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## An experimental study of removing impurity from a quartz ore by microbial flotation-acid leaching

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**Abstract:** The purity of a quartz ore is relatively low at a SiO<sub>2</sub> content of 97.18%, and the main impurity in the ore is Fe, Al, and Ca bearing minerals. The main component in an industrial waste bacteria (*WJ*) is polysaccharides, which may be used as depressors for inhibiting iron minerals in quartz flotation. Moreover, *WJ* belongs to microbial inhibitors because it is mainly composed of bacteria. As a result of this study, a concentrate grade of 99.88% at recovery over 80% was obtained under the condition of 2000 g/Mg *WJ* dosage, a grinding fineness of 70% -0.074 mm, pH 11.7, 400 g/Mg CaCl<sub>2</sub>, and 800 g/Mg NaOL in the flotation experiments for the quartz ore. Moreover, a SiO<sub>2</sub> grade of 99.97% at a recovery of 68.85% was obtained at an acid dosage of 40 kg/Mg by using mixed acid of H<sub>2</sub>SO<sub>4</sub>, HCl, HNO<sub>3</sub>, and HF in mass ratios of 20%, 30%, 20%, and 30%, respectively, in subsequent acid leaching of the quartz flotation concentrate. Zeta potential analysis before and after the interaction of quartz and hematite with *WJ* showed that *WJ* increased the zeta potential of hematite significantly but had little impact on the zeta potential of quartz, indicating stronger adsorption of *WJ* on hematite than on quartz. FTIR analysis showed that there exist not only -COOH, -CH<sub>2</sub>-, and -CH<sub>3</sub>, which are the functional groups of starch but also NH<sub>2</sub> and -C=O-NH- in *WJ*. The NH<sub>2</sub> and -C=O-NH- in *WJ* are the important groups for adsorption, so the depressing effect on hematite was better for *WJ* than starch.

**Keywords:** quartz purification, flotation, acid leaching, waste bacteria

### 1. Introduction

Quartz is one of the most widely distributed minerals on the earth's crust. Its physical and chemical properties are stable, and it is an important raw mineral material for human development and utilization. Quartz ore is mainly composed of SiO<sub>2</sub> with a little amount of aluminum, iron, magnesium, calcium, sodium, and potassium. The impurity minerals bearing aluminum in quartz ore are mainly feldspar, mica, kaolin, while the impurity minerals bearing iron are mainly hematite and goethite (Potapine, 1954; Guo and Guo, 1975).

The SiO<sub>2</sub> grade of ordinary quartz sand is 96%-99%, the impurity content of Fe<sub>2</sub>O<sub>3</sub> is less than 0.5%, and the content of Al<sub>2</sub>O<sub>3</sub> is less than 2.0%. It is mainly used for glass products, ceramic products, mechanical casting, cement products, chemical industry, and industrial fillers. The SiO<sub>2</sub> content of high-purity quartz sand is more than 99.95%, which is mainly used in aerospace, bioengineering, high-frequency technology, electronic technology, optical fiber communication, and military industry. Research on quartz ore purification has been widely concerned in the industry for less reserves of high-grade quartz ore in nature and rapid development of global optical fiber communication and semiconductor industry (Yang, 2004).

In the quartz ores, the gangue minerals are feldspar, mica, chlorite, clay, and iron minerals. The flotation is the most common method for quartz purification (Liu et al., 2019), and it is mainly adopted to remove the disseminated iron and aluminum. Also, flotation can remove the secondary pig iron which is mixed by crushing and grinding (Liu, 1993; Li and Xu, 1995). The results of a series of micro-flotation experiments showed that the longer the QAS carbon chain, the stronger the collection capacity

