Research on Technological Mineralogy and Beneficiation of an Ag-bearing Copper Ore from Sichuan Province, China

Shi Guiming¹,², Zhou Yichao¹ and Li Tao¹,a

¹College of Chemistry Biology and Environment, Yuxi Normal University, Yuxi 653100, China
²School of Resources and Environmental Engineering, Jiangxi University of Science and Technology, Ganzhou 341000, China

a Corresponding author: litao1976@yxnu.edu.cn

Abstract. This paper studied the mineralogy and mineral processing of a copper mine bearing-silver in Sichuan province. The raw ore contained 0.77% of copper, 8.2 g/t of silver and other gangue mineral. The research contents included: mineral properties and process mineralogy, grinding fineness, type and dosage of collector, type and dosage of inhibitor, opening and closed circuit test, etc. In the grinding fineness 70% of -0.074 mm, the copper concentrate contained copper grade of 25.76% and copper recovery rate of 85.84%, silver grade of 258.21 g/t and silver recovery rate of 80.83% was obtained by two roughing, one scavenging and one cleaning closed-circuit processes. The agents were sodium silicate and sodium hexametaphosphate as inhibitors of gangue minerals, butyl xanthate as collector, 2# oil as frother in roughing I, butyl xanthate as collector, 2# oil as frother in roughing II, sodium sulphide as oxide copper sulfide agent, butyl xanthate as collector, and 2# oil as frother in scavenging I.

1. Preface
Copper is a very important metal resource, which is widely used in power transmission, mechanical metallurgy, energy industry and electronic industry [1-2]. A silver-bearing copper ore in Sichuan province is composed of copper sulphide and copper oxide with a small amount of silver. The gangue mineral is quartz, feldspar, calcite and other minerals. In order to make better comprehensive use of the ore, it is increasingly important to find a reasonable and feasible copper oxide treatment method and improve the recovery rate of silver [3-8].

2. Ore properties

2.1 Multiple analysis and phase analysis of raw ore
Multiple analysis of raw ore was shown in table 1 and phase analysis was shown in table 2.

| Elements | Cu | Pb | Zn | Sn | Co |
|----------|----|----|----|----|----|
| Content  | 0.77 | 0.01 | 0.1 | 0.003 | 0.009 |
| Elements | Ag* | Mo | Bi | As | CaO |
| Content  | 8.2 | 0.009 | 0.01 | 0.002 | 8.28 |
| Elements | Ni | Au* | Al₂O₃ | Ga* | In* |

Table 1. Multiple analysis results of raw ore (%)
It can be seen in table 1 and table 2 that the primary valuable metal element in the ore is copper, follows by silver (8.2 g/t), thirdly other metal elements have low grade and no use value, such as Pb, Zn, Sn and so on. The primary gangue mineral is quartz, follows by Ca, Al and Mg minerals. The total copper grade of the ore is 0.77%, of which copper sulfide accounts for 83.12% (including primary copper sulfide and secondary copper sulfide) and copper oxide accounts for 16.88% (among which the free copper oxide is 6.49% and the bonded copper oxide is 10.39%). The theoretical recovery rate of this ore was difficult to exceed 90% because the bonded copper oxide was difficult to be recovered in the flotation process, and this part of bonded copper oxide was an important factor affecting the recovery rate of this copper ore. Silver was comprehensively recovered that was mixed up with the copper concentrate.

### 2.2 Mineral composition

The results of mineral composition analysis were shown in table 3.

| Minerals | Chalcocite | Bornite | Chalcopyrite | Malachite | Zirconite | Hematite |
|----------|------------|---------|--------------|-----------|-----------|----------|
| Content  | 0.56       | 0.04    | 0.04         | 0.12      | 0.001     | 0.35     |
| Minerals | Greenmica  | Chlorete | Limonite     | Carbonate | Feldspar, Quartz | / |
| Content  | 0.2        | 2.41    | 6.66         | 18.92     | 68.62     | / |

It can be seen in table 3 that the main useful minerals in the ore are chalcocite, malachite, chalcopyrite, bornite, etc, the main gangue minerals are quartz, feldspar, calcite, dolomite, limonite, chlorite, etc.

