Songklanakarin J. Sci. Technol.
41 (6), 1314-1318, Nov. - Dec. 2019

http://www.sjst.psu.ac.th

*Original Article*

# Froth flotation of mixed feldspar

Chairoj Rattanakawin[1*] and Benjapol Thacom[2]

[1] *Department of Mining and Petroleum Engineering, Faculty of Engineering, Chiang Mai University, Mueang, Chiang Mai, 50200 Thailand*

[2] *Primary Industries and Mines Office, Region 5, Department of Primary Industries and Mines, Mueang, Phitsanulok, 65000 Thailand*

Received: 15 July 2017; Revised: 13 February 2018; Accepted: 26 July 2018

## Abstract

The purpose of this research was to study a mixed feldspar processing. The study included characterization, flotation and evaluation. Characterization was carried out using hand lens, ore microscope, X-ray diffraction, X-ray fluorescent and electrokinetic measurement. Froth flotation was used to separate feldspar from micas, iron-bearing minerals and quartz using cationic, anionic and acid flotation respectively. Evaluation of the separation was done by using data from yield of feldspar, X-ray fluorescence and cone firing test. The feldspar yield was used to evaluate the process efficiency. Besides, chemical analysis, cone shrinkage, fired color and degree of vitrification were used to monitor the quality of the floated feldspar. The feldspar was furthermore compared to the standard feldspar samples obtained from a ceramic manufacturer. Finally, the finished feldspar was graded for using in various kinds of ceramics.

**Keywords:** ceramics, froth flotation, mineral processing, mixed feldspar

## 1. Introduction

Feldspar is one of the basis minerals used to make various types of ceramics, e.g. tiles, sanitary wares, table wares, etc. It can be used as ceramic body and glaze in order to decrease firing temperature and to increase the degree of vitrification. Due to deficiency in potassium feldspar for ceramic industries in Thailand, some of this feldspar is imported from neighboring countries (Rattanakawin, Phuvichit, Nuntiya, & Tonthai, 2005, 2006). To be self-sufficient on the supply of this ceramic raw material, other sources of alkaline minerals can be used. These minerals are syenite (Rattanakawin, Phuvichit, Panjasawatwong, & Supapia, 2010), pottery stone (Chanyavanich, 2003) and mixed feldspar. Mixed feldspars are broadly identified as granitic rocks having approximately the same amount of $K_2O$ and $Na_2O$ contents. They can be classified into various types regarding to their textures: fine-grained, porphyritic, and both textures. Aplite is a fine-grained granitic rock whereas pegmatite is typically a porphyritic, coarse grained granite. An aplite-pegmatite complex is a mixture of both porphyritic and fine-grained granitic rock. Therefore, the minerals founded in mixed feldspars are common constituents in granite such as feldspars, quartz, micas (muscovite and biotite) and small amount of iron-bearing minerals. However, most of mixed feldspars cannot be directly used as raw materials for high grade ceramics. In order to upgrade mixed feldspars, froth flotation (Rau, 1985) could be applied to separate feldspar from those micas and iron-bearing minerals, and quartz respectively. The purpose of this research was to study about the processing of mixed feldspar including characterization, flotation and evaluation respectively.

## 2. Methods

### 2.1 Characterization

The run-of-mine (ROM) feldspar was sampled from Amphoe Ban Tak, Tak (1875000-1878000N; 497000-499000E, Sheet no. 4742 I Series L7017 of the Royal Thai Survey topo-

*Corresponding author
Email address: chairoj@eng.cmu.ac.th

graphic map). The sample was characterized for its petrography, liberation size, mineralogical and chemical composition, electrokinetic and ceramic properties. Petrographic study was carried out by using hand lens. Liberation size was estimated by grain counting of each sieve size fraction of ground samples using ore microscope. Mineralogical study was done by X-ray diffraction using D8-Advance BRUKER linked with Intel Pentium IV Processor. The measuring conditions are as follows: Cu K-alpha radiation at 40 KV and 40 mA; start and stop angles at 5 and 78 degrees; scanning speed of 0.2 sec/step with increment of 0.02; detection with scintillation counter. The -200 mesh sample was packed into a hole on plastic plate. After that the well-packed sample was x-rayed with the above-mentioned conditions. The intensity of detected signals was then plotted as a function of 2θ. Finally the intensity peaks were selected, searched and matched with those of the standard minerals compiled by the JCPDS using computer program DIFFRAC PLUS.

