodynamic force in the direction perpendicular to the roller surface disperse the materials, keeping particles in the separation region in a loose state, thus improves the separation selectivity of magnetite particles. The airflow can enhance the difference of force between magnetite and gangue particles because of their difference in density and magnetic susceptibility, thus helps with the release of entrained non-magnetic particles. With the flow rate of air increase, the distance of non-magnetic and locked particles blown away from the roller will be increased.

Factors affecting the separation efficiency in the dry process of AOGMS are:

1) the size and magnetic susceptibility on the particles,
2) the strength and gradient of the magnetic field,
3) the flow rate and the flow pattern of the air,
4) the properties of the particles, such as hydrophobicity and cohesive force.

The above-mentioned factor 1) and 2) are related to the magnetic force. Factor 3) is related to the drag force. Factor 4) is the chemical properties of the particles, and it is related to the interaction force between particles.

2.2. AOGMS and it's working procedure

The magnetic separation method is a technique for separating the object particles by using the difference of magnetic property between the particles. Magnetic force F_M, the drag force F_D and gravity force F_G mainly act on the particle in this magnetic separation process in the fluid, and are expressed as follows (Senkaw et al., 2011):

$$F_m = \frac{V_P}{2}(\chi_P - \chi_m)\mathrm{grad}(H^2) \tag{1}$$

where V_P is particle volume, χ_P is magnetic susceptibility of a particle, χ_m is magnetic susceptibility of the air, H is external magnetic field intensity. The drag force F_D and gravity force F_G are expressed as:

$$F_D = C_D\frac{1}{2}\rho U^2\frac{1}{4}r_p^3 \tag{2}$$

$$F_G = \rho_p\frac{4}{3}\pi r_p^3 g \tag{3}$$

where C_D is the drag coefficient, ρ is medium density, U is flow velocity, r_p is particle radius, ρ_p is particle density and g is gravity acceleration. Resistance coefficient C_D is decided by Reynolds number Re. The Reynolds number is a ratio of fictitious force and viscous force in the fluid as shown as follows:

$$Re = \frac{\rho U d}{\nu} \tag{4}$$

where U is flow velocity, d is the characteristic length (here corresponds to particle diameter), ν is kinetic viscosity. When the Reynolds number is enough small ($Re < 1$) in a laminar flow, the drag force can be calculated by the following Eq. (5) which is named as Stokes's resistance law:

$$F_D = 6\pi\mu r_p U \tag{5}$$

where μ is the viscosity of the medium. The possibility of magnetic separation can be presumed from the balance between magnetic force, drag force and gravity. To achieve magnetic separation, the magnetic force on the magnetic particle should be larger than the resultant drag force and gravity.

The microscopic view of the magnetic separation in the dry process is shown in Fig. 2. When the aggregates of the magnetite particles and the gangue particles are attracted to the roller by magnetic force F_M, the magnetite particles would be separated in case drag force F_D is larger than the adhesion force F_A. In case the drag force is larger than the magnetic force, however, the magnetite particles would be blown away without attraction to roller. Therefore, to achieve the magnetic separation with the developed system, following relation (6) should be fulfilled. As shown in equation 6, appropriate drag force F_D is very important to disperse the materials, keeping particles in a loose state in the separation region, thus avoiding the gangue particle entrained into magnetite concentrate (Senkaw et al.,2013; Zheng et al., 2016; Zheng et al., 2017).

$$F_M > F_D > F_A \tag{6}$$

As shown in the above equation, the drag force F_D acting on the aggregates should be larger than the adhesion force between the particles F_A, and also should be smaller than magnetic force F_M. The adhesion force F_A is determined by surface properties and the size of two kinds of the particle, thus F_A is difficult to be changed, especially in the dry separation processing. Magnetic force F_M is determined by the characteristics and arrangement of the magnet, thus F_M is easy to be changed and enhanced to meet the requirement for recovering the magnetite. Drag force F_D is determined by flow velocity and viscosity of the medium when the particle size is constant. Compared to the traditional dry magnetic separator, magnetic force F_M and drag force F_D can be changed by adjusting the magnet and the flow rate of air in AOGMS system, and the more appropriate force field could be built for meeting the equation 6.

