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Improvement of Flotation Enrichment of Copper-Nickel Ores Based on the Selective Destruction of Mineral Aggregates in High-Energy Impact

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Abstract

The paper justifies factors and causes of hard washability of finely disseminated copper-nickel ore, the main of which are incomplete and insufficiently selective expansion of sulphide and rock-forming mineral aggregates due to low mechanical interactions in ball mills, with the result that a large number of non-ferrous and precious metals pass to concentration production wastes adding to technogenic accumulations. Technological possibilities of high-energy and high-velocity impact grinding in a disintegrator, wherein increased destructive effects lead to an increase in expansion of aggregates, were explored. The opportunity to control energy and free kick speed allows carrying out the destruction mainly along the boundaries of mineral intergrowths and reducing the amount of the fine fraction slurry in grinding products.

However, an increase in the disintegration rate to 7200 rpm did not result in obtaining flotation size products −0.071+0.02 mm, and a substantial part of ore remains in the larger, difficult-to-float condition. With a view to optimising opening of mineral associations by granulometric composition, the principle of stage grinding that allows consistently in the regimes of increasing energy effects regrinding larger ore fractions and liberating minerals from genetic associations with increased strength was proposed. This methodological approach allowed in the optimum rate mode destructing sulphide minerals and obtaining during flotation separation concentrates with increased content of non-ferrous metals, which offers opportunities for improvement of metallurgical methods for processing concentrates. More high-energy destruction allows liberating residual amounts of sulphides in rock associations and transferring into reject materials to 50 % of ore rocks. It is noteworthy that herewith, a large number of nickel compounds found in aggregates with rock formations are released, which is of great importance for increasing nickel extraction into concentrates. The carried-out research demonstrates that high-energy grinding is an advanced method for selective destruction of aggregates and mineral liberation in finely impregnated ores prior to concentration processes.

Key words: flotation enrichment, copper-nickel ores, destruction of aggregates, impact

INTRODUCTION

Despite significant achievements in development of progressive processes and equipment for ore-preparation and mineralogy of mineral raw materials difficult for concentration, concentration of some ores, especially with finely disseminated mineralization is characterised by underextraction of valuable components due to their losses in aggregates with rock-forming minerals and slurry products, which takes place during traditional grinding in drum mills [1, 2].

Enrichment of finely disseminated copper-nickel ores of the Norilsk deposits example is an example of the above. Thus, flotation wastes at the Talnakh concentration plant contain 0.62 % Ni and 0.13 % Cu, and the amount of platinum group metals in the Lebyazh'ye tailing dump reaches 1.5 g/t [3]. These contents of metals are often inherent to initial ores and are of interest as their extracting objects.

Decisions are being developed on isolating high-quality concentrates by nickel content, which will allow reduction of the flow of sulphur into a hydrometallurgical process [4].

However, herewith, a significant problem arises on under-extraction of nickel from tailing dumps as low-sulfur products. Problem solution is largely defined by sulphides liberation from the state of reciprocity of accretion. Minimising defect formation in the crystal structure of the surface of minerals, i.e. realization of selective, low-defect grinding that allows retaining differences in mineral wettability during their flotation separation, is an important task during expansion of aggregates.

The present work analyses opportunities of high-speed and high-energy ore destruction in a free kick disintegrator, the efficiency of which is demonstrated on an example of some ores and technogenic raw materials [5–8], however, as applied to thin embedded and partially emulsion interpenetrations of geomaterials, this destruction is still poorly studied.

