# Analysis of technological schemes and substantiation of the selection of the reagent regimes for copper-molybdenum ores flotation

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A comprehensive review of the principal process flowsheets of flotation beneficiation of porphyry copper ores is given in the paper along with the factors, influencing upon the beneficiation indicators, including copper and molybdenum extraction in the bulk and selective flotation cycles, in which the main problem is connected with selective separation of copper and molybdenum minerals from iron sulfide.
The paper presents the beneficiation process indicators of the leading world enterprises, processing porphyry copper ores. There are also reported the results of the recent investigations devoted to increasing the efficiency of flotation beneficiation and improvement of the reagent mode of porphyry copper ore flotation. On basis of the beneficiation practice data analysis, established were the lines of the promising investigations focused on development the means to increase the processing characteristics of porphyry copper ore flotation, especially in the aspect of decreasing the molybdenum losses with treatment of the tails. One of the very promising ways is an application of complex regents, which increase the flotation selectivity for copper, molybdenum and iron sulfides, probably in combination with existing reagent regimes on the porphyry copper ore processing plants too.

***Key words:*** porphyry copper ores, flotation, molybdenite, sulfide coppers, molybdenum flotation, reagent mode, extraction, concentrate.

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## Introduction

The bulk of copper and molybdenum is mined from porphyry copper ores. China, USA, countries of Latin America (Chile first of all), and Mongolia lead the porphyry copper ore processing (Table 1) [1–2]. It should be pointed out that this branch of industry is distributed throughout the world, since molybdenum is one of the key materials for the industry in a whole due to its main characteristics, namely, strength, durability, corrosion stability and heat resistance. Molybdenum is a metal which is used as a raw material for obtaining alloys, the most essential among which are high-temperature steels. Molybdenite, or molybdenum sulfide, is the predominant natural compound of this chemical element.

The main part of molybdenum in the world is manufactured by the Chile state company Codelco. Manufacturing data of the company during the last years are listed in Table 2. Production of porphyry copper ore in Mongolia is represented by a single company, Erdenet Mining Corporation. The ore reserves an amount of 1.4 billiard tons with content of Mo 0.0163 % and Cu 0.43 % (Table 3). It is significant that concentrating mills of Chile and Mongolia are characterized by stability of the process indicators of manufacturing and high-quality production of concentrates within recent years.

## Schemes and reagent regimes of copper-molybdenum ore flotation

All porphyry copper ores represent the principal type of copper-molybdenum deposits, located in the main within the bounds of three metallogenic belts: the Pacific, Mediterranean-Asian, Kazakh-Mongolian ones. This deposits are the main source of molybdenum and copper, and are usually associated with linear belts; rarely they are found as isolated deposits.

Extensive theoretical, experimental and industrial studies all over the world have by now allowed devising, examining and verifying in practice all the models for primary beneficiation of bulk and selective flotation of non-

Table 1
**Process indicators of the world leading concentrating mills, processing copper-molybdenum ores**

| Mill name, country | Ore processing, thous. t/day | Content, % | | Primary copper minerals | Number of stages | |
|---|---|---|---|---|---|---|
| | | Cu | Mo | | Crushing | Grinding |
| Highland Valley, Canada | 133 | 0.41 | 0.007 | Chalcopyrite, bornite | 1 | 2 |
| Copperton, USA | 120 | 0.75 | 0.05 | Chalcopyrite, bornite, chalcocite | 1 | 2 |
| La Caridad, Mexico | 90 | 0.6–0.8 | 0.02–0.04 | Chalcocite, chalcopyrite | 3 | 1 |
| Du Shan, China | 100 | 0.4–0.5 | 0.008 | Chalcopyrite | 3 | 1 |
| El Teniente, Chile | 90 | 1.07 | 0.027 | Chalcopyrite, chalcocite | 1 | 2 |
| Almalyk, Uzbekistan | 60 | 0.46 | 0.006 | Chalcopyrite, chalcocite | 3 | 2 |
| Erdenet, Mongolia | 86 | 0.43 | 0.0163 | Chalcopyrite, chalcocite | 3 | 2 |

Table 2
**The dynamics of the copper-molybdenum ore processing indicators of Codelco company in 2014–2018 years**

| Yield of concentrate, thous. t. | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|
| Mo | 30.63 | 27.68 | 30.64 | 28.67 | 24.03 |
| Cu | 1 671.80 | 1 731.70 | 1 707.50 | 1 733.90 | 1 677.50 |

