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The enrichment technology of slag from metallurgical processing of copper ore concentrate

G.A. Shevchenko[1], V.G. Shevchenko[1], V.A. Baranov[1], V.N. Spassky[2]

[1]Institute of Geotechnical Mechanics named by N. Poljakov of National Academy of Sciences of Ukraine, Dnipro, vgshevchenko@ua.fm

[2]LLC Innovation Campaign Kairos Is Group, Dnipro, spassky@ua.fm

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Abstract. The purpose of this research is the development of a technology for the enrichment of slag from metallurgical processing of copper ore concentrate based on the results of spectral, chemical, sieve and petrographic analysis. The results of spectral analysis indicate the copper content in all three samples of mineral raw materials at more than 1 %. The results of chemical analysis indicated a high copper content in the samples from 13.4 to 17.1%, as well as a high iron content from 9 to 18%. Analysis of the results of the sieve analysis showed that the largest amount of copper is contained in the size classes 0.063–0.05 mm at from 18.6 to 24.1 % and 0.04 mm at from 15.6 to 38 %. In accordance with the petrographic studies, the size of copper grains varies from 0.1–0.3 to 1–5 mm. The most common sizes of copper grains in the studied samples are 0.2-0.3 and 1-2 mm. Based on the results of spectral, chemical, sieve and petrographic analysis, a technology for the enrichment of copper-containing slags has been developed. Gravity wet enrichment technology with a capacity of 5 t/h with Cu recovery in the range of 80–95 % suggests the grinding of raw materials with a constant water supply up to 40 m^3/h from the sludge collector. The heavy fractions are fed to a magnetic separator and then to a classifier for the extraction of magnetic concentrate and slag, which after the separation of the fraction of 0.08-0.4 mm with the MVG screen can later be used as a raw material for the building industry. The light fractions after the concentration tables are fed to the classifier, on which the copper concentrate is released. The average density fractions are returned to the closed cycle for further grinding in a ball mill. However, such a wet enrichment scheme requires a continuous water supply and the sludge collector's presence, which cannot always be ensured. Therefore, the technology of slag dry enrichment with a particle size of 0–100 mm has also been developed. The central apparatus in the proposed enrichment technologies is the MVG vibrating screen, which is designed to separate bulk materials by particle size from 20 microns to several millimeters. Polyfrequency oscillations in the frequency range from several Hz to kHz are implemented on the screen, eliminating blockage of the sieve cells, destruction of the formed aggregates of stuck particles, ensuring their intensive movement in the layer and efficient passage of particles reaching the sieve surface through the cells. This type of vibration makes it possible to achieve much greater efficiency of separation and dehydration of materials than in traditional screens and to ensure continuous self-cleaning of the mesh, which contributes to the process of separation and dehydration. Due to the lack of tension, high durability of the working surface is ensured. Due to the transfer of minimum loads on the base, the screen is installed without arranging special foundations, including on the floors of buildings and structures. A standard-sized row of screens was developed with a screening surface area from 1 to 4 m^2 and a different number of tiers.

Key words: spectral, chemical, screening, petrographic analysis, enrichment technology, slag metallurgical redistribution of copper ore concentrate.

Технология обогащения шлака металлургического передела концентрата медной руды

Г.А. Шевченко[1], В.Г. Шевченко[1], В.А. Баранов[1], В.Н. Спасский[2]

[1]Институт геотехнической механики им. Н.С. Полякова НАН Украины, г. Днепр, vgshevchenko@ua.fm

