

THE RESULTS OF MAGNETIC SEPARATION USE IN ORE PROCESSING OF METALLIFEROUS RAW BASALT OF VOLYN REGION

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РЕЗУЛЬТАТИ ДОСЛІДЖЕНЬ ВИКОРИСТАННЯ МАГНІТНОЇ СЕПАРАЦІЇ У ПРОЦЕСІ РУДОПІДГОТОВКИ МЕТАЛОВМІСНОЇ БАЗАЛЬТОВОЇ СИРОВИНИ ВОЛИНИ

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ABSTRACT

Purpose. To determine the effectiveness of the electric field use in ore processing for extraction of native copper concentrate from raw basalt, to identify the most technologically advanced grain-size classes of the feed stock. To define the nature of the relationship between the amount of recoverable concentrate and the main dominant factors – separator field density and the coarseness of the prepared raw material.

Methods. We used the substantiated physical and chemical methods of elemental, mineral, fractional, particle size distribution analysis of the basalt rock mass under processing, methods of laboratory, semi-industrial and industrial research into crushing, grinding, classification, and electromagnetic separation processes at the stages of ore preparation of raw materials for the production of metalliferous industrial products. The methods of statistical modeling and experimental results regression analysis have been applied.

Findings. The preferred grain-size classes in the process of ore preparation and classification of basalt rock components for electrostatic separation were determined. The dependences of copper concentrate production from basalt, tuff and lava-breccia on the electrostatic field density while changing grain-size classes in the initial product were worked out. The regression dependences of the copper concentrate output on various relationships between grain-size classes in the initial material and the electric field density were obtained.

Originality. The content of native copper in basalt, lava breccia and tuff was established and the preferred grain-size classes in the process of ore preparation were identified. It is for the first time that the magnetic susceptibility of all three components of basalt raw material was determined, and the influence of the magnetic field on the output of titano-magnetite concentrate was shown as well as the rational grain size of ore preparation was determined. The dependences of the copper concentrate output have been established and the efficiency of the electrical separation in complex processing of basalt raw material has been proved.

Practical implications. The obtained research results indicate the feasibility of complex processing of basalt raw material, on the grounds of which the method of its treatment was developed.

Keywords: native copper, titano-magnetite, electrical separation, lava breccia, basalt, tuff

1. INTRODUCTION

Currently only basalt is used in quarry development, mainly for the production of crushed stone. Associated

tuff and lava-breccia are present as moldboard rock mass, which is stored as man-made deposit with a high content of native copper, iron, titanium and other valuable metals (Luca, 2012).

The research conducted has shown that basalt is a valuable mineral raw material that requires complex processing to extract useful components in amounts that may be of industrial interest and technologically extractable.

The presence of such impurities in the basalt body as lava-breccia and tuff does not devalue the idea of complex basalt processing, as these constituents contain the same beneficial components as basalt (Fiore, Scalice, Di Bella, & Valenza, 2015), the main of those being native copper and iron (titano-magnetite). Spectral analysis showed that they contain oxides of copper, rare and valuable metals whose recovery requires advanced technologies (Zhang et al., 2013).

Analysis of the available information about the use of magnetic separation in the loop processing of non-ferrous rare metal ores and placer deposits, shows that first non-ferrous metal is obtained, while iron concentrate is produced in the second place (Cervi, da Costa, & de Souza Junior, 2014). The same approach was applied to investigating magnetic separation of copper raw material from the basalt quarry. The standard methods of ore preparation for magnetic separation of raw materials were used: crushing, grinding, and screening. We studied the most effective size classes for magnetic separation (+0.63 ÷ 2.5 mm) and (+1.0 ÷ 0.63 mm).

The subject of the research was to determine the extent of magnetic susceptibility of all the three components of raw basalt from Rafalovskyi quarry – basalt, tuff and lava-breccia. Preliminary studies of basalt deposits indicated the presence of other metals with magnetic properties that allow to use magnetic methods and the corresponding equipment in their processing.

2. THE MAIN PART

2.1. Raw basalt magnetic separation

One of the research objectives was to learn the degree of magnetic separators' efficiency for extraction of copper minerals into the tailings of magnetic separation and to discover what grain-size class of the material corresponds to the maximum copper extraction.

Thus the investigated issue concerned the use of magnetic separation with the purpose of copper minerals' concentration in the separation tailings. The problem of magnetic separation application for its direct purpose – production of iron concentrate – was not considered, since it is secondary for our technology.

