Substantiation of the Erdenetiyn-Ovoo copper-molybdenum ore flotation technology with the use of tertiary acetylene alcohols

T. I. Yushina, Assistant Professor, Head of the Department of Beneficiation and Processing of Minerals and Technogenic Raw Materials¹, e-mail: yuti62@mail.ru

B. Purev, Post-Graduate Student, Department of Beneficiation and Processing of Minerals and Technogenic Raw Materials¹, e-mail: bayanokk@yahoo.com

B. Namuungerel, Director of Technical Operations of Concentrating mill², e-mail: namuun@erdenetmc.mn

¹ NUST MISiS, College of Mining, Moscow, Russia.

² Erdenet Mining Corporation, Ulan Bator, Mongolia.

The article presents the results of a study of the factors affecting the efficiency of the copper-molybdenum ore flotation. The objective of this work was to substantiate and develop a reagent mode for flotation of the Erdenetiyn-Ovoo porphyry copper ores, which makes possible extracting main copper and molybdenum minerals into corresponding concentrates more fully and selectively.

It is shown that the use of a DC-80 (2-methyl-3-buten-2-ol) flotation reagent in association with the main base mode reagents — an AERO MX-5152 (a mixture of allyl ethers of xanthogenic acids with *n*-butyloxycarbonyl-*O*-*n*-butylthionocarbamate) combined nonionized collector, a BK-901B (a composition of dialkyldithiophosphate and *O*,*N*-dialkyldithiocarbamate) blending ionized collector; diesel fuel; a MIBC (methyl isobutyl carbinol) frother; sodium sulphide Na₂S as a modifier and lime CaO as a pH regulator of the medium allows obtaining a noticeable, economically sound additional recovery of both copper and molybdenum.

Quantum chemical calculations have permitted to establish an important feature of the mechanism of interaction between the DC-80 molecules that can form stronger complexes based on π -bonds with metal cations of sulfide minerals in comparison with allyl ethers of xanthogenic acids. The energy indicators of the formation of bonds between Cu₂S, the DC-80 molecules and allyl ether of xanthic acid were calculated. There were shown the models of the assumed interaction of small mineral particles with air bubbles during flotation, which are determined by physical and chemical properties of the molecules of acetylene-containing reagents. The principal difference between the properties of the foam bubbles formed by acetylene-containing molecules for at least 50% and that of the ordinary foam bubbles formed by standard frothers has been demonstrated in the view of the mechanism of their fixing on the surface of small particles of sulfide minerals and the surface of the bubbles.

The optimal flotation mode, comprising a DC-80 reagent, BK-901B and AERO MX-5152 base collectors has been developed. The application of this mode will allow increasing the copper and molybdenum recovery into concentrates by 0.62% and 5.76%, respectively, reducing the flotation time by 35–40%, and improving the quality of resulting concentrates.

Based on the research results, it is recommended to incorporate the DC-80 acetylene reagent into the basic flotation mode for conducting pilot tests at the Erdenet Mining Corporation enterprises (Mongolia).

Key words: copper-molybdenum ores, flotation, reagent mode, tertiary acetylene alcohols, a DC-80 flotation reagent, complexes based on π -bonds, computer simulation of reagents, copper and molybdenum recovery.

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Introduction

Technical and economic indicators of enrichment of copper-molybdenum (porphyry copper) ores, which are represented by the most common, industrially significant natural form of molybdenum as a mineral molybdenite, are determined in many respects by the efficiency of the flotation reagent modes that allows achieving the most complete and selective extraction of copper and molybdenum into concentrates [1–7].

The development of new methods and modes of flotation, as a rule, is based on the search for creation of new reagents of various classes, which can significantly increase technological indicators of enrichment. One of the currently central directions of technological development of the porphyry copper ore enrichment is modifying the existing reagent modes of flotation [8–10].

