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## The effect of lizardite on talc flotation using carboxymethyl cellulose as a depressant

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**Abstract:** The effect of lizardite on talc flotation when using carboxymethyl cellulose (CMC) as a depressant was studied by micro-flotation experiments and adsorption measurements, zeta-potential measurements, magnesium ion dissolution analysis, and solution chemistry calculation. The results for the micro-flotation experiments showed that the addition of lizardite further decreased the floatability of talc at pH 8.5 when using CMC as the depressant. The mechanism was that magnesium ions dissolved from lizardite lattice, then formed hydrolyzed species of magnesium cations and interacted with talc surfaces, which promoted CMC adsorption, and thus decreasing talc floatability.

**Keywords:** talc, lizardite, flotation, CMC, magnesium ion

### 1. Introduction

Lizardite ( $(\text{Mg}_6)[\text{Si}_8]\text{O}_{20}(\text{OH})_4$ ) and talc ( $\text{Mg}_6[\text{Si}_4\text{O}_{10}](\text{OH})_8$ ) are magnesium bearing silicate minerals, which are usually associated with sulfide ores, such as nickel and/or copper sulfide ores, etc. (Feng et al., 2018; Yang et al., 2018; Liu et al., 2018 and 2019a). According to the crystal structure of talc, its surfaces consist of edge face and basal face. The  $-\text{SiOH}$  and  $-\text{MgOH}$  groups exist at the edge face, hence the edge face is hydrophilic (Fuerstenau et al., 1988; Malhammar, 1990; Jin et al., 2018a). However, there are no hydroxyl groups and active sites in the basal face of talc, which accounts for over 90% of the total surface. Therefore, talc is a naturally hydrophobic mineral (Jin et al., 2018b). Lizardite is different from talc. Crystal cleavage along the octahedral layer of lizardite is easy to occur, which exposes a significant amount of Mg-O bonds. The Mg-O bonds are very likely hydrated, and thus lizardite surfaces are hydrophilic without natural floatability (Feng et al., 2013).

Depressants are a crucial factor in the flotation separation of valuable minerals from gangue minerals (Liu et al., 2019b; Huang et al., 2019 and 2020; Chen et al., 2020). Previously studies have shown that talc and other Mg-bearing minerals can be depressed by polymeric depressants such as carboxymethyl cellulose (CMC), the carboxyl substituent groups along the cellulose chain (Shortridge et al., 2000; Parolis et al., 2008). The interaction of Mg-bearing mineral surfaces with CMC includes hydrogen, hydrophobic bonding, and chemical interaction (Khraisheh et al., 2005; Cuba-Chiem et al., 2008; Parolis et al., 2008). However, most of the literature only considered the situation that contained one kind of Mg-bearing gangue mineral.

Few studies have also revealed that talc and lizardite may interfere with the floatability of each other in the presence of polymeric depressants. For example, Feng et al. (2012) reported that the talc surface was easily coated by serpentine slimes and then further decreased the floatability of talc in the presence

of CMC. However, except for the “slime coating”, the lizardite particle itself may also affect the adsorption of CMC onto talc surface but the results remained unknown.

In the present study, the effect of lizardite on the flotation of talc using a CMC depressant was studied. This was accomplished using various methods, including micro-flotation and adsorption experiments, zeta-potential measurements, inductively coupled plasma (ICP) analysis, and solution chemistry calculations.

## 2. Materials and methods

### 2.1. Materials

The talc and lizardite samples were obtained from Guangdong and Gansu province, China, respectively. The crystals of the talc and lizardite were crushed manually and handpicked. The samples were dry ground and screened. The -74+37  $\mu\text{m}$  fraction of talc was used for the flotation, adsorption, and dissolution measurements, and the surface area of talc was obtained as 2.49  $\text{m}^2/\text{g}$ . The -74+37  $\mu\text{m}$  fraction of lizardite was used for the flotation experiments and ICP analysis. The -37  $\mu\text{m}$  fraction of talc was further ground to -5  $\mu\text{m}$  fraction for the zeta potential measurements. The purity of the samples was confirmed by X-ray diffraction (XRD) analysis and chemical compositions, and the results are shown in Fig. 1 and Table 1, respectively. It can be observed from Fig. 1 that no observable impurities bands occurred in the talc and lizardite sample, indicating that the purity of samples was high (over 95%).

