

## ORIGINAL PAPERS

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**Collector for Copper-Arsenic Ore Flotation****V. I. Ryaboy<sup>1</sup>, E. D. Shepeta<sup>2</sup>**<sup>1</sup>LLC "Mechanobr-OR", St. Petersburg, Russia<sup>2</sup>Institution of Science of the Khabarovsk Federal Research Center of the Far Eastern Branch of the Russian Academy of Sciences (KhFRTs FEB RAS), Khabarovsk, Russia

**Abstract:** Copper and scheelite concentrates are produced from scheelite-sulfide ores of the Vostok-2 deposit at the Primorsky processing plant. Chalcopyrite, gold, silver, and harmful impurities (arsenopyrite, pyrrhotite) are extracted into the copper concentrate. As a collector, dialkyldithiophosphate-type IMA-I413p reagent is used. Bulk sulfide concentrate is produced using activated carbon and trisodium phosphate; copper cleaner flotation is carried out in the medium of ferrous sulfate. The commercial copper concentrate contains 16 % copper, 33 g/t gold, and 280 g/t silver. The recovery of the metals is 67.6, 44.7, and 50.1 %, respectively. The weight fraction of arsenic in the ore fluctuates in the range of 0.04–0.25%, and that in the concentrate, 0.7–2.3 %. The enterprise looks for ways to increase recovery of the valuable metals and decrease content of arsenic in the copper concentrate to below 1% at the expense of increasing contrast in the separation of chalcopyrite from iron sulfides/arsenopyrite/pyrrhotite. For solving this problem, we performed a study of flotation properties of sulfide collectors based on dialkyldithiophosphates: BTF-15221, BTF -271, non-ionic collector Reaflot-277, and combinations of Reaflot-277 and IMA-I413p. Applying BTF-15221 collector allowed, as compared to the standard IMA-I413p reagent, to increase recovery of copper, gold, and silver and reduce arsenic content in the copper concentrate. The higher selectivity of BTF-15221 as compared to IMA-I413p was confirmed by the fact that the bulk of the increase in copper recovery and decrease in the weight fraction of arsenic in the copper concentrate was achieved in the selective cycle. Besides, during the study, surface activity and hydrophobizing ability of the water-soluble collectors were assessed. Using the example of BTF-15221, it was shown that improvement of the reagent collecting properties can be achieved not only due to increasing the surface activity of the reagent, but also at its decrease – in case of sufficient hydrophobizing ability of the reagent, close to that of the standard reagent. By adjusting these parameters through the use of low-molecular weight homologues of the main components, it is feasible to increase or decrease the selectivity and collecting ability of the reagent. Collector BTF-15221 is of practical interest for further testing in flotation of copper-arsenic and other ore types.

**Keywords:** copper-arsenic ores, dialkyldithiophosphate collector, hydrophobizing ability of water-soluble collectors, surface activity, flotation

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**Аннотация:** Из скарновой шеелит-сульфидной руды месторождения Восток-2 на Приморской обогатительной фабрике выделяют медный и шеелитовый концентраты. В медный концентрат извлекаются халькопирит, золото, серебро и вредные примеси арсенопирит, пирротин. В качестве собирателя используют реагент диалкилдитиофосфатного типа ИМА-И413п. Селекцию коллективного сульфидного концентрата осуществляют с применением активированного угля и тринатрийфосфата, медные перечистки проводят в среде железного купороса. Товарный медный концентрат содержит 16 % меди, 33 г/т золота и 280 г/т серебра. Извлечение металлов составляет соответственно 67,6, 44,7 и 50,1 %. Массовая доля мышьяка в руде колеблется в интервале 0,04–0,25 %, в концентрате 0,7–2,3 %. Для предприятия является актуальным повышение извлечения ценных металлов и снижение содержания мышьяка в медном концентрате менее 1 % за счет усиления контрастности разделения халькопирита и сульфидов железа арсенопирита, пирротина.