Preparation of samples for the research consisted in their preliminary crushing and grinding to the class size of less than 3 mm, in accordance with recommendations for the dry magnetic separation of feebly magnetic ores (Bulat, Naduty, & Malanchuk, 2010). The crushed rock mass was classified into four size classes. Magnetic part was defined in each class (in two or three levels), and non-magnetic part was identified by weight and by percentage to the sample weight.

The studies were conducted in the laboratory on the drum magnetic separator PBSU-0.5/0.2 during the process of dry magnetic separation. Mineralogical analysis was performed separately for magnetic and non-magnetic portion of a sample. The content of native copper in each subsample was assessed. Initial experimental data are shown in Table 1.

Table 1. Mineralogical and particle size distribution analysis of Rafalovskyi quarry basalt samples

Grain-size class, mm	Product	Mass, g	Output, %	Minerals' content	Copper content, %	Output	Extraction
2.5 + 1.6	—	—	—	—	—	—	—
	Magnetic 2	66	75.86	Basalt – 96 – 97%. Native copper – 3 – 4%	3.50	16.620	0.5820
	Non-magnetic	21	21.14	Basalt – 85%. Native copper – 15% (10% – exposed and in concretions – 5%)	13.00	5.290	0.6880
-1.6 + 0.8	Magnetic 1	19	17.43	Basalt – more than 99%. Native copper in concretions – occasional grains. Green copper – occasional grains. Red copper - occasional grains	0.01	4.786	0.0004
	Magnetic 2	51	46.79	Basalt – more than 99%. Native copper in concretions – occasional grains. Green copper – less than 1%	0.60	12.850	0.0770
	Magnetic 3	17	15.60	Basalt – more than 99%. Native copper in concretions – less than 1%	0.10	4.282	0.0040
	Non-magnetic	22	20.18	Basalt – 75 – 80%. Native copper 10 – 15%, copper in concretions – 5 – 7%. Quartz – 5%. Green copper in concretions 5 – 7%	15.00	5.542	0.8310
-0.8 + 0.25	Magnetic 1	5	4.31	Basalt – 100%. Green copper – occasional grains in concretions	0.01	1.259	0.0040
	Magnetic 2	31	26.72	Basalt – 100%	0.00	7.809	0.0000
	Non-magnetic	80	68.97	Basalt – 94 – 96%. Quartz – 2 – 3%. Native copper in concretions – 2 – 3%	1.50	20.150	0.3020
-0.25	Magnetic 1	8	9.41	Basalt – 100%	0.00	2.015	0.0000
	Magnetic 2	22	25.88	Basalt – 100%	0.00	5.542	0.0000
	Non-magnetic	55	64.71	Basalt – 99 – 100%. Native copper – up to 1%			0.1390
Total		397	100.00	Copper content in basalt sample 2.624%		100.000	2.6240

Thus, the research conducted on basalt, lava-breccia and tuff of Rafalovskyi quarry have shown the feasibility of further research into magnetic separation, as these three most typical rocks have high magnetic susceptibility: basalt produces 55% of magnetic product, lava-breccia – 33% and tuff – 54% (Bulat, Naduty, & Malanchuk, 2010).

Basalt dry magnetic separation. Basalt sample was subjected to crushing and sieving into 4 narrow classes within the range of 2.5...–0.25 mm. Basalt has the highest density among the three studied materials $2.6 \cdot 10^{-3} \text{ kg/m}^3$ (breccia – 1.8 kg/m^3 , tuff – 1.3 kg/m^3). Basalt crushing was performed so that the output of each of the four classes was approximately the same – about 20 – 30%.

2.2. Calculation results

During magnetic separation of basalt fine grained fractions, we have established that for the top two coarse grained classes there is a higher yield of the non-magnetic fraction.

At the same time, the content of copper in the non-magnetic fraction of big-size classes is very high:

13% and 15% (the last figure is the minimum condition of the finished copper concentrate).

Analysis of copper extraction (from the initial content) confirmed that copper is mainly extracted from the bigger size classes of $-2.5 + 0.8 \text{ mm}$. The total recovery from them constitutes $48.4 + 34.8 = 83.2\%$. The remaining percentage of recovery is $11.5 + 5.3 = 16.8\%$, comprised by the small class of $-0.8...-0.25 \text{ mm}$.

