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THE SEPARATION PERFORMANCE OF THE PULSATING HIGH–GRADIENT MAGNETIC SEPARATOR

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Abstract In order to develop the pulsating high–gradient magnetic separation technology, a laboratory pulsating high–gradient magnetic separator (PHGMS) has been manufactured.. Experiments on its separation performance were carried out. The results show that PHGMS can significantly increase the grade of the magnetic product and it can eliminate the matrix clogging. The characteristic curve of the pulsating fluid was measured and a formula for estimating the grade of the magnetic product from PHGMS was established.

INTRODUCTION

HGMS is an effective technique for extracting fine feebly magnetic particles and has been continuously applied to kaolin purification, waste water treatment and mineral processing. However, there still exist two problems: low grade of the concentrate and matric clogging as a result of serious mechanical entrapment of particles in the matrix. In order to resolve these problems, we have been investigating, since 1981, the performance of the vibrating HGMS and pulsating HGMS (PHGMS) and encouraging progress has been achieved [1 – 3].

THE EXPERIMENTAL PHGMS DEVICE

The experimental PHGMS device (Fig. 1) consists of a cyclic HGMS and a pulse generator and its working principle is shown in Fig. 2. The diameter and height of the separation canister are 80 mm and 240 mm, respectively. The background magnetic field is adjustable up to 1.2 T, with input power of 30 kW.

During the operation, first the water is introduced into the canister and the compartment. The d.c. motor which drives the eccentric–connecting rod system and causes the diaphragm to move up and down is then switched on. Consequently, the fluid in the canister is vertically pulsated.

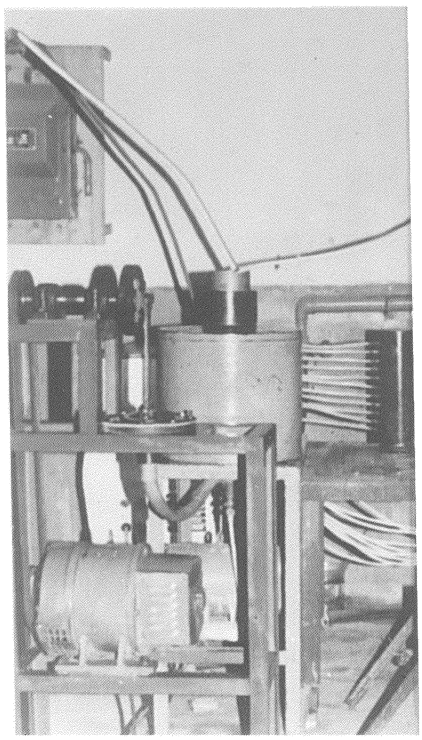

Fig. 1. The experimental PHGMS set–up.

The frequency f and stroke s of the pulsating fluid can be varied in the range of 0 8 Hz and 0 – 100 mm, respectively. The latter can be clearly observed and recorded by means of a calibrated glass tube at the top of the canister. The characteristic curve of displacement versus time of the fluid pulse, measured by oscillograph is shown in Fig. 3. The curve closely approximates the sine curve. The relationships between displacement y, velocity u, acceleration a of the pulsating fluid, and time t, are given by:

$$y = s \sin \omega t \tag{1}$$
$$u = s\omega \cos \omega t \tag{2}$$
$$a = -s\omega^2 \sin \omega t \tag{3}$$

where ω is the angular velocity of the eccentric wheel.

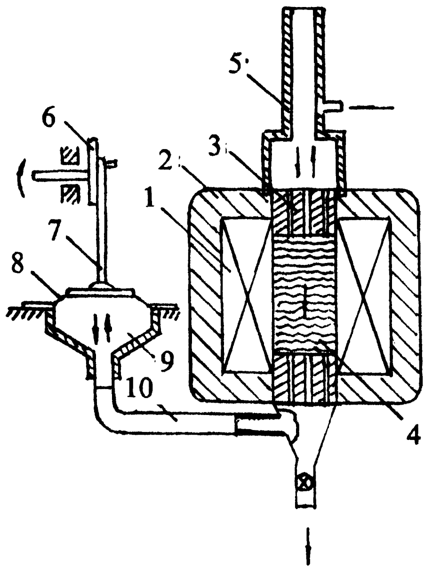

Fig. 2 Schematic diagram of PHGMS.
1–coils, 2–iron magnetic circuit, 3–magnetic pole, 4–matrix, 5–calibrated glass tube, 6–eccentric wheel, 7–connecting rod, 8–diaphragm, 9–pulsating compartment, 10–pulse transfer tube

In general, the maximum value among all instantaneous velocities and accelerations will play an important role in the concentration response and can be determined from eqs. (2) and (3).