3. Materials and methods

3.1. Description of sample

It is well known that the particle size distribution and the liberation degree of minerals are important factors affecting the separation efficiency of dry magnetic separation. To investigate the separation efficiency of the AOGMS for complicated iron ore, the material with wide-range size distribution and inadequate liberation degree was employed in this investigation. X-ray diffraction of this material is

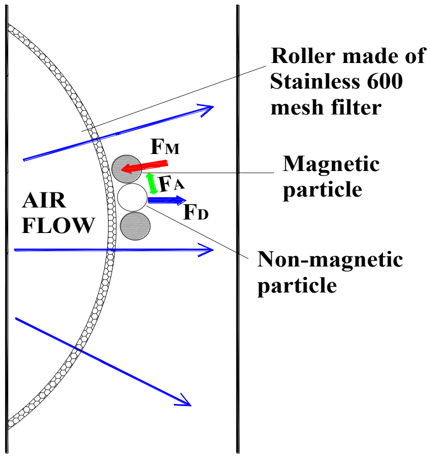


Fig. 2. Schematic diagram of magnetic separation using AOGMS

shown in Fig. 3. The principal gangue mineral in the ore is quartz, muscovite and chlorite. This material assayed 34.45% Fe_T, in which 18.52% Fe in magnetite mineral and 15.93% Fe in limonite mineral. The cumulative distribution of Fe_T is shown in Fig.4 as a function of size fraction. Fig.4 shows that the material was -3 mm, 76.55% of the material was below 1 mm, and 14.87% of the material was below 0.038 mm.

To better understand the content of Fe_T in different size fractions, wet screening and chemical analysis were employed. After these materials passed wet screening, each size fraction was filtered, dried, weighed, sampled and chemically analyzed. According to the chemical analysis results, the particle size distribution and content of Fe_T in the different size fractions were shown as Fig.5. The material assayed 37.42% Fe_T was in particle size between 0.15 and 1 mm, which accounted for the highest recovery of 36.66% of the total iron. The content of Fe_T in minus 0.038mm is the lowest and only had 21.50%. Depending on the ore mineralogy, the liberation degree of magnetite in feed is only 63.47%, and the liberation degree of magnetite in 2~3mm and 1~2mm fiction is 40.27% and 53.24% respectively. Owing to coarse particles with the inadequate liberation degree and the existence of many fine particles in this material, it's very difficult to recover magnetite efficiently in the dry separation process.

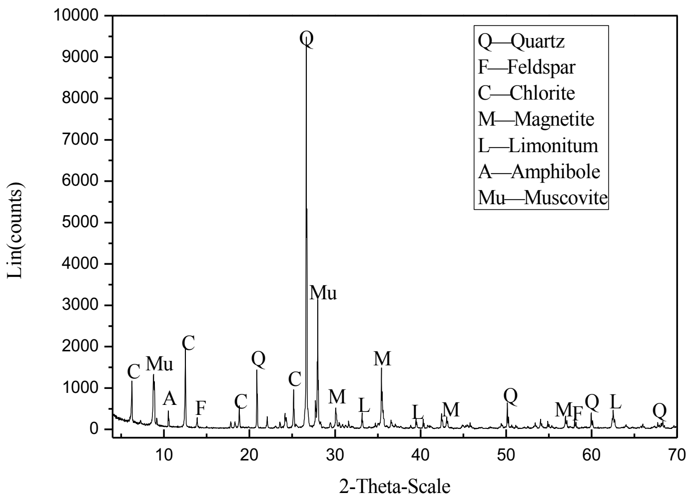


Fig. 3. X-ray diffraction of material

3.2. Separation tests

The magnetite particles in this sample were separated by a magnetic force generated by an AOGMS while exposing the sample to compressed air from an external compressor. In this magnetic field, the non-magnetic particles are subjected to gravity and air force, while the magnetic particles to gravity,

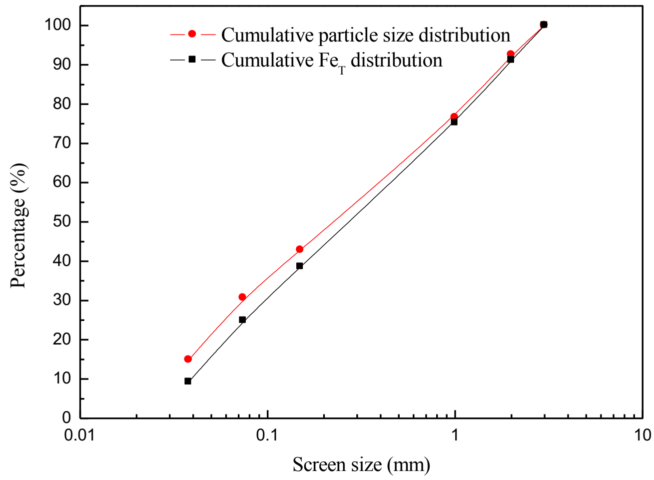


Fig. 4. Cumulative particle size distribution and cumulative Fe_T distribution versus particle size

