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Increasing Efficiency of Copper-Molybdenum Ore Flotation using Measurement of Pulp Absorption Capacity

V. V. Morozov[1], **Erdenezul Jargalsaikhan**[1,2], **I. V. Pestryak**[1]

[1] National University of Science and Technology MISiS (NUST MISiS), Moscow, Russia, dchmggu@mail.ru
[2]"ERDENET" GOK, Mongolia

Abstract: A promising line in development of reagent consumption automatic control systems is applying data on measuring collector concentration in the pulp aqueous phase. For effective using data on the concentration of the nonionic collector – allyl ester of amylxanthogenic acid – in the process of flotation, the studies were carried out and the method for analyzing its residual concentration in the flotation pulp liquid phase was developed. The developed spectral technique for measuring the concentration of amylxanthogenic acid allyl ester in the pulp aqueous phase showed stable results in the temperature range of 10 to 25 °C, pH range of 8.5 to 11.0. This allowed applying the technique to measuring residual concentration of AeroMX-5140 collector in the operation of bulk sulphide flotation in copper-molybdenum ore beneficiation. The laboratory tests allowed determining connection between the indicators of residual concentration with the main indicators of copper-molybdenum flotation. The studies showed that increasing the residual concentration of the non-ionic collector occurs with increasing its consumption and pH of the pulp aqueous phase. It is shown that significant increase in metal recoveries is observed at similar residual collector concentrations: for copper, in the range of 0.25 to 0.5 mg/l, and for molybdenum and pyrite iron, at the concentrations from 0.25 to 1 mg/l. The possibility of using the nonionic collector residual concentration as the informational indicator of the flotation process has been substantiated. It is proposed to use the ore absorption capacity in relation to the collector applied as an indicator of the ore grade. It is shown that using this indicator reduces relative variance for the dependences of the yields of individual ore types and increases the accuracy of determining the composition of the processed ore as a mixture of typical ore grades. An algorithm for automated control of the consumption of flotation reagents based on the advanced control of the processed ore elemental and mineral composition was developed and tested at Erdenet GOK processing plant, with the calculation of the pulp absorption capacity in relation to the nonionic collector, including the beneficiation process indicators determination using an economically-oriented optimization criterion. The expected economic effect from the reduction of metal losses amounted to USD 145 thous.

Keywords: copper-molybdenum ores, flotation, collector concentration, UV spectrophotometry, absorption capacity, regulation, optimization.

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Повышение эффективности флотации медно-молибденовых руд с использованием измерения поглотительной способности пульпы

Морозов В. В.[1], **Эрдэнэзуул Жаргалсайхан**[1,2], **Пестряк И. В.**[1]

[1]Национальный исследовательский технологический университет «МИСиС», г. Москва, Россия, dchmggu@mail.ru
[2]ГОК «Эрдэнэт», Монголия

Аннотация: Перспективным направлением разработки систем автоматического управления расходами реагентов является применение данных измерения концентрации собирателя в водной фазе пульпы. Для решения задачи применения данных о концентрации неионогенного собирателя – аллилового эфира амилксантогеновой кислоты – в процессе флотации были проведены исследования и разработана методика анализа его остаточной концентрации в жидкой фазе флотационной пульпы. Разработанная спектральная методика измерения концентрации аллилового эфира амилксантогеновой кислоты в водной фазе пульпы показала стабильные результаты в интервале температур

10–25 °C, интервале pH от 8,5 до 11,0, что позволило применить ее для измерения остаточной концентрации собирателя AeroMX-5140 в операции коллективной сульфидной флотации при обогащении медно-молибденовых руд. В результате проведения лабораторных исследований была установлена связь показателей остаточной концентрации с основными показателями медно-молибденовой флотации. Проведенными исследованиями установлено, что повышение остаточной концентрации неионогенного собирателя происходит при увеличении его расхода и pH водной фазы пульпы. Показано, что существенный рост извлечений металлов наблюдается при близких остаточных концентрациях собирателя: для меди в интервале от 0,25 до 0,5 мг/л, а для молибдена и пиритного железа – при концентрации от 0,25 до 1 мг/л. Обоснована возможность использования остаточной концентрации неионогенного собирателя в качестве информационного параметра флотационного процесса. Предложено использовать поглотительную способность руды по отношению к используемому собирателю в качестве параметра сортности руды. Показано, что включение данного параметра снижает относительную дисперсию для зависимостей выходов отдельных типов руды и увеличивает точность определения состава перерабатываемой руды как смеси типовых сортов руд. Разработан и проверен в условиях обогатительной фабрики ГОКа «Эрдэнэт» (Монголия) алгоритм автоматизированного управления расходами флотационных реагентов на основе опережающего контроля элементного и минерального состава перерабатываемой руды с расчетом величины поглотительной способности пульпы по отношению к неионогенному собирателю, включающий определение параметров процессов обогащения с использованием экономико-ориентированного критерия оптимизации. Ожидаемый экономический эффект от снижения потерь составил 145 тыс. долларов США.

