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Effect of technological factors on bacterial leaching of low-grade Ni-Cu sulfide ore^①

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[Abstract] The bioleaching of a low-grade Ni-Cu sulfide ore from Jinchuan Mine with *Thiobacillus ferrooxidans* (TF5) and *Thiobacillus thiooxidans* (TT) was investigated. The effect of pH, the initial cell numbers of bacteria, the pulp density and the ratio of TF5 and TT on leaching was described, and the favorable bioleaching conditions for the ore were experimentally confirmed. The aeration leaching, agitation leaching with air bubbling, and column leaching were respectively tested. The highest recovery was achieved in the aeration leaching. After leaching for 20 d with pulp density of 15%, the extractions of Ni, Cu and Co were respectively 95.4%, 48.6% and 82.6%.

[Key words] *Thiobacillus ferrooxidans*; *Thiobacillus thiooxidans*; low-grade Ni-Cu sulfide ore; bioleaching

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1 INTRODUCTION

Bacterial leaching with autotrophic bacteria, such as *Thiobacillus ferrooxidans* (T. f.), has been extended to some polymetallic sulfide ores^[1]. A few of papers on bioleaching of Ni-Cu sulfide ore were published. Torma^[2] reported that the leached Ni, Cu and Co were all over 60% in 10 d in shake flask leaching of a low-grade nickel sulfide ore with T. f.. The results from ZHONG et al^[3] showed that 70% ~ 80% Ni were bioleached in 7 d under optimized conditions. On the hand of technological study, Miller et al^[4] reported a study on the heap bioleaching in laboratory scale, and it resulted that 30% ~ 50% Ni were extracted in 70 d. Some factors that played an important role in the heap bioleaching of low-grade nickel sulfide ores were investigated by Southwood et al^[5]. Their conclusions were that the physical and chemical behaviors of the ore, the penetrability and ventilation of the heap were the essential factors, and the presence of a lot of silicate gangues should hinder the nickel dissolution. It was pointed out by Nakazawa^[6] that 75% Ni and 14% Cu was dissolved after bacterial leaching of 42 d using T. f. for a flotation concentrates of Ni-Cu sulfides. A recent report by Dew^[7] indicated that over 99% of Ni and 96% ~ 99% of Cu were dissolved for several nickel concentrates using thermophile bioleaching at 68~ 78 °C after treatment for 3~ 7 d in batch tests. Moreover, a 1 m³ pilot reactor for continuous bioleaching was established in March 1999, and would start to demonstrate the high temperature thermophile bioleaching soon.

The bacterial leaching of a low-grade Ni-Cu sulfide ore using *Thiobacillus ferrooxidans* (TF5) and

Thiobacillus thiooxidans (TT) was investigated and described in this paper. The important technological factors in the process were discussed.

2 EXPERIMENTAL

A low-grade Ni-Cu sulfide ore from Jinchuan Mine in Gansu Province of China was used in this study. The majority of minerals in the ore was pentlandite, pyrrhotite, chalcopyrite, pyrite and silicate gangues. It contained 0.68% Ni, 0.34% Cu and 0.022% Co. The particle size of the ore was 97% and 54% < 0.043 μm respectively in the tests.

Strains of *T. ferrooxidans* (TF5) and *T. thiooxidans* (TT) used in the study were provided by Institute of Microbiology, The Chinese Academy of Science and adapted in the ore pulp solutions. A Leighton culture medium was used for TF5 and a Starky medium for TT in the study.

The Ni, Cu and Co concentrations in leachates were determined by SAA, and the total Fe by spectrophotometer using the phenanthroline methods. The extracted yields of metals were calculated based on their concentration in leachates.

The cell numbers of bacteria in solutions were determined by direct counting with a microscopy and a Petroff-Hausser counting chamber.

3 RESULTS AND DISCUSSION

3.1 Technological conditions of bioleaching

All experiments for technological conditions of bioleaching were carried out in the way of shake flask at the temperature of 30 °C and shake rate of 180 r/min.

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3.1.1 Effect of pH

The ore was bioleached at pH = 2.5, 2.0 and 1.5 by TF5 to examine the effect of pH. The leached Ni and Cu with time is shown in Fig. 1. During leaching the pH of the pulp was controlled by adding sulfuric acid solution regularly.