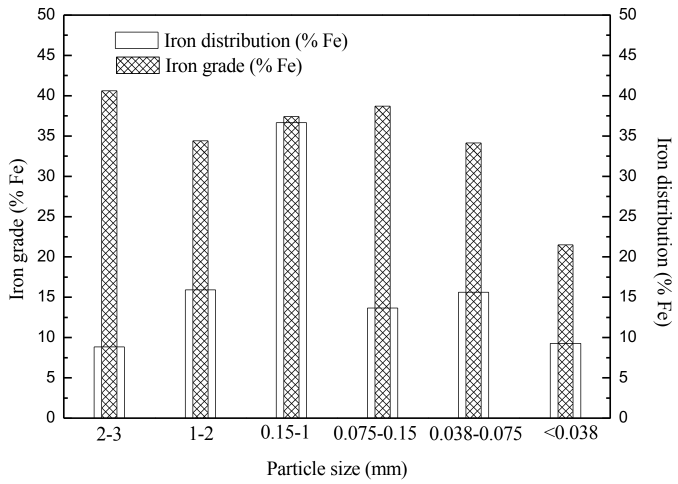


Fig. 5. Fe_T distribution as a function of size fraction

air and magnetic force. Thus, magnetite particles are attracted close to the surface of the separation roller and are transported to the region of the concentrate tank as the roller rotates. The non-magnetic minerals pass through the magnetic field under the effect of gravity and air force as tailings. Investigations were carried out under experimental conditions as shown in Table 1.

After the variables were optimized through the single factor tests, the AOGMS performance was compared with the dry magnetic separator without aerodynamic field under the same operating condition, such as the feed mass, the magnetic field intensity, and the rotation speed of the roller.

Table 1. Experimental conditions

Operating variables	Magnetic field intensity (Gs)	Rotation speed of roller (r/min)	Flow rate of air (m/s)	Feed mass (g)
Range	450-1250	30-75	0-0.8	100

3.3. Evaluation methods

Grade and recovery of magnetite concentrate were used to evaluate the performance of continuous lab-scale AOGMS. Besides, to compare the performance of AOGMS, the separation efficiency was also used, using the following equation (Zeng et al., 2015):

$$E = \varepsilon\left\{1 - \frac{\alpha(\beta_M - \beta)}{\beta(\beta_M - \alpha)}\right\} \tag{7}$$

where α is the feed grade, β is the concentrate grade, ε is the Fe recovery of concentrate, β_M is the maximum Fe grade of magnetite mineral (72.40% Fe), E is the separation efficiency.

A continuous lab-scale AOGMS as shown in Fig.1 was designed and constructed. Its main components are a magnetic system, a separation roller and an external compressor for supplying air passing through separating roller made of a stainless 600-mesh filter, an aerodynamic field is built up in the magnetic field of AOGMS. Magnetite particles are attracted onto the surface of the roller, while non-magnetic particles move downward to get a non-magnetic product, under the combined actions of magnetic force, centrifugal force, aerodynamic force, and gravity.

4. Results and discussion

4.1. Effect of magnetic field intensity on the separation performance without aerodynamic field

In the traditional dry magnetic separation process, the intensity of the magnetic field is the most dominant force that controls the number of magnetic particles going into the magnetic concentrate, thus producing a significant effect on the separation performance. The effect of magnetic field intensity on performance without the aerodynamic field was presented in Fig. 6. It is noted that a relatively low feed mass 100 g was used in this investigation.

From Fig.6, when the intensity of the magnetic field was set at a low level, most of the material under the action of gravity force and centrifugal force are not captured by the roller and thrown out of the separation region, except for the most fully liberated magnetite particles, which results in a higher concentrate grade but a lower iron recovery. As the intensity of the magnetic field increase, more magnetic particles, against the gravity and centrifugal force, go into the magnetic concentrate and the iron recovery improved. From Fig.6, the concentrate grade decreases, meanwhile, iron recovery increases as the intensity of the magnetic field, due to the increase of inter-particle force and the dispersibility decrease of material. Therefore, more non-magnetic particles and magnetically low-grade intergrowths are entrained into the magnetic concentrate.