Chemical composition of ROM, floated and standard feldspar samples was analyzed using X-ray fluorescence with The ED 2000 OXFORD and the Oxford XpertEase Windows™. Primary X-ray was generated using Rhodium Target. High voltage of 5 KV and 900 μA was set to measure Na, Mg, Al, Si, K at the Very Light Elements condition, whereas voltage of 12 KV and 600 μA was used to investigate Ca, Ti, and Fe at the Solids (S-V) condition. The reference and measuring samples were separately excited with the primary X-ray for 100 sec. and the emitted secondary X-ray was detected with the lithium drifted silicon detector. Three certified reference feldspars; NCSDC 61102, SRM 99a and SRM 70a (Rattanakawin *et al*., 2005) were used to create a standard calibration curve in which the chemical analysis (% weight of oxides) of all feldspar samples was compared and evaluated. Loss on ignition was also included in the analysis by determining the weight loss of the samples fired at 1,000 °C for one hour.

The electrokinetic property of well-extracted feldspar and quartz was measured using electrophoresis technique. The Zeta-Meter System 3.0+ was employed to measure zeta-potential of the diluted and well-dispersed feldspar and quartz at suspension pH ranging from 3-6. HCl and NaOH with concentrations of 0.1 and 1 mol/L were used to adjust the suspension pH. The applied voltages were set to be 100, 200 or 300 V. depending on observed velocity of the charged feldspar and quartz particles. Then the zeta potential can be calculated from the applied voltage and the velocity of the particles using Excel program.

Cone firing test was used to determine ceramic properties of ROM, floated and standard feldspar samples. The samples were coned and fired at 1280°C for 30 minutes. After that shrinkage, fired color and degree of vitrification of the cones were evaluated.

## 2.2 Flotation

Processing of ROM feldspar was conducted by means of froth flotation. Mechanical flotation of this feldspar was performed in the chosen conditions. In short, the procedure of batch flotation using Denver machine (Denver D-1, Serial no. 95671-1) was as follows:

1) Ball milling 1 kg of ROM feldspar at 50% wt. solids for 12 min to the passing size of about 35 Tyler mesh.
2) De-sliming at about 200 mesh by rinsing the suspended particles.
3) Adjust the ground pulp to 30% wt. solids.
4) Conditioning the pulp in laboratory cell at 1,100 rpm with $H_2SO_4$ at pH 2 and then amine as collector with dosage of 200 g/ton ROM feldspar for 5 min.
5) Addition of pine oil as frother about 50 g/ton feldspar.
6) Removal of micas by using this cationic flotation for 5 min.
7) Conditioning the residual pulp at 1,100 rpm for 5 min with $H_2SO_4$ to pH 2.5 and then sulfonate as collector with dosage of 300 g/ton feldspar, and pine oil about 50 g/ton in respect.
8) Removal of iron-bearing minerals by using this anionic flotation for 5 min.
9) Conditioning the remaining pulp at 1,100 rpm for 5 min. with hydrofluoric acid (HF) to pH 3, amine at 200 g/ton and pine oil about 50 g/ton.
10) Acid flotation of feldspar from quartz for 5 min.
11) Filter and dry the float and sink products.
12) Removal of iron contaminants from grinding and/or the remaining from ROM feldspar itself in the float product by using dry low-intensity magnetic bar.

More information regarding experimental procedure of feldspar flotation has been described at length by Rattanakawin (2015).

