Original Article

The effect of depressant sesbania gum on the flotation of a talc-containing scheelite ore

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\section*{ABSTRACT}

Sodium silicate (SS) has been widely used as a depressant for the scheelite flotation. However, low selectivity and large amount of SS remains a tough problem. In this work, the effect of depressant sesbania gum (SGM) on the flotation of a talc-containing scheelite ore was investigated through pure mineral flotation and run-of-mine ore flotation tests. The flotation tests showed that the selective separation between scheelite and talc was achieved using a new reagent schedule, i.e., a lower dosage of SGM (80 mg/L) and a new collector of sulfonated oleic acid (SNaOL, 40 mol/L) at pH 9.0. A concentrate with WO\textsubscript{3} grade of 52.0% and recovery of 78.4% was achieved by the run-of-mine ore batch flotation test. In addition, the mechanism of the selective separation was investigated by zeta-potential measurements, FTIR spectra and XPS analyses, which demonstrated that SNaOL absorbed more strongly and selectively on the “scheelite + SGM” surface than on the “talc + SGM” surface, while SGM could more selectively interact on the talc surface than on the scheelite surface. SGM absorbed on the talc surface by chemical adsorption between the Mg/Si atom of the talc surface and ---OH group in SGM molecule.

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\section*{1. Introduction}

Tungsten deposits are very abundant mineral resources in China. Scheelite, one of the most important tungsten-bearing minerals, is one of the strategic metals and concentrated mainly by flotation. Scheelite is the principle mineral of tungsten and usually associated with calcium-bearing minerals in ore deposits, such as calcite and fluorite, from which it could be separated by flotation [1–4]. In this study, the sample used is a special scheelite ore which contains talc. There is rare study about flotation of talc-containing tungsten minerals.

The Leiyang tungsten mine is located in Hunan Province, China. The tungsten minerals contain 1.52\% WO\textsubscript{3}, 25.01\% MgO, 16.85\% CaO, 11.02\% Al\textsubscript{2}O\textsubscript{3}, and 45.67\% SiO\textsubscript{2}. The ores are mainly composed of 2.54\% scheelite, 29.54\% talc, 19.67\% chlorite, 11.62\% calcite. The particle size measurement shows that the maximum particle size of scheelite is larger than 1 mm, and the minimum is 5 \textmu m. Additionally, –28 \textmu m frac-

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tion (fine particle) accounts for around 25% of the entire tungsten minerals. The main useful mineral in the ore is scheelite and the main gangue mineral is talc. Talc is a three-sheet phyllosilicate, due to the weak interlayer bonding force, the talc surface is electrically neutral, which has good natural floatability [5,6]. To limit the detrimental effect of talc on scheelite flotation, a talc removal process was carried out before flotation of scheelite. However, some fine tungsten minerals also float into the talc slime. The desliming flotation indicated that the talc slime removal rate could reach above 80%, while scheelite has a loss rate of over 17%. Thus, selective and high performance depressants should be used to depress talc instead of a talc removal process in advance. This work aims at flotation separation of scheelite from scheelite-talc system.

In the practice of scheelite ore flotation, the general method is to add depressant sodium silicate (SS) in a large amount in association with oleic acid (NaOL) [2,7]. However, using large amounts of depressants may contaminate the environment and suffer high cost [1,2]. Guar gum is one of the most widely used industrial depressants for talc in sulfide flotation [8,9], but it undergoes long term dependence on imports and high cost [6]. Sesbania gum (SGM) is taken from the endosperm of the sesbania seed and it has excellent water solubility. Sesbania plants are widely grown in the coastal provinces in China [10,11]. Thus, SGM possesses the advantage of being an abundant resource and low in price compared with conventionally used guar gum.

The previous works [12,13] demonstrated that, sesbania gum, one kind of polysaccharide, can achieve the separation of copper-nickel minerals from talc and chlorite with a higher selectivity and recovery compared with guar gum and sodium silicate. On the basis of a large number of tests on depressants, we selected SGM as the depressant of the talc-type tungsten minerals. In this work, SGM was considered as a depressant to improve the selectivity of scheelite flotation from scheelite-talc system. The mechanism of the selective separation was investigated through zeta-potential, FTIR spectra and XPS measurements.