[2]ООО «Инновационная кампания Кайрос Ис Групп», г. Днепр, spassky@ua.fm

Анотація. Мета досліджень - розробка технології збагачення шлаку металургійного переділу концентрату мідної руди на основі результатів спектрального, хімічного, ситового і петрографічного аналізу. Проведено спектральний, хімічний, ситової і петрографічний аналіз мінеральної сировини. Результати спектрального аналізу вказують на вміст міді у всіх трьох зразках на рівні більше 1%. Результати хімічного аналізу вказали на високий вміст міді в зразках від 13,4 до 17,1%, а також на високий вміст заліза від 9 до 18%. Аналіз результатів ситового аналізу показав, що найбільша кількість міді міститься в класах крупності 0,063-0,05 мм від 18,6 до 24,1% і 0,04 від 15,6 до 38%. Відповідно до петрографічних досліджень, розмір зерен міді коливається від 0,1-0,3 мм до 1-5 мм. Найбільш розповсюджені розміри зерен міді за дослідженими пробам - 0,2-0,3 мм і 1-2 мм. На підставі результатів спектрального, хімічного, ситового і петрографічного аналізу розроблена технологія збагачення мідьмістких шлаків. Технологія гравітаційного мокрого збагачення продуктивністю 5 т/годину з вилученням Cu в межах 80-95%. передбачає подрібнення вихідної сировини при постійній подачі води до 40 м^3/годину з шламонакопичувача. Важкі фракції надходять на магнітний сепаратор і далі на класифікатор для виділення магнітного концентрату і шлаку, який після виділення фракції 0,08-0,4 мм грохотом МВГ в подальшому може бути використаний в якості сировини для будівельної галузі. Легкі фракції після концентраційних столів надходять на класифікатор, на якому виділяється мідний концентрат. Середні по щільності фракції повертаються в замкнутий цикл для подальшого подрібнення в кульовому млині. Однак, така схема мокрого збагачення вимагає безперервної подачі води і наявності шламонакопичувачів, що не завжди може бути забезпечено. Тому, також розроблена технологія сухого збагачення шлаку з розміром частинок 0-100 мм. Центральним апаратом в запропонованих технологіях збагачення є вібраційний грохот МВГ, який призначений для поділу сипучих матеріалів по крупності частинок від 20 мікрон до декількох міліметрів. На ситі грохоту реалізуються полічастотні коливання в діапазоні частот від декількох Гц до кГц, при цьому виключається забивання осередків сита, забезпечується руйнування агрегатів, що утворилися з злиплих частинок, реалізується їх інтенсивне переміщення в шарі і ефективне проходження частинок, які досягли поверхні решета через осередки. Такий характер вібрації дозволяє домагатися значно більшої ефективності поділу і зневоднення матеріалів, ніж в традиційних грохотах і забезпечити постійне самоочищення сітки, що сприяє процесу поділу і зневоднення. Через відсутність натягу, забезпечується висока довговічність робочої поверхні. Через передачі мінімальних навантажень на підставу грохот встановлюється без облаштування спеціальних фундаментів, в тому числі на перекриттях будівель і споруд. Розроблено типорозмірний ряд грохотів з площею поверхні, що просіює від 1 до 4 м^2 і різним числом ярусів.

Ключові слова: спектральний, хімічний, ситової, петрографічний аналіз, технологія збагачення, шлак металургійної переробки концентрату мідної руди.

Introduction. Currently, the issues of improving the enrichment technologies of metallurgical wastes to increase the productivity and efficiency of extraction of useful components for their subsequent use are highly relevant (Cao, H. et al 2012, Chaabia, R. et al 2015, Lei, L. et al 2009, Mahmoudi, E. et al. 2018, Malanchuk, ZR, Malanchuk, E.Z. 2014, Rozendaal, A., Horn, R. 2013). When developing such technologies, it is important to take into account both the material composition of the raw materials (the content of an element and its compounds) and the features of the inclusions of useful components: their grain, shape, etc. For this, spectral, chemical, sieve and petrographic analysis of mineral raw materials are necessary.

The purpose of the research is the development of a technology for the enrichment of slag from metallurgical processing of copper ore concentrate based on the results of spectral, chemical, sieve and petrographic analysis.

Materials and research methods. The feedstock was slag from metallurgical processing of copper ore concentrate. For the analysis, several samples of slag from metallurgical processing of copper ore concentrate were taken (samples 567, 568, 569, 570).

The results of the spectral analysis are given in Table 1.

The analysis was performed using the "sprinkle method" on a STE-1 device with the ASI-10 annex. The results of the spectral analysis indicate the copper content in all three samples at more than 1 %. Among other elements with a relatively high content percentage, Ni, Zn, Co, Pb and Cd should be allocated. Os, Sb, Cd, U, Hf, Hg, Th, Ta, Au were not detected.

For a more accurate determination of the copper content, chemical analysis of samples was performed. The results of chemical analysis are given in Table 2. The results of chemical analysis indicated a high copper content in the samples from 13.4 to 17.1 %, as well as a high iron content from 9 to 18 %.

To determine the specific copper content by size class, a sieve analysis of the samples was carried out. The results of grain-size researches of samples of materials containing Cu are given in Table 3.

Analysis of the results showed that the greatest amount of copper is contained in the size classes of 0.063-0.05 mm from 18.6 to 24.1 % and of 0.04 mm from 15.6 to 38 %. The results of sieve analysis must be considered when drawing up the technological scheme of enrichment and the choice of the classifying means by size of copper-containing raw materials.

To determine the grain size, the shape of grains and their distribution over the samples, a petrographic

Table 1. Spectral analysis results

Sample №	The content of elements in % 10^{-3}																													
	Ba	Be	P	Cr	Pb	Sn	Ga	Ni	Y	Yb	Zn	Zr	Co	Ti	Cu	V	Ge	Mo	Li	La	Sr	Mn	Ti	W	Bi	Nb	Sc	Ce	Ag-6	As
567	<50	<0.1	70	200	500	150	0.2	200	-	-	700	5	5	30	»1%	3	<0.1	3	<1	2	<7	70	-	15	un.	0.1	-	-	150	-
568	<50	<0.1	70	150	700	100	0.3	150	-	-	≈1%	5	5	20	»1%	2	0.15	5	<1	2	<7	70	-	15	un.	0.1	-	-	150	-
569	<50	<0.1	50	200	≈1%	70	03	100	-	-	700	5	3	30	»1%	7	0.1	0,5	<1	2	<7	50	-	3	un.	0.1	-	-	150	-
Method sensi-tivity	50	0.1	50	0.1	0.1	0.1	0.1	0.1	1	0.1	1.5	5	0.5	1	0.1	0.3	0.05	0.05	1	2	7	1	0.1	0.5	un.	0.1	0.7	3	2	3