on quartz (Jiang et al., 2019). Besides, silicate bacteria were used to pretreat quartz for 3 days based on the metabolites of microorganisms, organic acids and polysaccharides dissolve quartz. With the increase of the surface dissolution area of quartz, the binding sites of quartz and dodecylamine increased, thereby improving the collection effect of dodecylamine (Teng and Wang, 2020). Some research on inhibitors of hematite and quartz were reported. For example, a new type of hematite macromolecular inhibitor was synthesized with multiple carboxyl groups and amino groups-polymaleic anhydride-triethylenetetramine (PMTA), and it exhibits a good depression performance compared to starch (Zhang et al., 2017). Besides, maizena, soluble starch, amidex, and amylose were used as inhibitors in the nano-emulsion system for micro-flotation of quartz and hematite. High performance of hematite depression was obtained for all inhibitors (80%-90% depression), and all depressants introduced into the nano-emulsion systems were efficient to promote depression of hematite (Paula et al., 2019). Other studies suggested that the interaction between the *Saccharomyces cerevisiae* (*S.c.*) with quartz and hematite caused obvious surface chemical changes. *S.c.* exhibited a higher surface affinity toward hematite when compared to quartz. *S.c.* cell adhesion was significantly higher on hematite, and quartz was rendered more hydrophobic, while hematite was more hydrophilic, after biotreatment (Natarajan and Padukone, 2012). Meanwhile, magnetic separation is mainly used to remove iron minerals in quartz ore and secondary pig iron mixed in crushing and grinding to improve the quality of quartz sand (Zhao et al., 2005). In Zivko's study, a high-gradient magnetic separation process for removing  $Fe_2O_3$  carriers from quartz raw materials was summarized through an electromagnetic separator (magnetic field strength of 1120 kA/m) (Zivko et al., 2017). In Lv's research, pulsating high gradient magnetic separation (PHGMS) was used to effectively remove iron impurities in quartz ore, and the iron removal rate is 89.82% (Lv et al., 2017). Since quartz is insoluble in acid (except HF), acid leaching is often used to remove the iron film on the surface of quartz particles and iron impurities. The dissolving speed of mica and feldspar is higher than quartz in HF solution, therefore, HF can be used as the main chemical leaching agent for quartz purification (Zhou, 2005). Research by Larsen et al (2019) showed that the purification of quartz in solutions containing mineral acids (such as  $H_2SO_4$ ) and sodium fluoride (NaF) was similar to the results of studies using hydrofluoric acid (HF), and combining separate H and F sources instead of using HF alone enables lower fluorine concentration. Li's study proposed to replace the outdated industrial strong acid with a mixture containing non-toxic renewable acid and very dilute HCl to simultaneously remove iron and aluminum impurities in quartz sand, with the best removal rates reaching 79.1% and 42.3%, respectively (Li et al., 2016). In a study by Tuncuk and Akcil (2014), the chemical leaching tests with different acids were carried out to remove iron impurities from quartz ore, with the highest removal rate of 86.6%.

With the over-exploitation and utilization of mineral resources, the reserves of high-grade quartz ores in nature are drying up, and the demand for high-grade quartz is growing because of the progress of science and technology, rapid development of high-tech industries such as optical communication, thin-film materials, optical power supply, electronic industry, laser, aerospace, large-scale and ultra-large-scale integrated circuits, military industry (Sun and Yin, 2001; Li, 2002). It is of great significance to study the purification of low-grade quartz ores. There are many gangue minerals and some silicate minerals in low-grade quartz ores, therefore the effect of removing impurity by magnetic separation and conventional flotation methods with starch as depressant is poor, and it is difficult to achieve a concentrate grade above 99%. Starch comes from food grain, and a lot of usage of starch has an important impact on the national economy and people's livelihood. The acid leaching method has some disadvantages such as high cost, serious equipment corrosion, and heating in some cases. Microorganism has wide sources and is environmentally friendly. Using waste bacteria (*WJ*) as an inhibitor of iron in silicon flotation is an effective and low cost, which can replace starch.

In this study, the flotation experiments on a quartz ore obtained from Chaoyang City, Liaoning Province, China was carried out to obtain an effective approach to purifying a low-grade quartz ore by microbial flotation-acid leaching for comprehensive utilization of low-grade quartz resources.

## 2. Materials and methods

### 2.1. Materials

200 kg representative quartz ore sample of 0-300 mm was obtained from a mine in Chaoyang City, Liaoning

Province, China. The sample was crushed in three stages. First, the sample was crushed using a jaw crusher in an open circuit, and then, a roller crusher was used in a close-circuit. The crushed sample was well mixed and subsampled for the chemical analysis as presented in Table 1.

Table 1. Chemical composition of quartz (wt%)

Composition	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	CaO	MgO	TiO <sub>2</sub>	K <sub>2</sub> O	Na <sub>2</sub> O
Content	97.18	1.80	0.34	0.28	0.04	0.09	0.16	0.11

As seen in Table 1, the main chemical composition in the quartz ore sample is SiO<sub>2</sub> at 97.18%. The main impurity composition is Fe<sub>2</sub>O<sub>3</sub> with minor impurities of Al<sub>2</sub>O<sub>3</sub>, CaO, K<sub>2</sub>O, and Na<sub>2</sub>O. The main objective of the experimental study was to remove iron and aluminum impurities and improve the content of SiO<sub>2</sub> in the quartz ore. Additionally, a representative sample of the quartz ore was selected to prepare for a light plate. Typical images under a light microscope are shown in Fig. 1.

The main mineral in the ore was quartz accounting for about 97%, and a small amount of mica, feldspar, pyroxene, and hematite existed in the ore. Quartz is often associated and inter-grown with mica, feldspar, and hematite. There were some very small spots on the surface of quartz grains. Some minerals dissipated in the quartz fracture, and some were embedded in the form of inclusions that existed in the ore. It can be seen from Fig. 1 (b) that some minerals were mixed in the quartz fractures. There are some connectives in the form of inclusions and gas-liquid intrusions of iron mineral (marked with the letter C in red), which have adverse effects on removing from the quartz ore by flotation.