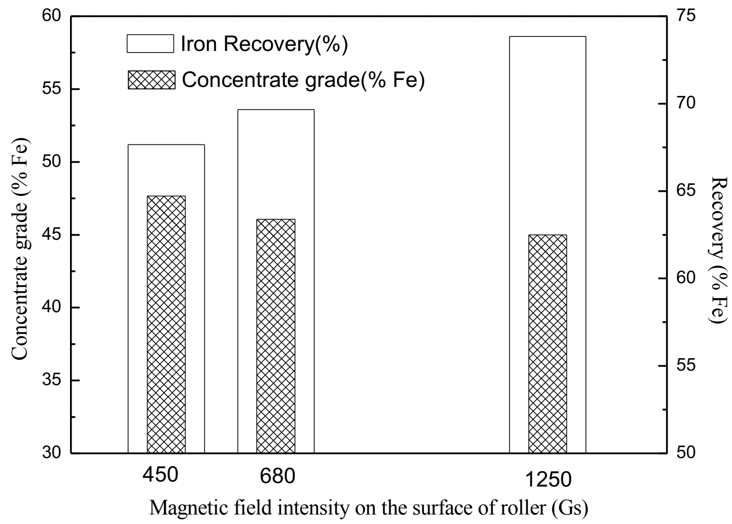


Fig. 6. Effect of magnetic field intensity on the separation performance of magnetic separation without aerodynamic field

4.2. Effect of airflow rate on the separation performance under the different intensity of the magnetic field

The air flow rate in the AOGMS process improves the separation selectivity of magnetic capture and has an effect on the separation performance of AOGMS. From Fig.7, the air flow has a very significant effect on the performance. An increase in the airflow rate improved the magnetic concentrate grade but reduced the iron recovery. It should be noted that relatively low intensity of the magnetic field 450 Gs was used in this investigation, to obtain a magnetic concentrate with high Fe grade.

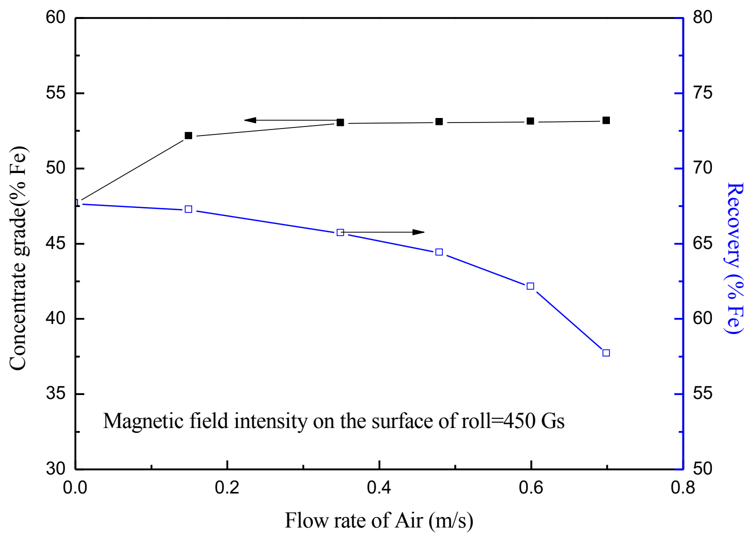


Fig. 7. Effect of the airflow rate on the separation performance at a magnetic field intensity of 450 Gs

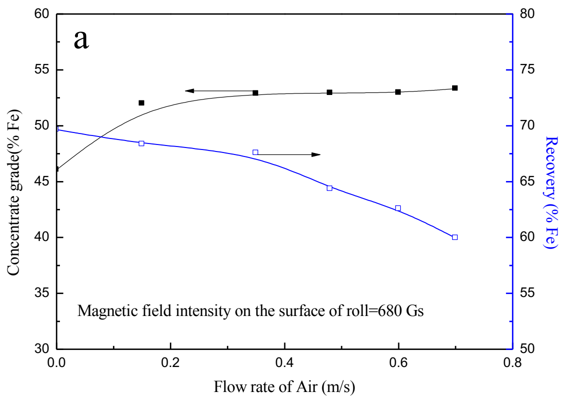
The most unique feature of the AOGMS process is the airflow rate in the direction perpendicular to roller surface, and it is crucially important that the airflow rate provides the appropriate drag force F_D so that the non-magnetic particles and their locked particles are thrown out of the separation region, so that the liberated magnetite particles are captured on the roller surface. Obviously, the higher airflow rate, the stronger the drag force F_D and competing forces upon particles, so that the higher the concentrate could be obtained based on the following equation:

$$\beta_m = \frac{\beta_{max}}{1+R_{nm}k\frac{F_A}{F_C}} \tag{8}$$

where β_m and β_{max} are the grade and the maximum grade of magnetic concentrate, respectively. R_{nm} is the mass ratio of non-magnetic to magnetic particles in the feed, k is constant, F_A is the sum of adhesion force between magnetic and non-magnetic particles, such as electrostatic force and friction force, F_C is the sum of competing forces, including drag force F_D, centrifugal force and gravity in the AOGMS process. From Eq. (8), it is apparent that β_m increases with an increase in the airflow rate because the competing force Fc increases with an increase in the airflow rate.

