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# TECHNOLOGY FOR PROCESSING QUARTZ–SERICITE ORE BY SELECTIVE GRINDING AND FLOTATION

*Sericite, an aluminosilicate group mineral, has a considerable economic value as it is used in many branches of industry, including the cosmetic industry, paint-and-varnish industry and in production of polymers. Vietnam possesses explored deposits holding commercial reserves of quartz–sericite ore. Producibility of marketable sericite concentrate was tested using quartz–sericite ore samples from the Ha Tinh Province.*

*The data on the material constitution of the test ore from the X-ray structural analysis, optical studies and electron microscopy allowed offering a supposition on the feasible effective processing of the test ore by selective grinding and classification in hydraulic cyclones, which was experimentally proved. An essential loss of sericite in tailings required studying additional recovery of sericite by other methods. The studies into properties of cationic collector ArmacT by the Fourier Transform Infrared Spectroscopy (FTIR) to determine the nature of chemical bonds in molecules, as well as the adsorption tests of this collector at sericite and quartz in different operating conditions confirmed applicability of this agent to extract sericite from middlings (tailings of gravity concentration) and enabled flotation optimization.*

*Based on the implemented studies and experimental processing of the test ore using selective grinding, classification in cyclones and flotation, the flow chart was developed for processing initial ore with the total mass fraction of $SiO_2$ 74.48%, $Al_2O_3$ 16.20%, $K_2O$ 3.52%, $Na_2O$ 0.59% with production of sericite concentrate with the average particle size of 10 µm and mass fractions of $SiO_2$ 49.33%; $Al_2O_3$ 34.56%; ($K_2O$+$Na_2O$) 9.12%. This product meets the quality standards imposed on the raw stock for various industries.*

***Keywords:*** *quartz–sericite ore, material constitution, sericite, quartz, selective grinding, classification, flotation, cationic collectors, adsorption, concentrates*

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## Introduction

Sericite is an aluminosilicate group mineral of fine dispersion, a partly hydrated mineral variety of white mica (muscovite). The chemical formula is $KAl_2[AlSi_3O_{10}](OH)_2$ or $KAl_2[AlSi_3O_{10}](OH,F)_2$,). The mineral has a low content of $K_2O$ and an increased content of $SiO_2$, MgO and $H_2O$. It represents an accumulation of cryptoflakes with a silky gloss [1–4].

The economic value of sericite develops from the use of the mineral in the paint-and-varnish industry, in manufacture of polymers and, specifically, in the cosmetic industry. The key suppliers of sericite products to the global market is China and Finland [4, 5]. The overall output of sericite products in 2018 totaled 340 000 t at the prices of USD 500/kg.

In view of the increase in the mineral resources and thanks to the provision of the industry with the own reserves, Vietnam started prospecting sericite in the 1990s. Much of the explored deposits however were small bodies of low-grade ore. An exception was the Ha Tinh Province which held sericite reserves initially appraised as several million tons of ore with the increased content of sericite [6, 7].

Manufacture of high-quality sericite products to meet the standards set by the cosmetic and paint-and-varnish industry for the feedstock [7] requires processing of crude ore with removal of ferric oxides and nonmetallic impurities (quartz, feldspar, etc.).

The studies into the material constitution of quartz–sericite ore from the Ha Tinh Province allowed substantiation of efficient processing technologies for the ore to produce high-quality sericite and quartz concentrates to satisfy the needs of the above mentioned industries in Vietnam.

### Ore composition

The X-ray crystal analyses of quartz–sericite ore samples from the Ha Tinh Provinces shows that the basic minerals are:

- sericite (sharply defined at the peaks at the angles θ of 10.3, 20.8, 31, 32.5, 41.5, 49.3 and 53 deg), with a formula:

$(K_{0.727}Na_{0.17}Ca_{0.011})(Al_{0.933}Fe_{0.016}Mg_{0.011})_2(Si_{0.782}Al_{0.221})_4O_{10}(OH)_2\cdot 5H_2O$;

- quartz [$SiO_2$];
- pyrophyllite [$Al(Si_2O_5(OH)$] (sharply defined at the peaks at the angles 2θ of 11.3, 19.5, 23.5, 24, 29, 31, 34, 46.2, 49.5 and 53.8 deg);
- kaolinite [$Al_2SiO_5(OH)_4$] and chlorite.

Moreover, there is little feldspar (albite) with a formula: [$(Na_{0.75}Ca_{0.25})(Al_{1.26}Si_{2.74}O_8$].

