

Flotation of copper-zinc ores using reagents based on acetylene alcohols

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The article presents the results of theoretical calculations and experimental studies to assess the possibility of using reagents based on acetylene alcohols as an additional collector in the flotation of copper-zinc ores. The correspondence of theoretical and calculated data to the results of flotation of copper-zinc ores with the use of acetylene reagents capable of forming π -complexes with zinc sulfides, mainly by the nucleophilic mechanism, is proved. The individual ability of the DMIPEC reagent to form π -complexes with zinc by nucleophilic and electrophilic mechanisms, as well as the individual ability of the molecules of the DC-80 reagent to attach to zinc atoms by the mechanism of substitution reaction was revealed.

Flotation studies in laboratory conditions on samples of sulfide ores of some deposits of Kazakhstan have obtained a significant increase in the level of extraction of target metals, including zinc, a decrease in zinc losses in copper concentrate by 7.8%, an increase in the quality of copper concentrate by 4.9% when used as an additional collector of reagents of the acetylene alcohols class.

Key words: acetylene reagents, sphalerite, wurtzite, zinc, non-transition metal, electronic state, π -complexes, quantum chemical calculation, extraction.

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Introduction

Copper-zinc, pyritic copper-zinc and polymetallic zinc-bearing ores are characterized by a complex material composition and are among the most difficult objects of beneficiation. These are sulfide ores in which zinc is mainly in the form of sphalerite ZnS. The main method of beneficiation of such ores is flotation. Despite the large number of studies and publications in this area, proposed and used in practice various technological modes, and schematic solutions [1], the development of new reagent modes of selective flotation of non-ferrous metal sulfides is still a very relevant scientific and technical task.

One of the effective methods of sulfide copper-zinc ore beneficiation is direct selective flotation, which includes relatively coarse grinding of the initial ore, flotation of copper sulfides with sphalerite depression by zinc-cyanide complexes, and then flotation of sphalerite activated by copper sulfate CuSO_4 [2].

Attempts to float sphalerite without activation by copper sulfate showed that the best recovery of sphalerite at optimal reagent mode is about 80% (Zn content – 32%). This value was achieved when N-phenylhydroxylamine (HCNPHA) was included in the reagent mode in the amount of 67 g/t as a collector. The main disadvantage of this technology was the increased recovery of pyrite together with sphalerite [3].

It is noted that the pH of the slurry, as well as the type of collector used, plays an important role in the benefi-

ciation of lead-zinc ore. For example, ethyl xanthate and Aero 3418 reagent is effective for lead flotation, and Aero 3477 reagent and amyl xanthate is effective for zinc flotation. The highest zinc content in concentrate and recovery rate of 42.9% and 76.7%, respectively, were achieved at pH = 6 in the presence of Aero 3477 as a collector.

An effective solution for galena and sphalerite flotation was the use of a selective collector mixture consisting of Aerophine 3418 and potassium amyl xanthate (PAX), which showed better recovery and efficient separation of sphalerite and pyrite [5].

Sufficiently high performance of selection in flotation of polymetallic ore was obtained with the inclusion of copper sulfide collector Z-200 (O-isopropyl-N-ethylthiocarbamate) in the reagent mode. Under optimum conditions, the recovery of Cu, Zn and Fe in the corresponding concentrates was 86.1%, 87.6% and 77.8%, and the content of major components in the concentrates was 20.31%, 45.97% and 63.39% [6].

The mixture of collectors with dixanthogenide additives in the amount of 10% increases the yield of unactivated sphalerite from Altai and Dalnegorsk deposits by 4%, from Sadonskoye deposit – by 5%, with Zn recovery in the concentrate of 60–81% [7].

Flotation of pyritic copper-zinc ore of Gaisky deposit with a mixture of butyl potassium xanthate, dithiophosphate and thionocarbamate allows to increase the extraction of copper and zinc in the collective concentrate while maintaining its quality, to achieve an increase in the total

extraction of copper and zinc, taking into account the extraction of iron in copper-zinc concentrate by 32.05% compared to the basic mode, when only butyl potassium xanthate was used as a collector [8].

In the presence of iron compounds, which take an active part in oxidation-reduction reactions in the processes of grinding and flotation, the separation of copper and zinc minerals is better at a concentration of sodium sulfide $5 \cdot 10^{-3} - 10^{-4}$ g-eq/l; with increasing concentration, the flotation activity of all minerals decreases; the optimum values for mineral separation are pH values not higher than 9.5. When cyanide is applied at rates greater than 50 g/t in the presence of iron compounds, flotation of all sulfide minerals is actively inhibited over a wide pH range [9].

At fractional separation of sphalerite of different generations zinc losses in copper concentrate are reduced by 2 times and zinc recovery is increased by 10% [10].