THE GRADE OF THE MAGNETIC PRODUCT

As has been mentioned above, PHGMS can significantly improve the grade of the magnetic product. In this section, this problem will be discussed in a greater detail.

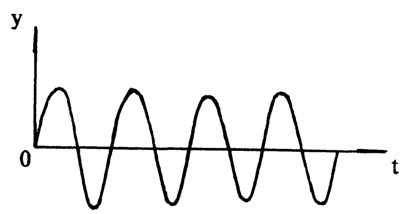

Fig. 3 Displacement versus time of the fluid pulse ($s = 32$ mm, $f = 1.67$ Hz)

In the absence of the pulsation, the purity of the magnetics from HGMS can be determined [4] as follows:

$$P_m = \frac{1}{1 + AK'(F_i/F_c)} \tag{4}$$

where A, K' and F_i are the mass ratio of the magnetic particles to the non–magnetic particles, a constant of proportionality and interparticle force, respectively. F_c is the competing force, including fluid drag F_d and the force of gravity F_g, i.e.

$$F_d = 6\pi\eta V_0 b \tag{5}$$

and

$$F_g = \frac{3}{4}\pi b^3 (D_p - D_f)g \tag{6}$$

where b and D_p are the radius and the density of the particle, respectively. η, D_f and V_0 are the viscosity, the density and the background velocity of the fluid, respectively. g is the acceleration of gravity.

In the presence of pulsation the overall competing force F_c includes, in addition to F_d and F_g, additional pulse drag force R_d and the pulse inertial force R_a due to the pulsation of the fluid, i.e. $F_c = F_d + F_g + R_d + R_a$. The additional pulse drag force R_d can be determined as

$$R_d = 6\pi\eta ub \tag{7}$$

where u is the velocity of the pulse fluid and is given by eq. (2). Hence,

$$R_d = 6\pi\eta bs\omega \cos \omega t \tag{8}$$

where $\omega = 2\pi f$, and f is the frequency of the eccentric wheel, so that

$$R_d = 12\pi^2\eta bsf \cos \omega t \tag{9}$$

The pulse inertial force R_a is commensurate with the force that makes the fluid in the same volume as mineral particles to obtain the acceleration a, i.e.

$$R_a = \frac{4}{3}\pi b^3 D_f a \tag{10}$$

where a is the acceleration of the pulse fluid and is given by eq. (3), so that

$$R_a = -\frac{4}{3}\pi b^3 D_f s\omega^2 \sin \omega t \tag{11}$$

and

$$R_a = -\frac{16}{3}\pi^3 b^3 D_f sf^2 \sin \omega t \tag{12}$$

Taking G_{max} as the theoretical grade of pure magnetic material to be captured, the grade of the magnetic product can be written as:

$$G_m = \frac{G_{max}}{1 + AK'(F_i/F_c)} \tag{13}$$

We often assume $V_0 = 38$ mm/s, $s = 32$ mm, $f = 1.67$ Hz in our experiment. According to these values, we can determine the relative value of the four competing forces exerted on the entrained non–magnetic particles as follows:

$R_{d\text{-max}}/F_d = 8.8$
$R_{a\text{-max}}/F_g = 0.2$
$R_{d\text{-max}}/F_g = 1, 2, 8, 93$ (d = 100, 75, 35 and 10 μm, respectively)
$R_{a\text{-max}}/F_d = 2, 1, 0.25, 0.02$ (for particle sizes as shown above).

Clearly, the pulse drag force R_d is a major force and plays an important role in increasing the grade of the magnetic product. The background fluid drag force F_d is much smaller than R_d; it is, however, accompanied by the downward flow of the fluid, so it is necessary for separation of non–magnetic particles from magnetic ones. The pulse inertial force R_a and the force of gravity F_g are proportional to the third power of the particle size (b^3) and can be important for coarse particles, while for fine particles these forces can be neglected.

It was found during the experiments that when the ore property and other conditions of separation are constant, the overall competing force has an optimum value denoted as F_o. In other words, the value of the grade of the magnetic product increases with increasing competing force F_c when $F_c < F_o$ but slightly decreases when $F_c > F_o$, and achieves its maximum only when $F_c = F_o$.

In the latter case, because excessive competing force would flush fine pure magnetic particles from the matrix into the tailings, eq. (13) must be modified as follows:

$$G_m = \frac{G_{max}}{(1 + K) + AK'(F_i/F_c)[(F_c - F_o)/F_c]^2} \qquad (14)$$

This formula has been used to estimate the grade of the magnetics in PHGMS. The constant K is used here because G_m is always smaller than G_{max}. In the case of non–pulsating HGMS, F_o and K are all equal to zero, so that eq. (14) is equivalent to eq. (13). for the same material, K, A, K' and F_i can be regarded as constant. Thus, eq. (14) can be expressed as

$$G_m = \frac{G_{max}}{K_o + K_1(1/F_c)\,[(F_c - F_o)/F_c]^2} \qquad (15)$$

Where $K_o = 1 + K$ and $K_1 = AK'F_i$ which can be determined by means of linear regressive method and computer on the basis of relative experimental data. Then, using thus determined K_o and K_1 and other given parameters, the grade of the magnetic product can be calculated.