The mineralogical analysis shows that 97–99% of the initial ore volume is quartz, sericite and potassium feldspar [$KAlSi_3O_8$], all represented by micro particles from a few hundred nanometers to a few hundred microns in size, in a state of close mutual intergrowth. The cementing material is volcanic ash transformed by weathering into the ultraflakes of sericite interbedded with clay flakes and superfine quartzite. Around 1–2% of total quartz is isometric fractured particles 0.1–2.5 mm in size. Seldom impurities of quartz porphyry are particles to 4 mm in size [8].

At the mean, the ore samples contain 74.48% $SiO_2$, 16.20% $Al_2O_3$, 0.23% $Fe_2O_3$, 3.52% $K_2O$ and 0.59% $Na_2O$. The mass fractions of arsenic and lead are 31.66‰ and 36.82‰, respectively.

The sieve analysis and sedimentation aimed to find grain composition of ore after 84% of the ore volume is milled down to –10 mm was followed by the chemical analysis of each size grade. The ratio of the contents of the basic components changes essentially depending on the particle size. The content of quartz gradulaly increases with larger particles, while the contents of $K_2O$ and $Al_2O_3$ increase with smaller particles. In the particles –10+0 μm in size, the contents of $K_2O$ and $Al_2O_3$ exceed 8.3% and 34%, respectively, which is twice as much as in the initial ore, while the content of quartz in these size grades is less than a half of its content in the initial ore.

Based on the studies into the material constitution of crude quartz–sericite ore, the investigation program is developed to analyze the ore processibility by the methods of selective grinding, classification and flotation [8, 10–14].

### Recovery of sericite by selective grinding and classification

The selective grinding tests used a laboratory attritioning scrubber with two propeller-type rotors which created high-velocity head-on flows. The control parameter was the yield of the size of – 45+0 μm.

The optimized operating conditions for the selective grinding of quartz–sericite ore include:

- the solid-to-liquid ratio S:L = 0.67;
- the rotation speed of the propeller mixer of the attritioning scrubber—1000 $min^{-1}$,
- the grinding time—45 min;
- the liquid glass (dispersing agent) consumption—900 g/t.

The control parameters in the tests aimed to optimize efficiency of classification of the ground quartz–sericite ore included the sericite content and recovery, as well as the contents and recoveries of $Al_2O_3$ and $K_2O$. An increase in the contents of both $Al_2O_3$ and $K_2O$ meant the increase in the content of sericite.

After preliminary experimental optimization of classification conditions, two processing circuits were proposed [9] as two-stage selective grinding with classification by the size of 100 μm in a cyclone with a diameter of 50 mm and by the size of 10 μm (circuit *a*) or 20 μm (circuit *b*) in a cyclone with a diameter of 25 mm, with manufacture of three products: high-quality sericite concentrate of –10+0 (–20+0) μm, middlings of –100+10 (20) μm and tailings of +100 μm. The processing data are compiled in **Table 1**.

Table 1 shows that when sericite ore is classified by the size of 10 μm after selective grinding, the content of sericite in the concentrate is higher (control by $Al_2O_3$ and $K_2O$) while the recovery is lower than in the classification by the size of 20 μm. The situation with the middlings is similar.

These circuits are recommended to be used subject to the concentrate quality standards, which are different in different industries. In order to ensure higher recovery of sericite, the concentrate should contain the material in the size range of –20+0 μm; and when the higher quality sericite concentrate is required, the particles should have the size of –10+0 μm.

The experimental processing tests of sericite ore by the method of selective grinding in an attritioning scrubber in combination with classification in hydraulic cyclones show that the middlings, i.e. the particles –100+10 (20) μm in size, contain around 50% of sericite and have almost the same contents of aluminum oxide and summed $K_2O+Na_2O$ as the initial ore has. Thus, the high amount of under-recovered sericite necessitates the research to be undertaken to find the ways of extracting such sericite.

In view of the fact that the mineral particles are very small and the main mineral components have the same density, it is expected to achieve the highest recovery of sericite in flotation. So, the further experiments aimed to test feasibility of selective flotation to extract sericite from middlings of the circuit which integrated selective grinding and classification in cyclones.

### Electrokinetic properties of sericite and quartz in flotation with cationic collector ArmacT

As known, grinding of mica exposes some bonds along the cleavage surfaces, and these bonds govern comparatively low hydration and relatively high floatability of the mineral. Mica flotation with cationic collectors is carried out in acid media [15].