Table 2. Chemical analysis results

Item №	Sample №	Results are given in % for the dried substance at 105 °C						
		Cu	Ni	Zn	Co	Pb	Cd	Fe
1	567	13.4	0.17	0.67	00043	0.40	0.0002	18
2	568	18.5	0.12	1.37	0.0049	0.67	0.0001	15
3	569	17.1	0.09	0.63	0.0032	0.89	0.0005	9

Table 3. Sieve analysis results

Item №	Size class, mm	Mass, g	Content, %
Material № 1			
1	+0.2	39.2	8.5
2	0.2 – 0.16	21.3	4.6
3	0.16 – 0.1	40.3	8.7
4	0.1 – 0.09	10.5	2.3
5	0.09 – 0.071	39.7	8.6
6	0.071 – 0.063	17.3	3.7
7	0.063 – 0.05	111.6	24.1
8	0.05 – 0.04	7.0	1.5
9	-0.04	175.5	38.0
Total:		462.4	100
Material № 2			
1	+0.2	109.6	22.4
2	0.2 – 0.16	48.2	9.8
3	0.16 – 0.1	80.6	16.4
4	0.1 – 0.09	14.9	3.0
5	0.09 – 0.071	50.3	10.3
6	0.071 – 0.063	15.1	3.1
7	0.063 – 0.05	91.1	18.6
8	0.05 – 0.04	3.9	0.8
9	-0.04	76.4	15.6
Total:		490.1	100
Material № 3			
1	+0.2	101.1	20.7
2	0.2 – 0.16	39.9	8.2
3	0.16 – 0.1	65.1	13.3
4	0.1 – 0.09	11.6	2.4
5	0.09 – 0.071	46.6	9.6
6	0.071 – 0.063	14.2	29
7	0.063 – 0.05	106.7	21.9
8	0.05 – 0.04	6.9	1.4
9	-0.04	95.9	19.6
Total:		488.0	100

analysis was performed. The analysis was performed using a POLAM R-111 microscope. The results show the following.

Sample № 567 (Fig. 1) - the bottom layer of melting. Dense, chipped dark grey, chipped shell, a massive texture, surface with greenish and brownish scurfs of copper and iron oxides, the content of which in this sample: Cu - 13.4 %; Fe - 18 %.

The sample consists of colourless long prismatic narrow (0.05 mm) grains from 0.3 mm to 1.5-1.8 mm long and more, which are randomly intertwined, and in some areas are parallel or cross. They have a cleavage, low birefringence, direct extinction , some up to 3º. In the composition of the sample, these grains prevail - 65-70 %. Between them there is a dark opaque (isotropic) substance - 20–25 % and single short column-like grains with cleavage and direct extinction 0.09 mm long (pyroxene?). In this mass, there are voids of an isometric form ranging in size from 0.05-0.1 mm, some up to 0.2 mm, and also xenomorphic, isotropic grains with “needles” similar to goethite of dark brown (reddish) colour – 5 %. In addition, there are peculiar inclusions of red colour with a brownish tint of irregular square, trapezoidal shape with a size of 0.25-0.3 mm, similar to native copper. Some of them have jagged contours. Most of the copper formations are surrounded by an opaque dark earthy mass. The number of these inclusions is ~ 5-7% (in the polish field). Chemical analysis shows the weight percentage of native copper in this sample to be 13.4 %. Copper grains are distributed relatively evenly throughout the sample volume, which can be clearly seen on the sample № 567 cut.

An exemplar of this sample has distinctly manifested magnetic properties that indicate the possible presence of pyrrhotite, magnetite, cubanite or other magnetic minerals.

Sample № 568 (Fig. 2) is relatively dense and heavy (up to 3-3.5 g/cm^3) slag of the third layer, in the upper right corner there are cuts of copper, ranging in size from 0.2 to 1.0 mm. The slag surface has a greenish scurf of copper oxides and a reddish scurf of Fe oxides, which suggests that the slag had remained in the dumps for a long period (for decades?). In general, the sample is of the same composition (with sample № 567), but the processes of replacement by an opaque dark mass of precisely colourless long prismatic grains are more intense. Relics of the latter are ~ 15-20 %. In transmitted light, dark matter has a lumpy shape, close to the isometric one. The size of the "lumps-balls" is 0.05 mm on average. On the periphery of these balls are scattered powder-like, dark gray fine particles with a metallic lustre, visible only in reflected light (chalcocite?, cuprite?). Optically their sizes cannot be determined. Opaque earthy substance is ~ 80-75 %. Single hair-like aggregates (sheaves) of a dark colour (0.01-0.03 mm) appear. In the upper right part of the sample cut, oval grains of copper are visible, ranging in size from 0.2 to 1.0 mm. The rest of the cut in reflected light shows smaller grains of native copper (0.2–0.3 mm), distributed relatively evenly in the sample mass. Probably, large-scale copper smelting is confined to the lower part of the melting layers.