В целях решения указанных задач были изучены флотационные свойства сульфидных собирателей на основе диалкилдитиофосфатов БТФ-15221, БТФ-271, неионогенного собирателя Реафлот-277 и комбинации Реафлот-277 и ИМА-И413п. Применение собирателя БТФ-15221 по сравнению со стандартным реагентом ИМА-И413п позволяет повысить извлечение меди, золота и серебра и снизить содержание мышьяка в медном концентрате. Более высокую селективность действия БТФ-15221 по сравнению с ИМА-И413п подтверждает факт, что основной прирост извлечения меди и снижение массовой доли мышьяка в медном концентрате получен в селективном цикле. В работе выполнена оценка поверхностной активности и гидрофобизирующей способности водорастворимых собирателей. На примере БТФ-15221 показано, что улучшение собирательных свойств реагентов может быть достигнуто не только при повышении поверхностной активности реагента, но и ее снижении при достаточно заметной гидрофобизирующей способности реагента, близкой к стандартному реагенту. Регулированием этих параметров за счет использования низко- и более высокомолекулярных гомологов основных компонентов можно повысить или понизить селективность и собирательную способность реагента. Собиратель БТФ-15221 представляет практический интерес для дальнейших испытаний на медно-мышьяковистых и других типах руд.

**Ключевые слова:** медно-мышьяковистые руды, гидрофобизирующая способность водо-растворимых собирателей, поверхностная активность, флотация

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## 1. Introduction

Skarn scheelite-sulfide ore of the Vostok-2 deposit belongs to complex ores. Along with the main scheelite concentrate, the Primorsky Processing Plant (PPP) produces copper concentrate, in which copper and precious metals (gold and silver) are concentrated. At present, at PPP, the task is to increase the recovery of valuable minerals through increasing the degree of separation of sulfide minerals in the bulk flotation cycle and depress arsenopyrite in the selection flotation cycle. This enables increasing output of standard copper concentrate with weight fraction of Cu of 16 %, and that of As of  $\leq 1.0$  %.

This can be achieved, first of all, through both selecting known and creating new more effective reagents on the basis of the existing theory and practice of reagents application, presented in [1–5, 6–13] and other publications.

Here are the main indicators of PPP performance for 2020: weight fraction in ore: Cu – 0.21 %, Au – 0.59 ppm, Ag – 3.7 g/t; weight fraction in copper concentrate – 16.3 %, 33.0 g/t, 280 g/t, recovery – 67.6, 44.7, 50.1 %, respectively. Average weight fraction of arsenic in the current ores is 0.10%, its fluctuation range is

0.04–0.25 %. In the copper concentrate, the range is 0.70–2.32 %.

For testing collecting properties of a new group of reagents, scheelite-chalcopyrite-pyrrhotite ore with the following weight fractions of the main components was selected:  $\text{WO}_3$  – 0.65 %, Cu – 0.22 %, Au – 1.6 g/t, Ag – 1.16 g/t, As – 0.007 %, S – 4.9 %.

Earlier, the authors, when selecting collectors from the class of water-soluble compounds based on dialkyldithiophosphates for flotation of copper-arsenic ores, used the concept of the effect of surface activity and hydrophobizing ability of a reagent on flotation properties [14, 17], which was later used to create a collector for flotation of silver-containing ores [17]. The presented study develops this line with the use of new water-soluble collectors based on dialkyldithiophosphates. High performance in copper recovery (at practically the same arsenic content in concentrate) was achieved through using a composition of water-soluble reagents based on dialkyldiophosphates and reagents with thioamide groups [15].

This led to the choice of the following group of collectors for the new research: BTF-15221, which, according to data of Mekhanobr-OR LLC

and Kvadrat Plus, showed positive results in flotation of a number of copper and gold ores; BTF-271, which is an analogue of the IMA-I413 used, and Reaflot-277 as a nonionic collector, which demonstrated positive results in previous tests.

## 2. Research Materials and Methods

*Method for determining hydrophobizing ability of water-soluble collectors.* Determination of hydrophobizing ability (h.a.) of water-soluble collectors was performed according to a refined method in comparison with that previously presented in [17].

Initial solution concentrations: 2% aqueous solution of dialkyldithiophosphate collector, pH 10.5, which was measured by a pH meter, 0.2 N zinc sulfate solution, 0.1 N sodium hydroxide solution, 0.1 N Trilon B solution and ammonia buffer solution.

