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Single and Coorperative Bauxite Bioleaching by Silicate Bacteria

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Abstract

Silicate bacteria generally placed in the species \textit{Bacillus circulans} and \textit{Bacillus mucilaginosus} and \textit{Bacillus edaphics} can liberated silicon from ores. Silicate bacteria from different resources have an obvious different abilities of desilicon. A single bioleaching and cooperative bioleaching (\textit{Bacillus circulans} and \textit{Bacillus mucilaginosus} and \textit{Bacillus edaphics}) was investigated by measurements of the leaching rate of silicon from bauxite. Results shows that the leaching rate of silicon with a mixed incubation of the tested three strains in accordance with the ratio of 2 : 2 : 1 is much higher than that of them respective, and also obviously higher than that of other forms of mixed culture by the three strains.

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1. Introduction

In recent decades, the bioleaching research has a great progress in mineral processing and metallurgy industry, because of the advantage of bioleaching treatments being friendly to environment. But up to now, to remove silicon from bauxite is conducted by physical and chemical technology. The traditional methods have many disadvantages with long flow sheet, high cost and serious pollution contrary to bioleaching process. Therefore, more attention has been paid to the biohydrometallurgical technology, and some basic experiments...
in laboratory has been done, though they have not been industrialized at present.

Silicate bacteria generally placed in the species Bacillus circulans (B·C) and Bacillus mucilaginosus (B·M) and Bacillus edaphics (B·E) was early widely used in biological fertilizers because of their ability of dissolving K and Si from soil minerals (that’s silicate ores), and now the fact is still so. Scholars [2-7] have proposed for future application as a biological leaching agent with silicate bacteria. They also conducted basic bioleaching experiments and found that in the presence of single silicate bacteria in leaching solutions, the leaching rate of silicon from silicate ores (feldspar, quartz, illite et al) were in the range of 25% to 80%. Desi SUN et al [8] reported that the rates of liberated silicon from bauxite, quartz and feldspar were different, respectively about 60%, 40%, 30%. Meantime, he also suggested that silicate bacteria obtained from different resources was slightly different in biological characteristics such as morphology, growing environmental conditions. And especially emphasized the obvious different ability of desilicon.

All bioleaching experiments with silicate bacteria mentioned above and reportedly were conducted by single culture. In fact, cooperative bioleaching of silicate ores with mixed culture will be expected to obtain higher leaching rate of silicon, because Lian reported that strains of silicate bacteria had a significant synergistic action in the leaching process. So, in this paper, we investigated the effect of single and cooperative bioleaching of bauxite on the rate of silicon dissolution by B·C, B·M, B·E.

2. Experimental

Bacteria strain and culture media: Two strains of B·C, B·M, were purchased from China Center of Industrial Culture Collection (CICC), the other strain of B·E was screen from bauxite soil sample from Gaoan (Jiangxi province, China) by our lab. The compositions of Ash medium (g/L) (for activating bacteria) are as follows: glucose 10.0, K2HPO4 0.2, MgSO4·7H2O, NaCl 0.1, CaCO3 0.1, pH7.2. The compositions of cultivating and bioleaching medium are the same as above except added 0.2g/L and 2.0g/L bauxite respectively. Before bioleaching of bauxite, the tested strains were first activated and sub-cultured in 500ml flasks respectively containing 100ml Ash medium and cultivating medium under conditions of temperature 30°C, culturing time 5-7 d in an orbital shaker (200r/min). When the cell population reached an exponential growth stage, the culture was filtered through a Whatman filter paper to remove the precipitate and the bacteria concentration was adjusted to 10^7 cells/mL. Cell numbers were counted microscopically using a counting chamber and this culture was used for the experimental inoculation.

Mineral: A complex concentrate bauxite from Jiaozuo (Henan province, China) containing diaspor65.2%,kaolinite14.1%, quartz4.5%, ferric oxide2.3% was used for this study. The ore was stage crushed in the laboratory in a jaw crushe and a cone crushe to about 0.074mm of particle size, then infused for some minutes and then put in air for 4h and dried at 50°C for 24h, finally sterilized by UV for 24h in asepsis room.