The industrial waste bacteria used in the test was taken from a beer factory in Shenyang and used as a flotation inhibitor (*WJ*). Physical property and micromorphology are shown in Fig. 2.

It can be seen from Figs. 2 (c) and (d) that the *WJ* is oval, about 3 × 6 μm in size, and the cell wall is visible, which is a microbial inhibitor. It was dead by testing.

Hydrochloric acid (HCl), sulfuric acid (H<sub>2</sub>SO<sub>4</sub>), nitric acid (HNO<sub>3</sub>), hydrofluoric acid (HF), Sodium hydroxide (NaOH), and sodium oleate (NaOL) used in the experiments were purchased from the reagent store. The name, specification, and manufacturer of the reagent are presented in Table 2

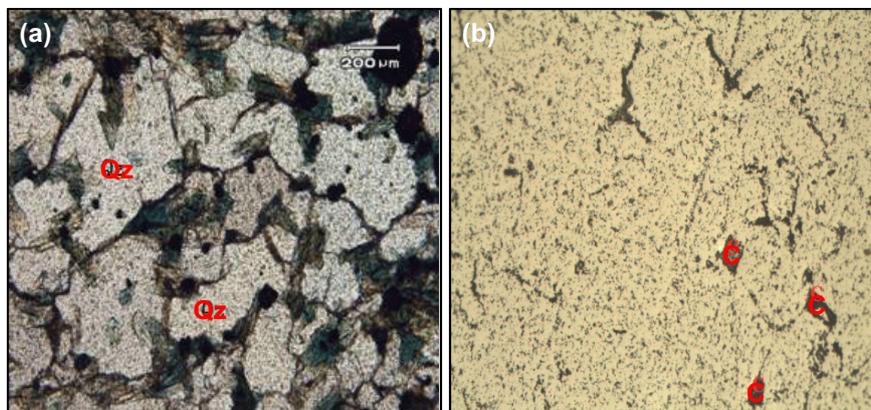


Fig. 1. Quartz ore images under a light microscope (a) the crystalloid structure of unequal granular and (b) enlarged section in 400 magnification

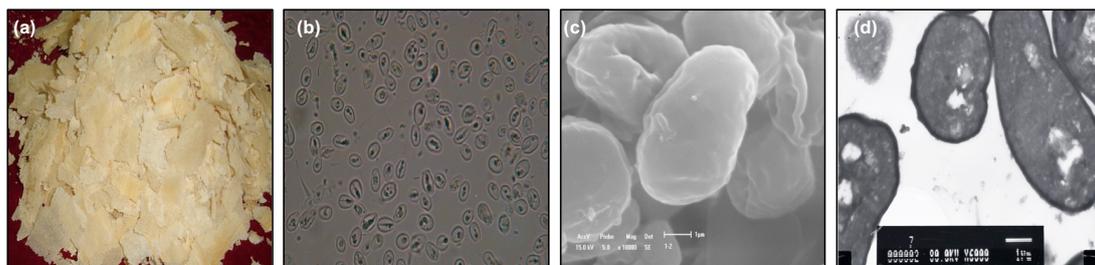


Fig. 2. The (a) macroscopic, (b) microscopic (at 1000 X), (c) scanning electron microscopy (SEM), and (d) transmission electron microscopy (TEM) images of *WJ*

Table 2. Reagents used in the experiments

Chemical formula	Specification	Manufacturer
HCl	Guarantee reagent (GR)	Shenyang Xindong Reagent Factory, China
H <sub>2</sub> SO <sub>4</sub>	Guarantee reagent (GR)	Shenyang Xindong Reagent Factory, China
HNO <sub>3</sub>	Guarantee reagent (GR)	Sinopharm Chemical Reagent Co., Ltd.
HF	Guarantee reagent (GR)	Sinopharm Chemical Reagent Co., Ltd.
NaOH	Analytical reagent (AR)	Tianjin Hengxing Chemical Reagent Manufacturing Co., Ltd.
C <sub>18</sub> H <sub>33</sub> NaO <sub>2</sub>	Analytical reagent (AR)	Tianjin Damao Chemical Reagent Factory, China

## 2.2. Methods

### 2.2.1. Flotation experiments

The combined process of flotation-acid leaching was used for the experiments. The flotation experiments were performed using an XFD flotation machine with a 1000 cm<sup>3</sup> flotation cell with a stirring rate of 1800 rpm at room temperature. In the flotation experiments, 500 g sample was placed in the cell with 800 cm<sup>3</sup> tap water. The slurry was stirred for 1 min, and HCl and NaOH were used to adjust the pH value of the suspension. Then, an additional stirring for 1 min, the adjuster was placed to the cell and stirred for 5 min. The NaOL was added into the suspension, and it was agitated for 3 min, and the flotation time was 3 min. After the flotation process, the products and tails were weighed and laboratory analyzed after the filtering and drying processes, and the flotation recovery was calculated.