At present, quantum-chemical studies are one of the key directions in the development of selectively acting reagents, which allow to establish a close relationship between

the spatial structure of molecules and the chemical activity of the formed compounds and have become a reliable tool for studying the structure of flotation reagent molecules and establishing the peculiarities of intermolecular interactions [11]. This approach was also used by us in our study of the flotation process of zinc sulfides in the presence of reagents belonging to the class of acetylene alcohols.

The aim of the work is to study the process of selective flotation of sulfide copper-zinc ores in the presence of reagents based on acetylene alcohols using the method of quantum-chemical evaluation of intermolecular interactions.

Results of the study

When forming an approach to selective flotation of zinc-bearing, including copper-zinc ores, it was taken into account that Zn belongs to the group of non-transition elements. There are a number of differences between non-transition and transition elements in that non-transition elements do not show variable valence, nor do they form compounds in which the *d*-layer would be unfilled. The metals of this group Zn, Cd and Hg are soft and low-melting, in addition, Zn and Cd are more electropositive elements than their table neighbors in the transition series. The strength of any *dπ*-bonding between metal and ligand is much weaker than that of *d*-transition elements. For elements of this group, complexes with olefins easily formed by transition metals are unknown, and the effect of stabilization by the ligand field has not been established [12].

The maximum filling of the *d*-layer with electrons, as well as the high value of the third ionization potential of 39.722 eV determine the constant valence of zinc equal to 2, which characterizes it as a non-transition metal. At the same time, the ability of zinc to form complex compounds with ammonia, amines and other reagents allows us to refer it to the group of transition elements as well [13].

The zinc atom has two electrons in the outer energy level, which are valence electrons: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2$. As a result of chemical interaction, zinc donates its valence electrons, i.e. is their donor, and turns into a positively charged ion: $Zn^0 - 2e \rightarrow Zn^{2+}$.

Peculiarities of material composition of zinc-bearing polymetallic ores cause significant technological difficulties of flotation separation of copper and zinc sulfides [9, 10]. Our studies have shown that the use of reagents based on acetylene alcohols, such as DMIPEC, DC-80, DC-100, etc., can significantly increase the efficiency of selective separation of sulfide minerals of polymetallic ores in the flotation process as well as the extraction of target metals in the corresponding concentrates [14–18].

In sulfide ores zinc can be found in the form of two polymorphic modifications differing not only by structural features, but also by conditions of formation. Sphalerite is characterized by cubic structure of the crystal lattice (Fig. 1), while wurtzite is characterized by hexagonal structure (Fig. 2).

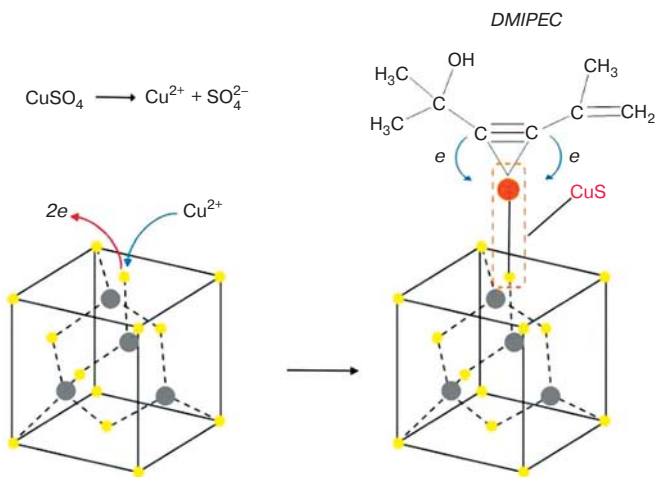


Fig. 1. Model of CuS-sphalerite (ZnS) + DMIPEC complex formation by nucleophilic mechanism

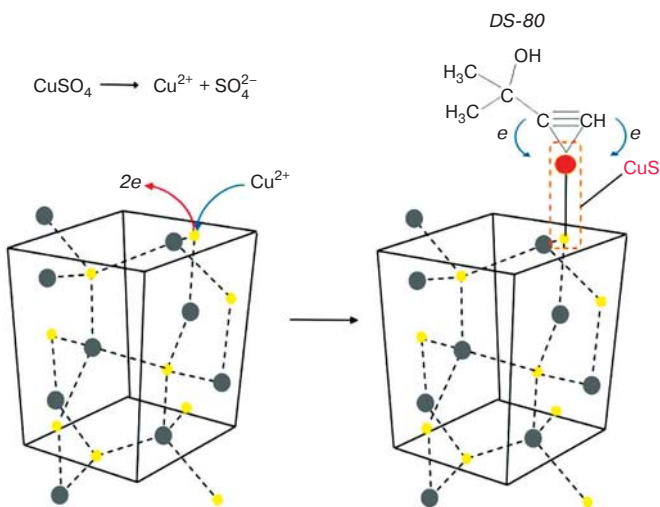


Fig. 2. Model of formation of CuS-wurtzite (ZnS) + DC-80 complex by nucleophilic mechanism, where: atoms: ● — S; ● — Zn