Bioleaching: Bioleaching of bauxite with single culture and mixed culture were carried out in shake flasks (volume 500mL) containing 100ml bioleaching medium under the conditions of temperature 30°C, culturing time 7d, 200r/min. Bioleaching of bauxite by single culture was conducted in inoculum with the initial cell density of 1×10^7 cells/mL. These experiments aimed to determine the optimal influencing factors by variation of temperature, pH and leaching time in bioleaching process. Cooperative bioleaching of bauxite by mixed culture was carried out in inoculum of different ratios of 1:1, 1:2, 2:1 of B·C and B·M or B·C and B·E. The inoculum ratios of B·C and B·M and B·E were 1:1:1, 2:2:1 and 1:1:2, when cooperative bioleaching of bauxite was processed by B·C and B·M and B·E. These tests aimed to determine the more appropriate inoculum ratios of the tested three strains.

Analytical methods: During the experiments, the leaching rate of silicon were measured as a function of time or temperature or pH. The amount of dissolved silicon in leachate was analyzed by an atomic absorption
spectrum (AAS). The pH value was measured with a pH meter, the temperature was measured by a mercury thermometer.

3. Results and discussion

3.1. Bio-leaching of bauxite with single culture

From figure 1 it can be seen that the three curves of the leaching ratio of Si as a function of temperature are similar, the evolution of the leaching ratio of Si was divided into two phases. The ratio in the first phase increases and decreases in the second phase with the leaching temperature. The strain of *Bacillus circulans* in the bioleaching solution can be adapted to ores and release silicon from bauxite, when the range of temperature was 28°C to 35°C, but can not develop and hardly dissolve silicon when the temperature was higher than 40°C or lower than 20°C, other two strains of *Bacillus mucilaginosus* and *Bacillus edaphics* were the same conditions. However, the bio-leaching abilities of the three strains respectively had an obvious difference in the leaching rate of desilicon, when the bauxite is processed by *Bacillus circulans*, the maximum ratio of dissolved silicon was 52.6% at the optimal temperature 32°C, but only 42.6% and 35.2% silicon extracted by *Bacillus mucilaginosus* and *Bacillus edaphics* respectively at the optimal temperature 30°C.

![Fig.1 Effect of temperature on silicon liberation from bauxite by silicate bacteria (pH7.2, velocity of shaker 200 r/min, leaching time 7d)](image)

The amounts of silicon bioleached by silicate bacteria at varying pH values are shown in Fig.2(a). The results reveal that the liberating rates of silicon in the presence of *Bacillus circulans* and *Bacillus mucilaginosus* and *Bacillus edaphics* have the same variation trend with increment of the pH value. When the pH value is ranged from 5 to 8.5, the three strains in the bio-leaching solution can develop and liberated silicon from bauxite. But when the pH value is less than 4.5 and beyond 9, they can hardly grow and dissolve silicon. The results also show that the three strains have an obvious different ability of liberating silicon from bauxite, 51.6% Si is liberated when using *Bacillus circulans*, but the rates of silicon are 43.45% and 24.55% by *Bacillus mucilaginosus* and *Bacillus edaphics* respectively. The three stains can all grow and reproduce rapidly at the optimal pH value of range limit of 7 to 8.

The variation tendence of leaching ratios of dissolved silicon with leaching time in the bio-leaching solution are shown in Fig.2(b). In the first one to three days, the silicate bacteria can barely liberated silicon from bauxite, and the cell numbers of the three strains in leaching solution have not obviously increase compared with the initial population of $1 \times 10^7$ cell/ml, this result shows that the silicate bacteria have not been completely adapted to the bio-leaching circumstance. When the leaching time is prolonged from 4 to 7 days,
the rate of dissolved silicon by silicate bacteria is rapidly increased. By measurement of the cell numbers in leachate, the cell population of the three strains is exponentially augmented, the maximum cell numbers is up to $8 \times 10^8$ cell/ml in the leachate of *Bacillus circulans*, and $6 \times 10^8$ cell/ml, $2 \times 10^8$ cell/ml in the leachate of *Bacillus mucilaginosus* and of *Bacillus edaphics* respectively. However, after 7 day, the rates of extracted silicon by the three strains are not obviously increased, the cell numbers in leaching solution are not obviously changed and even are reduced after 9 days, the reasons is that the glucose added in leaching medium as energy source have been completely consumed by silicate bacteria, this shows that the development of silicate bacteria is restrained because of lack of energy source. Sundesi et al [8] reported that the silicate bacteria would produce a great number of spores in the culture circumstance of lack of energy source and can not propagate, and had scarcely any ability of liberating silicon from silicate ores. But when adding a moderate amount of glucose or sucrose, the silicate bacteria can reproduce again and release silicon from silicate ores.