Ключевые слова: медно-молибденовые руды, флотация, концентрация собирателя, УФ-спектрофотометрия, поглотительная способность, регулирование, оптимизация.

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Introduction

A promising line in development of reagent consumption automatic control systems is applying data on measuring collector concentration in the pulp aqueous phase [1, 2]. For ionic collectors such as xanthates and aeroflots, the techniques have been developed and are applied, which involve direct UV spectrophotometry of reagents in filtrates of the flotation pulp liquid phase [3–5]. Flotation process with the use of nonionic collectors, measuring of which by direct spectrophotometric analysis is rather difficult, is more complicated [6].

At the Erdenet GOK processing plant (Mongolia), nonionic collectors – allyl esters of alkylxanthogenic acids – are used [7, 8]. For this class of substances, UV-spectral analysis technique was previously developed, which involves the extraction of esters of alkylxanthogenic acids into acetone and the measurement of optical density of the resulting solution at wavelengths of 355-358 nm [9]. However, this technique has not found practical application due to low precision of the analysis. Therefore, development of a technique for measuring the concentration of allyl esters of alkylxanthogenic acids, being the base material of AeroMX-5140 collector, in the pulp aqueous phase, which is effectively used in flotation of copper-molybdenum ores, is very urgent scientific and practical task.

Technique and findings of the spectral studies

For effective using data on the concentration of the nonionic collector – allyl ester of amylxanthogenic acid – in the process of flotation, the studies were carried out and the method for analyzing its residual concentration in the flotation pulp liquid phase was developed. The spectral analysis was performed using a PE-5400 UV spectrophotometer. The basic technique of taking spectra was used, which implies subtracting from the absorption spectrum of the sample of the ana-

lyzed solution the analogous spectrum of the control sample and the automated calculation of the concentration of the substance from the difference in absorption by UV radiation at fixed wavelengths [10].

The spectrally active fraction of AeroMX-5140 collector is characterized by three distinct absorption peaks, at 220, 255, and 273 nm, which are connected with electron transitions in the esters of alkylxanthogenic acids. For measurements, the extraction technique was used, including the operations of taking and purification of the liquid phase, extraction of nonionic components of the solution into an organic extractant, and producing and analysis of the UV spectra of the extractant with the extracted substances.

An important stage of research was selection of extractant, which ensures the most complete extraction of allyl ester of amylxanthogenic acid from the flotation pulp aqueous phase without extracting other organic substances into it. Both apolar and polar solvents: n-hexane, heptane, acetone, and pyridine were studied as the supposed extractants. As a result of the comparative tests, n-hexane was chosen as the extractant. Comparison of the measurement results showed that the ratio of extactant/sample aliquot in the range of 1:10 to 1:1, the use of n-hexane provides almost complete transition of the collector from the aqueous phase (by 94–96%). Analysis of the IR spectra showed that no extraction of other organic compounds, in particular alcohols, which form the base of the used frother - methyl isobutyl carbinol – took place in the process [11].

Analysis of the calibration graphs shows that in the concentration range of 0 to 1.5 mg/l, close to linear dependence of the sample optical density on the collector concentration is observed at wavelengths of 220 nm and 270 nm (Fig. 1). The range of the collector residual concentration at its reliable analysis amounts to 0.2 to 1.5 mg/l. In this range of values, the measurement error is 2.5–7.5%. At varying the ratio of extactant/sample aliquot in the range of 1:1 to 1:20, the reliably measured collector concentrations in the analyzed aqueous phase are in the range of 0.1 to 15 mg/l, being quite consistent with collector concentrations in bulk and selective flotation operations.

The developed technique was tested in relation to commercial pulps of bulk copper-molybdenum flotation and selective molybdenum flotation. It was confirmed that the developed technique provides the reliable measurement in the temperature range of 0 to 25 °C at pH from 8.5 to 11.0. The results obtained allowed recommending this technique for measuring the residual collector concentration in various flotation operations in the process of copper-molybdenum ore beneficiation.

