ISSN 1062-7391, Journal of Mining Science, 2017, Vol. 53, No. 6, pp. 1133–1140. © Pleiades Publishing, Ltd., 2017.
Original Russian Text © E.K. Yakubailik, I.M. Ganzhenko, A.D. Balaev, P.Yu. Butov, 2017, published in Fiziko-Tekhnicheskie Problemy Razrabotki Poleznykh Iskopaemykh, 2017, No. 6, pp. 182–190.

MINERAL DRESSING

Magnetic Parameters of Separation Products and Impurity Aggregates in Concentrates

E. K. Yakubailik[a]*, I. M. Ganzhenko[b], A. D. Balaev[a], and P. Yu. Butov[b]

[a]Kirensky Institute of Physics, Siberian Branch, Russian Academy of Sciences, Krasnoyarsk, 660036 Russia
**e-mail: churilov@iph.krasn.ru*
[b]EVRAZRUDA, Novokuznetsk, 654018 Russia

Received March 30, 2017

Abstract—The changes in separation performance and magnetic characteristics of separation products is traced along the processing circuit of Abagur concentrator at a laboratory scale in order to determine the limit content of magnetite iron in impurity aggregates in the concentrate. The wet magnetic analysis is carried out in the field of $H = 175$ kA/m, and the magnetic characteristics are determined in the vibration magnetic detector in the field up to 800 kA/m. The concentrate impurity content is governed by the relative content of barren rock and ore aggregates removable in concentration at the given level of the technology.

Keywords: Processing circuit, wet laboratory separation, concentrate impurity, magnetic characteristics.

DOI: 10.1134/S1062739117063233

INTRODUCTION

Abagur concentrator, Evrazruda, supplies the secondary iron ore concentrate, being the final dry magnetic separation product of multistage processing of Siberian primary magnetite concentrates, to West-Siberian smelter.

Iron content in the initial intermediate products of – 0.071 mm in size ranges within 50.9–47.1% of Fe_{total} and 46.0–42.4% of Fe_{mag} in magnetite ores; 36.0–41.2% Fe_{total} and 32.1–30.9% Fe_{mag} in weakly oxidized ores [1]. In the final product iron content reaches 65.3% of Fe_{total} and 63.8% of Fe_{mag} [2]. However iron associated with sulfur, silicates, and oxidized minerals is lost in tailings, while aggregates can remain in the magnetic product.

In every processing stage the iron content tends to grow in the magnetic product. Iron content in separation products regularly varies in the course of processing and influences the chemical composition and magnetic parameters of magnetic and non-magnetic products. Using the term “contamination degree” it is reasonable to state that magnetic characteristics of concentration products corresponds to impurity degree, viz., to a content of magnetite aggregates in every of the separation products.

The principal objective of the present work is to trace variations in magnetic characteristics in separation stages and to establish respective separation boundaries in terms of magnetite iron content in each size fraction of the concentrator feed under the operating processing circuit at Abagur concentrator [3].

Size classification of the initial feed and the laboratory wet magnetic analysis were performed by the technical department of Abagur concentrator and the Kirensky Institute of Physics, SB RAS. The magnetic characteristics of the study specimens were evaluated at the Kirensky Institute of Physics, SB RAS. The chemical assay of the initial and study specimens was executed at the Central Technological Laboratory, Evrazruda.

1. STUDY SPECIMENS

At Abagur concentrator four representative specimens of $-1+0$ mm in size were technologically selected for laboratory separation and other research purposes. They are classifier overflow, concentrate of the first stage, concentrate of the second stage, the final concentrate. The initial specimens were classified into four size fractions within $+1 \div -0.071$ mm before sieve and chemical analyses. The results of sieve and chemical analyses of Abagur disseminated specimens are summarized in Table 1.

The maximum Fe_{total} and Fe_{mag} content in $-0.071+0$ mm fraction in the final concentrate is 65.4 and 64.2%, respectively, increased relative to digital-analogues for classifier overflow: 41.6 and 36.4%. In fine fractions iron content is growing, but in the classifier overflow iron content is higher in the middle size fraction of $-0.2+0.071$ mm because of better grindability of rock minerals.