Fig. 1 – XRD spectra of scheelite (a) and talc (b).

Fig. 2 – Chemical structure of sesbania gum.

2. Experimental

2.1. Samples and reagents

The pure scheelite (CaWO4) and talc (Mg3[Si4O10](OH)2) samples were crushed and dry-ground in a porcelain ball mill and dry-sieved. The fraction of (−74 + 38) μm was used for single mineral flotation tests. Samples further ground to −5 μm in an agate mortar were used for zeta potential, FTIR spectra and XPS measurements. X-ray diffraction (XRD) spectra (Fig. 1) showed that the purities of scheelite and talc were 97.5% and 98%, respectively.

The sample of actual scheelite ore (containing talc) for batch flotation was obtained from Leiyang tungsten Mine of Hunan Province, China. The sample was crushed, grinded and screened below 3 mm. Hydrochloric acid (HCl), sodium hydroxide (NaOH), sesbania gum (SGM) and sulfonated oleic acid (SNaOL) used in this study were of analytical grade.

The chemical structure of SGM and SNaOL are shown in Fig. 2 [10] and Fig. 3 [14]. The molecular weight of SGM is about 3.0 × 105 and the molecular weight of SNaOL is 386. Deionized double distilled water was used for single mineral flotation,
zeta-potential, FTIR spectra and XPS experiments. Tap water was used for batch flotation tests. All experiments were conducted at room temperature. The resistivity of deionized water was about 18.5 MΩ cm.

2.2. Experimental methods

Single mineral and mixed binary minerals flotation tests were carried out in a mechanical agitation flotation machine (XFG) with a 40 mL plexiglass cell, and the impeller speed was set to 1700 rpm, while a 1500 mL cell was used for run-of-mine ores, at an impeller speed of 1590 rpm (XFG-type flotation machine). The flotation pulp for single and mixed minerals (a scheelite to talc mass ratio of 0.6) was prepared by adding 2.0 g of samples to 35 mL of water, while the flotation pulp of actual ores was obtained by 500 g samples and 1500 mL water. The pulp was conditioned for 1 min, after adjusting mineral suspension pH to the desired operating value, the depressant SGM and collector SNaOL were added and having a 3 min conditioning period, respectively. The flotation tests were carried out for 6 min. Both the froth product and tailing were filtered, dried and weighed. For single mineral flotation, the flotation recovery was calculated based on solid weight. For flotation tests of mixed minerals and actual ores, the flotation recovery was calculated based on solid weight ratio and WO3 grade between two products. At least three flotation tests were made for one experimental condition, and the average ratio and recovery were reported [15].

Zeta-potential measurements for scheelite and talc were carried out using a Nano-ZS90 zeta potential analyzer (Malvern, UK). The mineral suspension was prepared by adding 0.03 g of samples to 35 mL KNO3 (0.001 mol/L) solution. Subsequently, the desired reagents were added as the same order of flotation tests, and the suspension pH was adjusted using either HCl or NaOH. Then, the mineral suspension was magnetically stirred for 10 min. After standing for 5 min, the supernatant liquid was sucked out and used for zeta-potential measurements. The measurement errors were found to be within 4 mV after at least three measurements under each experimental condition, and the average values were reported.

For the Fourier transform infrared spectrum (FTIR) tests, 2.0 g of samples were added into 35 mL aqueous solution with or without 80 mg/L depressant SGM at pH 9, and ultrasound for 5 min. Next, the pulps were then centrifuged and the solids washed at least three times with distilled water and dried in a vacuum oven. The infrared spectra of solids were recorded using a Nicolet FTIR-740 spectrometer.

For the X-ray photoelectron spectra (XPS) measurements, 2.0 g of samples were added into 100 mL aqueous solution, followed by the addition of sesbania gum. After pH adjustment, the suspension was conditioned for 30 min. Next, the solid samples were washed three times using the deionized water with the same pH, and further dried in vacuum desiccators at 50 °C. XPS measurements were performed using a Kratos AXIS Ultra XPS system equipped with a monochromatic Al X-ray source operated at 150 W (the range of instrument error is 0.2 eV).