EXPERIMENTAL

Copper-nickel ores from Lighthouse mine that later became a part of the structure of the Komsomolskaya Mine were selected as a study object. The chemical composition of samples defined by the atomic absorption method using Varian AA 280 FS device contained, %: Ni 1.17; Cu 1.92; Fe 17.33. Ore minerals are presented by pyrrhotine $Fe_{1-x}S$, chalcopyrite $CuFeS_2$, and pentlandite (Fe,Ni)9S8, according to X-ray analysis (XPA of the V. S. Sobolev Institute of geology and mineralogy (IGM SB RAS). Their amount is 10–12 %, however, sphalerite ZnS, mackinawite $Fe_{1-x}S$, djerfisherite $K_3CuFe_{12}S_{14}$, and pyrite FeS_2 were found in very small amounts, according to the studies at Mehanobr [9]. Chrysotile $Mg_3[Si_2O_5](OH)_4$, lizardite $Mg_3[Si_2O_5](OH)_4$, smectite, micas, fieldspars, and quartz are a part of rock-forming minerals, their amount reaches 70 % (Fig. 1).

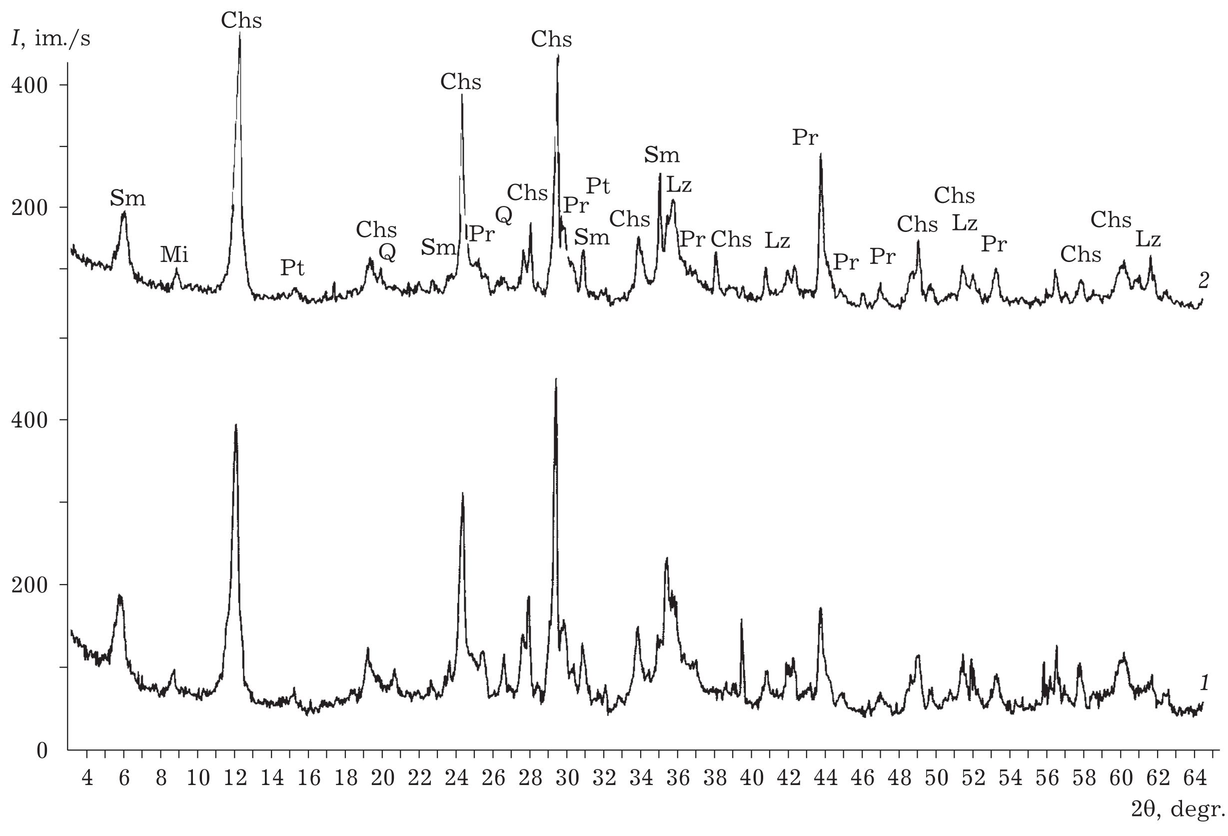

Fig. 1. X-ray diffraction patterns of initial (*a*) and crushed (*b*) samples in a disintegrator at 2400 rpm. Designation: Chs is Chrysotile, Lz is Lizardite, Sm is Smectite, Cp is Chalcopyrite, Pr is Pyrrhotite, Mi, – Mica, Q is quartz, Pt is pentlandite.