## 2.3 Evaluation

The finished float product was weighed, sampled, analyzed by X-ray fluorescence, and cone-fired respectively. Evaluation of the flotation was done using the yield of feldspar and its chemical composition, cone shrinkage, fired color, and degree of vitrification as criteria. The feldspar was furthermore compared with the ROM and standard feldspar samples obtaining from the raw material section of a ceramic manufacturer. Finally, the feldspar was graded for using in various kinds of ceramics.

## 3. Results and Discussion

## 3.1 Petrographic study of granitic rock

A rock sample is macroscopically characterized as aplite-pegmatite complex. This complex can be separated into two granitic rock types: aplite and pegmatite. The aplite is a light-gray aphanitic rock, fine-grained, composed mainly of feldspars, quartz, and muscovite with small amount of garnet. The pegmatite is a gray porphyritic rock, composed mostly of orthoclase, quartz and muscovite with a few biotite. Therefore this aplite-pegmatite complex consists largely of orthoclase, albite, muscovite and quartz with small amounts of biotite and garnet.

## 3.2 Grain counting using ore microscope

It appears from the grain counting of each sieve size fractions of ground ROM feldspar (Table 1) that an appropriate liberation size is about -35 Tyler mesh. Because there is a large amount of locked feldspar-quartz particles at sizes larger than this size. The -35 mesh particle should be suitable for froth flotation effectively. Therefore the ROM feldspar was specifically ground to meet this passing size prior to the flotation. A mostly complete liberation of the locked particles is not a normal practice in the mineral industry. Because further grinding will increase the costs significantly and also generates more slime leading to a higher flotation reagent consumption and lower production.

### 3.3 Mineralogical study using X-ray diffraction

The XRD trace of ROM feldspar (Figure 1) shows that orthoclase ($KAlSi_3O_8$), albite ($NaAlSi_3O_8$), muscovite and quartz are the major minerals. The orthoclase is K-feldspar while the albite is Na-feldspar. As a result, this feldspar is characterized as mixed feldspar. This is in accordance with the chemical analysis determined by XRF technique shown in Table 2 in which the percentages of $K_2O$ (4.65%) and $Na_2O$ (4.49%) are not different significantly.

### 3.4 Zeta potential measurement

Differences in sign and amount of surface charges on mineral particles in a suspension affect a flotation system. It is also expected that an optimum flotation could obtain where there is a large difference in sign and charges on feldspar and quartz surfaces for cationic collector adsorption. Figure 2 demonstrates the change in zeta potentials of the well-extracted feldspar and quartz as a function of pH adjusted by HF in addition of amine (200 g/ton). From the zeta potential-pH plot, point of zero charge (PZC) of quartz is pH 3.4. Nonetheless the PZC of feldspar cannot be observed due to its highly negative charges generated by the adsorbed fluosilicate ions ($AlSiF_6^{2-}$) on

Table 1. Grain counting of ground ROM feldspar; Feldspar (Feld.), Quartz (Qtz.), Locked feldspar and quartz particle (Feld.+Qtz.), and Muscovite (Musc).

| Size (Tyler mesh) | Feld. (%) | Qtz (%) | Feld+Qtz (%) | Musc (%) | Biotite (%) | Garnet (%) |
|---|---|---|---|---|---|---|
| +20 | 45.64 | 30.24 | 14.95 | 8.62 | 0.55 | trace |
| -20+28 | 28.59 | 12.73 | 11.61 | 46.00 | 1.07 | trace |
| -28+35 | 26.60 | 17.08 | 6.75 | 46.90 | 2.67 | trace |
| -35+48 | 29.50 | 21.50 | 3.87 | 41.75 | 2.67 | 0.71 |
| -48+65 | 30.53 | 27.44 | 1.94 | 34.02 | 5.36 | 0.71 |

