Ultrasonic pretreatment of spodumene with different size fractions and its influence on flotation

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ABSTRACT

The potential of ultrasonic pretreatment enhancing selective surface dissolution to improve the floatability of spodumene with different size fractions was verified and investigated. For coarse particles of \(-0.15 + 0.0385\) mm, compared with traditional pretreatment methods, ultrasonic pretreatment could optimize the physicochemical properties of the surface, markedly increased the amount of NaOL adsorbed on the mineral surface, and improved the floatability of the spodumene. For fine particles of \(-0.0385\) mm, both pretreatment methods (Ultrasonic and Traditional) could greatly increase the flotation recovery, but ultrasonic pretreatment had no obvious advantage compared with traditional method. ICP combined with XPS analysis were conducted to investigate the dissolution mechanism of spodumene surface in different pretreatment system. Si species on the surface of coarse particles were easily dissolved into the solution under the effect of ultrasound, which increases the relative content of Al and Li species on the surface. This was conducive to the adsorption of the collectors on the surface. However, the selective dissolution of the fine particle surface was weakened by excessive energy intake in the ultrasonic system, which neutralized the advantage brought by the large amount of dissolution, making the results obtained by the two preprocessing methods the same.

1. Introduction

Lithium, the lightest metal with outstanding physicochemical properties, is widely used in many field such as lubricant manufacturing, ceramics, and especially in energy storage [1–4]. With the explosive increase of the clean energy vehicles recently, lithium-ion batteries as energy storage systems is gradually moving towards the core position of the new energy industries [5–6]. The lithium-ion battery industry has reached a market size of 40 billion dollars now, and is still on a rapid rise [7].

Spodumene (LiAlSi\(_2\)O\(_6\)), offering a theoretical LiO content of 8.03%, is one of the most important lithium-bearing minerals occurring in pegmatite [8–9]. Flotation is the primary and effective beneficiation techniques for spodumene [10]. However, spodumene and its main gangue minerals (quartz, feldspar, mica, etc.) have highly similar surface and solution chemical properties, which makes the selective adsorption of flotation reagents difficult, so that high precision and efficiency in the process of spodumene flotation was hard to achieve [11].

In order to improve the floatability of spodumene, and increase the surface difference between spodumene and its gangue minerals. The pretreatment process of ore slurry has been widely used in the spodumene beneficiation industry. Researches and practices have shown that, before flotation, a long-term mechanical agitation pretreatment of the ore slurry with sodium hydroxide can greatly improve the efficiency and stability of the subsequent flotation process [12–13]. During the pretreatment process, irregular dissolution occurred on the mineral surface. The Si-O bond on the spodumene surface was easier to be break than the Al-O bond, so that more Si component are transferred to the liquid phase, and Al component accumulates on the surface, thereby increasing the adsorption capacity of collector on the spodumene [14]. Moreover, the surface of gangue minerals such as feldspar and quartz in the slurry cannot be selectively dissolved, which increases the difference in floatability between them and spodumene [15].

However, there are many drawbacks in the industrial practice of spodumene pretreatment. First, spodumene flotation plant was compelled to arrange multiple large-capacity agitation tanks because of the excessively long-term mechanical agitation (>2 h) pretreatment, which greatly increases the initial plant construction cost. Second, in order to accelerate the surface dissolution rate in the pretreatment process, a large amount of sodium hydroxide and sodium carbonate was

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existing pretreatment system, the flotation recovery of spodumene is not satisfactory (about 75% in practice). Therefore, a new pretreatment technology could greatly accelerate processing rate. Gui et al. found that ultrasound can effectively enhance the leaching rate and the extraction percentage on gold leaching in the Co-NH$_2$ system [18]. And according to the research of John et al., when dealing with landfilled metallurgical residues, ultrasonic treatment was able to achieve selective leaching of Pb. In their study, ultrasonic energy increased the leaching rate of Pb while had little effect on Ca dissolution [19]. Notably, ultrasonic technology had also made progress in the field of minerals and coal beneficiation recently, especially in pretreatment process before flotation [20–24]. Fang et al. verified that ultrasonic pretreatment of ilmenite was beneficial to achieve selective separation of ilmenite from gangue minerals in terms of selective surface dissolution [25]. In the ilmenite pretreatment system, ultrasound can enhance the dissolution of Fe and Mg species on the mineral surface, but has little effect on the dissolution of Ca species.

