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F. F. Mozheiko, D. Sc. (Chemistry), professor, Corresponding Member of Belarus NAS, chief researcher (IGIC NASB);
T. N. Potkina, PhD (Chemistry), senior researcher (IGIC NASB);
I. I. Goncharik, PhD (Engineering), senior researcher (IGIC NASB);
A. I. Voitenko, researcher (IGIC NASB);
V. V. Shevchuk, D. Sc. (Chemistry), head of department of fertilizers (IGIC NASB)

FOAMING AGENT EFFECT ON THE PHOSPHATE FLOTATION

The foaming agent effect of different chemical nature (pine oil, T-66 reagent, alcohols, kaprol) on the phosphate flotation by carboxyl collectors was investigated. It was established that the main flotation concentrate yield, the flotation rate and extraction of useful components (P_2O_5) in the foam product increases during the phosphate flotation by tall oil in the presence of pine oil or hexyl alcohol with increasing its consumption.

Introduction. Analysis of the separating plants, processing phosphorite ore shows that by washing, disintegrating and desliming of ground ore can be obtained product containing 18–21% P_2O_5, applicable only for phosphorite flour.

To obtain concentrate intended for the production of phosphate fertilizers containing not less than 24% P_2O_5 with a low content of harmful impurities (Fe_2O_3, Al_2O_3, MgO, CO_2), washed phosphate ore must be further enriched by flotation.

Flotation is a method of enrichment of minerals, based on differences in physical and chemical properties of minerals, marked in different abilities of minerals to be wetted with water. Being in fine-grained condition in an aqueous medium, the particles of some minerals are not wetted by water, but stick to the air bubbles contained in the water and rise to the surface, while other mineral particles are wetted with water and drown in it, or they are in suspension state.

Mineral floatability, i.e. the degree of wetting minerals with water, can be changed artificially when the surface is treated with flotation reagents.

Flotation reagents are called chemical substances that are put into the pulp to regulate and control the flotation process. They create the conditions for the selective flotation of minerals, i.e. the separation of minerals from the waste rock and minerals from each other, and provide the pulp saturation with resistant air bubbles that rise the flotable mineral particles to the surface.

Depending on the purpose the flotation reagents conditionally divided into five groups: collectors, frothers, suppressors, activators and the environment regulators. The last three of flotation reagents are collectively called modifiers [1–3].

The results of our studies on the influence of various reagent-collectors and modifiers on the qualitative and quantitative indicators of phosphate rock flotation were described previously [4, 5]. This paper presents the results of research on the effect of various organic reagents (foaming agents) on the flotation of phosphate ore from Mstislavl deposits.

Main part. The main purpose of foaming reagents is increasing of dispersion and stabilization of air bubbles in the pulp and increasing stability of foam, filled with particles of floated mineral.

In addition to the main action, foaming agents make bubbles floating-up slow, and sometimes influence the collective action of the reagents and the strength of the particles adhesion to the bubbles.

The organic materials and inorganic electrolytes possess foaming capacity. For mineral flotation organic substances appeared to be the most effective are mainly used.

Foaming agents are surface-active agents (surfactants) which can spontaneously adsorb at the water – air division with reducing the surface energy.

It is known [6] that the "clean" liquid does not have the capacity to form thermodynamically stable foam. To form stable, abundant and superfine foams foaming agents in relatively small quantities are injected to the liquids which facilitate the gas dispersion in the form of small bubbles and increase the stability of foam films.

Mechanism of foam bubbles formation bubbles is that in the interphase of the gaseous inclusion in the liquid medium containing surfactant adsorption layer is formed, the hydrophobic portion of which is directed to the air, and the hydrophilic part – in the aqueous phase.

The rate of formation of this layer is determined by the rate of diffusion of surfactant molecules from the depth of the solution to the surface of the inclusion. When exited to the surface to the surface of the solution, the bubble is surrounded by a double layer of oriented molecules.

According to the ability to form stable foams foaming agents are divided into two types:

1) foaming agents of the first type. These substances (inferior alcohols, acids, aniline, cresols) which molecules in the bulk solution and in the adsorbed layer are in molecular dispersed state.

Foams formed on their basis decay with outflow of interfilm liquid. Their stability increases with concentration increasing of foaming agent, reaching a maximum value to saturation of the adsorption layer, and then decreases to almost zero;

2) foaming agents of the second type (soaps, synthetic surfactants) form colloidal systems in the water, and their foams are highly resistant.

