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Effect of chemical composition on the surface charge property and flotation behavior of pyrophyllite particles

Xiaowen Liu^{*}, Mingjun Bai

School of Minerals Processing and Bioengineering, Central South University, Changsha 410083, China

Key Laboratory for Mineral Materials and Application of Hunan Province, Central South University, Changsha 410083, China

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ABSTRACT

The surface charge property and chemical composition are important for flotation investigation. First, the mineral phase and morphology of different pyrophyllite samples were analyzed. The isoelectric points of different pyrophyllite particles also were determined. Moreover, the effect of chemical composition on flotation recovery of pyrophyllite particles was studied. The isoelectric point (iep) of pyrophyllite particles shows negative correlation with the mass fractions of SiO_2 and Na_2O . At the point of zero charge of edge plane of pyrophyllite, the zeta potential of pyrophyllite particles displays negative correlation with mass fraction of SiO_2 . While it shows positive correlation with mass fraction of CaO and TiO_2 . Additionally, the flotation experiments of the pyrophyllite particles were conducted and the results showed that the flotation recovery has a positive correlation with mass fraction of SiO_2 , while negative correlation with mass fraction of Al_2O_3 , TFE , and iep. Therefore, the content of SiO_2 is beneficial to the flotation of the pyrophyllite particles.

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1. Introduction

Pyrophyllite is a hydrous layered aluminum silicate [$\text{Al}_2\text{Si}_4\text{O}_{10}(\text{OH})_2$] with a kind of 2:1 structure, consists of individual sheets of $\text{Al}(\text{O}, \text{OH})_6$ octahedra sandwiched between sheets of SiO_4 tetrahedra. The pyrophyllite is theoretically composed of 67% SiO_2 , 28% Al_2O_3 and 5% H_2O , in which Al is likely to be replaced by Fe or some like Mg, Ca, Na, or K [1–3]. Therefore, impurities in pyrophyllite ore are mainly quartz, feldspar, diaspore, dickite, chlorite and mica [4–6]. Pyrophyllite has been widely used in ceramic, plastic, rubber, pressure transmission medium, medical carrier and adsorption or photocatalytic materials due to its good physico-chemical characteristics, such as low thermal and electrical conductivity, low expansion coefficient, low reversible thermal expansion and excellent reheating stability [2,5,7–10]. There are a lot of literatures reported on the synthesis of nanocrystalline and clay mineral nanocomposites [10–22]. The pyrophyllite is also one of the main gangue silicates in diasporic bauxite [23–25], which is usually removed or recovered by flotation. In flotation system, the characteristics of minerals, such as electrical properties, chemical composition and particle size distribution, are

important factors influencing the flotation behavior [23,24,26–30]. Zeta potential represents the electric potential at the shear plane between a particle and the surrounding liquid when the charged particle moves in an electric field [31–33], and it is almost dependent on pH over a wide range [34]. Many behaviors can be significantly influenced by surface zeta potential such as the sorption of metal ions and the flotation behavior of minerals [27,35,36]. Therefore, charge properties of pyrophyllite should be considered for both the basal plane surface and edge plane surface. The excess of permanent negative charge of basal surface can be attributed to the isomorphic substitution of Si^{4+} replaced by Al^{3+} and Fe^{3+} in the tetrahedral layers and Al^{3+} by Mg^{2+} and Fe^{2+} in the octahedral layer [1,37]. Moreover, Johnson also have found that the zeta potential of basal surface can be affected by pH [38]. And as for the edge surfaces, the edges are considered to carry an alterable charge depend on the pH of solution, due to protonation and deprotonation of the surface hydroxyl groups [1,39]. Several literatures have reported the surface charge properties of montmorillonite and kaolinite [28,37,40–46]. While for pyrophyllite particles, little attention has been paid to investigate the relationship between the chemical composition, surface property and flotation recovery.

This paper is aim to investigate the effect of chemical composition on surface charge properties and flotation behaviors of pyrophyllite particles, which is of significant importance for pyrophyllite particles flotation.

^{*} Corresponding author.

E-mail address: lxwdr@csu.edu.cn (X. Liu).

2. Experimental

2.1. Materials and reagents

Five kinds of pyrophyllite samples were collected from Zhejiang, China. The chemical compositions of the samples are listed in Table 1. The samples were firstly crushed and ground by an agate mortar to less than 5 μm before X-ray diffraction analysis and zeta potential measurement. The samples were milled by ball milling to 50–100 μm for flotation tests. Analytical grade of HCl and NaOH were used for pH adjustment, analytical grade sodium oleate was used for flotation experiments, and doubly distilled water was used throughout this study.

The chemical compositions of the pyrophyllite particles were measured by X-ray fluorescence (Axios max, PANalytical, Netherlands). X-ray diffraction patterns were obtained using a DX-2700 instrument (Dandong Haoyuan Instrument Co. Ltd., China) using Cu K α radiation ($\lambda = 0.15406 \text{ nm}$) with an acceleration voltage of 40 kV and an emission current of 40 mA at a scanning rate of $0.02^\circ \text{ s}^{-1}$ from 5° to $80^\circ 2\theta$. The morphology of the pyrophyllite samples was characterized by scanning electron microscope (JSM-5600LV, JEOL, Japan) operated at 20 kV. The zeta potential of mineral suspension was measured by Zeta Plus instrument (Zeta Plus, Brookhaven, USA). The pyrophyllite particles were added into a 40 ml beaker. The solid concentration was about 0.02%. The suspension was agitated for 2 min and transferred to the testing vessel, after that the zeta potential measurement was made. Three measurements were repeated and showed a certainty of $\pm 5 \text{ mV}$. The pH of suspension was measured at the end of agitation with an accuracy of ± 0.02 using a REX Model PHS-3C pH meter.