Assay method: 10 ml of the dialkyldithiophosphate solution were added with 10 ml of the zinc sulfate solution to produce zinc dialkyldithiophosphate, which precipitates as a sediment or a paste-like product; then 3 g of sodium chloride (100 % activity) were added, and stirred with a glass rod until the salt dissolved. The suspension was allowed to settle for 1–2 h. After that, it was filtered through a fluted paper filter (Blue ribbon). Then ½ part of the solution was taken, added with 5 ml of the ammonia buffer solution, and titrated

with the Trilon solution in the presence of the eriochrome black indicator until the pink color turned blue. Calculation of h.a. was carried out according to the formula given in [17].

*Laboratory research for the ore and the plant products.* The assessment of flotation properties of the collectors was carried out using the samples of the sulfide flotation plant feed and using ore (tailings of core samples of metallurgical mapping program) prepared under laboratory conditions (crushing to 2 mm, grinding to  $P_{80}$  (80%) of  $-80+0 \mu\text{m}$ . At the same time, the amount (share) of sludge grain size fractions in the ore was approximately equal to that in the sulfide flotation plant feed. Grain-size distribution of the flotation feed (the ore ground in the laboratory) ore is presented in Table 1.

It should be noted that, in contrast to the laboratory conditions, in the processing plant's feed (under commercial conditions), at the same sludge portion, the portion of coarse categories of  $+160 \mu\text{m}$  increases significantly: from 1.76 % (lab conditions) to 18.9% (commercial conditions), and content of the components of interest also increases: Cu – up to 4.4 %, As – up to 12.1 %, S – up to 8.0 % due to redistribution from medium size categories of  $-80+15 \mu\text{m}$ . This should be taken into account when predicting the processing results under commercial conditions.

Table 1

**Distribution of the main elements in the sulfide flotation feed by size categories  
(for the ore ground in the laboratory)**

Size category, μm	Yield, %	Weight fraction, %			Recovery, %		
		Cu	As	S	Cu	Cu	As
Sulfide flotation feed (ore ground in the laboratory)							
+250	0.76	0.15	0.009	5.56	0.53	1.03	0.86
−250+160	1.00	0.10	0.008	2.93	0.47	1.21	0.60
Total: +160	1.76	0.12	0.008	4.07	1.00	2.24	1.45
−160+80	18.21	0.16	0.008	4.17	13.67	22.00	15.42
−80+15	58.54	0.23	0.006	5.89	63.15	53.04	70.03
−15+0	21.49	0.22	0.060	3.00	22.18	22.72	13.09
Total: -80+0	80.03	0.23	0.007	5.11	85.33	75.76	83.12
Ore	100.00	0.21	0.007	4.92	100	100	100





In the +80  $\mu\text{m}$  size categories, the presence of intergrowths of chalcopyrite with quartz and pyrrhotite was observed, while with decreasing grain size, the proportion of the intergrowths decreased, the intergrowths become smaller, they were closed and complex, including association of several minerals: quartz-pyrrhotite-chalcopyrite. In the -80  $\mu\text{m}$  size categories, the intergrowths are absent.

The testing process for these collectors included: 1) bulk flotation cycle: rougher sulfide flotation and scavenging sulfide flotation ( $t = 10$  min), cleaner flotation of the bulk sulfide concentrate ( $t = 5$  min); 2) copper cycle: rougher copper flotation and scavenging copper flotation ( $t = 10$  min), and two copper concentrate cleaner flotation stages ( $t = 10$  min). The volume of cells of the flotation machines was 1.0-0.5-(0.3; 0.2; 0.1) L. The cell volume in the cleaner flotation depended on the yield of the bulk sulfide concentrate. In the tests, weight of samples in the open cycle ranged from 0.5 to 1.0 kg; in the closed cycle, 6 one-kilogram samples was used, and the calculation was performed based on the results for the latest three samples.

The tests were carried out using tap water (pH 6.8) and process water (pH 8.6, suspension of 5.3–7.7 g/l). Ionic composition of the process water, mg/l: sulfate ions – 800, copper cations – 0.06, zinc – 0.022, molybdenum – 0.003, arsenic – 0.02, tungsten – 0.004, silicon – 3.0, iron – 30.

