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T. I. YUSHINA[1], *Head of Department, Associate Professor, Candidate of Engineering Science, yuti62@mail.ru*
NGUEN THU THUY[1], *Probationer*
A. M. DUMOV[1], *Associate Professor, Candidate of Engineering*
NGUEN VAN TRONG[1], *Probationer*

[1] *National University of Science and Technology – NUST MISIS, Moscow, Russia*

STUDY OF THE POSSIBILITY OF SELECTIVE FLOTATION OF QUARTZ-FELDSPAR ORE OF QUANG NAM DEPOSIT (VIETNAM)

The article presents the results of the study of the possibility of selective flotation of the main minerals of quartz-feldspar ore of Quang Nam deposit (Vietnam) - mica and feldspars in the presence of cationic collector ArmacT, in order to remove iron-bearing minerals and isolation of mica and feldspars into high quality concentrates. The adsorption regularities of the ArmacT cationic collector on mineral surfaces were studied. Results of zeta potential measurements showed that at pH = 2 the functional group of ArmacT collector has a significantly higher affinity for mica compared with both feldspar and quartz. Analysis of Fourier transform infrared spectra showed that the highest intensity of ArmacT adsorption on mica is observed at pH = 2, while the highest sorption intensity for feldspar and quartz was observed at pH = 5. The possibility of reducing the iron content during flotation obtaining feldspar concentrate from quartz-feldspar ore samples of Quang Nam deposit was investigated. Experiments performed under laboratory conditions on the DENVER flotation machine allowed us to determine the following optimal conditions for the selective flotation of mica and iron-bearing minerals, which allowed us to obtain high-quality mica and feldspar concentrates:

– pH regulator concentration (H_2SO_4) – 2000 g/t;
– the collector concentration (sodium oleate and ArmacT) was 300 g/t and 200 g/t, respectively;
– flotation time 3 min.

***Keywords:** quartz-feldspar ore, flotation, mica, iron-bearing minerals, cationic collector, infrared spectroscopy, reagent regime, feldspar concentrate, micaceous concentrate*
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Introduction

Most feldspars are solid solutions of the ternary system of isomorphic series K[AlS$_{13}$O$_8$] – Na[AlS$_{13}$O$_8$] – Ca[Al$_2$S$_{12}$O$_8$], he end members of which are orthoclase (Or), albite (Ab) and anorthite (An) respectively.

Feldspars are aluminum silicate with cations of Na, K, Fe, Ca, Ba, etc. [1–3]. In nature, feldspars such as albite (NaAlS$_{13}$O$_8$) and orthoclase-microcline (KAlS$_{13}$O$_8$), usually contain impurities of clay, mica group minerals (especially biotite and muscovite), iron oxides, tourmaline, rutile and sphene.

In the world practice of enrichment of feldspar raw materials the first stage is the removal of material with a grain size less than 25 microns, i.e. sludge

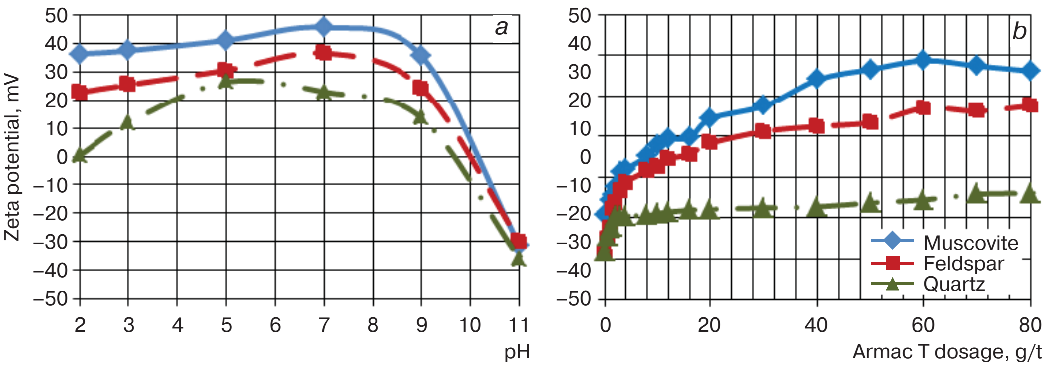

Fig. 1. (*a*) Effect of pH on the zeta potential when adding ArmacT with a concentration of 40 g/t; (*b*) Dependence of zeta potential on ArmacT collector concentration for mica, quartz, and feldspar at pH = 2