First, to select a collecting agent, its optimal consumption and pH of the liquid phase in the pulp, the flotation tests of monomineral fractions of sericite and quartz were performed in the Hallimond tube. The earlier research showed the best results with the cationic collector ArmacT (primary tallow amine acetate salt, manufacturer Nouryon Surface Chemistry AB) [9]. Then, the representative samples of the ore were subjected to flotation on a Denver laboratory flotation machine.

**Figure 1** depicts the zeta potential of sericite and quartz as function of pH at ArmacT consumption of 40 g/t. Ions $NH^{3+}$, being the major cations, adsorb at the negative-charge surface of sericite and quartz.

As pH grows from 2 to 7, the zeta potential of sericite gradually increases from 35 mV to 45 mV. The further increase in pH (shift to the alkaline range) leads to a gradual decrease in the zeta potential of sericite, which is explained by the change of the charge of the mineral surface. When pH rises to 10, the values of the zeta potential pass through 0 and become negative; when pH=11 the zeta potential of sericite equals –31.35 mV.

At pH=2 the zeta potential of quartz is almost zero. An increase in pH to 5 induces a rapid increase in the zeta potential over 25 mV. As pH continues growing to 9, the zeta potential smoothly lowers to 14 mV. When pH grows to 9.5, the zeta potential passes through 0 to the range of negative values, and at pH=11 the zeta potential of quartz equals –36 mV.

This is a result of the overrun of the amine solubility limit, transition of the amines into molecular form and their sedimentation in alkaline solutions with the formation of a typical colloid. The experiments show that quartz has the lower zeta potential than sericite at any pH, which allows a supposition that ArmacT should have its functional group more allied to the surface of sericite than quartz.

**Table 1. Experimental sericite concentration by selective grinding and classification in cyclones**

| Circuit | Product | Yield (%) | Content, % | | | | Recovery, % | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $SiO_2$ | $Al_2O_3$ | $K_2O$ | $Na_2O$ | $SiO_2$ | $Al_2O_3$ | $K_2O$ | $Na_2O$ |
| *a* | Sericite concentrate (–10+0 μm) | 19.46 | 49.61 | 34.43 | 8.02 | 0.62 | 13.00 | 39.83 | 42.99 | 24.13 |
| | Middlings (–100+10 μm) | 56.82 | 76.46 | 16.66 | 3.54 | 0.45 | 58.48 | 56.28 | 55.41 | 51.14 |
| | Tailings (+100 μm) | 23.72 | 89.34 | 2.76 | 0.24 | 0.52 | 28.53 | 3.89 | 1.59 | 24.73 |
| *b* | Sericite concentrate (–20+0 μm) | 26.94 | 52.44 | 32.76 | 7.37 | 0.69 | 19.02 | 52.47 | 54.70 | 37.18 |
| | Middlings (–100+20 μm) | 51.68 | 80.34 | 13.61 | 2.83 | 0.41 | 55.89 | 41.82 | 40.29 | 42.38 |
| | Tailings (+100 μm) | 21.38 | 87.20 | 4.49 | 0.85 | 0.48 | 25.09 | 5.71 | 5.01 | 20.45 |

**Figure 2** illustrates the zeta potential versus ArmacT consumption at pH=2. With the increasing consumption of ArmacT, the zeta potentials of sericite and quartz also grow in the region of positive values. Furthermore, as the consumption of ArmacT grows, the zeta potential of sericite increases much faster than the zeta potential of quartz (38 mV and 5 mV, respectively, at the collector consumption of 60 g/t), which also is reflective of the functional group of ArmacT to be more allied to sericite than to quartz. As the consumption of ArmacT exceeds 60 g/t, the zeta potential of sericite decreases somewhat (approximately by 5–6 mV). The zeta potential of quartz gradually grows with the increase in ArmacT consumption but not higher than 6 mV. Probably, the cause lies in the fact that quartz before addition of the collector occurs in the deionized water, at pH of 2, and has zero charge.