However, it is noteworthy that the biggest class of $-2.5 + 1.6 \text{ mm}$ is not separated efficiently: the output of tailing is small (output into non-magnetic fraction is $\sim 5\%$ against 16.62% into magnetic), copper extraction into the two products differs only slightly (22% into magnetic and 26% into non-magnetic product), i.e. copper of the higher bigger size class is divided approximately equally between the magnetic and nonmagnetic products (Bulat, Naduty, & Malanchuk, 2010).

For all fine grained classes (1.6 mm) there is another trend: the extraction of copper into non-magnetic product is consistently higher than into magnetic. That is, during the basalt magnetic separation the feedstock coarseness should not exceed 1.6 mm. Average results of basalt magnetic separation are presented in Table 2.

Table 2. Basalt magnetic separation indicators

Grain-size class, mm	Output percentage from input, %	Content of Cu, %	Production of Cu, %	Magnetic, %			Non-magnetic, %		
				Output	Content	Production	Output	Content	Production
-2.5 + 1.6	21.91	5.79	48.39	16.62	3.5000	22.20	5.29	13.00	26.21
-1.6 + 0.8	27.46	3.33	34.80	21.91	0.3700	3.10	5.54	15.00	31.68
-0.8 + 0.25	29.22	1.03	11.53	9.07	0.0014	0.00	20.15	1.50	11.52
-0.25	21.41	0.65	5.28	7.56	0.0000	0.00	13.85	1.00	5.28
Total	100.00	10.80	100.00	55.16	3.8714	25.30	44.83	3.05	74.69

Copper extraction analysis (from the initial content) confirmed that copper is mainly contained in bigger size classes of $-2.5 + 0.8 \text{ mm}$. The total recovery from them constitutes $48.4 + 34.8 = 83.2\%$.

Copper extraction into non-magnetic product, compared with the magnetic one is steadily higher for fine grained classes (-1.6 mm). This indicates that during basalt magnetic separation the feedstock coarseness must be less than 1.6 mm.

Dry magnetic separation of lava-breccia showed the output of magnetic and non-magnetic fractions at

38.13% and 61.88% , respectively (Table 3). And, for all fine grained classes, the amount of non-magnetic fraction is consistently higher than that of the magnetic product, the copper content in the nonmagnetic fraction being not much higher than in the raw material (1.66% versus 1.36%).

Both fractions – magnetic and nonmagnetic – were very rich in copper (0.87 and 1.66%), which testifies to the need for additional recleaning. This can be explained by the presence of concretions.

Table 3. Parameters of lava-breccia dry magnetic separation

Grain-size class, mm	Output percentage from input, %	Content of Cu, %	Production of Cu, %	Magnetic, %			Non-magnetic, %		
				Output	Content	Production	Output	Content	Production
-2.5 + 1.6	31.25	1.37	31.30	12.50	1.16	10.67	18.75	1.50	20.66
-1.6 + 0.25	52.81	0.89	34.50	20.63	0.24	3.65	32.19	1.30	30.80
-0.25	15.94	2.92	34.20	5.00	2.75	10.10	10.94	3.00	24.10
Total	100.00	5.18	100.00	38.13	4.15	24.42	61.88	5.80	75.56

In the sample of lava-breccia, the copper extraction into non-magnetic fraction is higher than into magnetic (75.6% versus 24.4%). Analysis of the results also indicates the appropriateness of feedstock preparation with grain size less than 1.6 mm.

Tuff magnetic separation identified the high content of magneto-susceptible material by weight – 54% . Parameters of tuff dry magnetic separation are presented in Table 4. The magnetic fraction is represented only by big

size classes of $-2.5 + 0.1 \text{ mm}$. Classes of -0.1 mm of feedstock and non-magnetic fractions have the highest content of copper – near 0.77% .

Crushed tuff is effectively divided by magnetic separation resulting in substandard copper concentrate. According to chemical analysis, big size tuff classes – $2.5 + 0.25 \text{ mm}$ – which are in the magnetic product, contain $36 - 39\%$ of iron.