RESULTS AND DISCUSSION

Thin interpenetration of ore formation explains the fact that even such light minerals, as quartz and fieldspars with a density of lower than 2.89 g/cm^3, at separation in $CHBr_3$ partially pass to a heavy fraction, and chalcopyrite and pyrrhotine were found in in the light part of separation.

Impact grinding in a disintegrator (DEZI-11 device) leads to the destruction of the major part of aggregates (see Fig. 1), and the amount of chrysotile and smectite is increasing in the light product during similar separation. Additionally, a big advantage of the method consists in an opportunity to regulate the speed and the magnitude of the energy of a free kick. There is no significant difference in the ratios of minerals by density gradation during the use of a drum mill.

The efficiency of expansion of minerals was assessed by the effectiveness of flotation enrichment as the most used method of concentration of minerals, especially sulphide. Disintegrator destruction was carried out in dry mode, as a far-reaching process [10].

Destruction characteristics of the ore under study were studied at a rotation rate of the rotors in the disintegrator of 2400, 3600 and 7200 rpm. The granulometric composition of dispersed products demonstrates that increasing the number of rotor rotation and the free kick speed, the dispersion and the yield of flotation classes of 0.071 mm and 0.02 mm are increasing (Table 1). However, resulting from a single-pass of identical samples through the integrator, the increased amount of a class of +0.071 mm remains, in which aggregates are not open yet in the required size. This indicator is 38.1 % even at 7200 rpm. The increased yield of a class of 0.02 mm hardly susceptible to flotation selection of a class of 0.02 mm also takes place.

The regrinding of large fractions to 0.071 mm size in the transition to the increased intensity of destruction, especially at 7200 rpm is increasingly approaching the optimum granulometric composition (see Table 1).

Analysis of the granulometric composition of desintegration products demonstrated that the process at the maximum impact speed best corresponds to the requirements of the flotation process, however, it is advisable to transfer the entire product to the state size of less than 0.071 mm prior to enrichment. Butyl xanthate C_4H_9OCSSK in the amount of 200 g/t was used as a collector during flotation. A mixture of polypropylene glycol monoesters in the amount of 100 g/t was the frother. Sulphuric acid made the acidity of the medium to pH ~ 4.5. A collective concentrate of sulphide minerals and tailings of the process that were analysed for the content of Cu, Ni and Fe were obtained resulting from enrichment (Table 2). Chalcopyrite and pyrrhotine are most actively floated in the selected mode. Copper extraction into the concentrate (valuable product) reaches 89.5 % already during its fourfold increase, compared to existing, what is regarded in enrichment technology as a quite satisfactory indicator. Nickel extraction mainly happens due to pentlandite flotation and amounts to only 39.5 %, its content in the concentrate increased only twice. Such low indicators are explained as follows.

Nickel in this ore is found in three forms, such as finely disseminated sulphide, mainly as pentlandite, emulsion, mainly in pyrrhotine, and silicate, which accounts for 20–25 % of the metal from its total content in the ore. Nickel enters the lattice of silicates and is extracted only in small amounts that are 3–5 % from its content in the silicate form during its flotation, extraction intensification is reached by special mechanical and mechanochemical effects and other methods.