Table 3
**Performance indicators of Erdenet Mining Corporation in 2011–2018 years**

| Indicator | Metal | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Ore processing, overall, thous. t | | 26,100 | 26,030 | 26,045 | 26,126 | 28,000 | 31,180 | 31,438 | 31,520 |
| Metal content in the ore, % | Cu | 0.54 | 0.542 | 0.53 | 0.526 | 0.516 | 0.51 | 0.495 | 0.43 |
| | Mo | 0.017 | 0.016 | 0.016 | 0.019 | 0.020 | 0.018 | 0.018 | 0.016 |
| Metal content in concentrate, % | Cu | 23.67 | 23.50 | 23.23 | 23.03 | 23.35 | 23.25 | 23.36 | 23.08 |
| | Mo | 49.19 | 48.39 | 48.73 | 49.32 | 49.11 | 49.81 | 50.6 | 50.38 |
| Metal extraction, % | Cu | 86.35 | 86.3 | 86.3 | 86.55 | 88.22 | 87.56 | 89.28 | 89.49 |
| | Mo | 45.10 | 45.00 | 45.07 | 40.77 | 44.94 | 45.58 | 51.64 | 53.86 |
| Yield of metal in concentrate, thous. t | Cu | 121.60 | 121.68 | 119.16 | 119.03 | 127.51 | 139.16 | 139.00 | 135.57 |
| | Mo | 1.957 | 1.904 | 1.819 | 1.999 | 2.5571 | 2.577 | 2.914 | 2.764 |

ferrous metal ores, which is the dominant method for their beneficiation [3].

Flotation processing flowsheets of copper-molybdenum ores flotation are built taking into account the dissemination of sulfide minerals, their amount, phase composition and potential slurry formation, which exert essential influence upon the number of flotation stages.

The two-stage scheme is the most rational one for flotation of copper-molybdenum ores; it is successfully used abroad at modern concentrating mills of middle and large productive capacity [4].

Reagent regimes used for treatment of these ores are based on physical-chemical peculiarities of molybdenite, copper sulfides and nonmetallic minerals. Usage of present-day chemical reagent and development of process regimes allows achieving a significant level of molybdenite extraction into the concentrate.

One of the main challenges of selective flotation is the separation of sulfide minerals in order to concert them into corresponding concentrates. Irregular distribution of minerals with close physical-chemical surfaces properties complicate the process of selective interaction with collecting reagents, especially for finely disseminated ores. The contrast fuzziness by spectra of mineral floatability leads to significant losses in heteronymic concentrates, amounting to 10–30% in general [5].

Increase of selectivity when separating bulk flotation concentrates is the major problem faced by the dressers. Different approaches are used to solve it; for example, stage ore-preparation taking into account mineralogical and granulometric ore composition, elaboration of new beneficiation apparatus and schemes, improvement of schemes for minerals sepa-

| Coarseness of grinding, % of a –0,074 mm class | Copper concentrate, % | | Molybdenum concentrate, % | |
|---|---|---|---|---|
| | Content | Extraction | Content | Extraction |
| 50 | 41 | 87 | 55 | 52 |
| 60 | 27–29 | 90–91 | 52–54 | 64–68 |
| 60 | 33 | 84.1 | 58 | 58 |
| – | 24–50 | 80 | 48–50 | – |
| 60 | 42 | 83 | 55 | 42 |
| 60 | 18–20 | 80–82 | 25–35 | 56 |
| 65–70 | 23 | 90 | 50 | 53 |

ration by particle size, selection and creation of new selective reagents, including with the use of computer simulation of prospective reagents [6–10].

A diversity of factors, which forms the surface and flotation properties of the same minerals, is connected not only with the size of particles, but also with the composition of incorporated aggregates, presence and distribution of the face imperfections and impurities in the lattice, a level of minerals oxidability in the metamorphism process. As long as flotation is a very complicated physical-chemical process with great number of interconnected factors, a flotation rate constant is accepted as the main criterion which determines characteristics of the totality of factors. The process parameters, such as coarseness of mineral grinding, are set for its value as well as optimal beneficiation scheme and reagent regimes are selected.

Primary porphyry copper ores are mainly represented by molybdenite-chalcopyrite ores. Molybdenum content in them varies within the limits of 0.005–0.2%. In the zones of secondary enrichment copper is represented mainly by chalcocite and bornite. Pyrite and copper sulfides, along with fine dissemination in the rock, closely coalesce, forming aggregates interspersed in the bedrock. The disseminated texture is also a characteristic feature for molybdenite, and aggregates which include fine grains of the same bedrock [4].