containing clay minerals, which prevent flotation of mica. The next step is flotation of mica at pH 2.5–3.5 in the presence of H_2SO_4 [4–11]. Mica minerals are usually flotated using long-chain aliphatic amines (12–18 C) [12–14]. After removal of micaceous tailings, metal oxides (Fe and Ti) are flotated either with oleate at pH = 5–5.5 or with sulfonates at pH = 3–3.5. In addition to oleate and sulfonates, succinamates, soaps of various vegetable oils [4, 15], sarcosine and hydroxamate collectors [16, 17, 14] can also be used for flotation of metal-oxide minerals.

Between the mica and metal oxide flotation stages, the pulp is dewatered in hydrocyclones or spiral classifiers. The purpose of dewatering is to remove water containing residual reagents, namely amines.

Rao and Forssberg [18] measured the zeta potentials of quartz and microcline as a function of sulfate concentration in the presence of tallow 1,3-diaminopropane at different pH values. Zeta-potential measurements show that increasing sulfate concentration causes diamine-sulfate complexes to appear on the surface, which leads to a decrease in zeta-potentials of both quartz and microcline. Rao et al. [19] studied the adsorption of amino-oleate on the muscovite and biotite minerals by Fourier transform infrared spectroscopy (FT-IR) and found no adsorption of oleate on any of the minerals when used individually. However, when the amine concentration increases in the presence of $5{\cdot}10^{-5}$ mol/L oleate, proportional adsorption of oleate is observed on the surfaces of muscovite and biotite. In the work of Vidyadhar et al. [20] showed that the presence of oleate together with diamine significantly increases the extraction of microcline at pH = 2, although when only one oleate is used, the necessary extraction is not provided.

In order to obtain high-quality feldspar concentrate suitable for use in the ceramic and glass industries, coloring impurities, i.e. oxides of iron, titanium and other metals, must be removed. Although high-intensity permanent magnet separators are used for ores with low iron content, flotation is still necessary in many cases, especially for ores containing large amounts of titanium and iron oxides [21].

Materials and methods

Studied sample

Studies were carried out on samples of quartz-feldspar ores from Quang Nam deposit (Vietnam) [22]. The sample consisted of 25–27% albite; 12–14% potassium feldspar, 26–28% muscovite, 28–30% quartz. The fraction of other minerals is about 1–2%. Chemical composition of the sample (%): SiO_2 – 75,22; Al_2O_3 – 14,22; K_2O – 5,29; Na_2O – 3,37; Fe_2O_3 – 0,74. Weight loss on calcination – 0,44%.

Research methods

The spectra were studied with a FT-IR Perkin Elmer Spectrum One at the Institute of Environmental Technology, Vietnam Academy of Science and Technology.

The zeta potential was measured with a ZETA METER 4.0 zeta meter at the Institute of Geology, Vietnam Academy of Sciences and Technology.

Flotation experiments were performed using a Denver flotation unit with chamber volumes of 500, 1000, and 2000 ml.

Tall amine acetate with the brand name ArmacT by Akzo Nobel (Nourion) was used as a cationic collector for mica and feldspar flotation.

The chemical composition was analyzed by atomic adsorption on an atomic absorption spectrometer AAS and by inductively coupled plasma mass spectrometry ICP at the Center for Geological and Experimental Analysis and the Institute of Environmental Technology at the Vietnam Academy of Science and Technology.

Results and discussion

Measurements of zeta potential

The dependence of zeta potential on mica, feldspar, and quartz as a function of pH at ArmacT concentration of 40 ppm is shown in **Fig. 1a**. The value of zeta potentials for both mica and feldspar gradually increased from 35 mV and 25 mV to 45 mV and 35 mV, respectively, with an increase in pH from 2 to 7. In an alkaline environment, the zeta potentials for both mica and feldspar gradually decreased. This is confirmed by the change in the sign and magnitude of the charge to −31.35 mV and −29.76 mV for mica and feldspar, respectively, when the pH is increased to 11. However, the zeta potential of quartz at pH = 2 was almost zero. Increasing pH to 5 causes a sharper increase in zeta potential to the value of 25 mV. As pH increases to 9, the value of zeta potential gradually decreases, and as pH increases from 9 to 11, it sharply decreases to −36 mV. This is due to the formation of a typical colloidal solution due to exceeding the solubility limit of the amine and its transition to the molecular form in an alkaline environment. It was found that at any pH value the zeta potential of feldspar and quartz is lower than that of mica.