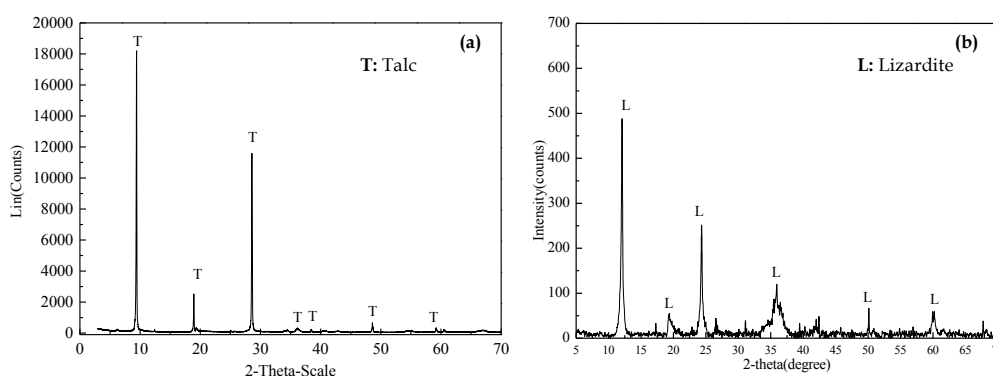


Fig. 1. XRD pattern of (a) talc and (b) lizardite samples

Table 1. Chemical composition of talc and lizardite

Sample	MgO	SiO <sub>2</sub>	CaO	Fe	Al <sub>2</sub> O <sub>3</sub>
Talc	31.68	63.82	/	0.87	0.10
Lizardite	39.85	41.26	0.17	4.18	0.72

Sodium butyl xanthate (SBX) with 88% purity, obtained from Zhuzhou Flotation Reagent Company was used as a collector. Analytical-grade methyl isobutyl carbinol (MIBC), purchased from Shanghai Aladdin Biochemical Technology Ltd, was applied as a frother. Analytical-grade sodium carboxymethyl cellulose (CMC) (degree of substitution (DS)=1.2, molecular weight=250,000), obtained from Aladdin Industrial Ltd, was used as a depressant. Analytical-grade NaOH and HCl, obtained from Sinopharm Chemical Reagent Ltd, were utilized as pH modifiers, and deionized (DI) water (Milli-Q, Millipore Corp., 18.2  $\text{m}\Omega \cdot \text{cm}$  resistivity) was used for all the experiments.

## 2.2. Methods

### 2.2.1. Micro-flotation experiments

The micro-flotation experiments were performed in an XFGC-1600 flotation machine (made in Jilin Exploration Machinery Plant, China) at an impeller speed of 1800 rpm. For each experiment, mineral

particles of 2 g were mixed with 40 cm<sup>3</sup> DI water in a plexiglass flotation cell. The pH of the pulp was adjusted by NaOH and HCl solution, and the pulp was conditioned for 3 min. Then SBX and MIBC were added into the suspension and conditioned for another 3 min and 1 min, respectively. Afterward, the pH value of the slurry was recorded, and the froth products were collected for 4 min. For single mineral experiments, the dry weights of the concentrate and tailings were determined, and the recovery was calculated. For the mixed-mineral flotation experiments, the contents of talc in the concentrates and tailings were assayed and used for the recovery calculation. Error bars in the plots for the measurements represent one standard deviation of uncertainty obtained from two independent runs.

### 2.2.2. Zeta-potential measurements

Zeta potential measurements were performed using a Coulter Delsa440sx Zeta Analyzer instrument. 40 mg of -5 μm samples were added into 80 cm<sup>3</sup> of 1×10<sup>-3</sup> mol/dm<sup>3</sup> KNO<sub>3</sub> background electrolyte solution, and the mixed samples were dispersed in a beaker using a magnetic stirrer for 5 min. When needed, the lizardite supernatant was mixed with talc. After 20 min settling of lizardite particles, the talc suspension was collected for the zeta-potential measurements. The zeta-potential of each sample was measured three times, and the average value was reported in this study. The standard deviation was calculated, and was presented as an error bar in the corresponding figures.