In the cubic packing (face-centered cubic packing – FCC) of sphalerite, the nodes of the FCC are occupied by S atoms, and the centers of the four tetrahedral cells are occupied by Zn atoms. There is no center of symmetry in this structure, these structures are polar. In the hexagonal packing of wurtzite, the densest packing is formed by parallel layers of S anions, Zn cations fill half of the tetrahedral cells.

The unit cell structure of sphalerite shows that Zn atoms are densely surrounded by S atoms, which makes them inaccessible for the formation of chemical bonds in the process of interaction with reagents-collectors during flotation.

The drawing of a unit cell of sphalerite is made in the graphic vector editor INKSCAPE 0.92 (5da689c313, 2019-01-14).

For the development of effective reagent mode of sphalerite flotation important is the fact that zinc belong to the elements of the main subgroup, the outer shells of which contain only *s*- and *p*-electrons and is the so-called group of non-transition elements. These elements are characterized by the formation of only doubly charged cations [19]. In non-transition metals, the second outer electron layer is fully packed with electrons (eight or eighteen). Non-transition elements form typical σ -bonds with sulfur atoms (non-metal) at the expense of outer shell electrons [20].

According to the coordination bond theory, the change in heat of hydration of non-transition metals is inversely proportional to their ionic radii. So, for example, Zn^{2+} cation as well as Ca^{2+} cation at large distances will have close potential, but at distances equal to bond lengths, the “effective charge” of zinc will be greater. This is due to the fact that d-electrons on average spend only part of their time at long distances from zinc, greater than the chemical bond length. For this reason, the “effective charge” of zinc can be ~10% higher than its nominal charge of +2 [21].

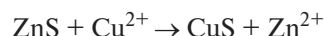
According to the traditional scheme of selective flotation in the head of the process after grinding the ore to a coarseness of 85–95% of the class –0.074 mm flotatate copper sulfides at depression of sphalerite and pyrite, at the same time in the composition of the basic reagent mode of flotation added additional acetylene collector DMIPEC, which promotes selective flotation of unoxidized copper sulfides.

When sphalerite is flotated from copper flotation tailings, it is activated with copper sulfate and extracted into zinc concentrate. The model of interaction of acetylene reagent molecule DMIPEC and DK-80 with copper cation by nucleophilic mechanism on the surface of copper sulfate activated sphalerite is shown in Fig. 1, and wurtzite in Fig. 2. For successful flotation, the surface of sphalerite must be covered with a thin film of copper sulfide CuS at least 25–30% of the monolayer.

Thus, the flotation of sphalerite from copper flotation tailings after its activation with copper sulfate confirms

the realization of the fundamental nucleophilic mechanism of interaction between flutable sulfides atoms, in this case copper, and the acetylene triple bond of DMIPEC reagent molecules and explains the selective separation of sulfides: in copper flotation – copper recovery, in zinc flotation – zinc recovery.

Activation of sphalerite surface with copper ions is carried out using copper sulfate. In this case, a copper sulfide film is formed on the surface of sphalerite due to the exchange reaction, which is oxidized according to the known mechanism and becomes capable of forming compounds with sulfhydryl collectors – xanthates and aerofloats:



Selective complexes are formed between the copper cation and the acetylene bond by a nucleophilic mechanism depicted in 3D model format in Fig. 3.

For a ground state (Fig. 4, a), π -complex $[Cu^0 + C_2H_2]$ in the MO method is characterized by nucleophilic substitution, when there is an electron transfer from the $2p_y$ -orbital of the nucleophile (C_2H_2) to the lowest free MO of the ligand $4s$, resulting in the formation of $2p_y4s$ -hybridized MOs. The model of $2p_y4s$ -hybridization of MOs (b) in the formed π -complex is shown in Fig. 4, b.