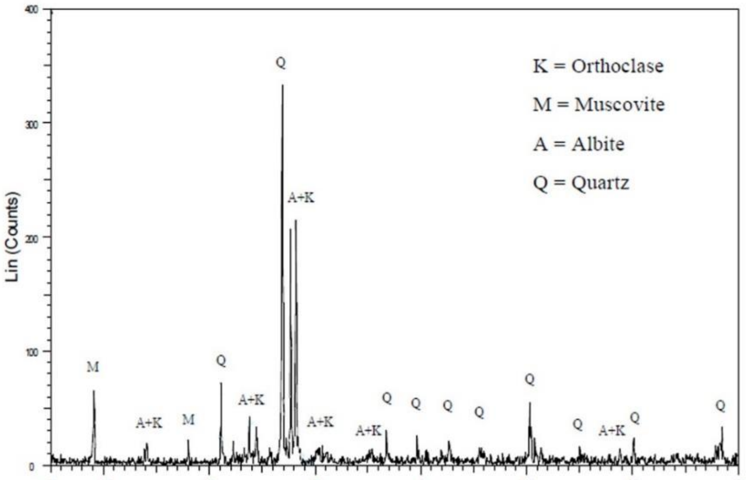


Figure 1. XRD trace of ROM feldspar.

Table 2. Chemical analysis of ROM, floated and standard feldspar samples.

| Sample | $SiO_2$ (%) | $TiO_2$ (%) | $Al_2O_3$ (%) | $Fe_2O_3$ (%) | MgO (%) | CaO (%) | $Na_2O$ (%) | $K_2O$ (%) | LOI (%) |
|---|---|---|---|---|---|---|---|---|---|
| ROM feldspar | 74.87 | 0.04 | 14.52 | 0.44 | 0.05 | 0.57 | 4.49 | 4.65 | 0.37 |
| Floated feldspar | 68.53 | 0.01 | 17.87 | 0.12 | 0.05 | 0.81 | 6.60 | 5.69 | 0.32 |
| FK-SK/7 (Standard) | 66.55 | 0.06 | 19.30 | 0.56 | 0.17 | 1.07 | 3.55 | 7.96 | 0.77 |
| FK-AN/Body (Standard) | 68.47 | 0.01 | 17.84 | 0.10 | 0.03 | 1.37 | 5.81 | 5.94 | 0.44 |

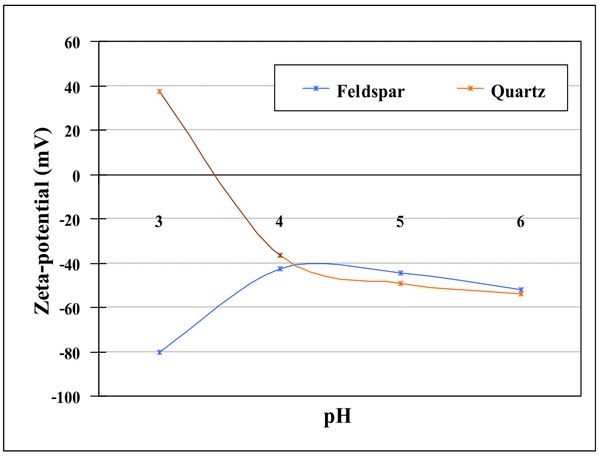


Figure 2. Zeta potentials of feldspar and quartz samples as a function of pH.

aluminum sites (Fuerstenau, Miller, & Kuhn, 1985). At pH 3, quartz is positively charged so the amine ions cannot physically adsorb. Therefore the quartz surface is wetted and remains hydrophilic. On the other hand, flotation of feldspar can occur at this pH because the adsorption of amine on alumino-fluosilicate sites induces the hydrophobic surfaces ($AlSiF_6^{2-}NH_3R$) and makes it readily for froth flotation.

### 3.5 Flotation

The chemical composition, cone shrinkage, unfired and fired color, degree of vitrification, and yield of floated feldspar were compared to those of ROM and standard samples (Rattanakawin *et al*., 2005) obtained from a ceramic manufacturer. These are shown in Tables 2 and 3 respectively.