To verify the potential of enhancing floatability of spodumene with different size fractions by ultrasonic pretreatment, micro-flotation and collector adsorption tests were conducted to compare the effect of traditional and ultrasonic pretreatment. Inductive coupled plasma-optical emission spectrometry (ICP-OES) analysis was performed to study the dissolution behavior of spodumene in different pretreatment systems. And the effect of ultrasound on the surface physicochemical properties of spodumene was investigated by x-ray photoelectron spectroscopy (XPS) analysis.

### 2. Materials and method

#### 2.1. Samples and reagents

The spodumene crystal in this study was obtained from Koktokay Rare Metal Mine, Xinjiang, China. The samples were crushed and screened to obtain the particles below 1.6 mm. The iron contained impurities were removed by a high gradient magnetic separator. The spodumene crystal in this study was obtained from Koktokay Rare Metal Mine, Xinjiang, China. The samples were crushed and screened to obtain the particles below 1.6 mm. The iron contained impurities were removed by a high gradient magnetic separator. The chemical composition and X-ray diffractometry of the samples, which were used to study the chemical characteristics and mineral compositions, were shown in Table 1 and Fig. 1, respectively. It is shown that the purity of the spodumene particles is >95% as the samples contained 7.80% Li$_2$O. Then the samples were ground in a ceramic pot to obtain three main particle size fraction: − 0.015 + 0.074 mm, −0.074 + 0.0385 mm and − 0.0385 mm. Moreover, 3% hydrochloric acid was used to clean metal impurities (such as Ca$^{2+}$ and Fe$^{3+}$) from the spodumene surface. Sodium hydroxide (NaOH) (>98%, Xilong Scientific) and hydrochloric acid (HCl) (>36%, Xilong Scientific) were used in pretreatments and flotation experiments. Sodium oleate (NaOL) (>97.0%, Sinopharm Chemical Reagent Co., Ltd) was used as the collector in the micro-flotation tests. Deionized water (DI water) with a resistivity of 18.2 MΩ-cm was used for the experiments.

#### 2.2. Method

##### 2.2.1. Pretreatment test

The spodumene particles were pretreated in an adjustable ultrasonic blender before flotation. Fig. 2 shows the schematic diagram of ultrasonic pretreatment equipment. The detail information of this device was shown in Table 2. In each pretreatment tests, 3 g spodumene particles and 3% hydrochloric acid were used to study the dissolution behavior of spodumene in different pretreatment systems. And the effect of ultrasound on the surface physicochemical properties of spodumene was investigated by x-ray photoelectron spectroscopy (XPS) analysis.

| Components | SiO$_2$ | Al$_2$O$_3$ | Li$_2$O | K$_2$O | Na$_2$O | Fe$_2$O$_3$ | CaO |
|------------|--------|------------|--------|--------|--------|------------|-----|
| Content/%  | 63.46  | 27.42      | 7.80   | 0.23   | 0.31   | 0.94       | 0.15|

![Fig. 1. XRD spectrum of spodumene samples.](image1)

![Fig. 2. Schematic diagram of the ultrasonic pretreatment device.](image2)

| Equipment | Operating frequency (kHz) | Ultrasonic power (W) | Agitation speed (rpm) | Company |
|-----------|--------------------------|----------------------|----------------------|---------|
| Ultrasonic stirrer | 45–100 | 0–100 | 0–6000 | Kunshan ultrasonic instrument Co., LTD |