Table 4. Parameters of tuff dry magnetic separation

Grain-size class, mm	Output percentage from input, %	Content of Cu, %	Production of Cu, %	Magnetic, %			Non-magnetic, %		
				Output	Content	Production	Output	Content	Production
-2.5 + 0.63	36.1	0.31	21.01	29.94	0.29	16.38	6.14	0.40	4.63
-0.63 + 0.1	22.7	0.45	19.26	19.09	0.42	15.13	3.65	0.60	4.13
-0.1	41.2	0.77	59.83	0.00	0.00	0.00	41.18	0.77	59.8
Total	100	1.53	100.01	49.03	0.71	31.51	50.97	0.71	68.6

The results obtained allowed to determine the standard equipment size: for the feedstock size of -2.5 + 0.1 mm it is recommended to use magnetic separators of PBS type, and for finer grade – electromagnetic separators of EBC type is recommended.

The following investigation was aimed at studying the influence of magnetic field influence on separation of tuff, basalt and lava-breccia which is needed for substantiated choice of magnetic separators type. Experiments were conducted for two fine grade classes of each rock. The magnetic field varied in the range 0.08 – 1.3 T (Table 5).

Table 5. Mass fraction of magnetic separation concentrate (10⁻³ kg) at different magnetic field density

Induction	Tuff		Basalt		Lava-breccia	
	-2.5 + 0.63	-0.63 + 0.1	-2.5 + 0.63	-0.63 + 0.1	-2.5 + 0.63	-0.63 + 0.1
T	mm	mm	mm	mm	mm	mm
0.08	63.2	30.5	73.6	29.0	51.3	21.0
0.16	59.5	37.0	76.4	35.5	60.5	26.2
0.30	51.7	37.7	68.0	40.5	64.4	31.6
0.44	49.7	31.9	63.5	38.5	68.5	36.4
0.58	44.8	32.5	60.5	30.4	63.1	28.5
1.30	6.2	5.8	10.6	7.6	20.2	12.9
Non-magnetic	56.4	33.4	29.4	18.5	36.2	21.4
Total	331.5	208.8	382.0	200.0	364.2	178.0

According to Table 5, the product output in percent and the total output of concentrate were calculated. With reliability of 0.95 the mean square error of class output determination was in the confidence interval 0.5 – 1.2%. To determine the relationship between the magnetic concentrate output by grade classes, the standard method of pair correlations was used. Using the Microsoft Office Excel software, approximating dependences were built and one approximating curve was chosen out of 6 possi-

ble, based on the conditions of the maximum likelihood of approximation coefficient R² and the presence of physical content in this dependence.

Fine grain size was set as the limit value of arithmetic average, which is the most widespread approach. Indicators of magnetic concentrate output for relatively big 2.5 + 0.63 mm and smaller size classes -0.63 + 0.1 mm and graphical interpretation of the output relationships versus induction field are shown in Figure 1.

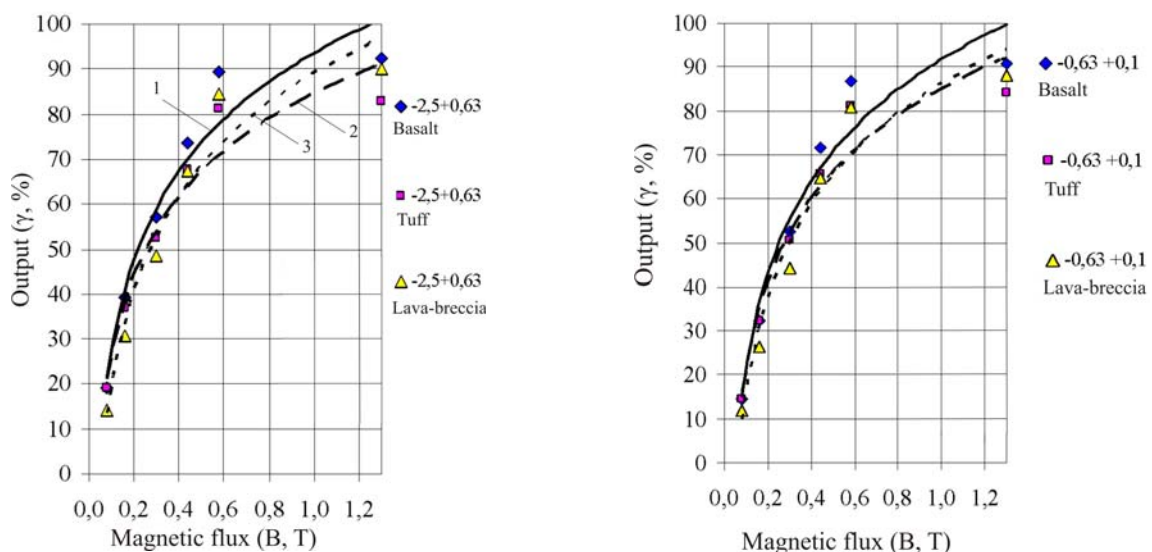


Figure 1. Magnetic product output distribution versus the magnetic field for basalt (1), tuff (2) and lava-breccia (3): (a) -2.5 + 0.63 mm; (b) -0.63 + 0.1 mm

