Extraction of Non-Ferrous Metals from Waste Deposits (on Example of Industrial Sites in the Murmansk Region)

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Summary

Difficult sulfide ores of non-ferrous metals and some nonconventional raw materials, particularly those of technogenic origin, are increasingly being involved in processing nowadays. Processing of the raw materials from technogenic deposits is the most effective way for operating mining companies to enlarge the available mineral resources, to improve the resources utilization efficiency, to reduce resource-intensity of products and to remediate the surrounding environment.

The results of floatation of copper-nickel dressing tailings have been studied. A technology of dry magnetic separation of the dumps the Allarechensk copper-nickel deposit is suggested. A method for geotechnological treatment of substandard Ni, Cu and Co containing sulfide material is developed.

Keywords: non-ferrous metals, technogenic deposits, sulphates, floatation, magnetic separation

Introduction

Sulfide-containing wastes are the most environmentally hazardous wastes. Wastes occupy vast lands, violate the existing hydrologic and geo-hydrologic regime and induce secondary dust pollution of the air basin and natural water bodies, also they contain floatation reagents and minerals able to transform into soluble toxic compounds and thus produce adverse effect on the environment. The storage of wastes is accompanied by oxidation of sulfide minerals and formation of sulfuric acid (Acid mine drainage) and iron and non-ferrous metal sulphates. Hypergenic changes of technogenic products are more rapid compared to a natural geological medium [1].

As a rule, the conventional processing methods are ineffective for processing of such mineral resources due to peculiar forms of occurrence of valuable minerals, their high degree of dispersivity and changes of physical and physico-chemical surface properties. That's why the development of new high-tech and environmentally safe processes decreasing the environmental impact of the sulfide-containing wastes and providing effective and complex extraction of valuable components from ores and the processing wastes is an urgent geo-ecological and economic objective [2].

Area description/Materials and methods

A pilot study of floatation-based reextraction of non-ferrous metals from current tailings of the "Pechenganikel" smelter, "Kolskaya GMK" JSC, was carried out in collaboration with Institute of Comprehensive Exploitation of Mineral Resources Russian Academy of Sciences (A.A. Lavrinenko, Dr. Sc. (Engineering), Sarkisova L.M., PhD (Engineering), Glukhova N.N., postgraduate student).

The distribution of metal concentrations in fractions is given in Table 1. The potassium butyl xanthate (PBX) was used as a collector and methyl-isobutyl carbinol (MIC) - as a foaming agent. Blue copper was added to activate pyrrhotite. Two flowsheets were tested:

1. Crushing of tailings in a grinding mill up to 90% of the grade -71μm followed by floatation;
2. Desludging of tailings using a water cyclone according to the grade 20 μm, further grinding of sands from the cyclone up to 90% -71μm followed by floatation.

The first flowsheet included one floatation process and reagent consumption was as follows: blue copper – 30 g/ton; PBX – 160 g/ton and MIC – 70 g/ton.

The second flowsheet included three floatation processes and the reagent consumption was as follows:
Floatation no.1: blue copper – 30 g/ton; PBX – 100 g/ton and MIC – 50 g/ton.
Check floatation no 1: PBX – 50 g/ton and MIC – 20 g/ton.
Check floatation no 2: PBX – 50 g/ton and MIC – 20 g/ton.

Another research target was a technogenic deposit "Waste dumps of the Allarechensk deposit", located in the Pechenga district of the Murmansk region. The deposit represents rock refuses formed during ore extraction in the primary deposit of sulfide copper-nickel ores, where opencast mining was stopped in 1971. The rocks of the dumping site represent overburden chiefly valueless gneisses, granite-gneisses, amphibolites and enclosing rocks mineralized to different extents: peridotites, olivinites, contact amphi-

Tab. 1 Distribution of metal concentrations in tailing fractions

Tab. 1 Rozkład stężenia metali w osadach

Size of particles, μm	Ni concentrations, %	Co concentrations, %	Cu concentrations, %
-10+0	0.11	0.003	0.05
-20+10	0.13	0.004	0.04
-40+20	0.15	0.007	0.05
-71+40	0.18	0.007	0.06
-100+71	0.20	0.008	0.08
-200+100	0.21	0.009	0.08
+200	0.23	0.009	0.11
Average	0.19	0.007	0.07

Tab. 2 Results of semi-industrial testing of magnetic separation of ore from the dumping site

Tab. 2 Wyniki semi-industrialnych testów separacji magnetycznej rudy z składowiska