3. Results and discussion

3.1. Single mineral flotation test results

Previous reports showed that oleic acid (NaOL) has a strong collecting power for scheelite than for calcite [1,16]. In this work, sulfonated oleic acid (SNaOL) was used to improve its collecting ability for scheelite. The flotation behaviour of scheelite and talc using SNaOL as a collector was evaluated by the single mineral flotation.

The effects of pH and SNaOL dosage on flotation recoveries of both scheelite and talc were studied by single mineral flotation tests, and the results are shown in Fig. 4. Fig. 4a shows that the flotation recoveries of scheelite and talc were very high by using SNaOL as collector, and the recovery of these two minerals did not change as the pH was increased. Fig. 4b shows that the recoveries of these two minerals increase rapidly with an increasing of SNaOL dosage at pH 9.0, and reach 95.54% and 98.45%, respectively, when the SNaOL dosage is 40 mg/L. Talc shows good natural floatability without flotation reagents.
(the flotation recovery was above 65%). These indicate that it is difficult to separate scheelite from talc without the addition of depressant. A selective depressant for talc is needed. The SNaOL dosage of 40 mg/L was chosen to conduct following flotation tests.

The effects of pH and SGM dosage on flotation recoveries of both scheelite and talc using SNaOL 40 mg/L are shown in Fig. 5. The result in Fig. 5a shows that after adding SGM, the flotation recovery of talc was reduced by 80%, while that of scheelite decreased slightly. At pH 9.0, the flotation recoveries of scheelite and talc were about 85.52% and 22.45%, respectively. It is shown from Fig. 5b that with the increase of SGM dosage, the recovery of talc dropped sharply, and it was below 17% when the SGM dosage was higher than 80 mg/L. For scheelite, the recovery was between 85% and 95% with an increase in SGM concentration. SGM had higher selectivity for depressing of talc than scheelite, and it may be possible to separate scheelite away from talc by using SGM as depressant and SNaOL as collector. The SGM dosage of 80 mg/L and pH 9 were preferred in the following experiments.

### 3.2. Mixed mineral flotation test results

A mixed binary minerals flotation test was carried out to evaluate the separation performance of the new reagent schedule (80 mg/L of SGM depressant, 80 mg/L of SNaOL collector at pH 9.0), the best results achieved are displayed in Table 1.

<table>
<thead>
<tr>
<th>System</th>
<th>Products</th>
<th>Ratio (w%)</th>
<th>Grade (%)</th>
<th>Recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>WO₃</td>
<td>MgO</td>
</tr>
<tr>
<td>Mixed binary</td>
<td>W concentrates</td>
<td>37.6</td>
<td>74.4</td>
<td>2.9</td>
</tr>
<tr>
<td>mineral flotation</td>
<td>Tailings</td>
<td>62.4</td>
<td>2.6</td>
<td>29.1</td>
</tr>
<tr>
<td>tests</td>
<td>Feed</td>
<td>100.0</td>
<td>29.4</td>
<td>19.3</td>
</tr>
</tbody>
</table>

3.3. Run-of-mine ores flotation test results

Bench-scale locked cycle tests on a run-of-mine scheelite ore were carried out under different reagent schedules. The closed flotation circuit including one roughing, two scavenging and six cleaning, and the flowsheet and conditions are described in Fig. 6. The locked cycle tests results are presented in Table 2.

The results presented in Table 2 indicate that when compared to the comparative system, the WO₃ grade and recovery increased dramatically when the locked cycle tests were carried out in the new reagent system. As shown in Table 2, a concentrate with WO₃ grade of 52.0% and recovery of 79.6% was achieved by using the new reagent schedule of SGM + SNaOL. Meanwhile, a concentrate with WO₃ grade of 54.6% and recovery of 68.8% was produced by using the comparative reagent schedule of SGM + NaOL, a concentrate with WO₃ grade of 47.6% and recovery of 82.5% was produced by using the comparative reagent schedule of guar gum + SNaOL.