### 2.2.2. Leaching experiments

The acid leaching was performed using an XJT II leaching stir leaching machine with a 750 cm<sup>3</sup> leaching cell. The 400 g flotation concentrate was placed on the cell and adjusted the pulp concentration of 50%-55% by adding tap water. The acid was placed and agitated 2 h. The flowsheet of the flotation and leaching processes is shown in Fig. 3.

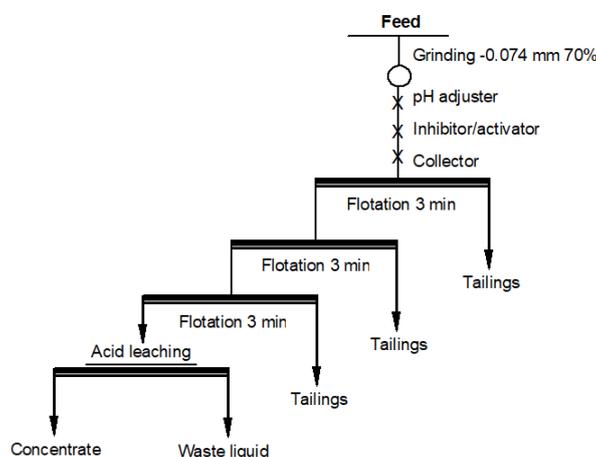


Fig. 3. Experimental flowsheet

### 2.2.3. Zeta potential measurements

The zeta potential measurements for the samples were carried out using the JS94H micro electrophoresis instrument. First, the quartz and hematite samples were ground to -5 μm with a ZXM-1 vibration mill. Second, about 0.5 g of the mineral sample was added into the WJ solution at desired concentrations. Next, the pH value of the solution was adjusted with HCl or NaOH, and the suspension was stirred for 5 min, and finally, then the measurements were performed. Each sample was measured 4-6 times, the interference number was removed, the remaining values were averaged.

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

X-ray photoelectron spectroscopy (XPS) analyses for the samples were performed at room temperature in an ultra-high vacuum system with the surface analysis system (ESCALAB 250Xi/ThermoFisher). The

element distribution of *WJ* was analyzed by PHI Quantera SXM X-ray Photoelectron Spectroscopy (XPS) using an Ar<sup>+</sup> sputtering gun at an acceleration voltage of 1 kV.

### 2.2.5. Scanning electron microscope (SEM) and Energy dispersive spectrum (EDS) analyses

A small amount of powder *WJ* sample was taken and sprinkled it on the conductive glue of the clean Scanning electron microscope (SEM) sample stage, and Au was sprayed on the sample surface. The Zeiss-SIGMA HD scanning electron microscope of Germany was used for the analysis. When the sample was analyzed, the scanning voltage and current were adjusted according to the conductivity of the sample and Energy dispersive spectrum (EDS) spectrum.

### 2.2.6. Fourier transform infrared (FTIR) spectra

First, the spectrally pure KBr background was collected, then the prepared sample was mixed to be with KBr in an appropriate ratio, pressed in the tablet, and put it into a Nicolet 380 FT-IR infrared spectrometer for the analysis.

## 3. Results and discussion

The magnetic separation experiments were performed using an LHGC-500F Slon vertical ring high gradient Magnetic separator at a magnetic field intensity of 640 to 1600 kA/m due to the presence of hematite in the quartz ore. The content of Fe<sub>2</sub>O<sub>3</sub> in the magnetic concentrate was 0.17% which was slightly lower than the content of Fe<sub>2</sub>O<sub>3</sub> in the crude, indicating that the iron in the quartz ore was not effectively removed. The reason may be that the Fe<sub>2</sub>O<sub>3</sub> in the ore was low, and the iron was closely associated with quartz. Therefore, the flotation experiments were carried out.

### 3.1. Flotation experiments

The flotation process of quartz ore is similar to the reverse flotation of iron ore by depressing iron and floating silica. NaOL is commonly used as a collector of magnesite in the separation flotation of Mg and Ca, Si of magnesite ore, and the collector of quartz in the separation flotation of Fe and Si of iron ores or silica ores (Hao et al., 2018; Sun et al., 2020). CaCl<sub>2</sub> is usually used as an activator for the separation flotation of iron and silica (Liu et al., 2013; Hao et al., 2018). Causticized starch is commonly used as an inhibitor for iron minerals in the separation flotation of iron and silica (Hao et al., 2018). The impurities in the quartz ore cannot be effectively removed by using many kinds of starch and many steps. The SiO<sub>2</sub> grade of the concentrate is below 99% regardless of low recovery. The depressing effect of starch was dependent upon the carbon chain length, and the effect of amylopectin was better than that of amylose (Ma et al., 2006). The polysaccharides are the main composition of *WJ*, the molecular weight of polysaccharides in microbial is larger than that of starch in its complex structure, and contains more polar groups with inhibitory effect on iron minerals than starch (Bernard and Jack, 2005). Therefore, the industrial waste bacteria *WJ* was used as the depressant to iron in quartz flotation to improve the grade of quartz by removing impurities, which conclusion was similar to that of Natarajan et al (2012).