Comparing the chemical analyses, especially $\%Na_2O$ $+\%K_2O$ and $\%Fe_2O_3$ of the floated product to those of ROM feldspar indicates that froth flotation technique can virtually upgrade the product qualities. For examples, $\%Na_2O+\%K_2O$ increases from 9.14 to 12.3 while $\%Fe_2O_3$ decreases from 0.44 to 0.12. Furthermore, amount of the alkaline content is greater than that of the standard samples. The iron content is much less than that of the FK-SK7 sample. It also appears from the cone firing test that the floated product has white color, very good vitrification, and higher percentage shrinkage on firing comparing to the ROM and standard samples. This appearance verifies the effectiveness of flotation technique to process this mixed feldspar. This is due to the ceramic-tinted constituents such as micas and iron-bearing minerals can be removed by cationic and anionic flotation respectively. Reduction on quartz by acid flotation results in more vitreous and shrinkage of the fired cone. The overall quality of floated feldspar is better than of the FK-SK7 sample. This finished product can be certainly used as ceramic body in tiles, sanitary and table wares.

## 4. Conclusions

Due to the huge reserve of mixed feldspars in Thailand (Rattanakawin *et al*., 2005, 2006), it is very promising to further develop this mineral resource for ceramic industries. From the mineral processing viewpoint, it is capable to apply froth flotation to process mixed feldspars effectively. The quality of floated feldspar is suitable for using in various kinds of high-grade ceramics. In conclusion, the sustainable development of this mixed-feldspar resource will definitely secure our own sufficiency economy.

Table 3. Cone shrinkage, unfired and fired color, degree of vitrification, and yield of floated feldspar comparing to those of ROM and standard feldspar samples.

| Sample | Fired cone | % Shrinkage (on firing) | Unfired color | Fired color | Degree of vitrification | Yield |
|---|---|---|---|---|---|---|
| ROM feldspar |  | 38.78 | Brown | Light brown | Moderate | - |
| Floated feldspar |  | 56.75 | Light brown | White | Very good | 40.39% |
| FK-SK/7 (Standard) |  | 46.92 | Brown | Greyey white w/ brown spots | Moderate | about 20% |
| FK-AN /Body (Standard) |  | 47.67 | Brown | White | Good | about 50% |

Note: Amount of slime removed prior to flotation is about 12% by weight.

## Acknowledgements

We gratefully acknowledge the Department of Primary Industries and Mines for funding this research.

## References

Chanyavanich, C. (2003). Thai raw material: Green-hearth selection. *Proceedings of the Conference on Advancing with Minerals for Ceramics,* (pp. 62). Chiang mai, Thailand.

Fuerstenau, M. C., Miller, J. D., & Kuhn, M. C. (1985). *Chemistry of Flotation.* New York, NY: Society of Mining Engineers of the American Institute of Mining, Metallurgical and Petroleum Engineers.

Rattanakawin, C. (2015). Experiment 8: Feldspar Flotation. In *Lecture note on Laboratory of Mineral Processing II* (pp. 43-50). Chiang Mai, Thailand: Chiang Mai University.

Rattanakawin, C., Phuvichit, S., Nuntiya, A., & Tontahi, T. (2005). *Value-adding and processing of feldspar of northern region, Thailand*. Bureau of Primary Industries, Department of Primary Industries and Mines, Bangkok, Thailand.

Rattanakawin, C., Phuvichit, S., Nuntiya, A., & Tonthai, T. (2006). *Value-adding and processing of feldspar of eastern region, Thailand*. Bureau of Primary Industries, Department of Primary Industries and Mines, Bangkok, Thailand.

Rattanakawin, C., Phuvichit, S., Panjasawatwong, Y., & Supapia, S. (2010). Processing of hornblende syenite for ceramics. *Songklanakarin Journal of Science and Technology, 32*(2), 189-195.

Rau, E. (1985). Feldspar. In N. L. Weiss (Ed.), *SME Mineral Processing Handbook* (pp. 29-9 – 29-11). New York, NY: Society of Mining Engineers of the American Institute of Mining, Metallurgical, and Petroleum Engineers.