With a view to identifying the most optimum modes for expansion of aggregates that allow isolating concentrates with higher contents of nonferrous metals, ore fractions of different sizes obtained from the products ground at modes with

TABLE 1

Results of sample reduction at various disintegration intensities

Size grade, mm	Rotor speed, rpm		
	2400	3600	7200
	Fraction yield, %		
+0.071	79.6	71.4	38.1
-0.071+0.02	13.3	20.9	40.6
-0.02	7.1	7.7	21.3
Total	100.0	100.0	100.0

TABLE 2

Results of sample (fraction +0.071 mm) further reduction at various disintegration intensities

Size grade, mm	Rotor speed, rpm	
	3600	7200
	Fraction yield, %	
+0.071	56.8	21.6
-0.071+0.02	16.6	23.1
-0.02	6.1	12.1
Всего	79.5	56.8

TABLE 3

Flotation of sulphides of a fraction of -0.071 + 0.0 mm obtained by one-time grinding in the disintegrator (Rotor speed,7200 rpm)

Product characteristic	Yield, %	Chemical composition, %			Extraction, %		
		Cu	Ni	Fe	Cu	Ni	Fe
Foam, collective concentrate	23.4	8.14	2.38	23.35	89.5	39.5	26.8
The sample from Chamber, tails	76.6	0.29	0.84	19.45	10.5	60.5	73.2
Initial	100.0	2.12	1.20	20.36	100.0	100.0	100.0

increasing destruction intensity were analysed (Table 3).

A rod mill was used as an aggregate for ore preparation to less than 2 mm size being disintegrator supplies. From chemical analyses data, it follows that fractions ground at 2400 and 3600 rpm are characterised by the maximum content of copper and nickel. Consequently, the concentration of chalcopyrite and partially pyrrhotine in them is maximal. The thinnest fractions of 0.2 mm are characterised by the increased metal content. This is also typical for a fraction obtained by destruction at 7200 rpm from already depleted part of the ore.

Iron, being an element of the majority of minerals from this ore, behaves to some extent symbatically to non-ferrous metals during grinding increasingly concentrating in a class of 0.071 + 0.02 mm. A similar picture is not observed in products obtained upon lower desintegration intensity. The minimum amount of iron is recorded in fractions of 0.071 mm, as typical for non-ferrous metals. These results allow considering that detectable iron to the prevailing extent ranks among sulphide minerals, only a small part refers to magnetite.

Rock-forming minerals are uncovered at the maximum speed of impacts, peaks of their reflexes are increasing in the X-ray diffraction pattern, in the first turn, this relates to chrysotile, lizardite, and magnetite, peaks of which were earlier recorded (Fig. 2).

However, the main achievement of high-speed destruction consists in the expansion of residual aggregates of chalcopyrite and pyrrhotite with rock minerals, with the result that an opportunity of flotation re-extract of indicated sulphides appears.