Fig. 1. Sample 567

This sample also has magnetic properties, and the surface is covered with greenish and brownish scurf of copper and iron oxides. In this sample, according to the chemical analysis, copper is 18.5 % (the largest amount). Iron is 15 %, but its mineralogical composition cannot be determined after melting.

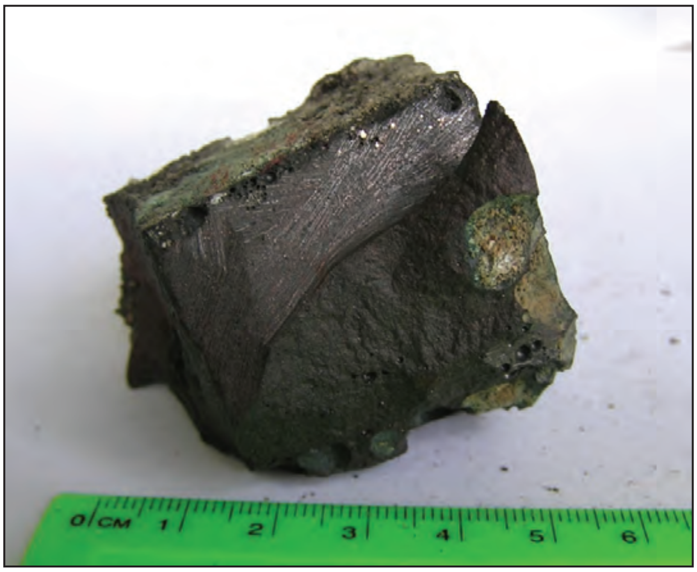

Fig. 2. Sample 568

Sample № 569 (Fig. 3) consists of a granular mass uneven in size, dark, brownish-black colour of cemented lumps with a diameter from 0.1 to 1.2 mm, in which there are: voids (from 0.1 to 0.55 mm), red

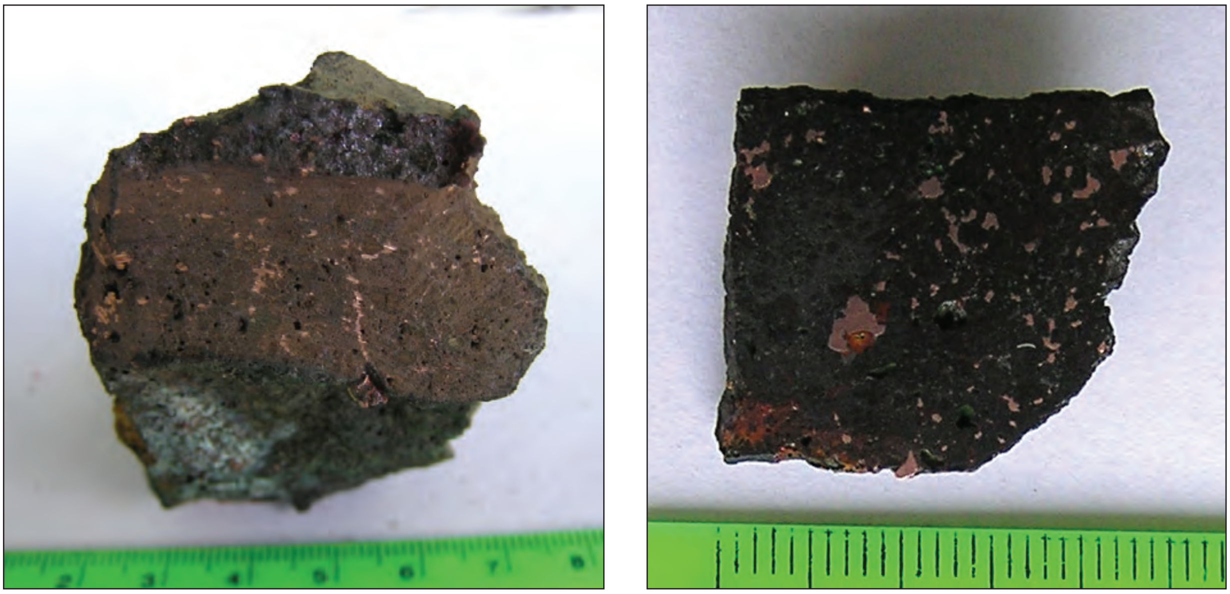

Fig. 3. Sample 569

isotropic inclusions (from 0.07 to 0.5 mm) of native copper, hair-like clusters and colourless clear grains (carbonates?) that surround the copper formations.

A dark shell is visible around individual copper formations, just as in a lumpy mass. Shell thickness is 0.02 mm. The copper content of ~ 15-17 % does not exclude the presence of copper formations in the dispersed state in a dark lumpy mass. In accordance with chemical analysis, in this sample native copper is 17.1 % , represented by relatively large grains. Grains ranging in size from 0.1 to 3-5 mm are visible on the cut of the sample. Large grains are more often represented by filamentous, dendritic forms, curved petals, less commonly isometric, spheroidal formations (probably this is copper that has fallen into cavities). Copper grains are evenly distributed in the sample mass.