The following correlation equations were worked out:

– for size class – 2.5 + 0.63 mm:

$$1 - \text{basalt: } \gamma = 28.6 \ln(B) + 93.63, R^2 = 0.94 ;$$

$$2 - \text{tuff: } \gamma = 25.08 \ln(B) + 84.59, R^2 = 0.94 ; \quad (1)$$

$$3 - \text{lava-breccia: } \gamma = 29.95 \ln(B) + 89.1, R^2 = 0.95 ;$$

– for class – 0.63 + 0.1 mm:

$$1 - \text{basalt: } \gamma = 30.28 \ln(B) + 91.75, R^2 = 0.94 ;$$

$$2 - \text{tuff: } \gamma = 27.32 \ln(B) + 85.05, R^2 = 0.94 ; \quad (2)$$

$$3 - \text{lava-breccia: } \gamma = 30.15 \ln(B) + 86.16, R^2 = 0.95 .$$

It is clear from Figure 1 that with induction increase, the coarser class, the greater dependencies variation. For further analysis, the dependencies for two size classes were built, separately for each rock material (see Figure 1). The analysis showed that the difference in the outputs of the two fine classes is not significant, that is why it is reasonable to analyze a bigger size class of 2.5 + 0.1 mm.

For the total class size – 2.5 + 0.1 mm the correlation dependencies of concentrate output versus the induction field are as follows:

$$1 - \text{basalt: } \gamma = 29.8 \ln(B) + 92.99, R^2 = 0.94 ;$$

$$2 - \text{tuff: } \gamma = 25.94 \ln(B) + 84.77, R^2 = 0.94 ; \quad (3)$$

$$3 - \text{lava-breccia: } \gamma = 30.02 \ln(B) + 88.13, R^2 = 0.95 .$$

As shown in Figure 2, all three rocks are characterized by relatively close dependencies of concentrate output on induction. Thus, for low values of induction up to 0.2 T (range of magnetic separators PBM, PBS type) and for induction of 1.3 T (electromagnetic separators ERS, EBC type) the average deviation of output is up to 10% of relationships, which is acceptable for practical processes. This allows to build a generalized statistical model suitable to describe the function of concentrate output versus induction for a mixture of all three rocks with the initial size of – 2.5 + 0.1 mm (Figure 3).

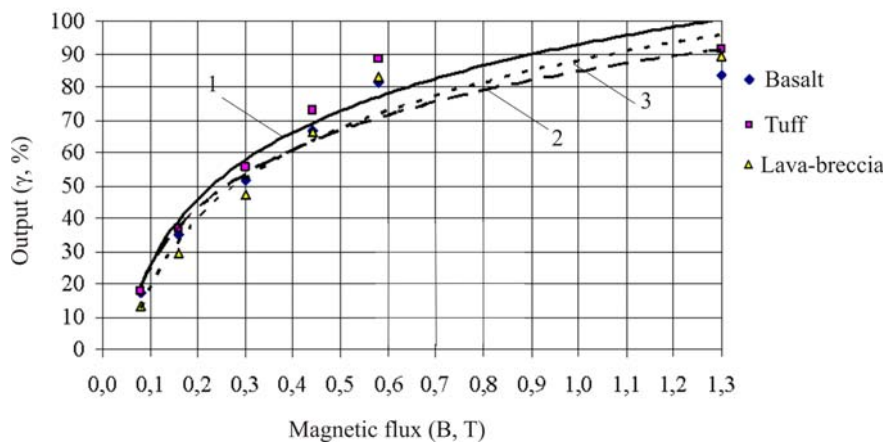


Figure 2. Size class – 2.5...+0.1 mm output into concentrate versus magnetic field for: 1 – basalt; 2 – tuff; 3 – lava-breccia

With the high probability of approximation the generalized model of magnetic concentrate output versus magnetic field has the following character:

$$\gamma = 28.38 \lg(B) + 88.629, R^2 = 0.947, \quad (4)$$

where:

γ – concentrate output, %;

B – magnetic field (T).