![Figure 2](image-url) Fig.2 Effects of pH and leaching time on desilicon from bauxite by silicate bacteria (Conditions for pH experiments: temperature 30°C, shaker 200 r/min, leaching time 7d; Conditions for leaching time experiments: temperature 30, pH 7.2, shaker 200r/min)

3.2. Bauxite bioleaching with mixed cultures

It can be seen from the Fig.3 that the three silicate bacteria in the leaching process of desilicon from bauxite are synergistic, the proportions of different bacterial inoculum effect with different desilication.

When *Bacillus circulans* and *Bacillus mucilaginosus* are mixed and inoculated into leaching solutions in certain proportions of 1 to 1, 1 to 2 and 2 to 1, the maximum liberated silicon ratios are respectively 60.25%, 57.2% and 53.2%, above about 9%, 6% and 2% respectively compared with single bioleaching by *Bacillus circulans*, and above about 17%, 14% and 10% respectively compared with that of *Bacillus mucilaginosus*. (Fig.3 a). The results state clearly that the bioleaching ability of mixed culture is much stronger than that of single culture, especially when the inocula ratio is 1 to 1. The reason is that different silicate bacteria isolated from different circumstances have a good synergistic effect when mixed together.

In Fig.3(b), it also exhibits the same change trend of leaching ratio of Si as a function of time as in Fig.2. When *Bacillus circulans* and *Bacillus edaphics* are mixed in leaching culture under the inocula ratios of 1 to 1, 1 to 2 and 2 to 1. But the maximum rates of desilicon are 47.84%, 56.2% and 32%, respectively, above 32%, 23% and 8% compared with single bioleaching by *Bacillus edaphics*, the stronger ability of desilicon than that of single *Bacillus edaphics* should be contributed to *Bacillus circulans* inoculated. But compared with the rate of desilicon by single bioleaching with *Bacillus circulans*, only about 5% Si is augmented at the inocula
proportion of 2 to 1, and even 9% and 24% Si are decreased at the inocula proportions of 1:1 and 1 to 2, the capacity reduction of desilicon is mainly contributed to Bacillus edaphics in mixed culture.

When Bacillus circulans and Bacillus mucilaginosus and Bacillus edaphics are together inoculated into leaching systems at the ratios of 1 : 1 : 1, 2 : 2 : 1 and 1 : 1 : 2, respectively, 58%, 66% and 40% Si is liberated from bauxite. In comparison with single bioleaching by Bacillus circulans and mixed culture of two strains of Bacillus circulans and Bacillus mucilaginosus, the rates of desilicon are respectively increased about 14% and 6% at the inocula ratio of 2 : 2 : 1, but reduced considerable percentage points or increased little when the inocula ratios are two others (Fig. 3 c). The above analysis shows that the tested three strains can promote growth each other and have a much stronger ability of desilicon from bauxite than that of their respective.

Fig. 3 Effects of mixed culture on desilicon from bauxite (a: the mixed culture of B·C and B·M; b: the mixed culture of B·C and B·E; c: the mixed culture of B·C, B·M and B·E)
4. Conclusions

The tested three strains of silicate bacteria can reproduce well and liberate silicon from bauxite in almost the same bioleaching environmental conditions, the optimum growing circumstance is temperature 30°C (except \textit{B·C}, 32°C), pH 7.2 and leaching time 7d. But their abilities of desilicon from bauxite have an obvious difference, the \textit{B·C} has the more capacity of desilicon than \textit{B·M} and \textit{B·E}, and the ability of desilicon by the \textit{B·E} is weakest.

The leaching rate of silicon with mixed incubation of \textit{B·C} and \textit{B·M and B·E} in accordance with the ratio of 2 : 2 : 1 is much higher than that of \textit{B·C} and \textit{B·M and B·E} alone, and also obviously higher than that of other forms of mixed culture by the three strains. The silicate bacteria obtained from different sources obviously promote to grow each other and are synergistic in releasing silicon from ores.

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References