The results indicate that the leached Ni and Cu were higher at pH = 2 than at others. It seems that a lower pH (< 2) may hinder the growth of bacteria in the one side, and it is favorable to prevent ferric ions in leachates from precipitation and then to the bioleaching. All of bioleaching tests in follows were carried out at pH = 2.0.

3.1.2 Effect of initial cell numbers

The results from tests with different cell numbers of TF5 in bioleaching show that the leached Ni and Cu were increased with the most fast rate when the initial cell numbers of bacterial were ranged from 3×10^7 to 6×10^7 per milliliter. Furthermore, when the initial cell numbers were in this range, the appearance of the color of Fe^{3+} ions was observed at the first. The redox potential also at first arrived up to 650 mV (vs SCE), and the pH value in the pulp is early arrived at a steady value.

3.1.3 Effect of solid density of ores

Bioleaching of the ore in 5% and 10% solid density was tested, and the leaching of Ni and Cu is shown in Fig. 2. It is clean that the leached Ni is markedly higher in lower solid density for both savage and adapted bacterial. In the shake flask leaching, the movements and mechanical actions of ore particles on bacteria may disturb their growth, and in a higher solid density these more effective actions would decrease the extracted yields in bioleaching^[8].

3.1.4 Leaching with mixed culture of TF5 and TT

It was reported that chalcopyrite was dissolved more effectively by the mixed culture of T. f. and T. t than by T. f. only^[1], and for flotation concentrate of Ni-Cu sulfide ore there was no difference between them^[6]. Our experiments show that in the mixed culture leaching with T. f. and T. t at a certain ratio, based on the condition of same initial total cell numbers, the extracted yield of Ni and Cu at the ratio of 2:1 increases a few percent more than with T. f. only, as shown in Fig. 3. In the bioleaching processes with other ratios the extracted yield is lower than with T. f. only. On the other hand, it was observed that the acid consumption for pH control during the