All the ores are concentrated according to the settled manufacturing schemes, which traditionally include the following stages:

– ore reduction up to the size of 60–65% of a –0,074 mm class, with adding to the mill the lime in the quantities enough for pyrite suppression and carrying out bulk and cleaning flotation;

– further regrinding of roughing concentrates up to the size of 85–90% of a –0,074 mm class for copper flotation with obtaining the copper concentrates meeting the GOST (State standard) requirements;

– bulk molybdenum flotation at optimal pH values 8–12, with the regulated feed of lime and the reagent mode, allowing to obtain the peak for copper and molybdenum extraction. The functional diagram of porphyry copper-molybdenum ore beneficiation for the obtention of copper and molybdenum concentrates, and the pyrite one if cost-effective, is shown in Fig. 1;

– selection of the bulk copper-molybdenum concentrates; method of separation depends on the content of valuable components in the concentrate and amount of sulfides, which are readily or with difficulty amenable to thermal treatment [4]. Thermal treatment during selection is not applied at the plants which process primary sulfide ores or their considerable portion.

In spite of the fact the fact that every company forms its own approach to optimization of the “costs-profit” indicators, the main principle of selecting the reagent regimes, including combination of collecting reagents. In recent decades, mixtures of collectors of different classes became very widely used during flotation of various types of ores, including the copper-molybdenum ones. The mixtures of collectors provide higher selective effect towards copper and molybdenum sulfides and demonstrate high selectivity towards pyrite [11–15].

Combination of weak and strong collectors is mainly used for flotation of primary pyrite ores, and more rarely for the chalcocite ones if grinded coarsely [4]. The collectors, applied in the bulk cycle are as follows: xanthates and dithiophosphates with various length of hydrocarbon radical, dixantogenides, isobutyl dithiophos-

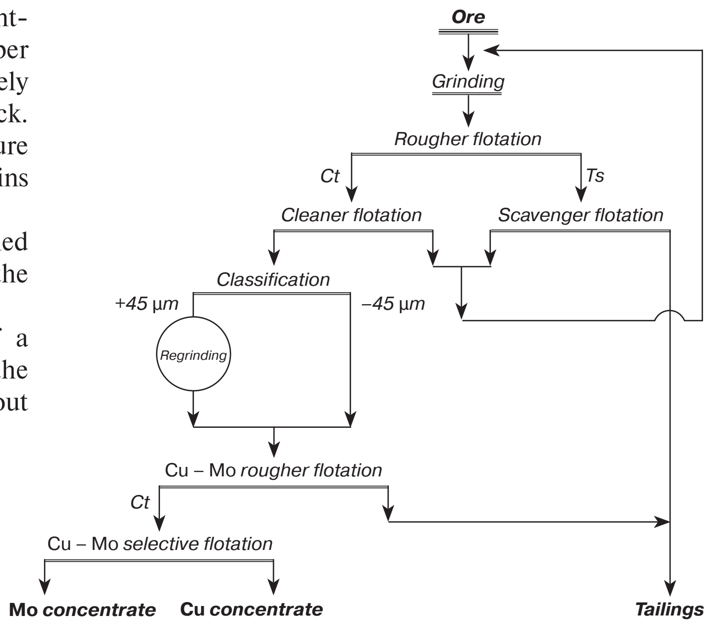


**Fig. 1.** Typical scheme of beneficiation of copper-molybdenum ores

phates (Minerec type reagent), thiocarbamates (Z-200 reagent), allyl ethers of xanthic acids, apolar oils. Use of xanthates combined with modified dithiophosphates, thiocarbamates make it possible to optimize the process of selective adsorption of collectors on the surfaces of sulfides and their required concentration in the pulp liquid phase. Synthetic alcoholic reagents (pine oil, methylisobutylcarbinol (MIBC), T-80, OPSB and their combinations) are used as frothers. MIBC came to the forefront as a reagent more selectively affecting molybdenite in a bulk and especially in the selective cycle [4]. Lime, sodium sulphide, water glass, sodium hexametaphosphate, sulphur dioxide, etc., serve as modifiers of flotation.