It is traced the decline in an amount of coarse fractions through classifier overflow (28.5%) to the final concentrate (7%) and growth of the volume of fine fractions through classifier overflow and concentrate of stage I (41.5 and 38.5%) to the final concentrate (65.2%).

Mineralogical specification of the initial separation feed, viz., classifier overflow is in brief ~58% of basic ore mineral magnetite, ~4% of sulfides: pyrite, pyrrhotine, ~36% of non-metal minerals, there are serpentine, carbonates, pyroxene, garnet, and epidote.

2. LABORATORY-SCALE SEPARATION OF PRODUCTS

The laboratory wet magnetic separation (WMS) of Abagur concentrated products was executed on three size fractions (mm): $-1+0.2$, $-0.2+0.071$, and $-0.071+0$ at 25T analyzer: magnetic field intensity $H = 175$ kA/m.

Let consider separation results on "principal" separation fraction of $-0.071+0$ mm in size. Separation results and iron content in the resultant fractions are reported in Table 2, while data on the initial samples are cited in Table 1.

Table 1. Sieve and chemical analyses of classification products

Specimen	Fraction, mm	Yield, %	Content, %	
			Fe_{total}	Fe_{mag}
Classifier overflow	$+1$	3.5	32.3	26.8
	$-1+0.2$	28.5	40.3	35.9
	$-0.2+0.071$	26.5	45.3	41.0
	$-0.071+0$	41.5	41.1	36.5
	Total	100.0	—	—
Concentrate of stage I	$+1$	5.0	35.3	30.0
	$-1+0.2$	35.3	46.5	42.2
	$-0.2+0.071$	23.1	54.5	52.6
	$-0.071+0$	36.6	60.8	58.8
	Total	100.0	—	—
Concentrate of stage II	$+1$	0.3	35.4	30.3
	$-1+0.2$	8.5	37.6	33.7
	$-0.2+0.071$	28.5	56.2	53.4
	$-0.071+0$	62.7	63.2	61.2
	Total	100.0	—	—
Final concentrate	$+1$	0.3	37.5	33.5
	$-1+0.2$	7.0	39.3	36.2
	$-0.2+0.071$	27.5	58.0	55.7
	$-0.071+0$	65.2	65.4	64.2
	Total	100.0	—	—

Table 2. Magnetic analysis of fractions containing magnetite ($H = 175$ kA/m), %

Specimen	Fraction, mm	Magnetic product			Non-magnetic product		
		Yield	Fe_{total}	Fe_{mag}	Yield	Fe_{total}	Fe_{mag}
Classifier overflow	– 1 + 0.2	76.9	49.3	46.3	23.1	10.0	1.23
	0.2 + 0.071	73.2	57.8	55.7	26.8	11.3	1.05
	– 0.071 + 0	55.8	65.9	64.7	44.2	9.5	0.38
	Total	64.5	57.9	55.9	32.0	10.0	0.70
Concentrate of stage I	– 1 + 0.2	92.9	49.2	45.2	7.1	11.1	2.38
	0.2 + 0.071	94.3	57.5	55.7	5.7	12.6	1.90
	– 0.071 + 0	91.0	65.6	64.4	9.0	11.1	1.87
	Total	87.1	56.8	54.4	6.9	11.4	2.09
Concentrate of stage II	– 1 + 0.2	90.0	40.9	37.0	10.0	8.8	2.51
	0.2 + 0.071	95.6	55.5	53.6	4.4	11.6	1.77
	– 0.071 + 0	94.1	65.7	64.9	5.9	12.6	3.26
	Total	93.9	60.7	59.4	5.8	11.8	2.73
Final concentrate	– 1 + 0.2	96.1	42.5	39.4	3.9	9.5	2.61
	0.2 + 0.071	98.0	56.5	54.6	2.0	12.5	3.26
	– 0.071 + 0	97.8	66.2	65.6	2.2	13.7	5.29
	Total	97.4	61.9	60.7	2.3	12.9	4.48

Total values minus + 1 mm fraction (grade and amount)

At the initial technological stage the classifier overflow yield (Table 1) is 41.5% of the study size fraction containing: Fe_{total}—41.1, Fe_{mag}—36.5%. The laboratory separation of the overflow (Table 2) yields 55.8% of the magnetic product, containing: Fe_{total}—65.9 and Fe_{mag}—64.7%. At the final processing stage the final concentrate (Table 1) at the initial coarseness 65.2% of – 0.071 + 0 mm contains: Fe_{total}—65.4 and Fe_{mag}—64.2%. Separation enables to extract 97.8% of the magnetic Fe-containing product: Fe_{total}—66.2 and Fe_{mag}—65.6% (Table 2).