Dependence of zeta potential on ArmacT concentration at pH = 2 (**Fig. 1b**) shows that the zeta potential of mica, feldspar, and quartz also increases in the positive region as the

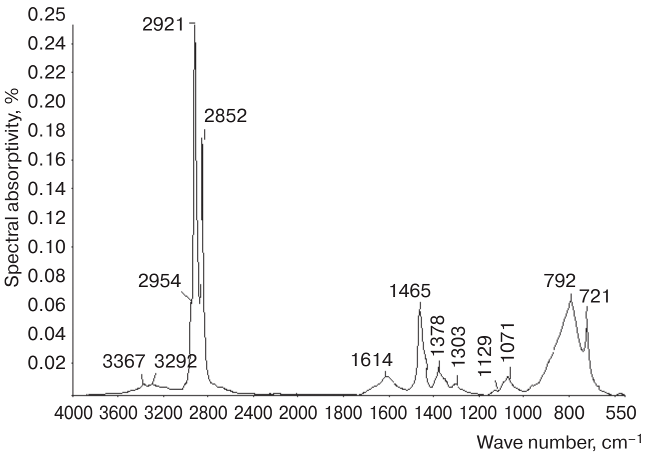

Fig. 2. Fourier transform infrared spectra of the ArmacT collector

dosage of ArmacT increases. Obviously, the zeta potential of mica is much higher compared to feldspar and quartz, and also grows significantly faster with increasing ArmacT dose. The data indicates that the ArmacT molecule has a functional group in its structure that has a higher affinity for mica than feldspar and quartz. However, the zeta potential value for both mica and feldspar decreases slightly when the ArmacT concentration exceeds 60 g/t. The zeta potential value for quartz increased steadily (≤6 mV) when the dosage of the ArmacT collector was increased.

Fourier Transform Infrared Spectroscopy

The ArmacT reference spectra are shown in **Fig. 2**. The spectra of the collector clearly show peaks characteristic of alkyl chains, the valence vibrations of groups $v_{as}(CH_3)$ 2954 cm^{-1}, $v_{as}(CH_2)$ 2921 cm^{-1} and $v_s(CH_2)$ 2852 cm^{-1}. The peak appears in the ArmacT spectrum at 3367 3367 cm^{-1} due to $v_{as}(NH_2)$ and $v_s(NH_2)$. The peaks at 1465 and 1378 cm^{-1} are characterized as strain oscillations $\delta(CH_2)$. A characteristic CN stretch band was also observed at 1303 cm^{-1} and 1071 cm^{-1}.

Additionally, Fourier-transformed infrared spectra were taken at pH = 2, 3, and 5 for mica (**Fig. 3a**), feldspar, and quartz treated by ArmacT with concentration of 40 g/t. The spectrogram shows bands characteristic of alkyl chains – the valence vibrations of the $v_{as}(CH_3)$ group, $v_{as}(CH_2)$ and $v_s(CH_2)$ groups between the 3000–2800 cm^{-1} regions are at 2957 cm^{-1} or 2958 cm^{-1}, 2921 cm^{-1} and 2852 cm^{-1}. From the analysis of the dependencies shown in Figure 3, it is clear that the highest intensity of ArmacT adsorption on mica is observed at pH = 2. Feldspar and quartz at this pH value adsorb ArmacT much weaker. The highest intensity of ArmacT adsorption on the surface of both feldspar and quartz is observed at pH = 5.

From the analysis of **Fig. 3b** it is clear that at pH = 2 ArmacT is better adsorbed on mica at different rates of ArmacT. Analysis of the obtained experimental dependencies of the intensity of the alkyl chain bands at pH = 2 showed that the intensity increased with increasing ArmacT concentration for both mica and feldspar and quartz, indicating an increase in ArmacT adsorption on the surface of all minerals.

