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Improving the quality of magnetite concentrates due to high-frequency demagnetization

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Abstract. The paper presents theoretical substantiation of the feasibility of applying high-frequency demagnetization before separation to obtain iron ore concentrates with close to the theoretically possible quality. It was determined that the length of magnetite floccules under the influence of a constant magnetic field with an induction of 0.25 T reaches 0.3 mm, while the average particle size amounts to 0.015 mm. Under the action of the magnetic field with a decreasing strength amplitude at a frequency of 70 kHz, complete destruction of magnetite floccules into individual particles was achieved. A comparative analysis of the flocculation rate showed that with a decrease in the size of the magnetite particles, it is necessary to increase the frequency of the alternating magnetic field in order to prevent flocculation. Thus, the flocculation rate is directly related to the size of the magnetite particles. To achieve 95% of the theoretically possible quality of the concentrate, ten steps of high-frequency demagnetization with decreasing amplitude of magnetic field strength with a subsequent magnetic re-cleaning separation are required. In such a way, the intensity of the magnetic product purification increases 14 times due to the release of non-magnetic particles from the body of the floccules.

1. Introduction

It is known from the practice of magnetic separation that induced magnetic flocculation prevents the successful separation of minerals due to the presence of non-magnetic phase particles in the concentrate. Also, magnetic flocculation caused by residual induction significantly affects the processes of fine sedimentation, flotation, thickening, filtration and grinding of strongly magnetic materials [1-8].

A floccule formed in a magnetic field, moving relative to the pulp flow, can partially increase the content of valuable minerals by washing away non-magnetic particles located on its surface. Since these non-magnetic particles are not affected by magnetic forces in the pulp, they are held due to the force of friction.

Suppose the floccules in the pulp are reshaped, for example, by an alternating magnetic field. In that case, a new surface is formed after each reshaping, and the release of non-magnetic particles increases. Suppose this magnetic product is subjected to high-frequency demagnetization. In that case, a homogeneous mass will first form, and floccules will appear again after falling into a magnetic field. Still, the distance between non-magnetic particles will be more significant than in the previous separation step. As a result, the body of the floccule will contain fewer non-magnetic particles. That is, the separation performance should improve [9-13]. Thus, it is advisable to apply high-frequency demagnetization not only before a non-magnetic separation but also before a magnetic one, during re-

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cleaning or control operations; that is, high-frequency demagnetization is advisable before any operation of separation [14-21].

An experimental study of the sedimentation of particles of a magnetite suspension speaks in favour of the thesis about the expediency of demagnetization. As a result of high-frequency demagnetisation, the sedimentation rate of the suspension decreases by almost three times, indicating that the floccules were wholly destroyed to the size of individual particles. At the same time, there is a sharp boundary between the layers of magnetic mass (lower dark layer) and non-magnetic mass (upper light layer), i.e., as it should be: heavy magnetite-containing particles settle first and faster, and then light, released non-ore grains continue settling [22-31]. The study of the classification of finely dispersed magnetite in an upward laminar flow also confirmed the effect of demagnetization on the efficiency of the classification process. The presence of floccules significantly distorts the solid phase's granulometric composition, making hydraulic classification practically impossible since a significant number of fine particles are trapped in the underflow product. However, in cases when magnetite floccules are completely broken after applying a high-frequency magnetic field with a decreasing strength amplitude, the classification of demagnetized particles becomes about five times more effective [32].

Based on the results of experimental studies, it was suggested that high-frequency demagnetization of the magnetite suspension before each subsequent separation step should increase the efficiency of the process, particularly before a non-magnetic separation and a magnetic one.

The work aims to substantiate the possibility of obtaining iron ore concentrates with a quality close to the theoretically possible due to the application of high-frequency demagnetization before each separation step.

2. Methods

The magnetite concentrate from the PJSC Northern Mining and Processing Plant, obtained after three stages of magnetic separation and four stages of grinding to a particle size of less than 0.04 mm, was used as the object of the study on the degree of floccule destruction. The research was carried out based on the Center for the processing of mineral and man-made raw materials of the Dnipro University of Technology.