### 3. Experiments

#### 3.1 Grinding fineness experiment

The aim of grinding was to facilitate the separation of useful minerals from gangue minerals. The grinding fineness had a great influence on the benefication, so it was necessary to determine the suitable grinding fineness. Under the grinding fineness of -0.074 mm respectively 65%, 70%, 75%, 80%, 85%, the exploratory experiment was carried out with 60 g/t butyl xanthate, 20 g/t 2# oil in the roughing I, 40 g/t butyl xanthate, 10 g/t 2# oil in the roughing II, the process was shown in figure 1, the results were shown in figure 2.
Figure 1. Flowchart of grinding fineness experiment.

Figure 2. Results of grinding fineness experiment.

Figure 2 shows that the grade and recovery of copper concentrate is increased with the increase of grinding fineness. When grinding fineness of -0.074mm accounts for more than 70%, the increase range of copper concentrate grade and recovery tends to be flat. Therefore, the grinding fineness was determined to 70% of -0.074 mm by considering the grinding cost and actual situation.

3.2 Collector type experiment
Considering that five collectors had been used in the field, included butylamine aerofloat, 25# aerofloat, ethyl thiamate, butyl xanthate, and isoamyl xanthate, individual contrast test and combined test of five collectors (the dosage ratio was 1:1:1:1:1) were carried out to investigate the performance of the collector. Under the grinding fineness -0.074 mm (70%), 60 g/t collector, 20 g/t 2# oil in the roughing I, 40 g/t collector, 10 g/t 2# oil in the roughing II, test process was shown in figure 1, the results were shown in figure 3.
It can be seen in figure 3 that the copper concentrate grade and recovery rate are both higher with butyl xanthate as collector, isoamyl xanthate collection ability is more powerful, but less selective compared with butyl xanthate, the collection ability of 25# aerofoam and butylamine aerofoam are worse than butyl xanthate and the flotation index is not good, ethyl thiamate is good selectivity and weak collection ability that lead to the low recovery rate because the copper with coarse particle size can not be effectively collected, the use of combined collector not only greatly increase the cost of the agent, but also the copper concentrate grade and recovery rate are poor. It can be seen from above that butyl xanthate was selected as collector.

3.3 Collector dosage experiment in roughing I
Test conditions: the grinding fineness of -0.074 mm (70%), variable butyl xanthate, 20 g/t 2# oil in the roughing I, 40 g/t butyl xanthate, 10 g/t 2# oil in the roughing II, test process was shown in figure 1, the results were shown in figure 4.

3.4 Inhibitor dosage experiment
According to the results of technological mineralogy, the primary gangue minerals in the ore were quartz, dolomite, calcite, etc. Sodium silicate and sodium hexametaphosphate were added successively as inhibitors, and the dosage test was carried out. Test conditions: the grinding fineness of -0.074 mm (70%), variables dosage of sodium silicate and sodium hexametaphosphate, 60 g/t butyl xanthate, 20
g/t 2# oil in roughing I, 40 g/t butyl xanthate, 10 g/t 2# oil in roughing II, test process was shown in figure 1, the test results were shown in figure 5 and figure 6.

![Figure 5. Results of sodium silicate dosage experiment.](image)

![Figure 6. Results of sodium hexametaphosphate dosage experiment.](image)

It can be seen from figure 5 and 6 when sodium silicate is added to 2000 g/t, the grade increases by 1.94 percentage points, and the grade increases by a small margin and the recovery rate of copper concentrate decreases with the increased of sodium silicate. Therefore, the amount of sodium silicate was set at 2000 g/t. As the sodium hexametaphosphate dosage increases, copper concentrate grade gradually increases. The copper concentrate grade increases little, but the recovery rate decreases by 1.21 percentage points when the sodium hexametaphosphate dosage exceeds 2000 g/t. Taken together, the sodium hexametaphosphate dosage was 2000 g/t. It can be seen from the test of sodium silicate and sodium hexametaphosphate that the recovery rate of concentrate was basically unchanged after adding sodium silicate and sodium hexametaphosphate, but the concentrate grade increased with the increased of inhibitor dosage. Inhibitor can or cannot add if concentrate grade achieved manufacturer's requirement standard.

