10. Oliazadeh M., Vazirizadeh A. Removing impurities from iron ores: methods and industrial cases. *XXVIII IMPC, Quebec*. 2016. pp. 1–13.
11. Pelevin A. E. Production of hematite concentrate from hematite-magnetite ore. *GIAB*. 2020. No. 3(1). pp. 422–430.
12. Bhadani K., Asbjörnsson G., Hulthén T., Evertsson M. Application of multi-disciplinary optimization architectures in mineral processing simulations. *Minerals Engineering.* 2018. pp. 27–35. DOI:10.1016/j.mineng.2018.08.029
13. Papalambros P. Y., Wilde D. J. Principles of optimal design: modeling and computation. New York : Cambridge University Press, 2017. 376 p. EM

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T. N. MATVEEVA[1], *Head of Department, Doctor of Engineering Sciences*
V. V. GETMAN[1], *Senior Researcher, Candidate of Engineering Sciences, viktoriki.v@gmail.com*
A. Yu. KARKESHKINA[1], *Leading Engineer*

[1] *Research Institute of Comprehensive Exploitation of Mineral Resources – IPKON, Russian Academy of Science, Moscow, Russia.*

FLOTATION EXTRACTION OF TIN FROM TAILINGS OF SULFIDE-TIN ORE DRESSING USING THERMOMORPHIC POLYMER*

The possibility of using a thermomorphic polymer with a phosphine group as a collecting reagent for the selective concentration of tin during flotation enrichment of sulfide-tin tails was first investigated in the work. A detailed description of the experimental scheme of flotation concentration of sulfide-tin ore tailings and the reagent mode are given. The main mineral of tin is cassiterite, highly brittle and inclined to sludging, which leads to large losses of tin with tails; the granulometric composition of the initial tails of the Solnechnyi mining and processing plant has showed that 50% of the sample is represented by size grade of –0.04 mm. The output of a slimy product of –20 μm is 20% with a tin content of 0.46% (according to chemical analysis). This product is one of the sources of tin losses (up to 33.5%) in the flotation concentration process and requires additional technological solutions. It has been shown that the use of selective concentration of the +20 μm class using a thermomorphic polymer (TMPF) for flotation of tin ores allows not only to reduce the loss of tin with thin classes, but also significantly increase the flotation rate of cassiterite and technological parameters when beneficiating mature tailings of tin-sulfide ore processing. The main tin flotation using TMPF results in obtaining a rough tin concentrate I with a content of 0.55% Sn and extracting 49% of the operation. Rough tin concentrate II with a content of 0.38% Sn and 42% recovery was obtained by reextraction using TMPF. The total recovery of tin in the combined rough tin concentrate amounted to 90.71% of the operation. Subsequent purification of the obtained concentrate and gravity enrichment on the table concentrator will make it possible to obtain the concentrates richer in tin content required for their further processing. Further research will be aimed at developing scientifically based technological solutions to improve the quality of rough tin concentrate and extracting tin from the sludge product –0.02 microns using new reagent compositions.

Keywords: *sulfide-tin tails, cassiterite, sulfide minerals, enrichment tails, flotation, reagents-collectors, thermomorphic polymer, selective concentration*
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Introduction

At the current state of tin ore enrichment in Russia it is necessary to involve into processing mineral raw materials with a low content of valuable components, complex mineral composition and uneven inclusions of cassiterite. Now, the main source of tin in Russia is a man-caused raw material in the form of enrichment tailings of sulfide-tin ores with a tin content of 0.2–0.35%. Given the steady increase in tin prices on the world market, growth in inland consumption of metal and availability of raw materials, there is every reason to restore the domestic tin industry.

Specialists of the Uralmekhanobr Institute have developed a complex multi-stage scheme with the use of gravitational methods, table flotation, flotation and magnetic separation [1]. The high brittleness of cassiterite and its sludging ability leads to large tin losses with gravity tails. Cassiterite is extracted from gravity enrichment sludges by flotation, however, the tin losses with flotation tails are also high – about 15%. Thus, the extraction of cassiterite from sludge products and the search for an effective flotation method from tin-containing sludges is a topical scientific task, which includes the development of ways to enhance the contrast of minerals by modifying their surface with complexing reagents that provide selective flotation of non-ferrous, rare and precious metals into concentrates [2, 3].