For this complex scheelite ore (containing talc), SGM showed an excellent depression effect on talc and SNaOL displayed a good collection for tungsten minerals, which is demonstrated by the high level grade (52%) and high level recovery (79.6%) of WO₃ achieved with the new reagent schedule of SGM + SNaOL.

### 3.4. Selective adsorption mechanism of flotation reagents on scheelite and talc

In order to investigate the reasons for the new reagent schedule selectively depress on talc and selectively collect for
Fig. 6 – Flowsheet and corresponding conditions of bench-scale locked cycle tests.

Table 2 – The results of run-of-mine scheelite ores flotation tests using different reagent schedule at pH 9.0.

<table>
<thead>
<tr>
<th>System</th>
<th>Products</th>
<th>Ratio (w/%)</th>
<th>Grade (%)</th>
<th>Recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>WO₃</td>
<td>MgO</td>
<td>WO₃</td>
</tr>
<tr>
<td>The new reagent schedule of SGM + SNaOL</td>
<td>W concentrates</td>
<td>2.2</td>
<td>52.0</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td>Tailings</td>
<td>97.8</td>
<td>0.3</td>
<td>25.1</td>
</tr>
<tr>
<td></td>
<td>Feed</td>
<td>100.0</td>
<td>1.5</td>
<td>24.7</td>
</tr>
<tr>
<td>The comparative reagent schedule of SGM + NaOL</td>
<td>W concentrates</td>
<td>1.9</td>
<td>54.6</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td>Tailings</td>
<td>98.1</td>
<td>0.48</td>
<td>25.7</td>
</tr>
<tr>
<td></td>
<td>Feed</td>
<td>100.0</td>
<td>1.5</td>
<td>25.3</td>
</tr>
<tr>
<td>The comparative reagent schedule of guar gum + SNaOL</td>
<td>W concentrates</td>
<td>2.7</td>
<td>47.6</td>
<td>6.7</td>
</tr>
<tr>
<td></td>
<td>Tailings</td>
<td>97.3</td>
<td>0.3</td>
<td>24.9</td>
</tr>
<tr>
<td></td>
<td>Feed</td>
<td>100.0</td>
<td>1.5</td>
<td>24.4</td>
</tr>
</tbody>
</table>
scheelite, the mechanism of the selective separation was studied by zeta-potential and FTIR measurements. Zeta-potential of both scheelite and talc minerals before and after interacting with flotation reagents as a function of pH was measured, and the results are shown in Fig. 7.

The zeta-potentials of scheelite and talc before and after interacting with different reagents are shown in Fig. 7. It indicates that before interacting with any reagent, the isoelectric point (IEP) of pH 4.5 and pH 2.0 were obtained for scheelite and talc, respectively, which are in agreement with previous reports [4,17]. After the two minerals were treated with non-ionic SGM, the zeta-potentials increased, it was likely that the adsorption of SGM on mineral surfaces prevented the adsorption of hydroxyl on mineral surfaces [18]. In contrast to that, the zeta potential shift ascribed to the addition of anionic SNaOL was negative. Fig. 7 also shows that, for scheelite zeta-potentials, the addition of SNaOL causes a greater decrease (by 35 mV) compared with about 32 mV for the addition of SGM + SNaOL, indicating that SNaOL can absorb on the scheelite and “scheelite + SGM” surface. In contrast to that, for the zeta-potentials of talc (pH > 6), the addition of SGM causes a greater increase (by 30 mV) compared with about 29 mV for the addition of SGM + SNaOL, indicating that SGM can absorb on the talc surface and SNaOL cannot absorb on the “talc + SGM” surface.

These illustrate that SGM can selectively interact on the talc surface and SNaOL can further favourably absorb on the “scheelite + SGM” surface, while the addition of SNaOL causes a negligible effect on the adsorption of SGM onto talc minerals. The difference of SNaOL adsorption on “scheelite + SGM” and “talc + SGM” surfaces can explain a high tungsten recovery and absolute depressed flotation of talc using a “scheelite + SNaOL” reagent schedule. Those results were consistent with flotation experiments. Based on the above analysis, we propose the selective adsorption model of SGM and SNaOL on the surfaces of scheelite and talc as shown in Fig. 8.