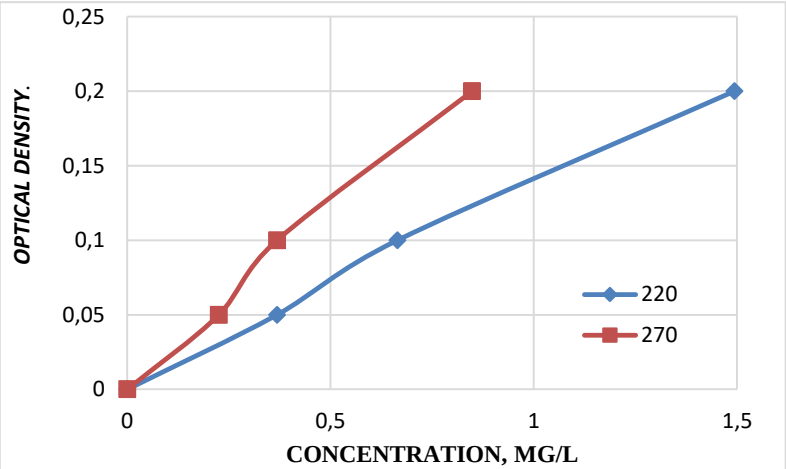

Fig. 1. Calibration curves of the AeroMX-5140 collector at 220 nm and 270 nm

Techniques and findings of flotation studies

According to the developed technique for analyzing the collector concentration, tests on the flotation of copper-molybdenum ores were carried out under the conditions of varied pH and the collector consumption, which are the main parameters of the bulk copper-molybdenum flotation reagent regime [12].

The ore preparation flow sheet included fine crushing an ore sample to the size of –2.5 mm, grinding/comminution the ore in rod and ball mills to 45–75% passing 65 μm. The comminuted ore was fed to the bulk flotation, carried out at the mode used at the operating processing plant of the Erdenet GOK. Methyl isobutyl carbinol (as frother) and AeroMX 5140 reagent as collector were added into the bulk flotation operation. Caustic soda was used as the pH regulator. The bulk flotation of sulfides was carried out for 5 min in a mechanical flotation machine with the cell volume of 1 l. A sample of the liquid phase was taken from the flotation tail, and the liquid phase pH and the collector concentration were measured.

The results showed that, with increasing pH of the pulp aqueous phase, the residual concentration of allyl ester of amylxanthogenic acid, being the main fraction of the collector used, also increases (Fig. 2).

The dependence of the recovery of valuable components on the collector concentration obtained based on the test findings is similar in shape to the dependences obtained with the use of ionic collector, xanthate [12]. Then increase in the collector concentration in the pulp aqueous phase with increasing pH is due to the action of hydroxyl ions on the surface of minerals, as well as oxidation and hydrophilization of their surface [1, 2, 5].

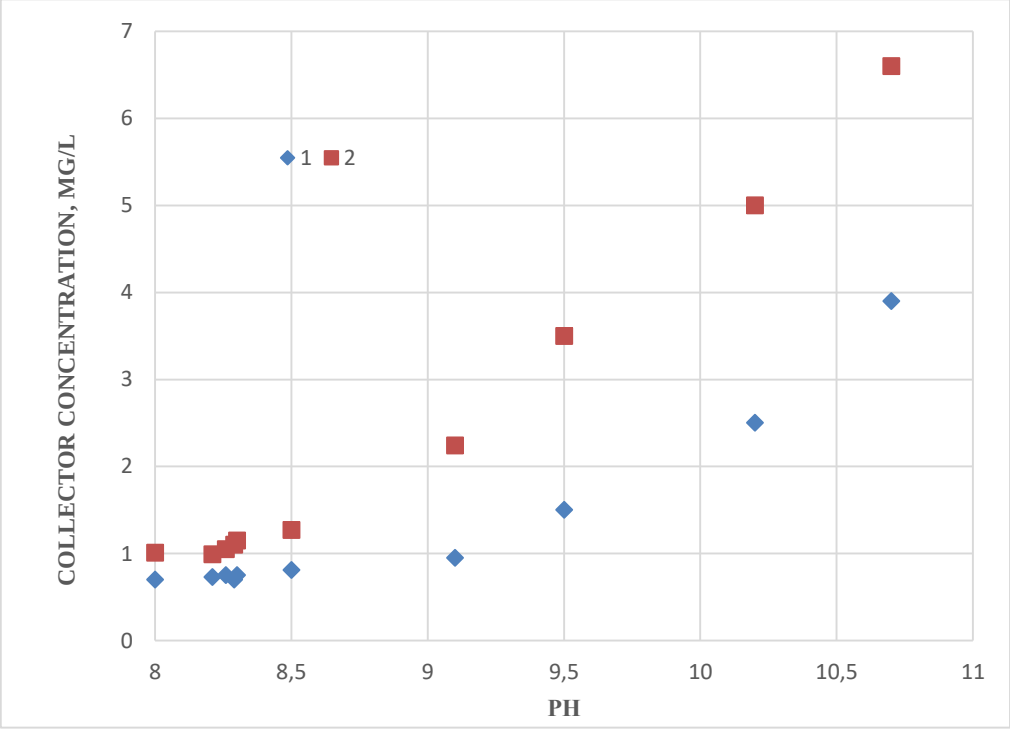

Fig. 2. Varying the residual collector concentration in the pulp aqueous phase as function of pH of the pulp aqueous phase:
1 – at the consumption of AeroMX-5140 of 10 g/t; *2* – at the consumption of AeroMX-5140 of 15 g/t