### 2.2.3. Adsorption experiments

Adsorption experiments were conducted by an Elementary Liquid TOCII instrument. For each experiment, 2 g talc samples were added into 40 cm<sup>3</sup> DI water which contained a desired amount of CMC. When required, the DI water was replaced by lizardite supernatant, then the pulp pH was adjusted to 8.5 with NaOH/HCl. The suspension was conditioned for 20 min to ensure the adsorption equilibrium, then the suspension was filtered and the filtrate was collected for adsorption experiments. The residual CMC concentration in the filtrate was calculated from the standard calibration curve. The adsorption amount was calculated based on Eq. 1:

$$\Gamma = \frac{(C_i - C_r)}{S \cdot m} \quad (1)$$

where  $\Gamma$  stands for the adsorption density in mg/m<sup>2</sup>,  $C_i$  and  $C_r$  represent the initial and residual concentration of CMC respectively in mg/dm<sup>3</sup>,  $S$  is the specific surface area of talc (0.225 m<sup>2</sup>/g measured by BET method),  $V$  is the volume of CMC solution in dm<sup>3</sup> while  $m$  is the mass of mineral samples in g.

### 2.2.4. Magnesium ion dissolution analysis

Lizardite samples of a predetermined quantity were added into a solution of the desired pH. The total volume of the suspension was 100 cm<sup>3</sup>. The suspension was conditioned for 10 min at the desired pH value, ensuring that the dissolution equilibrium was achieved, then the suspension was filtered. Magnesium ion concentration of the filtrate was measured by Inductively Coupled Plasma Optical Emission Spectrometry (Leeman Labs Prodigy7/USA).

## 3. Results and discussion

### 3.1. Micro-flotation experiments

Figure 2 shows the floatability of talc and lizardite in the absence and presence of CMC as a function of pH. As shown in Fig. 2, the talc flotation recovery was over 90% while the lizardite flotation recovery was below 15% across the entire pH range in the absence of CMC, which agrees on the previous literature (Feng et al., 2013; Jin et al., 2018b). The effect of CMC on the lizardite flotation was minor. However, the recovery of talc increased with the increase of pH values in the presence of CMC, suggesting that the adsorption of CMC on the talc surface may be decreased with the increasing pH.

To evaluate the interference of lizardite with the talc flotation in the presence of CMC, the micro-flotation experiments were conducted with the talc sample at pH 8.5 as a function of CMC concentrations with and without the lizardite (Fig. 3). As shown in Fig. 3, the talc recovery decreased from 90% to 50% with an increase in the CMC concentration from 0 to 60 mg/dm<sup>3</sup>. When the CMC concentration was above 60 mg/dm<sup>3</sup>, the talc recovery maintained nearly constant. However, with the

addition of 5 g/dm<sup>3</sup> lizardite, 10 g/dm<sup>3</sup> lizardite, 20 g/dm<sup>3</sup> lizardite, the flotation recovery of talc decreased to 40%, 25%, and 13%, respectively, and reached the constant recovery at 100 mg/dm<sup>3</sup> CMC concentration. As such, the mixing talc with lizardite effectively enhanced the depression performance of talc in the presence of CMC.

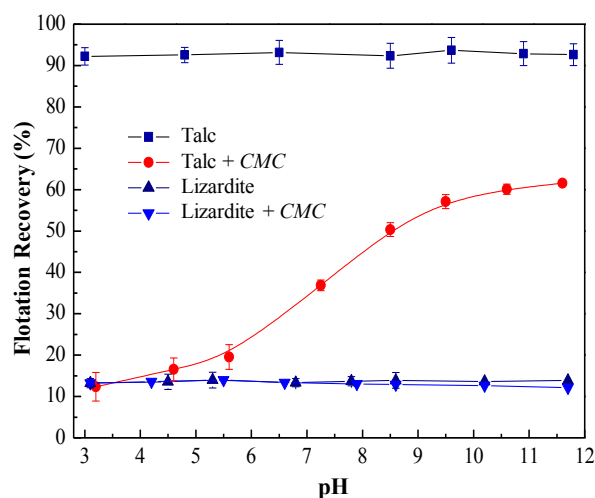


Fig. 2. Flotation recovery of talc and lizardite as a function of pH (CMC=60 mg/dm<sup>3</sup>, SBX=1×10<sup>-4</sup> mol/dm<sup>3</sup>, MIBC=1×10<sup>-4</sup> mol/dm<sup>3</sup>)