The illustrative non-magnetic product yield of the laboratory separation of – 0.071 + 0 mm fraction is 44.2% in the overflow, total 2.2% in the final concentrate, namely, impurity content of this final concentrate amounts to 2.2% for this size fraction.

The data in Table 2 are used to calculate stepwise variations in iron content identified as ΔFe_{mag}. The results are summarized in Table 3, where the data on iron content in non-magnetic products are cited for comparison.

Given that ΔFe_{mag} in the magnetic product of the overflow was 28.2% in the laboratory tests, it was as little as 1.4% in the final concentrate.

Table 3. Iron content variations in separation products in (– 0.071 + 0 mm fraction), %

Specimen	Initial	Magnetic		Non-magnetic	
	Fe_{mag}	Fe_{mag}	ΔFe_{mag}	Fe_{mag}	Fe_{total}
Overflow	36.5	64.7	28.2	0.38	9.5
Concentrate of stage I	58.8	64.4	5.6	1.87	11.1
Concentrate of stage II	61.2	64.9	3.7	3.26	12.6
Final concentrate	64.2	65.6	1.4	5.29	13.7

The alternative situation is with non-magnetic products: $Fe_{mag} = 0.38\%$ for overflow, $Fe_{mag} = 5.29\%$ for the final concentrate; Fe_{total} tends to grow from 9.5% (overflow) up to 13.7% (the final concentrate). Thus, by the data in Tables 2 and 3 barren aggregates are washed off from the ore feed under processing: 44.2% impurity content in the classifier overflow versus 2.2% impurity content in the final concentrate. Thereto, magnetite iron content in poor ore aggregates discharged to tailings reaches its real limit and presents the target separation margin for magnetite iron at Abagur iron ore concentrator. The analytical data on the non-magnetic fraction size content in the final concentrate factually justifies this statement.

To conclude, from the data in Table 2 we determine that the magnetite iron separation margin for Abagur concentrator is its content: 2.61% for $-1+0.2$ mm fraction; 3.26% for $-0.2+0.071$ mm fraction; 5.29% for $-0.071+0$ mm fraction.

3. MAGNETIC CHARACTERISTICS OF LABORATORY-SCALE SEPARATION PRODUCTS

The compensation process realized in magnetic fields up to 800 kA/m at the automated vibration magnetometer enabled to measure magnetic parameters: the specific saturation magnetization σ_s, specific residual saturation magnetization σ_{rs}, coercive force H_c, which allow their separation in the magnetic field of the separator [4]. The procedure for measurement of magnetic properties at the vibration magnetometer is described in [5].

Magnetic characteristics of Abagur final concentrate are known and reported in [2], however the data on magnetic products of Abagur concentrator and their separation products are not published.

Magnetic parameters of initial specimens were measured on $-0.071+0$ mm fraction. Magnetic characteristics of magnetic and non-magnetic separation products of all the technological products were also measured on $-0.071+0$ mm fraction; the magnetic parameters of non-magnetic products of the final concentrate were determined on all three size fractions (Table 4). Values of the specific saturation magnetization σ_s for initial specimens at the processing stages from overflow through to the final concentrate differ appreciably, namely, it is 46.6 for overflow and 81.4 Am^2/kg for the final concentrate. Nevertheless, σ_s values of magnetic products of laboratory separation are close: 74.6 (overflow) and 82.4 Am^2/kg (final concentrate) because of different iron content in respective specimens (Table 2).