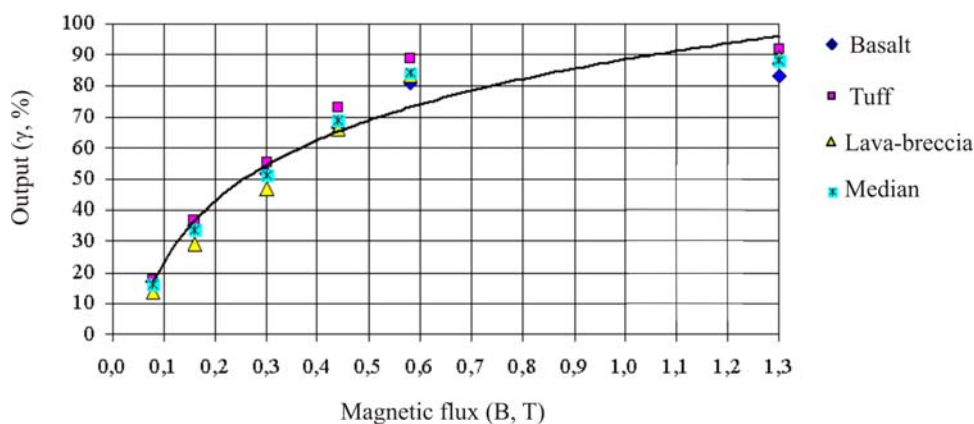


Figure 3. Generalized relationship of magnetic separation concentrate output versus magnetic field for tuff, basalt and lava-breccia

If all three rocks with grain size $-2.5 + 0.1$ mm will be subjected to magnetic separation together, the concentrate output can be evaluated via the generalized model using equation (4). The dependencies (1) – (3), shown in Figures 1 and 2 can be used for more detailed analysis.

Here the following question arises: how can copper get into the magnetic fraction (especially in coarse grained classes), if all the copper minerals are non-magnetic? There are two reasons for this. The first explanation suggests that though mineralogy clearly shows that the deposit field is rich in native and oxidized (not sulfide) copper (Table 1), the basalt raw material still contains copper sulfide, i.e. chalcopyrite, and more importantly, typically associated with chalcopyrite – pyrite and pyrrhotine. While pyrite and chalcopyrite (copper pyrite, CuFeS_2) are non-magnetic, pyrrhotine FeS_2 is a strongly magnetic mineral. It is pyrrhotine that is extracted during separation, and copper minerals are extracted with it in the form of concretions (Tabosa & Rubio, 2010).

The second reason for copper extraction into magnetic coarse grained concentrate is that the concretions of copper are extracted with native iron, magnetite, titanomagnetite and copper iron sulfides, for example, bornite Cu_3FeS_2 . Mineralogical analysis identified the presence of all these minerals in Rafalovskyi quarry rocks. Thus the high yield of magnetic fraction with the separation is linked with them.

The main conclusions on basalt magnetic separation consist in the following: firstly, if the feedstock size is $-2.5 + 0$ mm, there is a high yield of the magnetic fraction – 55 (16%), and secondly, the amount of copper in the tailing increases 1.7 times as compared with the initial copper content (from 2.6 to 4.4%). However, both obtained products are saleable in terms of copper content, which testifies to the insufficient copper minerals' exposure in the input and the need to reduce grain size.

To improve copper extraction into magnetic separation tailings the achieved rate of copper increment (1.7 times) can be increased (up to 2 – 3 times). This can be done if feedstock size is reduced, or at least the coarse grained class is removed from the input, that is basalt should be crushed to 1.6 mm size. At the same time, fine grinding improves the quality of magnetic product in iron content; since, as we know from ore mining and dressing plants (OMDP) experience, iron minerals' exposure is achieved after very fine grinding – up to 95% of the class – 0.05 mm.

ABSTRACT (IN UKRAINIAN)

Мета. Визначення ефективності використання електричного поля у процесі рудопідготовки для виділення концентрату самородної міді з базальтової сировини, встановлення найбільш технологічних класів крупності переробленої сировини й характеру залежності кількості добутого концентрату від основних домінуючих факторів – напруженості поля сепаратора та крупності підготовленої сировини.