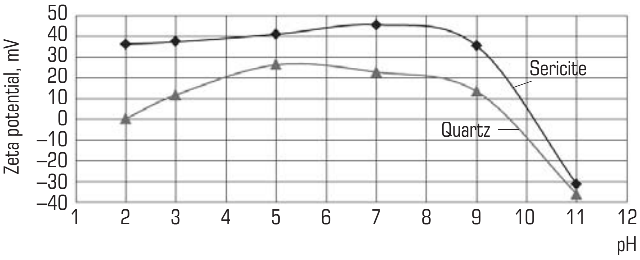

Fig. 1. Effect of pH on zeta potentials of sericite and quartz in flotation with ArmacT at consumption of 40 g/t

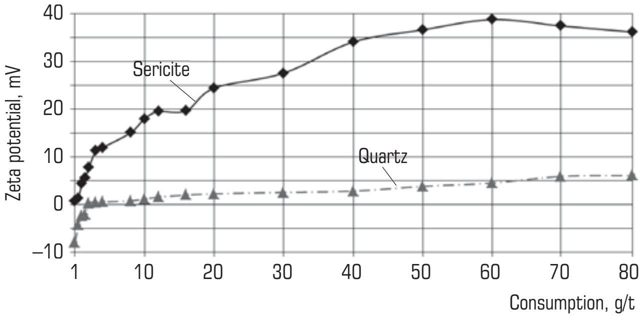

Fig. 2. Zeta potential of sericite and quartz at pH=2 versus consumption of ArmacT

## IR spectroscopy of cationic collector adsorption at sericite and quartz surface

The collecting agent ArmacT manufactured by Nouryon Surface Chemistry AB (Akzo Nobel before 2018) [16] is a tallow amine acetate with the alkyl group of 14–18 carbon atoms (around 5% C14, 30% C16, 65% C18) and is used as a cationic collector in flotation of sericite. The agent has a specific gravity of 0.845 and a molecular weight of 324 g/mole, and is used in flotation tests as a 1% solution in distilled water.

The studies into the adsorptive selectivity of the cationic collector toward sericite and quartz involved the method of the Fourier Transform Infrared Spectroscopy (FTIR) which determined the nature of chemical bonds in a molecule [17]. The relative adsorption of ArmacT at sericite and quartz was defined by the infrared light absorption band intensity, which was connected with excitation of free oscillations of the atomic groups in the test substance. The intensity is expressed in terms of the assymetrical oscillations ($v_{as}$) and symmetrical oscillations ($v_s$) in tension. In this manner, it is possible to characterize the alkyl band by $v_{as}(CH_3)$, $v_{as}(CH_2)$ and $v_s(CH_2)$, as well as to determine the range of amine by $v_{as}(NH_2)$ and $v_s(NH_2)$. It is possible to have an additional information from the measurement of the peak area in the amine absorption range. The reference ranges of the collector ArmacT have the distinct peaks typical of the alkyl chains, $v_{as}(CH_3)$ 2954 $cm^{-1}$, $v_{as}(CH_2)$ 2921 $cm^{-1}$ and $v_s(CH_2)$ 2852 $cm^{-1}$. The peak at 3367 $cm^{-1}$ is governed by the oscillations $v_{as}(NH_2)$ and $v_s(NH_2)$. The peaks at 1465 and 1378 $cm^{-1}$ are defined as $\delta(CH_2)$. A typical band of tension is observed at 1303 $cm^{-1}$ and 1071 $cm^{-1}$.

The analysis of the FTIR spectra in sericite and quartz treated with ArmacT at the consumption of 40 g/t and at pH of 2, 3 and 5 (**Figs. 4*a*** and **4*b***) reveals the distinct absorption bands in the absorption