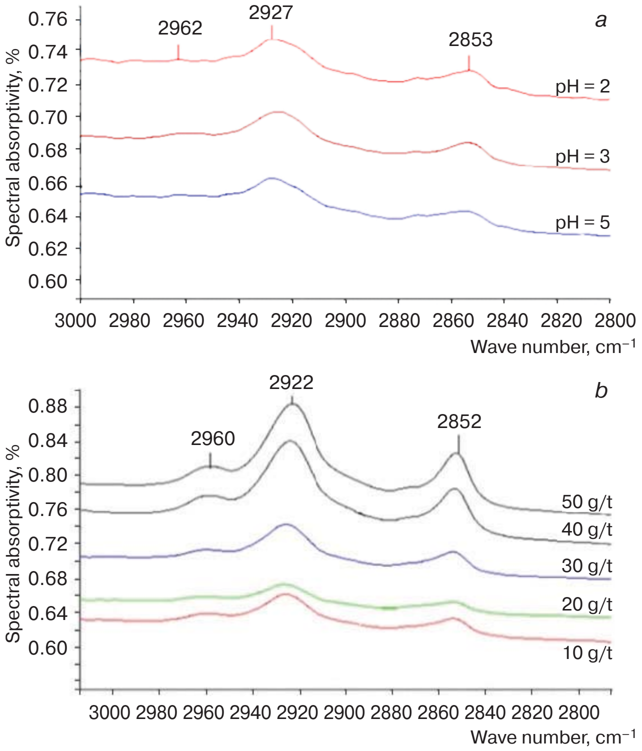

Fig. 3. (*a*) Adsorption of ArmacT with concentration of 40 g/t on mica at different pH values; (*b*) Adsorption of ArmacT at different concentrations on mica at pH = 2

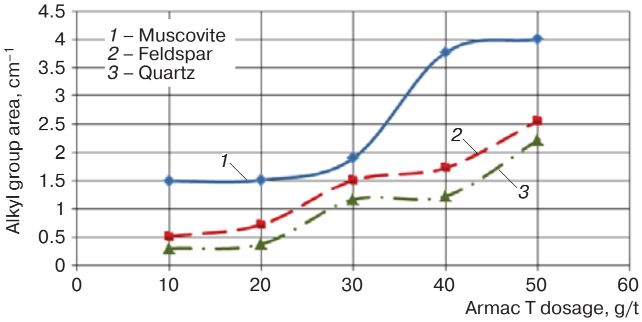

Fig. 4. Alkyl band width (3000–2800 cm^{-1} range) of mica, feldspar, and quartz spectra as a function of ArmacT concentration

The greater width of the alkyl chain peaks (3000–2800 cm^{-1}) of mica spectra compared to quartz and feldspar (**Fig. 4**) indicates that ArmacT has a greater affinity for the mica surface (in terms of fixation of its molecules on the surface). This was proved by observing the peak widths under the alkyl chain bands between the 3000–2800 cm^{-1} regions, which were measured and plotted (see Fig. 4) as a function of ArmacT concentration (10 to 50 g/t). The increase in the width of the alkyl region peaks of mica, feldspar, and quartz corresponds to an increase in ArmacT concentration.

Flotation of mica and iron-bearing minerals

Experiments on flotation of feldspar ore samples from Quang Nam were performed on a DENVER laboratory flotation

Table 1. Influence of H_2SO_4 concentration on mica flotation

H_2SO_4, concentration g/t	Product	Yield %	Content, %			Extraction, %		
			Na_2O	K_2O	Fe_2O_3	Na_2O	K_2O	Fe_2O_3
1200 (pH ≈ 4)	Mica concentrate (foam product)	16.23	1.78	7.68	3.24	8.57	23.56	71.06
	Chamber product	83.77	3.68	4.83	0.26	91.43	76.44	28.94
	Initial ore	*100.00*	*3.37*	*5.29*	*0.74*	*100.00*	*100.00*	*100.00*
1600 (pH ≈ 3,5)	Mica concentrate (foam product)	15.48	2.03	8.04	3.52	9.32	23.53	73.63
	Chamber product	84.52	3.62	4.79	0.23	90.68	76.47	26.37
	Initial ore	*100.00*	*3.37*	*5.29*	*0.74*	*100.00*	*100.00*	*100.00*
2000 (pH ≈ 3)	Mica concentrate (foam product)	14.72	1.74	8.10	3.74	7.60	22.54	74.40
	Chamber product	85.28	3.65	4.80	0.22	92.40	77.46	25.60
	Initial ore	*100.00*	*3.37*	*5.29*	*0.74*	*100.00*	*100.00*	*100.00*
2400 (pH ≈ 2)	Mica concentrate (foam product)	15.01	2.18	8.94	3.57	9.71	25.37	72.41
	Chamber product	84.99	3.58	4.65	0.24	90.29	74.63	27.59
	Initial ore	*100.00*	*3.37*	*5.29*	*0.74*	*100.00*	*100.00*	*100.00*