Bulk flotation of copper, molybdenum and iron sulfides is carried out in a neutral or alkaline medium. Sodium sulphide (0.1–0.3 kg/t) is used to activate flotation of oxidized copper minerals and slurry peptization. Copper-molybdenum concentrate is cleaned in alkaline medium, produced by lime, at pH of 9–11, providing depression of iron sulfide flotation. Bulk copper-molybdenum concentrate contains about 12–25% of copper and 0.1–0.6% of molybdenum. Before separation it is thickened and is subjected to oxidative steaming with lime (1 kg/t) for 1–4 h at a temperature of 85–95 $^{o}$C, treatment by sodium sulphide, oxidants or low-temperature roasting in order to eliminate the larger part of collector from mineral surfaces or to destruct it. Separation of copper-molybdenum concentrates is based on depression of copper sulfides with molybdenite flotation. Separation of chalcopyrite-molybdenite concentrates is fulfilled applying sodium sulfide or hydrosulfide in a strongly alkaline medium (pH of 10–12).

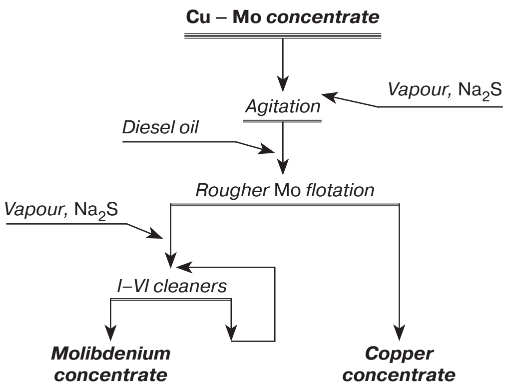


**Fig. 2.** Process scheme of selection of copper-molybdenum concentrates (Erdenet Mining Corporation)

Unfortunately, in spite of a large amount of research, there is a lacking of scientifically justified recommendations on the application of one or other method of selection of copper-molybdenum concentrates depending on their mineralogical composition that has to be done merely by experimental research [4].

*Porphyry copper ores of Erdenetiin Ovoo deposit* are dressed according to a process flowsheet at two sections. The first one includes rougher, scavenger, middlings and cleaning flotations. The second section is focused on selection of copper-molybdenum concentrate, which includes 6 cleaning flotations of molybdenum concentrate. Process flowsheet of molybdenum flotation is represented in Fig. 2. Technological regime of grinding and flotation is given in Table 4.

The following reagents are used for ore-dressing: lime, collectors, frother, sodium sulphide, water glass. Collectors of different manufacturers are used as collectors at concentrating mills: BK-901B (China), AeroMX (Cytec Company, USA). Ratio of BK-901B and AeroMX-5140 collectors is changed depending on content of primary copper forms in the ore being processed. The higher is the content of primary copper, the greater is the consumption of AeroMX and, correspondingly, less that of BK-901B. In case of low content of primary copper minerals, the ratio of collectors increases towards BK-901B. The MIBC frother is used to adjust foaming. Polyacrylamide, a high-polymeric flocculant, is used for flocculation of mineral particles with the purpose of the settling time reduction and acceleration of thickening the concentrates [15]. A technology with batching of sodium sulphide in combination with nitrogen, being fed into floatation machine instead of air, is used at the plant in a selection cycle. The nitrogen usage allows to reduce consumption of sodium sulphide and to increase processing indicators [16].

*El Teniente deposit* in Chile is the largest assured porphyry copper orebody (copper resources exceed 70 million tons) and is genetically related to magmatic activity of late Miocene – early Pliocene on western mountainsides of Cordillera de Los Andes. The process in the ore

Table 4
**Reagent conditions of the copper-molybdenum ore flotation at a concentrating mill of Erdenet Mining Corporation**

| Manufacturing operation | I, II, III and IV sections | | | | | V and VI sections | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Consumption of reagents, g/t of ore | | | | | | | | | |
| | BK-901B | Aero MX | $Na_2S$ | MIBC | pH | BK- 901B | Aero MX | $Na_2S$ | MIBC | pH |
| Load of mills | 0–6 | 4–16 | – | – | CaO | 0–8 | 4–16 | – | – | CaO |
| Rougher flotation | – | – | 30–50 | 8–17 | 9.5–10.5 | – | – | 30–50 | 8–15 | 9.5–0.5 |
| Scavenger flotation | 1.0–2.0 | 1.0–2.0 | 8–12 | – | – | 1.0–2.0 | 1.0–2.0 | 8–12 | – | – |
| Rougher flotation of middlings | – | 0.3–0.5 | 5–10 | – | – | – | 0.3–0.5 | 5–10 | – | – |

preparation division of El Teniente is divided into three sections. The floatation process is carried out in four sections:

– at the first section there is conducted a cycle of rough flotation, including rougher, scavenger, cleaning and reflotating operations;

– at the second section rougher copper flotation takes place;

– at the third section the bulk copper-molybdenum concentrate separation is fulfilled;

– the fourth section includes the auxiliary beneficiation processes.