To increase the flotation activity of cassiterite from fines, proposed is a method of preliminary selective concentration of sludge particles containing tin using a thermosensitive polymer with a phosphine group – TMPF. The peculiarity of the polymer is that when when heated to 32–33 °C, the structure of its molecule changes, which leads to a transition from a liquid aggregate state to solid one; at the same time, the hydrophilicity/hydrophobicity parameters of the molecule change, resulting in the formation of solid hydrophobic particles [4, 5]. Researchers of IPKON have developed a technique for flotation separation of fines containing noble and non-ferrous metals in the presence of thermomorphic polymers with functional groups for gold and platinum [4–7]. Thermomorphic polymers were obtained based on N-isopropylacrylamide and N-acryloxysuccinimide with the addition of a polymerization initiator [8–10].

Earlier studies on the cassiterite flocculation using a thermomorphic polymer have showed that TMPF is adsorbed

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on the mineral surface, exhibits flocculating properties with respect to the mineral sludge fractions and can act as a promising reagent for tin extraction from tin sulfide products [11]. It is known that phosphorus-containing reagents are used as selective collectors during flotation of tin-containing ores and form Sn–O–P or Sn–P bonds with tin [12–14].

The aim of the work is to concentrate fine particles of tin-containing products by flotation enrichment of sulfide-tin tailings using thermomorphic polymer TMPF as an additional collector in combination with fatty acids of tall oil.

Objects and methods of research

The study is focused on enrichment tailings of sulfide-tin ores of the Solechnyi mining and processing plant (MPP). The tails are a material of different sizes, most of which consists of aggregates – a cemented fine fraction. Earlier, a qualitative and quantitative analysis of the sample of the initial stale tailings was carried out [15], which showed that ore minerals are represented by chalcopyrite, pyrrhotite, pyrite, cassiterite, and rock minerals – quartz and silicates. A distinctive feature is the presence of sulfide oxidation products. Cassiterite is found mainly in aggregates with quartz and chalcopyrite.

The granulometric composition of the initial tails of the Solechnyi MMP showed that a size class of –0.071 mm represents 53.2% of the sample (**Table 1**).

Sulfide flotation has been carried out in a Mechanobr flotation machine with a chamber volume of 0.5 dm^3; tin flotation has been carried out in a 0.25 dm^3 chamber. The following reagents have been used: collectors – butyl potassium xanthate (BPX), dibutyldithiocarbamate (DBDTC), thermomorphic polymer (TMPF), tall oil fatty acids (TOFA); activator – copper sulfate ($CuSO_4$); waste rock depressor – liquid glass; foaming agents – MIBC and T-80. The magnetic fraction (magnetite) was separated on a tubular analyzer (Davis Tube), the current in the electromagnet coil block has been regulated using a rheostat (up to 1.5 A). Desludging according to –20 µm class was carried out by sedimentation analysis.

The morphology and elemental composition of the enrichment products were studied using an analytical scanning electron microscope (ASEM) LEO 1420VP equipped with an INCA 350 X-ray energy dispersive microanalyzer.

Description of the experimental process flowsheet of flotation of enrichment tailings of the Solechnyi MPP sulfide-tin ores

The source tailings of sulfide-tin ores weighing 300 g were crushed in a laboratory ball roller mill up to 85% of a –0.071 mm grade. After grinding, the product has been sent to sulfide flotation. The reagent mode of the main sulfide flotation chosen based on the previously obtained results of the collector reagent (DBDTC) flotation tests on the tailings of sulfide-tin ore enrichment [15]. Experimental data have shown that the use of DBDTC as an additional collector together with BPX in a ratio of 1:3 allows to increase the extraction of copper, lead, zinc and silver into a collective sulfide concentrate and reduce the loss of these metals with flotation tailings.