The complexity in the enrichment of the Erdenetiyn-Ovoo copper-molybdenum ores is caused not only by the mineral composition peculiarities and the presence of more than four types of ore, but also by the low content of target metals. According to the Hancock-Luyken formula [11] $\eta = (\varepsilon - \gamma)/(100 - \alpha)100\%$, where ε is a recovery, γ is an yield of beneficiation concentrate, α is the content of valuable mineral component in the feed ore, which sets the enrichment efficiency level η , the process will be very effective for copper at $\eta > 75\%$; for molybdenum the effective process corresponds to the level of $\eta < 75\%$, but $> 50\%$. However, in the current market conditions for prices of main metals, the profitability of production for the Erdenetiyn-Ovoo porphyry ores with a metal content of Cu – 0.522% (the share of primary copper is 68.20%, that of oxidized one is 2.30%), Mo – 0.016%, and the base

recovery level for Cu of 88.74% and for Mo of 53.11%, remains still low [12].

The basic reagent mode of flotation at the Erdenet Mining Corporation concentration mill consists of the following reagents: collectors — an AERO MX-5152 combined nonionized collector containing a mixture of allyl ethers of xanthogenic acids with *n*-butyloxycarbonyl-*O*-*n*-butylthionocarbamate, and a BK-901B blending ionized collector, which is a composition of dialkyldithiophosphate and *O*,*N*-dialkyldithiocarbamate; diesel fuel; MIBC (methyl isobutyl carbinol) as a frothing agent; Na₂S (sodium sulphide) as a modifier and lime (CaO) as a pH regulator of the medium [13].

In the course of mineralogical analysis of final tailings it has been found that copper is lost for the most part in classes larger than 0.10 mm and by 50–65% as aggregates of sulfides larger than 0.02 mm. This gives an indication of the possibility and expediency of the coarse size regrinding while simultaneously removing already disclosed free particles.

Arguments in favour of choosing tertiary acetylene alcohols as collecting reagents for flotation of copper sulfide and molybdenum sulfide

In the earlier studies we have determined that the use of reagents based on tertiary acetylene alcohols, including DC-80, can increase the recovery of a number of metals into corresponding concentrates. During flotation of non-ferrous metal ores, these reagents behave as selective additional collectors-frothers and at consumption of 3–35 g/t, they can practically reduce the flotation time by half; increase extraction of copper up to 3.5%, zinc up to 10–12%, gold up to 8–10%; improve quality of resulting concentrates; heighten stability of the flotation process indicators and to lessen the ecological burden on the environment in the neighborhoods of flotation plants [14–16]. The ДМИПЕС (ДМИПЭК) and DC-80 (ДК-80) tertiary acetylene alcohols used as additional collectors during flotation of copper-molybdenum ores of such companies as Codelco (Chile), The Agarak Copper and Molybdenum Mine Complex (Armenia) and the Teghout concentrating mill (Armenia) have demonstrated good results in increasing extraction of copper and molybdenum both in a bulk cycle and on their selective segregating [16].

When studying the flotation process of Erdenetiyn-Ovoo porphyry copper ores, an inclusion of 12 g/t of DC-80 acetylene alcohol into the basic reagent mode has allowed obtaining an additional recovery of copper at the level of 1.29% and molybdenum of 5.76% [16]. In addition to the flotation activity, tertiary acetylene alcohols are characterized by indicators of toxicity, fire safety, and water solubility that are favorable for industrial use. Based on the results obtained, we conducted further laboratory studies of flotation of copper and molybdenum sulfides using tertiary acetylene alcohols DC-80 as an additional selective collector with foaming properties, and justification of the mechanism of its effect in the flotation system. The active

substance of DC-80 is dimethylethynylcarbinol (DMEC), which corresponds to the chemical name and has the structural chemical formula $\text{HC}\equiv\text{C}-\text{C}(\text{CH}_3)_2(\text{OH})$.

It is known that acetylene π -complexes of transition metals (Me), which contain acetylene or its derivatives as a ligand, play an important role not only in organometallic and organic chemistry, but also in flotation of sulfide minerals, including oxidized ones, as shown in [14–16]. Bond in the complex between the Me atom and ligand is implemented by overlapping unoccupied Me orbital with acetylene bonding orbital (a donor-acceptor type bond) and filled Me *d*-orbital with antibonding acetylene π -orbital (a dative bond) [17–18]. Models for representation of the “Me-acetylene” bond are shown in Fig. 1 and 2.

Allyl ethers of xanthogenic acids (AEXA) are nonionized water insoluble reagents that are fed into grinding cycle. The functional group reaction centers of the reagent are sulfur atoms, whose reaction with an oxidized surface of sulfide metals is well studied and is determined solely by the molecule structure of these reagents [19–20].

