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Classification of demagnized magnetite in an upward laminar flow

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Abstract.
The paper presents experimental results of completely demagnetized fine ferromagnetic particles classification in an upward laminar flow. The efficiency of classification was estimated and mathematical model of the process was defined using software for data analysis and visualization SigmaPlot. The attention is paid to the fact, that classification of demagnetized particles is about 5 times more effective. It can be explained with the fact of magnetic flocculation. That is, fine ferromagnetic particles form large floccules, and if these floccules are not broken, all of them fall into underflow product, regardless to the fineness of the sample. Conclusions are drawn about the fact that residual magnetization of magnetite particles effects on the efficiency of their classification. Moreover, classification of completely demagnetized magnetite allows to reduce its cost, as the number of grinding equipment can be significantly reduced.

Keywords:
Demagnetization
magnetic flocculation
hydrosizer
laminar flow
effectiveness

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Introduction. The average size of inclusions of magnetite in the iron ores of the Kryvyi Rih basin is about 80 microns. When enriching magnetite quartzites, a preliminary three-stage grinding in ball mills to a fineness of less than 50 microns is used to release ore grains. The mills operate in a closed circuit, which requires the classification of magnetite. Particles larger than the specified size return to the mill and form a circulating load. Since the classification efficiency is less than 100%, a part of the product of the finished size class is returned to the mill together with large particles, which leads to over-grinding of ore, a decrease in the productivity of the mill and, as a result, an increase in the cost of the concentrate. Therefore, increasing the efficiency of magnetite classification is a relevant task.

Purpose: determination of the effect of residual magnetization of magnetite particles on the efficiency of their classification in an upward laminar flow.

Materials and Methods. The study was conducted on a laboratory model of a hydrosizer, which is a device for hydraulic classification in an upward laminar flow of liquid. For classifying, there was taken a sample of magnetite concentrate after the 3rd stage of grinding with a content of -40 μm class of about 70%. Experiments were conducted with magnetized and completely demagnetized samples. After processing the experimental data, the quantitative characteristics and particle size composition of the obtained products were determined, as well as the classification efficiency in each case. Mathematical processing and plotting were carried out using software for data analysis and visualization SigmaPlot.

Problem Statement. Magnetic separation is applied after each grinding stage. Separation after the first two stages is intended for the removal of waste, and after the third provides the concentrate. Getting into the zone of action of the magnetic field of the separator, magnetite is magnetized and, since it has residual magnetization, it becomes a magnet itself. Magnetized particles of magnetite aggregate and form floccules, the size of which is much larger than the particles themselves, and can reach hundreds of micrometers. When classifying such magnetite in a hydrocyclone, the floccules are partially destroyed due to the turbulent movement of the flow, but then they form again. This leads to a decrease in classification efficiency, as particles of the finished size class enter the overflow product and return to the mill.

Findings and Discussion. The problem can be solved by completely demagnetizing the magnetite. To do this, it must be placed in an external alternating magnetic field, the induction amplitude of which is greater than the residual magnetization of magnetite and decreases with time. In this case, the magnetite particles will remagnetize according to the hysteresis curves, and with a decrease in the amplitude of the external magnetic field to zero, the residual magnetization will also decrease to zero. Demagnetization of particles will occur if the particles are stationary relative to the external magnetic field [1].

If the magnetized particle has the ability to rotate in space, as in the case when it is an integral part of the suspension, then when the direction of the external magnetic field changes, it will rotate in such a way that the remanent magnetization vector becomes collinear with the field vector and coincides with it in the direction. In this case demagnetization is not possible. The forces of inertia and resistance of the medium in which it is located prevent the rotation of the particle. As the size of the particle decreases, the speed of its rotation in the external field increases, that is, it will rotate through a larger angle in less time [2]. The time of the external magnetic field changing should be so small that the particle does not have time to significantly change its position in space. The calculated and experimental data show that for magnetite particles smaller than 10 μm, the required frequency of field change is tens of kilohertz [3, 4].

At present, to demagnetize magnetite in suspension, special-wound solenoids are used as part of a resonant circuit, which operate at an industrial frequency of 50 or 60 Hz. A special winding provides a gradual decrease in the magnetic field induction when the particle moves along the axis of the solenoid, through which an alternating current constantly flows. However, the efficiency of such an apparatus is low, since the frequency is more than two orders of magnitude lower than the required one.