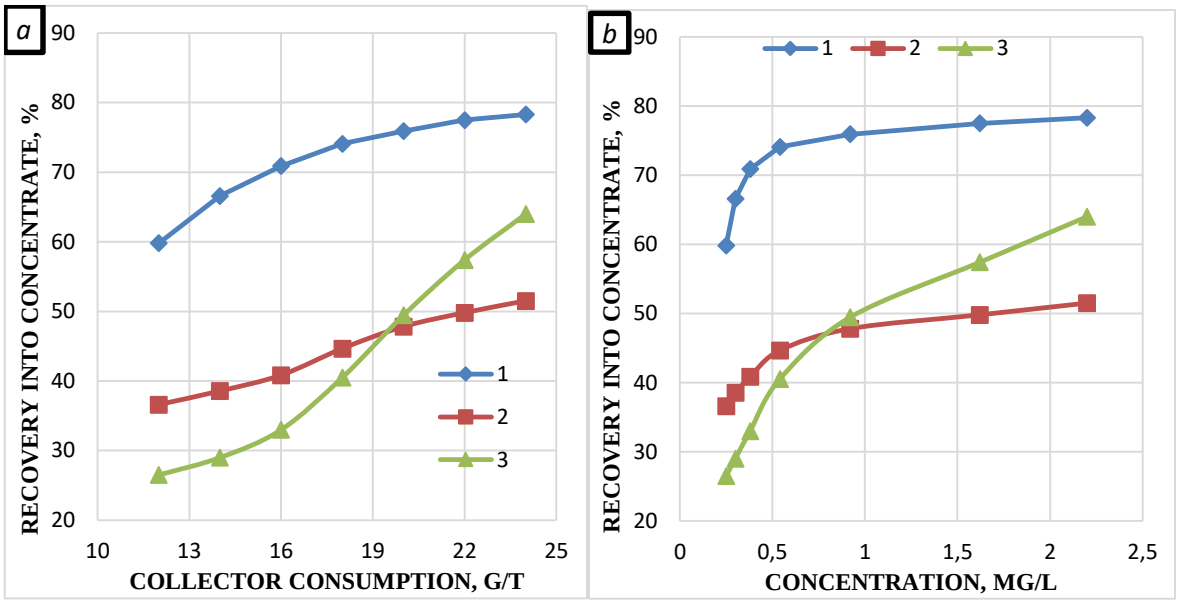

Fig. 3. Graphic experimental dependences of the recovery of copper (1) and molybdenum (2) sulfides and pyrite (3) on the consumption (a) and concentration (b) of AeroMX-5140 collector (pH 10.3)

This result substantiates the possibility and expediency of using the measured residual concentration of the nonionic collector as an indicator of the flotation process for its optimization or automatic regulation of the reagent treatment.

This conclusion is confirmed by the results of the tests, in which the collector consumption in flotation operation was varied. The flotation tests were carried out at constant grain size of 63% passing 74 μm and pH 8.5. The results showed that increasing recovery of copper minerals occurs at the residual collector concentration of 0.25 to 0.5 mg/l, and that of molybdenum and pyrite minerals, at the residual collector concentration of 0.25 to 1 mg/l (Fig. 3).

The nature of the obtained dependences of the minerals flotation abilities on the residual concentration fundamentally differs from the analogous dependences obtained with the use of ionic collectors [1, 12]. According to the data of foreign and domestic researchers, the concentration of xanthate required for complete flotation of sulfide minerals of copper and iron in alkaline medium differs by a factor of 10 or more [2, 13]. The similar shape of the dependences "metal recovery - collector concentration" for the considered sulfide minerals, showed in Fig. 3, allows concluding that the most probable mechanism for fixing nonionic collector such as allyl ester of amylxanthogenic acid is interaction with an unoxidized sulfide surface [13].

According to the testing data obtained, in the liquid phase of the bulk copper-molybdenum flotation pulp, it is advisable to maintain the collector concentration of at least 0.2–0.25 mg/l. It should be noted that significant increase in the residual collector concentration may be due to unsatisfactory conditions for the collector interaction with the surface of the floated minerals. In this case, the nonionic collector residual concentration will be determined by a combination of factors and cannot be applied as basic criterion for regulating the consumption or pH of the medium. Therefore, to create effective systems and algorithms for controlling the flotation reagent scheme, additional studies are required.

Another, more effective approach is the flotation process control based on the on-line control of disturbing factors of the process. In our study, the measured value of the residual collector concentration was used in algorithms for controlling the flotation process based on controlling the processed ore grade.