From Fig.7, when the airflow rate was at 0.15 m/s, the concentrate grade is improved significantly with a slight change in recovery. As the airflow rate increases, the dispersion effect of the aerodynamic and the competing forces upon particles increases, so that more non-magnetic particles and fine magnetic particles are discarded out of the magnetic field, resulting in improved concentrate grade at the expense of recovery. A particular airflow rate is related to the characteristics of the material and intensity of the magnetic field. After the airspeed reached an excessively high level, the recovery decreased drastically as a result of too strong competing forces upon the particles. The AOGMS process achieved a much better separation performance than that when the airflow rate was zero.

For exploring the possibility of improving separation efficiency further, the airflow rate tests were carried on under the condition of the increased intensity of the magnetic field. From Fig. 8, as the intensity of the magnetic field increases, more magnetic particles, against the drag force and the centrifugal force, go into the magnetic concentrate and the performance is significantly improved. Under the condition of high-level intensity of magnetic field 1250 Gs, it is clear that this AOGMS was able to achieve a high-grade concentrate with a little reduction in Fe recovery by optimizing the airflow rate. This was contributed to the aerodynamic field in the magnetic field. From Fig. 8, the Fe recovery increased as the intensity of the magnetic field increased from 680 to 1250 Gs. Under the condition of magnetic 1250 Gs, the concentrate grade continued to keep a high-level and recovery had a slight reduction when the airflow rate was 0.68 m/s(Fig. 8b), due to the capture of more adequate liberation magnetite particles by strong magnetic field and the good loose state of material under the condition of the high airflow rate.



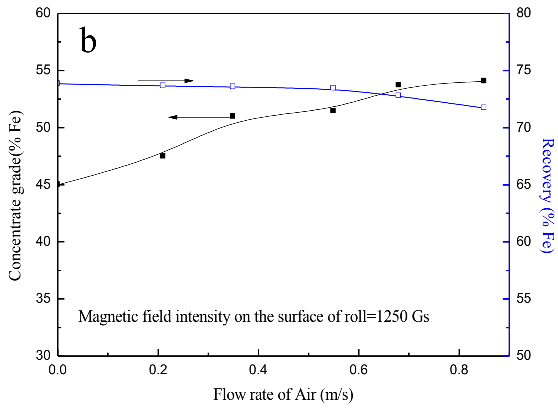


Fig. 8. Effect of the airflow rate on the separation performance at an increased magnetic field intensity of 680 Gs (a), 1250 Gs (b)

4.3. Effect of the rotation speed of roller on the separation performance

Normally, the rotation speed of roller in the dry magnetic separation process has a very significant effect on the separation performance. An increase in the rotation speed of roller improves the concentrate grade but reduces the iron recovery. As the rotation speed of roller increases, the centrifugal force upon particles increases, so that more non-magnetic particles and fine magnetic particles were discarded out of the magnetic field, resulting in improvement of concentrate grade at the expense of recovery. The effect of the rotation speed of roller on performance is shown in Fig. 9.

Although a similar trend was found in Fig.9, it seems that the rotation speed of the roller has a little significant effect on the separation efficiency in the AOGMS process. A slight change in Fe grade and recovery was found when the rotation speed of roller increases from 30 to 75 r/min. The reason is that the aerodynamic field can supply enough drag force and competitiveness for dispersing material, and discarding the gangues and locked particles, even though under the condition of strong intensity of the magnetic field. Thus, under the condition of strong intensity of the magnetic field, the centrifugal force brought by the rotation speed of the roller does not show as a significant factor in the AOGMS process. As we all know, as the rotating speed of the roller increases, the processing capacity of the separator will increase accordingly. Give that Fe recovery does not decrease significantly as the rotation speed of roller increases in the AOGMS process, the processing capacity of the AOGMS can be improved by increasing the rotation speed of the roller.

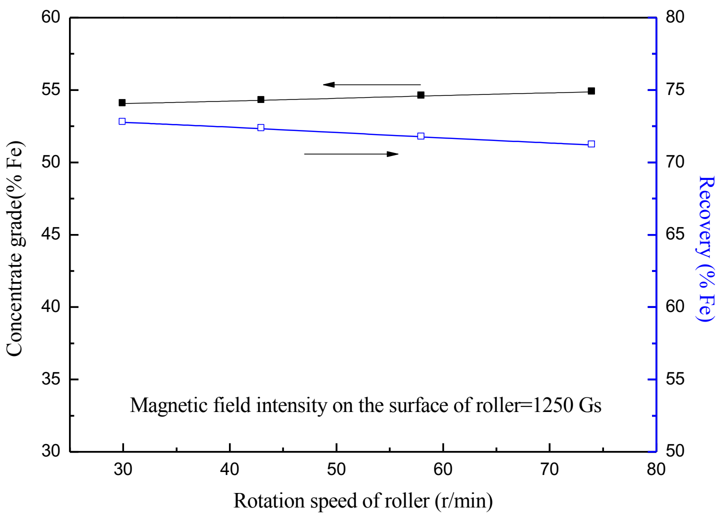


Fig. 9. Effect of the rotation speed of roller on separation performance at a magnetic field intensity of 1250 Gs and an airflow rate of 0.38 m/s