Table 2. Influence of sodium oleate concentration on mica flotation

Concentration of sodium oleate, g/t	Product	Yield %	Content, %			Extraction, %		
			Na_2O	K_2O	Fe_2O_3	Na_2O	K_2O	Fe_2O_3
100	Mica concentrate (foam product)	13.96	1.17	9.51	3.64	4.85	25.10	68.67
	Chamber product	86.04	3.73	4.61	0.27	95.15	74.90	31.33
	Initial ore	*100.00*	*3.37*	*5.29*	*0.74*	*100.00*	*100.00*	*100.00*
200	Mica concentrate (foam product)	14.35	1.47	9.74	3.67	6.26	26.42	71.17
	Chamber product	85.65	3.69	4.54	0.25	93.74	73.58	28.83
	Initial ore	*100.00*	*3.37*	*5.29*	*0.74*	*100.00*	*100.00*	*100.00*
300	Mica concentrate (foam product)	14.72	1.74	8.10	3.74	7.60	22.54	74.40
	Chamber product	85.28	3.65	4.80	0.22	92.40	77.46	25.60
	Initial ore	*100.00*	*3.37*	*5.29*	*0.74*	*100.00*	*100.00*	*100.00*
400	Mica concentrate (foam product)	14.96	1.71	8.54	3.65	7.59	24.15	73.79
	Chamber product	85.04	3.66	4.72	0.23	92.41	75.85	26.21
	Initial ore	*100.00*	*3.37*	*5.29*	*0.74*	*100.00*	*100.00*	*100.00*

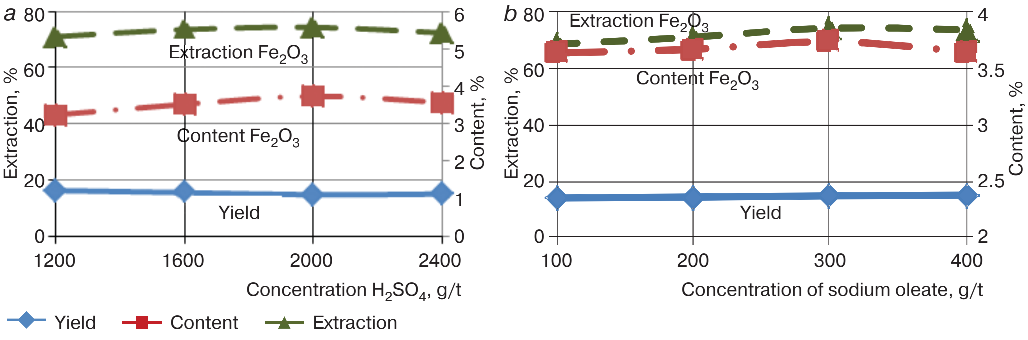

Fig. 5. (*a*) Influence of H_2SO_4 concentration on indicators of mica flotation: foam product yield, extraction and Fe_2O_3 content; (*b*) Influence of sodium oleate concentration on indicators of mica flotation: foam product yield, extraction and Fe_2O_3 content