Sample no.	Weight of the sample, ton	Product	Output of the operation, %	Concentrations, %		Extraction, %	
				Ni	Cu	Ni	Cu
1	789.8	Magnetic	14.81	3.55	2.00	88.40	75.97
		Non magnetic	85.19	0.081	0.11	11.60	24.03
		Initial	100.00	0.59	0.39	100.00	100.00
2	786.3	Magnetic	3.78	1.18	0.74	49.52	33.68
		non magnetic	96.22	0.047	0.057	50.48	66.32
		Initial	100.00	0.090	0.083	100.00	100.00

Tab. 3 Results of tailing floatation according to the first flowsheet

Tab. 3 Wyniki osadów poflotacyjnych według pierwszego schematu

Product	Output, %	Concentrations, %		Extraction , %	
		Ni	Cu	Ni	Cu
Concentrate	9.34	0.67	0.3	33.73	44.00
Tailings	90.66	0.14	0.04	66.27	55.00

Tab. 4 Results of tailings floatation according to the second flowsheet

Tab. 4 Wyniki osadów flotacyjnych według drugiego schematu

Process	Product	Output		Concentrations , %		Extraction, %			
		of the operation	of the init. sample	Ni	Cu	of the operation		of the init. sample	
						Ni	Cu	Ni	Cu
Desludging using water cyclone	Liquid phase	22.24	22.24	0.16	0.05	19.32	18.52	19.32	18.52
	Sands	77.76	77.76	0.19	0.06	80.68	81.48	80.68	81.48
Floatation I	Conc. 1	8.83	6.87	0.59	0.30	27.17	43.61	21.92	35.54
1 check floatation	Conc. 2	6.17	4.80	0.31	0.11	10.14	10.80	8.18	8.80
∑concentrates		15.00	11.66	0.48	0.22	37.31	54.42	30.10	44.34
2 check floatation	Conc. 3	18.03	14.02	0.44	0.20	3.93	4.15	3.17	3.38
∑concentrates		18.03	14.02	0.44	0.20	41.24	58.57	33.27	47.72
Tailings		81.97	63.74	0.14	0.03	58.96	41.43	47.4	33.76
Initial		100	77.76	0.18	0.06	100	100	80.67	81.48

bolites, etc. There are two morphological types of ore in the dumping site: massif (solid) and impregnated ores. For both types the principal ore minerals are: pyrrhotite, pentlandite and rarely chalcopyrite the latter occurs in close paragenetic correlation with magnetite [3].

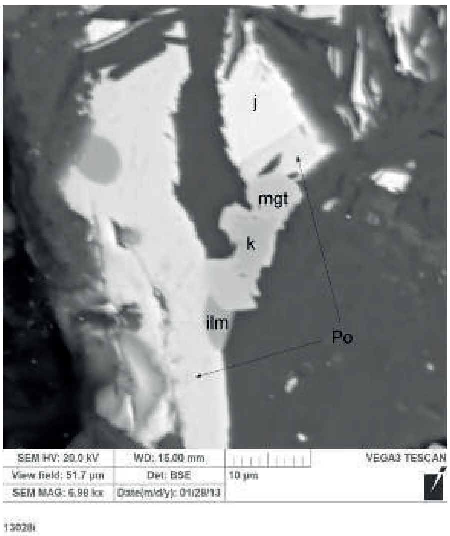
To study the application of magnetic separation two semi-industrial samples of the fraction 60+10 mm were carried out to demonstrate efficiency of the method (Table 2).

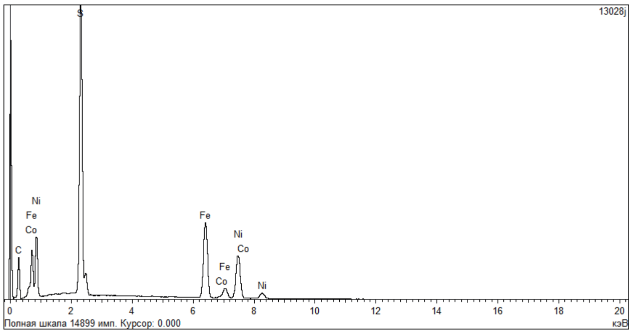
The Table 2 shows that the magnetic separation suggests the coarse concentrate accessible for pyrometallurgical processing even at low nickel concentrations in the initial product (0.09%). The losses which take place during the processing of the second sample don't essentially influence the extraction index, because they mostly relate to poor and low-grade ores having the share of silicate nickel (not accessible for pyrometallurgical concentration) equal to 11% and 25% of total nickel respectively.