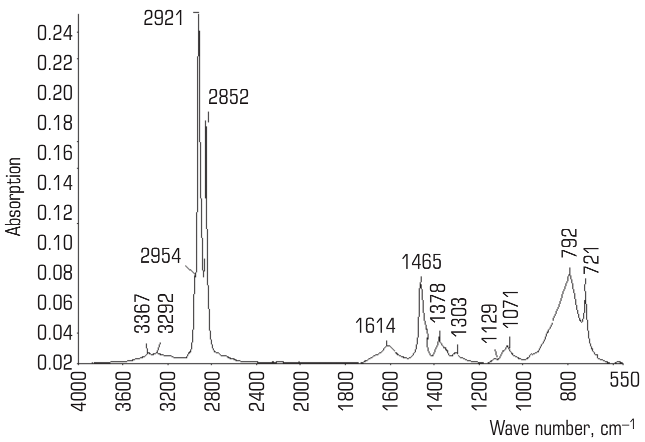

Fig. 3. Fourier Transform Infrared Spectra of collector ArmacT

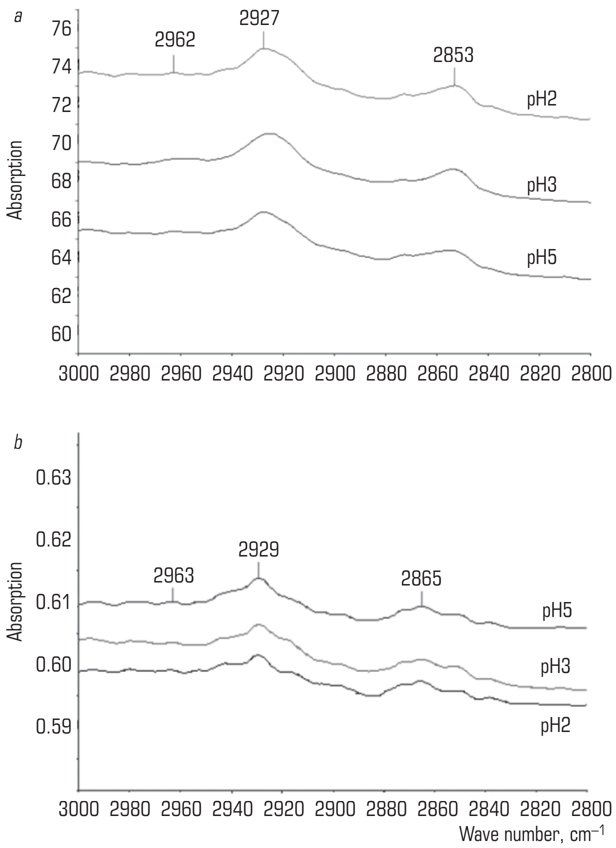

**Fig. 4. Adsorption of ArmacT at consumption of 40 g/t and different values of pH at sericite (*a*) and quartz (*b*)**

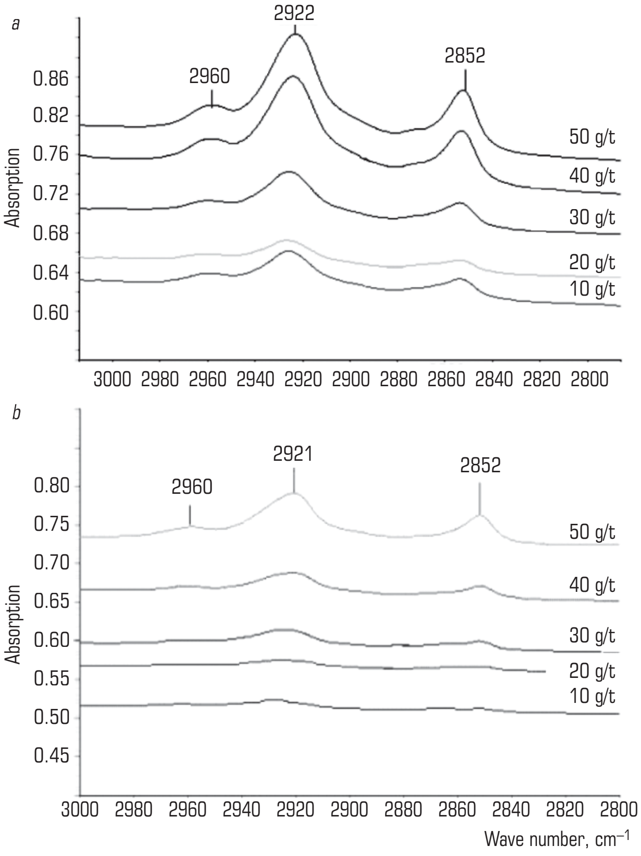

**Fig. 5. Adsorption of ArmacT at different consumptions and at pH=2 at sericite (*a*) and quartz (*b*)**

spectrum. The spectrogram contains the bands typical of the alkyl chains, $v_{as}(CH_3)$, conditioned by the valence vibrations of C-H groups (2921 cm$^{-1}$ and 2852 cm$^{-1}$), as well as the assymetrical and symmetrical vibrations $v_{as}(CH_2)$ and $v_s(CH_2)$ in the wavelength range of 3000–2800 cm$^{-1}$. The absorption band at the wave number 1465 cm$^{-1}$ is governed by the deformation vibrations of C-H groups in the alkyl chains, and the wide **band 3292–3367 cm$^{-1}$ is connected with the symmetrical valence vibrations of N-H groups.** A group of bands in the wave number range of 1071–1378 cm$^{-1}$ conforms with the valence vibrations of C-N groups [18, 19]. The highest absorption intensity of ArmacT at sericite is observed at pH=2 regarding quartz, the effect of the interaction with ArmacT is weaker at pH=2, and the highest intensity of the bands is observed at pH=5 (Fig. 4*b*).