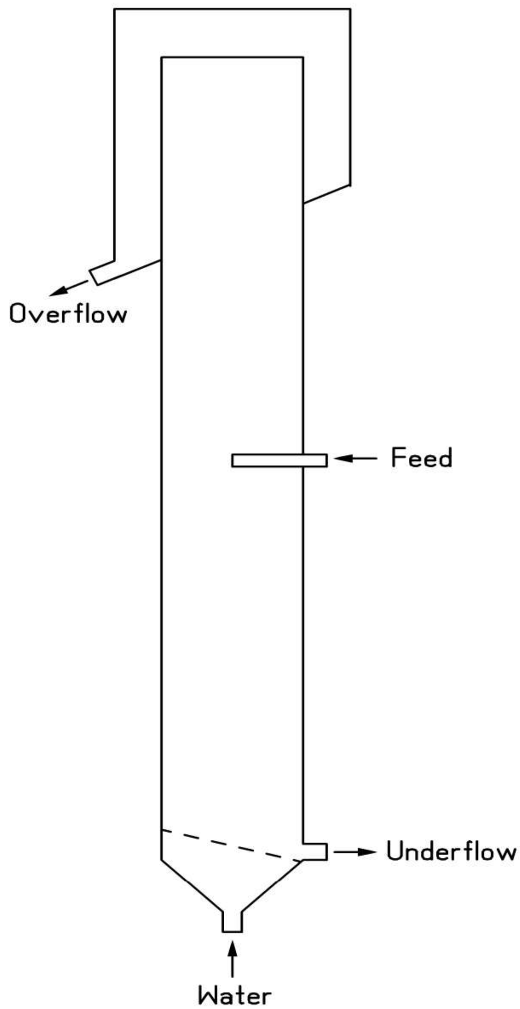

Figure 1
Schematic diagram of a laboratory hydrosizer

It is more energetically advantageous to use the pulsed demagnetization mode. To do this, one can use a solenoid with a conventional winding, included in the circuit, the resonant frequency of which corresponds to the one necessary for the complete demagnetization of particles of a given size. After filling the solenoid with a magnetized suspension, damped oscillations are excited in the circuit by a current pulse, which create an alternating magnetic field inside the circuit with a decreasing amplitude. Moreover, the amplitude value of the induction of the field of the first oscillation should be greater than the residual magnetization of magnetite. All particles inside the solenoid after damping of oscillations will be completely demagnetized. The pulse repetition period must be less than the ratio of the length of the solenoid to the flow rate of the suspension in it [5].

Pilot studies of the classification of demagnetized magnetite in hydrocyclone ГЦ 150 showed that the efficiency increased compared to magnetized one from 74 to 81.1%. In both cases, the density of the underflow was maintained as high as possible. However, the movement of the suspension in the hydrocyclone is fundamentally turbulent, so the efficiency of classifying any particles smaller than 50 μm does not exceed 85%.

The hydrosizer has a higher separation accuracy, since the process is carried out in a laminar or close to it mode. The classification of magnetized and demagnetized magnetite after the third stage of grinding was carried out on a laboratory device, the schematic diagram of which is shown in Fig. 1. Hydrosizer is a tube made of transparent plastic with a diameter of 32 and a height of 250 mm. At the bottom of the tube there is a grate to equalize the flow rate in the cross section, under which clean water is supplied with a constant adjustable flow rate. The upper part of the tube is equipped with an annular chute to collect and remove the overflow. The initial suspension is fed into the middle of the tube by means of a spiral feeder. Particles, the terminal velocity of which is greater than the speed of the upward flow, fall down onto the grate, from where they are periodically removed through the underflow pipe. Particles with a lower terminal velocity rise up and are removed through the annular chute. Classification was performed at an updraft velocity of 0.0138 m/s.

Magnetite was magnetized by placing it in a uniform magnetic field with an induction of 0.12 T. The results of the experiment are shown in Table 1.

During particle size classification, the original sample is separeted in one or another way into several products that differ in particle size. Hence it follows that classification efficiency is the recovery of a certain particle size fraction into one of the separation products. In our case, the classification efficiency was determined from the expression:

$$E = \frac{\gamma_i}{\sum_i^n \gamma_i} \cdot 100\%, \quad (1)$$

where γ_i – yield of a certain particle size fraction in one of the classification product; $\sum_i^n \gamma_i$ – the total amount of this fraction in all products of the classification.

