



# Role of magnesium-bearing silicates in the flotation of pyrite in the presence of serpentine slimes

Siyuan Yang<sup>a,b</sup>, Baohua Xie<sup>b</sup>, Yiping Lu<sup>b</sup>, Chao Li<sup>a,\*</sup>

<sup>a</sup> School of Chemical Engineering, The University of Queensland, Brisbane, Queensland 4072, Australia

<sup>b</sup> School of Mineral Processing and Bioengineering, Central South University, Changsha 410083, PR China

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## ABSTRACT

Flotation is the most effective separation solution used in sulphide ore beneficiation. In sulphide ore flotation, the interaction between the valuable sulphide minerals and the gangues are complex. Serpentine, a common magnesium-bearing silicate mineral in sulphide ores, can largely depress the flotation of the valuable sulphide minerals by adhering at their surfaces (i.e. slime-coating). In contrast, quartz can mitigate the depressing of the valuable minerals by serpentine. This work studied the effect of two common magnesium-bearing silicate minerals in sulphide ores (i.e. pyroxene and olivine) on the flotation of pyrite which was used as a model sulphide mineral. It was found that, similar to quartz, pyroxene and olivine could significantly improve the recovery of pyrite depressed by serpentine. Zeta potential measurements and turbidity experiments showed that serpentine could aggregate with pyroxene and olivine in aqueous solution via electrostatic interaction. Furthermore, DLVO calculation revealed that serpentine preferentially interacted with pyroxene and olivine rather than pyrite, resulting in increased pyrite recovery by stripping serpentine from pyrite surface.

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## 1. Introduction

Flotation has been widely used in mineral processing for the separation and concentration of mineral ores by exploiting the differences in hydrophobicity of the various minerals in the ores. Each year, more than a billion tons of sulphide ores are beneficiated via flotation throughout the world [1–3]. Sulphide minerals are often associated with silicate gangues, including quartz, magnesium-bearing and aluminum-bearing silicates. Sulphide ore flotation is a concentration process by removing the gangue minerals from the valuable sulphide minerals. Specially, magnesium-bearing silicates need to be removed to the greatest extent as magnesium oxide (MgO) has high smelting point which can cause technical problems in the down-stream metallurgical processing [4].

Serpentine ( $\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4$ ) is a common magnesium-bearing silicate gangue in sulphide ores [5], and flotation of sulphide ores associated with serpentine is complex, owing to the interactions between sulphide minerals and serpentine, especially in the flotation of copper-nickel sulphides [6]. The easy-to-slime serpentine can adhere at the sulphide mineral surfaces and restrain collector adsorption on the sulphide minerals, resulting in hydrophilic mineral surfaces [7]. The process is known as “slime coating”. Slime coating is directly related to the surface charge difference between the sulphide minerals and serpentine in aqueous

solution [8,9]. Serpentine has a point of zero charge (PZC) at pH value of 9.5 while sulphide minerals normally have PZCs below 7 [10]. Flotation of sulphide minerals is normally performed under weakly alkaline conditions at which the positively charged serpentine can interact with the negatively charged sulphide minerals through electrostatic attraction [5,11]. To overcome the adhesion of serpentine on sulphide minerals, dispersants are usually added in flotation to mitigate the slime coating [12]. Carboxymethyl cellulose (CMC) or sodium silicate can be used to disperse the ultrafine serpentine particles [9,13,14]. However, high reagent dosages are normally required, not only imposing detrimental impact on environment but also causing high capital cost [15].

Instead of using dispersants, it was found that the slime-coating of serpentine at sulphide mineral surface can be mitigated by the presence of quartz, a common gangue mineral in sulphide ores [5]. The PZC of quartz is about 2 in aqueous solution [16]. Quartz is much more negatively charged than sulphide minerals at weak alkaline solution. Thus, positively charged serpentine is preferred to aggregate with quartz rather than with sulphide minerals. The coagulation of particles with different characteristics (e.g. size, chemical composition, or surface charges), which irreversibly leads to a solid or a gel-like structure in a suspension, is known as heterocoagulation [17]. The heterocoagulation between quartz and serpentine can facilitate the separation of sulphide minerals from serpentine [5].

The finding above naturally leads one to investigate the effect of other gangue minerals on the separation of sulphide minerals from serpentine. Natural serpentine is originated from the alteration of

\* Corresponding author.

E-mail address: [cli7@uq.edu.au](mailto:cli7@uq.edu.au) (C. Li).

pyroxene ( $\text{MgSiO}_3$ ) or olivine ( $\text{Mg}_2\text{SiO}_4$ ) after hydrothermal metamorphism [18]. Hence, serpentine usually coexists with pyroxene and olivine [19]. However, no work has been dedicated to investigate the role of pyroxene and olivine in the flotation of sulphide minerals. It is still unclear whether pyroxene and olivine act as serpentine to restrain the concentration of sulphide ores or, in contrast, act as quartz to alleviate the slime coating. Better understanding of the interactions between serpentine and other gangues could eliminate the use of dispersants in flotation of sulphide ores associated with serpentine.

In this work, a comparative study was performed to investigate the effect of quartz, pyroxene and olivine on flotation of pyrite which is used as a model material for sulphide minerals. Note that the pyrite has been coated by serpentine slimes. This allows us to study whether the presence of pyroxene and olivine can deteriorate or enhance the flotation performance of sulphide ores. In addition, pyroxene and olivine are common gangue minerals not only in sulphide ores but also in some oxide minerals, such as ilmenite and chromite [20,21]. Therefore, this research would also potentially improve the understanding of roles of these magnesium-bearing silicate gangues in the flotation of some oxide ores.