Copper-molybdenum ore of El Teniente deposit is processed at two concentration mills (Colon and Sewell), then the middling products are united for further treatment and obtaining the finished concentrates of copper and molybdenum (Fig. 3). Data on these mills are gathered over the past 20 years; different types of ores of lower quality have been processed during this period, and therefore, the concentration reagent regimes have been corrected for their effective flotation. At the Colon and Sewell concentration mills the xanthate-based collecting agents and diesel oil are used, Dow250 reagent serves as a frother [17]. Extraction into the primary concentrate amounts to 85% of copper and 60% of molybdenum.

It should be noticed that pyrite concentrate, concentrates of gold, silver, rhenium and selenium are obtained at a Chuquicamata plant as by-products.

*Bute and Anaconda (USA)* mills are also of interest among foreign enterprises. Grinding is realized in two different streams. Ore-pebble grinding with the use of rod mill in a closed loop with hydrocyclones and two ore-pebble mills in a closed loop with hydrocyclones is applied in one of them. The overflow of hydrocyclones of the rod mill is directed to the mud flotation, the overflow of hydrocyclones of pebble mills is floated separately. Lime, isopropyl xanthate; thiocarbamate are fed to the mud flotation; pine oil, methylamyl alcohol, pyrophosphate are fed to the sand one. Pulp density is 17% during mud flotation and 30% during the sand one. Such reagents as Z-200, ethyl xanthate, aeroflot are used as collectors at different concentrating mills. Sulphide-oxidized ore is subject to hybrid process following the method given by V. Ya. Mostovich [17].

*At one of the Climax concentrating mills in USA* is processed a material, in which molybdenite is finely disseminated into quartz veins. Content of molybdenite is up to 0.8%, besides, wolframite, hubnerite, pyrite, chalcopyrite, monazite and cassiterite are also present in the ore. The ore is grinded up to the size –0.59 mm, molybdenite is floated with synthetic hydrocarbons, kerosene, pine oil and sodium salt sulfonated monoglyceride of coconut oil fatty acids. Pyrite, chalcopyrite and other impurities are separated in a process of multistage reduction and reflotation. Rough concentrate is regrinded in four stages: the first one is performed in a ball mill; the 2$^{nd}$, 3$^{rd}$ and 4$^{th}$ stages are fulfilled in a pebble one. Pine oil, soda and cyanides are added to the rough concentrate for cleaning operations. There are extracted 90% of general or 98% of sulfide molybdenum into molybdenum concentrate containing 54% Mo.

Rather low content of metals (up to 0.35% of copper and up to 0.018% of molybdenum) in porphyry copper ores and comprehensive mineralogical composition are among the main factors greatly retarding a potential of flotation efficiency increasing.