Determination of optimal flotation conditions using the criterion of the pulp absorption capacity

The dependence of flotation ability of minerals on the residual concentration of the nonionic collector can be used for adjusting the algorithms for optimizing the flotation regime parameters, for example, the collector consumption. A well-known approach to controlling the collector consumption is the calculation and use of the criterion of the pulp solid phase absorption capacity (AC), calculated as the quotient of the amount of absorbed collector (q) by the weight of solid phase in the pulp (Q) according to the following equation [14]:

$$AC = \Delta q/Q. \quad (1)$$

The pulp absorption capacity in relation to the collector in the course of flotation of hypergene altered sulfide porphyry ores is to a greater extent related to the mineral composition of the host rocks than to the composition of ore minerals. To determine the reasons for the increase in the pulp absorption capacity, the tests were carried out on the collector interaction with the main rock-forming minerals of copper-molybdenum ores. As seen from Table 1, sericite, which is the main mineral of hypergene replacement (metasomatic sericitization process), has the highest absorption capacity in relation to the collector. The least absorption capacity is characteristic for unaltered porphyry minerals of granosyenite and granodiorite. This difference in the ability to absorb the collector was first noted in the thesis research of E. Zhargalsaykhan [15].

Analysis of data presented in Table 1 also showed the pulp pH influence on the absorption capacity of rock-forming minerals. Increasing pH from 10.1 to 10.35 reduces the absorption capacity of rock-forming minerals by 7–12%.

The use of the pulp absorption capacity as a criterion for the flotation process is due to objective reasons, namely, significantly difference in the capacity values for the individual groups of primary and secondary minerals. These differences give grounds for using the pulp absorption capacity as a criterion for revealing the processed ore grade.

Table 1

Absorption capacity of rock-forming minerals in relation to AeroMX 5140 collector at its initial concentration of 10 mg/l [15]

Minerals and rocks	pH	Collector absorption, mg/kg
Granosyenite and granodiorite	10.1	0.45
	10.35	0.41
Quartzite	10.1	0.55
	10.35	0.50
Metamorphized quartz	10.1	1.77
	10.35	1.52
Sericite	10.1	4.42
	10.35	4.10

Improvement of the algorithm for automated control of the flotation process using the pulp absorption capacity parameter.

The best results in the automated control of flotation processes are achieved when using model-based control systems and algorithms which use the results of determining the processed ore composition and grade. Increasing the efficiency of flotation reagent scheme automated control systems is achievable on the basis of development and application of economically oriented combined criteria, in particular, by including the optimization criteria in the control algorithm [16]. This approach can be improved at the expense of expanding the range of the flotation process measured parameters, for instance, including the collector concentration and the absorption capacity of the flotation pulp solid phase in relation to the collector used.

Steps of the automated control of grinding and flotation processes, shown in Fig. 4, includes the operations of assessing the processed ore grade and economically oriented optimization [17].

The flotation process is controlled at two levels. The optimal parameters of the grinding and flotation processes are calculated on the basis of data on the ore grades, and the determination of the reagent scheme parameters is carried out using economically oriented optimization criteria [16].

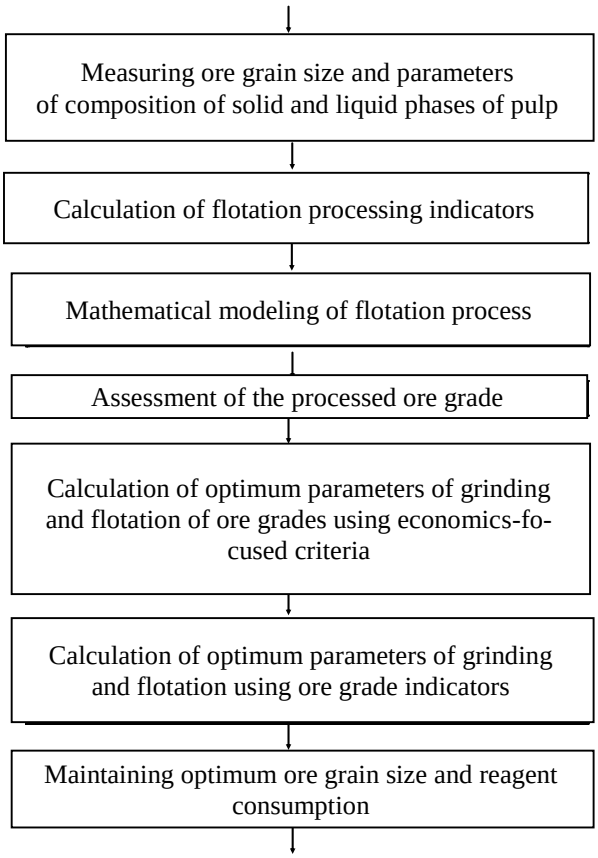

Fig. 4. Steps of the flotation process control based on the ore grade assessment

The prepositional task of the algorithm is to select the optimal reagent scheme for processing of typical ores. This work is carried out using representative samples of different types of the ores involved in processing. The optimal reagent scheme for processing of the current ore is determined taking into account the advanced assessment of its grade. This method was developed and implemented at the Erdenet GOK, where X-ray fluorescence and visiometric analysis data are used to determine the ore properties [16, 17].