Table 4. Magnetic characteristics of initial specimens and products

Specimen	Product	Fraction, mm	σ_s	σ_{rs}	H_c	$\sigma_H = 80$	$\sigma_H = 111$	$\sigma_H = 175$
			Am^2/kg		kA/m	Am^2/kg		
Classifier overflow	Initial	$-0.071+0$	46.6	3.3	5.0	31.5	36.6	41.6
	Magnetic	$-0.071+0$	74.6	4.6	3.2	55.1	62.2	69.0
	Non-magnetic	$-0.071+0$	0.67	0.07	12.6	0.34	0.42	0.49
Concentrate of stage I	Initial	$-0.071+0$	75.2	7.6	4.6	56.9	63.3	69.2
	Magnetic	$-0.071+0$	81.8	9.1	4.6	62.9	70.0	75.8
	Non-magnetic	$-0.071+0$	1.93	0.16	7.9	1.1	1.3	1.6
Concentrate of stage II	Initial	$-0.071+0$	78.4	8.9	5.0	60.4	66.6	72.4
	Magnetic	$-0.071+0$	81.7	9.5	4.7	63.8	70.0	75.7
	Non-magnetic	$-0.071+0$	3.83	0.3	7.1	2.2	2.7	3.2
Final concentrate	Initial	$-0.071+0$	81.4	8.9	4.7	62.6	69.1	75.4
	Magnetic	$-0.071+0$	82.4	9.6	4.8	64.3	70.4	76.3
	Non-magnetic	$-1+0.2$	3.96	0.18	4.4	2.4	2.8	3.4
	Non-magnetic	$-0.2+0.071$	2.72	0.14	1.5	1.8	2.1	2.4
	Non-magnetic	$-0.071+0$	4.5	0.35	7.2	2.8	3.3	3.8

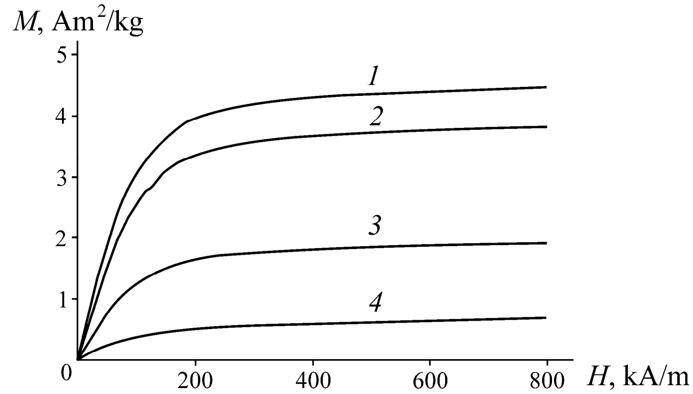

Fig. 1. Basic curves of magnetization of non-magnetic products, $-0.071+0$ mm size fraction: *1*—final concentrate; *2*—concentrate of the second stage; *3*—concentrate of the first stage; *4*—overflow.

The non-magnetic separation products explicitly exhibit growth of such magnetic parameters as the specific saturation magnetization, etc. in parallel with the growth of magnetite iron amount from 0.38 to 5.29%: σ_s—0.67 (overflow) and 4.5 Am^2/kg (final concentrate). Basic magnetization curves for non-magnetic products of all the specimens through the processing flowsheet are plotted in Fig. 1, where the increment of the magnetic parameters growth for non-magnetic separation products is obvious.

Coercitive force H_c of the non-magnetic product explicitly declines from 12.6 to 7.2 kA/m through the overflow to the final concentrate with increase in amount of $-0.071+0$ mm fraction.

Specific magnetic susceptibility χ for $-0.071+0$ mm fraction (Table 5) is calculated based on values of the specific magnetization σ in different magnetic fields and the magnetic field intensity H. Figure 2 demonstrates relationships of specific susceptibility χ of magnetic and non-magnetic products produced from the final concentrates. The shape of the given relationship for separation products is similar to graphs $\chi(H)$ for magnetites and rough concentrates of strongly magnetic ores [6, 7].

Data in Table 5 indicate that specific magnetic susceptibility χ of magnetic products exceeds appreciably, be precise, by three orders the susceptibility of non-magnetic ones. The maximum susceptibility domain is approximately two times greater for non-magnetic products. It is important to emphasize that magnetic products do not exhibit growth of the specific susceptibility through the separation diagram. As for non-magnetic products, their susceptibility used to grow ~8 times through the processing stages. As a whole, the data on specific susceptibility χ correlate with variations in "specific saturation magnetization σ_s through processing stages.