For acetylene reagents selectivity towards transition metal atoms of sulfide minerals is determined by the presence of carbon-carbon $C \equiv C$ -bond, which is characterized by reactions of electrophilic Ad_E and nucleophilic Ad_N addition, with Ad_N addition reaction being the priority, as limiting the rate of addition. This is due to the fact that in alkynes the *sp*-hybridized carbon atom has a higher electronegativity, the positively charged nuclei of carbon atoms of alkynes are shielded on the outside to a lesser extent than in alkenes and alkanes. This provides priority to the nucleophilic nature of the addition reaction in the rate-determining stage of the reaction when the triple bond of acetylene reagents interacts with the metal atoms of sulfides. Thus, the unhybridized $2pp$ -orbitals of the acetylene bond provide the formation of a π -complex with the $4s$ -orbital of the copper atom. Thus, a unique

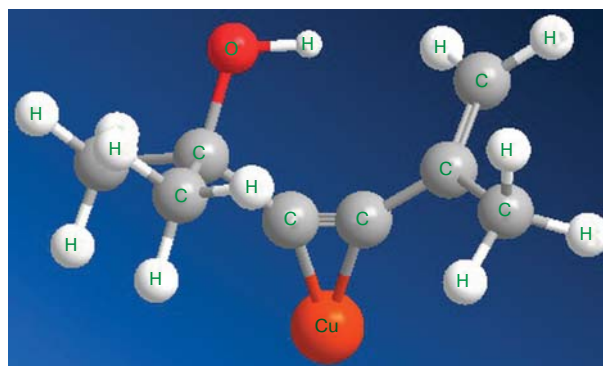


Fig. 3. 3D model of the π -complex $[CuS + DMIPEC]$ formed by a nucleophilic mechanism in the (HUMO) state

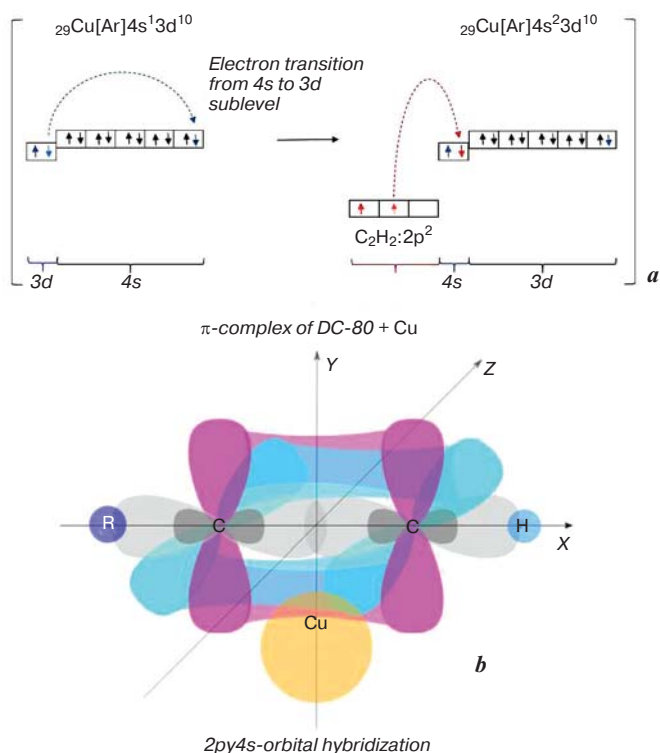


Fig. 4. Presumptive electronic configuration of the π -complex (a) formed by the acetylene reagents via a nucleophilic mechanism; configuration of the $2py4s$ – MO hybridization (b) in the formed complex, where: R – (OH, CH_2 and CH_3 of the corresponding reagents DC-80 and DMIPEC)

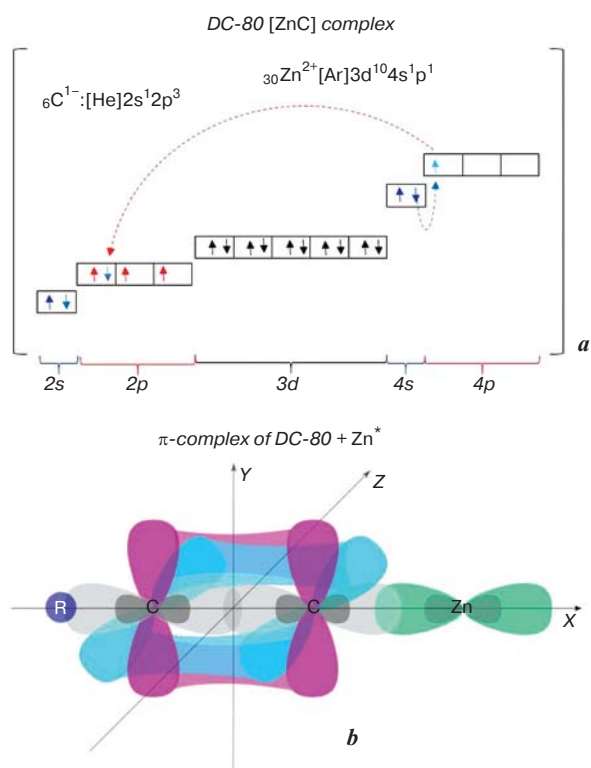


Fig. 5. Presumptive electronic configuration of the complex formed by the Zn^{2+} atom with the end C atom of the DK-80 reagent molecule, by substitution mechanism (a), and the $4sp$ hybridization configuration of MO (b): where: R – (OH, CH_2 and CH_3 correspond to DC-80)

selective flotation based on the interaction of $\text{C} \equiv \text{C}$ -bonding of acetylene reagents with sulfide atoms, which are in the unoxidized form, is provided.