The algorithm for determining the ore grade is described in detail in [15, 18] and involves determination of an ore similarity with the main metallurgical types of ores. The final task of determining the ore grade is formulated as the task of determining the shares of the main metallurgical ore types in it.

The calculation of the ore grade was carried out using a multi-criteria method for calculating affiliation with the ore types [15, 17]. The area of finding the task solution is represented by five typical ore types. Mathematical part of the system provides calculation of the supplied ore grade based on eight or more significant parameters of the ore (the content of copper, molybdenum, and iron in the ore, the weight fraction of oxidized, secondary sulfide copper minerals in the ore, that of primary minerals of copper, pyrite and sericite).

Based on findings of the performed studies, it was proposed to use the ore absorption capacity in relation to the applied AeroMX-5140 collector as an additional parameter of the ore grade, determined using the basic equation (1) or its analogues, taking into account the influence of the medium pH and the ore grain size. To determine the absorption capacity of the main identified ore types, the results of measuring the residual collector concentration in the pulp liquid phase in laboratory conditions (the results were obtained in the course of flotation treatment of these ore types) were used. When performing the research and testing, a sample taken from the main bulk flotation cycle was filtered, and the concentration of the spectrally active phase of the AeroMX-5140 collector was determined in the liquid phase of the sample using the developed technique, described in Section 1. For calculation of the absorption capacity, tests were carried out in narrow ranges of pH (10.3–10.4) and the collector consumption (12–18 g/t).

These studies have confirmed that the basic types of ores processed at the Erdenet GOK processing plant are characterized by unequal absorption capacity in relation to the collector. Analysis of the results of the research on bulk copper-molybdenum flotation using the AeroMX 5140 collector showed that mixed oxidized and mixed sericitized ores are most prone to the collector absorption (Table 2).

Table 2

Average collector concentration and pulp absorption capacity in bulk flotation for typical ores

Processed ore type	Flotation parameters				
	pH	Collector consumption, g/t	Collector concentration, mg/kg		Absorption capacity (AC), %
			initial	residual	
1. MFO	10.35	15.0	7.8	2.6	66.7
2. MSSO	10.35	15.0	7.8	1.8	76.9
3. LPO	10.35	15.0	7.8	3.0	63.5
4. MOO	10.35	15.0	7.8	1.5	80.1
5. MSO	10.35	15.0	7.8	1.4	84.1

Note. MFO – massive fresh ores; MSSO – mixed secondary sulfidized ores; LPO – lean pyritized ores; MOO – mixed oxidized ores; MSO – mixed sericitized ores

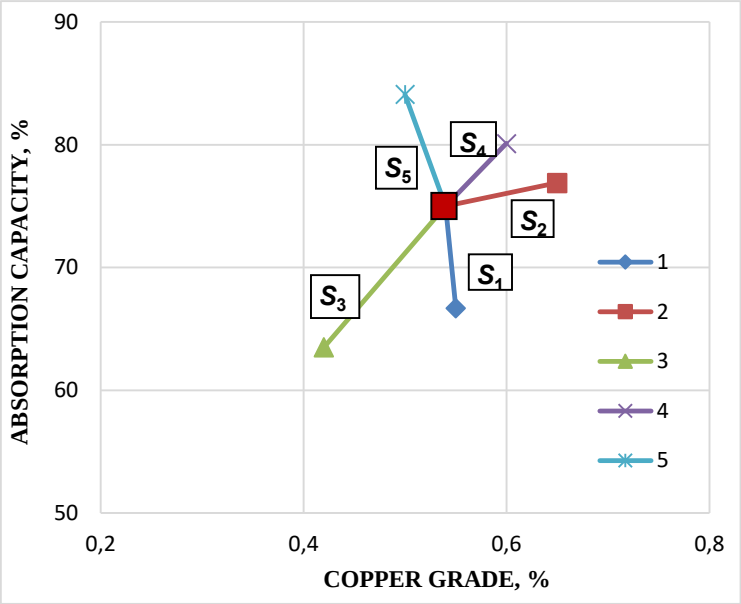

Fig. 5. An example of assessing the ore component composition in two-dimensional space "Copper grade - Absorption capacity of the pulp":
1 – massive fresh ores; *2* – mixed secondary sulfidized ores; *3* – lean pyritized ores; *4* – mixed oxidized ores; *5* – mixed sericitized ores; *6* ( ) – currently extracted ore; S_1, S_2, S_3, S_4, S_5 – deviations of the currently extracted ore parameters from the parameters of the typical ores

The applied method of calculating the ore grade is based on determining the degree of its "similarity" to each of five types of ore. In proportion to this similarity, the relative proportions of these five ore types in the ore arrived for processing are determined [18]. The calculation algorithm initially determines the distance from the point, coordinates of which correspond to the processed ore parameters, to each of the points, coordinates of which correspond to the basic types of ores. The closer the point corresponding to the incoming ore (the sixth type) to any of the points corresponding to the parameters of a certain ore type (*1*–*5*) on the diagram, the higher the relative proportion of the selected ore grade (type) (*1*–*5*) in the ore currently mined (incoming).