The reagent test mode: liquid glass (100+50) g/t (rougher flotation and cleaner flotation – for reducing the losses of scheelite with sulfides; agitation of the pulp with the reagent ( $t_{ag} = 2$  min), variable sulfide collector (15(45)+5(15)) g/t in the rougher and scavenging flotation ( $t_{ag} = 0.5$  min), pine oil to the rougher flotation of 10 g/t ( $t_{ag} = 1$  min). Separation (selective flotation) of the bulk concentrates: activated carbon (C) – 50–100 g/t ( $t_{ag} = 10$  min), trisodium

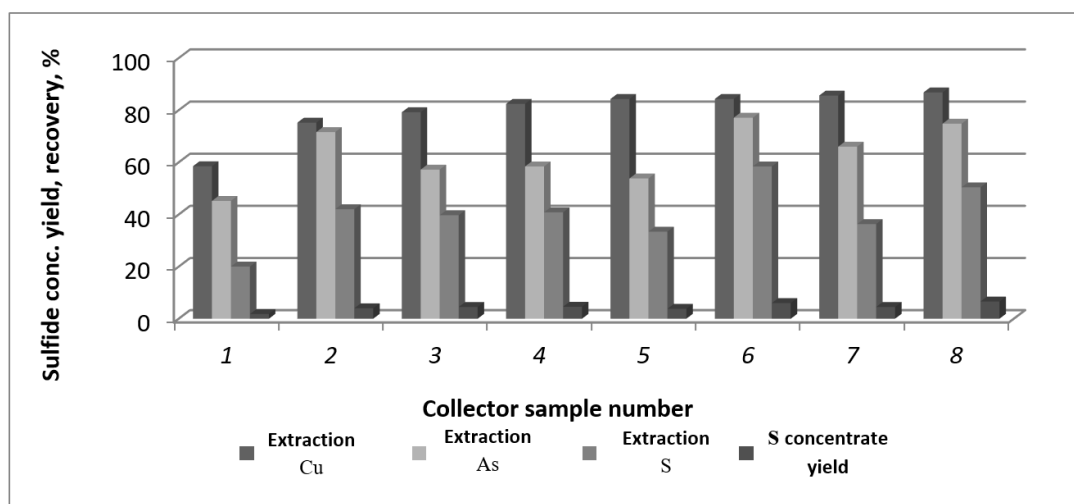
phosphate (TSP) – (50+25) g/t (rougher flotation and 1st cleaner flotation,  $t_{ag} = 5$  min). For the plant products, to enhance arsenic depression, copper cleaner flotations were carried out in ferrous sulfate medium, at the pulp pH 7.3–6.5. The initial pH of the pulp of the rougher copper flotation and cleaner copper flotation stages was about 8.0–8.8.

It should be noted that according to the PPP process balance data, at the standard beneficiation process based on the mixture of reagents IMA-I413p+Kkh<sub>but</sub>, 60 % of the chalcopyrite losses belong to the bulk flotation cycle tailings, (weight fraction of Cu of 0.036 %) and 40 % to the copper selective flotation tailings (weight fraction of Cu of 0.75 %). In terms of grain size, 10 % of the total copper losses belong to losses with the coarse size category of +160  $\mu\text{m}$ , 40 % to the category of -160+15  $\mu\text{m}$ , and 50 % to the sludge size category of -15  $\mu\text{m}$ . Arsenic is almost completely depressed into the sludge, and the rest (+15  $\mu\text{m}$ ) passes into the copper concentrate.

The use of the combination of IMA-I413p and Kkh<sub>but</sub> leads to increasing the extraction of chalcopyrite by 1–2 % relative to the use of dialkyldithiophosphate, but at the same time the flotation activity of arsenopyrite increases. In cleaner flotation under commercial conditions, reduced pulp levels in a flotation machine are used, which promote reducing arsenic content in the concentrate, but significantly increases its amount in the selective cycle feed. All this necessitates the search for new collectors, combining high collection activity for copper and selectivity for arsenopyrite.

### 3. Findings of flotation tests

At the first testing stage, the tests with PPP feed were carried out with process water (with suspension of 5.3 g/l) up to obtaining sulfide concentrates, using all samples scheduled for testing. Weight fraction of the main components in the flotation feed, %: Cu – 0.24, As – 0.08, S – 3.14. Fig. 1 shows the best results from the test series for determining the optimal consumption for each collector.