When modeling the process of complexation on the surface of copper sulfides, the fact that the formation of metal acetylenides requires special conditions or the presence of soluble copper salts has been taken into account. In the case of formation of surface complexes, the initial copper compounds are insoluble, so there are no copper cations, but only non-integer charges on the copper atom are present.

The reaction between alkynes-1 (a DC-80 reagent) with the terminal triple bond and copper sulfate CuSO_4 proceeds with retention of the triple bond in the resulting complex (Fig. 3). This ability of alkynes-1 to substitute proton for a metal atom, like the acids, is caused by the fact that carbon atom is in a state of *sp*-hybridization. As a result, the carbon atom is more “enriched” with electron density and proton becomes mobile.

Fig. 1. Model of π -complex, formed by interaction of Cu_2S with a DC-80 molecule

Fig. 2. Model of π -complex, formed by interaction of the Cu_2S oxidized surface with a DC-80 molecule

Fig. 3. Interaction reaction between DC-80 and copper sulfate

Fig. 4. Optimized computing π -models of the DC-80 complexes with metal cations (*Me*)

Alkynes, which have no hydrogen atoms in the case of triple bond, do not enter into such a reaction, which makes it possible to distinguish them from one another.

Existence of π -bonds determines the potentiality of alkynes (a DC-80 reagent) to enter into reactions of electrophilic addition. The triple bond π -electron density in alkynes is located more compactly than that in alkenes, so it is less accessible for interaction with different reagents. Therefore, reactions for alkynes are slower than for alkenes.

In the reaction of substituting a DC-80 proton with a Cu (Mo) metal atom, the corresponding salts are formed when CuSO_4 or MoS_2 interact with the terminal carbon atom of the triple bond in the DC-80 molecule.

Modeling and calculating elementary quantum-chemical parameters of organo-metallic structures formed in the flotation system were performed using the methods of molecular mechanics, semiempirical and ab initio quantum-chemical techniques using the ChemBio3D 11.0 package included in the ChemBioOffice 2008 suite of scientific applications (for Windows), developed by Cambridge Soft Corporation.

The MM2 technique was chosen as an intermediate step for preliminary optimization of the structure of complex organic compounds.

The MM2 (Molecular mechanics) technique is designed for modeling and calculating organic molecules. It takes into account the potential fields generated by all the atoms of the calculated system, in comparison with other methods of molecular mechanics. Calculations of the total potential energy for the DC-80 complex and various Me cations were performed using the optimized computing model shown in Fig. 4.

Data on the elementary quantum-chemical parameters for the DC-80 molecule and various complexes with Me cations are listed in Table 1.

The difference in the potential energy value of the resulting complexes indicates the availability of the DC-80 reagent selectivity for cations of the transition metal salts

(Table 1). From a chemical point of view, the reaction between alkynes-1 molecules with a terminal triple bond and transition metal salts proceeds with retention of the triple bond in the formed complex. The results of calculations of the elementary quantum-chemical parameters for the DC-80 π -complexes with various Me cations based on the optimized computing models shown in Fig. 4 are listed in Table 2.

Large contrast by difference in the potential energy of the formed π -complexes allows us to judge the existence of significant selectivity of DC-80 molecules for cations of sulfide metals from the transition group (Table 2).

Comparison of the calculated indicators (Table 3) of the elementary quantum-chemical parameters of formation

Table 1

Indicators of the elementary quantum-chemical parameters for the DC-80 molecule and various complexes with Me cations

Parameter	Type of metal cation				Molecule 2-Methyl-3-butyn-2-ol
	Cu	Mo	Fe	Re	
Stretch	0.1794	0.1770	0.1829	0.4020	0.1815
Bend	0.5725	0.5727	0.5721	11.9534	0.5714
Stretch-Bend	0.0569	0.0570	0.0584	0.0566	0.0585
Torsion	1.1957	1.1959	1.1969	1.1957	1.1968
Non-1.4 VDW	-1.5960	-1.5104	-0.9657	-1.6562	-0.9970
1.4 VDW	2.3783	2.2968	2.3673	2.0759	2.3526
Dipole/Dipole	1.0190	1.0192	1.0186	1.0194	1.0189
Total energy, kcal/mol	3.8059	3.8081	4.4305	15.0472	4.3826