Results and discussion

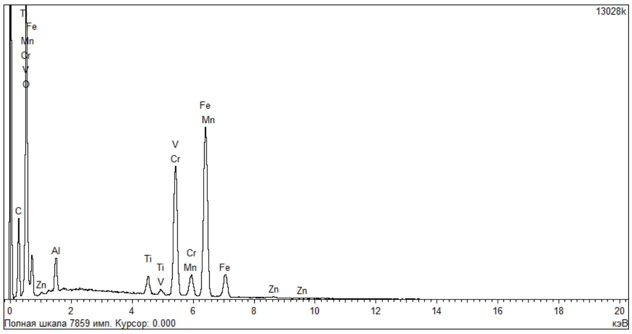
The results of floatation of copper-nickel tailings are given in Tables 3 and 4. A careful study of the received concentrates and floatation tailings was carried out to analyze the insufficient extraction of copper and nickel into the concentrates especially regarding the first flowsheet (at the Institute of Mineralogy, Ural Branch of the Russian Academy of Sciences E.V. Belogub and colleagues performed a detailed study of the concentrate and flotation tailings). The bulk of the received concentrate consists of fragments of nonmetallic minerals with sulfide inclusions. There are magnetite, chromite and titanic iron. Pyrrhotite dominates among sulfides, there is some pentlandite in subordinate quantities. Chalcopyrite, covelline and individual grains of pyrite were also found. Pyrrhotite chiefly occurs in the form of monomineral inclusions in nonmetallic fragments and sometimes aggregates with magnetite, chalcopyrite and pentlandite or contains flame interpositions of pentlandite. Pentlandite chiefly aggregates with pyrrhotite and forms interpositions in it, also it was found in aggregations with magnetite, seldom with chalcopyrite (Fig. 1). Pentlandite occurs in monomineral grains-inclusions in nonmetallic fragments.

Its structure can't be accurately defined due to close aggregations with pyrrhotite and small size of pentlandite grains. Nevertheless, energy-dispersive spectra clearly testify to the presence of this mineral. There is a constant admixture of cobalt in pentlandite and there is copper admixture in some grains. Chalcopyrite occurs in small quantities and chiefly in the form of monomineral inclusions in nonmetallic fragments, seldom aggregates with pyrrhotite and magnetite and very seldom with pentlandite. Covelline sometimes develops along the queres of chalcopyrite. Py-





Spectrum 13028j



Spectrum 13028k

Fig. 1 Aggregation of pentlandite (point j) with pyrrhotite. Pyrrhotite in its turn aggregates with magnetite and titanic iron, chromite inclusion (point k) is inside magnetite. To the right: energy dispersive spectra of pentlandite (spectrum 13028j) and chromite (spectrum 13028k). SEM VEGA3 TESKAN, analyst I. A. Blinov.

Rys. 1 Agregacja pentlandytu (punkt J) z pirotynu. Pirotyt z kolei reaguje z magnetytem i żelazem tytanowym, chromit (punkt K) jest wewnątrz magnetytu. Z prawej: widmo energii dyspersyjnej pentlandytu (spectrum 13028j) i chromitu (spectrum 13028k). SEM VEGA3 TESKAN, analityk I. A. Blinov