Table 5. Specific magnetic susceptibility of separation products in different fields

Specimen	Product	Maximum χ H, kA/m		Susceptibility χ H, kA/m		
		H	χ	$H=80$	$H=111$	$H=175$
Overflow	Magnetic	4.6	1.1	0.27	0.12	0.03
	Non-magnetic	14.7	4.9	2.6	1.7	0.7
Concentrate of stage I	Magnetic	6.3	1.4	0.26	0.11	0.03
	Non-magnetic	13.0	16.0	8.5	5.0	2.0
Concentrate of stage II	Magnetic	6.6	1.4	0.26	0.11	0.04
	Non-magnetic	11.7	32.2	17.1	8.9	3.9
Final concentrate	Magnetic	10.9	1.4	0.26	0.12	0.03
	Non-magnetic	19.5	40.1	20.3	12.5	4.0

The magnetic product—$\chi\times10^{-3}$, non-magnetic product—$\chi\times10^{-6}$ m^3/kg

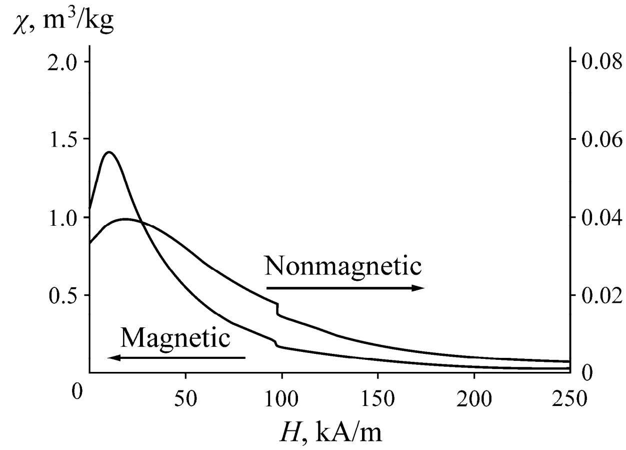

Fig. 2. Relationship of the specific magnetic susceptibility χ of separation products versus magnetic field intensity; the final concentrate, $-0.071+0$ mm fraction ($\chi \times 10^{-6}$).

4. MAGNETIC PARAMETERS AND IMPURITY CONTENT OF SEPARATION PRODUCTS

Impurity content in magnetic separation products is assessed at "reference" magnetic field intensity H at a laboratory wet magnetic analyzer. The "reference" magnetic field intensity H is suggested equal to 175 kA/m at Abagur concentrator. Interrelation of a grade and impurity content in the wet magnetic separation concentrate, the dependence of these parameters on separation field, magnetic system design in magnetic separators, and mechanical characteristics are established in [8–10].

A contamination degree of the concentrate with non-rejected barren rock and poor intergrowths is specified with magnetite iron content Fe_{mag} in a non-magnetic fraction of the laboratory separation. It is explicit in Tables 2, 3, that Fe_{mag} in the non-magnetic fraction successively ascends through processing stages: from 0.38% in classifier overflow for $0.071+0$ mm fraction to 5.29% in the final concentrate.

Magnetic parameters of non-magnetic products tend to grow in parallel (Table 4): specific saturation magnetization σ_s increases from 0.67 in classifier overflow to 4.5 Am^2/kg in the final concentrate. The dynamics of specific magnetic susceptibility χ of non-magnetic products develops in a similar way (Table 5), the maximum susceptibility changes from 4.9 up to $40.1 \cdot 10^{-6}$ m^3/kg, the specific susceptibility in the magnetic field $H = 175$ kA/m increases from 0.7 up to $4.0 \cdot 10^{-3}$ m^3/kg. Such magnetic parameter alteration justifies the conclusion drawn based on the data on the laboratory separation products: barren intergrowths are washed off in the course of processing; the non-magnetic product produced from the final concentrate is represented solely with ore aggregates of marginal magnetite iron grade.