Table 1

| Multi-element analysis of the samples. |
|---------------------------------------|
| Components | SiO$_2$ | Al$_2$O$_3$ | Li$_2$O | K$_2$O | Na$_2$O | Fe$_2$O$_3$ | CaO |
| Content/%  | 63.46  | 27.42      | 7.80   | 0.23   | 0.31   | 0.94       | 0.15|

![Table 2](image3)

![Table 2](image4)
with different size range were mixed with 37 ml NaOH solution (500 mg/L) to form a slurry with a solid content of 7.5%. The agitation speed is 3000 rpm in both pretreatment system, and the ultrasonic frequency was fixed at 45 kHz with power of 100 W in the ultrasonic system. Samples obtained by different treatment methods were rinse 4 times by 150 ml of deionized water until the pH value of the rinse solution reached 6.6 (Natural pH in the air). In this study, particles size and pretreatment time were taken as variables to investigate the effect of traditional and ultrasonic pretreatment on different size fractions of spodumene particles.

2.2.2. Micro-flotation tests

The micro-flotation tests of spodumene samples were conducted in a 60 ml cell XFGC_III flotation machine under the agitation speed of 1890 rpm. First, 3 g spodumene particles pretreated in different pretreating system were mixed with 36 ml DI water. As illustrated in Fig. 3, the slurries were agitated for 3 min to adjust the pH at 8 ± 0.1 by 1% concentration of NaOH and HCl solution. Then, the collector NaOL of 200 mg/L (determined by exploratory experiments) was added into the pulp and agitated for 4 min to make the particles and collectors fully active. Finally, the mineralized froths, the concentrates, were collected 5 min by scraping the froth layer every 5 s. Afterward, the spodumene concentrates were filtered, dried and weighed, respectively so that the recovery could be calculated. Each recovery data in this study was the average of the three tests, and the standard deviations of the three measurements have been marked in each figure.

2.2.3. Adsorption test

In this study, the adsorption tests were used to investigate the capacity of sodium oleate adsorbing on spodumene with different particle size and pretreatment method. In each test, 3 g samples were pretreated by NaOH solution under traditional mechanical agitation or ultrasonic pretreatment. The preparation process is the same as the flotation process. Fig. 4 shows the spodumene recoveries as a function of pretreating time in the presence of 200 mg/L NaOL with different particle size fractions.

![Spodumene recoveries as a function of pretreating time in the presence of 200 mg/L NaOL](image_url)
process. The sample was put in to the flotation cell and mixed with NaOL solutions in different concentrations. After blending, the pulp was transferred to a centrifuge field of 8000 rpm for 20 min to remove solid particles. The total organic carbon (TOC) in the supernatant was quantitatively detected by the TOC-L CPH analyzer (Shimadzu, Japan). Based on the difference between the initial and residual NaOL concentrations, the calculation formula of NaOL adsorption capacity on spodumene surface could be expressed as Eq. 1.

\[
\text{Adsorption capacity} = \frac{C \times (T_i - T_p) \times c_i}{1000mT_i}
\]

where \(C\) an \(c_i\) are the volume and volume concentration of the sodium oleate solution respectively, \(T_i\) is the initial TOC of the sodium oleate solution under the concentration of \(c_i\), and \(T_p\) is the residual TOC of the supernatant of pulp after adding spodumene particles, \(m\) is the mass of the particle.

2.2.4. Inductive coupled plasma-optical emission spectrometry analysis

Inductive coupled plasma-optical emission spectrometry (ICP-OES) was used to study the dissolution behavior of spodumene with different particle size fractions and pretreatment systems. Firstly, 3 g spodumene samples with different size ranges were mixed with 37 ml NaOL solution of 500 mg/L and pretreated for 20 min in the traditional pretreatment system and ultrasonic pretreatment system respectively. Then, the pulp was transferred to a centrifuge field of 8000 rpm for 20 min to remove solid particles. Finally, the supernatants of the centrifuged pulp were diluted ten times to be measured by an ICP-OES analyzer (Spectro Blue SOP, Germany).