#### 3.1.1. Effect of grinding fineness

The influence of grinding fineness was investigated under the condition of pH 10, 2000 g/Mg *WJ*, 400 g/Mg CaCl<sub>2</sub> as the activator, and 800 g/Mg NaOL as the collector. The results are shown in Fig. 4. As shown in Fig. 4, the SiO<sub>2</sub> grade of the quartz concentrate increased initially and then decreased, the recovery decreased at first and then increased with the increase of grinding fineness. The optimum grinding fineness was 70% passing -0.074 mm in consideration of concentrate grade and recovery.

#### 3.1.2. Effect of pulp pH

5% NaOH was used to adjust the pH value of pulp. The effect of pH was investigated under the condition of grinding fineness of 70%-0.074 mm, *WJ* dosage of 2000 g/Mg, CaCl<sub>2</sub> dosage of 400 g/Mg, and NaOL dosage of 800 g/Mg. The results are shown in Fig. 5. As seen in Figure 5 that the concentrate grade increased at first and then decreased with the increasing pH. The concentrate grade was 99.87%

when the pH in pulp was 11.7. The recovery decreased slowly when the pH increased from 4 to 12. The optimum pH was to be 11.7.

### 3.1.3. Effect of NaOL dosage

The effect of NaOL dosage was investigated under the condition of grinding fineness of -0.074 mm 70%, pH 10, *WJ* dosage of 2000 g/Mg, and  $\text{CaCl}_2$  dosage of 400 g/Mg. The results are shown in Fig. 6. The concentrate grade increased with the increasing NaOL dosage in the range of 400-800 g/Mg, and the concentrate grade decreased with a further increase of NaOL dosage over 800 g/Mg. The recovery always increased with the increasing NaOL dosage. The concentrate recovery increased slowly when the NaOL dosage was over 800 g/Mg. The optimum NaOL dosage was to be as 800 g/Mg.

### 3.1.4. Effect of *WJ* dosage

The effect of *WJ* dosage was investigated under the condition of grinding fineness of 70% -0.074 mm, pH 10,  $\text{CaCl}_2$  dosage of 400 g/Mg, and NaOL dosage of 800 g/Mg. The results are shown in Fig. 7. As shown in Fig. 7, the concentrate grade increased and the recovery decreased with the increasing *WJ* dosage in the range of 500-2000 g/Mg. The concentrate grade increased slightly, while the recovery decreased greatly with the *WJ* dosage over 2000 g/Mg. Therefore, the optimum dosage of *WJ* was 2000 g/Mg, at this point, the concentrate grade was 99.88%, the yield was 85.74%, and the recovery was 80.12%. The impurity removal rate of flotation was 96.33%.