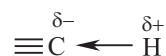
The generalized electrons involved in MO hybridization become simultaneous hybrid electron orbitals without leaving the orbitals of their atoms. No external additional energy is required for the formation of π -complexes formed by the nucleophilic mechanism.

An important factor for flotation is the transition of the zinc atom from the $4s^2$ state to the $4sp$ state, which has an energy of 370 kJ/mol. This is much lower than the ionization energy of $\text{Zn} \rightarrow \text{Zn}^{2+} I_1 + I_2$, which is 2500 kJ/mol. For this reason, it is more energetically advantageous for zinc to transfer electrons from the s to the p -sublevel than to lose them.

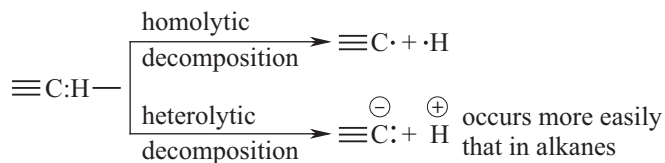
The electronic state of the complexes formed between the reagent atoms of DC-80 and Zn^{2+} atoms in the excited state is shown in Fig. 5, a. The $4sp$ -hybridization pattern of MO (b) in the formed complex is shown in Fig. 5, b.

Chemical interaction of reagents with zinc atoms is possible by obtaining additional energy from the external environment when the zinc atom moves to the excited state $^{30}\text{Zn}^{2+}$. Further, sulfur atoms are oxidized and as a result of substitution reaction, the oxidized sulfate ion SO_4^{2-} is replaced by the terminal carbon atom "C" of the terminal acetylene reagent DC-80, with energy for $\text{Zn} - \text{C}$ equal to 18.72226 J/mol.

Of particular interest for terminal acetylene reagents (with hydrogen at the terminal triple bond) is the C – H bond, which allows to enter into reactions of substitution of hydrogen at the triple bond, which has weak acidic properties. This bond has a noticeable polarity associated with a larger fraction of the s -state of the hybrid orbital and, consequently, with a greater proximity of the electron pair of the $\equiv \text{C} - \text{H}$ bond to carbon:



As a result of the shift of the s -bond electron cloud from the hydrogen atom to the carbon atom, the hydrogen atom becomes partially positively charged. The dissociation energy of the carbon-hydrogen bond in acetylene $\equiv \text{C} - \text{H}$ is higher than in ethylene; sp -hybridization makes it difficult to perform homolytic decomposition of the $\equiv \text{C} - \text{H}$ bond to form radicals, but it makes it easier to perform heterolytic decomposition of the bond to form ion.



By S_R (Radical substitution reactions) it is also possible to obtain acetylenides of univalent metals in ammonia solutions of Ag^{1+} and Cu^{1+} oxides.

The interaction of DMIPEC reagent with copper cations was evaluated by performing quantum-chemical

calculations. To calculate the bond formation energy of acetylene reagent complexes with metal cations of the crystal lattice of sulfide minerals, the authors used the computer simulation program Chem Bio Draw Ultra 14.0 and Chem Bio 3D Ultra 14.0, a specialized complex of Chem Office by Cambridge Soft corporation.

Calculation of complexes formed by DMIPEC reagent molecules with copper cations was performed by the MM2 program application — by the molecular mechanics method, using the ChemBio3D 11.0 package, included in the Chem Bio Office 2008 (for Windows) package, developed by the company SambridgeSoft Corporation. In the framework of the MM2 molecular mechanics method, the total energy of the studied Cu+DMIPEC complexes (**Table 1**), is the sum of energy terms: chemical interaction energy, valence angle energy, torsional interaction energy, Van der Waals interaction energy, electrostatic interaction energy and is expressed in kcal/mol. The MM2 method is developed for modeling and calculations of organic molecules and complexes. It takes into account the potential fields formed by all atoms of the calculated system [22].

The calculated data of total potential energy of complexes formed by molecules of DMIPEC reagent with Cu cations showed that at formation of π -complex with triple acetylene bond by nucleophilic mechanism has an energy of 2926.4720 kcal/mol, at formation of π -complex with double bond of molecule by electrophilic mechanism the energy is one order of magnitude lower and equal to 216.8387 kcal/mol. When the acetylene molecule

of DMIPEC reagent interacts with the copper cation of unoxidized sulfide, the nucleophilic mechanism is more preferable, which determines the selectivity of flotation.