2.2.5. X-ray photoelectron spectroscopy analysis

The X-ray photoelectron spectroscopy (ESCALAB 250Xi, Thermo Fisher-VG Scientific, USA) was used to analyse the element distribution and NaOL adsorption conditions on spodumene surfaces pretreated by different pretreatment methods. The preparation process of the sample in this experiment is similar to the flotation process. The slurries were transferred directly to the centrifugal field to achieve solid–liquid separation after the reagent (NaOL solution of 200 mg/L) was fully mixed with the mineral. Then, the solid particles were transferred and dried to be measured.

3. Results and discussion

3.1. Flotation test

Micro-flotation experiments are conducted to study the flotation performance of spodumene with different size fractions and pretreatment systems. Fig. 4 shows the relationship between pretreating time and flotation recovery of spodumene particles treated by different pretreating methods.

As is shown in Fig. 4(a), for the particles size of \(0.15 + 0.074\) mm, both pretreatment method (traditional mechanical agitation and ultrasonic pretreatment) can improve the subsequent flotation recovery. The flotation recovery increased significantly with the increase of pretreating time. When the mechanical agitation time increases from 0 to 20 min, the recovery increases from 14.17% to 55.56%. But when the pretreating time exceeds 20 min, the flotation recovery does not increase further. Notably, compared with the traditional method, ultrasonic...
pretreatment shows a stronger effect on improving the flotation recovery of spodumene particles. Only 10 min of ultrasonic pretreatment, the flotation recovery of can reach the maximum value of the traditional method. It means that for the same pretreatment result, ultrasonic pretreatment only takes half the time of the traditional method. More importantly, with the extension of the pretreating time, ultrasonic pretreatment can further increase the subsequent flotation recovery. When the ultrasonic pretreating time reaches 25 min, a satisfactory flotation recovery of 95.67% can be achieved.

Fig. 4 (b) shows that, for the spodumene particles of \(0.074 + 0.0385\) mm, the effect of the two pretreatment methods on the flotation performance of spodumene particles is similar to that of \(0.15 + 0.074\) mm particles. Only 5 min of ultrasonic pretreatment can increase the subsequent flotation recovery to the effect of 20 min of traditional pretreatment. When the pretreatment time exceeds 15 min, the flotation recovery of spodumene particle treated by ultrasonic pretreatment is twice that of the particles treated by the traditional method.

Things started to get a little different when dealing with \(0.0385\) mm spodumene particles. As is shown in Fig. 4(c), although both pretreatment methods can significantly improve the recovery, ultrasonic pretreatment does not show any advantages. With the increase of processing time, both pretreatment methods can increase the flotation recovery from 10.21% to approximately 66.40%, indicating that the traditional mechanical agitation pretreatment method is sufficient, and the ultrasonic pretreatment cannot further improve the floatability of the spodumene.

3.2. Adsorption test

The flotation recovery of mineral particles is directly related to the adsorption amount of the collector (NaOL in this study) on the spodumene surface. In this section, particles of different sizes fraction have been subjected to two different pretreatment systems (traditional mechanical agitation and ultrasonic pretreatment). The sodium hydroxide concentration was fixed at 500 mg/L at the pretreatment process, and the pretreatment time is 20 min. At five different collector concentrations, the adsorption amount of NaOL on the particle surface was investigated to compare the effect of different pretreatment methods on the adsorption amount of the collectors on the mineral surface.

As is shown in Fig. 5(a) and (b), for the spodumene samples of \(-0.074 + 0.0385\) mm, the effect of the two pretreatment methods on the flotation performance of spodumene particles is similar to that of \(-0.15 + 0.074\) mm particles. Only 5 min of ultrasonic pretreatment can increase the subsequent flotation recovery to the effect of 20 min of traditional pretreatment. When the pretreatment time exceeds 15 min, the flotation recovery of spodumene particle treated by ultrasonic pretreatment is twice that of the particles treated by the traditional method.