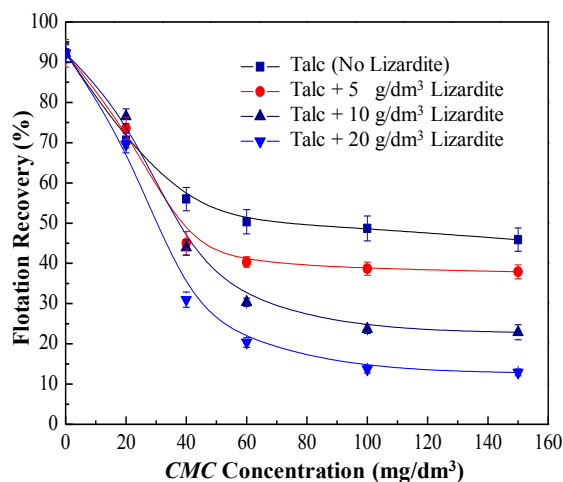


Fig. 3. Flotation recovery of talc as a function of CMC concentration in the absence and presence of lizardite (Talc=50 g/dm<sup>3</sup>, SBX=1×10<sup>-4</sup> mol/dm<sup>3</sup>, MIBC=1×10<sup>-4</sup> mol/dm<sup>3</sup>, pH=8.5)

### 3.2. Adsorption experiments

The adsorption amount of CMC on the talc surface directly affects the floatability of talc. Hence the adsorption of on the talc surfaces was performed. It can be seen from Fig. 4 that the adsorption amount of CMC on the talc surface increased with the increase in initial CMC concentration, and the isotherms which were reached their adsorption plateau when the CMC concentration is 80 mg/dm<sup>3</sup>. However, at the same CMC concentration, the amount of adsorbed CMC at talc surface in the lizardite supernatant is more than that in deionized water, and the more the lizardite concentration is in the supernatant, the more the CMC adsorption will be at talc surface, this can support flotation results in Fig. 4.

### 3.3. Zeta potential measurements

The effects of lizardite and CMC on the zeta potential of talc are shown in Fig. 5. It can be seen from Fig. 5 that the surface charge of bare talc is negative across the entire pH range and the zeta potential of talc

significantly decreased with the increase in the pH, which is similar to the early literature reports (Wang et al., 2016; Jin et al., 2018b; Liu et al., 2019c). In the presence of CMC, the zeta potential of talc became more negative, (decreased by 5 mV), indicating the adsorption of CMC on the talc surfaces.

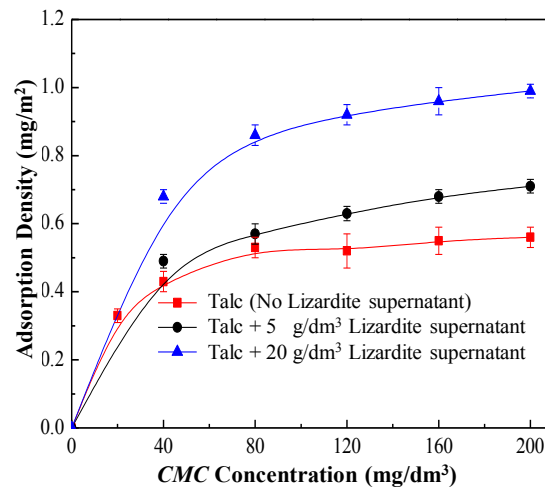


Fig. 4. Adsorption isotherms onto talc surface at pH 8.5

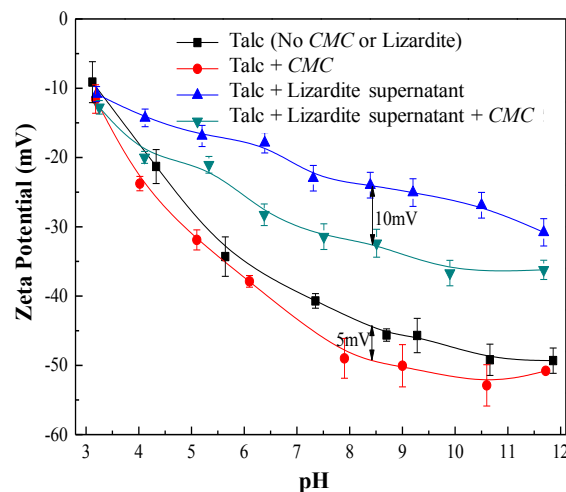


Fig. 5. Zeta potential of talc as a function of pH in the absence and presence of CMC

Fig. 5 also illustrates that the zeta-potential of talc conditioned with the lizardite supernatant was less negative than that of bare talc, indicating that the cations dissolved from lizardite lattice and then interacted with the talc surface. After the addition of CMC, the zeta potential of talc decreased by approximately 10 mV at pH 8.5 compared to the talc which was treated with lizardite, suggesting that the interaction of CMC with lizardite supernatant treated talc was stronger than that of CMC with bare talc. It was consistent with the adsorption results. This probably related to the electrostatic interaction between talc and CMC, when the talc was treated with lizardite supernatant, the surface negative charge decreased and then the electrostatic repulsion of talc with CMC was decreased (especially at the routinely performed pH value, i.e., 8.5) which contributed to the CMC adsorption.

