



## The role of some special ions in the flotation separation of pentlandite from lizardite



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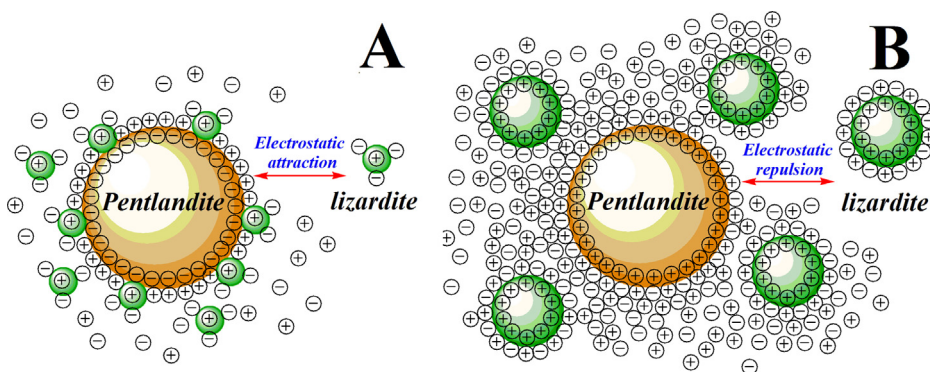
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### HIGHLIGHTS

- Constitution ions were found to significantly improve pentlandite recovery efficiency.
- Improved recovery was due to the zeta potential changes of the mineral surfaces and the aggregation of lizardite particles.
- Constitution ions dispersed lizardite particles from pentlandite surfaces by making the surfaces of pentlandite and lizardite particles homocharged.
- The bimodal distribution of lizardite particles was observed in constitution ion solutions.
- The formation of spongy lizardite fibers was a novel factor interfering with the flotation of pentlandite, which was repressed efficiently in constitution ion solutions.

### GRAPHICAL ABSTRACT

Model for the changes of pentlandite–lizardite system in deionized water (A) and high concentration NiCl<sub>2</sub> solution (B).



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### ABSTRACT

In this work, the flotation of pentlandite/lizardite system was studied in deionized water, brine and solutions containing some special “constitution ions” with different ionic strengths, respectively. The flotation results show that the “constitution ions” significantly improve the recovery efficiency of pentlandite compared with deionized water or brine. The possible mechanisms responsible for the improved flotation separation in these special solutions are investigated by electrokinetic studies, scanning electronic microscopy (SEM) analysis and size distribution tests. Experimental results demonstrate that the reconstitution of electrical double layer mitigates the coating of lizardite particles on pentlandite surfaces and induces the aggregation of lizardite particles for the enhanced recovery of pentlandite.

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## 1. Introduction

Nonferrous metal nickel, called the “vitamin of industry”, is a very important raw material for the production of various types of steel and alloys [1]. Currently pentlandite ((Fe, Ni)<sub>9</sub>S<sub>8</sub>) is the main source of nickel worldwide and is typically concentrated

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by froth flotation. Lizardite ((Mg, Fe)<sub>3</sub>Si<sub>2</sub>O<sub>5</sub>(OH)<sub>4</sub>) is the common magnesium silicate gangue mineral found in sulphide nickel–copper ores, which interferes with the concentration of pentlandite in the froth flotation process. Edwards et al. discovered that the depressed pentlandite flotation is due to the “slime coating” of lizardite on the pentlandite surface, which decreases the hydrophobicity of the pentlandite particles and therefore reduces collector adsorption [2]. From then on, the flotation separation of pentlandite from lizardite in fresh water has been investigated by a great number of researchers [3–7].

In an effort to conserve freshwater resources, many base metal sulfide flotation plants have introduced reused water, underground water or even seawater as a conventional practice [8]. Peng and Seaman had demonstrated that pentlandite flotation was poor in deionized water because of high lizardite gangue entrainment, while saline water improved pentlandite flotation and reduced lizardite entrainment significantly [9], which indicated the importance of electrolytes in saline water for the improved pentlandite flotation. By compressing the electrical double layer, electrolytes have been found to mitigate the coating of lizardite particles on pentlandite surfaces and induce lizardite particle aggregation. Based on our prior experience in the flotation of copper–nickel sulfide ore, we expected that some special ions which constitute the study objects (pentlandite and lizardite) could exhibit good behaviors in pentlandite flotation. For this purpose, solutions containing Mg<sup>2+</sup>, Fe<sup>3+</sup>, Ni<sup>2+</sup> and S<sup>2-</sup> with different ionic strengths were utilized to conduct flotation tests. The aim of the present work is to survey the effects of these “constitution ions” on the interaction between lizardite and pentlandite. Comparative studies using deionized water and brine were also performed to evaluate the superiority of “constitution ions”.