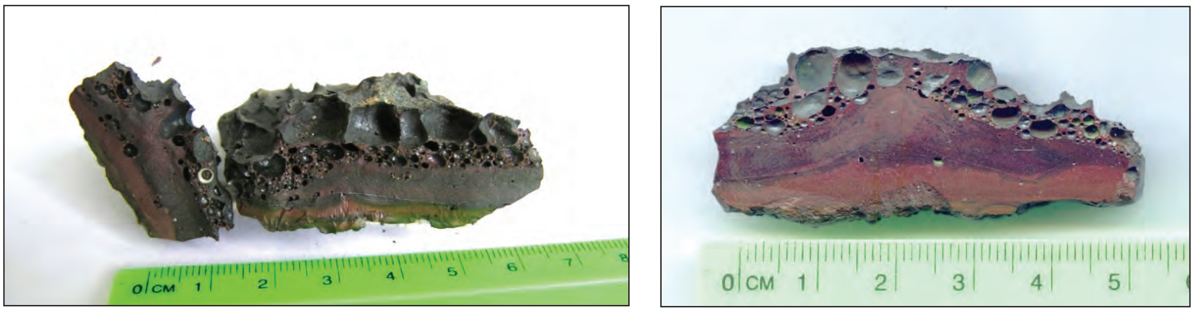

Fig. 4. Sample 570

There is no noticeable magnetism in this sample; probably there are few magnetic minerals. Iron in the sample is about 9 %.

Sample № 570 (Fig. 4) is a spongy, porous, relatively light (1.2-1.4 g/cm^3) slag of the upper (first) melting layer. This layer is characterized by a very weak magnetism, relatively low contents of Fe and Cu.

On the basis of the conducted petrographic analysis, it can be concluded that the parent rocks with a certain content of ore minerals may have been ultrabasites and basic rocks. In the sample of slag № 567, areas of the primary structure are observed — non-metallic minerals fragmentarily create a structure similar to the "diabase" one. The second (№ 568) and the third (№ 569) samples demonstrate an increase in the intensity of secondary transformations in the slag composition.

The content of native copper in the slag according to chemical analysis ranges from 13.4 to 18.5 %. Iron content ranges from 9 to 18%. In accordance with petrographic studies, the size of copper grains ranges from 0.1–0.3 to 1–5 mm. Drip melts of copper up to 1-2 cm are identified on particular samples, but their number is insignificant. The most common sizes of copper grains for the studied samples are 0.2-0.3 and 1-2 mm. Large grains of 5 mm or more in size are relatively few and they are more likely to have dendritic or leafy forms. Ore minerals are likely: sulfides and oxides of copper, iron and zinc.