### 3.4. Magnesium ion dissolution analysis

Figure 6 shows the concentration of magnesium ions dissolved into solution under various lizardite content levels at pH 8.5. As shown in Fig. 6, about 6 mg/dm<sup>3</sup> magnesium ions were dissolved from the lizardite lattice when the solid concentration of lizardite was 5 g/dm<sup>3</sup>. When the solid concentration was increased to 10 g/dm<sup>3</sup> and 20 g/dm<sup>3</sup>, the magnesium ion concentration was increased to 13.63 mg/dm<sup>3</sup> and 18.61 mg/dm<sup>3</sup>, respectively, combined with the flotation results in Fig. 3, indicating that

in the talc pulp the more the magnesium ion is, the lower the talc recovery will be. The zeta potential results showed that the addition of lizardite into talc suspension reduced its surface charge (Fig. 5). As such, it might indicate that magnesium ions, dissolved from lizardite lattice, were adsorbed/precipitated onto the negatively charged talc surfaces, which altered the surface charge of talc and enhanced the CMC adsorption.

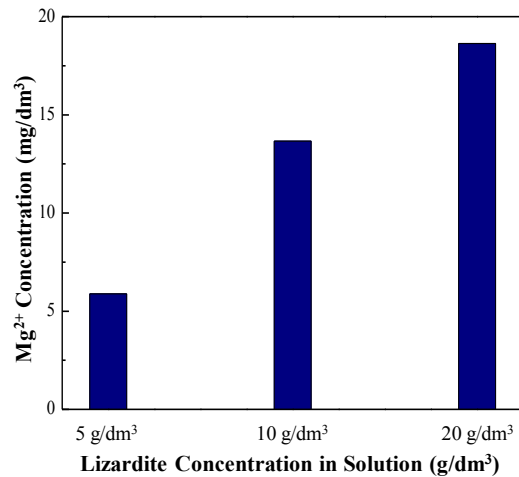


Fig. 6. The concentration of Mg ions dissolved into solution under various lizardite content levels at pH 8.5

The magnesium ions dissolved from lizardite lattice and might form cation complexes in the pulp through hydrolysis. When the solid concentration of lizardite was 20 g/dm<sup>3</sup>, the magnesium ions in solution is 18.61 mg/dm<sup>3</sup>. According to the solution chemistry calculation, the species distribution diagrams of 18.61 mg/dm<sup>3</sup> (7.66×10<sup>-4</sup> mol/dm<sup>3</sup>) magnesium ions as a function of pH value are presented in Fig. 7. It can be seen from Fig. 7 that the positively charged Mg<sup>2+</sup> species dominates when the pH is below 10.05 and Mg(OH)<sub>2(s)</sub> precipitate species dominates at pH>10.05 (Liu et al., 2005; Somasundaran and Wang, 2006). At pH 8.5, the positively charged Mg<sup>2+</sup> and MgOH<sup>+</sup> species are expected to be adsorbed on the talc surface by electrostatic attraction, which modifies the surface chemistry of the talc and thus facilitating the adsorption of CMC and resulting in greater depression (Parolis et al., 2008).

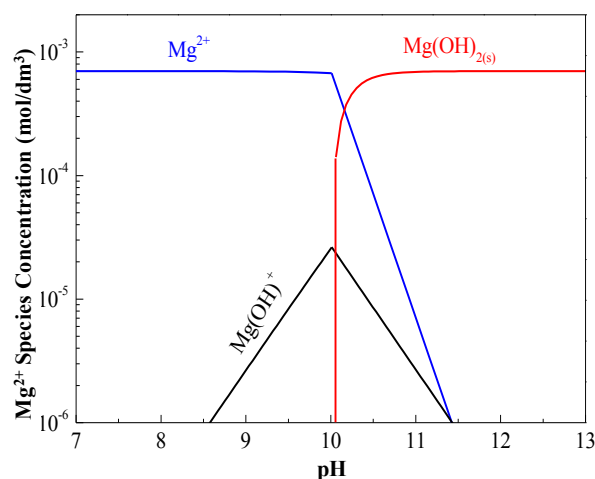


Fig. 7. Species distribution diagrams of 7.66×10<sup>-4</sup> mol/dm<sup>3</sup> magnesium ions as a function of pH