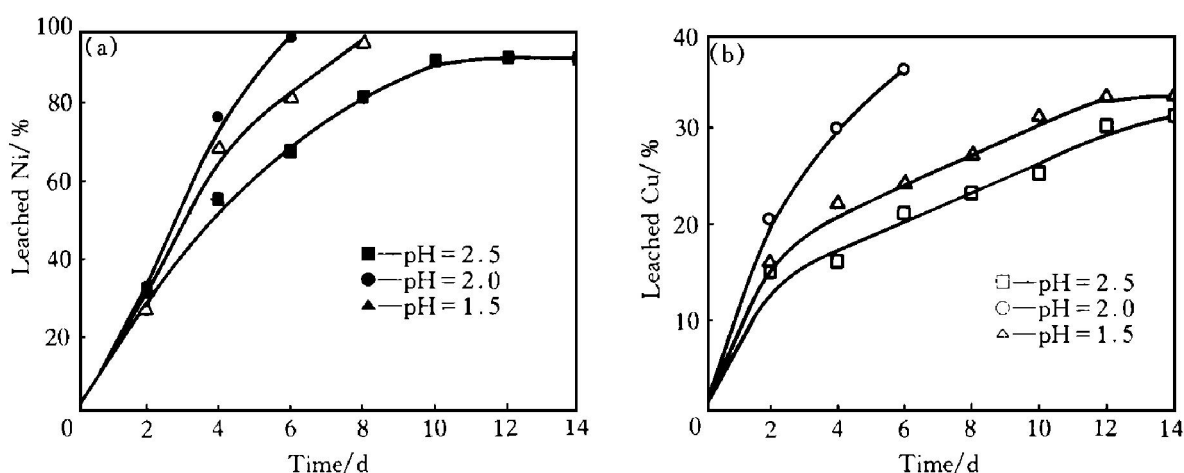


Fig. 1 Effect of pH on leaching of Ni and Cu

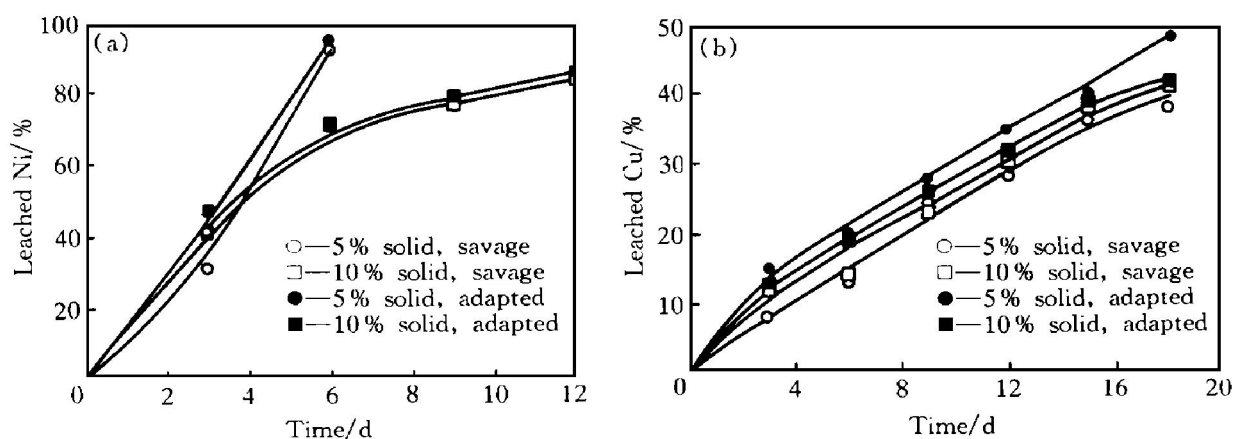


Fig. 2 Effect of pulp density on Ni and Cu leaching

bioleaching with mixed culture was lower than with T. f. only. In addition, the redox potential was higher in the process with the mixed culture of the ratio of 2:1. So adding some TT to TF5 is favorable to bioleaching of the ore. However, the fact that over adding of TT resulted in decreasing dissolution of Ni and Cu indicates that the major action came from TF5 in this bioleaching process.

3.1.5 Optimum technological conditions

In summary for the technological study, the following optimized conditions for bioleaching of low-grade Ni-Cu sulfide ores by thiobacillus are confirmed.

- 1) The pH would be controlled at 2.0.
- 2) The initial cell number of bacteria would be 3×10^7 per milliliter or so.
- 3) A lower solid density of ores may be favorable to the bioleaching in shake flask tests.
- 4) The ratio of TF5 to TT at 2:1 would be more favorable.

However, the highest dissolved yield of Cu in the bioleaching of the low-grade Ni-Cu sulfide is 50% or so. Therefore the key technological factor is to get over the barrier from passivation of chalcopyrite in bioleaching, as that in oxidation leaching with sulfuric solutions^[9].

3.2 TECHNOLOGY TESTS

Aeration leaching, agitation leaching with air bubbling, and column leaching were respectively tested under above optimized conditions.

3.2.1 Aeration bioleaching

The aeration bioleaching in 5%, 15% and 25%

solid density of ores were carried out. In the tests the aerating rate was 60 L/h, the initial cell numbers were 5×10^6 per gram of ores. The leaching of Ni and Cu in the tests are listed in Table 1. It is indicated that the leaching of Ni and Co achieved 95% and 82% respectively in 15% solid density.

3.2.2 Agitation bioleaching with air bubbling

The tests for agitation bioleaching with air bubbling were carried out at 35 °C and the agitation rate of 300 r/min. The experimental results in the solid density of 15%, 25% and 30% are listed in Table 2. It is shown that the highest extraction yields of Ni, Cu and Co are achieved in the solid density of 25%.

As the energy source for bacterial growth, a higher sulfide density in the pulp will favor to the bioleaching of low-grade sulfide ore. It was confirmed by measurement that the cell numbers of bacteria in solutions leaching with 25% solid density were more higher than that with 15% solid density. However, as discussed above, the more effective mechanical actions in the pulp with a higher solid density might disturb bacterial growth and decrease the extraction of valuable metals. Experimental results indicate that 25% solid density is most suitable for this process.