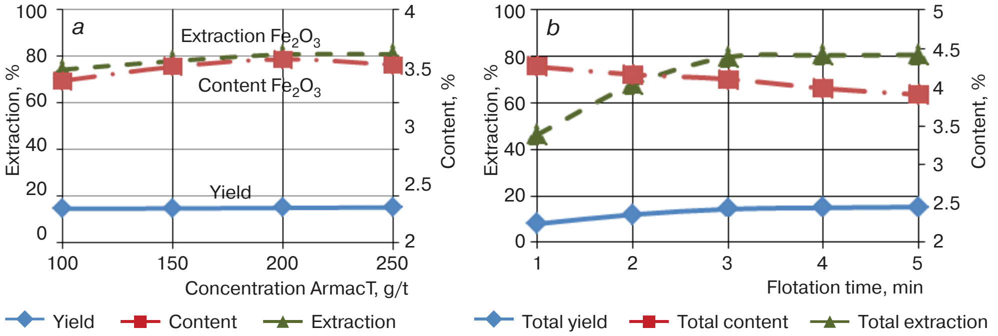

Fig. 6. (*a*) Influence of ArmacT concentration on mica flotation indicators: foam product yield, extraction and Fe_2O_3 content; (*b*) Influence of flotation time on mica enrichment indicators: foam product yield, extraction and Fe_2O_3 content

Table 3. Influence of ArmacT collector concentration on mica flotation

Concentration of ArmacT, g/t	Product	Yield %	Content, %			Extraction, %		
			Na_2O	K_2O	Fe_2O_3	Na_2O	K_2O	Fe_2O_3
100	Mica concentrate (foam product)	14.72	1.74	8.10	3.74	7.60	22.54	74.40
	Chamber product	85.28	3.65	4.80	0.22	92.40	77.46	25.60
	Initial ore	*100.00*	*3.37*	*5.29*	*0.74*	*100.00*	*100.00*	*100.00*
150	Mica concentrate (foam product)	14.85	1.45	9.44	3.89	6.39	26.50	78.06
	Chamber product	85.15	3.70	4.57	0.19	93.61	73.50	21.94
	Initial ore	*100.00*	*3.37*	*5.29*	*0.74*	*100.00*	*100.00*	*100.00*
200	Mica concentrate (foam product)	15.07	1.83	8.05	3.97	8.18	22.93	80.85
	Chamber product	84.93	3.64	4.80	0.17	91.82	77.07	19.15
	Initial ore	*100.00*	*3.37*	*5.29*	*0.74*	*100.00*	*100.00*	*100.00*
250	Mica concentrate (foam product)	15.32	2.52	10.03	3.91	11.46	29.05	80.95
	Chamber product	84.68	3.52	4.43	0.17	88.54	70.95	19.05
	Initial ore	*100.00*	*3.37*	*5.29*	*0.74*	*100.00*	*100.00*	*100.00*

machine. Samples were ground for 40 minutes in a ceramic ball mill to a particle size of 61.47% grade - 0.074 mm. Solid-liquid ratio = 0,5.

Determination of the optimal concentration of the pH regulator

Based on the results shown in **Table 1** and **Fig. 5a**, it was concluded that by increasing the concentration of H_2SO_4 from 1200 g/t to 2000 g/t, the yield of mica products decreased from 16.23% to 14.72%; Fe_2O_3 content increased from 3.24% to 3.74%; Fe_2O_3 extraction increased from 71.06% to 74.40%. When the H_2SO_4 concentration was further increased to 2400 g/t, the yield of mica in the foam product increased from 14.72% to 15.01%, but the Fe_2O_3 content and extraction decreased. At H_2SO_4 concentration of 2000 g / t content of å(K_2O+Na_2O) in the mica concentrate is 9.84%, increasing the concentration of H_2SO_4 to 2400 g/t, the content of å(K_2O+Na_2O) in the mica concentrate increases to 11.12%, ie, increasing the concentration of H_2SO_4 causes increase in losses of feldspar with mica concentrate. To ensure effective mica flotation without significant loss of feldspar, it is required to maintain an optimal concentration of H_2SO_4 equal to 2000 g/t during mica flotation, which corresponds to pH = 3.

Determining the optimum collector concentration

Determination of the optimum concentration of sodium oleate. Based on the results shown in **Table 2** and **Fig. 5b** it was concluded that by increasing the concentration of sodium oleate from 100 g/t to 300 g/t the yield of the foam product (mica concentrate) increased from 13.96% to 14.72%; Fe_2O_3 content in it also slightly increased (from 3.64% to 3.74%), and the maximum Fe_2O_3 extraction (74.40%) was achieved at a sodium oleate concentration of 300 g/t. With further increase in the concentration of sodium oleate, the yield of mica concentrate will also increase, but the Fe_2O_3 content will decrease to 3.65%, and, accordingly, the Fe_2O_3 extraction in the mica concentrate will decrease to 73.79%. Thus, the optimum concentration of sodium oleate in mica flotation is 300 g/t.