The degree of floccules destruction was determined by microscopic studies. Since finely dispersed magnetite particles have a significant residual magnetization and begin to aggregate even under the influence of the Earth's magnetic field, a magnetite suspension in liquid paraffin, which solidified over time, was used for research. This made it possible to fix the particles in space and prevent the side magnetic field from affecting them. At the same time, the density and viscosity of paraffin in a liquid state do not hinder the movement of magnetite particles under the influence of an applied magnetic field or when using a demagnetizing device.

Demagnetization was carried out using the laboratory device developed by the authors for magnetite suspension degaussing, which has a design of a typical solenoid where damped oscillations are excited [33]. Magnetite suspension passes through this solenoid. The apparatus generates high-frequency electromagnetic oscillations with a frequency of 20-70 kHz with decreasing amplitude of the magnetic field strength [33,34].

The value of non-magnetic particles trapping during flocculation was determined analytically, according to the discrete probability distribution, which is the number of events occurring in a fixed interval of time if these events occur with a known constant mean rate and independently of each other (Poisson distribution):

$$p(k) \equiv P\left(Y = k\right) = \frac{\lambda^{k}}{k!} \cdot e^{-\lambda}, \tag{1}$$

where k – the number of events; λ – the expectation value of a random variable (mean number of events in a fixed interval).

The dependence of the flocculation rate on the frequency of the external magnetic field was determined using a mathematical model of the movement of magnetite-containing particles under the action of secondary magnetic fields at different from 0 initial field strength $H_0 = \mathrm{var}$, taking into account the change of the magnetic field in time. The equation of the movement of a particle taking into account the change of magnetic field in time has the form [35]:

$$U = \frac{A \cdot (B \cdot \sin(\omega t) - \omega \cdot \cos(\omega t) + \omega)}{B^2 + \omega^2}, \tag{2}$$

where A, B – coefficients characterizing the size, shape, density and magnetic permeability of particles; ω – frequency of the external magnetic field, Hz; t – the time during which the magnetization axis of the particle will have time to orient itself according to the direction of the external magnetic field, s.

$$A = \frac{\mu_0 \cdot (H_0 \cdot d_1 \cdot d_2)^2 \cdot k_1 \cdot k_2}{\pi \cdot \left(\delta_1 \cdot d_1^3 + \delta_2 \cdot d_2^3\right) \cdot r_{12}} \cdot \left(1 + \frac{k_1 \cdot d_1^3}{\left(d_1 + r_{12}\right)^3}\right) \cdot \left(1 + \frac{k_2 \cdot d_2^3}{\left(d_2 + r_{12}\right)^3}\right), \tag{3}$$

where $\mu_0 = 1.26 \cdot 10^{-6}$ – magnetic constant, Hn/m; H_0 – the strength of the external magnetic field, A/m; d_1, d_2 – particles size, m; k_1, k_2 – volumetric magnetic susceptibility of solid phase particles, SI units; δ_1, δ_2 – density of solid phase particles, kg/m^3; r_{12} – the distance between the particles of the solid phase in the suspension, m.

$$B = \frac{18 \cdot \mu}{\delta \cdot d^2}, \tag{4}$$

where μ – relative magnetic permeability, dimensionless; δ – density of solid phase particles, kg/m^3; d – particles size, m.

3. Results and discussion

In the course of research, it became necessary to visually estimate the size of floccules from magnetite particles formed due to the action of a primary or secondary magnetic field. The magnetite concentrate from PJSC Northern Mining and Processing Plant was used for the study. This concentrate is the raw material for further flotation. It is ground to a grain size of less than 0.04 mm in order to ensure the maximum release of the ore grains and extraction of magnetite-containing particles. During the study of the granulometric composition, it was determined that the average particle size of magnetite amounts to 0.015 mm.