4.4. Comparison of the separation performance

To further study the effect of the aerodynamic field on the separation efficiency of the magnetic separation process, compare the differences in the weight and Fe_T content of magnetic concentrate and tailings products from the magnetic separation with and without aerodynamic field, magnetic separation experiments using the AOGMS and the traditional dry magnetic separator were repeated. The AOGMS was operated at the parameters determined in the preliminary test work, such as the intensity of magnetic field on roller surface = 1250 G, the rotation speed of roller =30 r/min, and the airflow rate = 0.68 m/s. The traditional dry magnetic separator was also operated under the same conditions, such as the intensity of the magnetic field, the rotation speed of the roller, and the feed mass. The results are shown in Table 2.

Table 2. Separation performance of -3mm iron ore with AOGMS vs. traditional dry separator without aerodynamic field

Separation methods	Concentrate			Tailings	Separation
	Weight(%)	Grade (%Fe_T)	Iron recovery(%)	grade(%Fe_T)	efficiency(%)
Without aerodynamic field	56.53	45.00	73.84	20.73	33.74
With aerodynamic field (AOGMS)	46.67	53.69	72.76	17.61	51.06
Feed	100.00	34.45	100.00	–	–

Without aerodynamic conditions: intensity of magnetic field on roller surface = 1250 G, rotation speed of roller =30 r/min and airflow rate = 0 m/s; With aerodynamic (AOGMS) conditions: intensity of magnetic field on roller surface = 1250 G, rotation speed of roller =30 r/min and airflow rate = 0.68 m/s;

From Table 2, the AOGMS achieved a much superior separation performance to the traditional dry magnetic separator, even Fe_T recovery of concentrate obatined from the AOGMS is 1.08 % lower. The AOGMS achieved a much higher grade 53.69 % and separation efficiency 51.06 %, compared to the traditional dry magnetic separator. The reason is that compared with the traditional magnetic separation process, the magnetic separation process with the aerodynamic field reduces the magnetic concentrate weight by 9.86%, while the loss rate of iron metal in tailings only increases by 3.12%, which means that the competitiveness enhanced by the aerodynamic field urges more gangue minerals or low-grade locked particles into tailings. It also provides the evidence that AOGMS process can obtain the concentrate with high Fe grade and has better separation performance by removing efficiently most of the non-magnetic minerals.

4.5. Chemical analysis and X-ray diffraction

To study the reason why the aerodynamic field increases the Fe content in the magnetic concentrate, the chemical analysis and X-ray diffraction were carried out on the concentrate obtained with and without the aerodynamic field. The contents of Fe, SiO_2 and Al_2O_3 and the mineral composition in the magnetic concentrate were analyzed.

As shown in Fig. 10 and Fig. 11, SiO_2 and Al_2O_3 are the major factors affecting the Fe content in iron products, meanwhile, SiO_2 and Al_2O_3 primarily originate from quartz and mica minerals respectively. The purpose of magnetic separation is to remove quartz and mica as much as possible, thereby reducing the content of SiO_2 and Al_2O_3 in Fe concentrate. From Fig. 10 and Fig. 11, it can be seen that both AOGMS and traditional magnetic separator can remove quartz and mica, but their removal efficiency is different. The traditional magnetic separator can reduce SiO_2 and Al_2O_3 content in this sample from 32.47% to 22.97% and 10.51% to 7.24%, respectively, thus increasing the iron content from 34.45% to 45.24% in magnetic concentrate. While the AOGMS can decrease SiO_2 content from 32.47% to 16.74% and Al_2O_3 content from 10.51% to 5.29%, thus increasing iron concentrate content from 34.45% to 54.07%. The concentrate from AOGMS has a lower content of quartz and muscovite than that from the traditional separator. It is clear that the AOGMS was capable of achieving a better concentrate at a high recovery from this sample.