Determining the optimal concentration of the ArmacT collector. Analysis of **Table 3** and **Fig. 6a** shows that the best results of mica flotation are achieved at ArmacT concentration of 200 g/t. Mica concentrate yield (foam product) is 15,07%, Fe_2O_3 content is 3,97% at extraction of 80,85%; content of (K_2O+Na_2O) – 9,88%. Increasing ArmacT concentration to 250 g/t increases mica concentrate yield, Fe_2O_3 extraction also increases to 80.95%, but results in loss of significant amount of feldspar with mica concentrate. The (K_2O+Na_2O) content in the foam product is 12.55%, and feldspar losses in it increase by 9.40% compared to losses at ArmacT 200 g/t.

Study of the effect of flotation time on mica flotation

The results of the experiments presented in **Table 4** and **Fig. 6b** show that with a flotation time of 3 minutes the Fe_2O_3 extraction reaches 79.80%, which corresponds to the content of 4.11% Fe_2O_3 in the mica concentrate. As the flotation time increases, the yield of the foam product increases slightly, the Fe_2O_3 extraction in the mica concentrate (foam product 4 in **Table 4**) and in the mica concentrate 5 (foam product 5 in Table 4) is low (less than 1%), and the (K_2O+Na_2O) content in this product is increased (about 13%). Thus, at a flotation time of 3 minutes the maximum efficiency of mica flotation was achieved. With increasing the time of flotation the efficiency of flotation worsens due to removal of feldspar in the foam.

Conclusion

Analysis of the results of studies of flotability of the main mineral components of quartz-feldspar ore of Quang Nam deposit showed the possibility in principle of selective flotation of mica and feldspars in the presence of cationic collector ArmacT and sodium oleate, to remove iron-bearing minerals and separation of mica and feldspars into high quality concentrates.

The regularities of adsorption of the cationic collector – tallow acetate amine ArmacT on the surface of minerals were studied. It was found that the zeta potential of feldspar and quartz is lower than that of mica at any pH. At pH = 2, the zeta potential of mica, feldspar, and quartz also increases with increasing ArmacT concentration, but mica has a much higher value in mV than feldspar and quartz. Results of zeta potential measurements showed that at pH = 2 the functional group

Table 4. Influence of flotation time on mica enrichment indicators

Flotation time, min	Product	Yield %	Content, %			Extraction, %		
			Na_2O	K_2O	Fe_2O_3	Na_2O	K_2O	Fe_2O_3
1	Mica concentrate (foam product) 1	8.03	1.62	7.59	4.27	3.86	11.52	46.34
1	Mica concentrate (foam product) 2	4.01	1.74	8.01	3.97	2.07	6.07	21.51
1	Mica concentrate (foam product) 3	2.34	1.94	8.25	3.78	1.35	3.65	11.95
1	Mica concentrate (foam product) 4	0.58	3.28	9.79	0.97	0.56	1.07	0.76
1	Mica concentrate (foam product) 5	0.33	3.35	9.84	0.62	0.33	0.61	0.28
	Chamber product	84.71	3.65	4.81	0.17	91.83	77.08	19.16
	Initial ore	*100.00*	*3.37*	*5.29*	*0.74*	*100.00*	*100.00*	*100.00*

of ArmacT collector has a significantly higher affinity for mica compared to feldspar and quartz.

Analysis of Fourier transform infrared spectra shows that the highest intensity of ArmacT adsorption on mica is observed at pH = 2, while the highest intensity of sorption for feldspar and quartz is observed at pH = 5.

The opportunity of reduction of iron content during flotation reception of feldspar concentrate from quartz-feldspar ore samples is investigated, optimum conditions of selective flotation of mica and iron-bearing minerals which have allowed to receive the high-quality mica and feldspar concentrates are defined: the concentration of pH regulator (H_2SO_4) – 2000 g/t; the concentration of collectors (sodium oleate and ArmacT) – 300 g/t and 200 g/t respectively; time of flotation 3 min.

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