Table 2

Indicators of the elementary quantum-chemical parameters for the DC-80 molecules and various π -complexes with metal cations (*Me*)

Parameter	Type of metal cation			
	Cu	Mo	Fe	Re
Stretch	389.4894	207.0368	228.5387	211.6274
Bend	2604.7856	2088.8946	2132.8587	2094.3114
Stretch-Bend	-95.9352	-25.8493	-13.8702	-26.3231
Torsion	1.2056	1.2061	1.2073	1.2063
Non-1.4 VDW	-1.3764	-1.3914	-0.8618	-1.3880
1.4 VDW	2.6639	2.7174	2.6517	2.6749
Dipole/Dipole	0.9843	0.9803	0.9998	0.9826
Total energy, kcal/mol	2901.8171	2273.5944	2351.5233	2283.0916

Table 3

Indicators of the elementary quantum-chemical parameters of formation of π -complexes of allyl ether of xanthic acid and dimethylethynylcarbinol with Cu and Mo cations

Indicator	Type of a metal cation and model of the rated object			
	DMEC (DC-80)	AEXA (AERO MX-5152)	DMEC (DC-80)	AEXA (AERO MX-5152)
	Cu		Mo	
Stretch	389.4894	19.6677	207.0368	9.0527
Bend	2604.7856	204.9716	2088.8946	265.1203
Stretch-Bend	-95.9352	-20.1385	-25.8493	-9.9912
Torsion	1.2056	-0.3558	1.2061	-0.4672
Non-1.4 VDW	-1.3764	-2.9297	-1.3914	-3.0906
1.4 VDW	2.6639	3.9440	2.7174	4.9832
Dipole/Dipole	0.9843	1.1574	0.9803	0.9349
Total energy, kcal/mol	2901.8171	286.1367	2273.5944	266.4519

Fig. 5. Computing model for π -complex of allyl ether of xanthogenic acid (AeroMX-5152) with Me cation

of π -complexes by molecules of allyl ether of xanthic acids (AERO MX-5152) (Fig. 5) and molecules of dimethylethynylcarbinol (DC-80) with Cu and Mo cations has showed that the total energy of formation of π -complex of DC-80 molecules is an order of magnitude higher than that of allyl ether of xanthic acids (AERO MX-5152), with both the Cu cation and Mo cation.

According to calculations, the total energy of π -complex formation for DC-80 molecules with respect to Cu cations is 2901.8171 kcal/mol, that to Mo cations is 2273.5944 kcal/mol; for Aero MX-5152 molecules for Cu is 286.1367 kcal/mol and for Mo is 266.4519 kcal/mol. This distinction between the complex formation to total energies indicates that DC-80 molecules have a selective effect on Cu and Mo, while this selectivity is not observed for AERO MX-5152 molecules.

Calculation of the elementary quantum-chemical parameters of complexes makes it possible to

understand the impact of the bond structure in a hydrocarbon chain of reagents and transition metal atoms upon the reactivity, and to determine the reason for orienting influence of the bond location in reagent molecules.

The virtual environment in computer simulation represents some idealized conditions that differ significantly from the actual conditions of industrial flotation. Nevertheless, it provides some quantitative and qualitative visual notions of the character of the interaction between the reagents and atoms of floated minerals, and calculated indicators allow establishing their common nature and trends. The structure closest to the real structure of complexes

can be determined by studying separately the construction, configuration, and conformation of a molecule, or by determining all these characteristics, applying simultaneously X-ray or neutron diffraction analysis, IR spectroscopy, and NMR.

Thus, it was shown that the selected reagents, models and the technique of semiempirical calculations make it possible to simulate the interaction processes between DC-80 molecules with cations of the metals of transition groups of the porphyry copper-molybdenum ore under study, and computation of the elementary quantum-chemical parameters of generated complexes allows predicting the choice of optimal reagents that provides achieving the intended aims.

Fig. 6. Scheme of implementation of flotation studies

Investigation of the influence of DC-80 acetylene alcohols on the porphyry copper ore flotation parameters

The studies were carried out according to the scheme shown in Fig. 6 on the ore of the following composition: Cu – 0.522% and Mo – 0.016%.