As the foaming agents of the first type hydroxyl polar group reagents (various alcohols) are widely used, because it has strong hydrophilic properties and is usually poorly attached to the surface of the mineral particles, and at the same time it is well absorbed at the boundary of the solution – gas, thus resulting in the solution foaming. Therefore, these agents have weak aggregative properties, which favorably affects the selectivity of flotation.

Compounds whose molecules contain carboxyl polar groups, that is carboxylic acids and their soaps, have not only strong aggregative but also strong foaming properties, and foaming properties in unsaturated homologs are more pronounced than in their marginal counterparts.

They are called foamer-gatherer reagents. This feature allows the carboxyl gatherers to cause flotation activity of many minerals, including phosphorites, without the use of foaming reagents.

However, the presence of high foaming properties of this kind collectors makes difficult, and sometimes eliminates regulation of the flotation process regardless of the collective operation, which causes problems in concentrating, especially in transportation and dewatering of flotation products.

We investigated the effect of foaming agents with different chemistry (pine oil, T-66, alcohols, kaprol) on flotation of phosphate nodular ore by carboxylic collectors (tall oil, soap sulfate, sodium oleate).

Table 1 presents flotation results obtained while using a constant amount of pine oil at different consumption of the collector.

Table 1

Effect of pine oil on phosphate flotation depending on tall oil consumption (reagent consumption controller: soda – 3,000 g/t, alkali silicate – 1,000 g/t)

Reagent consumption, g/t,		Concentrate, % P_2O_5			Tailings, % P_2O_5
Tall oil	Pine oil	γ	β	ε	
2,000	–	77.3	19.4	95.7	3,0
2,000	50	78.3	19.2	96.1	2.7
1,500	–	75.2	19.6	94.3	3.6
1,500	50	76.9	19.4	95.2	3.2
1,000	–	70.2	20.3	91.5	4.4
1,000	50	72.8	19.9	92.6	4.1

Note. γ – output; β – content; ε – extraction. The same for Tables 2 and 3.

From these data it follows that the positive effect of foam is more pronounced at lower consumption of tall oil. The use of 50 g/t foaming agent increases output and enhances the extraction of phosphate component in the main flotation concentrate at a lower consumption of the collector, namely, 1,500 g/t instead of the required 2,000 g/t in the absence of pine oil. This is very important in terms of reducing the amount of expensive and scarce reagents-gatherers and improvement of economic indicators of phosphate flotation.

Effect of foaming reagents consumption with different chemistry on qualitative and quantitative indicators of phosphate ore flotation by tall oil are shown in Table 2.

Table 2

Impact of foaming agent consumption on the flotation qualitative and quantitative indicators of phosphate ore washed by tall oil (consumption of soda – 3,000 g/t)

Reagents consumption, g/t			Concentrate, % P_2O_5			Tailings % P_2O_5
Tall oil	Alkali silicate	Foaming agent	γ	β	ε	
Foaming agent – tall oil						
2,000	1,000	–	77.3	19.4	95.8	3.0
2,000	1,000	25	78.3	19.1	95.7	3.1
2,000	1,000	50	78.0	19.2	96.1	2.7
1,500	1,000	–	75.2	19.6	94.1	3.6
1,500	1,000	40	76.1	19.5	94.8	3.4
1,500	1,000	75	74.0	19.8	93.7	3.7
1,500	1,000	100	77.6	19.2	95.4	3.2
1,500	1,000	100	73.8	19.8	93.5	3.8
1,000	750	–	70.2	20.3	91.5	4.4
1,000	750	50	72.8	19.9	92.6	4.1
1,000	750	100	77.5	19.1	95.0	3.4
Foaming agent – hexanol						
1,000	750	25	69.3	20.8	92.2	4.0
1,000	750	50	72.0	20.2	93.0	3.9
1,000	750	75	74.3	19.7	93.7	3.8
Foaming agent – kaprol						
1,000	750	–	69.6	20.7	92.3	4.0
1,000	750	50	73.4	19.8	93.0	4.1
1,000	750	100	71.5	20.0	91.6	4.6
Foaming agent – T-66						
1,000	750	25	66.5	21.2	90.2	4.5
1,000	750	50	71.1	20.2	91.8	4.4
1,000	750	100	71.7	19.9	91.6	4.6

In all cases, a general tendency to increase the yield of the main flotation concentrate and enhance extraction of useful component with increasing consumption of foaming agent.