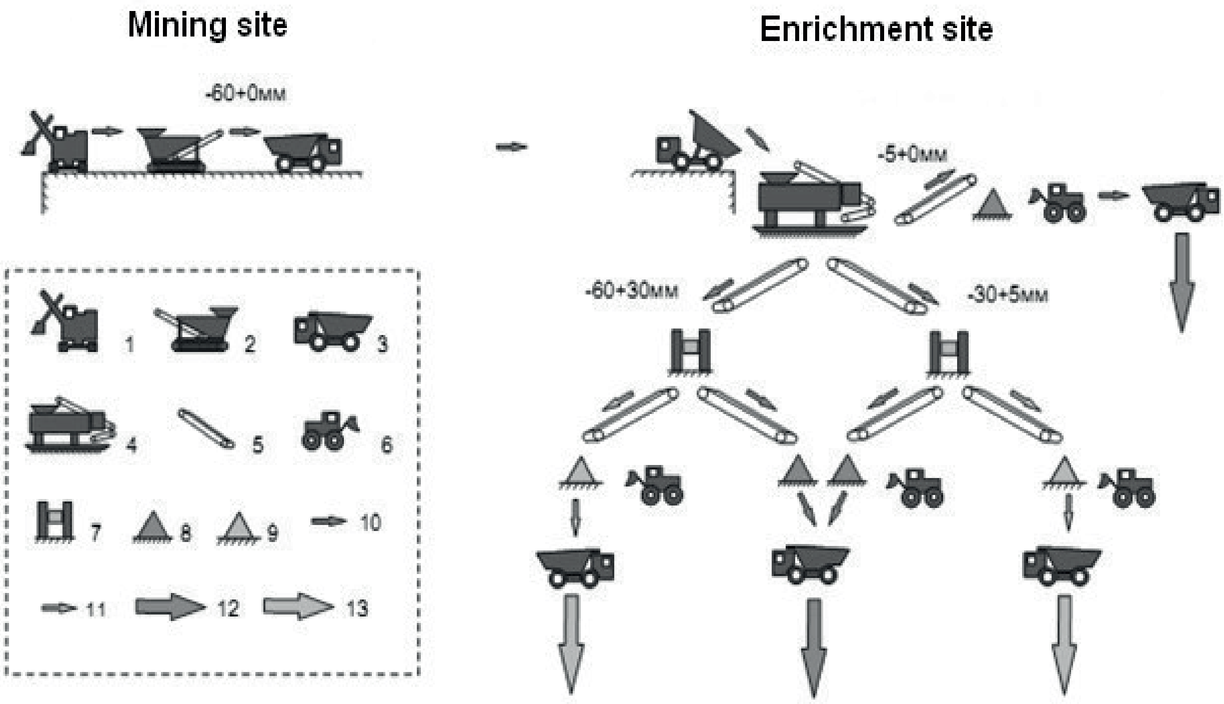


Fig. 2 Project machine flowsheet for processing of the rock mass from technogenic deposit “Waste dumps of the Allarechensk deposit”: 1 – excavator; 2 – self-propelled primary sizer-complex (jaw crusher); 3 – tip truck; 4 – secondary breaking facility (screening in closed cycle with a crusher); 5 – belt conveyor, 6 - automatic loader; 7 – magnetic separator; 8 – concentrate, fine industrial product, 9 – enrichment wastes, 10 – flows of the ore, concentrate, fine industrial product; 11 – waste flows, 12 – transportation to temporary storage site; 13 – transportation to dumping sites.

Rys. 2 Schemat technologiczny maszyny do przeróbki mas górotworu z składowisk technogennych “Składowiska odpadów Allarechensk”: 1 - koparki; 2 - samobieżne podstawowe kruszarki szczękowe; 3 - ciężarówka; 4 – wtórne rozdrabnianie (przesiewanie w obiegu zamkniętym z kruszarką); 5 - przenośnik taśmowy, 6 - automatyczne ładowarki; 7 - separator magnetyczny; 8 - koncentrat, końcowy produkt przemysłowy, 9 - odpady ze wzbogacania, 10 - przepływ rudy, koncentrat, końcowy produkt przemysłowy; 11 - strumienie odpadów, 12 - transport do tymczasowego składowiska; 13 - transport do składowisk.

rite was found in the form of several monomineral grains in nonmetallic fragments; one aggregation with magnetite and one aggregation with pyrrhotite and pentlandite were found. There were some difficulties with optical separation of small monomineral grains of pentlandite and pyrrhotite. Though, the performed scanning electron microscopy (SEM) with electronic differential analyzer (EDA) clearly determines absolute domination of pentlandite compared to pyrite among thin inclusions in nonmetallic minerals and small free grains.

The pilot studies and comparison of economic values of different ways of ore dressing suggest the following technological flowsheet for primary processing of the rock mass from the technogenic deposit “Waste dumps of the Allarechensk deposit” (Fig. 2). Two working sites should be equipped in the deposit area: mining and enrichment sites. The first one is located in the upper tier of waste rock in the vicinity of the mine face. The rocks there are broken and can be easily excavated during both summer and winter periods. The excavated ore is uploaded into a feeding bin of a self-propelled primary sizer-complex of the type Terex/Pegson Metrotrak 900×600 equipped by a jaw crusher. The crushed rock with dominating gain size of -60+0 mm goes from the discharge conveyor tracks into one of the two uploading alternating tip trucks. The complex proceeds with the excavator along the mine face and provides weighted-average capacity no less than 70 tons per hour, including operational down time, spotting and time-scheduled maintenance. There is no necessity in intermediate storages for the crushed rock in the extraction site.