It is obvious that magnetite aggregates entrapped as an impurity to the final concentrate actually truly determine the factual separation point of the material in terms of magnetite iron in the practiced processing technology, viz., 2.61% for $-1+0.2$ mm fraction, 3.26% for $0.2+0.071$ mm fraction, and 5.29% for $-0.071+0$ fraction. Magnetic parameter values complete these experimental results.

Thus, magnetic parameters of non-magnetic products are proportional to Fe_{mag} magnetite iron content in them. Notable are both their dynamics in contamination of separation products in processing stages (in $-0.071+0$ mm fraction: 44.2%—overflow; 9.0%—concentrate of stage I; 5.9%—concentrate of stage II, and 2.2%—the final concentrate) and difference in separation boundaries for different size fractions of the final concentrate.

5. POTENTIALS TO IMPROVE IRON CONCENTRATE GRADE

In recent years a good deal of research is undertaken to find ways to improve magnetic separation performance in the iron ore processing inn terms of the current mined ore types, their mineralogy, magnetic properties, magnetic separation techniques and apparatuses. Outstanding are research findings of the Moscow State Mining University in collaboration with the Mikhailovsky and Lebedinsky Mining and Processing Plants, Voronezh Rudgormash plant [11–14].

The research findings on magnetic properties and magnetic processing of Siberian iron ores, full-scale tests of innovative magnetic separators at crushing and ore-preparation plants of Evrazruda are reported in [3].

Many-years cooperation of the Institute of Physics and Abagur concentrator of Evrazruda provides reliable grounds to formulate "trends and procedures" intended to lower iron loss in tailings to improve the final concentrate grade: higher intensity and gradient of the magnetic field in separation, higher frequency of polarity inversion and a higher contact angle of a magnetic system, magnetic preparation of a material before separation (flocculation and deflocculation), separation in alternative magnetic fields, and classification of concentrates (fine screening).

Lately, Abagur concentrator implemented the project aimed at improvement of the final concentrate grade. Within the framework of the project the magnetic systems of separators were updated with new neodymium-iron-boron-alloy systems. Pilot tests in the first and second stages of magnetic separation and thickening made it possible to establish that separators PBM-P-90/250 equipped with Nd-Fe-B alloy system in the rough separation stage (stage I) yield the concentrate where the content of Fe_{total} is reduced by 0.78%, Fe_{mag} by 1.77%; in tailings the content of Fe_{total} is less by 0.49%, Fe_{mag} by 0.34%. In the thickening stage Fe_{total} content gets higher by 0.31%, Fe_{mag} by 0.54%; in tailings content of Fe_{total} is less by 0.33%, Fe_{mag} is less by 0.37%. In the second magnetic separation stage the content of Fe_{total} in the concentrate increases by 0.51%, Fe_{mag} by 0.48%; in tailings Fe_{total} is less by 0.16%, Fe_{mag} by 0.02%. At present 23 separators equipped with new magnetic systems (8 units at the first magnetic separation stage, 11 units at the second stage and 4 units at thickening stage) are operating at the plant.

In the grinding circuit of the second magnetic separation stage Eriez DRW9 demagnetizing device (with field intensity $H = 50$ kA/m) is mounted at the feeding line of GTsK (M)-380 hydrocyclon. Demagnetization (defloculation) improves the grade of thickened hydrocyclon product, thus the content of -0.071 mm final fraction increased by 2%, the increment of 3% is gained for hydrocyclon sands. The specific productivity of the second-stage mills is increased by 2.5% for the final size fraction at the circulating load of the second-stage mill increased by 22%.

12 Stack Sizer screens, Derrick Co., USA, were mounted to improve control of final concentrate size at the concentrator. The screen feed is the second-stage concentrate of the magnetic separation circuit. The oversize product is recirculated to hydrocyclons for classification, while undersize product is fed to thickening.

CONCLUSIONS

Abagur ore specimens of $-0.071+0$ mm in size were used in the laboratory separation studies and measurements of magnetic characteristics.