In comparison with examined foaming agent compounds hexanol shows better results, especially pine oil. Their action, as mentioned above, becomes apparent in the reduced consumption of tall oil, i.e. 1,000 g/t pine oil at a rate of 100 g/t This supplies increase output ratio by 7% and increase extraction by 3.5% P_2O_5. The quality of the concentrate does not change meanwhile.

The introduction of a foaming agent also significantly affects the kinetics of flotation. Thus, the use of pine oil (100 g/t) at a flow rate of tall oil 1,000 g/t causes reducing time of the main flotation by ~1.5 min. So for the first 2 min the output of concentrate significantly increases (by ~18%) and extraction of useful components (by ~21%).

When mineral flotation mixtures of micellar surfactants with low solubility in organic substances are used – hydrocarbons, alcohols, etc., which are more active than individual substances. Particularly, pine oil is used in the flotation of potash ores, distillation residue from the production of butyl alcohol and reagent T-66. It is known that the effect of these compounds on foaming surfactant solutions due to their colloidal solubility (solubilization) and is determined by their concentration in the system.

Introduction to solutions of anionic surfactants solubilizered compounds provides a significant change in the parameters of the adsorption layer. In the presence of solubilizers in solution there is a noticeable reduction in the surface tension, which facilitates the foaming through more dense packing of the molecules in the adsorbed layer, thereby increasing its strength. Therefore it was of interest to study their effect on the foaming ability of sulfate soap.

It was established that of all the additives used the greatest effect on foaming of sulfate soap has a distillation residue from the production of butyl alcohol. Even at the consumption of 25 g/t of ore foam height increases up to 6.7 cm versus 5.0 cm without it. With further increase in its concentration in the solution up to 50 g/t foam height is reduced up to 5.9 cm, and then does not change. As for pine oil, it has almost no effect on the foaming up to 100 g/t, and then further increase of its consumption, there is some reduction in height of foam column.

Introduction of electrolytes in the foam mixture containing sulfate soap and organic additives (pine oil, residual oil) in the amount of 1,200 and 50 g/t, respectively, has a positive effect on the foaming, and with increasing concentrations foam height first increases to a maximum and then decreases. Most clearly it is expressed in the presence of Na_3PO_4 and Na_2CO_3 (Fig. 1).

Foaming process is based on the phenomenon of reducing the surface tension of foaming solutions. Shown [7] that $d\sigma / dC$ (σ – surface tension, C – concentration of foaming solution) for solutions forming stable foam, a negative value with the largest absolute value. Foam stability formed in surfactant solutions is the higher the greater the concentration gradient between the Gibbs adsorption layer and the bulk solution.

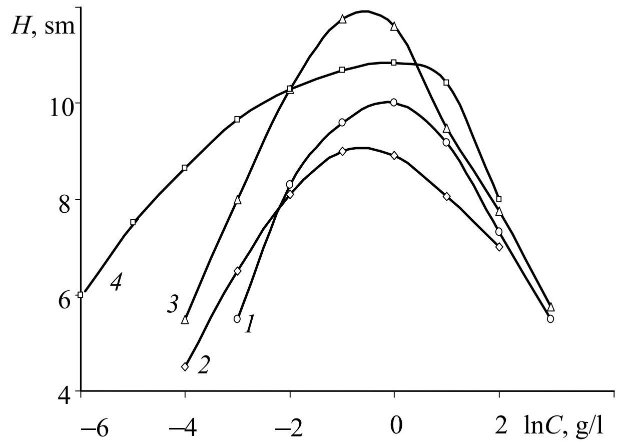

Fig. 1. Dependence of sulfate soap foaming in the presence of organic additives (*1*, *4* – pine oil; *2*, *3* – residual oil) from the concentration of inorganic electrolytes: *1*, *2* – Na_2CO_3; *3*, *4* – Na_3PO_4

In this regard, we have determined the concentration dependence of the surface tension of water and aqueous salt solutions of low molecular weight fatty acids and alcohols. The isotherms received are shown in semilogarithmic system of coordinates in Fig. 2.

Evidently, increasing the ionic strength of the investigated surfactants (both acids and alcohols) causes the isotherm shift toward lower concentrations only at high electrolyte supplements. The form of the isotherm being unchanged, there is a marked reduction in σ with appropriate concentrations of surfactants. The observed difference increases with increasing concentration of foaming solution.