Based on the findings of the studies, showing significance of the pulp absorption capacity parameter for the flotation process, it is recommended to use this parameter for determining the ore grade. The algorithm for recognizing the ore grade is explained using the example of the two-parameter system "Copper grade – Absorption capacity of the pulp in relation to the collector", shown in Fig. 5. It should be noted that the "Absorption capacity of the pulp in relation to the collector" parameter is a completely independent parameter, as evidenced by the independent spatial distribution of the characteristics of the ore types in the selected coordinate system.

As seen from Fig. 5, the ore arrived for processing is clearly recognized as the mixture of the selected ore types even in the two-parameter system. In practice, the system comprising 8 parameters was used: the grades of metals, contents of minerals, the ratios of minerals and mineral groups, so that the task of determining the ore grade was correctly solved with high degree of certainty. By equipping the system with the collector concentration sensor and calculating the absorption capacity of the pulp in relation to the collector, the ore grade recognition system (involving nine parameters) becomes even more accurate.

When determining the ore grade, in addition to the absorption capacity, the parameters of the typical ores are used, presented in Table 3 [15, 19].

Table 3

Parameters of the typical ores used in determining the current ore grade [15, 19]

Indicator	Ore type				
	MFO	MSSO	LPO	MOO	MSO
The ratio of the weight fractions of primary and secondary copper sulfides	2.1	0.50	0.45	0.75	0.57
The ratio of weight fractions of primary and oxidized copper minerals	18.5	15.4	21.4	10.4	17.6
The ratio of the weight fractions of chalcopyrite and pyrite	0.77	1.5	0.45	0.86	0.67
Weight percent of copper in ore	0.53	0.57	0.39	0.55	0.52
Weight percent of molybdenum in ore	0.015	0.028	0.013	0.02	0.025
Weight percent of iron in ore	1.50	1.09	1.15	1.22	1.30
Weight percent of sericite in ore	0.12	0.15	0.1	0.17	0.34
Weight percent of porphyry minerals in ore	0.45	0.40	0.48	0.39	0.22
Absorption capacity in relation to collector, %	66.7	76.9	63.5	80.1	84.1

Table 4

Statistical characteristics of the dependences of the individual types (grades) proportions in the processed ore

Ore type	Determinacy indicator R^2		Residual variance	
	not taking into account collector concentration	taking into account collector concentration	not taking into account collector concentration	taking into account collector concentration
MFO	0.77	0.81	0.26	0.22
MSSO	0.74	0.78	0.28	0.23
LPO	0.71	0.76	0.26	0.21
MOO	0.75	0.79	0.27	0.22
MSO	0.77	0.82	0.26	0.21

According to the algorithm used, after normalization and assessment of the parameters significance, the values of the relative proportions of the typical ores in the processed ore are determined [18].

Initially, the normalized deviation (S_i) of the parameters of a mixture of ores (Z_n) from the parameters of the typical ores (Z_{ni}) is calculated by the following formula:

$$S_i = (|Z_n - Z_{ni}|) / Z_{ni} \text{ , at } i = 1\ldots5. \quad (2)$$

Then the normalized values of the similarity of the parameters of the mixture of ores S_i with the parameters of the typical ores are calculated using the following formula:

$$D_i = 1 / S_i, \text{ at } i = 1\ldots5. \quad (3)$$

The value of the relative share of each type of ore (γ_i) is calculated by the following formula:

$$\gamma_i = kD_i / \sum(kD_i), \text{ at } i = 1\ldots5, \quad (4)$$

where k are the coefficients of significance of individual parameters of the ore.

To confirm the feasibility and possibility of using the absorption capacity (AC) as an additional indicator of ore grade, the calculation and analysis of the residual variance of the initial data array in relation to the resulting function was used when determining the incoming ore grade. Such an assessment is based on the possibility of reducing random fluctuations and, correspondingly, the accumulated relative variance by using an additional stable and adequate parameter.

The calculation results showed that the AC parameter inclusion reduces the relative variance when determining the dependences of the proportions of individual ore types (grades) from 0.26-0.28 to 0.21-0.23 (Table 4). The obtained result evidences increasing the model adequacy and the accuracy of determining the processed ore grade.