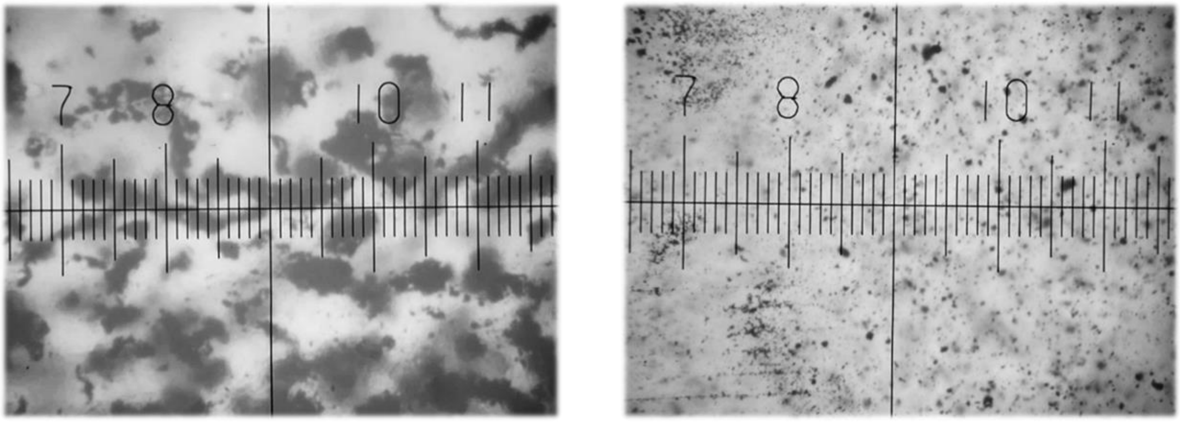
Visual assessment of floccular size was performed by photographing magnetite suspension in solidified paraffin with a 56-fold magnification and superimposing a measuring ruler with a dimension value of 0.01 mm on the image.

The results of the study are shown in Figure 1. Initially, the suspension was magnetized under a constant magnetic field with an induction of 0.25 T, corresponding to the standard induction value in commonly used wet magnetic separation. Under the action of this field, the magnetite particles formed floccules up to 0.3 mm in size (Figure 1, *a*).

It is worth noting that the termination of the external magnetic field action does not lead to the destruction of floccules due to the fact that the magnetite particles have a high residual magnetization. That is, they remember the influence of the magnetic field. This is the reason for the phenomenon of secondary magnetic flocculation, which occurs when the action of the magnetic field has stopped, but the magnetite particles have not been demagnetized.

At the next stage of the study, this pre-magnetized suspension was exposed to a high-frequency magnetic field with a decreasing strength amplitude at a frequency of 70 kHz. As a result of such influence, it was possible to obtain completely demagnetized magnetite particles separated from each other (Figure 1, *b*). At the same time, the sample was shielded from the Earth's magnetic field. The study of particle sizes gives reason to conclude that almost all particles have a size of less than 0.02 mm.

Therefore, complete demagnetization of magnetite particles was achieved. This will have a significant impact on the parameters of the further magnetic separation of the demagnetized suspension, in particular the extraction and quality of the magnetite concentrate, as it allows the release of an additional amount of non-magnetic fraction that was trapped inside the floccules and led to the impurity of the magnetic separation concentrate.



a *b*

Figure 1. Microphotographs of magnetite pulp x56, division value of 0.01 mm:
a – pulp particles magnetized by a permanent magnetic field with an induction of 0.25 T;
b – pulp particles after demagnetization by an alternating field with a frequency of 70 kHz

Evaluate the number of non-magnetic particles that can theoretically be released from floccules due to the application of high-frequency demagnetization. Non-magnetic particles fall into floccules randomly. Therefore, their trapping can be characterized by a certain probability. Flocculation occurs due to the intensive movement of magnetic particles towards each other. On their way, they can meet a non-magnetic particle, and the likelihood of such an appointment depends on the concentration of non-magnetic particles. The distribution of particles in the pulp is subject to Poisson's law and can be described by an exponential function:

$$P_{app} = 1 - \exp(-n), \tag{5}$$

where n – the number of non-magnetic particles in the path of movement of magnetic ones.

A non-magnetic particle will be trapped in a floccule if enough quantity of magnetic particles K collide with it. In this case, the probability of trapping will be:

$$P_{tr} = 1 - P_{app}^{K}. \tag{6}$$

The value K depends on the ratio of the number of magnetic n_m and non-magnetic particles in the pulp in a sphere of a certain radius r from the surface of the flocculation centre.