The produced crushed rock is entirely delivered by tip trucks to the enrichment site where it comes through technological operations beginning with screening (classification to -60+30mm; -30+5mm and -5+0mm) in a closed cycle with secondary crushing, and ending with magnetic separation according to the defined grain-size classes.

The processing products are loaded into tip trucks using automatic loader and wastes are delivered to stock dump, concentrate and fine-graded product are delivered to temporary storage site.

The magnetic separation used in the flowsheet has several advantages compared to other methods: no need for circulating water, wide temperature range for application, energy efficiency, simplicity and reliability. Besides, only self-propelled and mobile facilities are used in the process. As a result the project doesn't need any major construction work which could decrease the project investment attractiveness.

Conclusion

There are far less sulfides in tailings compared to the received concentrate. The bulk of tailings is represented by fragments of nonmetallic minerals with small inclusions of sulfides and magnetite. There are chromite and individual grains of titanic iron and gold. The sulfides are represented chiefly by monomineral grains of pyrrhotite in nonmetallic fragments and by aggregations of pyrrhotite and pentlandite, aggregations of pentlandite and pyrrhotite with magnetite and pyrrhotite and pentlandite with chalcopyrite occur more rarely. Chalcopyrite also occurs and more often in the form of monomineral separations in nonmetallic fragments, more rarely in aggregations with pentlandite. Covelline sometimes develops along the queres of chalcopyrite. Nonmetallic minerals are represented in all samples by pyroxenes, amphiboles, chlorite, serpentine and olivine.

The analysis shows that upgrading of floatation circuit, finer grinding and selective flocculation of sulfides are necessary for more complete concentration of the minerals. At the same time the received concentrates can be subjected to further hydrometallurgical processing.

Taking into account low efficiency of the magnetic separation for processing of the classes -3 mm pilot studies were carried out to show that the ores of the technogenic deposit "Waste dumps of the Allarechensk deposit" are favorable for bioleaching due to their structure-texture properties. A sequence of sulfide bioleaching was determined: pyrrhotite → pentlandite → chalcopyrite, pyrite. The bioleaching of the pentlandite is favored by its crystalline structure, fissility and substitution by secondary minerals promoting destruction of the mineral.

Unfavorable factors are:

- high share of minerals in the rock structure having increased sorption capacity;
- the structures of the rock-forming minerals is dominated by bioleaching resistant minerals with aluminosilicate structure, i.e. amphiboles, chlorite and olivine;
- aggregations of pentlandite with pyrrhotite, the latter has lower electrode potential, thus the pyrrhotite is leached in the first place and act as an anode in the pentlandite-pyrrhotite galvanic pair, and promotes inhibition of bacteria in the beginning of the leaching process;
- small quantity of aggregations of pentlandite with chalcopyrite, where the latter has higher electrode potential and represents cathode in pentlandite-chalcopyrite galvanic pair and promotes destruction of pentlandite.

It is absolutely obvious that application of expensive agitation methods is unfavorable due to technical-economic indices. Heap biological leaching may be the most promising and efficient method, its net cost is 2-3 times less compared to tank method, while the process takes about one year.

Nowadays a Finnish company "Talvivaara Mining Company Plc." which develops poly-metallic ore deposit and operates there Talvivaara nickel producing mine has experience in using of heap bacteriological leaching of metals.

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Ekstrakcja metali nieżelaznych z depozytów odpadowych (na przykładzie terenów przemysłowych w regionie Murmańsk)

W ostatnich czasach w przetwórstwie rośnie udział trudnych rud siarczkowych metali nieżelaznych i innych niekonwencjonalnych materiałów surowcowych, w szczególności tych pochodzenia tektonicznego. Przetwarzanie materiałów surowcowych z depozytów tektonicznych w działających przedsiębiorstwach wydobywczych jest najbardziej efektywnym sposobem zwiększenia dostępnych źródeł minerału, polepszenia wydajności wykorzystania zasobów, zredukowania zasobo-chłonności produkcji oraz przywrócenia do otaczającego środowiska. Zbadano wyniki flotacji miedziowo-niklowych odpadów ze wzbogacania. Zaproponowano technologię suchej separacji magnetycznej zwałów depozytów miedziowo-niklowych ze złoża Allarechensk. Opracowano metodę geotechnologicznej obróbki Ni, Cu i Co znajdujących się poniżej normy, a zawierających materiał siarczkowy.

Słowa kluczowe: metale nieżelazne, składowiska technogenne, siarczany, flotacjai, separacja magnetyczna