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Comparative investigation on magnetic capture selectivity between single wires and a real matrix

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ABSTRACT

High gradient magnetic separation (HGMS) achieves the effective separation to fine weakly magnetic minerals through a magnetic matrix. In practice, the matrix is made of numerous magnetic wires, so that an insight into the magnetic capture characteristics of single wires to magnetic minerals would provide a basic foundation for the optimum design and choice of real matrix. The magnetic capture selectivity of cylindrical and rectangular single wires in concentrating ilmenite minerals were investigated through a cyclic pulsating HGMS separator with its key operating parameters (magnetic induction, feed velocity and pulsating frequency) varied, and their capture selectivity characteristics were parallelly compared with that of a real 3.0 mm cylindrical matrix. It was found that the cylindrical single wires have superior capture selectivity to the rectangular one; and, the single wires and the real matrix have basically the same capture trend with changes in the key operating parameters, but the single wires have a much higher capture selectivity than that of real matrix.

Introduction

High gradient magnetic separation (HGMS) has achieved wide applications in the field of mineral processing in the recent 20–30 years [1], and it is effectively applied for concentration of weakly magnetic minerals such as oxidized iron minerals, ilmenite and wolframite, and for removal of such minerals from non-metallic ores such as quartz and feldspar [2,3]. The effective operation of a HGMS process is achieved through a magnetic matrix, which generates magnetic field gradient in the vicinity of magnetic wires in a background magnetic field and thus a sufficiently strong magnetic force to magnetic particles from slurry [4,5]. In practice, such a matrix is made of numerous magnetic wires with regular arrangements [6], so that a deep insight into the magnetic capture characteristics of single wires to magnetic minerals would provide a basic foundation for the optimum design and choice of real matrix.

In fact, numerous works have been reported on the material, geometry, orientation and magnetic field simulation [7–9] for several kinds of magnetic wires. For the widely used cylindrical wires, the capture dynamics of single wire to fine weakly magnetic particles and the combinatorial effect of such wires on pulsating HGMS performance were particularly discussed in the recent years [10,11]. It should be noted that the mass weight of ilmenite minerals captured on single cylindrical wire and its dependence on the key parameters of pulsating HGMS process were quantitatively determined in the recent period [10]. These creative works have provided theoretical and experimental foundations for the improvement of HGMS performance, but they involve almost no magnetic capture selectivity for a single magnetic wire, and whether there is significant difference between a single wire and a real matrix is not clear until today.

In this work, the magnetic capture selectivity of cylindrical and rectangular single wires were investigated using a cyclic pulsating HGMS separator with its key operating parameters (magnetic induction, feed velocity and pulsating frequency) varied, and their capture selectivity characteristics were parallelly compared with that of a real 3.0 mm cylindrical matrix.

Experimental

Cyclic pilot-scale PHGMS separator

A typical cyclic pilot-scale pulsating HGMS separator [11] was used for the investigation, as this method is widely applied in the field of mineral processing. From Fig. 1, the separator is mainly composed of magnetic pole, magnetic yoke, magnetic matrix, energizing coils and pulsation mechanism. When the separator is operated, a direct current flows through the energizing coils and a

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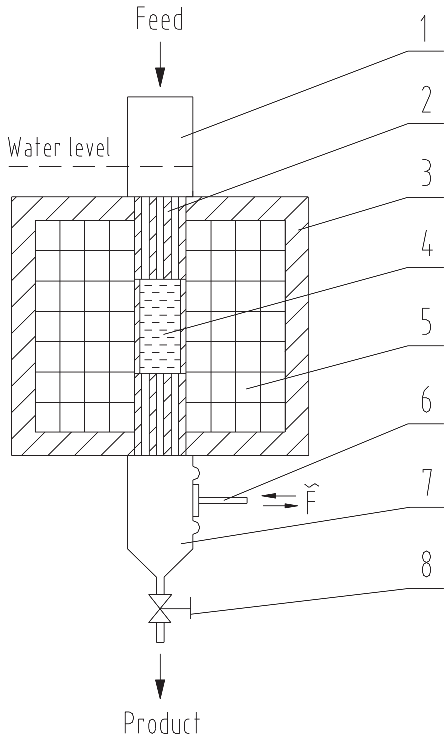

Fig. 1. Cyclic pilot-scale pulsating HGMS separator. 1 = feed box, 2 = magnetic pole, 3 = magnetic yoke, 4 = magnetic matrix, 5 = energizing coils, 6 = pulsating mechanism, 7 = product box, 8 = valve.

magnetic field is built up in the separating zone of the separator. At first, the separating zone is filled up with flowing water, and the water level in the separating zone is maintained constant by adjusting the valve below the pulsating mechanism. The slurry is fed from the feed box into the separating zone and magnetic particles are attracted onto matrix, while non-magnetic particles pass through the matrix, going out of the product box to produce a tailings (or non-magnetic) product under the combined actions of magnetic force, hydrodynamic drag and gravity. The pulsating mechanism drives the slurry in the separating zone up and down, keeping particles in the matrix in a loose state to achieve an enhanced separation efficiency. When a batch of feed is finished, the current is switched off and the magnetic particles are washed down to produce a magnetic product.