Consider the patterns of non-metallic particle trapping in case the material is subjected to demagnetization before the subsequent separation step.

The volume of the floccule is:

$$V = \frac{4}{3} \cdot \pi \cdot b^2 \cdot a, \tag{7}$$

and the surface at $a > b$ is:

$$S = 2 \cdot \pi \cdot a \cdot \left(a + \frac{b^2}{\sqrt{a^2 - b^2}} \ln \frac{a + \sqrt{a^2 - b^2}}{b} \right). \tag{8}$$

The distance between non-metallic particles is:

$$r = d \cdot \left(\sqrt[3]{\frac{0.65}{p \cdot P_n}} - 1 \right). \tag{9}$$

The use of high-frequency demagnetization ensures that all non-magnetic particles are released from the body of the floccule and without demagnetization – only from its surface. Estimate the number of released particles in both cases, provided that $b = a/2$:

$$n_V = \frac{V}{r^3} = \frac{4 \cdot \pi \cdot a^3}{12 \cdot d^3 \cdot \left(\sqrt[3]{\frac{0.65}{p \cdot P_n}} - 1 \right)^3} = \frac{\pi \cdot a^3}{12 \cdot d^3 \cdot \left(\sqrt[3]{\frac{0.65}{p \cdot P_n}} - 1 \right)^3}, \tag{10}$$

where p – content of solid in the pulp; P_n – content of non-metallic grains in the pulp; a, b – size of the floccule; d – size of particles

Suppose that $p = 0.35$; $P_n = 0.1$; $a = 3\ mm$; $d = 0.05\ mm$.

Then the amount of free non-magnetic particles that can be released into the waste product is:

– in case of high-frequency demagnetization:

$$n_V = \frac{V}{r^3} = \frac{\pi \cdot 3^3}{3 \cdot 0.05^3 \cdot \left(\sqrt[3]{\frac{0.65}{0.35 \cdot 0.1}} - 1 \right)^3} = 51000, \tag{11}$$

– without demagnetization:

$$n_s = \frac{S}{r^2} = \frac{\pi \cdot 3^2}{3 \cdot 0.05^2 \cdot \left(\sqrt[3]{\frac{0.65}{0.35 \cdot 0.1}} - 1 \right)^2} = 3700. \tag{12}$$

Thus, the intensity of separation increases by 14 times. In the case of using preliminary high-frequency demagnetization, the intensity of purification of the magnetic product depends on the ratio of the sizes of floccules and individual particles. Accordingly, the greater this ratio is, the more productive the demagnetization effect will be.

Consider the case of re-cleaning operations taking place in distinct separators – steps. The action of the magnetic field leads to repeated flocculation. However, there will be less and less non-magnetic material in the further separation steps.

After the first separation step, the enriched product will contain the amount of non-magnetic fraction equal to:

$$P_{tr} = P_m \cdot p_n = P_m \cdot P_n \cdot p. \tag{13}$$

Therefore, the further process of high-frequency demagnetization and subsequent separation steps will be an iterative one:

$$P_{tr(i+1)} = P_{tr(i)} \cdot (P_m \cdot p), \tag{14}$$

that is, the change in the content of non-metallic grains trapped in the floccules is proportional to the concentration of particles in the pulp, which is determined by an exponential relationship:

$$P_{tr(i)} = P_{tr0} \cdot \exp(-i \cdot P_m \cdot p). \tag{15}$$

The required number of high-frequency demagnetization and subsequent separation steps i can be found as:

$$i = \frac{\ln\left(\frac{P_{tr(k)}}{P_{tr0}}\right)}{-P_m \cdot p}. \tag{16}$$

For commonly used conditions of magnetic separation, the number of steps will be about 10. The calculation was made for conditions when the content of solid in the pulp is $p = 0.3$, the content of the magnetic fraction in the concentrate will amount $P_m = 0.95$.

Therefore, it is possible to obtain high-quality magnetite concentrate by using high-frequency demagnetization before each subsequent step of magnetic separation, and the number of re-cleaning operations can be realized in practice.