Методика. У роботі використані апробовані фізичні та хімічні методи аналізу елементного, мінерального, фракційного, гранулометричного складу переробки базальтової гірської маси, методи лабораторних, напівпромислових і промислових досліджень процесів дроблення, подрібнення, класифікації, електромагнітної сепарації на етапах рудопідготовки сировини до отримання металовмісних промпродуктів. Застосовані методи статистичного моделювання і регресійного аналізу результатів експериментальних досліджень.

Результати. Встановлено класи крупності у процесі рудопідготовки і класифікації складових базальтової гірської маси до електросепарації. Виявлено залежності виходу мідного концентрату для базальту, туфу та лавобрекчії від напруженості електричного поля при варіюванні вмістом різних класів крупності у вихідному

3. CONCLUSIONS

The magnetic susceptibility of all the three components of basalt raw material – tuff, basalt and lava-breccia – was established experimentally. This fact testifies to the appropriateness of including magnetic separation operation to separate titanomagnetite of the ground mass into the technological scheme of complex waste-free processing of basalt raw material.

Dry magnetic classification of basalt, tuff and lava-breccia by fine grained size classes indicated that, the most promising in terms of output from the initial amount and copper extraction in each size class (in %) are the following classes: ($1.6 + -2.5$ mm), ($-1.6 + 0.8$ mm) ($0.8 + 0.25$ mm) and ($0.25 + 0.1$ mm).

The results of the research into the magnetic susceptibility of the raw material were generalized in the form of experimental and regression dependences of tuff, basalt and lava-breccia output versus separator magnetic field. A generalized regression model of outputs for all three components was developed.

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продукті. Отримано регресійні залежності виходу мідного концентрату від різних співвідношень між класами крупності у вихідному продукті та від напруженості електричного поля.

Наукова новизна. Встановлено процентний вміст самородної міді у базальті, лавобрекчії, туфі та показані кращі класи крупності у процесі рудопідготовки. Вперше визначена магнітна сприйнятливості всіх трьох складових базальтової сировини, показано вплив величини магнітного поля на вихід концентрату титаномагнетиту й визначена раціональна крупність рудопідготовки. Вперше встановлено залежності виходу мідного концентрату й показана ефективність використання операції електричної сепарації при комплексній переробці базальтової сировини.

Практична значимість. Отримані результати досліджень вказують на доцільність комплексної переробки базальтової сировини, і на цій основі розроблений спосіб її переробки.

Ключові слова: *самородна мідь, титаномагнетит, електрична сепарація, лавобрекція, базальт, туф*

ABSTRACT (IN RUSSIAN)

Цель. Определение эффективности использования электрического поля в процессе рудоподготовки для выделения концентрата самородной меди из базальтового сырья, установление наиболее технологичных классов крупности перерабатываемого сырья и характера зависимости количества извлекаемого концентрата от основных доминирующих факторов – напряженности поля сепаратора и крупности подготовленного сырья.

Методика. В работе использованы апробированные физические и химические методы анализа элементного, минерального, фракционного, гранулометрического состава перерабатываемой базальтовой горной массы, методы лабораторных, полупромышленных и промышленных исследований процессов дробления, измельчения, классификации, электромагнитной сепарации на этапах рудоподготовки сырья к получению металлосодержащих промпродуктов. Применены методы статистического моделирования и регрессионного анализа результатов экспериментальных исследований.

Результаты. Установлены предпочтительные классы крупности в процессе рудоподготовки и классификации составляющих базальтовой горной массы к электросепарации. Установлены зависимости выхода медного концентрата для базальта, туфа и лавобрекчии от напряженности электрического поля при варьировании содержанием разных классов крупности в исходном продукте. Получены регрессионные зависимости выхода медного концентрата от различных соотношений между классами крупности в исходном продукте и от напряженности электрического поля.

Научная новизна. Установлено процентное содержание самородной меди в базальте, лавобрекчии и туфе, а также показаны предпочтительные классы крупности в процессе рудоподготовки. Впервые установлена магнитная восприимчивость всех трех составляющих базальтового сырья, показано влияние величины магнитного поля на выход концентрата титаномагнетита и определена рациональная крупность рудоподготовки. Впервые установлены зависимости выхода медного концентрата и показана эффективность использования операции электрической сепарации при комплексной переработке базальтового сырья.

Практическая значимость. Полученные результаты исследований указывают на целесообразность комплексной переработки базальтового сырья, и на этой основе разработан способ его переработки.

Ключевые слова: *самородная медь, титаномагнетит, электрическая сепарація, лавобрекція, базальт, туф*

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