**Fig. 1. Diagram of the yield of the bulk concentrate and the extraction of copper, arsenic, and sulfur into the concentrate for the tested samples of sulfide collectors, g/t:**

1 – sample 275 (200+80); 2 – sample 276 (200+80); 3 – IMA-I413p (45+5); 4 – sample 277 + IMA-I413p (40+10, ratio of 1:1); 5 – sample 277 (45+5); 6 – Kh<sub>but</sub> (60+20); 7 – BTF-15221 (35+5); 8 – BTF-271 (45+5)

With sulfide concentrate yield of 3.8–4.6 % for sample 277 and the combination of reagents IMA-I413p+sample 277 (1:1), 3–5 % increase in copper recovery was obtained as compared to the standard collector, with selectivity in relation to arsenopyrite to be close to standard flotation process mode. When using BTF 15221 and 271, at the yield of 4.5–6.6 %, the maximum increase in copper recovery was achieved (to 6–8 %) with increasing the arsenic recovery by 9–18 % as compared to IMA-I413p; however, the process selectivity was higher as compared to using the combination of the

standard reagent IMA-I413p and Kh<sub>but</sub>. The recovery of pyrrhotite, the main sulfide mineral that determines sulfur recovery, for all the new collector samples ranged 20 to 40 %, for Kh<sub>but</sub> was 58.4 %, and for IMA-I413p, 39.7 %.

Findings of the tests for assessing the flotation activity of the reagents allowed selecting, for the final testing stage, the collectors BTF 15221, 271, and the combination of IMA-I413p with the BTF-277 sample in the ratio of 1:1. The results of the final closed cycle tests to obtain copper concentrate are presented in Table 2.

**Table 2**

**Performance of the tested collectors to obtain copper concentrate**

Test #	Collector, g/t	Copper concentrate								
		Yield, %	Weight fraction, %, g/t				Recovery, %			
			Cu	As	Au	Ag	Cu	As	Au	Ag
Chalcopyrite-pyrrhotite laboratory-ground ore, tap water										
Weight percent in ore: Cu – 0.22 %, As – 0.007 % (Cu:As = 31.4:1), Au – 1.6 g/t, Ag – 1.16 g/t										
1	IMA-i413p 30	0.84	16.00	0.10	54.20	56.00	61.09	12.00	28.46	40.55
2	BTF 15221 30	0.90	18.53	0.07	57.80	67.00	75.80	9.00	32.51	51.98
3	BTF 15221 40	0.95	17.67	0.09	71.70	64.50	76.30	12.21	42.57	52.82
4	BTF 271 40	0.88	18.18	0.10	64.51	61.43	72.72	12.57	35.48	46.60
5	IMA+ 277 (1:1) 30	0.97	15.36	0.13	55.00	61.70	67.72	18.01	33.34	51.59
6	Reaflot277 45	0.90	15.00	0.10	55.13	57.00	61.36	12.86	31.01	44.22
Chalcopyrite-arsenopyrite-pyrrhotite ore, PPP classifier overflow, recycled water										
Weight percent in ore: Cu – 0.16 %, As – 0.14 % (Cu:As = 1.1:1), Au – 0.69 g/t, Ag – 3.6 g/t										
7	IMA-i413p 30	0.83	14.48	4.57	38.10	231.8	75.12	27.09	45.83	53.44
8*		0.65	18.27	0.94	43.57	278.5	74.22	4.36	41.04	50.28
9	BTF 15221 30	0.76	16.17	5.75	41.84	282.0	76.81	31.21	46.08	59.53
10*		0.64	18.85	0.86	45.42	297.3	75.40	3.93	42.13	52.85
*The tests on Cu selective flotation were carried out with cleaner flotation s of the copper concentrate in ferrous sulfate medium: FeSO <sub>4</sub> 1st cleaner flotation to pH 7.2 (6.9) – 2nd cleaner flotation to pH 6.8 (6.7)										