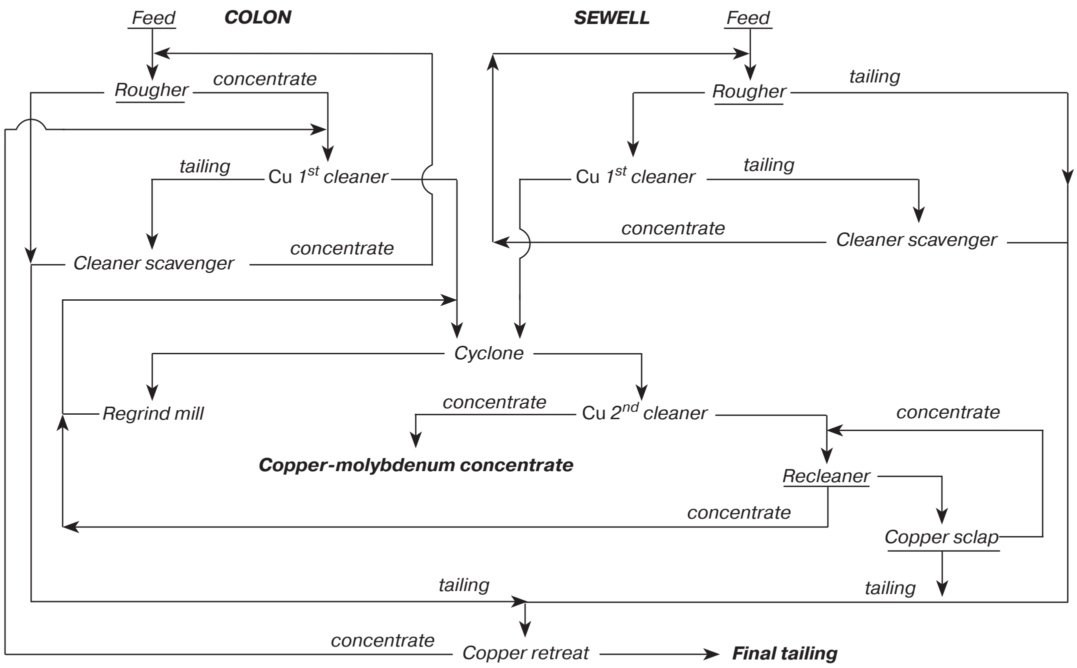


**Fig. 3.** Process scheme of flotation of porphyry copper ores of the El Teniente deposit (Codelco Company)

Frequently, the use of traditional sulfhydric collectors for copper-molybdenum ores lacks the projected results in consequence of chemical sorption of xanthates at the surfaces of almost all sulphide minerals, including pyrite.

One way to increase an efficiency of selective extraction of concentrates is provided by the method based on application of reagent-depressors combined with the feeding of different gases (nitrogen, carbonic acid, oxygen) to the pulp so as to essentially increase the extraction of the reguired metals and to decrease the losses of metals in different concentrates.

A new method of intensification of molybdenite extraction from copper-molybdenum concentrates has been applied by *Gibraltar Mines Ltd. (Canada)* for selective molybdenite flotation. It is based on substitution of pulp airing by air by nitrogen, which allows to fourfold cut down the consumption of NaHS as a depressor of copper minerals and to improve in that way the selectivity. A practical implementation of this approach was taken up at concentrating mills in USA, Canada, Peru, Mongolia, etc.

The elaboration of new flotation methods is based, as usual, on a search or generation of new flotation reagents of different classes, enabling to significantly increase the beneficiation process indicators. In this way, the reasonable consumption of sulfhydric-type collectors of the Orfom series, developed and manufactured by Philips Chemical company (USA), successfully replaced xanthates, dithiophosphates, thicarbamates when flotating molybdenum and copper- molybdenum ores.

High quality of concentrates and extraction of metals into them at high mud content in the ores may be achieved with the use of the scheme of divided sand and mud flotation (concentration mill of Almalyk Mining and Metallurgical Complex, Republic of Uzbekistan); the schemes with coarse ore grinding and reflotation of sulphides from the sand part of tails after their regrinding (the El Salvador mill, Chile) and without regrinding (concentration mill of Balkhash Mining-Metallurgical Combined Enterprise, Kazakhstan).

## New lines of investigation of the copper-molybdenum ore flotation

The DMIPEC (ДМИПЭК) and DC-80 (ДК-80) tertiary acetylene alcohols have been tested as additional collectors of the standart mode 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). They have demonstrated important results with regard to increase of copper and molybdenum extraction both in the bulk cycle and on the selective separation [18].

It was found that application of DMIPEC and DC-80 reagents encourages an increase of extraction of metals into concentrates. In order to reveal the reasons of such increase of extraction, quantum chemical calculations of mechanism and force of the DMIPEC reagent interaction with sulphides of non-ferrous metals have been carried out by means of determination of stabilization energy of the resultant complexes. It is shown that ethylene and acetylene bonds play a part of the reaction center when DMIPEC and DC-80 reacts with the surface of sulphide minerals, and interaction between the reagents and metal cations on the surface results in formation of molecular $\pi$-complexes [19].

During flotation of non-ferrous metal ores, the DMIPEC and DC-80 reagents show themselves as selective additional collectors with foaming properties. At consumption of 3–35 g/t they allowed to reduce the flotation time owing to almost two times increase the flotation rate. Extraction of copper increases by 3.5%, zinc — up to 12%, gold — up to 8–10%. Their application permit to improve quality of obtained concentrates, to raise stability of the flotation process indicators and to decrease the ecological burden on the environment in the surroundings areas of the flotation plants [20].