Based on the above results and discussion, Fig. 8 lists a schematic diagram of the proposed interaction mechanism between talc and CMC in the absence/presence of lizardite. Magnesium ions were dissolved from lizardite lattice and the Mg(II) complexes were formed in the pulp through hydrolysis. The complexes were adsorbed onto the talc surfaces in the talc-lizardite system, which decreased the negative charge of talc surfaces and, then the amount of ionized carboxyl groups of CMC

is greater for the adsorbed layer in the presence of magnesium ions (Cuba-Chiem et al., 2008). Therefore, CMC depression performance in the flotation of talc was enhanced when lizardite co-existed. However, this interaction is also probably pertinent to the mechanism of bonding of polysaccharides to the magnesium ion at talc surfaces and will be the subject of further research.

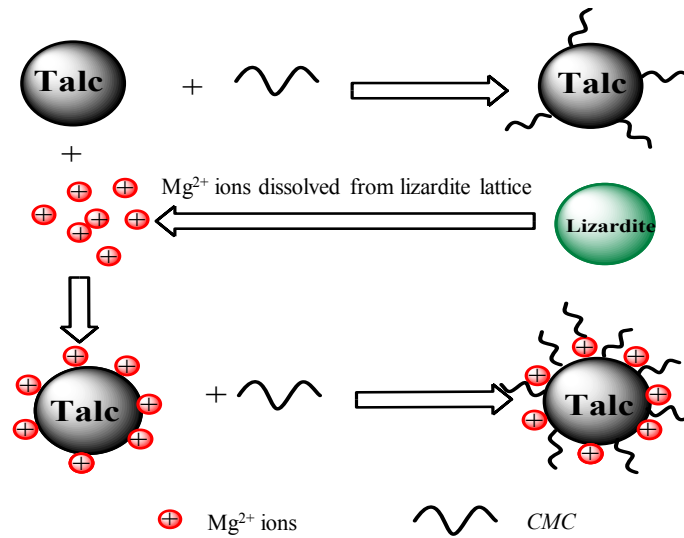


Fig. 8. Schematic for the interactions of CMC with talc with the lizardite at pH 8.5

#### 4. Conclusions

This study aimed to understand the effect of lizardite on the flotation performance of talc when CMC was used as a depressant. The results for the micro-flotation experiments showed that the talc recovery decreased with the increase in the lizardite content when the CMC was utilized. The results for zeta potential measurements and ICP analysis indicated that magnesium species originated from lizardite lattices adsorbed onto the talc surfaces. As such, the negative zeta potential of talc decreased, which reduced the electrostatic repulsion between talc and CMC. The less repulsion resulted in more CMC adsorption and enhanced talc depression.

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#### References

- CHEN, Y., ZHANG, G., SHI, Q., YANG, S., LIU, D., 2020. Utilization of tetrasodium iminodisuccinate to eliminate the adverse effect of serpentine on the flotation of pyrite. *Miner. Eng.*, 150, 106235.
- CUBA-CHIEM, L.T., HUYNH, L., RALSTON, J., BEATTIE, D.A., 2008. In situ particle film ATF-FTIR studies of CMC adsorption on talc: The effect of ionic strength and multivalent metal ions. *Miner. Eng.*, 21(12-14), 1013-1019.
- FENG, B., LU, YI-PING., FENG, Q.M., DING, P., LUO, N., 2013. Mechanisms of surface charge development of serpentine mineral. *Trans. Nonferrous Met. Soc. China*, 23(4), 1123-1128.
- FENG, B., LU, Y., FENG, Q., ZHANG, M., GU, Y., 2012. Talc-serpentine interactions and implications for talc depression. *Miner. Eng.*, 32(4), 68-73.
- FENG, B., PENG, J., ZHANG, W., NING, X., GUO, Y., ZHANG, W., 2018. Use of locust bean gum in flotation separation of chalcopyrite and talc. *Miner. Eng.*, 122, 79-83.
- FUERSTENAU, M.C., LOPEZ-VALDIVIESO, A., FUERSTENAU, D.W., 1988. Role of hydrolyzed cations in the natural hydrophobicity of talc. *Int. J. Miner. Process.*, 23(3-4), 161-170.
- HUANG, Z., CHENG, C., LI, K., ZHANG, S.Y., ZHOU, J.R., LUO, W.H., LIU, Z.W., QIN, W.W., WANG, H.L., HU, Y.J., HE, G.C., YU, X.Y., QIU, T.S., FU, W., 2020. Reverse flotation separation of quartz from phosphorite ore at low temperatures by using an emerging Gemini surfactant as the collector. *Sep. Purif. Technol.*, 246: 116923.

