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HYDROMAGNETIC SEPARATION OF POLYMETALLIC PARTICLES

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Abstract. A method of separation of polymetallic waste materials is proposed, based on the treatment of ferromagnetic suspensions in a relatively homogeneous magnetic field. The method considers the case of opposite orientation of the kinetic energy E_k and the potential energy E_p, which hinders the magnetic flocculation. Polymetallic particles of size 40-70 μm are suspended in aqueous medium at a ratio solid: water = 1:3 to 1:6. Three different polymetallic materials have been studied – pyrite dross, iron concentrate and iron waste material. The process is realised in several steps with increasing field intensities up to the degree of magnetic saturation of the particles. This allows selective separation of suspensions of materials with similar chemical composition. The method enables the utilization of ferromagnetic waste materials and reduces the energy consumption expenses.

Keywords: polymetallic waste materials, utilization of waste materials, hydromagnetic separation, multi-step process of separation.

AIMS AND BACKGROUND

The transformation of polymetallic waste materials into a secondary mineral resource is of great importance. The large variety of their compositions and properties determines also the variety of the methods of their processing and utilization. For this reason, it is the combined methods that are preferred most often in this respect[1-6]. The method of direct reduction of pelletized powders at 1100°C (Ref. 7) is applied for processing of waste materials from the cast iron- and steel-making industry. Some methods for dry high-gradient magnetic separation of iron-containing waste powders have also been developed[8,9]. They have found a partial application in the practice as their successful utilization depends also on the character, the phase composition and the chemical composition of the waste material.

EXPERIMENTAL

Method. Upon treating a ferro-magnetic suspension in a relatively homogeneous magnetic field the vector difference between the potential-magnetic energy and the kinetic energy of the particles causes a specific dynamic picture.

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Favourable conditions for the separation of the particles, possessing a definite, precisely determined chemical composition, are created at specific field intensity and velocity of the suspension passing through. The orientation of the field and the direction of the movement determine the fundamentals of the method and the conditions of its application.

Ferro-magnetic particles of a definite size acquire a respective magnetic moment M in a field, characterized by the intensity H:

$$M = \chi V H$$

The magnetic energy, transformed into potential energy E_p of a particle with a volume V, is equal to:

$$E_p = \int \chi V \, dH = \tfrac{1}{2} \chi H^2 V$$

The kinetic energy E_k of the same particle is expressed by the known equation:

$$E_k = \tfrac{1}{2} m v^2$$

The ratio between E_p and E_k has a meaning when the direction of their action is defined in accordance with the scheme, represented in Fig. 1. Depending on the field orientation and the direction of the flow, the two quantities E_p and E_k can be orientated either in the opposite direction or in the same direction. In the case of unidirectional orientation of the two quantities, the magnetic flocculation of all particles with magnetic properties is accelerated. This is the basic principle of magnetic compressors and separators. This well known principle and its application are not the subject of our study.

In the case of opposite orientation of the kinetic energy and the potential energy the magnetic flocculation is hindered. This principle underlies the basis of the method of separation of polymetallic composites, proposed by us[10].

Under the effect of the field H, a magnetic moment M is induced in the particles parallelly to the direction of the field. It gives rise to a magnetic field H_p inside the particles, orientated in the opposite direction with respect to the external field H. The value of H_p is determined by the degree of magnetization J of the particles, respectively by the content of ferro-magnetic material in them and by the coefficient of demagnetization N with maximum value $N_{max} = 12.56$, when the direction of the field is perpendicular to their cross-section[11]:

$$H_p = -NJ, \qquad E_p = \tfrac{1}{2} H_p^2 \chi V$$

The magnitude of H_p obtains the maximum value, when the magnetic saturation of the particles is reached in a field of intensity H_s for which $J \rightarrow$ max. The value of H_s for the various materials is known from the current literature[12]. At a definite intensity of the field $H < H_s$ the degree of separation of particles with a different content of the ferromagnetic component is determined by the magnitude of E_k, i.e. by the linear velocity with which the suspension is moving through the

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zone of the magnetic field in a direction opposite to that of E_p (Fig. 1). It is obvious that in the case of $E_p > E_k$ at H = const. the magnetic flocculation is not disrupted. The value of E_p is different for particles of the same mass but having various ferromagnetic composition. This enables the passing of fractions with a lower magnetic potential through the magnetic zone. The composition and the amount of the separate fractions are to be regulated by the linear velocity of the particles. The alteration of the linear velocity is in accordance with the critical velocity of the particles, which is defined by the equation of Aerov and Todess[13]:

$$v_f d_a / \gamma = A_r / (1400 + 5.22 v A_r) \qquad A_r = g d_a^3 (\rho_s - \rho) / v^2 \rho_s$$

where v_f is the velocity of minimum fluidisation; $d_a = d_p\,\varphi$; φ – shape factor; A_r – Archimed number; ν – viscosity; $\nu \approx 1$ cSt = 10^{-6}m^2/s (for water); ρ_s and ρ – density of the material and of the medium.