Flotation tests were carried out by using an XFG5-35 flotation machine (mechanical agitation) with a 40 mL plexiglass cell, at an impeller speed of 1650 rpm. The mineral suspension was prepared by adding 2.0 g of sample to 30 mL of deionized water. The concentration of sodium oleate is $2 \times 10^{-4} \text{ mol/L}$. Once the collector (sodium oleate) was added, the suspension was agitated for 3 min. The flotation lasted for 4 min before the products were collected, dried, and weighed. The recovery was calculated based on the weights of the dry products obtained.

3. Results and discussion

3.1. Phase analysis of the pyrophyllite samples

The XRD patterns of the samples are shown in Fig. 1. The results indicate that all the five samples are mainly consist of pyrophyllite (JCPDS 25-0022), but there are still little montmorillonite (JCPDS 13-0135) in samples Py-QT1, Py-QT2, Py-QT3 and quartz (JCPDS 46-1045) in sample Py-GH.

The SEM of the five samples are similar, in the photographs of sample Py-QT1, the particles are in the form of aggregation, and the size of pyrophyllite particles is about 50–100 μm (Fig. 2a). Pyrophyllite in the particles is foliated, the size is about 2–4 μm in width, and 0.1 μm in thickness (Fig. 2b).

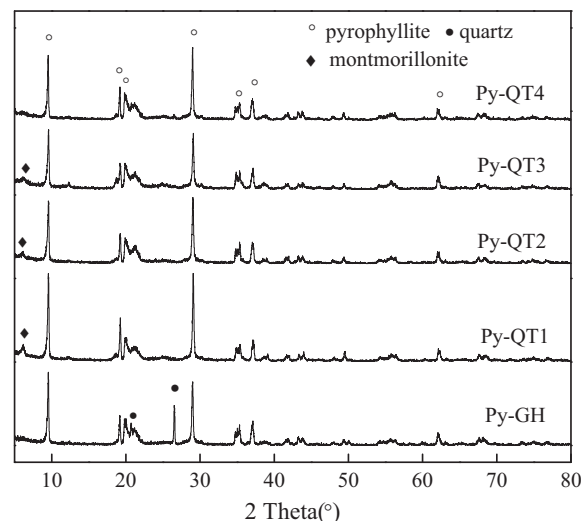


Fig. 1. The X-ray powder diffraction patterns of the pyrophyllite samples.

3.2. Zeta potentials of the pyrophyllite samples as a function of pH

The zeta potentials of the pyrophyllite samples as a function of pH are shown in Fig. 3. The results indicate that different pyrophyllite particles have similar trends between zeta potentials and pH. But the values of zeta potentials are different from pyrophyllite particles when measured under the same condition. The isoelectric points (iep) of the pyrophyllite particles obtained by reading the intercept of the trend lines with the horizontal dotted line of zero mV are given in Table 2. The measured iep of pyrophyllite particles varies from 2.35 to 3.46, which are different from the point of zero charge calculated value 2.47 given by YSD equation [47,48].

3.3. Effect of chemical composition on the zeta potentials of the pyrophyllite samples

Fig. 4 shows the relationships between isoelectric point (iep) and chemical composition (wt%) of the pyrophyllite samples. The iep of pyrophyllite particles shows negative correlation with the mass fractions of SiO_2 and Na_2O , which correlation coefficients are 0.70 and 0.83, respectively.

Fig. 5 shows the relationship between zeta potential ($\text{pH} = 6.26$) and chemical composition (wt%) of the pyrophyllite samples. At the point of $\text{pH} = 6.26$, there is no net proton charge or rare net proton charge at the edge of the pyrophyllite particles. Hence, the zeta potential mainly is caused by the isomorphous substitution of the basal plane [48]. The zeta potential of pyrophyllite particles shows negative correlation with mass fraction of SiO_2 , its correlation coefficient is 0.76. While the zeta potential of pyrophyllite particles shows positive correlation with mass fraction of CaO and TiO_2 , its correlation coefficient are 0.79 and 0.81, respectively.

Table 1

The chemical composition (wt%) of the pyrophyllite samples by XRF.

Sample	SiO_2	Al_2O_3	MgO	CaO	TFe	TiO_2	K_2O	Na_2O	H_2O^+	LOI
Py-GH	65.95	27.81	0.640	0.022	0.10	0.12	0.067	0.108	0.62	5.92
Py-QT1	57.94	31.33	0.013	0.087	0.18	0.29	0.020	0.095	0.45	7.32
Py-QT2	60.12	30.70	0.009	0.064	0.11	0.24	0.014	0.110	0.53	6.89
Py-QT3	55.76	32.61	0.016	0.088	0.45	0.12	0.100	0.100	0.46	8.20
Py-QT4	61.57	31.10	0.013	0.081	0.18	0.19	0.049	0.120	0.35	6.53

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