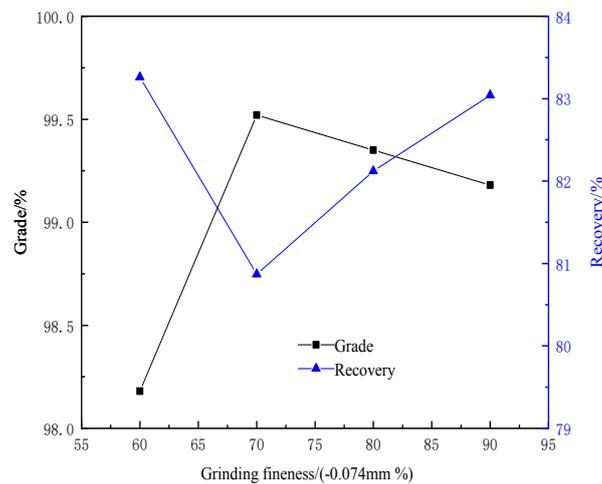


Fig. 4. Influence of grinding fineness on quartz flotation

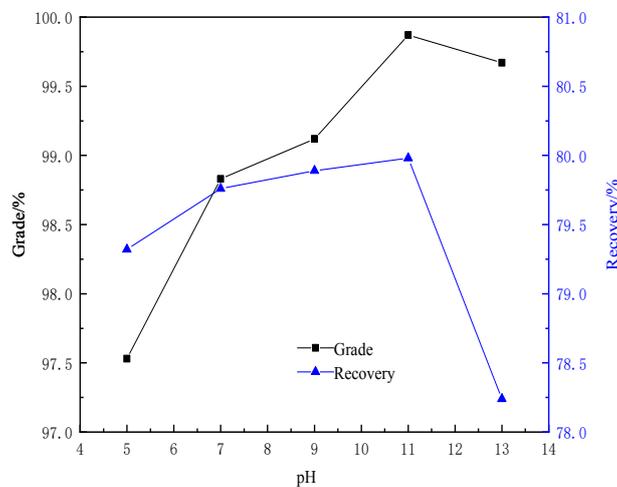


Fig. 5. Influence of pH on flotation results

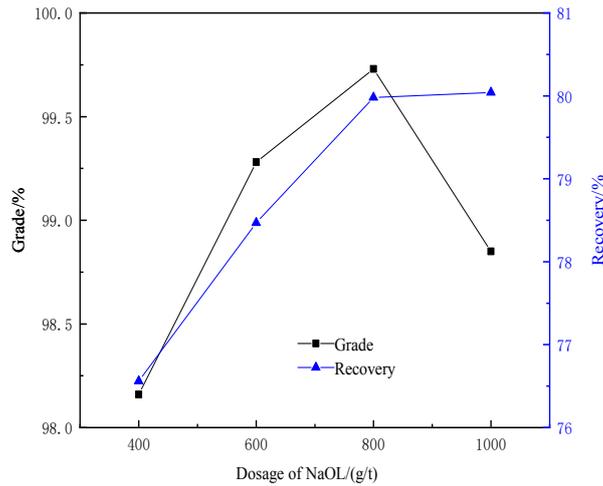


Fig. 6. Influence of dosage of NaOL on quartz flotation

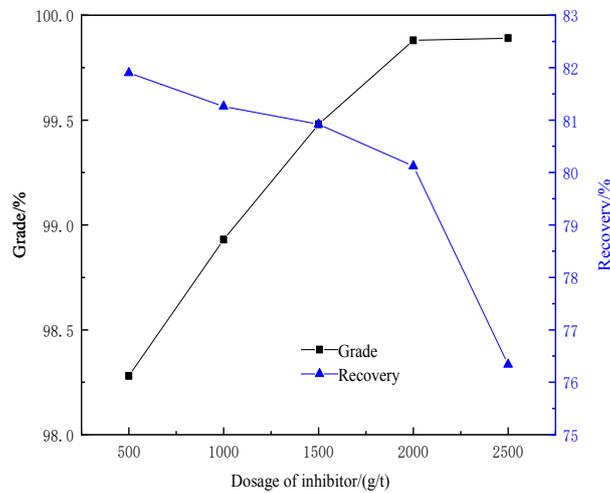


Fig. 7. Influence of dosage of WJ on quartz flotation

### 3.2. Acid leaching experiments

The effect of removing impurity was better by flotation, but the concentrate grade was still lower than 99.9%. The acid leaching experiment was performed under the condition of pulp concentration of 50%-55%, a temperature of 80°C using a heating jacket, the acid leaching time of 2 h, and the acid dosage of 40 kg/Mg by using mixed acids of H<sub>2</sub>SO<sub>4</sub>, HCl, HNO<sub>3</sub>, and HF in mass ratios of 20%, 30%, 20%, and 30% respectively. The sample after the leaching process was washed with water, filtered, and dried. The results for the leaching process on the quartz concentrate are presented in Table 3. The concentrate grade of quartz was 99.97%, and the recovery was 68.85%. The impurity removal rate of acid leaching was 2.93%.

Table 3. Chemical composition of quartz concentrate (wt%)

Composition	SiO <sub>2</sub>	Fe	Al <sub>2</sub> O <sub>3</sub>
Content (%)	≥99.97	≤0.01	≤0.01
Recovery (%)	68.85	—	—

### 3.3. Zeta potential measurements

Zeta potentials of before and after the interaction between WJ and hematite or quartz were determined, and the results are shown in Fig. 8.

The isoelectric point (*IEP*) of microorganisms reflects the charge balance between anionic and cationic acid-alkali base groups, which is produced by cell surface components, such as lipopolysaccharide, lipoproteins, and bacterial surface proteins. According to the report of Bernard and Jack (2005), the Point of Zero Charge (*PZC*) is  $\text{pH}=2.0\text{-}2.8$  when the main component of the cell surface is gluconic acid or other polysaccharides containing carboxy, while the *PZC* is  $\text{pH}\geq 3.2$  when the main compositions of cell surface are protein molecules rather than polysaccharides. As shown in Fig. 8, the *PZC* of *WJ* was  $\text{pH}=2.6$ , the surface of *WJ* cells mainly consisted of gluconic acid or other polysaccharides.