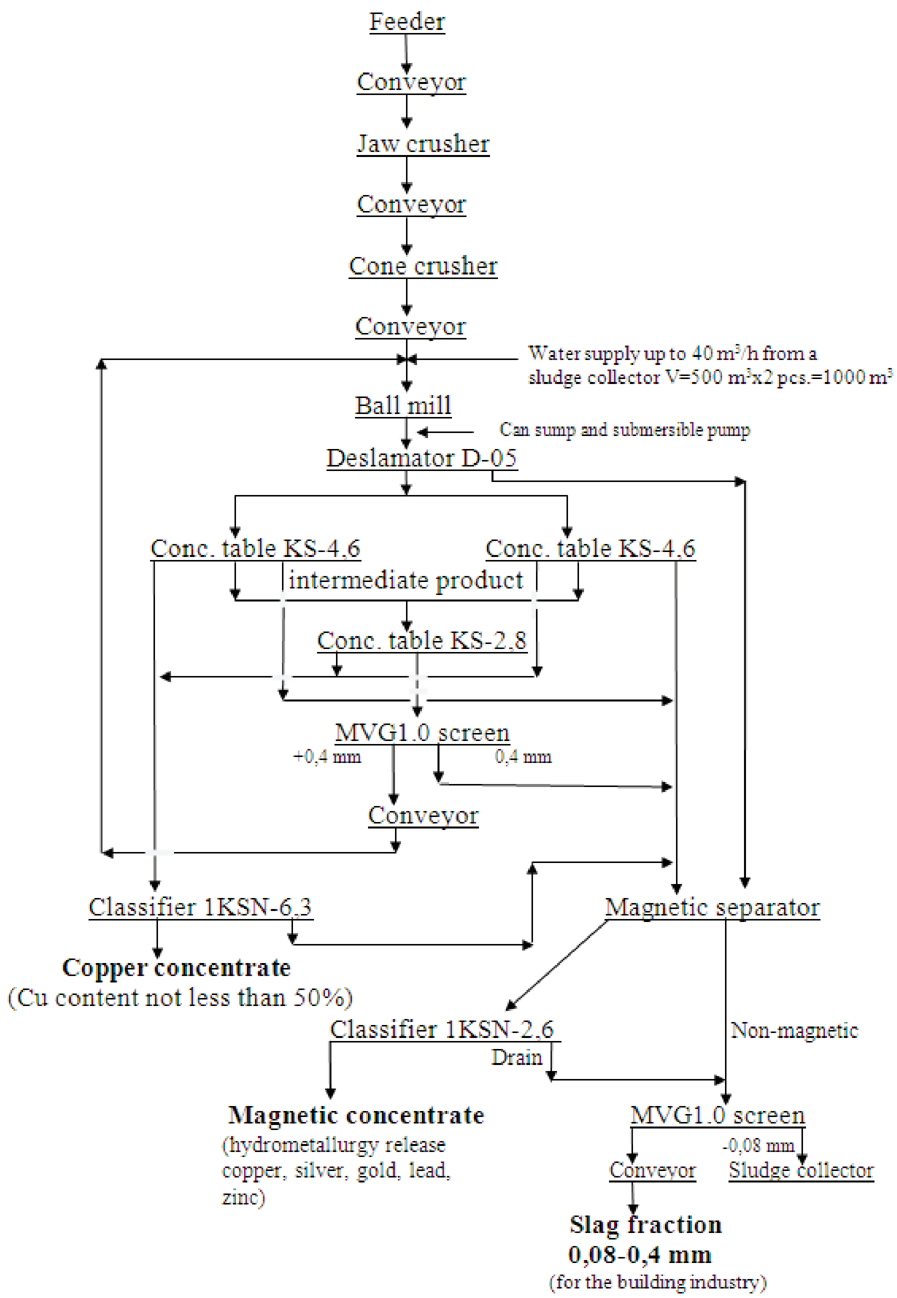

Fig. 5. Gravity enrichment scheme for copper-containing slags

Results and their analysis. Based on the results of spectral, chemical, sieve and petrographic analysis, a copper-containing slags enrichment technology has been developed.

The gravity enrichment scheme with a capacity of 5 t/h with Cu recovery in the range of 80–95 % is shown in Fig. 5. The nomenclature of the technology equipment is given in Table 4.

To ensure the operation of the wet enrichment technology, electrical cabinets, electrical equipment and lighting, grounding, slurry pipeline and drain chutes, trunk pipeline, adjustable water pipes with stop valves, electric pipes, cable and electrical wiring, abrasion resistant hose, metal constructions, ladders, crossings, platforms will also be required. The total electrical power of the equipment chain will be 104.1 kW.

The technology of wet gravity enrichment involves the grinding of raw materials sequentially in a jaw crusher, a cone crusher and a ball mill. Grinding in a ball mill occurs at a constant flow of water up to 40 m^3/h from the sludge collector. After grinding, the raw material is fed into a slug catcher and further to the concentration tables, where the separation by density occurs. The heavy fractions are fed to a magnetic separator and then to a classifier for separating magnetic concentrate and slag, which, after separating a fraction of 0.08-0.4 mm at the MVG screen, can be used as a raw material for the building industry. The light fractions after the concentration

Table 4. The nomenclature of the equipment technology of wet enrichment of copper-containing slag with a capacity of 5-6 t/h

Item №	Type of equipment	Quantity, pcs	Electric power, kW
1	Feeder PK-10	1	3,0
2	Conveyor LK-12-650	6	13.2
3	Jaw crusher	1	11
4	Cone crusher	1	11
5	Ball mill MSC-1,6	1	22
6	Slug catcher D -05	1	-
7	Concentration table KS-4,6	2	4.4
8	Concentration table KS-2,8	1	1.5
9	Sand/submersible pump 63/23	1	11.0
10	Multi-frequency screen MVG1.0	2	2.4
11	Magnetic drum separator (60 m^3/h)	1	5.5
12	Spiral qualifier 1KSN-6,3	1	3.0
13	Spiral qualifier 1KSN-2,6	1	1.1
14	Sump	1	-
15	Centrifugal pump 60 m^3/h on a pontoon with a check valve and start system	1	15.0
	Total		104.1