It follows from the IR spectra in Fig. 5a that at pH=2 ArmacT adsorbs better at sericite at different consumtions. The spectra in Figs. 5a and 5b also show that the intensity of the bands of the alkyl chain grows with the increasing consumption of ArmacT both in sericite and quartz, which means the increased adsorption of ArmacT at the surface of all minerals. As sericite has the alkyl chain ranges higher than quartz (Fig. 6), it is possible to conclude that the surface of sericite is more allied to ArmacT.

The proof of this conclusion follows from the comparison of the peak areas under the bands of the valence vibrations of C-H groups in the alkyl chain between the ranges 3000–2800 cm$^{-1}$, which are measured and laid on the plot of the total area of the absorption bands versus the consumption of ArmacT in the ranges from 10 to 50 g/t (Fig. 6). As the consumption of ArmacT grows, the peak areas under the related vibration bands of the alkyl chain atoms regularly increase on sericite and quartz, and the increase in the peak area on sericite is more pronounced, which agrees with the inference on the preferable attachment of the reagent at the surface of sericite rather than quartz.

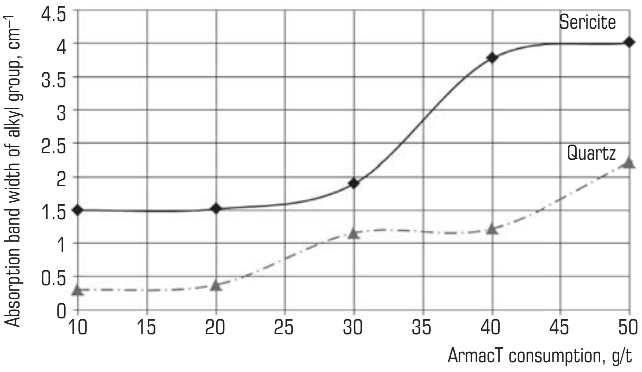

**Fig. 6. Width of alkyl group absorption band (range 3000–2800 cm$^{-1}$) in spectra of sericite and quartz as function of ArmacT consumption**

### Floatability of sericite and quartz with cationic collector ArmacT

The analysis of sericite flotation efficiency in different reagent regimes (pH values, consumption of ArmacT, consumption of liquid glass depressor $Na_2SiO_3$ and flotation time) has allowed optimization of flotation parameters (**Figs. 7*a*–7*d***):

- pH of the medium — from 2 to 2.5;
- content of solid in the pulp — 20%;
- consumption of cationic collector ArmacT— 400 g/t;
- consumption of liquid glass — ~ 2000 g/t;