The positive effect of aliphatic alcohols comrade and inorganic electrolytes on foaming sulfate soap is due to the ability of alcohols to solubilization in soap micelles and the influence of electrolytes to reduce the surfactant concentration at which the saturation of the adsorption layer, leading to a more stable adsorption layer on the gas – liquid, resulting in increasing the foaming and foam stability.

The foam-forming ability of sulphate soap in the presence of alcohols is correlated with flotation indicators of phosphate ore. Studies have shown (Table 3), that the introduction of alcohols (residual oil, T-66) at 25 g/t P_2O_5 recovery in concentrate increased up to 93.5 and 95.4 wt % versus 92.9 wt % without them, and the content – up to 21.0–22.6 wt % against 20.5% wt %. Pine oil has the same effect.

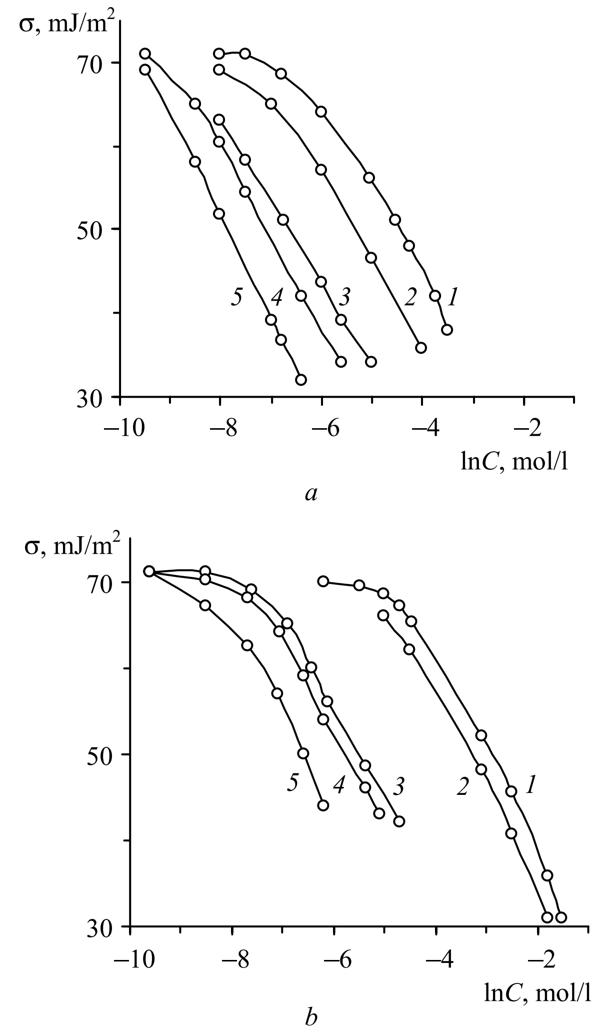

Fig. 2. Isotherms of the surface tension of water and aqueous salt solutions of fatty acids and alcohols:
a) *1* – caproic acid aqueous solution;
2, *3* – caproic acid solution with additives NaCl (1 and 2 M); *4* – aqueous solution of caprylic acid;
5 – caprylic acid solution with the additive of NaCl (2 M);
b) *1*, *3* – aqueous solutions of amyl and heptyl alcohols;
2 – amyl alcohol with the additive of KCl (1 M);
4, *5* – heptyl alcohol solution with the additive NaCl (1 and 2 M)

Thus, it is shown that the introduction of organic additives in sulfate soap increases its foaming, which affects positively on the qualitative and quantitative indicators in the flotation of phosphate rock nodular.

Study of the effect of various foaming agents on the phosphate flotation by sodium oleate – the most efficient collector of phosphate mineral- shows that in this case, all the studied foaming agents do not have any significant positive impact on the parameters of concentration and reducing the consumption of primary flotation reagent – sodium oleate.

Even such foam as pine oil, in comparison with its effect on the flotation of phosphate ore by tall oil and sulphate soap shows little positive impact.