\*The tests on Cu selective flotation were carried out with cleaner flotation s of the copper concentrate in ferrous sulfate medium: FeSO<sub>4</sub> 1st cleaner flotation to pH 7.2 (6.9) – 2nd cleaner flotation to pH 6.8 (6.7)

Table 3

Losses of valuable metals in final tailings in the tests of the laboratory ore sample

Collector; consumption, g/t (Test #)	Product	Weight fraction, %, g/t			Recovery, %			The proportions of total losses, %.		
		Cu	Au	Ag	Cu	Au	Ag	Cu	Au	Ag
IMA-I413p; 30 (No. 1)	Sulfide flotation tailings	0.02(8)	1.0 (0)	0.4 (5)	11.0 (5)	55.45	34.53	27.7	77.5	58.1
	Cu flotation tailings	0.63	2.5 (0)	2.8 (0)	28.8 (6)	16.09	24.92	72.3	22.5	41.9
<u>BTF 15221;</u> <u>30 (No. 2)</u>	Sulfide flotation tailings	0.02(9)	0.8 (4)	0.4 (0)	12.3 (4)	47.92	30.93	49.0	71.0	64.4
	Cu flotation tailings	0.29	3.5 (7)	2.3 (0)	11.8 (6)	19.57	17.09	51.0	29.0	35.5
<u>BTF 15221;</u> <u>40 (No. 3)</u>	Sulfide flotation tailings	0.02 (7)	0.7 (3)	0.3 (4)	10.7 (1)	40.38	25.60	45.2	70.3	54.3
	Cu flotation tailings	0.24	2.2 (6)	2.1 (0)	12.9 (9)	17.05	21.58	54.8	29.7	45.7

Table 3 shows the losses of copper, gold, and silver in the tests 1–3 in the bulk flotation cycle (sulfide flotation tailings) and in the selective flotation cycle (Cu flotation tailings).

The low recovery of gold and silver was due to the ore material composition. Precious metals occurred in a finely dispersed native state (basic size of 5–75  $\mu\text{m}$ ), isomorphically substitute for Fe, Cu, As in sulfides. The non-extractable forms included: gold in quartz in the form of thin leather coats on quartz surface, inside quartz particles, at Au particle size of 0.01–0.2(0.3) mm; silver in heavy metal carbonates, quartz and silicates; and in arsenopyrite in the form of drop-shaped particles. Therefore, the main losses of precious metals were connected with the bulk flotation cycle, in which the bulk of sulfide tailings was separated.

#### 4. Review of the results

All the tested new collector samples provided an increase in the flotation recovery of copper, gold, and silver as compared to the standard IMA-I413p collector sample, with which the total recovery of valuable minerals amounts to 129.1 %, at the consumption of 30 g/t. In the row of increasing the total recovery, the reagents were arranged as follows, %:

$$\begin{aligned}
 & \text{Reaflot 277 (45 g/t – 136.6)} < \\
 & < \text{BTF-271 (40 g/t – 154.8)} < \\
 & < \text{BTF-15221 (30 g/t – 160.3)} < \\
 & < \text{BTF-15221 (40 g/t – 171.7)}.
 \end{aligned}$$

The highest performance on recovery of copper and accompanying precious metals at the lowest weight share of arsenic in the concentrate was achieved with BTF-15221 reagent at the consumption of (25+5) g/t. Increasing the collector consumption to (35+5) g/t allowed increasing the metals recovery, but with increasing the recovery of arsenopyrite into the concentrate. The use of the combination of Reaflot-277 nonionic collector and IMA-I413p (the total recovery of 153 %) increased copper recovery compared to IMA-I413p, but to a lower extent as compared to BTF-15221 and with lower selectivity of the flotation process.

It should be noted that, for the BTF-15221 sample, a large proportion of the losses decline belonged to the selective flotation cycle that was confirmed by the data presented in Table 3. This evidences higher selectivity of the reagent as compared to the standard IMA-I413p collector.