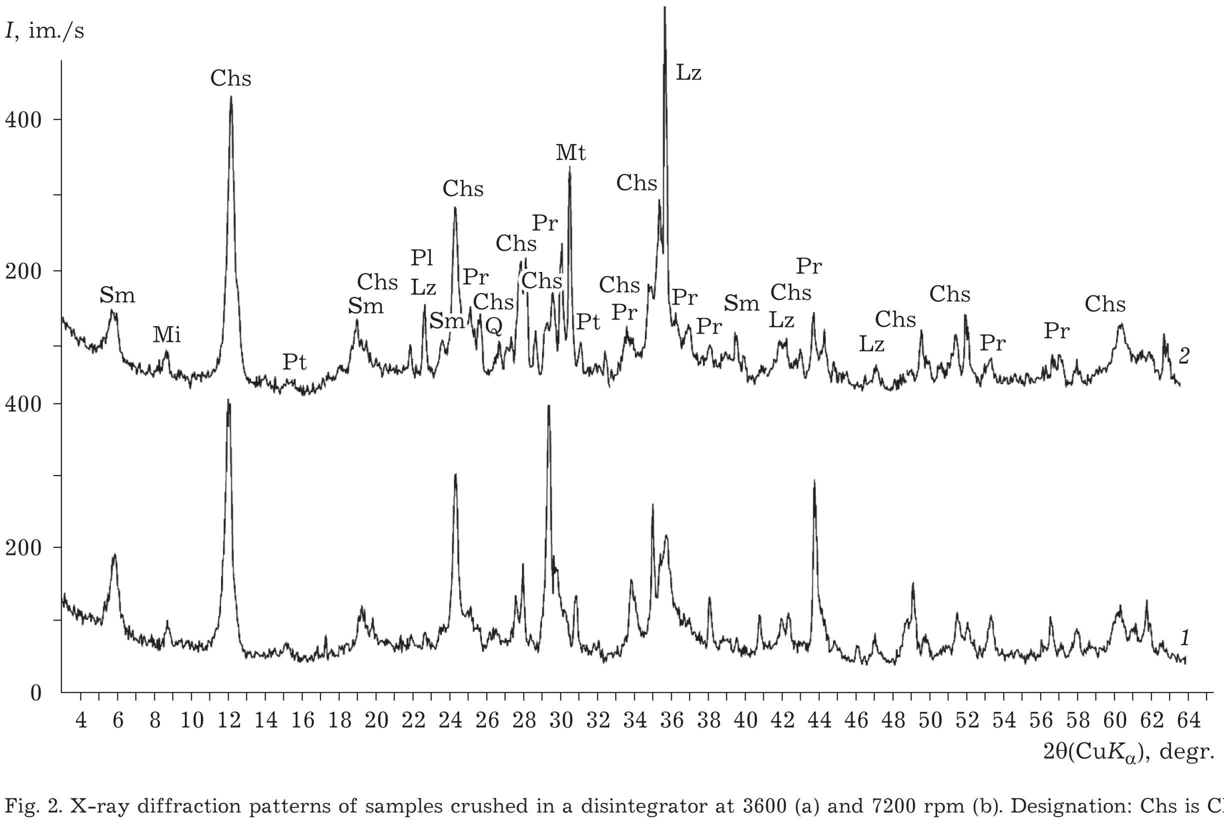

Fig. 2. X-ray diffraction patterns of samples crushed in a disintegrator at 3600 (a) and 7200 rpm (b). Designation: Chs is Chrysotile, Lz is Lizardite, Sm is Smectite, Cpr is Chalcopyrite, Pt is Pyrrhotite, Mi, is Mica, Q is quartz, Pt is pentlandite, Mt is magnetite.

TABLE 4

Change in the chemical composition of the ore in the grinding process in the disintegrator

Disintegrator, grinding mode	Size grade, mm	Fraction Yield, %	Chemical composition, %			Extraction, %		
			Copper	Nickel	Iron	Copper	Nickel	Iron
Rod mill	+0.071	91.1	2.39	1.12	16.39	91.27	89.37	91.20
	−0.071+0.02	5.6	2.18	1.34	16.35	5.11	6.55	5.59
	-0.02	3.3	2.62	1.41	16.21	3.62	4.08	3.81
	Total	100.0	2.38	1.14	16.37	100.0	100.0	100.0
Disintegrator, 2400 rpm	+0.071	72.6	2.12	1.08	14.81	70.99	71.62	76.29
	−0.071+0.02	12.1	3.63	1.78	19.63	20.38	19.66	16.82
	−0.02	6.4	2.91	1.49	14.84	8.63	8.72	6.89
	Total	91.1	2.36	1.20	14.09	100.0	100.0	100.0
Disintegrator, 3600 rpm	+0.071	51.8	0.93	0.69	11.11	36.35	48.91	58.64
	−0.071+0.02	15.2	3.94	1.69	20.20	45.16	35.14	31.28
	−0.02	5.6	4.38	2.08	17.64	18.49	15.95	10.08
	Total	72.6	1.56	1.00	13.51	100.0	100.0	100.0
Disintegrator, 7200 rpm	+0.071	19.7	0.34	0.35	9.88	10.14	15.40	28.11
	−0.071+0.02	21.0	1.09	0.87	14.50	35.75	40.88	43.39
	−0.02	11.1	3.12	1.76	17.78	54.22	43.72	28.50
	Total	51.8	1.23	0.86	13.35	100.0	100.0	100.0

A fraction of −0.071+0.02 mm is regarded as the most effective class during flotation separation of sulphides, therefore, it is advisable to have the maximum content of non-ferrous metals precisely in this size range, though this ratio is not always attainable for finely disseminated ores.