The sulfide flotation tailings have been sent to wet magnetic separation, as a result of which magnetic and non-magnetic products were obtained.

Before the main tin flotation, the non-magnetic product was activated with copper sulfate ($CuSO_4$ consumption was 200 g/t). Pretreatment of cassiterite with copper sulfate activates the mineral flotation and increases the amount of the collecting reagent fixed on it [11, 16]. Flotation studies conducted earlier on cassiterite using a thermomorphic polymer and preliminary $CuSO_4$ activation of the mineral has showed that the mineral yield increases to 87%, which is 26% higher than that without preliminary activation [11].

Table 1. Granulometric composition of the initial tails of the Solechnyi MPP

Size class, mm	Yield, %	Sn content, %	Sn distribution, %
+0.01	35.61	0.185	24.05
–0.1+0.071	11.19	0.195	7.95
–0.071+0.04	16.53	0.289	17.44
–0.04+0	36.67	0.378	50.57
Total	100.00	0.274	100.00

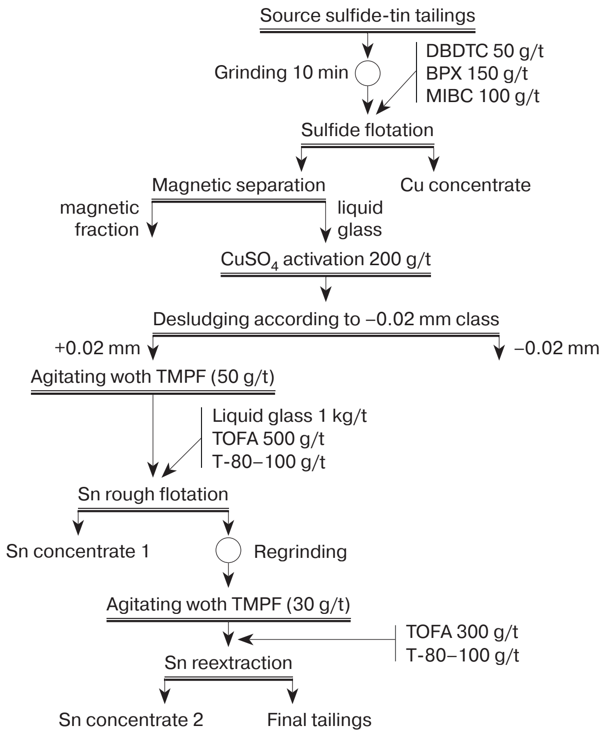

Fig. 1. Experimental scheme of flotation enrichment of the Solnechnyi MMP sulfide-tin tailings

After desludging and agitating with TMPF, the product was sent to tin flotation. The agitating operation involves pulp preheating in the presence of a thermomorphic polymer (consumption is 50 g/t) to 30 °C in the mixing mode. Tin flotation was carried out with the tall oil fatty acids in the presence of liquid glass – a depressor of rock minerals and T-80 foamer (**Fig. 1**). The main tin flotation tailings were sent to regrinding for additional liberation of the valuable component grains. The Sn additional recovery also has included pulp heating with TMPF and flotation with TOFA. As a result, the following products were obtained: rough Sn – concentrate 1, rough Sn concentrate 2 and final tailings.

Discussion of the research results

Sulfide flotation using reagents DBDTC:BPX (1:3) allowed to obtain a copper concentrate with a yield of 15%, Cu content of 9% and extraction of 93%. Tin content in the sulfide