Basic conditions for flotation: the mill is fed by AERO MX-5152 – 8.0 g/t, BK-901B – 2.0 g/t, CaO – 0.75 g/t, $t_{grind} = 14$ minutes; to the main flotation enters MIBC – 15.0 g/t, $t_{basic} = 5$ minutes, $t_{cont} = 7$ minutes. In the studied modes, a tertiary acetylene alcohol (the DC-80 reagent) was used. The results of the investigations are shown in Fig. 7.

Laboratory studies of flotation of the Erdenetiyn-ovoo porphyry copper-molybdenum ores has showed that the use of the DC-80 reagent in combination with the basic composition of AERO MX-5152 and BK-901B collecting reagents and the MIBC foaming agent allows increasing the extraction of Cu into a bulk concentrate by 0.4% and Mo by 6.50%, with a total Cu recovery rate of 85.40% and Mo of 62.71%. It should also be noted that simultaneously with the extraction of metals, the yield of the bulk flotation concentrate has also increased from 1.96 to 2.02%.

Research on the main technological indicators in the bulk flotation cycle (total bulk concentrate, total tails of bulk concentrate) have been carried out on the ore No. 8 of the phase composition as follows: (Cu – 0.522%, Cu (sulphide) – 68.20%, Cu (oxidized) – 2.30%, Mo – 0.016%). Experimental conditions: CaO – 650 g/t was fed to the mill and CaO – 500 g/t was fed to the main flotation for the basic reagent mode (into the mill: AERO MX-5152 – 8.0 g/t, BK-901B – 2.0 g/t. To the main flotation: MIBC – 15.0 g/t); for the test mode (into the mill: AERO MX-5152 – 8.0 g/t, BK-901B – 2.0 g/t, DC-80 – 12.0 g/t). In all the experiments 15.0 g/t of the MIBC foaming agent was fed to the main flotation. The best results of statistical tests are shown in Table 4.

The results of the investigations have showed that adding the DC-80 reagent to the basic flotation mode provides an additional extraction of Cu 0.49% and Mo 2.76%, the concentrate yield is at the level of the basic test (base 4.15%, investigated 4.12%), extraction of iron in a basic mode is 30.88%, in the investigated one – 30.86%, which indicates selectivity of the DC-80 reagent for sulphide minerals.

Fig. 7. Results of bulk flotation (extraction of copper and molybdenum into a bulk concentrate)

The selectivity of the DC-80 acetylene reagent, determined by its characteristic collecting properties, suggests that this will have a favorable effect on flotation of small particles of sulphide minerals. To this end, studies were conducted on the influence of the ore grinding fineness upon distribution of minerals by class in concentrates and indicators of a bulk flotation in the presence of the DC-80 reagent, during which positive changes in the mineral content in the size range $45 \leq d < 75 \mu\text{m}$ were observed: in the ore – 65.84%, in the concentrates of bulk flotation with the basic test – 85.89%, with DC-80 – 92.15%.

When considering the size range in the limits of $20 \leq d < 45 \mu\text{m}$, the growing number of small particles in the concentrates obtained under the reagent flotation modes that include DC-80 acetylene alcohols becomes obvious. Extractions of minerals of small classes into a bulk concentrate with the use of the DC-80 reagent increases by 6.26%. It is obvious that the pulp optimal granulometric composition, which provides, all other things being equal, an increase in the Cu and Mo recovery during flotation of porphyry copper ore, should be shifted towards a gain in the content of small classes, which is naturally associated with the content and distribution of metals in the ore.

To confirm the revealed facts, additional researches have been conducted to identify the influence of the fineness of ore grinding (flotation feed) on flotation indicators (Table 5).