According to the separation flowsheet in the interval from the overflow to the final concentrate the increment of the magnetic fraction yield amounts to 42%, Fe_{mag} "grade" increment is 0.9%; the non-magnetic fraction yield is respectively reduced by 42%, while Fe_{mag} in this fraction increases from 0.38 up to 5.29%. There are grounds to conclude that barren and poor ore aggregates with less impurity content used to accumulate gradually in the non-magnetic product of the final concentrate.

The content of magnetite iron Fe_{mag} in non-magnetic products of the final concentrate actually governs the material separation boundary in terms of Fe_{mag} in different size fractions within the operating processing flowsheet at the concentrator. Magnetic characteristics of non-magnetic fractions are proportional to magnetite iron Fe_{mag} content in them and impurity content in the concentrate. This statement justifies the boundaries of separation of the materials under processing within size fractions.

REFERENCES

1. Yakubailik, E.K., Kilin, V.I., Chizhik, M.V., Ganzhenko, I.M., and Kilin, S.V., Magnetic Characteristics of Primary Concentrates Supplied as a Feedstock to Abagur Enrichment-Agglomeration Plant, *J. Min. Sci.*, 2013, vol. 49, no. 1, pp. 153–159.
2. Ganzhenko, I.M. and Yakubailik, E.K., Reduction in Magnetite Loss at Abagur Concentrator, *Obogashch. Rud*, 2015, no. 1, pp. 22–25.
3. Kilin, V.I., *Povyshenie effektivnosti magnitnoi separatsii magnetitovykh rud* (Improvement of Magnetic Separation Performance on Magnetite Ore), Chita: Chita Gos. Univer., 2011.
4. Lomovtsev, L.A., Nesterova, N.A., and Drobchenko, L.A., *Magnitnoe obogashchenie sil'nomagnitnykh rud* (Magnetic Processing of Strong Magnetic Ores), Moscow: Nedra, 1979.
5. Balaev, A.D., Boyarshinov, Yu.V., Karpenko, M.M., and Khrustalev, B.P., Automated Magnetometer with Superconducting Solenoid, *Pribory Tekhnika Eksperimenta*, 1985, vol. 3, pp. 167–168.
6. Rychkov, L.F. and Lomovtsev, L.A., Magnetic Susceptibility of Strongly Magnetic Ores at Different Magnetic Field Intensities, *J. Min. Sci.*, 1978, vol. 14, no. 6, pp. 623–625.
7. Yakubailik, E.K., Kilin, S.V., Kilin, V.I., and Ganzhenko, I.M., Magnetic Properties and Wet Magnetic Separation of Siberian Rough Iron Ore Concentrates, *GIAB*, 2013, no. 2, pp. 114–124.
8. Laurila E. On the Magnetic Permeability of Mixtures Containing Ferromagnetic Particles and Porous Ferromagnetic Materials, *Ann. Acad. Scientiarum Fennicae*, Ser. A, VI Phys., 70, 1961.
9. Derkach, V.G., Ore Motion Dynamics in Magnetic Underfeed Separators, *Obogashch. Rud*, 1964, no. 3, pp. 22–25.
10. Derkach, V.G., *Spetsial'nye metody obogashcheniya poleznykh iskopaemykh* (Special Mineral Processing Techniques), Moscow: Nedra, 1966.
11. Karmazin, V.V., New Perspectives of Iron Ore Production Advance in Russia, *Byull. Nauch.-Tekhn. Ekon. Inf. Chern. Metallurg.*, 2011, no. 4, pp. 22–28.
12. Karmazin, V.V., Andreev, V.G., and Pozharsky, Yu. A., Updating of Machinery and Techniques for Staged Processing of Lebedinsky and Mikhailovsky Magnetic Quartzites, *Byull. Nauch.-Tekhn. Ekon. Inf. Chern. Metallurg.*, 2012, no. 3, pp. 26–33.
13. Ulubabov, R.S., New Ways to Improve the Poor Magnetite Ore Mining and Processing Performance, *Byull. Nauch.-Tekhn. Ekon. Inf. Chern. Metallurg.*, 2009, no. 12, pp. 21–25.
14. Pelevin, A.E., Ways to Improve Iron Concentrate Grade, *Byull. Nauch.-Tekhn. Ekon. Inf. Chern. Metallurg.*, 2013, no. 12, pp. 11–14.