The paper [21] is devoted to perfection of the copper-molybdenum ore reagent mode at the Erdenet Mining Corporation concentration mill of, where the DMIPEC and DC-80 reagents have been tested in laboratory conditions. Combination of solidophilic acetylene and hydrophilic alcoholic groups in molecule structure of the reagents imparts the properties of collectors-frothers to them. The results of the conducted experiments have showed that the tertiary acetylene alcohols usage as additional collectors is more effective when fed in parts both on at the preparatory cycle (grinding) and on bulk and selective flotation cycles in combination with the reagents used at the factory, including: BK-901 (dialkyldithiophosphate dialkyldithiocarbamates), AEROMX-5152 (from 15 to 40% of allyl ether of xanthic acid), diesel oil of the «E» («Э») sort and MIBC (methylisobutylcarbinol). Extraction of copper and molybdenum has been increased by 1–1.5% and 6–8% respectively.

When studying the pH and pulp potential influence on selective molybdenite extraction from copper-molybdenum bulk concentrate of the Sungun copper mine (Iran), it was established that addition of 16 kg/t of $Na_2S$ into flotation pulp followed by rapid airing reduces an oxidation-reduction potential (ORP) of the pulp. Maximal molybdenite extraction from Mo-Cu concentrate has been achieved at pH = 10.5 and ORP $\leq$ 300 MV. It has been also proved that airing by nitrogen at a foaming stage leads to lowering of the pulp potential and decrease in $Na_2S$ consumption from 16 to 6 kg/t. In such conditions, molybdenum extraction of 92.88% has been reached [22].

It is supposed that lower flotation extraction of molybdenite as compared with extraction of copper sulfides stimulated by a series of factors, including morphology of particles, natural hydrophobicity and possible formation of mud coatings in the presence of nonmetallic minerals, innate for skarn ores [22].

Molybdenite flotation from porphyry copper ore is more sensitive to the pulp liquid phase parameters than flotation of sulfide copper minerals. Molybdenite extraction into bulk concentrate in *Kennecott Utah Copper* highly varies and is always lower than that for copper. Particularly low molybdenite extraction has been observed in the presence of lime skarn ore. It has been established that molybdenite extraction is higher and more stable at a reduced content of solids in pulp (27% instead of 35%) [23].

There were revealed several factors, which may affect molybdenite flotation; all of them are connected with specific properties of this mineral. Predominant splitting along the slightly coupled S-S layers may give singular hydrodynamic behaviour (low collision efficiency because of flat and elongated shape of particles) and anisotropy on hydrophobicity (both hydrophobic and hydrophilic faces, highly reactive edges) of the molybdenite particles. It is shown that edges of molybdenite particles have noticeably less angle of moistening in comparison with faces, particularly, at high pH (about 10) in typical flotation medium [23].

Presence of mud of silica-alumina minerals has negative impact on copper floatability during processing the porphyry ores. There have been studied the ores, containing different types of silica-alumina minerals in various amounts, as well as copper sulfides (chalcopyrite and chalcocine), for the purpose of determining the silica-alumina minerals impact on copper flotation and the ways of reducing their negative effect. It has been demonstrated that muscovite and vermiculite have the most effect on flotation of copper sulfides. To solve this problem, two types of reagent-depressors have been used: a) dextrin at dosage of 100, 200 and 600 g/t; b) mixture of dextrin, sodium silicate and sodium hexametaphosphate at component ratio (20%, 40% and 40% by mass, respectively) and consumption of 200 and 300 g/t. Mixture of reagents (b) at 200 g/t elevates copper extraction and brings down extraction of $Al_2O_3$ and $SiO_2$ into concentrate. Pulp flotation with the reduced pulp density relative to the one being used now (24% instead of 29%) is proposed as an alternative solution. Growth of copper and molybdenum extraction has been accomplished on lessening extraction of $Al_2O_3$ and $SiO_2$ [24].

In [25] there are represented the results of applying synthesized 4Amino-3-thioxo-3,4-dihydro-1,2,4-triazine-5(2H)-one (ATDT) as a depressor for selective molybdenite flotation and extraction from chalcopyrite. The extended laboratory testing has showed that ATDT is a very powerful depressor for chalcopyrite; the selection index of Mo-Cu concentrates greatly increases in the presence of ATDT. The results of the studies have confirmed that ATDT may be chemisorbed on the chalcopyrite surface through S and N atoms with formation of pentamerous chelate rings. Molecules of ATDT are not practically sorbed on the molybdenite surface.