Since the values of P_m and P_n are related to each other by a ratio:

$$P_m + P_n = 1, \tag{17}$$

the product of these values represents the probability of non-magnetic particles trapping. Since this probability asymptotically tends to the abscissa but never crosses it, there will always be a non-zero probability of non-magnetic particles trapping, and obtaining pure concentrates using only magnetic separation is theoretically impossible.

Therefore, it is necessary to exclude the effect of particles on each other, that is, to demagnetize them. This means it is possible to achieve high concentrate quality using magnetic separation together with high-frequency demagnetization, and the number of re-cleaning steps can be realized in practice.

Since the demagnetized magnetite will form floccules again under the action of the field of magnetic separator with a commonly used magnetic system, it is proposed to apply magnetic separation in an alternating magnetic field. This will contribute to improving separation indicators by reducing the flocculation rate of fine magnetite particles.

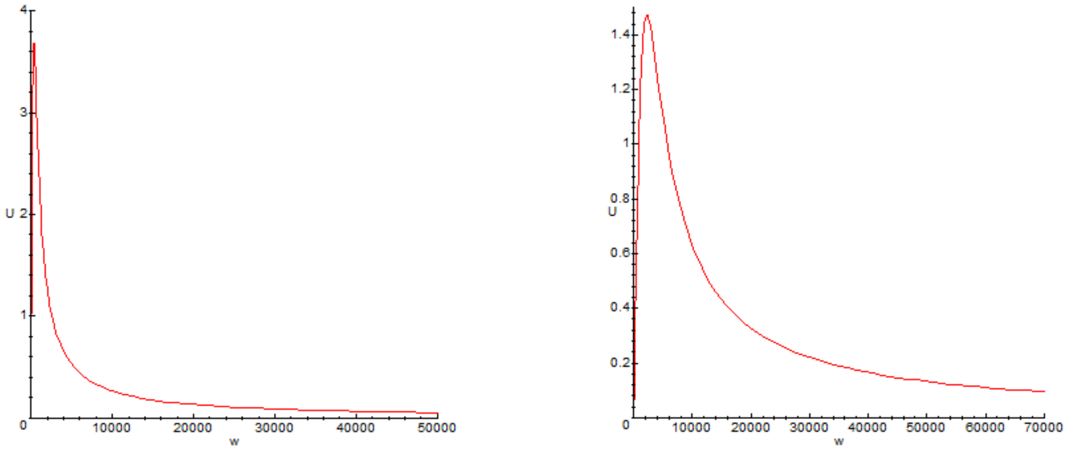
Considering the fact that it is not possible to measure experimentally the rate of movement of finely dispersed particles in the magnetic separator bath, we will carry out an analytical assessment of the dependence of the flocculation rate on the frequency of the external magnetic field using a mathematical model of the movement of magnetite-containing particles under the action of secondary magnetic fields [35].

It was assumed that the range of use of the mathematical model proposed by the author in [35] is from 0 to 1000 Hz since, at the time of publication, the capabilities of electrical components were quite limited and did not allow the creation of devices for generating electromagnetic oscillations with a frequency of tens of kHz. However, suppose a decrease in the flocculation rate occurs under the influence of an external field of relatively low frequency. In that case, it is logical to assume that in case of a significant increase in the frequency, the flocculation rate should also notably decrease.

The characteristics of the magnetic separation concentrate from PJSC Northern Mining and Processing Plant were taken as initial data for the modelling. Consider the movement of two magnetite-containing particles of $d_1 = d_2 = 1 \cdot 10^{-4}$, and $4 \cdot 10^{-5}$ m in size, with magnetic susceptibility of $\mathrm{k}_1 = \mathrm{k}_2 = 5$ SI units, densities of $\delta_1 = \delta_2 = 5000$ kg/m^3, the distance between them of $\mathrm{r}_{12} = \mathrm{d}$, located in a field with a strength of $\mathrm{H}_0 = 10^4$ A/m. These particles interact through the secondary magnetic fields.

Plot the dependences of the flocculation rate on the frequency of the external magnetic field. Considering that the mean values of the components $\sin(\omega t)$ and $\cos(\omega t)$ are equal to 0, the dependence (2) is plotted based on the averaged values.