To compare the reagents used in sphalerite flotation, calculations (**Table 2**) of the total energy of reagent complexes formed between Zn atoms and reagents were performed: DC-80, butyl potassium xanthate (BPX) and dialkyl dithiophosphate (DADTP).

Based on the calculated indicators, the investigated formed complexes can be arranged in a row by increasing total energy of the complexes: DC-80 < BPX < DADTP, which means a similar sequence in the priority of the order of their formation. Calculations have shown that the terminal acetylene reagent DC-80 can participate in the reaction of substitution of terminal hydrogen, and as well as the BPX sulfhydryl collectors, DADTP afloat, form complexes with zinc cations, but significantly weaker ones.

The presented theoretical and calculated data allow us to consider that a common property for acetylene reagents is their ability to form π -complexes with copper and zinc sulfides. The reagent DMIPEC, containing conjugated acetylene (triple) and ethylene (double) bonds in its molecules, capable of forming π -complexes by nucleophilic and electrophilic mechanisms, has more universal properties. Molecules of the reagent DC-80, which is a tertiary terminal acetylene alcohol, are capable of attaching to zinc atoms by the mechanism of substitution reaction.

Confirmation of the above assumptions and quantum-chemical calculations was obtained during flotation studies

Table 1
Calculated indicators of Cu + DMIPEC π -complexes

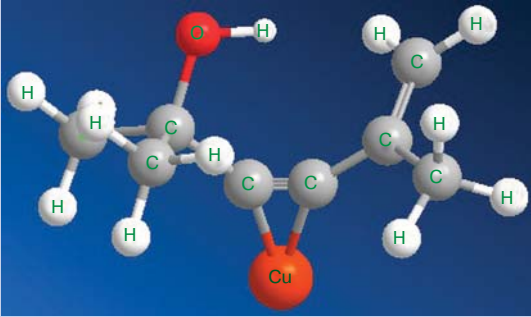
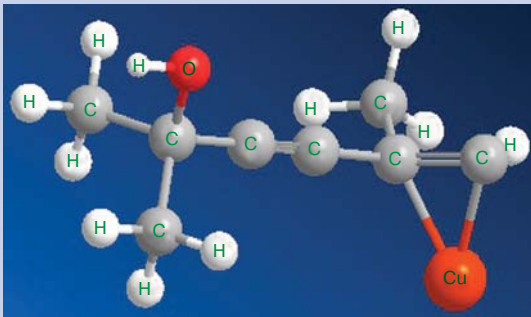
3D-model of Cu + DMIPEC π -complexes formed by mechanism:			
Nucleophilic		Electrophilic	
			
Calculated indicators of π -complexes (kcal/mol)			
Stretch	387.1917	Stretch	29.1613
Bend	2641.9818	Bend	166.2102
Stretch-Bend	-101.5654	Stretch-Bend	-15.0039
Torsion	-0.1604	Torsion	31.2967
Non-1.4 VDW	-5.9965	Non-1.4 VDW	-1.0295
1.4 VDW	5.0590	1.4 VDW	5.1254
Dipole/Dipole	-0.0383	Dipole/Dipole	1.0785
Total energy	2926.4720	Total energy	216.8387

Table 2
Calculated indicators of Zn π -complexes

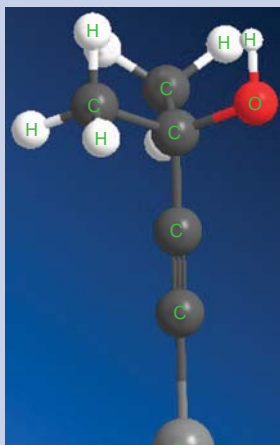
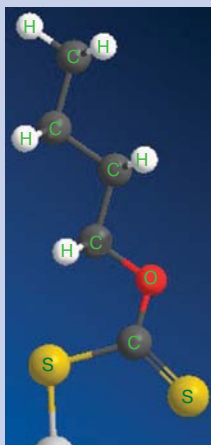
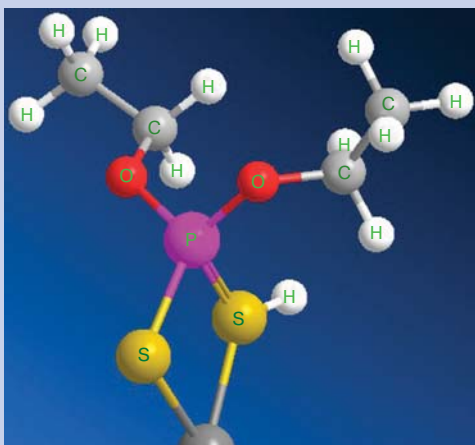
3D model of Zn π -complexes formed with reagents:					
DC-80		BPX		DADTP	
					