## 2. Materials and methods

### 2.1. Materials

Lizardite and pentlandite were obtained from Donghai, Jinchuan in China. X-ray powder diffraction (XRD) data confirmed that lizardite was 99% pure and pentlandite was 96.8% pure. Optical microscope images showed that both of the samples were almost free of impurities [10]. The lizardite sample was ground by agate ball mill, while pentlandite was crushed to the average particle size below 75 μm.

Sodium Butyl Xanthate (NaBX) was used as the collector and Methyl Isobutyl Carbinol (MIBC) acted as the frother. Electrolyte solutions with different ionic strengths employed in all experiments were prepared by adding MgCl<sub>2</sub>, FeCl<sub>3</sub>, NiCl<sub>2</sub>, Na<sub>2</sub>S or NaCl into deionized water and stirred for 1 h, respectively. All the reagents described above were of analytical grade.

### 2.2. Methods

#### 2.2.1. Zeta potential measurements

Zeta potential was determined using a Malvern Zetasizer nano ZS zeta potential meter. Zeta potentials of pentlandite and lizardite in deionized water with a background electrolyte solution of 10<sup>-3</sup> M KNO<sub>3</sub> were measured; while zeta potential measurements in electrolyte solutions were conducted without a further addition of KNO<sub>3</sub>. For each measurement, 30 mg of sample was added to 10 mL deionized water or electrolyte solutions and ultrasonicated for 30 min, then stirred for 10 min before the measurement was taken.

#### 2.2.2. Size distribution measurements

The size distribution of lizardite particles was determined using a Malvern Zetasizer nano ZS zeta potential meter. For each mea-

surement, 0.3 g of sample was added to 10 mL of deionized water or electrolyte solutions and ultrasonicated for 30 min, then stirred for 10 min before the measurement was taken.

#### 2.2.3. Flotation tests

Mineral flotation tests were carried out in an inflatable hanging slot flotation machine (XFGC II) with the impeller rotation speed set at 2000 r/min [10]. The slurry was prepared by adding 1.0 g of pentlandite and 1.0 g of lizardite to 50 mL of deionized water or electrolyte solutions. The conditioning time was allotted as follows: 5 min for the homogenate period, 2 min for the collector and 2 min for the frother, respectively. Then flotation was performed for a total of 4 min. The floated and unfloated particles were collected, filtered and dried to calculate flotation recovery (based on solid weight and phase analysis distributions between the two products).

#### 2.2.4. Scanning electron microscopy

A HITACHI S-4800 scanning electron microscope (SEM) equipped with an energy dispersive X-ray spectrometer (EDXS) was used to produce images and analyze the elemental composition of the surfaces of mineral samples.

#### 2.2.5. FTIR study

The infrared spectra of mineral samples were recorded with a NEXUS 670 Spectrometer. Approximately 1 mg of the desired powder sample was thoroughly mixed with 200 mg of spectroscopic grade KBr and pressed into pellets.

## 3. Results and discussion

### 3.1. The changes of surface characteristics of pentlandite and lizardite in the presence of constitution ions

Previous studies showed that the electrokinetic method was a suitable and sensitive approach to elucidate the structure of the electrical double layer [11]. Therefore, zeta potential measurements of pentlandite and lizardite were carried out to study the functions of different ions. As shown in Fig. 1, in deionized water, pentlandite was strongly negatively charged with a zeta potential about -15 mV; while lizardite was strongly positively charged with a zeta potential about 12 mV, similar to the studies of Edward et al., Bremmell et al. and Feng et al. [2,12,13]. In brine (NaCl), when the ionic concentration increased, the absolute values of zeta potentials of both pentlandite and lizardite decreased significantly, which reached a minimum value (close to zero but without number sign change) when the ionic strength exceeded approximately 1 M. This is consistent with the observations by Peng and Bradshaw [14]. However, the effects of electrolyte solutions of MgCl<sub>2</sub>, FeCl<sub>3</sub>, NiCl<sub>2</sub> and Na<sub>2</sub>S indicated that constitution ions (Mg<sup>2+</sup>, Fe<sup>3+</sup>, Ni<sup>2+</sup> and S<sup>2-</sup>) played a special role on the mineral surface as compared with Na<sup>+</sup> or Cl<sup>-</sup>. All these electrolytes changed the surface characteristics of pentlandite and lizardite, which was evidenced by the presence of the humps. In these solutions, when the ionic concentrations of the electrolytes increased from 0 M to 3 M, zeta potentials of pentlandite and lizardite in absolute value first increased sharply to reach a maximum, then decreased and finally dropped close to zero. During this process, constitution ions could even reverse the zeta potential signs of mineral surfaces at relatively low concentrations. Since changes of surface conductance can scarcely be expected to play a part in these measurements, this observation proved that the role of Mg<sup>2+</sup>, Fe<sup>3+</sup>, Ni<sup>2+</sup> and S<sup>2-</sup> was distinctly different from that of Na<sup>+</sup> or Cl<sup>-</sup>. Modi and Fuerstenau had discovered the similar experimental phenomena when measuring streaming potential of corundum, and they attributed the striking difference between the curves to specific adsorption [15].

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