3.2.3 Column bioleaching

A test of column bioleaching for the low-grade Ni-Cu sulfide ore was carried out at the normal temperature. The results are listed in Table 3. It is shown that the dissolved Ni, Cu and Co in this leaching is lower than that in the aeration leaching and the agitation leaching with air bubbling, and the leaching period is remarkably longer. In the view of energy consumption and commercial operation cost, however

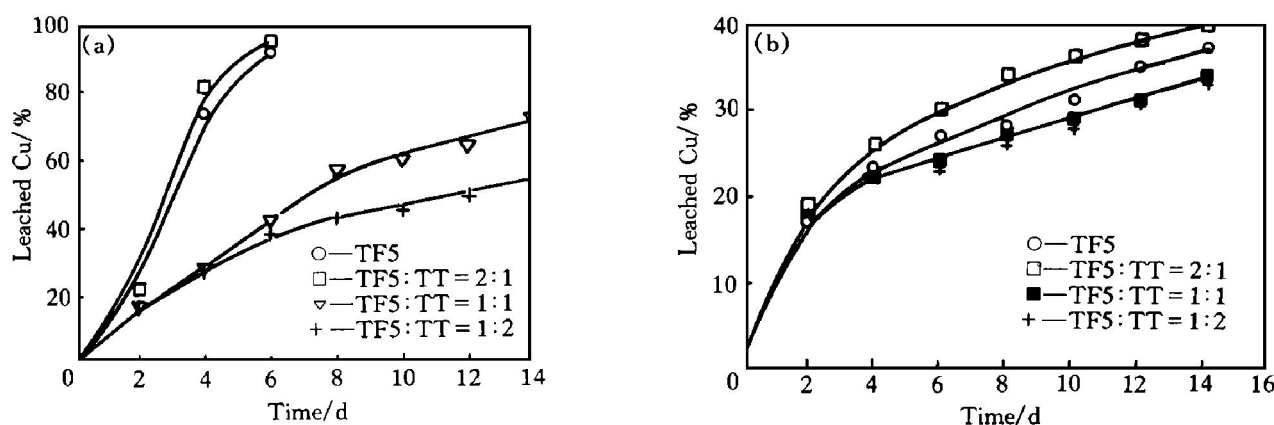


Fig. 3 Effect of mixed culture leaching on Ni and Cu dissolution

Table 1 Leached Ni, Cu and Co in aeration bioleaching

No.	Solid density/ %	Leaching time/ d	Mass loss/ %	Composition of residue/ %			Percentage of leaching/ %		
				Ni	Cu	Co	Ni	Cu	Co
1	5	20	22	0.11	0.23	0.005 6	87.3	46.2	80.2
2	15	20	20	0.039	0.22	0.004 8	95.4	48.6	82.6
3	25	20	18	0.16	0.24	0.006 4	80.2	42.3	76.2

Table 2 Leaching results in agitation bioleaching with air bubbling

No.	Solid density/ %	Leaching time/ d	Mass loss/ %	Composition of residue/ %			Percentage of leaching/ %		
				Ni	Cu	Co	Ni	Cu	Co
1	15	14	20	0.23	0.26	0.0066	73.5	39.1	76.0
2	25	14	18	0.19	0.23	0.0058	78.2	43.5	78.4
3	30	14	18	0.25	0.28	0.0072	69.8	33.1	73.3

Table 3 Results from column bioleaching

L: S	Leaching time/ d	Mass loss/ %	Composition of residue/ %			Percentage of leaching/ %		
			Ni	Cu	Co	Ni	Cu	Co
40: 1	49	14	0.41	0.25	0.017	48.5	37.5	33.6

er, the column bioleaching might be the best way for the low-grade ore.

4 CONCLUSION

The low-grade Ni-Cu sulfide ore can be bioleached by *thiobacillus ferrooxidans*. Experiments confirmed that the leaching of Ni, Co and Cu would achieve 92% ~ 94%, 82% ~ 86% and 45% ~ 48% respectively in the shake flask leaching at pH = 2.0 and 30 °C with the initial cell numbers of 3×10^7 /mL. With the optimum conditions, 95.4% Ni, 48.6% Cu and 82.6% Co were leached out by aeration bioleaching in 20 d, and 80.2% Ni, 45.2% Cu and 78.4% Co by agitation bioleaching with air bubbling in 14 d, and 48.5% Ni, 37.5% Cu and 33.6% Co by column bioleaching in 49 d.

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