Calculated indicators of π -complexes (kcal/mol)					
Stretch	0.1796	Stretch	0.5085	Stretch	7.4515
Bend	0.5717	Bend	2.3213	Bend	296.9333
Stretch-Bend	0.0578	Stretch-Bend	0.2111	Stretch-Bend	-6.8560
Torsion	1.1966	Torsion	0.0073	Torsion	31.5675
Non-1.4 VDW	-1.1569	Non-1.4 VDW	-0.6278	Non-1.4 VDW	-2.5959
1.4 VDW	2.3180	1.4 VDW	5.9992	1.4 VDW	5.6520
Dipole/Dipole	1.0190	Dipole/Dipole	1.8005	Dipole/Dipole	-1.3108
Total energy	4.1858	Total energy	10.2201	Total energy	330.8416

Table 3
Component balance based on the results of closed circuit flotation experiments to assess the flotation ability of DMIPEC reagent (copper-zinc polymetallic ore of Maleevskoye deposit)

Product name	Yield, %	Content, %				Recovery, %				Selectivity coefficient, % $E_{Cu} - E_{Zn}$
		Pb	Zn	Cu	Fe	Pb	Zn	Cu	Fe	
Test No. 1. OPSB reagent of OOO PO "Khimprom" (Kemerovo) - standard										
Head Cu concentrate	5.21	5.11	4.00	23.86	28.23	41.74	5.27	36.58	5.85	79.52
Scavenging Cu concentrate 2	10.01	3.20	4.42	20.16	32.69	50.27	11.20	59.43	13.04	
Total Cu concentrate	15.22	3.85	4.28	21.43	31.16	92.02	16.48	96.00	18.89	
Cu scavenger tails	84.78	0.06	3.89	0.16	24.01	7.98	83.52	4.00	81.11	
Ore	100.0	0.64	3.95	3.41	25.10	100.0	100.0	100.0	100.0	
Test No. 2. DMIPEC reagent PJSC "MCC "EuroChem" (Moscow)										
Head Cu concentrate	3.40	6.76	2.55	23.41	25.74	37.33	2.25	25.31	3.55	87.41
Scavenging Cu concentrate 2	8.09	4.45	3.07	27.56	26.42	58.36	6.42	70.76	8.65	
Total Cu concentrate	11.49	5.13	2.92	26.33	26.22	95.69	8.66	96.07	12.20	
Cu scavenger tails	88.51	0.03	3.99	0.14	0.14	4.31	91.34	3.93	87.80	
Ore	100.0	0.62	3.87	3.15	24.70	100.0	100.0	100.0	100.0	

on samples of zinc-bearing sulfide ores of a number of deposits.

At flotation of Maleevskoe deposit ore (Republic of Kazakhstan), belonging to copper-zinc polymetallic type (Table 3), with the use of DMIPEC reagent was found an increase in the quality of copper concentrate by 4.9%, a decrease in iron content by 4.94% and an

increase in the selectivity factor (difference of copper and zinc recoveries in copper flotation operations) by 7.89%, while maintaining the level of copper recovery in copper concentrate compared to the basic experience.

There is a decrease of zinc losses in copper concentrate by 7.8%, which, taking into account its content in

Table 4

Component balance based on the results of closed circuit flotation experiments to assess the flotation ability of flotation agent DMIPEC

Product name	Yield, %	Content, %				Recovery, %				Selectivity coefficient, % ($E_{Cu+} + E_{Pb}$) - E_{Zn}
		Pb	Zn	Cu	Fe	Pb	Zn	Cu	Fe	
Test No. 1. Reagent C-7 of "Clariant" company (Germany) – standard										
Cu – Pb concentrate	11.08	14.20	2.80	19.20	21.94	84.68	2.65	87.29	11.89	169.32
Cu – Pb scavenger tails	88.92	0.32	12.80	0.35	20.25	15.32	97.35	12.97	88.11	
Ore	100.0	1.86	11.69	2.45	20.44	100.0	100.0	100.0	100.0	
Test No. 2. DMIPEC reagent PJSC "MCC "EuroChem" (Moscow)										
Cu – Pb scavenger tails	10.19	14.80	2.36	20.00	19.00	84.85	2.09	87.64	9.66	170.40
Ore	89.81	0.30	12.75	0.32	20.54	14.92	97.91	12.16	90.34	
Ore	100.00	1.78	11.69	2.33	20.38	100.0	100.0	100.0	100.0	

Table 5

Results of Zhezkent deposit sulfide ores flotation with application of DMIPEC reagent