The mechanism of selective depression of SGM on minerals was further investigated by FTIR and XPS analyses. FTIR spectra of both scheelite and talc after interacting with depressant SGM were measured, and the result is displayed in Fig. 9. As shown in Fig. 9, the characteristic bands of scheelite appeared at 817.5 cm\(^{-1}\) and 511.2 cm\(^{-1}\) corresponded to the bending vibration and asymmetric stretching vibration of W–O bond, respectively [1,19]. The spectrum of talc presented characteristic bands at 3676.5 cm\(^{-1}\), 1446.4 cm\(^{-1}\), 1018.2 cm\(^{-1}\) and 673.6 cm\(^{-1}\), which was corresponded to –OH stretching vibration, Si–O stretching vibration, Mg–O vibration and Si–O bending vibration, respectively [20]. Fig. 9a shows that after treating by 80 mg/L SGM, the band of original scheelite at 817.5 cm\(^{-1}\) shifted to 818.1 cm\(^{-1}\), other band shared no change and no new bands appeared, illustrating that there was no obvious adsorption occurred between scheelite and SGM. Fig. 9b shows that after interacting with SGM, the spectrum of talc presented a new strong sharp band at 814.1 cm\(^{-1}\), besides, the bands of Si–O shifted from 1446.4 cm\(^{-1}\) to 1443.1 cm\(^{-1}\) and Mg–O shifted from 1018.2 cm\(^{-1}\) to 1008.9 cm\(^{-1}\), respectively. It implied that the chemisorption occurred between talc and SGM.

Table 3 – Binding energies of elements on talc surface.

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Binding Energy (eV)</th>
<th>Chemical Shift (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mg 1s</td>
<td>Si 2p</td>
</tr>
<tr>
<td>Without SGM (at pH 9.0)</td>
<td>1295.97</td>
<td>152.02</td>
</tr>
<tr>
<td>With 80 mg/L SGM (at pH 9.0)</td>
<td>1294.64</td>
<td>150.43</td>
</tr>
</tbody>
</table>

The XPS analysis was performed to further confirm that SGM mainly interacts with talc. The XPS spectra of Mg (1s), Si (2p) were collected on talc. Fig. 10 and Table 3 show the narrow Mg (1s) and Si (2p) spectra for talc before and after interacted with SGM. They indicate that the changes of binding energy in Mg (1s) and Si (2p) after interaction with SGM were –1.33 and –1.59 eV, illustrating that SGM interacted with both Mg and Si under alkaline condition. This phenomenon demonstrates that SGM depressant could absorb on talc surface by chemical adsorption between the Mg/Si atom of the talc surface and –OH group in SGM molecule. These all agreed well with zeta-potential results.

4. Conclusions

In this study, a new reagent schedule using sesbania gum (SGM) as a depressant and sulfonated oleic acid (SNaOL)
Fig. 8 – The suggested adsorption model of SGM and SNaOL on the surfaces of scheelite and talc.

Fig. 9 – FTIR spectra of scheelite (a) and talc (b) after interacting with depressant SGM.

Fig. 10 – XPS Mg (1s) and Si (2p) spectra of talc before (a, c) and after (b, d) treated with SGM.
as a collector, was developed to separate scheelite from scheelite-talc system. The flotation results demonstrated that SGM + SNaOL was a high selectivity reagent schedule for the flotation separation of tungsten minerals from talc. Zeta-potential, FTIR and XPS measurements indicated that SNaOL could absorb more strongly and selectively on the “scheelite + SGM” surface than on the “talc + SGM” surface, while SGM could more selectively interact on the talc surface than on the scheelite surface and it absorbed on the talc surface by chemical adsorption between the Mg/Si atom of talc surface and –OH group in SGM molecule. This study solved the problem that flotation separation depended on guar gum between scheelite and talc and provided technical support for flotation recovery of similar ore which contains talc.

Conflicts of interest

The authors declare no conflict of interest.

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