Experimental and Calculated values of the grade of the magnetic fraction from PHGMS, for four sets of samples composed of wolframite and quartz particles, are summarized in Table I. The results indicate that both values, for the same sample, and obtained under the same conditions, are very close to each other.

Table I. Experimental and calculated values of the grade of the magnetic fraction from PGHMS

Samples		Method	Grade of magnetics, WO_3(%)				
d	WO_3		$s\cdot f$/(cm·Hz)				
(μm)	(%)		2.7×0.83	3.2×1.67	2.7×2.50	1.4×3.33	0.8×4.17
−76+40	14.06	Tested	61.48	70.12	69.56	69.63	65.37
		Computed	61.14	69.19	69.11	69.12	67.50
−40+20	13.86	Tested	59.67	67.50	64.93	65.06	61.85
		Computed	59.30	65.22	65.16	65.17	64.00
−20+10	13.31	Tested	59.78	68.24	67.45	67.34	64.14
		Computed	59.54	67.28	67.20	67.21	65.66
−10+0	21.78	Tested	59.40	64.37	63.52	66.60	64.11
		Computed	59.36	64.87	64.70	64.93	64.07

THE SEPARATION PERFORMANCE OF PHGMS

The best method for the evaluation of the separation performance of PHGMS is to perform comparative experiments with PHGMS and non–PHGMS. To this end, enrichment experiments, by removing non–magnetic mineral impurities from magnetic components , and extracting fine weakly magnetic values from low–grade materials were carried out.

In the enrichment experiments, a mixture of wolframite and quartz was used. The grade and the fineness of the mixture sample were 14.79% WO_3 and 80% –40 μm. The experimental results are shown in Fig. 4. The test results indicate the the enrichment ration is dependent on the pulse intensity ($s\cdot f$) and when compared with the non–PHGMS (with PHGMS performed at the maximum pulse intensity), the grade of the concentrate and the efficiency increased by 16.4% and 27.87%, respectively. An increase in the recovery was also observed. The grade of 69.57% of the mags, achieved in our tests is only 3.53% lower than the grade of pure wolframite in the sample. It is thus clear that PHGMS is very efficient in increasing the enrichment.

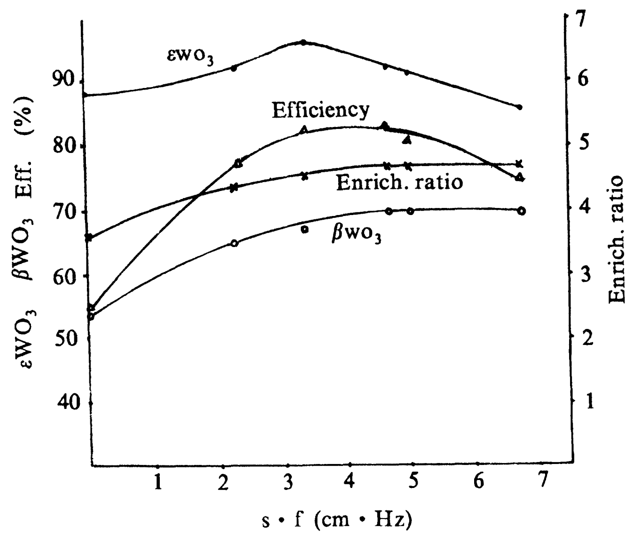

Fig. 4 The grade of the mags and the enrichment ratio, as a function of pulse intensity.
Experimental conditions: $B_0 = 1$ T, $V_0 = 38$ mm/s, matrix: expanded metal. ϵ – recovery, β – grade.

In the experiments of removing impurities of non–magnetic metallic mineral from magnetic components, a concentrate from the slime table of Tie Shanlong Tungsten Mine in Jiangxi was used as a sample. The sample contained 55.70% WO_3 and 1.40% Sn. The particle size was 90% –75 μm. Most tungsten minerals are wolframite while tin is in cassiterite, which, although a valuable mineral, was considered to be an impurity in our experiments. Gangue minerals include quartz, tourmaline, calcite, fluorite etc.

Experimental results are illustrated in Figs. 5 and 6. It is clear that the removal rate of tin and the grade of the mags increased from 24.30% to 84.58% and from 59.29% to 67.37%, respectively. The Sn content in the magnetics dropped from 1.20% to 0.30% when the stroke was increased from 0 to 36.6 mm. This feature of PHGMS can be applied not only to the separation of W–Sn minerals, but also of Cu–mo and Cu–Pb minerals and others.