At a low frequency of the external magnetic field (200 Hz for a grain size of 0.1 mm and 400 Hz for a grain size of 0.04 mm), a sharp increase in the flocculation rate is observed, and its decrease begins only with the further increasing of the magnetic field frequency. This can be explained by the fact that under the action of a low-frequency electromagnetic field, magnetite particles manage to orient their axes of easy magnetization along the magnetic field. That is, the already existing floccules begin to be reformatted due to the movement of their particles along the magnetic field.



a *b*

Figure 2. Dependence of the flocculation rate on the frequency of the external magnetic field: *a* – for particles with a size of 0.1 mm; *b* – for particles with a size of 0.04 mm

Analyzing the obtained plots (Figure 2), it can be concluded that the dependences of the flocculation rate on the frequency of the external magnetic field vary according to the equations:

$$U_{0.1} = \frac{2649 \cdot \omega}{360 + \omega^2}, \tag{18}$$

$$U_{0.04} = \frac{6623 \cdot \omega}{2250 + \omega^2}. \tag{19}$$

However, with an increase in the external magnetic field frequency, the final destruction of magnetite floccules begins since the particles no longer have time to orient themselves along the imposed magnetic field. It can also be concluded from Figure 2 that the flocculation rate directly relates to the size of the solid phase particles. Thus, for particles with a size of 0.1 mm, the flocculation rate values are in the range of 3.65-0.1 m/s, and for particles with a size of 0.04 mm in the range of 1.45-0.1 m/s. The frequency required for complete demagnetization of magnetite particles depends on their size. In particular, a decrease in the flocculation rate to 0.1 m/s for particles with a size of 0.1 mm takes place at an external field frequency of 50 kHz, while for particles with a size of 0.04 mm – at a frequency of 70 kHz. It should be noted that the rate of particle flocculation depends not only on their size but also on their shape, magnetic permeability, density, and inertia force. In more detail, the authors describe the method of determining the frequency of the external magnetic field for demagnetising thin ferromagnetic particles in [34].

The study results show that with an increase in magnetic field frequency, the flocculation rate decreases and asymptotically tends to zero. This again indicates that separation in a high-frequency magnetic field is a high-potential task, as it contributes to obtaining pure concentrates.

4. Conclusions

The length of magnetite floccules under the influence of a constant magnetic field with an induction of 0.25 T reaches 0.3 mm, while the average particle size amounts to 0.015 mm. Under the action of a high-frequency magnetic field with a decreasing strength amplitude at a frequency of 70 kHz, complete destruction of magnetite floccules into individual particles was achieved.

A comparative analysis of the dependence of the flocculation rate on the frequency of the external magnetic field showed that with a decrease in the size of the magnetite particles, it is necessary to increase the frequency of the alternating magnetic field in order to achieve similar indicators of the reduction in the flocculation rate. In particular, a decrease in the flocculation rate to 0.1 m/s for particles with a size of 0.1 mm takes place at an external field frequency of 50 kHz, while for particles with a size of 0.04 mm – at a frequency of 70 kHz. The flocculation rate is directly related to the size of the magnetite particles. For particles with a size of 0.1 mm, the flocculation rate values are in the range of 3.65-0.1 m/s, and for particles with a size of 0.04 mm in the range of 1.45-0.1 m/s.

Thus, the application of demagnetization by a high-frequency magnetic field with decreasing strength amplitude followed by magnetic separation in an alternating magnetic field is justified since this method of separation contributes to the improvement of separation indicators by reducing the rate of particle flocculation.

Demagnetization of magnetite concentrate before subsequent magnetic re-cleaning steps increases the intensity of the magnetic product purification by 14 times due to the release of non-magnetic particles from the body of the floccules. It also reduces the number of re-cleaning operations to obtain the required concentrate quality to 10, simultaneously allowing to obtain 95% of the theoretically possible concentrate quality. This means that it is possible to achieve high quality of magnetite concentrate using high-frequency demagnetization together with magnetic separation in an alternating field, and the number of re-cleaning steps can be realized in practice.