The results of investigations (Table 5) have showed that the increase in the ore grinding fineness in the bulk flotation feeding by only 13.8% gives an additional recovery

Table 4

Comparison of the main processing indicators of the basic and investigated flotation modes

Experiment	Product name	Yield, %	Content, %			Recovery, %		
			Cu	Mo	Fe	Cu	Mo	Fe
Basic (A)	Total bulk concentrate	4.15	10.94	0.314	20.28	88.85	73.11	30.88
	Total tails of a bulk flotation	95.85	0.059	0.0050	1.97	11.15	26.89	69.12
	Feed	100.0	0.511	0.018	2.73	100.0	100.0	100.0
Investigated (B)	Total bulk concentrate	4.12	11.17	0.376	20.95	89.34	75.87	30.86
	Total tails of a bulk flotation	95.88	0.057	0.0051	2.02	10.66	24.13	69.14
	Feed	100.0	0.515	0.020	2.80	100.0	100.0	100.0

Table 5

Results of bulk flotation of the ore of various grinding size

ORE No. 18. Phase analysis (Cu – 0.526%, Cu _I – 71.29%, Cu _{ox} – 3.99%, Mo – 0.024%)									
Basic mode									
Product name	Yield		Content, %			Recovery, %			Conditions of experiments
	g	%	Cu	Mo	Fe	Cu	Mo	Fe	
The 1st bulk flotation concentrate	173.95	2.90	14.769	0.574	23.90	81.29	63.53	26.36	<i>t_{grind}</i> — 15.0 min; To the feeding of bulk flotation: (–75μm — 59.74%); Into the mill, g/t: CaO — 800, AERO MX-5152 — 8.0, BK-901B — 2.0; To rougher flotation: pH = 10.15 MIBC — 15.0 g/t; Time of bulk flotation: <i>t_{fl.rough}</i> = 5'; <i>t_{fl.scav}</i> = 7'; <i>t_{1st bulk fl}</i> = 5
Tails of the 1st bulk flotation concentrate	65.47	1.09	0.655	0.091	4.16	1.36	3.79	1.73	
Rougher bulk flotation concentrate	239.42	3.99	10.909	0.442	18.50	82.64	67.32	28.09	
Scavenger bulk flotation concentrate	146.42	2.44	1.331	0.113	6.47	6.17	10.53	6.01	
Total bulk flotation concentrate	385.84	6.43	7.275	0.317	13.93	88.81	77.85	34.10	
Total tailings of scavenger bulk flotation	5613.92	93.57	0.063	0.006	1.85	11,19	22.15	65.90	
Initial feeding	5999.76	100.00	0.527	0.026	2.628	100.00	100.00	100.00	
Investigated mode									
The 1st bulk flotation concentrate	161.55	2.69	16.199	0.627	24.98	83.57	64.74	25.09	<i>t_{grind}</i> — 20.0 min; To the feeding of bulk flotation: (–75μm — 68.01%); Into the mill, g/t: CaO — 800, AERO MX-5152 — 8.0, BK-901B — 2.0, DC-80 — 12.0; To rougher flotation: pH = 10.15 MIBC — 15.0 g/t; Time of bulk flotation: <i>t_{fl.rough}</i> = 5'; <i>t_{fl.scav}</i> = 7'; <i>t_{1st bulk fl}</i> = 5'.
Tails of the 1st bulk flotation concentrate	59.56	0.99	0.544	0.109	4.49	1.03	4.15	1.66	
Rougher bulk flotation concentrate	221.11	3.69	11.982	0.487	19.46	84.61	68.89	26.75	
Scavenger bulk flotation concentrate	141.42	2.36	1.216	0.101	6.33	5.49	9.13	5.57	
Total bulk flotation concentrate	362.53	6.04	7.782	0.337	14.34	90.10	78.02	32.32	
Total tailings of scavenger bulk flotation	5636.54	93.96	0.055	0.006	1.93	9.90	21.98	67.68	
Initial feeding	5999.07	100.00	0.522	0.026	2.681	100.00	100.00	100.00	

Size of the bulk flotation feed
(–75 μm 59.74%) Size of the bulk flotation feed
(–75 μm 68.01%) **Fig. 8.** Pie charts for granulometric distribution of minerals in the bulk flotation feed

of Cu by 1.29% and Mo by 0.17%. Based on the data in Table 5, pie charts are constructed for granulometric distribution of minerals in flotation products (Fig. 8).

Analysis of fractional distribution of the minerals has showed that an increase in the content of a class size –75 μm in the flotation feeding from 59.74% to 68.01%, i.e., by 13.8% only, leads to the raise in the content of fractions –32 μm by 3%, +20 μm by 3%, +45 μm by 3%, whereas the amount of a fraction +75 μm is reduced by 6%.