Sample No.	Product name	Yield, %	Content, %			Recovery, %			Flotation conditions
			Cu	Zn	Fe	Cu	Zn	Fe	
B 125	Cu head	6.1	25.65	1.60	28.47	30.13	4.02	7.01	MIBC 5 + 2 g/t 1% sol. $E_{Cu} - E_{Zn} = 26.11\%$ Fresh water*
B 126	Cu – Zn concentrate	11.6	21.81	7.44	27.33	48.71	35.57	12.79	
B 127	Cu – Zn middlings	5.3	10.42	15.31	25.20	10.63	33.44	5.39	
B 128	Tailings Dump	77.0	0.71	0.85	24.09	10.63	26.97	74.81	
	Ore	100	5.19	2.43	24.79	100	100	100	
B 141	Cu head	12.0	23.56	2.31	28.50	53.75	10.96	13.85	DMIPEC 5 + 2 g/t $E_{Cu} - E_{Zn} = 42.79\%$ Fresh water
B 142	Cu – Zn concentrate	13.2	14.74	13.24	26.29	36.99	69.08	14.11	
B 143	Cu – Zn middlings	4.2	5.54	7.99	29.61	4.42	13.26	5.04	
B 144	Tailings Dump	70.6	0.36	0.24	23.44	4.84	6.7	67.00	
	Ore	100	5.26	2.53	24.70	100	100	100	
B 137	Cu head	20.32	18.85	3.84	25.98	72.83	31.10	21.44	DMIPEC 20 g/t $E_{Cu} - E_{Zn} = 41.73\%$ Fresh water
B 138	Cu – Zn concentrate	10.51	10.37	13.95	26.50	20.72	58.01	11.32	
B 139	Cu – Zn middlings	4.30	3.66	3.94	31.40	2.99	6.75	5.48	
B 140	Tailings Dump	64.87	0.28	0.16	23.44	3.46	4.14	61.76	
	Ore	100	5.26	2.50	24.62	100	100	100	

* Fresh water: that is the water from an external source

ore (3.87%) is 3 kg/t of ore, as well as higher quality of copper concentrate – 20% (Table 4), which together provides a significant total economic effect.

In experiments with application of DMIPEC reagent copper-lead concentrate with lead 14.80%, zinc 2.36 %, copper 20.00%, iron 19.00% was obtained, with lead recovery 84.85% and copper 87.64%. The selectivity coefficient (sum of copper and lead recoveries minus zinc recovery in the copper-lead flotation operation) was 170.40%. An increase in copper recovery of 0.35% was obtained, which in terms of copper content in ore (2.33%) is 0.08 kg of copper per ton of ore. The reduction in zinc loss was 0.55%, which is 0.64 kg/t of ore considering the ore Zn content (11.7%), also provides an economic benefit.

The study of flotation properties of acetylene reagent DMIPEC was also carried out on sinter-polymetallic ore of Zhezkent deposit (Republic of Kazakhstan) with copper content 5.2% and zinc 2.43% (Table 5).

Additional copper extraction in Cu flotation head concentrate ranges from 23.62 to 42.7%, additional zinc

extraction in Cu flotation head concentrate ranges from 6.94 to 27.08%, concentrate yield increased by 14.22%. At a DMIPEC rate of 20 g/t, total copper losses with tailings decreased by 7.17% to 3.46%. This ore is characterized by natural activation of zinc sulfide by copper cations. The addition of the acetylene reagent DMIPEC to the basic reagent regime notably increases the extraction of copper and zinc into both the copper flotation head concentrate and the copper-zinc concentrate. Separation of the collective concentrate into single-name selective copper and zinc concentrates is carried out according to known schemes by sequential operations of depression and activation of zinc sulfide flotation.

Conclusion

Thus, the theoretical and calculated data of specific flotation properties of acetylene reagents in relation to unactivated and activated by copper sulfate zinc sulfides were confirmed experimentally on sulfide zinc-containing polymetallic ores.

Quantum-chemical calculations have established that these reagents are characterized by:

- the ability common to all acetylene alcohols to form π -complexes with copper and zinc sulfides, mainly by nucleophilic mechanism;
- universal ability of DMIPEC reagent to form π -complexes with copper and zinc by nucleophilic and electrophilic mechanisms;
- individual ability of reagent DC-80, molecules of which are tertiary terminal acetylene alcohols, to attach itself to zinc atoms by the mechanism of substitution reaction, which is a weak interaction, confirming the selectivity of the reagent action towards unactivated zinc sulfide.

Flotation studies in laboratory conditions on samples of sulfide zinc-containing ores of some deposits of Kazakhstan showed a significant increase in the level of extraction of target metals, including zinc, reduction of zinc losses in copper concentrate by 7.8%, improving the quality of copper concentrate by 4.9%, when used as an additional collector reagents from the class of acetylene alcohols.

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