The study of the effect of BTF-15221 in comparison with IMA-I413p on the plant feed of sulfide flotation in the course of the scheelite-chalcopryrite-arsenopyrite-pyrrhotite ore processing showed that the process selectivity sharply decreases with BTF-15221 (see Table 2, tests 7 and 9). Applying the IMA-I413p collector, in contrast to BTF-15221, did not allow obtaining the standard grade copper concentrate. To obtain, from this ore, the standard grade copper concentrate with the IMA-I413p collector,





adding iron sulfate to cleaner copper flotations was required (see Table 2, tests 8 and 10). Under these conditions, the increase in the total recovery of valuable minerals was 4.8 % only (170.4% with BTF 15221 and 165.5 % with IMA-I413p) versus 30% for the scheelite-chalcopyrite-pyrrhotite ore.

The tests indicated that the problem of finding an efficient selective collector for arsenous ores is still relevant.

The selective effect of dialkyldithiophosphate collectors as compared to xanthates is due to the formation of unstable complexes with iron that improves the chalcopyrite/iron-containing minerals (arsenopyrite and pyrrhotite) separation. In contrast to xanthates, dialkyldithiophosphates exhibit noticeable surface activity at the liquid-gas interface (l-g). The influence of surface-active properties of collectors, including dialkyldithiophosphates, was studied by many researchers [18–25]. It was found that high surface activity of the reagent promotes formation of a large number of small air bubbles in the pulp, and the efficiency of fine particles recovery increases. This was confirmed by flotation processing practice. Due to the reagent transition from the solid-liquid interface to the liquid-gas interface, the water layer between the particles and the air bubbles decreased, the mineral particles adhesion to the bubbles increased, the flotation rate increased, and finally the flotation performance was improved [18, 23].

Taking into account the surface-active properties and hydrophobizing ability [8, 9], an assessment of flotation properties of the reagents proposed for testing in this study was carried out.

The values of surface tension of 1% aqueous solution of the collector characterize their surface activity: IMA-I413p, 54.7 mN/m; BTF-271, 55.2 mN/m; and BT-15221, 57.7 mN/m. At the same time, the hydrophobizing ability values were (%): 54.0, 34.6, and 53.0 respectively.

Consequently, in the studied reagents series, the most surface-active reagent, having higher hy-

drophobicity, was IMA-I413n, and the least surface-active reagent was BTF-15221; and the least hydrophobicity was observed for BTF-271.

At low consumption of collectors (up to 20 g/t), in bulk flotation cycle of the open-cycle tests, the collecting properties of BTF 271 and BTF 15221 reagents proved significantly inferior to those of IMA-I413p standard collector. At the same consumption of collectors, the yield of sulfide concentrate with the use of the new collectors was lower by 1.6–1.4 % (compared to the standard one), the copper recovery was lower by 6 % with BTF 271 and by 3.5% with BTF 15221, that of arsenic, by 15-10% lower, and that of sulfur, by 4–10 % lower.

### Key findings

The data obtained confirm the existing definite relationship between the surface activity and the hydrophobizing ability of the compared reagents. This dependence was also observed in the series of tests in the study [17], where the most effective sample of IMA-208 showed higher surface activity and higher hydrophobizing ability in comparison with IMA-I413.

However, increasing the amount of adsorbed collector on the surface of minerals (increasing the coverage area) with the growth of the collector concentration in the pulp reduces the effect of surface activity and the hydrophobizing ability of the reagent, especially at insignificant difference of the values.

With increasing consumption of the collectors (BTF-271,15221) (at 30–45 g/t), or in the closed cycle tests, the collecting activity of the new collectors in the bulk cycle increased due to increasing the reagent concentration in the pulp. The flotation efficiency for the associated sulfide minerals approached the performance of the less selective collector KX<sub>but</sub> (the consumption of 50 g/t), at advanced recovery of chalcopyrite.



The determining factor in the bulk sulfide concentrate separation was the strength of the collector's fixation on the surface of the valuable minerals.

### 5. Areas of further research

The created BTF 15221 collector sample proved of undoubted interest for further commercial tests on copper-arsenopyrite and other types of ores with possible correction of its collecting strength and selectivity through varying its con-

sumption in flotation cycle, pulp density, temperature, and other process parameters. It is planned to conduct commercial tests of the collector at the PPP in 2021.

Based on the BTF 15221 collector high efficiency on chalcopyrite flotation in the selective copper flotation cycle, the modeling of the reagent flotation properties continued through the introduction of new low molecular weight homologues into its composition.

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