Hydrogen peroxide ($H_2O_2$) is often used as an oxidizing agent in different branches of industry. The aqueous solution of $H_2O_2$ is also used for selective flotation of chalcopyrite and molybdenite. However, the peroxidation method had failed and besides, an excessive consumption of reagent has increased the cost of the reagent flotation mode; as a result, the method has been considered as economically non-feasible. Efficiency of mineral oxidation in the presence of hydrogen peroxide may be heightened with the help of ferrous iron, when Fenton reagent is used as catalyst, since it is more powerful oxidant. The results of flotation tests demonstrate that selective flotation of chalcopyrite and molybdenite is possible at low concentration of the aqueous solution of $H_2O_2$ providing addition of the ferrous salts. Moreover, at that the conditioning time may be reduced as well [26].

Copper and molybdenum at the Chile deposits are extracted together, and then they are extracted in the selection process, which includes several flotation stages with the use of sodium hydrosulfide (NaHS) as a depressor of copper. However, there exist ecological problems concerned with potential emissions of toxic and badly smelt sulphuretted hydrogen gas, which may touch neighbouring settlements and have negative impact on the environment. This problem leads to the need for elaboration of new technologies eliminating NaHS usage in the process of selective flotation of copper and molybdenum minerals. It has been shown that reagents – the derivatives of lignine may be used for selective flotation extraction of Cu and Mo minerals. In this technology, molybdenite is suppressed by an action of derivatives of lignine (lignosulphonates), whereas copper sulfides remain hydrophobic and are floated. Use of lignine derivatives in the processes of the copper-molybdenum minerals selective flotation is an environmentally friendly alternative to sodium hydrosulfide NaHS [27].

In the paper [28] it is reported a simple and efficient process, namely, usage of a mixture of surface-active substances O-isopropyl-N-ethylthionocarbamate (IPETC) and 4-tert-Butylbenzyl mercaptan (BBSH). The results of investigations has showed that collecting capability of BBSH is slightly higher than that of IPETC, but the latter is more selective collector for pyrite than BBSH. Complex collector has demonstrated better characteristics; its collecting capability towards chalcopyrite is higher than that of IPETC, and its selectivity towards chalcopyrite and pyrite is higher than that of BBSH. Displayed has been an advantage of applying the mixture of IPETC and BBSH reagents, resulting in a synergetic effect, which significantly exceeds common technological indicators and characteristics of flotation.

Shortage of sweet water for mining operations in arid areas in different parts of the world set the mineral resource companies thinking about the seawater utilization as an alternative source during minerals processing. Studies have showed that molybdenite flotation is suppressed at high pH values in sea-water as a result of activity of magnesium and calcium hydroxycomplex, which fasten onto facets of molybdenite particles thus lowering its hydrophoby. The results of research on the interaction between molybdenite and kaolin are represented in [29]. The findings allow to conclude that kaolin have more depressing effect on molybdenite in seawater than in fresh water. Magnesium and calcium are cations which have the most important influence upon strengthening the interaction between molybdenite and kaolin.

## Conclusion

– Porphyry copper ores are dressed according quite simple schemes of bulk-selective flotation with the obtaining of copper and molybdenum concentrates. The cycle of selection of copper-molybdenum concentrates usually includes rougher, scavenger flotation and 4–8 cleaning operations, with regrinding the concentrates of some cleaning stages or middlings in a number of cases.

– In a bulk cycle, there are used the collecting agents which are selective towards pyrite and contributory for essential reduction of lime consumption. As a rule, these are the mixtures of ionogenic and nonionic collectors or the mixtures of strong and weak collectors with various length of hydrocarbon radical.

– Analysis of modern methods of developing the promising technologies of copper-molybdenum ore beneficiation has showed that the main problems of flotation are still selectivity; availability to float large mineral particles and their aggregates, as well as oxidized minerals; gain in extraction of accompanying components; elaboration and application to production of non- or low-toxic reagents; utilization of combinations of ionogenic and nonionic (nonpolar) collecting agents.

– The process indicators of the porphyry copper ores beneficiation may be raised by applying the innovative solutions based on the research-guidance foundation and confirmed by industrial tests. Modification of the existing reagent regimes of flotation is the most topical line for improving the processing technologies of porphyry copper ores. Development of new methods and regimes of flotation, as a rule, is based on a search or generation of new reagents of different classes, enabling to significantly increase the beneficiation process indicators.

– It was demonstrated that tertiary acetylene alcohols, which have achieved good results on the growth of copper and molybdenum extraction both in the bulk and selective cycles by 1–15% (Cu) and 6–8% (Mo), may serve as prospective additional collecting reagents in the process of copper-molybdenum ore flotation.

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