The developed algorithm was tested in the automated process control system of grinding and bulk flotation processes at the processing plant of the Erdenet GOK. The algorithm of automated regulation provides for regulation of the consumption of reagents, taking into account the ore material composition and grade and the beneficiation indicators [17].

The ore grade was assessed based on data of the ground ore elemental composition analysis, produced by the Amdel-ISA submersible X-ray fluorescence analyzer installed at the cyclone overflow, and the visiometric ore grade analyzer at feeding finely crushed ore into the MShTs-1A mill of the grinding-flotation circuit of the processing plant. The measurement of the collector residual concentration was carried out in the liquid phase of the scavenging bulk flotation tailings sample, taken by the sampler of the PRO-1 system of sample delivery of the AR-31 analyzer. The collector was extracted from the sample by n-hexane. The analysis of the collector concentration was carried out by UV-spectral method.

The results of the of the processed ore grade analysis, presented in the form of graphs of changes in the relative proportion of the individual ore grades (types), shown in Fig. 6, were used to calculate the parameters of the grinding and bulk flotation processes.

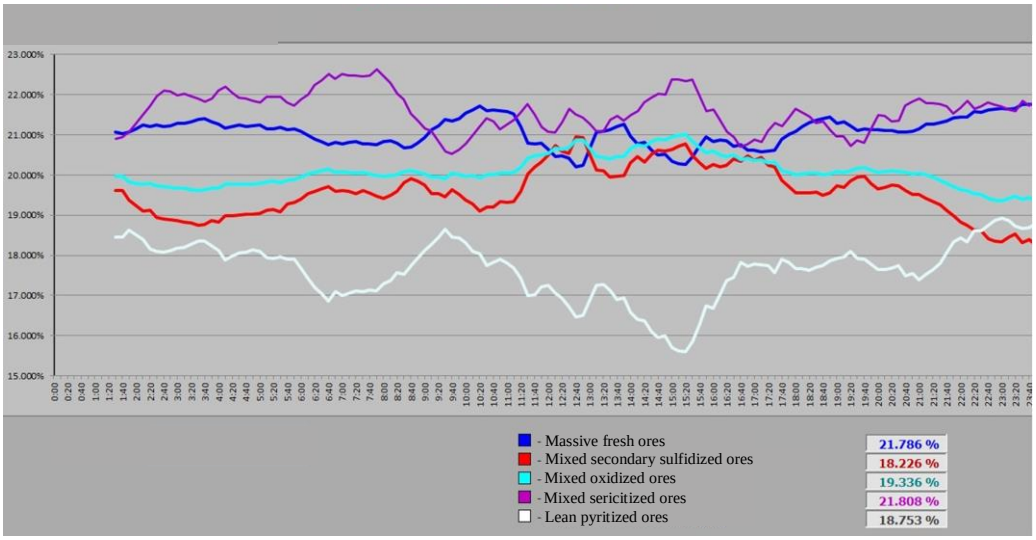

Fig. 6. Graph of ore grade change on the feed conveyor of the MShTs-1A mill

The test results showed that the use of the developed control algorithm, including applying economically oriented optimization criteria, enables increasing efficiency of the copper-molybdenum ores beneficiation. The assessment of the economic effect from the use of the system and the updated algorithm was carried out by calculating the reduction of the normalized losses of valuable components per 1 ton of ore. The effect amounted to 9 cents per 1 ton of ore. In terms of the circuit productivity and taking into account the reagent costs, the economic effect will amount to USD145 thous.

Conclusion.

Using the spectral technique for measuring the residual concentration of the spectrally active fraction of the AeroMX 5140 nonionic collector (allyl ester of amylxanthogenic acid) in the aqueous phase, the dependences of the nonionic collector residual concentration on the collector consumption and pH of the copper-molybdenum flotation pulp aqueous phase were determined. The

possibility of using the nonionic collector residual concentration as the indicator of the flotation process has been established. As an indicator of the processed ore grade, it was proposed to use the normalized absorption capacity of the ore in relation to the collector used, calculated as the ratio of the difference between the calculated and measured collector concentration to the calculated difference. It is shown that using the pulp solid phase absorption capacity as the indicator reduces the relative variance for the dependences of the yields of the individual ore types from 0.26-0.28 to 0.21-0.23. This result confirms the conclusion about increasing the model adequacy and the accuracy of determining the processed ore grade at the expense of using the pulp absorption capacity as an additional indicator. An algorithm for the automated regulation of the consumption of reagents, taking into account the processed ore elemental and mineral composition and the pulp absorption capacity in relation to the collector used, has been developed and tested in the operating Automated Process Control System of the processing plant. The economic effect of the reduction of copper and molybdenum losses when extracting into the commercial concentrates amounted to USD145 thous.

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