Description of sample

A low-grade ilmenite ($FeTiO_3$) ore assaying 4.16% TiO_2 was used for the investigation. From Table 1, the dominant gangue elements in the material are SiO_2, Al_2O_3, CaO and MgO. The material is controlled in a narrow particle size distribution, with 35.86% by mass weight distributed in the 0.074–0.150 mm fraction and 57.98% in the 0.037–0.074 mm fraction; the TiO_2 contents of these two fractions are 3.92% and 4.43%, respectively.

Methods

The Magnetic Capture Analysis (MCA) method [10] was used to analyze the capture selectivity characteristics of single wires. As shown in Fig. 2, in the method circular holes are regularly drilled in two non-magnetic plates, and with four non-magnetic cylinders, the two plates are welded to form a frame for inserting single wires. In the two plates, the holes are drilled in the vertical lines at a given interval between the lines; every two neighboring holes in each vertical line are set in a pair with spacing L, and this spacing is gradually increased from line to line of the holes, as illustrated in Fig. 2. When the magnetic wires are inserted in the frame at a sufficiently large spacing to avoid the magnetic coupling effect between the wires, such a matrix is used for analyzing the magnetic capture characteristics of single magnetic wires.

In this investigation, cylindrical wires of 1.5, 2.0 and 3.0 mm diameters and a rectangular wire of 2.0 mm circumcircle diameter were used as single wires; for each kind of wire, 6 wires are inserted in the MCA method-made matrix at a distance of 15.0 mm in the horizontal direction and 40.0 mm in the vertical direction between wires, as shown in Fig. 3. For each investigation, the matrix was placed in the pulsating HGMS separator; then, excessive material (300 g) was fully mixed in a stir beaker at around 10% solid concentration, and was evenly fed to the separator within 10–20 s. The material was separated in the matrix for an excessively long time of 6.5 mins, to ensure that all wires in the matrix reach full capture for magnetic particles from slurry. Meanwhile, a real matrix made of 171 cylindrical wires of 3.0 mm diameter was parallelly used for separating the material, under the exactly same operation conditions with those of single wires.

It should be noted that for all the investigations, the pulsating stroke of the pulsating HGMS separator is fixed at 6.0 mm, and the TiO_2 grade of capture deposits collected from the single wires and real matrix is adopted for evaluating the magnetic capture selectivity. The feed velocity is determined by measuring the feed volume flow rate, as shown in Table 2.

Results and discussion

Effect of magnetic induction on capture selectivity

Magnetic induction is a dominant parameter in the operation of pulsating HGMS process, and thus its influence on the capture selectivity was firstly investigated, at a controlled feed velocity of 4.36 cm/s and a pulsating frequency of 190 r/min. From Fig. 4, for both the cylindrical and rectangular single wires and the 3.0 mm real matrix, the TiO_2 grades of captured ilmenite deposits are increased with increase in the magnetic induction from 0.3 T to 0.7 T, beyond which they are gradually reduced with further increase from 0.7 T to 1.5 T. However, it is obvious that the reductions in the TiO_2 grades from the single wires are much gentle than that from the real matrix. The cylindrical single wires have distinctively higher capture selectivity than that of the rectangular one, as a result of its smaller curvature and lower magnetic field gradient.

But, the most important discovery of this investigation is that the single wires have achieved a much higher capture selectivity than that of the real matrix; e.g., at the optimum magnetic induction of 0.7 T, the TiO_2 grade of capture deposits from the 3.0 mm cylindrical single wire reaches as high as 27.25%, while it is only

Table 1
Main chemical composition of material.