In the experiments of extracting weakly magnetic minerals from low–grade materials, wolframite ore slimes were chosen as a sample. The slimes contain 0.64% WO_3 and originated from the Pangushan Tungsten Mine, Jiangxi. Metallic minerals in the sample were wolframite, scheelite, pyrite, bismuthinite, sphalerite, limonite and chalcopyrite, while the gangue minerals were quartz, mica, tourmaline and calcite. The test results are shown in Fig. 7.

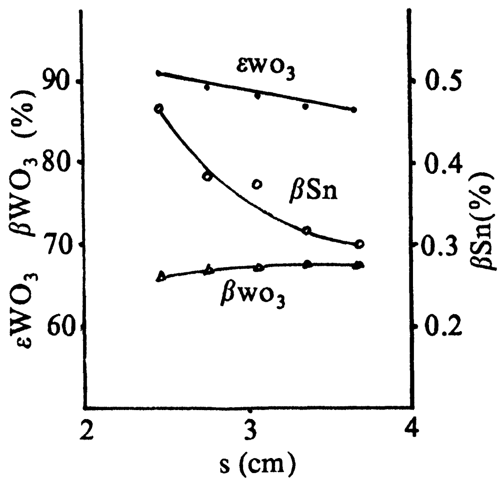

Fig. 5. The grade of the mags and the recovery as a function of stroke. $B_0 = 1$ T, $V_0 = 38$ mm/s, matrix: expanded metal.

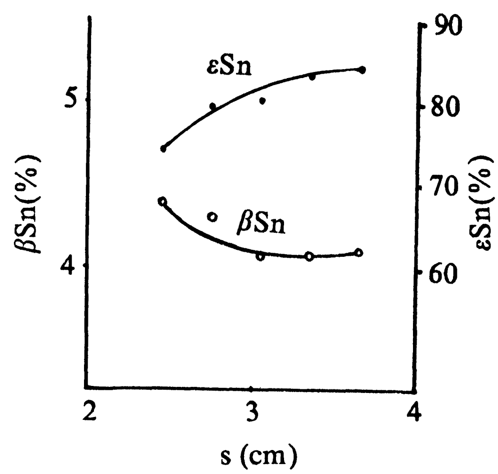

Fig. 6. The grade of the non–mags and the recovery, as a function of stroke. $B_0 = 1$ T, $V_0 = 38$ mm/s, matrix: expanded metal.

It is clear that PHGMS has a good extracting and enrichment ability for fine, feebly magnetic values in low–grade ore slimes. When compared with non–PHGMS, PHGMS increases the enrichment ratio by a factor of 15 to 22, at the same recovery. This performance of PHGMS can be used to extract fine particles of weakly magnetic values from a variety of final tailings.

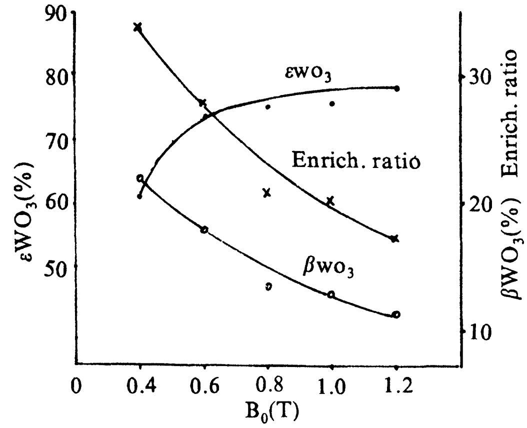

Fig. 7. The grade of the mags and the enrichment ratio, as a function of magnetic field intensity. V_0 = 38 mm/s, matrix: expanded metal.

CONCLUSIONS

Pulsating high–gradient magnetic separator consists of high–gradient magnetic separator and pulse generator. The generator induces vertical pulses of the fluid in the canister. The particles are thus exposed to a pulse competing force which is much greater than the force of gravity and acts in alternate directions. This force can thus flush entrained non–magnetic particles from the matrix, significantly increasing the grade of the mags, and still maintaining high recovery. The experimental investigation into the upgrading of a concentrate, the removal of impurities and the extraction of fine weakly magnetic components has proved a unique performance of PHGMS. The fact that PHGMS has been recently applied in the iron ore industry shows that further development can be expected.

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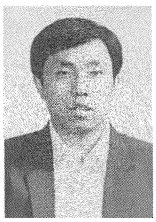

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Keywords: pulsating high–gradient magnetic separation, pulse generator, pulse competing force, frequency, stroke, wolframite