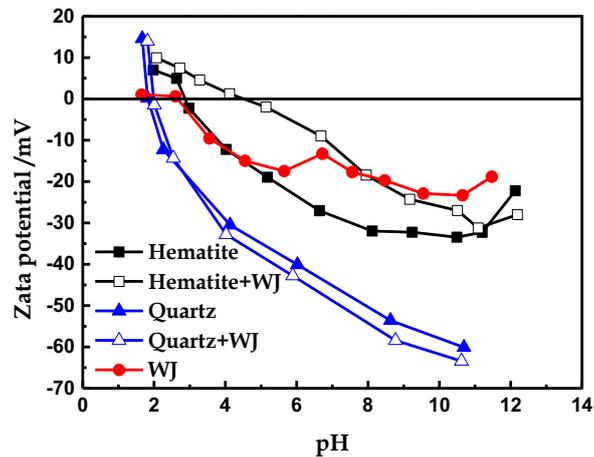


Fig. 8. Zeta potential-pH profile of the hematite and quartz in the presence of *WJ*

The zeta potential of hematite increased in magnitude to a negative value with the increasing pH. The *IEP* of hematite was 2.89, and the pH value was 10.49 when the negative value of the dynamic potential of hematite was highest in magnitude. The zeta potential of hematite increased to a negative value with the increasing pH after the interaction with *WJ*, and its *IEP* increased to  $\text{pH}=4.55$ . This indicated that *WJ* could adsorb on the surface of hematite, and influence on the zeta potential of hematite minerals.

The zeta potential on the surface of quartz increased to a negative value with the increasing pH. The *IEP* of quartz was 1.81, and the pH value was 10.69 when the negative value of the zeta potential of quartz was highest in magnitude. The zeta potential of quartz increased to a negative value with the increasing pH after the interaction with *WJ*, and its zero electric point marginally increased. As a result, *WJ* showed no obvious effect on the zeta potential of quartz mineral. The adsorption function of hematite-*WJ* was stronger than that of quartz-*WJ*.

### 3.4. Elemental composition, groups, and inhibition mechanism of *WJ*

The elemental composition of *WJ* was analyzed by X-ray photoelectron spectroscopy (*XPS*) and Energy dispersive spectrometer (*EDS*), and the results are shown in Fig. 9 and Table 4. Additionally, the chemical groups of *WJ* were analyzed by *FTIR* as shown in Fig. 10. According to Fig. 9(a), *WJ* surface mainly consisted of C, N, O, Mg elements (also containing H element, which cannot be detected by *XPS*), and a small amount of P and S. According to Fig. 9(b) and Table 4, *WJ* surface was mainly composed of C, N, and O elements, and a small amount of P, S and Na elements (also containing H element, which cannot be detected by *EDS*). K and Ca were detected in the suspension of *WJ*. The elements of K and Ca cannot be detected by *XPS* and *EDS* for their small amount or distribution in the cell.

As shown in Fig. 10, the broad strong peak at about  $3417.6\text{ cm}^{-1}$  was assignable to the stretching vibration absorption peak of the hydroxyl groups (a combination of OH and  $\text{NH}_2$  bands). Hydrogen bond association existed in *WJ* because the peak of  $3417.6\text{ cm}^{-1}$  was wider. The peaks at  $2963.13\text{ cm}^{-1}$ ,  $2926.29\text{ cm}^{-1}$  and  $1454.36\text{ cm}^{-1}$  were  $\text{CH}_3$ ,  $\text{CH}_2$  stretching vibration absorption peak, and  $\text{CH}_2$  shearing vibration absorption peak, and  $\text{CH}_3$  antisymmetric bending vibration absorption peak in the long hydrocarbon chain, respectively. The absorption peak near  $1654.36\text{ cm}^{-1}$  was the stretching vibration

peak of C=O and C-NH<sub>2</sub> (amide I band). The peak near 1540.7 cm<sup>-1</sup> was the bending vibration peak of band N-H and the stretching vibration peak of the C-N (amide II band). The peak near 1399.83 cm<sup>-1</sup> was the C-O stretching vibration of COOH in glucuronic acid and C-N-C stretching vibration of protein (amide IV band). The peak at 1239.67 cm<sup>-1</sup> would be the stretching vibration peak of C-N and P=O stretching vibration (amide III band). The peak at 1041.7 cm<sup>-1</sup> was C-O stretching vibration and S=O stretching vibration in the sugar hydroxyl group. The peak at 567.36 cm<sup>-1</sup> should be stretching vibration absorption peak of thiophosphoryl P=, and stretching vibration absorption peak of P-O- (C) (Wen et al., 2020).