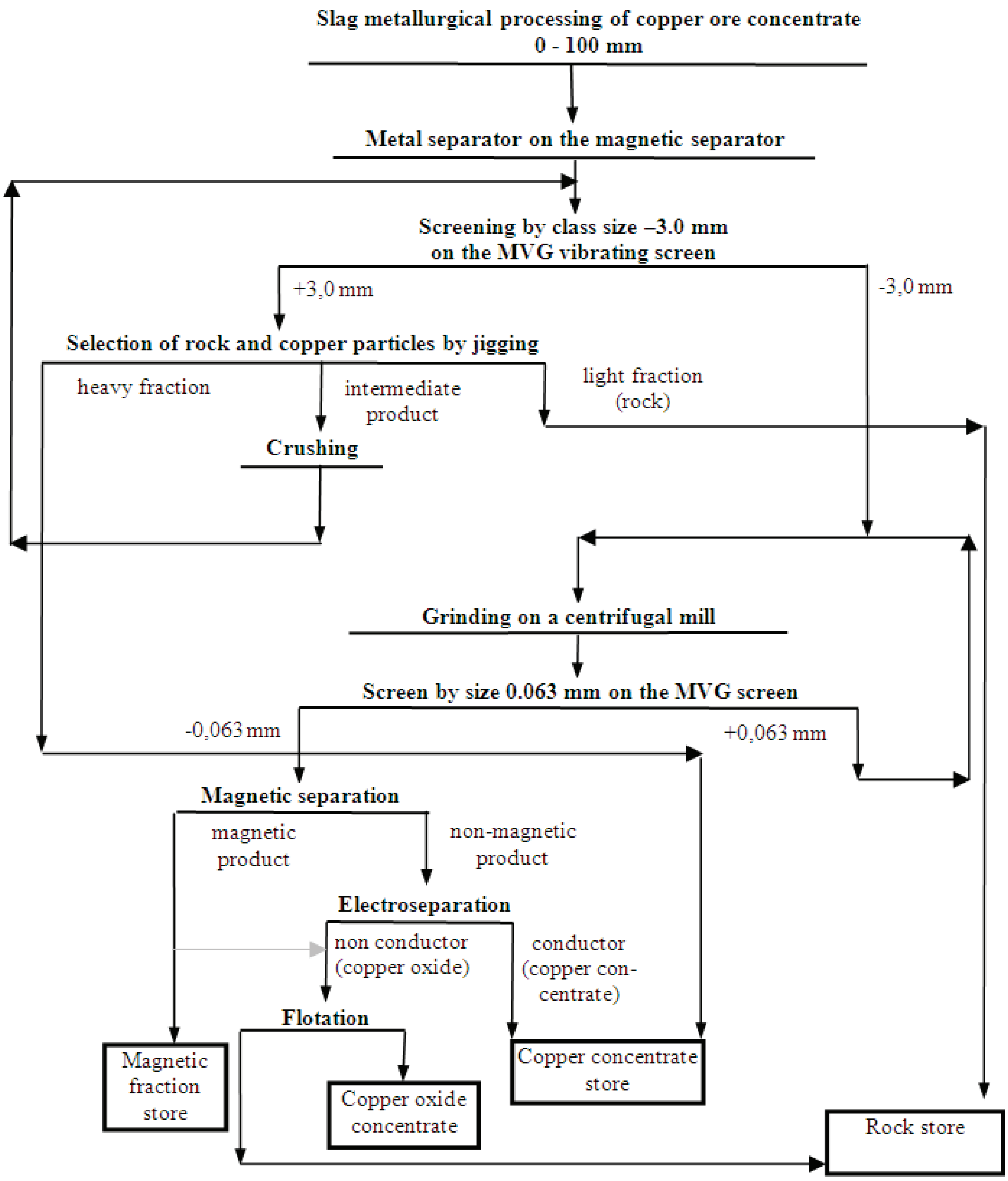

Fig. 6. Technological scheme for the enrichment of slag from metallurgical processing of copper ore concentrate with a particle size of 0-100 mm

tables are fed to the classifier, on which the copper concentrate is released. The average density fractions are returned to the closed cycle for further grinding in a ball mill.

However, such a wet enrichment scheme requires a continuous supply of water and the presence of sludge tanks, which cannot always be ensured.

The technological scheme of dry enrichment of slag with a particle size of 0–100 mm is shown in Fig. 6. Slag metallurgical concentrate of copper ore is fed to the magnetic separator, which provides for the separation of pieces of metal found in the raw material. Next, the concentrate is fed to the MVG vibrating multi-frequency screen for classification by size 3 mm. The –3 mm fraction is fed to grinding in a centrifugal mill. Fraction +3 mm - enters the jigging machine. After jigging, the light fraction (rock) enters the rock store, the heavy fraction (copper) to the copper concentrate store, and the intermediate product goes to crushing, and then is fed back to the MVG screen for classification by 3 mm. After grinding in a centrifugal mill, screening of 0.063 mm on the MVG multi-frequency screen takes place. The fraction +0.063 mm in a closed cycle is fed back to grinding, and the fraction -0.063 mm enters the magnetic separator. The magnetic product enters the store of the magnetic fraction for the subsequent extraction of iron, the non-magnetic product enters the electric separator, in which copper concentrate is released, which then enters the store, and copper oxide, supplied to the flotation, to separate the copper oxide itself from the rock.

The central apparatus in the proposed enrichment technologies is the MVG vibrating screen, developed at the Institute of Geotechnical Mechanics named after M.S. Polyakov NAS of Ukraine, which is designed to separate bulk materials by particle size from 20 microns to several millimeters (Shevchenko, G.A. et al 2016). Screening or separation of solid particles from slurries or suspensions and their dehydration at the MVG screen is carried out on woven meshes or rubber sieves performing polyfrequency vibrational oscillations.

Polyfrequency oscillations are implemented on the screen sieve in the frequency range from several Hz to kHz, thus blockage of the sieve cells is eliminated, destruction of the formed aggregates of stuck particles is ensured, their intensive movement in the layer and effective passage of the particles reaching the sieve surface through the cells is realized. This type of vibration makes it possible to achieve significantly greater efficiency of separation and dehydration of materials than in traditional screens and to ensure continuous self-cleaning of the mesh, which promotes to the process of separation and dehydration. Due to the lack of tension, high durability of the working surface is ensured. Due to the transfer of minimum loads on the base, the screen is installed without arranging special foundations, including on the floors of buildings and structures.