Considering the above, gradational disintegration with sequential regrinding of products of +0.071 mm in modes of higher impacts was used.

A scheme for sample preparation and enrichment is given in Fig. 3. Three products with a size of −0.071+0.0 mm isolated in the speed of bumps of minerals on desintegrator beaters of 2400, 3600 and 7200 rpm were subjected to flotation. Reactant regime did not change compared to those selected in previous experiments (see Table 5). The highest indicators were obtained resulting from the enrichment of fractions isolated during the second speed mode (Table 4).

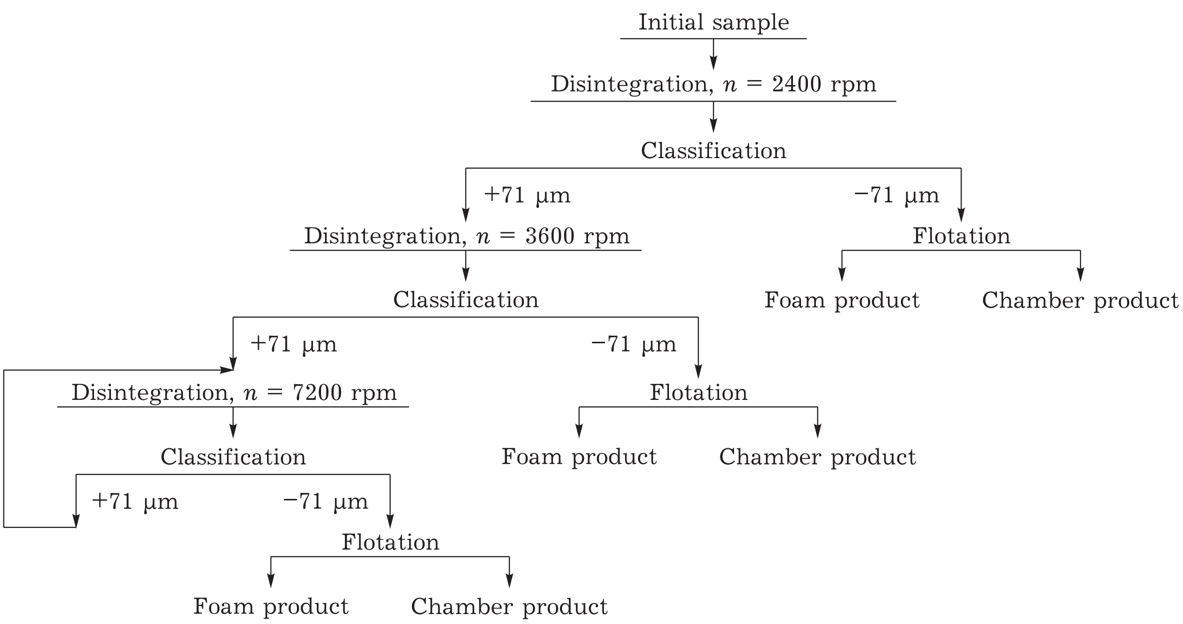

Fig. 3. Scheme of staged disintegration and flotation of samples.