## 2. Experimental

### 2.1. Materials and reagents

Pyrite and silicate minerals (quartz, serpentine, pyroxene and olivine) (>92% pure) were obtained from different sources in China. All samples used in the experiments were crushed and ground to the particle size as desired. Pyrite sample with a particle size range of 38–150  $\mu\text{m}$  was obtained through wet sieving. The silicate minerals were finely ground and the particle size distributions of them are shown in Fig. 1. Since serpentine is a group of sub-minerals, the examination by X-ray diffraction showed that it consisted of lizardite and minor chlorite. Lizardite is volumetrically the most abundant serpentine species [22].

Potassium amyl xanthate (PAX) (Tokyo Chemical Industry Co., Ltd, Japan) was used as collector and Methyl Isobutyl Carbinol (MIBC) (Sigma-Aldrich, USA) was used as frother. Sodium hydroxide (NaOH) and hydrochloric acid (HCl), for adjusting pH, were obtained from the Sinopharm Chemical Reagent Co., Ltd., China. All the reagents were of analytical grade. Deionized water was used in all experiments in this work.

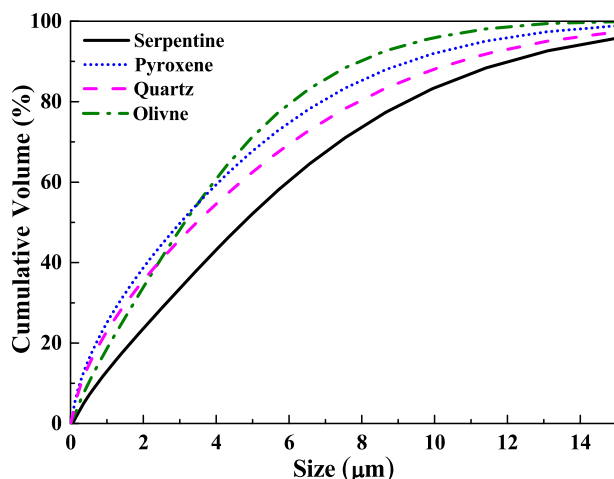


Fig. 1. Size distributions of the silicate minerals.

### 2.2. Micro-flotation

Micro-flotation tests were conducted using an XFGII agitation flotation machine with a 40 mL cell at a fixed agitation speed of 1800 rpm. 50 g/L of pyrite was used in all flotation experiments in this study. 2.5 g/L of serpentine was used when needed. The mixture ratio of pyrite to serpentine was chosen based on previous studies according to industry process [5]. The other silicate mineral (pyroxene, olivine or quartz) was added at a concentration as needed. The pH was adjusted by adding HCl or NaOH stock solution. The PAX was added at a dosage as desired and 10 mg/L MIBC was used in this study. The conditioning time for PAX and MIBC was 2 min and 1 min, respectively. The concentrate was collected for 3 min in each flotation test. All flotation experiments were conducted at room temperature. The concentrates and the tailings were filtered, dried, and weighed. The concentrate and the tailings of each test were assayed to calculate the pyrite recovery.

### 2.3. Turbidity measurements

The mineral suspension was prepared by mixing 1 g mineral particles with 40 mL water in the flotation cell, and agitated for 3 min to disperse the solids thoroughly in water. 10 mL of the stock mineral suspension was pipetted out and diluted to 100 mL in a beaker. Then, the pH of the diluted suspension was adjusted as needed using NaOH or HCl solutions, followed by agitating at 1800 rpm for 10 min using a magnetic stirrer. After settling for 10 min, 25 mL supernatant was sampled and measured immediately using a turbidity meter (WGZ-3/3P) to determine the turbidity values.

### 2.4. Zeta potential measurements

Zeta potentials of pyrite and the silicate minerals were measured using a Js94H zeta potential analyzer. Mineral samples were finely ground to <2  $\mu\text{m}$  using an agate mortar and a pestle. For each measurement, 50 mg of mineral sample was added to 30 mL aqueous solution, magnetically stirred for 10 min and the pH was adjusted using HCl or NaOH solutions. All measurements were conducted in 0.1 mol/L  $\text{KNO}_3$  solution to maintain the ionic strength.

## 3. Results and discussion

### 3.1. Effects of silicate minerals on the flotation of pyrite slime-coated by serpentine

This section presents the effect of introducing a silicate mineral on the flotation of pyrite slime-coated by serpentine at various flotation conditions by changing collector dosage, pH and the concentration of the introduced silicate mineral.

#### 3.1.1. Collector concentration

Fig. 2a shows the effect of different silicate minerals (serpentine, pyroxene, olivine and quartz) on pyrite flotation as a function of PAX dosage at pH 9. The concentration of pyroxene, olivine and quartz was added at 2.5 g/L. The flotation of pure pyrite under different pHs is also shown in Fig. 2a for comparison. It is seen from Fig. 2a that the maximum flotation recovery of pyrite alone was achieved at the PAX dosage of  $1 \times 10^{-4}$  M, after which further increasing of PAX dosage did not increase the pyrite recovery. However, pyrite flotation was significantly depressed by serpentine throughout the PAX concentration varied in this study. This effect is similar to the previous study [5]. For example, the recovery of pyrite was decreased from 91% to 32% at the dosage of  $1 \times 10^{-4}$  M PAX. Higher collector dosage would be needed to mitigate the detrimental effect of serpentine while pyrite recovery still cannot be restored as with the absence of serpentine. For example, at the PAX dosage of  $2.0 \times 10^{-4}$  M, the flotation recovery of pyrite slime-coated

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