Table 3

Effect of pine oil, T-66, the distillation residue from the production of butyl alcohol on qualitative and quantitative indicators of phosphate ore flotation (P_2O_5 content in the ore – 15.04 wt %, consumption of alkali silicat – 750 g/t, sulfate soap – 1,000 g/t)

Reagents consumption, g/t		Concentrate, % P_2O_5			Tailings % P_2O_5
Soda	Foa-ming agent	γ	β	ε	
Pine oil					
3,000	–	68.7	20.4	93.1	2.1
3,000	10	69.2	20.7	95.2	2.3
3,000	25	67.8	21.4	96.0	1.8
3,000	100	66.3	21.8	96.1	1.7
1,000	–	68.1	20.5	92.9	3.3
T-66					
1,000	25	66.3	21.4	94.4	2.5
1,000	100	66.4	21.6	95.4	2.1
1,000	150	66.3	21.7	95.7	2.0
Residue from the production of butyl alcohol					
1,000	25	67.0	21.0	93.5	3.0
1,000	50	66.8	21.1	93.7	2.8
1,000	100	66.4	21.3	94.0	2.7

At higher consumption of pine oil (200 g/t of ore) a noticeable increase in the extraction of P_2O_5 froth by 0.9%, but the quality of P_2O_5 concentrate becomes worse by ~1%. Apparently, in the flotation of phosphate by sodium oleate, combining collective and foaming properties, supplemented outside blowing agent for improving the main flotation is not necessary.

Introduction to the flotation by sodium oleate of alcohol foaming agent plays a role in dehydration, filtration and sludge flotation.

Some studies were carried out to improve the quality of the main flotation of phosphate rock concentrate by sodium oleate. It is shown that in the result of the first cleaner it is possible to get phosphate concentrate containing more than 24% P_2O_5. In order to further improving the quality of the concentrate the conditions of the second cleaner were studied. It is shown that as a result of the second cleaner without introducing the supplemented reagents one can obtaine concentrate containing 25.3% P_2O_5 and 90.4% of the extraction operation.

But in this case, the commercial product has the high content of P_2O_5 (15.8%). In order to increase the extraction of P_2O_5 (94%) at this stage and to get concentrate of good quality (~25%), the second cleaner should be given an additional amount of sodium oleate.

It should be noted that, S : L is of great importance as for the primary flotation, and the cleaners. Liquefaction pulp to 1 : 6 results in a reduction of recovery, deterioration in the quality of the concentrate. In more dense pulp (S : L = 1 : (2–3)) reagent consumption is reduced and the flotation decreases. In the second cleaner introduction of hexyl alcohol has a positive effect and increases the extraction of P_2O_5 in the concentrate.

During the third recleaner without introducing the reactants can be achieved only 50% P_2O_5 recovery from the operation. Additional introduction of reagents at this stage of the process significantly improves the performance of flotation. As it shown in Table 4, the introduction of soda, sodium silicate and sodium oleate, even separately, allows to increase the extraction of P_2O_5 in the finished product maintaining high quality.

Better results are obtained at consumptionof 0.5 kg/t soda, 0.25 kg/t alkali silicate, 0.1 kg/t sodium oleate. Extraction of P_2O_5 thus reaches 94.2% from the transaction. To reduce the loss of P_2O_5 with nonutilizable waste, tailing inspection cleaners were conducted in the main flotation by sodium oleate.

It is established that dump waste product containing ~1% P_2O_5 can be obtained by reflotation of the chamber product with additional reagent consumption regardless of the basic flotation.

At the same time about 80% P_2O_5 is extracted with content P_2O_5 in the concentrate 7%, which is then directed to the main flotation process.

Thus, the recleaner produces high quality phosphate rock concentrate containing about 27% P_2O_5, with high phosphate mineral extraction to the finished product (90–94% of the washed ore).

Conclusion. Increasing the efficiency of the flotation process can be achieved through the use of various combinations of surface-active substances. Generalizing basic information and our experimental data, the principles combining of new reagents, collectors and frothers in the flotation of phosphate rock can be stated as follows:

– the main component of surface active agent combination in the flotation of phosphate rock is carboxylic acids (unsaturated, saturated, normal and isometric structure, monocarboxylic, dicarboxylic) and their soaps;

– addition of alcohols to carboxylic soaps increases the surface activity of soaps and regulates the foam flotation properties (three phase). Alcohols do not have a collective action. In addition, alcohols peptize thin slimes;

– of the examined frothers the best results in the flotation of phosphate rock by tall oil are obtained in the presence of pine oil and hexyl alcohol, rate consumption of which increases the main flotation concentrate output and increases the rate of flotation and the extraction of useful components (P_2O_5) in the froth;

– in the flotation of phosphate by sulfate soap the pine oil and T-66 are the most effective foaming agents. Alcohol fraction under such consumption does not significantly affect the performance of phosphate rock flotation;

– additional introduction of foam is not required in the flotation of phosphate by the most efficient collector – sodium oleate, combining collective and good foaming properties.

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