Elements	TFe	TiO_2	SiO_2	Al_2O_3	CaO	MgO	Cr_2O_3	MnO	S	P	Loss
Content (%)	18.15	4.16	34.87	14.73	8.06	9.25	0.02	0.19	0.31	0.03	10.24

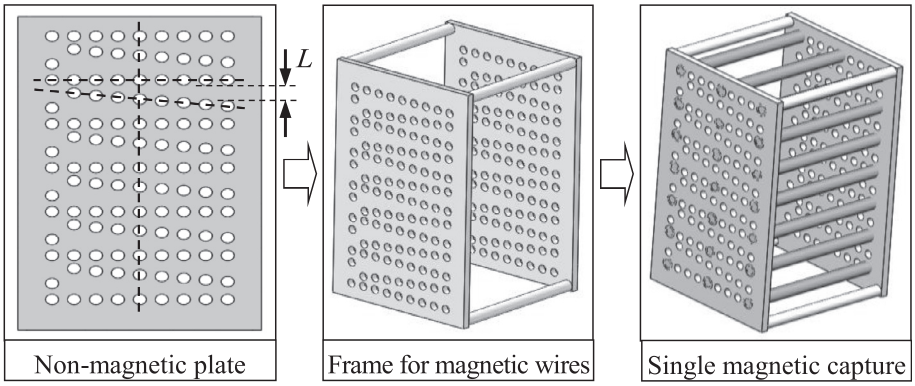

Fig. 2. Experimental device of Magnetic Capture Analysis (MCA) method.

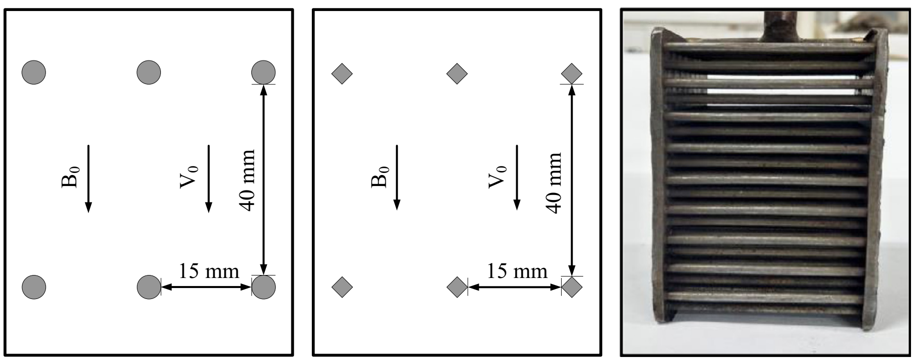

Fig. 3. Cylindrical (left) and rectangular (middle) single wires and a 3.0 mm diameter real matrix (right).

Table 2
Relationship between feed volume flow rate and feed velocity.

Feed volume flow rate (ml/s)	0	50	100	150	200	250	300
Feed velocity (cm/s)	0	1.09	2.18	3.27	4.36	4.45	6.54

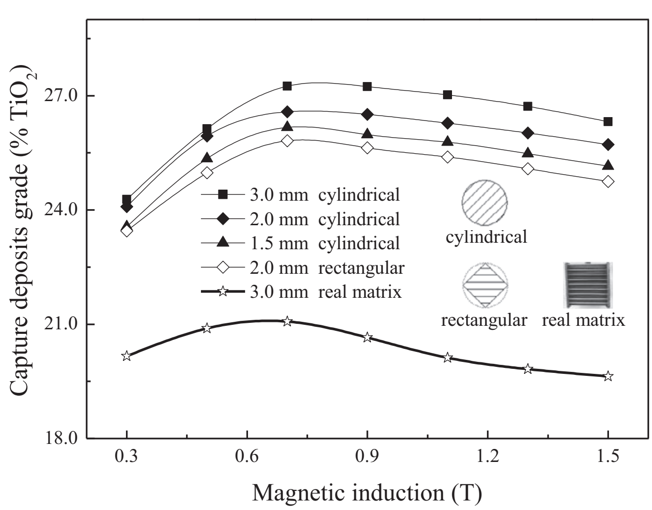

Fig. 4. Effect of magnetic induction on capture selectivity. feed velocity = 4.36 cm/s, pulsating frequency = 190 r/min.

21.07% TiO_2 for the 3.0 mm real matrix. Apparently, such a selective difference between the single wire and the real matrix may mainly be resulted from the magnetic coupling between magnetic wires in the matrix, wherein the fluid flow is also significantly complicated as numerous magnetic wires are assembled in the real matrix.

It is clear that the capture selectivity of single wires is not so sensitive to the variations in the magnetic induction after it reached 0.7 T, as that of real matrix; namely, the single wires maintain high capture selectivity even under strong magnetic inductions.

Effect of feed velocity and pulsating frequency on capture selectivity

In a pulsating HGMS process, the feed velocity and the pulsating frequency of slurry in the separating zone of the separator determine the hydrodynamic drag acting upon a magnetic particle, thereby generating their effects on the capture selectivity. As shown in Figs. 5 and 6, similar to the effect of magnetic induction as discussed above, the single wires and the real matrix have basically the same capture trend while the feed velocity and the pulsating frequency are gradually increased, but again the single wires have a much higher capture selectivity than that of real matrix.