The particles, detained in the zone of magnetic irradiation, form gradient fields, which cause realignment of the particles into needle-like flocculates. Their growing up to a specific size leads to the precipitation of the flocculates on the bottom of the apparatus. The separation of the polymetallic composites in fields of increasing intensity enables the separation of fractions with decreasing magnetic susceptibility. The collinear orientation of the field along the direction of the moving suspension is a prerequisite for the opposite orientation of the kinetic energy E_k and of the potential energy E_p.

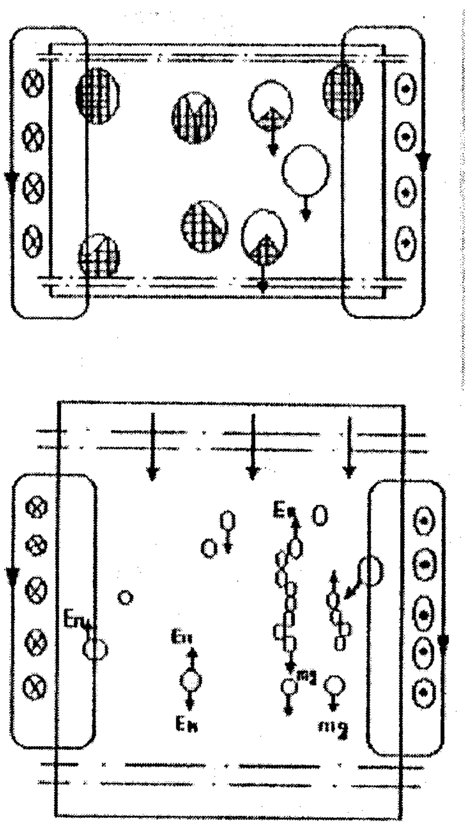

Fig. 1. Scheme of the orientation of E_p and E_k depending on the field orientation

Application of the method. The separation of polymetallic waste materials with different magnetic susceptibility of the particles has been carried out by means of the apparatus, shown in Fig. 2. The polymetallic waste material with size of the particles 40-70 µm is dispersed in water at a ratio solid: liquid = 1:3 ÷ 1:6. The suspension is fed into apparatus 2 through the central tube 1. Water is fed at a velocity, depending on the values of E_p and E_k, in a counterflow with respect to the suspension flowing out. The apparatus 2 is placed

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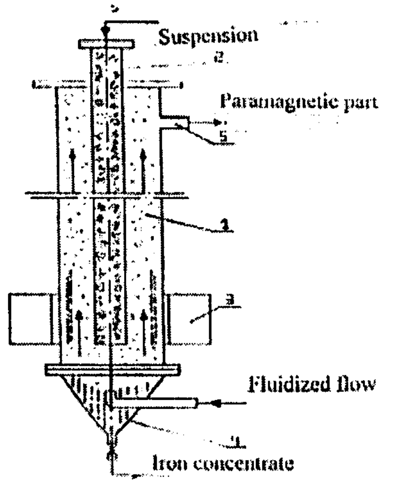

Fig. 2. Technological scheme of apparatus for hydromagnetic separation of pollymetallic particles

inside the space of solenoid 3 with orientation of the field, according to Fig. 1, collinear in regard to the ascending flow. The magnetic moment of the dry material is 95 Mme at 25°C and H=380 Oe. The linear velocity of the suspension reaches a value of 10 cm/s inside the ring-like space, limited between tube *1* and the wall of the apparatus 2 (Fig. 2). The ferromagnetic fraction is separated in the conical part of the apparatus and the suspension possessing higher E_k of the particles with lower content of the ferromagnetic component is removed from apparatus 1 and filtered or separated in fields of higher intensity. The chemical composition of three polymetallic materials, representing interest from industrial point of view, denoted provisionally as A, B and C, is listed in Table 1. The results from the separation in a magnetically structured bed (MSB) are represented in the same table. The ratio between E_k and E_p is determined as a non-dimensional index in regard to the finest particles of the processed mass, without taking into account the resistance of the environment.