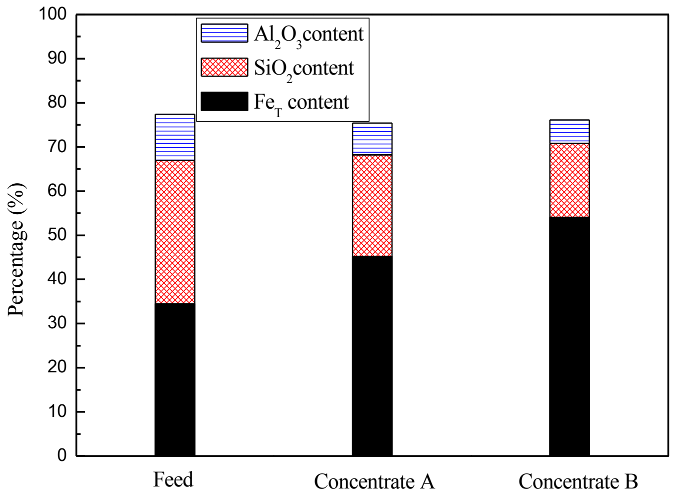


Fig. 10. Fe_T, Al_2O_3, SiO_2 content of the concentrate from AOGMS vs. Traditional dry separator. (Concentrate A= Fe_T concentrate from the traditional dry magnetic separator without aerodynamic field, Concentrate B=Fe_T concentrate from the AOGMS process)

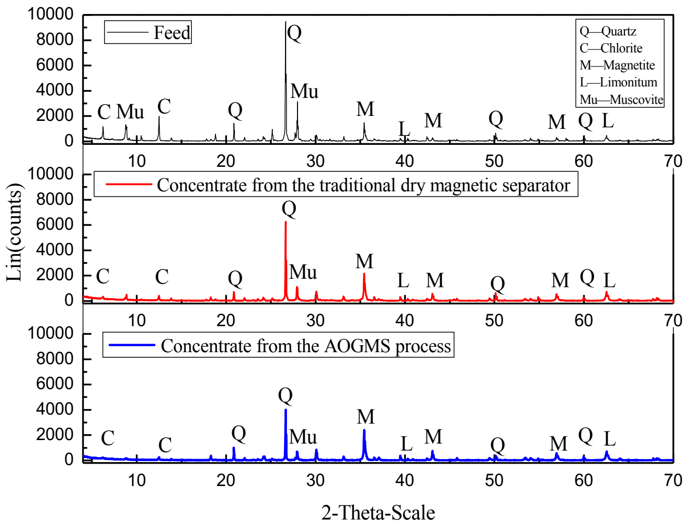


Fig. 11. X-ray diffraction of the concentrate obtained from the AOGMS and the traditional dry magnetic process

4.6. Separation efficiency as a function of size fraction in the concentrate

To study the effect of the aerodynamic field on the separation efficiency of each particle fraction, iron recovery and grade in concentrate as a function of particle size are shown in Fig.12. From Fig. 12a, iron recovery in various sizes of concentrate obtained by AOGMS is slightly lower than that of concentrate obtained by the traditional magnetic separator, which is due to extra competitiveness provided by airflow. From Fig. 12b, by comparing the Fe_T grade in all size fractions between feed and concentrate from the traditional magnetic separator, it can be seen that the traditional magnetic separator can effectively improve Fe_T content in the intermediate particle size, i.e. 0.075-0.15mm. However, Fe_T content in the coarse particle (2-3mm) and the fine particle (< 0.038mm) is not satisfactory, which is due to the inadequate liberation degree of the coarse particles and the stronger interaction force between the fine particles. By comparing Fe_T content in all size fractions of magnetic concentrate obtained from the traditional magnetic separator and the AOGMS, it can be noted that the concentrate from AOGMS has a higher iron grade in each size fraction. With the decrease of grain size, the increase of iron content shows an increasing trend. The iron grade in 0.038-0.075mm friction can be increased from 21.50% to 46.90%, and that in -0.038 mm friction can be increased from 34.13% to 60.30%.