TABLE 5

Flotation of sulphides of a fraction of -0.071+0.0 mm obtained by successive sample reduction

Rotor speed, rpm	Product characteristic	Yield, %	Chemical composition, %			Extraction, %		
			Copper	Nickel	Iron	Copper	Nickel	Iron
2400	Concentate, foam	6.1	8.08	2.60	23.10	25.4	12.7	7.3
	Tails, chamber	13.9	0.54	1.38	18.09	3.8	15.5	13.7
3600	Concentate, foam	4.6	14.1	3.26	30.11	29.9	12.0	7.2
	Tails, chamber	13.4	0.36	1.39	20.28	2.4	14.1	14.1
7200	Concentate, foam	10.9	6.10	2.43	25.50	34.6	21.4	14.4
	Tails, chamber	51.1	0.15	0.58	16.23	3.9	23.8	43.2
	Initial	100.0	1.93	1.24	19.22	100.0	100.0	100.0

TABLE 6

Cumulative results of flotation enrichment of copper-nickel ore crushed in various modes

Enrichment products	Yield, %	Chemical composition, %		Extraction, %	
		Copper	Nickel	Copper	Nickel
Concentrate	21.6	8.03	2.65	90.36	45.76
Wastes (tails)	78.4	0.25	0.84	9.64	54.24
Initial sample	100.0	1.93	1.24	100.0	100.0

Copper content in flotation concentrate is 14.1 % with the extraction of almost 30 %. The former in initial ore is 1.93 %. Thus, it is realistic to isolate separate concentrate with high copper content with technological advisability.

The amount of nickel in this concentrate is also highest from those reached in presented experiments and amounted to 3.26 %, however, extraction did not exceed 12.0 %. From the analysis of X-ray diffraction patterns, it follows that the maximum expansion of sulphides takes place in the second mode of impact (see Fig. 1, 2).

Destruction mode of aggregates with a mechanical impact speed of 7200 rpm, whereby the most depleted aggregates are unlocked of all sulphide minerals present in the sample of sulphide minerals is particularly effective, with the result that flotation concentrate is isolated with the highest yield of 10.9 %. Although the quality of concentrate is second only to the above products, the highest extractions of Cu and Ni (34.6 and 21.4 %) prove broad opportunities of disintegrating grinding during expansion of aggregates.

Analysing the results of flotation separation of ore depending on speed modes of disintegration, one should allocate a particularly important result, under which destruction at highest energy impacts under comparison allows separating reject material with copper content of 0.15 % and the yield of 51.1 % from the entire ore mass, which is the most important achievement of experimental studies.

We did not manage to reduce nickel content of less than 0.58 % in flotation wastes, which is explained by its presence in resistant mechanically locked silicate formations. Mechanochemical activation followed by autoclave leaching is an effective technology of extraction of non-ferrous metals from such geomaterials [11].

Thus, using sequential swelling of mechanical loading prior to ore separation, the following qualitative and quantitative calculated indicators of the ultimate concentrate were obtained (Table. 6).

From comparison of indicators of flotation enrichment of completely ground ore in high-speed disintegration mode (7200 rpm) and sequential regrinding of the product (+ 0.071 mm) at high mechanical impact regimes, it follows that the concentrate quantities and quantities are relatively close, however, when using the second option, it is possible to obtain a part of flotation concentrate with high copper and nickel contents. As already noted, the use of the second option allowed isolation of almost half of ore mass with dumped copper content.

CONCLUSIONS

1. The high efficiency of high energy intensive grinding in a free kick disintegrator was demonstrated during expansion of finely disseminated minerals of valuable metals.

2. As applied to copper-nickel ores of the Norilsk deposits, an opportunity of selective release of chalcopyrite, pyrrhotite, and pentlandite from ore aggregates based on a change in mechanical impact intensity by a rotation rate of the rotors in the disintegrator has been explored. An opportunity to obtain flotation concentrates with high copper and nickel contents at the optimum impact speed has been found experimentally.

3. An increase in mechanical loads to a certain value of 7200 rpm allows unlocking aggregates of sulphide minerals from the most complex and resistant finely disseminated associations, with the result that during flotation enrichment it is possible to increase metal extraction and recycle more than a half of ore mass as final tailings with 0.15 % minimum copper content of and 0.58 % maximum nickel content. It is these indicators that are the main advantages of ore disintegration in free kick mode.

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