Fig. 5(c) shows that, for the fine particles of \(-0.0385\) mm, at five different collector concentrations, there is no significant difference in the effects of the two pretreatment methods on the amount of agent adsorbed on the mineral surface. Besides, it is clear that although more collectors are adsorbed on fine-grained particles \((-0.0385\) mm), the flotation recovery is not as good as that of coarse particles \((-0.15 +
The quality of the dissolution treatment is more than twice than that of traditional mechanical agitation. During the pretreatment, the sodium hydroxide concentration was fixed at 500 mg/L, and the pretreatment time was 20 min.

Table 3 displays the composition of the pretreated surface is determined by both the chemical environment of the mineral surface and affects the fine-grained flotation performance (see in section 3.4). Therefore, separated treatment of fine-grained and coarse-grained minerals and increasing the dosage of collectors when dealing with fine particles may be needed in spodumene processing.

### 3.3. Inductive coupled plasma-optical emission spectrometry analysis

Studies have shown that spodumene floatability was influenced by pretreatment in terms of changing the composition of the main elements (Si, Al and Li) on the particle surface. ICP-OES tests are used to study and compare the surface dissolution characteristics of spodumene with different particle size and pretreatment systems. During the pretreatment process, the sodium hydroxide concentration was fixed at 500 mg/L, and the pretreatment time was 20 min.

Fig. 6 shows the concentration of each element species (Si, Al and Li) in the solution after different pretreatment process. It is clear that a significant increase of elements dissolved from spodumene surface is observed with the reduction of particle size. Notably, ultrasound can promote the dissolution of surface components compared with traditional mechanical agitation in each particle size fraction. In general, the amount of mineral surface components dissolved during the ultrasonic treatment is more than twice than that of traditional mechanical agitation.

However, the increase of surface components dissolution may not directly promote the adsorption of collectors on the spodumene surface. The ratio of Si component to Al and Li in the dissolution liquid is a quantitative basis for measuring the selectivity of surface dissolution.

As is shown in Fig. 7(a), both pretreatment systems can selectively dissolve the Al and Si elements on the spodumene with values of Si/Al higher than 2. It indicates that more Si component on the surface are transferred to the solution, while Al “remains” on the surface, that is advantageous for the adsorption of collectors. In addition, as the particle size decreases, the Si/Al in the solution decreases significantly. This is due to the decrease in particle size, which causes all surface atoms to be activated and become easier to transfer to the liquid phase. It is obvious that, when the particle size is less than 0.0385 mm, the value of Si/Al is close to 2, indicating that the selectivity of dissolution behavior is reduced. It is shown in Fig. 7(b) that, the Li element on the mineral surface also shows obvious selective dissolution behavior, with the value of Si/Li in the solution various from 2.57 to 5.85 with different particle size and pretreatment method.

Surprisingly, in every particle size fraction, the values of Si/Al and Si/Li in the ultrasonic pretreatment system are always lower than that of the traditional mechanical agitation, indicating a higher dissolution selectivity in the mechanical agitation system. It seems to conflict with the flotation and adsorption test results in section 3.1 and 3.2. It is because not all spodumene surfaces are dissolved during the pretreatment process, making it possible to increase the Al/Si of the entire surface by extending the dissolved surface area. The final element composition of the pretreated surface is determined by both “quality” and the “quantity” of the dissolution. Therefore, further characterization and analysis of the particle surface is necessary to confirm the final pretreatment results of different pretreating process.