References

[1] Mladetskyi I K, Berezniak O O, Kuvaiev V M, Kuvaiev Ya G and Berezniak O O 2019 *Zminni mahnitni polya v separatsiyi i rozmahnichuvanni tonkykh feromahnitnykh materialiv* Dnipro University of Technology 128 ISBN 978-617-7822-12-6

[2] Mladetskyi I, Beshta O, Berezniak O and Kuvaieva T 2019 Improving iron ore preparation cost efficiency through concentrate yield maximization *Sustainable development of resource-saving technologies in mineral mining and processing. Multi-authored monograph* Petrosani Romania: UNIVERSITAS Publishing 174-193

[3] Pivniak H H, Pilov P I, Pashkevych M S and Shashenko D O 2012 Synchro-mining: Civilized solution of problems of mining regions' sustainable operation *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu* **3** 131-138

[4] Bazaluk O, Ashcheulova O, Mamaikin O, Khorolskyi A, Lozynskyi V and Saik P 2022 Innovative activities in the sphere of mining process management *Frontiers in Environmental Science* **10** 878977

[5] Vagonova O G and Volosheniuk V V 2012 Mining enterprises' economic strategies as derivatives of nature management in the system of social relations *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu* **2** 127-134

[6] Kulikov P, Aziukovskyi O, Vahonova O, Bondar O, Akimova L and Akimov O 2022 Post-war Economy of Ukraine: Innovation and Investment Development Project *Economic Affairs (New Delhi)* **67(5)** 943-959

[7] Stukalo N, Lytvyn M, Petrushenko Y and Omelchenko Y 2020 The achievement of the country's sustainable development in the conditions of global threats *E3S Web of Conferences* **211** 01029

[8] Haiko H and Biletskyi V 2015 First metals discovery and development the sacral component phenomenon *Theoretical and Practical Solutions of Mineral Resources Mining* 227-231

[9] Berezniak O 2022 Improving the efficiency of iron ore processing: demagnetization *Sustainable production and consumption in the industry: challenges and opportunities. Collection of scientific articles* Ed.: Shvets V, Paliekhova L Dnipro-Cottbus Accent **184** 68-70

[10] Mladetskyi I K, Kuvaiev V M and Berezniak O O 2018 Demagnetization of fine ferromagnetic materials *Topical issues of resource-saving technologies in mineral mining and processing. Multi-authored monograph* Petrosani Romania UNIVERSITAS Publishing 90-110