3.5 Collector dosage experiment in roughing II
Test conditions: the grinding fineness of -0.074 mm (70%), 2000 g/t sodium silicate and 2000 g/t sodium hexametaphosphate, 60 g/t butyl xanthate, 20 g/t 2# oil in roughing I, variable butyl xanthate, 10 g/t 2# oil in roughing II, test process refer to figure 1, roughing II produced concentrate named copper concentrate 2 which not merged with roughing I produced concentrate, the test result were shown in figure 7.
It can be seen in figure 7 that with the increases of collector dosages, the copper recovery rate gradually increases. When the collector amount exceeds 40 g/t, the recovery rate of copper concentrate 2 changes unobvious and the grade decreases significantly as the collector dosage continues to increase. Therefore, collector dosage was determined to 40 g/t in the roughing II.

3.6 Open circuit experiment
The open circuit test process was added one cleaning and one scavenging in the process of figure 8, and the test results were shown in table 4.

Table 4. Results of open-circuit experiment (%).

| Items            | Yield | Grade | Recovery |
|------------------|-------|-------|----------|
| Copper concentrate | 2.40  | 26.38 | 81.64    |
| Copper middling 1 | 0.41  | 3.08  | 1.63     |
| Copper middling 2 | 1.60  | 2.42  | 4.99     |
| Copper middling 3 | 1.30  | 0.11  | 0.18     |
| Tailing          | 94.29 | 0.10  | 11.55    |
| Raw ore          | 100.00| 0.78  | 100.00   |

The results in table 4 shows that the better indexes is obtained by adopting the experimental process of two roughing, two scavenging and one cleaning, which the copper concentrate grade is 26.38%, the recovery rate is 81.64%, and the tailing contained 0.10% of copper. The grade of copper middling 3 obtained by the second scavenging is 0.11% and the recovery rate is 0.18%, indicated that the copper mineral had been basically recovered. Considering the production cost and economic benefits, the second scavenging is unnecessary. Finally, the technological process of tow roughing, one scavenging and one cleaning was determined.

3.7 Closed-circuit experiment
The closed-circuit test process was shown in figure 8, and the final test results of copper concentrate silver-bearing were shown in table 5.
Figure 8. Flowchart of close-circuit experiment.

Table 5. Results of close-circuit experiment (%).

| Items          | Yield | Grade | Recovery |
|----------------|-------|-------|----------|
|                |       | Cu    | Ag*      |
| Copper concentrate | 2.57  | 25.7  | 258.2  |
| Tailing        | 97.43 | 0.11  | 1.62    |
| Raw ore        | 100.0 | 0.77  | 8.21    |

It can be seen from table 5 that a good index of 25.76% copper grade, 85.74% copper recovery, 258.21 g/t silver content and 80.83% silver recovery were obtained by closed-circuit test.

4. Conclusions
(1) The copper grade of raw ore is 0.77% and the oxidation rate is 16.88%, among which the free copper oxide content is 6.49% and the combined copper oxide content is 10.39% that belongs to oxy-sulfur mixed copper ore contained 8.2 g/t silver. The copper sulfide is easy to be selected, and the copper oxide is relatively difficult to be selected especially the combined copper oxide, which is basically not available. The primary useful minerals in the ore are chalcocite, chalcoprytite, bornite and malachite, etc. Gangue minerals are mainly quartz, feldspar, calcite, dolomite, limonite, chlorite, etc.

(2) Under the grinding fineness -0.074 mm of 70%, copper concentrate contained copper grade of 25.76%, copper recovery rate of 85.84%, silver grade of 258.21 g/t, silver recovery rate of 80.83% were obtained by a closed-circuit processes of two roughing, one scavenging and one cleaning. The agents were sodium silicate and sodium hexametaphosphate as inhibitors of gangue minerals, butyl xanthate as collector, 2# oil as frother in roughing I, butyl xanthate as collector, 2# oil as frother in roughing II, sodium sulphide as oxide copper sulfide agent, butyl xanthate as collector, 2# oil as frother in scavenging I.
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