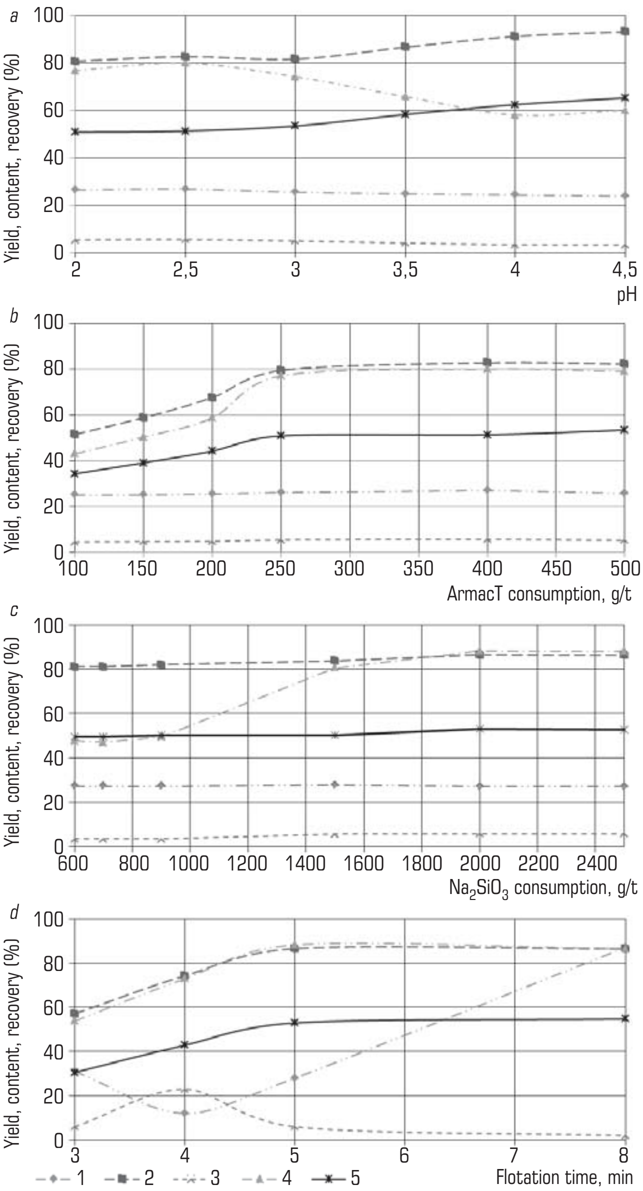

**Fig. 7. Sericite flotation efficiency versus experimental conditions:** ***a*** **— pH value;** ***b*** **— consumption of cationic collector ArmacT;** ***c*** **— consumption of depressing liquid glass $Na_2SiO_3$;** ***d*** **— flotation time;**
1 — content of $Al_2O_3$, %; 2 — recovery of $Al_2O_3$, %; 3 — content of $K_2O$, %; 4 — recovery of $K_2O$, %; 5 — yield, %

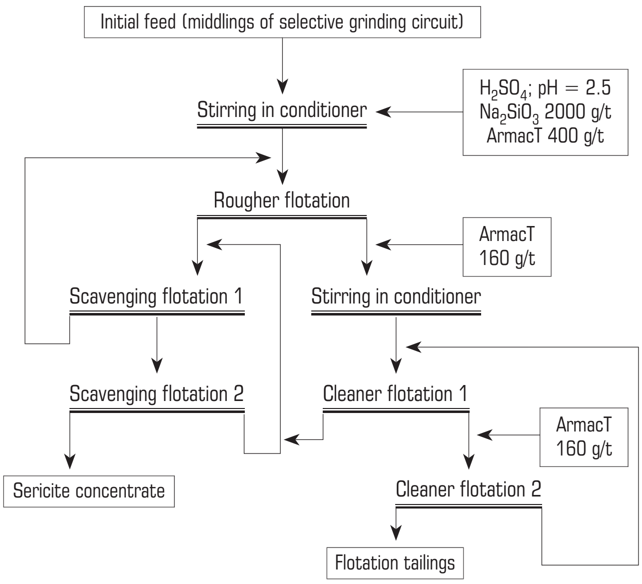

**Fig. 8. Closed-cycle flotation circuit for −100+10 µm size material**

- flotation time — 5–6 min.

Based on the obtained results and with regard to the optimized conditions and regimes, the flotation circuit is developed for middlings of the selective grinding of quartz–sericite ore (**Fig. 8**). The concentrate yield is 35.49% of the flotation feed; the contents: $SiO_2$ 49.33%, $Al_2O_3$ 34.56%, $K_2O+Na_2O=9.12\%$; the actual flotation yield: $Al_2O_3$ 73.62%, $K_2O$ 82.71% and $Na_2O$ 68.61% (**Table 2**). Furthermore, the flotation tailings with the content of $SiO_2$ 91.39%, after increasing the silicon oxide content to 93%, can be assumed as a quartz-bearing feedstock for the ceramics manufacture.

**Table 3** describes the balance of metals in the integrated flowchart, with the selective grinding and cyclone classification circuits to produce the first concentrate and with the flotation circuit to produce the second concentrate. With reference to the initial feed, the yield of the concentrates is 39.63% at the recovery of $Al_2O_3$ 81.26%; $K_2O$ 88.85% and $Na_2O$ 59.26%.

The comparative analysis of the compositions of sericite concentrates produced from Ha Tinh ore and the concentrates used as a feedstock in the paint-and-varnish industry and in production of polymers (**Table 4**) shows that the contents of the test components, namely, $Al_2O_3$, $K_2O$ and $Na_2O$ in Ha Tinh concentrates matches or exceeds the contents of the same components in the concentrates of other companies, while the content of ferric oxides is much lower (0.15–0.16% as against 1.07–3.66%). The content of silicon oxide is also lower than in the concentrates of other companies, as a rule. These results prove that it is possible to produce sericite concentrates from Ha Tinh ore, at the market-competitive quality.

The flow chart was tested in the continuous operation mode on a semi-commercial plant having capacity of 100 kg/h. Around 40 kg of concentrate was produced.