RESULTS AND DISCUSSION

The vector difference between E_p and E_k in the case of collinear orientation of the field in regard to the direction of suspension movement is 0.72. The particle size varied within the 40-50 μm interval. The results, represented in Table 1, indicate a quite different degree of extraction of the various elements. The degree of extraction is highest in the case of Fe. This tendency is stable and it is reproduced with the three polymetallic compositions. The chemical composition of the concentrate, obtained on the basis of the elaborated hydromagnetic method, justifies its application in the metallurgical production. The composition A is characterized by a relatively high content of Cu and S. Their amount can be reduced by means of diminishing η of the extracted iron. The different degree of extraction of the separate elements and their compounds is an indication of their relatively non-homogeneous distribution in the particles of the concentrate. This fact determines also the applicability of the elaborated method to the studied objects, representing mass waste in the chemical industry. The magnetic flocculation causes the appearance of gradient fields that change locally the magnetic potential of the particles. Conditions are created for the deterioration of η, which requires increasing of the residence time interval of the mass inside the magnetic space or creating a local increase in the kinetic energy by means of feeding the reverse flow tangentially. The investigations show that the increased pathway for the precipitation of the flocculates and the number of the particles in one aggregate influence the degree of separation. It was established, on the basis of the law of Stocks, that the needle-like flocculates, formed as a result of the field orientation, should contain up to 30-40×10³ particles of average diameter 45 μm. This fact implies that the average length of the flocculates should not exceed 8-10 mm, which was confirmed experimentally. The degree of separation can be regulated using the difference between the magnetic potential and the kinetic energy of the particles, depending on the linear velocity of the suspension and on the intensity of the magnetic field. The realization of the process in several steps enables obtaining concentrates with a different composition of a specific desired product.

Table 1. Chemical composition (wt.%) of the starting and of the final polymetallic material

Component	Starting material			Final material			Degree of extraction		
	A	B_{kk}	C_o	A'	B'	C'	$\eta_{A\%}$	$\eta_{B\%}$	$\eta_{C\%}$
Fe	53.93	50.44	47.33	55.63	52.18	55.16	68.5	70.1	63.4
Mn	0.23	8.00	7.21	0.20	3.52	1.82	13.0	56.0	74.8
Cu	0.62	0.12	0.10	0.21	0.05	0.08	66.1	58.3	20.0
Pb	0.36	0.45	0.22	0.30	0.25	0.12	16.7	44.4	45.5
Zn	0.64	0.48	0.50	0.51	0.31	0.28	10.9	35.4	44.0
SiO_2	16.36	8.83	9.21	6.22	5.24	6.10	61.9	40.6	33.8
Al_2O_3	2.56	1.32	2.10	1.11	1.00	1.05	56.6	24.2	50.0
CaO	0.88	1.52	1.85	0.71	1.13	1.25	19.3	25.7	32.4
K_2O	0.55	-	-	0.25	-	-	-	-	-
MgO	-	0.82	0.95	-	0.51	0.47	-	37.8	50.5
Na_2O	0.22	-	-	-	-	-	-	-	-
S	3.65	0.74	0.25	1.62	0.31	0.14	55.1	58.1	44.0
Ba	-	3.36	3.50	-	1.81	1.45	-	46.1	58.6

A – pyrite dross; B_{kk} – iron concentrate; C_o – iron waste material; field intensity H = 380 Oe; linear velocity V = 5.2 cm/s; particle diameter d_r < 600 μm; temperature 20°C; aqueous medium (1:5); apparatus diameter – 90 mm; degree of iron extraction – η.

CONCLUSIONS

1. The vector difference between the magnetic potential and the kinetic energy E_k of particles with diameter < 100 mm enables the separation of ferromagnetic suspensions with a different degree of phase heterogeneity.

2. The realization of the process in several steps with field intensities up to the value of magnetic saturation of the particles enables a selective separation of suspensions of concentrates with similar chemical compositions.

3. The method creates an option for the utilization of ferromagnetic waste materials and concentrates on the basis of increasing the content of iron in parallel to diminishing the share of the non-magnetic impurities in the final concentrate, which brings a reduction of the expenses due to power consumption decrease in the metal-producing process.

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