#### 3.4. X-ray photoelectron spectroscopy (XPS) analysis

XPS analysis is adopted to explore the direct evidence for the surface element content changes on the spodumene surface. Table 3 displays the relative atomic concentration of main elements on the surface of spodumene particles with different particle size processed by traditional mechanical agitation and ultrasonic pretreatment. During the pretreatment, the sodium hydroxide concentration was fixed at 500 mg/L and the pretreatment time was 20 min.

| Elements | Samples (Atomic%) | Traditional pretreatment | Ultrasonic pretreatment |
|----------|-------------------|--------------------------|-------------------------|
|          | 0.15 - 0.074 mm   | 0.074 - 0.0385 mm        | -0.0385 mm              |
| Al2p     | 25.34             | 25.87                    | 27.74                   | 28.24                   | 24.69                   | 24.83                   |
| Li1s     | 21.69             | 24.34                    | 19.44                   | 25.82                   | 23.04                   | 23.03                   |
| Si2p     | 52.97             | 49.79                    | 52.82                   | 45.94                   | 52.27                   | 52.14                   |
pretreatment process, the sodium hydroxide concentration was fixed at 500 mg/L in each test, and the pretreatment time was 20 min. As is shown in Table 3, after ultrasonic processing, the content of Si atoms on the surface of coarse-grained spodumene particles (-0.15 + 0.074 mm and -0.074 + 0.0385 mm) is lower than that of traditional mechanical agitation pretreatment. Correspondingly, the proportion of Al atoms and Li atoms on the surface increases. It indicates that, as far as the entire surface is concerned, ultrasonic pretreatment can make more Si dissolve from the surface of the spodumene crystals and increase the proportion of Al and Li on the surface, thus showing a higher selectivity than traditional method. However, for spodumene particles of -0.0385 mm, there is almost no difference in the surface element content after treated by two different pretreatment methods, indicating that the final results of the effects of these two pretreatment methods on the mineral surface are similar.

In general, the surface dissolution behavior of spodumene with different particle sizes during the pretreatment process can be roughly described by Fig. 8. For coarse particles, the energy of ultrasonic input activated the Al and Li atoms on the surface, the selectivity of surface dissolution was slightly reduced. However, the ultrasonic energy can also extend the area of dissolved spodumene surface, which eventually leads to an increase in the content of Al and Li species on the surface in total. For spodumene particles finer than 0.0385 mm, ultrasound treatment will lead to a more serious decline in the dissolution selectivity. Fortunately, the large amount of dissolution makes up for the loss caused by the decrease in selectivity.

Further, high resolution spectra of O elements are analyzed to provide in-depth understanding of the adsorption of NaOL on spodumene surface. Fig. 8 shows the O1s XPS spectra of the spodumene surface after NaOL treatment. The pretreated spodumene surface mainly contains the following three chemical states of oxygen: Si-O-Si, Si-O-Al, and >Al-O-H (the signal of “>” represent the spodumene surface). Si-O-Si and Si-O-Al, with the binding energies of 532.35 eV and 532.32 eV respectively, constitute the interior and part of the surface of the spodumene crystal, and >Al-O-H (530.54 eV) is the surface component of the hydrated spodumene surface. After treated by NaOL, a new peak attributed to NaOL -(C=O)-O- components was observed at 533.16 eV. The atomic concentrations of O1s species on spodumene with different particle sizes and pretreatments methods are shown in Table 4.

As is shown in Table 4, the concentration of -(C=O)-O- component on the ultrasound treated surface is 16.11% which is higher than 10.06% (NaOL concentration on the surface treated by traditional method), indicating that the selective dissolution of the surface caused by ultrasound can more effectively increase the adsorption density of the NaOL on the spodumene surface. The surface conditions of -0.074 + 0.0385 mm particles in different pretreatment systems (Fig. 9 (a) and (b)), for the particles of -0.15 + 0.074 mm, the peak area of the NaOL component on the surface treated by ultrasound increases is larger than that of traditional process. Meanwhile, in Table 4, the concentration of -(C=O)-O- component on the ultrasonic treated surface is 16.11% which is higher than 10.06% (NaOL concentration on the surface treated by traditional method), indicating that the selective dissolution of the surface caused by ultrasound can more effectively increase the adsorption density of the NaOL on the spodumene surface. The surface conditions of -0.074 + 0.0385 mm particles in different pretreatment systems (Fig. 9 (c) and (d)) are similar to those of -0.15 + 0.074 mm particles, revealing that the ultrasonic