The lab-scale and semi-commercial tests have proven good possibilities for producing sericite and quartz concentrates suitable for manufacturing high-quality ceramics and polymeric coatings. The Department of Polymer Material Technology at the Vietnam Academy of Science and Technology approved applicability of such sericite products in the paint-and-varnish

**Table 2. Balance of metals in flotation circuit in Fig. 8 for middlings of selective grinding of quartz–sericite ore**

| Product | Yield (%) | Content, % | | | | Recovery, % | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $SiO_2$ | $Al_2O_3$ | $K_2O$ | $Na_2O$ | $SiO_2$ | $Al_2O_3$ | $K_2O$ | $Na_2O$ |
| **Initial feed** (selective grinding circuit middlings) | **100.00** | **76.46** | **16.66** | **3.54** | **0.45** | **100.00** | **100.00** | **100.00** | **100.00** |
| Sericite flotation concentrate | 35.49 | 49.33 | 34.56 | 8.25 | 0.87 | 22.90 | 73.62 | 82.71 | 68.61 |
| Tailings (quartz concentrate) | 64.51 | 91.39 | 6.81 | 0.95 | 0.22 | 77.10 | 26.38 | 17.29 | 31.39 |

industry. Van Xuan Ha Tinh company certified usability of these sericite and quartz products as a feedstock for manufacturing high-quality ceramics.

The further improvement of economic value of sericite concentrates aims at making the concentrates applicable in the cosmetic industry, but, in accordance with the recommendations of the Vietnam Academy of Science and Technology, it can be feasible after additional removal of heavy metals, which calls for advancing the research.

**Table 3. Balance of metals in integrated processing flow chart for quartz–sericite ore**

| Product | Yield (%) | Content, % | | | | Recovery, % | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $SiO_2$ | $Al_2O_3$ | $K_2O$ | $Na_2O$ | $SiO_2$ | $Al_2O_3$ | $K_2O$ | $Na_2O$ |
| **Initial ore** | **100.00** | **74.29** | **16.82** | **3.63** | **0.50** | **100.00** | **100.00** | **100.00** | **100.00** |
| Sericite concentrate of selective grinding | 19.46 | 49.61 | 34.43 | 8.02 | 0.62 | 13.00 | 39.83 | 43.01 | 24.15 |
| Sericite concentrate of flotation | 20.17 | 49.33 | 34.56 | 8.25 | 0.87 | 13.39 | 41.43 | 45.84 | 35.11 |
| **Total, concentrates** | **39.63** | **49.47** | **34.50** | **8.14** | **0.75** | **26.39** | **81.26** | **88.85** | **59.26** |
| Tailings of selective grinding circuit (+100 μm) | 23.72 | 89.34 | 2.76 | 0.24 | 0.52 | 28.53 | 3.89 | 1.57 | 24.68 |
| Tailings of flotation (quartz concentrate) | 36.65 | 91.39 | 6.81 | 0.95 | 0.22 | 45.09 | 14.84 | 9.58 | 16.06 |

## Conclusions

Based on the implemented investigations, the technology has been developed and substantiated for processing quartz–sericite ore from the Ha Tinh Province. The technology allows obtaining the competitive marketable products such as:

1. High-quality sericite concentrate –10+0 (–20+0) μm in size in the circuit including selective grinding in attritioning scrubber and ball milling in combination with classification in cyclones;
2. Sericite concentrate of the quality conformable with the standards imposed on the raw stock for some industries (from middlings—tailings of gravity concentration, in flotation cycle using collecting agent ArmacT);
3. Quartz concentrate (flotation tailings) which, after raising the content of silicon oxide to 93–95%, can be a feedstock for the ceramics industry.

The production technology of sericite and quartz concentrates is approved on a semi-commercial scale. The quality of the concentrates and their applicability in the paint-and-varnish and ceramics industries are certified.

**Table 4. Quality of concentrates produced from ore from different deposits in South East Asia**

| Ore deposit and/or company | Content, % | | | | |
|---|---|---|---|---|---|
| | $SiO_2$ | $Al_2O_3$ | $K_2O$ | $Na_2O$ | $Fe_2O_3$ |
| Ha Tinh, Vietnam | 49.61 | 34.43 | 8.02 | 0.62 | 0.16 |
| | 49.33 | 34.56 | 8.25 | 0.87 | 0.15 |
| Hebei, China; ATSM | 53.00 | 26.38 | 7.29 | – | 3.66 |
| China; THC Ltd | 69.58 | 18.2 | 6.02 | | 1.07 |
| Anshan, China; AMG, concentrate GA-1–GA-8* | 47–68 | 18–32 | – | – | – |
| Malasia; INCI | 45–55 | 26–36 | > 8 | – | < 2.6 |
| Malasia; MPSI | 45.50 | 36.70 | 8.80 | | 2.50 |

* Products GA-1–GA-8 feature mostly maximal coarseness—from 35 μm (GA-1) to 3.2 μm (GA-8).

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