For example, in our case, the efficiency of classification by the +50 μm class for an overflow demagnetized product amounted:

$$E_{+50} = \frac{\gamma_{+50}}{\sum \gamma_{+50}} = \frac{0.86}{2{,}95} \cdot 100 = 29.15\%. \quad (2)$$

Table 1

Estimated values of classification efficiency and yields of separation products

Magnetized					
Overflow			Underflow		
Size class, microns	Yield, %	Classification efficiency, %	Size class, microns	Yield, %	Classification efficiency, %
+50	0.31	10.20	+50	2.73	89.80
-50+40	4.14	18.55	-50+40	18.18	81.45
-40	14.74	19.75	-40	59.91	80.25
Total:	19.18		Total:	80.82	
Demagnetized					
Overflow			Underflow		
Size class, microns	Yield, %	Classification efficiency, %	Size class, microns	Yield, %	Classification efficiency, %
+50	0.86	29.15	+50	2.09	70.85
-50+40	19.75	91.35	-50+40	1.87	8.65
-40	73.04	96.83	-40	2.39	3.17
Total:	93.65		Total:	6.35	

As can be seen from the table, in the process of classifying magnetized magnetite, more than 80% of the product

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got into the underflow product as a result of the formation of floccules. That is, the classification practically did not occur. Under the same conditions, more than 93% of the demagnetized magnetite got into the overflow product, because all particles moved separately, and there was no magnetic interaction between them.

Graphically, the dependences of classification efficiency on particle size are shown in Fig. 2 and 3.

It follows from Fig. 3, that the boundary grain size of the separation is 63 µm, moreover, the experimental data were approximated with an RMS confidence of 0.999 by an equation of the form:

$$E = 1.392 + \frac{98.664}{1+\exp\left(-\frac{d-63.617}{7.392}\right)}, \quad (3)$$

where E – classification efficiency, d – particle size, µm.

In the case of magnetized magnetite, it was not possible to find an analytical dependence approximating the results with an error of less than 10%. This can be explained by the fact that the classification process is determined not by the size of the particles, but by the complex mechanism of their magnetic interaction.

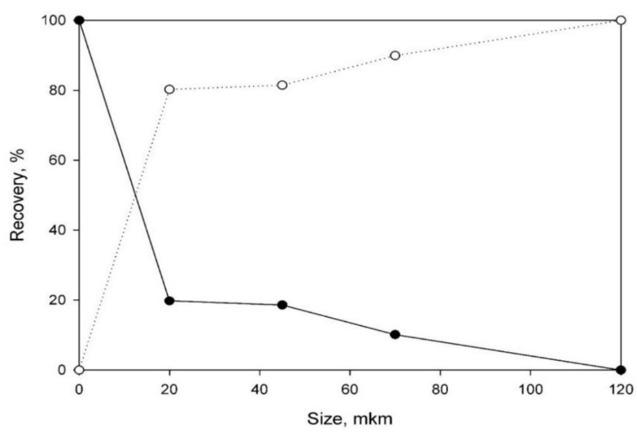

Figure 2
Dependence of the classification efficiency of magnetized magnetite on the particle size

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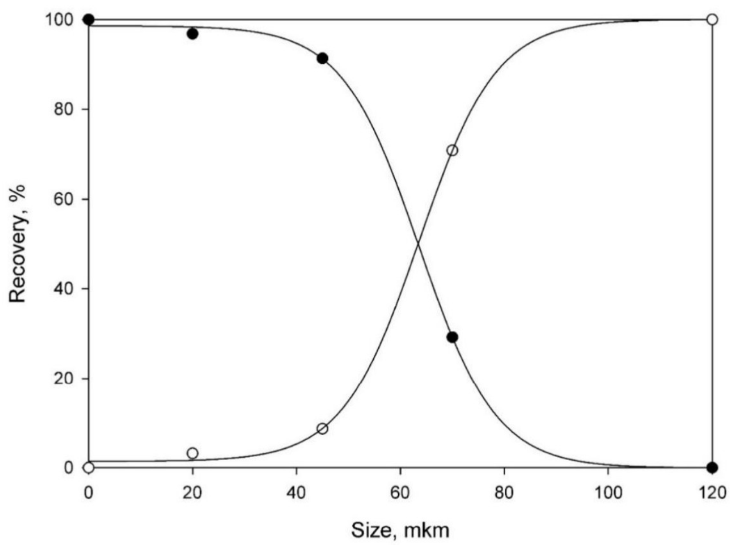

Figure 3
Dependence of the classification efficiency of demagnetized magnetite on the particle size

At a flow rate of 0.0138 m/s, the specific volumetric productivity of the hydrosizer is 39.03 $m^3/h/m^2$. With a solid content in the feed of 120 kg/m^3, its productivity will be 4.68 $t/h/m^2$ with the classification efficiency of more than 96%.

Conclusions

Residual magnetization of magnetite particles effects on the efficiency of their classification in an upward laminar flow. Magnetized ferromagnetic particles form large floccules, which practically disables the process of classification.

Classification of completely demagnetized particles is about 5 times more effective, since in this case there is no magnetic interaction between the particles.

Since more than a half of the cost of magnetite concentrate is determined by the cost of its grinding, the use of the classification of completely demagnetized magnetite in a hydrosizer will significantly reduce its cost.

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