Multi-frequency screens can operate at high temperatures, in corrosive environments, in the water environment, in the mining, building, chemical, food, pharmaceutical industries, as well as in powder, ferrous and non-ferrous metallurgy to separate and dehydrate any bulk materials, purify polluted water, etc. A standard-sized row of screens was developed with an area of screening from 1 to 4 m^2 and a different number of tiers. The technical characteristics of the MVG screen with a screening area of 2 m^2 are given in Table 5.

Conclusions.

1. When developing technologies for enrichment of metallurgical production wastes, it is important to

Table 5. Technical characteristics of the MVG2.0 screen

Name of parameters, units of measurement	Value
Frequency of forced oscillations of the box, Hz	25
Number of motor vibrators, type IV-25-25	2
Motor vibrator engine power, kW	2.3
Separation size, mm	0.02–20
Conventional dimensions of the screening surface: - width, mm - length, mm	 1000 2600
Effective separation area, m^2	2.6
Angle of sieve surface, degree	0-10
Overall dimensions of the screen, mm - length - width - height at angle of sieve surface 0^0	 3810 1636 1607
Screen weight (without frame), kg	2800

take into account both the material composition of the raw material (the content of elements and their compounds) and the features of the inclusions of useful components: their grain size, shape, etc. This requires spectral, chemical, sieve and petrographic analysis of mineral raw materials.

2. The results of spectral analysis indicate the copper content in all three samples at a level of more than 1 %. The results of chemical analysis indicated a high copper content in the samples from 13.4 to 17.1 %, as well as a high iron content from 9 to 18 %. Analysis of the results of the sieve analysis showed that the largest amount of copper is contained in the size classes of 0.063–0.05 mm from 18.6 to 24.1 % and of 0.04 mm from 15.6 to 38 %. The results of spectral, chemical and sieve analysis must be considered when drawing up the technological scheme of enrichment and the choice of means of classifying copper-containing raw materials by size.

3. According to petrographic studies, the size of copper grains varies from 0.1–0.3 to 1–5 mm. Drip melts of copper up to 1-2 cm are determined on particular samples, but their number is insignificant. The most common sizes of copper grains for the studied samples are 0.2-0.3 and 1-2 mm. Large grains of 5 mm or more in size are relatively few and they are more likely to have dendritic or leafy forms.

4. Based on the results of spectral, chemical, sieve and petrographic analysis, a technology for the enrichment of copper-containing slags was developed: gravity wet enrichment with a capacity of 5 t/h with Cu extraction within 80–95 % and a dry enrichment technology of slag with a particle size of 0–100 mm.

5. The central apparatus in the proposed enrichment technologies is the MVG vibrating screen, which is designed to separate bulk materials by particle size from 20 microns to several millimeters. Polyfrequency oscillations are implemented on the sieve screen in the frequency range from several Hz to kHz, thus blockage of the sieve cells is eliminated, destruction of the formed aggregates of stuck particles is ensured, their intensive movement in the layer and effective passage of the particles reaching the sieve surface through the cells is realized. Such a nature of vibration allows a significantly greater efficiency of separation and dehydration of materials to be achieved than in traditional screens and constant self-cleaning of the mesh , which promotes the process of separation and dehydration. Due to the lack of tension, high durability of the working surface is ensured. Due to the transfer of minimum loads on the base, the screen is installed without arranging special foundations, including on the floors of buildings and structures. A standard-sized row of screens was developed with a screening surface area from 1 to 4 m^2 and a different number of tiers.

References

Cao, H., Wang, J., Zhang, L., Sui, Z., 2012. Study on Green Enrichment and Separation of Copper and Iron Components from Copper Converter Slag. Procedia Environmental Sciences, 16, 740-748.

Chaabia, R., Bounouala, M., Boukelloul, M.L., 2015. A preliminary study on Anini deposit iron ore enrichment (Algeria) in order to use it in metallurgical industry. Scientific Bulletin of National Mining University.4, 44-50.

Lei, L., Hua, W., Jianhang, H., 2009. Study development of the comprehensive utilization of copper slag. J. Energy for Metallurgical Industry, 28(1), 44-48.

Mahmoudi, E., Moore, F., Asadi, S., 2018. Leached caps mineralogy and geochemistry as supergene enrichment fertility indicators, Meiduk and Parkam porphyry copper deposits. SW Iran Journal of Geochemical Exploration, 194, 198-209.

Malanchuk, Z.R., Malanchuk, E.Z., 2014. The results of studies of the distribution of native copper in rock mass Volhynia (Ukraine). The 1st International Academic Congress «Fundamental and Applied Studies in the Pacific and Atlantic Oceans Countries», «Tokyo University Press, 322–325.

Rozendaal, A., Horn, R., 2013. Textural, mineralogical and chemical characteristics of copper reverb furnace smelter slag of the Okiep Copper District, South Africa. Minerals Engineering, 52, 184-190.

Shevchenko, G.A., Shevchenko, V.G., Lebed, G.B., 2016. Methodical recommendations for use resource technologies and means fine classification by size and dewatering waste uranium ore. Mining of mineral deposits. 10(1), 69-76.