- HUANG, Z., CHENG, C., LIU, Z.W., ZENG, H., FENG, B., ZHONG, H., LUO W.H., HU, Y., GUO, Z., HE, G.C., FU, W., 2019. *Utilization of a new Gemini surfactant as the collector for the reverse froth flotation of phosphate ore in sustainable production of phosphate fertilizer*, J. Clean. Prod., 221, 108-112.
- JIN, S., SHI, Q., FENG, Q.M., ZHANG, G.F., CHANG, Z.Y., 2018a. *The role of calcium and carbonate ions in the separation of pyrite and talc*. Miner. Eng., 119, 205-211.
- JIN, S., SHI, Q., LI, Q., OU, L., OUYANG, K., 2018b. *Effect of calcium ionic concentrations on the adsorption of carboxymethyl cellulose onto talc surface: flotation, adsorption and AFM imaging study*. Powder Technol., 33, 155-161.
- KHRAISHEH, M., HOLLAND, C., CREANY, C., HARRIS, P., PAROLIS, L., 2005. *Effect of molecular weight and concentration on the adsorption of CMC onto talc at different ionic strengths*. Int. J. Miner. Process., 75(3-4), 197-206.
- LIU, C., AI, G.H., SONG, S.S., 2018. *The effect of amino trimethylene phosphonic acid on the flotation separation of pentlandite from lizardite*. Powder Technol., 336, 527-532.
- LIU, C., ZHANG, W.C., SONG, S.S., LI, H.Q., 2019b. *Effects of lizardite on pentlandite flotation at different pH: Implications for the role of particle-particle interaction*. Miner. Eng., 132, 8-13.
- LIU, C., ZHU, G.L., SONG, S.S., LI, H.Q., 2019b. *Flotation separation of smithsonite from quartz using calcium lignosulphonate as a depressant and sodium oleate as a collector*. Miner. Eng., 131, 385-39.
- LIU, C., ZHANG, W.C., SONG, S.S., LI, H.Q., 2019c. *A novel method to improve carboxymethyl cellulose performance in the flotation of talc*. Miner. Eng. 131, 23-27.
- LIU, W., ZHANG, S., WANG, W., ZHANG, J., YAN, W., DENG, J., 2015. *The effects of Ca(II) and Mg(II) ions on the flotation of spodumene using NaOL*. Miner. Eng., 79, 40-46.
- MALHAMMAR, G., 1990. *Determination of some surface properties of talc*. Colloids Surf. A Physicochem. Eng. Asp., 44, 61-69.
- PAROLIS, L.A.S., MERWE, R.V.D., GROENMEYER, G.V., HARRIS, P.J., 2008. *The influence of metal cations on the behaviour of carboxymethyl celluloses as talc depressants*. Colloids Surf. A Physicochem. Eng. Asp., 317(1-3), 109-115.
- SHORTRIDGE, P.G., HARRIS, P.J., BRADSHAW, D.J., KOOPAL, L.K., 2000. *The effect of chemical composition and molecular weight of polysaccharide depressants on the flotation of talc*. Int. J. Miner. Process., 59(3), 215-224.
- SOMASUNDARAN, P., WANG, D.Z., 2006. *Solution Chemistry: Minerals and Reagents*. Elsevier.
- WANG, X., LIU, R., MA, L., QIN, W., JIAO, F., 2016. *Depression mechanism of the zinc sulfate and sodium carbonate combined inhibitor on talc*. Colloids Surf. A Physicochem. Eng. Asp., 501, 92-97.
- YANG, S., XIE, B., LU, Y., LI, C., 2018. *Role of magnesium-bearing silicates in the flotation of pyrite in the presence of serpentine slimes*. Powder Technol., 322, 1-7.