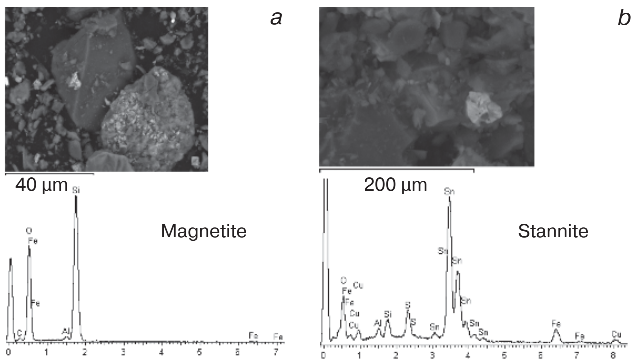

Fig. 2. Study of the magnetic fraction particles by ASEM LEV 1420VP

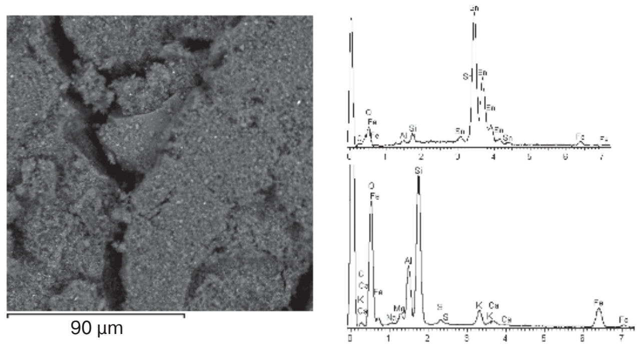

Fig. 3. Study of a –20 µm class by ASEM LEV 1420VP

concentrate is 0.38%; extraction is 16.3%. Magnetic fraction with a yield of ≈ 5.5% and Sn content of ≈ 0.29% was obtained during wet magnetic separation. The losses of tin with a magnetic fraction are 4.4%.

The research on magnetic fraction on an analytical scanning electron microscope showed that the magnetic material is a mixture of magnetite coated with films of silicates, Cu–$FeSnS_4$ stannite (**Fig. 2**), as well as their aggregates with quartz, silicates, chromites and other rock-forming minerals. Losses of tin with a magnetic fraction are inevitable, since tin minerals are in close mutual germination with iron oxides. In the future, when developing a scheme for flotation enrichment of sulfide-tin tailings of the Solechnyi MPP, magnetic separation should be excluded, since application of this operation is economically impractical in case of a low yield of the magnetic fraction.

In the process of desludging of the sulfide flotation tailings according to –20 µm class, a slime product with a yield of 20% and tin content of 0.46% was obtained. According to microscopic studies on an analytical scanning electron microscope, it was found that the slime material is a mixture of cassiterite, silicates, iron oxides and other rock minerals (**Fig. 3**). This product is one of the sources of tin losses (33.5%) during flotation enrichment and requires further additional technological solutions.

A +20 µm class was sent to tin flotation. The indices of flotation studies are given in **Table 2**.

The main tin flotation using TMPF has resulted in obtaining of a rough tin concentrate 1 with Sn content of 0.55% and extraction of 49% from the operation. Scavenger flotation using TMPF allowed to obtain rough tin concentrate 2 with Sn content of 0.38% and extraction of 42% from the operation. Thus, the total extraction of tin into the combined concentrate was 90.71% of the operation. Tin flotation tailings with a tin content of 0.1% are final ones, tin losses with them are about 10%.

The research results presented in this paper proved the efficiency of using a thermomorphic polymer with a phosphine group as a collecting reagent for selective tin concentration during flotation enrichment of sulfide-tin tailings and were taken into account when developing a functional gravity-flotation technological scheme for tin extracting from mature tailings of sulfide-tin ore enrichment [17]. The technological scheme included gravity enrichment of sulfide flotation tailings to obtain a gravity concentrate with a tin content of 0.92% and subsequent flotation enrichment. The flotation scheme included the main tin flotation and cleaner operations using

Table 2. Results of flotation research on enrichment of a +20 µm class

Product	Output from operation, %	Sn content, %	Sn recovery from operation, %
Rough Sn concentrate 1	30.69	0.55	48.97
Rough Sn concentrate 2	37.56	0.38	41.75
Combined concentrate	68.25	0.45	90.71
Tailings	31.75	0.10	9.29
Source product	100	0.34	100.00

TMPF reagent, as a result of which obtained was a concentrate with Sn content of 5.40% and extraction of 17.47% of the feedstock (72.55% from the operation), which meets the requirements for further metallurgical processing.