The assumed model of fixing small mineral particles on the shell of an air bubble in a foam layer is shown in Fig. 9.

According to the model presented in Fig. 9, the foam bubbles formed by acetylene-containing molecules for at least 50% differ in adsorption properties from the ordinary foam flotation bubbles against small and fine particles of sulfide minerals. Such properties of the bubbles can provide an additional extraction of metals.

Raising the extraction of mineral particles of the fine size classes provides selectivity of collecting action of acetylene reagents by adsorption of acetylene alcohol molecules on the surface of sulfide minerals. An interaction of molecules of acetylene reagents with the surface of minerals of fine classes in the flotation process of porphyry copper-molybdenum ores was noted for the first time. Model of interaction of large and small mineral particles with air bubbles in the flotation mode with a DC-80 reagent is shown in Fig. 10.

Fig. 9. Model of fixation of small mineral particles on the shell of an air bubble in a foam layer:
1 – mineral; 2 – a DC-80 molecule of the foam bubble outer layer; 3 – water shell of the foam bubble; 4 – a DC-80 molecule of the foam bubble inner layer; 5 – gas inside the foam bubble

Fig. 10. Model of fixing large and small mineral particles on an air bubble in a foam layer:
1 – foam bubble in a foam layer; 2 – large mineral particle; 3 – bimolecular shell formed by molecules of the standard and acetylene-containing frothers; 4 – molecule of an acetylene-containing reagent; 5 – effective area of a hydrophobic action; 6 – molecules of an ordinary collector, adsorbed on a large mineral particle

During flotation in the presence of acetylene alcohols, the surface of non-oxidized sulfide minerals is hydrophobized by adsorption of DC-80 molecules on metal cations, with the formation of π -complexes, but further interaction of the hydrophobic parts of the molecules leads only to a partial hydrophobic interaction that occurs over the hydrophobized surface only. The sulfide mineral oxidized environment interacts with the other molecules of hydrophobizers and is characterized by its own hydrophobic interaction between the hydrophobic parts of molecules. There is no hydrophobic interaction between them, but the wettability of the mineral surface decreases.

For this reason, not only the adsorption of acetylene reagent molecules on cations of sulfide minerals is of importance, but also the presence of molecules of this reagent at the phase interface in hydrophobic layer of the

bubble shell, since the energy of hydrophobic interaction (5, Fig. 10) in the foam layer is supplemented with the energy of the formed π -complexes (Fig. 9).

Conclusions

– There is justified and developed a reagent mode of porphyry copper ore flotation with the use of a tertiary acetylene alcohol – the DC-80 reagent, that interacts with the sulfide and oxidized surfaces of copper and molybdenum minerals by the mechanism of formation of complexes based on π -bonds, reducing the wettability of the mineral surfaces and providing their additional hydrophobization.

– The use of the DC-80 reagent for flotation of potentially non-recoverable thin micron and submicron particles that do not have sufficient mass and move with the liquid in an inertialess mode is substantiated. The proposed models of interaction of small mineral particles with air bubbles during flotation are determined by the inherent physical and chemical properties of molecules of acetylene-containing alcohols. A fundamental difference between the properties of the foam bubbles formed by acetylene-containing molecules for at least 50% and the properties of the ordinary foam bubbles formed by standard frothers by the mechanism of their fixing on the surface of small particles of sulfide minerals.

– Justified is the use of acetylene-containing alcohol DC-80 as an additional collector with foaming properties in combination with the sulfur-containing BK-901B ionized collector and AERO MX-5152 nonionized collector. The functional group of sulfur-containing collectors is a sulfur atom, the reaction of which with the oxidized surface of sulfide metals has been much studied; the difference in their selectivity is determined solely by the properties of the structure of molecules of these reagents.

– A new flotation mode comprising the DC-80 reagent at a consumption rate of 12 g/t and BK-901B and AERO MX-5152 base collectors has been developed. The improvement of process indicators when optimizing the flotation mode becomes apparent in increasing the recovery into a bulk flotation concentrate of copper by 1.29% and molybdenum by 5.76%.

– It is recommended to include the DC-80 acetylene reagent into the basic flotation mode for conducting pilot tests at the Erdenet Mining Corporation plants (Mongolia).

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