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**Table 4**

| Particle size          | -0.15 + 0.074 mm | -0.074 + 0.0385 mm | -0.0385 mm |
|------------------------|------------------|--------------------|------------|
|                         | Tradition Ultrasound | Tradition Ultrasound | Tradition Ultrasound |
| Al-O-Si Be (eV)         | 532.35 532.32     | 532.29 532.32      | 532.28 532.34 |
| FWHM (eV)              | 1.99 1.95         | 2.01 1.95          | 1.99 1.98   |
| Number (%)             | 40.60 40.54       | 39.35 39.88        | 42.38 41.41 |
| Si-O-Si Be (eV)         | 531.39 531.39     | 531.37 531.39      | 531.48 531.49 |
| FWHM (eV)              | 1.92 1.93         | 1.89 1.90          | 1.92 1.90   |
| Number (%)             | 39.54 40.34       | 34.38 35.77        | 39.36 39.24 |
| NaOL Be (eV)           | 533.19 533.15     | 533.15 533.15      | 532.22 533.10 |
| FWHM (eV)              | 1.94 1.91         | 1.98 1.95          | 1.94 1.88   |
| Number (%)             | 10.06 9.80        | 16.11 13.47        | 7.30 7.54   |
| >Al-O-H Be (eV)        | 530.50 530.58     | 530.58 530.46      | 530.56 530.56 |
| FWHM (eV)              | 1.88 1.87         | 1.87 1.92          | 1.88 1.88   |
| Number (%)             | 9.80 10.44        | 10.15 10.07        | 10.96 11.80 |
pretreatment method is able to replace the traditional pretreatment method in coarser particle size fractions. However, for fine particles of ~0.0385 mm, compared with traditional methods, ultrasonic pretreatment does not show advantages on the adsorption of collectors. In addition, the proportion of NaOL on the surface of ~0.0385 mm particles is only about 7% (Table 4) which is smaller than that of coarse particles (16.11% and 13.47% in Table 4). Combined with the adsorption test results in section 3.2, although fine particles can adsorb more NaOL, a larger surface area will reduce the adsorption density of the collectors on the particle surface and hinder the flotation process.

4. Conclusion

In this paper, the potential of pretreating spodumene particles with different size fraction by ultrasound to improve the particle floatability...
was verified and investigated. The dissolution mechanism of spodumene surface in two pretreatment systems (ultrasonic and traditional) and its influence on subsequent NaOL adsorption and flotation have been studied and compared. The main conclusions are as follows.

(a) For coarse particles (-0.15 + 0.074 mm and −0.074 + 0.0385 mm), the pretreatment time could be greatly shortened by ultrasound. And under the same pretreatment time, the flotation recovery of the particles treated by ultrasound was almost twice that of the traditional pretreatment. And for fine particles (-0.0385 mm), both pretreatment methods can greatly increase the rate of spodumene flotation from 10.21% to approximately 66.40%, but ultrasound has no obvious advantage that shows in coarse particles.

(b) In the ultrasonic pretreatment process of coarse particles, a large amount of Si species on the surface were transferred to the solution, while Al and Li species “remained” and accumulated on the surface, which is conducive to the adsorption of the NaOL on the spodumene surface.

(c) For spodumene particles of −0.0385 mm, ultrasound treatment would lead to a serious decline in the dissolution selectivity because of excessive energy supply. Fortunately, the amount of dissolution makes up the loss caused by the decrease in selectivity. It makes ultrasonic pretreatment fail to show advantages compared with traditional methods in this particle fraction.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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CRediT authorship contribution statement

Haoran Chu: Conceptualization, Methodology, Writing – original draft. Lanlan Chen: Visualization, Investigation. Dongfang Lu: Writing – review & editing, Validation, Funding acquisition. Yuhua Wang: Data curation, Supervision. Xiayu Zheng: Software, Validation.