Conclusions

The effectiveness of using thermomorphic polymer TMPF as an additional collector of cassiterite during flotation extraction of tin from mature tailings of sulfide-tin ore enrichment is shown.

It was found that the use of a composition of TMPF and TOFA reagents makes it possible to obtain total rough concentrate with a tin content of 0.45% and allocate more than 30% of the material entering the tin flotation into a dump with a tin content of less than 0.1%.

The use of TMPF during cleaner operations in the gravity-flotation scheme of enrichment of mature tailings of sulfide-tin ores will allow to obtain a tin concentrate with Sn content of 5.40% that meets the requirements of KOSH-3 (slime tin concentrate, flotation or gravity, with tin content not less than 5%) grade, suitable for further metallurgical processing.

References

1. Gazaleeva G. I, Nazarenko L. N, Shigaeva V. N Development of a technological scheme for the enrichment of a rough concentrate containing fine slimes of tin and copper minerals. *Obogashchenie Rud*. 2018. No. 6(378). pp. 20–26. DOI: 10.17580/or.2018.06.04
2. Leistner T., Embrechts M., Leibner T. et al. A study of the reprocessing of fine and ultrafine cassiterite from gravity tailing residues by using various flotation techniques. *Minerals Engineering*. 2016. Vol. 96–97. pp. 94–98.

3. López F. A., García-Díaz I., Rodríguez Largo O. et al. Recovery and purification of tin from tailings from the Penouta Sn–Ta–Nb Deposit. *Minerals*. 2018. Vol. 8, No 1.
4. Chanturiya V. A., Nedosekina T. V., Ivanova T. A., Getman V. V., Nedosekin D. A. Method for extraction of non-ferrous and noble metals. Patent RF, No. 2390382 C2. Applied: 15.04.2008. Published: 27.05.10. Bulletin No. 15.
5. Chanturiya V. A., Matveeva T. N., Ivanova T. A., Getman V. V. Mechanism of interaction of cloud point polymers with platinum and gold in flotation of finely disseminated precious metal ores. *Mineral Processing and Extractive Metallurgy Review*. 2016. Vol. 37, No. 3. pp. 187–195.
6. Matveeva T. N., Chanturia V. A., Gapchich A. O. Finely dispersed micro- and nano-gold recovery using thermomorphic polymer with diphenylphosphine. *Journal of Mining Science*. 2017. Vol. 58(3). pp. 131–140.
7. Getman V. V. Investigation of the interaction of thermomorphic polymers with non-ferrous and noble metal ions. *XV Russian annual conference of young researchers and graduate students with international participation : Physical chemistry and technology of inorganic materials.* Moscow, 2018. pp. 425–427.
8. Bergbreiter D. E., Case B. L., Liu Y.-S., John W. Poly(Nisopropylacrylamide) Soluble Polymer Supports in Catalysis and Synthesis. *Macromolecules*. 1998. Vol. 31, No. 18. pp. 6053–6062.
9. Bergbreiter D. E. Using soluble polymers to recover catalysts and ligands. *Chemical Reviews*. 2002. Vol. 102, No. 10. pp. 3345–3384.
10. Francoise M. Winnik Fluorescence Studies of Aqueous Solutions of Poly(N-isorrorulacrulamide) below and above Their LCST. *Macromolecules*. 1990. Vol. 23. pp. 233–242.
11. Chanturia V. A., Matveeva T. N., Getman V. V. The study of flocculation of cassiterite during flotation of tin-containing ores based on the use of thermomorphic polymer. *Tsvetnye Metally*. 2018. pp. 13–22. DOI: 10.17580/tsm.2018.08.03
12. Kurkov A. V., Pastukhova I. V. The flotation method of ores of rare metals and tin. Patent RF, No. 2381073. Applied: 11.08.2008. Published. 10.02.2010. Bulletin No. 4.
13. Guichen G., Yuexin H., Jie L. et al. In Situ Investigation of the Adsorption of Styrene Phosphonic Acid on Cassiterite (110) Surface by Molecular Modeling. *Minerals.* 2017. Vol. 7(10). DOI:10.3390/min7100181
14. Li F. X., Zhong H., Zhao G., Wang S., Liu G. Y. Flotation performances and adsorption mechanism of α-hydroxyoctylphosphinic acid to cassiterite. *Applied Surface Science*. 2015. Vol. 353. pp. 856–864.
15. Matveeva T. N., Chanturia V. A., Gromova N .K., Lantsova L. B. Effect of tannin on compound collector adsorption and stibnite and arsenopyrite flotation from complex ore. *Journal of Mining Science*. 2018. Vol. 53(6). pp. 1108–1115.
16. Gazaleeva G. I., Nazarenko L. N., Shigaeva V. N., Vlasov I. A. Features of the processing of tin-containing tailings of the solar mining and processing plant. *Journal of Mining Science*. 2018. Vol. 54(3). pp. 150–156. EM