The hydrodynamic drag resulting from feed velocity in pulsating HGMS process is a competing force against the capture of magnetic particles by magnetic force, so that its variation changes the capture selectivity. It is sufficiently inferable from Fig. 5 that the feed velocity has a drastic control on the capture selectivity of sin-

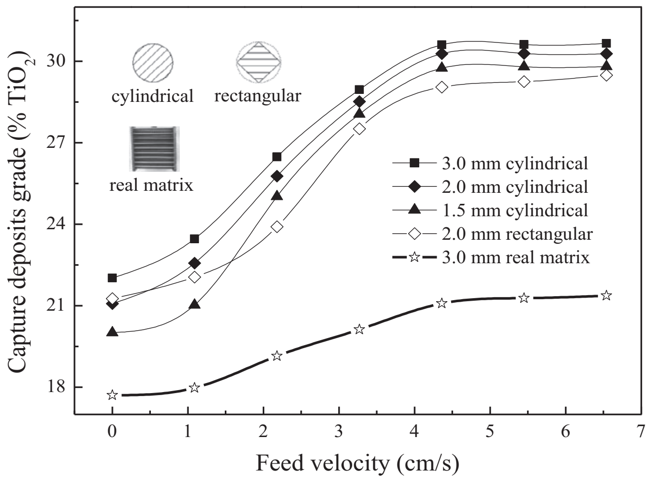

Fig. 5. Effect of feed velocity on capture selectivity. magnetic induction = 1.0 T, pulsating frequency = 190 r/min.

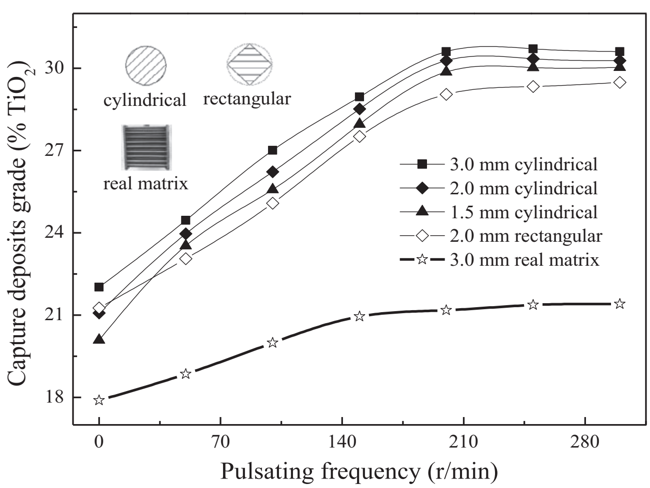

Fig. 6. Effect of pulsating frequency on capture selectivity. magnetic induction = 1.0 T, feed velocity = 4.36 cm/s.

gle wires; but, this control is significantly weakened in a deep matrix, as the penetration of fluid into the matrix and its impinging effect onto magnetic deposits captured on the wire surfaces is significantly reduced in the matrix. It is also inferable from Fig. 5 that for a given material, the single magnetic wires and the real matrix have basically the same optimum feed velocity, and it is 4.36 cm/s for the present conditions.

From Fig. 6, the effect of feed velocity on the capture selectivity is simply duplicated by the pulsating frequency of slurry in the matrix, as they follow the same rule while competing against the magnetic capture to magnetic particles in the pulsating HGMS process. In the process, the pulsating energy is transmitted to the separating zone and drives the slurry up and down, keeping particles in the matrix pile in a loose state, so that magnetic particles are selectively captured by the matrix and nonmagnetic particles are dragged out through the matrix pile [11]. As can be seen from Fig. 6, for the cylindrical, rectangular wires and the real matrix, the capture selectivity increases with increase in the pulsating frequency. But, the single wires and the real matrix have the different optimum pulsating frequencies, and it is clear that in the real matrix a smaller pulsating frequency is required to achieve the highest capture selectivity than that of single wires; under the same conditions, the optimum pulsating frequency is around 150 r/min for real matrix and it is around 200 r/min for the cylindrical and rectangular single wires. When the pulsating frequency is higher than 200 r/min, the capture selectivity of single wires is 7–10% TiO_2 higher than that of real matrix, as cleraly illustrated in Fig. 6.

Conclusions

(1) The cylindrical single wires have superior capture selectivity to the rectangular one, and this capture rule was reconfirmed in this investigation. The single wires and the real matrix follow the same capture selectivity trend when the key parameters of pulsating HGMS separator vary, but the single wires have a much higher capture selectivity than that of real matrix.

(2) Both the single magnetic wires and the real matrix have the most optimum values for the operating parameters of a HGMS process, to reach the highest capture selectivity. For the present ilmenite material, the single cylindrical and rectangular wires and the real matrix have basically the same optimum magnetic induction and feed velocity, but the real matrix requires a slightly smaller pulsating frequency than that of single wires.

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