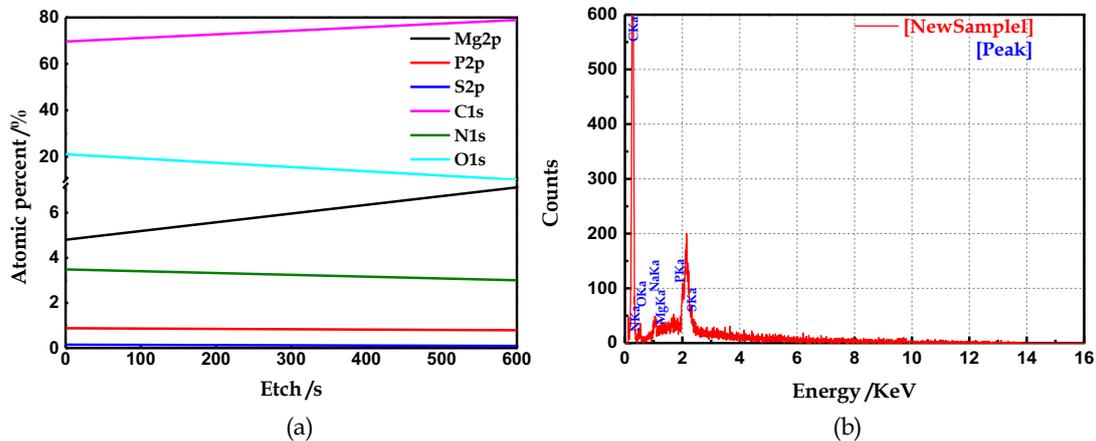


Fig. 9. Elemental composition in *WJ* by (a) XPS and (b) EDS

Table 4. Elemental content in *WJ* by EDS (wt%)

Element	C	N	O	Na	P	S
Content (%)	43.067	25.803	26.649	1.009	2.097	1.374

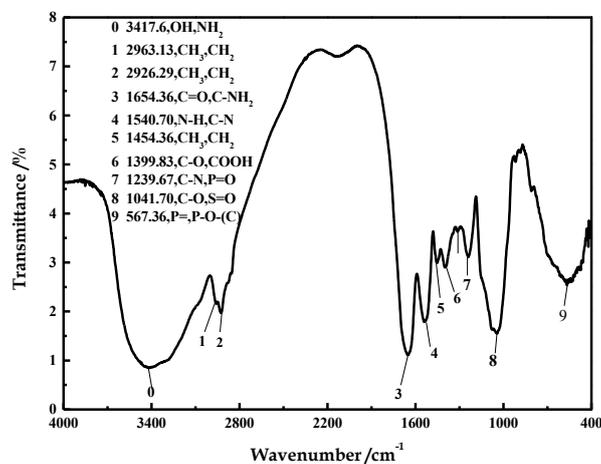


Fig. 10. FTIR analysis of *WJ*

Caustic starch is the most commonly used inhibitor for iron minerals in the separation of iron and silica by flotation. Starch is polymerized by a glucose molecule, that is, a polysaccharide. The main elements in starch are C, H, and O. In general, the groups in causticized starch are C-O-C, CH<sub>2</sub>, COOH, C=O, and OH (Zhu, 2005). Polysaccharide was the main component in *WJ* at a content of 50%-65%, and the others were protein at a content of 20%-25%. *WJ* mainly consisted of the elements of C, H, O and N, and Na, K, Ca, and Mg in traces. There were NH<sub>2</sub>, -C=O-NH-, P=O, and S=O in addition to groups of C-O-C, CH<sub>2</sub>, COOH, C=O, and OH. FTIR results showed that NH<sub>2</sub>, -C=O-NH-, OH, and COOH participated in the interaction of *WJ* with hematite, and NH<sub>2</sub> was the strongest and COOH was the weakest. The chemical interaction was the main action, and the hydrogen bond and static electricity force existed (Liu et al., 2013).

#### 4. Conclusions

The results obtained from this study indicated that *WJ* as industrial waste bacteria were an ideal inhibitor for the quartz flotation to remove the impurities from a quartz ore. A concentrate grade of 99.88% at a recovery of more than 80% was achieved under the condition of the grinding fineness of 70% -0.074 mm, pH 11.7, CaCl<sub>2</sub> dosage of 400 g/Mg, NaOL dosage of 800 g/Mg, and *WJ* dosage of 2000 g/Mg by one roughing flotation of rougher and two cleaning flotation on a quartz ore of 97.18% SiO<sub>2</sub>. The concentrate grade of quartz was 99.97%, and the recovery was 68.85% after the acid leaching by using mixed acid of H<sub>2</sub>SO<sub>4</sub>, HCl, HNO<sub>3</sub>, and HF in mass ratios of 20%, 30%, 20%, and 30%, respectively under the condition of pulp concentration of 50%-55%, the temperature of 80°C, the acid leaching time of 2 h, and the acid dosage of 40 kg/Mg in mixed acid as the leaching agent.

The zeta potential analysis showed that *WJ* showed good selectivity for hematite and quartz. *SEM* and *FTIR* analysis of *WJ* showed that *WJ* was a microorganism, and its chemical composition was mainly polysaccharide consisting of C-O-C, CH<sub>2</sub>, COOH, C=O, and OH groups as starch. Therefore, *WJ* could be used as an inhibitor for iron in the separation of iron and silica flotation. *WJ* consisted of NH<sub>2</sub>, -C=O-NH-, and other polar groups as well, therefore the inhibition effect of *WJ* in the iron minerals was greater than that of starch. Additionally, *WJ* has more obvious advantages of abundance, low price, and green compared with the starch because *WJ* is industrial waste, and starch comes from grain.

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