[11] Arvidson B R 2013 Processing High-Grade Concentrates from Challenging Low-Grade Iron Ore Deposits *Trans Indian Inst Met* **66** 467-474
[12] Hossein Elahidoost, Saeed Sheibani, Shahram Raygan, Leila Hosseini and Nader Esmaeili 2022 Mechanism of magnetite iron ore concentrate morphology affecting the pellet induration process *Advanced Powder Technology* **33** 103883
[13] Alaei S P and Dahlberg E D 2022 Effect of Magnetic Interactions on Magnetic Remanence in a Fine Particle System *IEEE Transactions on Magnetics* **58** 1-9
[14] Cherniaiev O, Anisimov O, Saik P, and Akimov O 2024 Theoretical substantiation of water inflow into the mined-out space of quarries mining hard-rock building materials *IOP Conf. Series: Earth and Environmental Science* **1319(1)** 012002
[15] Bazaluk O, Kuchyn O, Saik P, Soltabayeva S, Brui H, Lozynskyi V and Cherniaiev O 2023 Impact of ground surface subsidence caused by underground coal mining on natural gas pipeline. *Scientific Reports* **13 (1)** 79-89
[16] Gorova A, Pavlychenko A, Borysovs’ka O and Krups’ka L 2013 The development of methodology for assessment of environmental risk degree in mining regions *Annual Scientific-Technical Collection - Mining of Mineral Deposit* 207-209
[17] Gorova A, Pavlychenko A and Borysovs'ka O 2013 The study of the ecological state of waste disposal areas of energy and mining companies *Annual Scientific-Technical Collection - Mining of Mineral Deposits* 169-171
[18] Turpak S M, Taran I O, Fomin O V and Tretiak O O 2018 Logistic technology to deliver raw material for metallurgical production *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu* **1** 162-169
[19] Borysovs'ka O and Pavlychenko A 2015 Environmental aspects of the use of overburden rocks for hazardous waste detoxification *Theoretical and Practical Solutions of Mineral Resources Mining* 253-259
[20] Caie Zhang and Shuaishuai Lu 2023 CFD study on the influences of size distribution and density of magnetite ore particles on hydrocyclone classification process *Powder Technology* **427** 118711
[21] Jintian Wu, Bin Xu, Yujuan Zhou, Zhonglin Dong, Shouguo Zhong and Tao Jiang 2023 A novel process of reverse flotation-hydrogen reduction for preparation of high-purity iron powder with superior magnetite concentrate *Separation and Purification Technology* **307** 122784
[22] Long Bing, Xie Jiawen, Huang Weisheng, Xu Tao, Xu Daogang and Wu Jiangyueen 2022 Experimental Study on Beneficiation of Coarse Concentrate from Shizhuyuan Magnetite Mine *Multipurpose Utilization of Mineral Resources* **43(4)** 41-47
[23] Xu B, Zhou Y, Ma Y, Wu J, Li Q, Yang Y and Jiang T 2020 A Study of Processing High-Grade Magnetite Concentrates by Combination of Magnetic Separation and Reverse Flotation Separation to Prepare Raw Materials for Ferrite Magnet, *149th Annual Meeting and Exhibition of the Minerals, Metals and Materials Society* Springer Science and Business Media Deutschland GmbH, San Diego, CA, United States 595-601
[24] Yosep Han, Seongmin Kim, Byunghun Go, Sujeong Lee, Seongkyun Park and Ho-Seok Jeon 2021 Optimized magnetic separation for efficient recovery of V and Ti enriched concentrates from vanadium-titanium magnetite ore: Effect of grinding and magnetic intensity *Powder Technology* **391** 282-291
[25] Zhanglei Zhu, Wanzhong Yin, Huili Han, Shaohang Cao, Bin Yang and Donghui Wang 2020 Investigation on the influence of surface roughness on magnetite flotation from the view of both particle-particle and bubble-particle interactions *Colloids and Surfaces A: Physicochemical and Engineering Aspec*ts **595** 124681
[26] Delgadillo J A, Lopez-Valdivieso A and Tello A 2008 Optimization of a grinding and classification circuit of a magnetite ore processing plant through computer simulation *Mining, Metallurgy & Exploration* **25** 223-228

[27] Parry L G 2013 Physical Principles of Demagnetization *Developments in Solid Earth Geophysics* **3** 217-220

[28] Richard R Doell, Allan Cox 2013 Analysis of Alternating Field Demagnetization Equipment *Developments in Solid Earth Geophysics* **3** 241-253

[29] Clark D A 2014 Methods for determining remanent and total magnetisations of magnetic sources - a review *Explor. Geophys.* **45** 271-304

[30] Béguin A and Fabian K 2021 Demagnetization energy and internal stress in magnetite from temperature-dependent hysteresis measurements *Geophysical Research Letters* **48** e2021GL096147

[31] Baynes T M, Russell G J and Bailey A 2002 Comparison of stepwise demagnetization techniques *IEEE Transactions on Magnetics* **38** 1753-1758

[32] Berezniak O and Berezniak O 2022 Classification of demagnetized magnetite in an upward laminar flow *Scientific Collection «InterConf+»* **25(125)** 168-176

[33] Berezniak O and Berezniak O 2015 Pulse method of magnetite demagnetizing *Theoretical and Practical Solutions of Mineral Resources Mining* Leiden CRC Press/Balkema 547-550

[34] Berezniak O O and Mladetskyi I K 2019 Vyznachennya chastoty rozmahnichuvannya tonkykh feromahnitnykh chastynok *Zbahachennya korysnykh kopalyn: naukovo-tekhnichnyy zbirnyk* **73(114)** 106-111

[35] Mladetskyi I K 1992 *Osnovy prognozirovaniya vykhodnykh pokazateley razdeleniya flokuliruyushchikh materialov pri mokroy magnitnoy separatsii* Doctoral dissertation (Dnipropetrovsk Mining Institute, Ukraine)