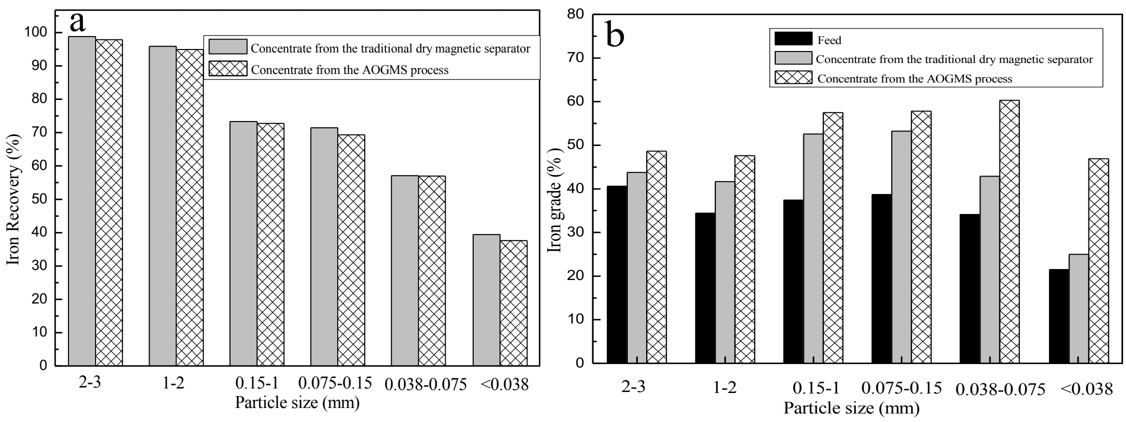


Fig. 12. Iron recovery (Fig.12a) and grade (Fig.12b) as a function of size fraction in concentrate from the AOGMS process and the traditional dry magnetic separator

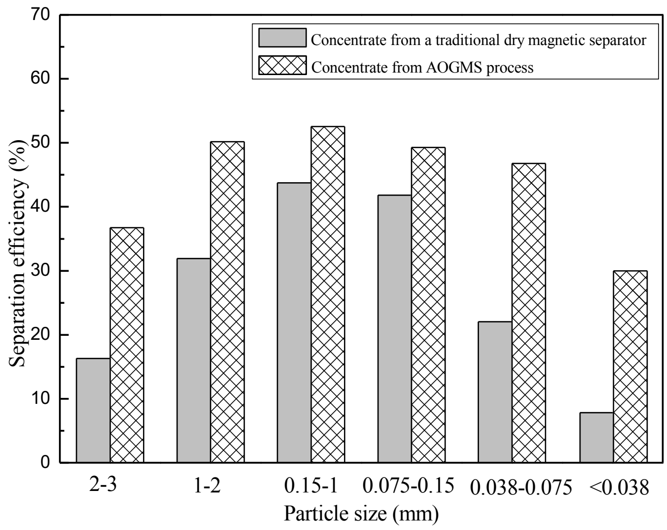


Fig. 13. Separation efficiency as a function of size fraction in concentrate from the AOGMS process and the traditional dry magnetic separator

In Fig. 13, separation efficiency as a function of size fraction in concentrate from the AOGMS process and the traditional dry magnetic separator changes in a similar shape close to the parabola. Owing to the inadequate liberation degree of the coarse particles and the stronger interaction force between the fine particles, the separation efficiency of coarse and fine particles is much lower than that of intermediate particles. Compared with the traditional magnetic separator, the AOGMS can improve the separation efficiency of magnetite in each size fraction, especially in coarse and fine fractions. The separation efficiency in 2-3mm fraction can be increased from 16.31% to 36.75%, and that in 0.038-0.075mm fraction and -0.038 mm fraction can be increased from 7.88% to 29.97% and 22.05% to 46.79%, respectively. The reason is that airflow can provide appropriate competitiveness in the separation process, thus, the interference of locked particles and fine gangues on iron concentrate can be alleviated.

5. Conclusions

It can be seen from the results and discussion above that:

(1) Compared to the traditional drum dry magnetic separator, an aerodynamic force in the direction perpendicular to the roller surface was introduced in the AOGMS process. The aerodynamic force can improve the appropriate drag force and enhance the difference between magnetite and gangue particles based on their difference in density and magnetic susceptibility, thus facilitates the release of entrained non-magnetic particles.

(2) The aerodynamic in the AOGMS process disperses the material, keeping the particles in a loose state, thus improving the separation selectivity of magnetic particles. It is crucially important for the airflow rate matching with the magnetic field appropriately for removing the non-magnetic and magnetic locked particles from the separation region while avoiding loss of fine magnetic particles, especially in high-intensity magnetic fields.

(3) The chemical analysis results of concentrate indicate that the content of Al_2O_3 and SiO_2 in concentrate from AOGMS is lower than that from traditional dry drum magnetic separator, the reason is that the AOGMS process could efficiently remove quartz and muscovite from iron ore.

(4) Due to the poor liberation degree of the coarse particles and the stronger interaction force between the fine particles, the separation efficiency of coarse and fine particles is significantly lower than that of intermediate particles. Compared with the traditional magnetic separator, AOGMSN can improve the separation efficiency of magnetite in each size fractions, especially in coarse and fine fractions. It's beneficial to reduce energy consumption in mineral processing and melting.

It was thus concluded that the AOGMS is a new generation of the continuous dry magnetic separator with a higher beneficiation ratio, and the AOGMS provided a potential technique for separating magnetite particles from iron ore with wide-range particle size.

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