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T. I. YUSHINA[1], *Head of Department, Associate Professor, Candidate of Engineering Science, yuti62@mail.ru*
NGUEN THU THUY[1], *Probationer*
A. M. DUMOV[1], *Associate Professor, Candidate of Engineering*
NGUEN VAN TRONG[1], *Probationer*

[1] *National University of Science and Technology – NUST MISIS, Moscow, Russia*

STUDY OF THE POSSIBILITY OF SELECTIVE FLOTATION OF QUARTZ-FELDSPAR ORE OF QUANG NAM DEPOSIT (VIETNAM)

The article presents the results of the study of the possibility of selective flotation of the main minerals of quartz-feldspar ore of Quang Nam deposit (Vietnam) - mica and feldspars in the presence of cationic collector ArmacT, in order to remove iron-bearing minerals and isolation of mica and feldspars into high quality concentrates. The adsorption regularities of the ArmacT cationic collector on mineral surfaces were studied. Results of zeta potential measurements showed that at pH = 2 the functional group of ArmacT collector has a significantly higher affinity for mica compared with both feldspar and quartz. Analysis of Fourier transform infrared spectra showed that the highest intensity of ArmacT adsorption on mica is observed at pH = 2, while the highest sorption intensity for feldspar and quartz was observed at pH = 5. The possibility of reducing the iron content during flotation obtaining feldspar concentrate from quartz-feldspar ore samples of Quang Nam deposit was investigated. Experiments performed under laboratory conditions on the DENVER flotation machine allowed us to determine the following optimal conditions for the selective flotation of mica and iron-bearing minerals, which allowed us to obtain high-quality mica and feldspar concentrates:

– *pH regulator concentration (H_2SO_4) – 2000 g/t;*
– *the collector concentration (sodium oleate and ArmacT) was 300 g/t and 200 g/t, respectively;*
– *flotation time 3 min.*

Keywords: *quartz-feldspar ore, flotation, mica, iron-bearing minerals, cationic collector, infrared spectroscopy, reagent regime, feldspar concentrate, micaceous concentrate*
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Introduction

Most feldspars are solid solutions of the ternary system of isomorphic series $K[AlS_{13}O_8]$ – $Na[AlS_{13}O_8]$ – $Ca[Al_2S_{12}O_8]$, he end members of which are orthoclase (Or), albite (Ab) and anorthite (An) respectively.

Feldspars are aluminum silicate with cations of Na, K, Fe, Ca, Ba, etc. [1–3]. In nature, feldspars such as albite ($NaAlS_{13}O_8$) and orthoclase-microcline ($KAlS_{13}O_8$), usually contain impurities of clay, mica group minerals (especially biotite and muscovite), iron oxides, tourmaline, rutile and sphene.

In the world practice of enrichment of feldspar raw materials the first stage is the removal of material with a grain size less than 25 microns, i.e. sludge