Beneficiation and leaching study of a muti-Au carrier and low grade refractory gold ore

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Abstract. Detailed mineralogy and beneficiation and leaching study of a muti-Au carrier, low grade refractory gold ore from a beneficiation plant in Henan Province, China, was investigated. Mineral liberation analysis, scanning electron microscopy, element phase analysis and etc. by a mineral liberation analyser were used for mineralogical characterization study of this ore. The present work describes an experimental study on the effect of traditional parameters (such as grinding fineness and reagent regimes), middling processing method and flowsheet construction on the total recovery and the assay of the flotation concentrate. Two-step flotation and part of middling combined to the flotation tailing for gold leaching process resulted in high gold grade (g.t⁻¹) and gold recovery (%) for this refractory gold ore. This process opens the possibilities of maximizing Au grade and recoveries in a muti-Au carrier and low grade refractory gold ore where low recoveries are common.

1. Introduction

Dependence on low-grade and refractory ores has increased globally and will continue to increase in the near future because of the rapid depletion of high-grade gold ores [1-3]. Besides the low grade, among these refractory gold ores, gold are contained in different gold-carriers, such as gangue, pyrite, native gold, fissure gold and etc. In addition to process and reagent development, an understanding of the mineralogy and associations of the minerals in the ore is critical for optimizing operations. The same conditions do not yield optimal valuable mineral recovery and concentrate grade because of differences in mineralogy [3].

Sulfur and micro-grained native gold ores represent a significant challenge, since they are not amenable to gold recovery by direct cyanidation whereas flotation is commonly adaptable for them. The gold contained in the form of very finely disseminated and encapsulated sulfide is inaccessible to the cyanide solution during direct cyanidation.

The flowsheet of one rough-five cleaners-three scavengers with mixed collectors of butyl xanthate and butyl dithiophosphate was used for a refractory gold ore from Shuanglong Gold Mine of Shanxin, which contained arsenic and carbon with fine dissemination of gold particles [4]. In micro-fine-grained gold ore containing arsenic and sulfur from the Hubei Province, it may be beneficial to involve measures of stage grinding-enhanced dispersion of slime-activated gold-carrier to acquire qualified Au concentrate [5].

The feed from a gold mine in Henan province in this study containd low grade gold which are in the form of pyrite-encapsulating gold, pyrite replaced by limonite-encapsulating gold, gangue-encapsulating gold, liberated native gold and fissure gold. Under an optical microscope, the gold size mostly distributes in the range of 1-10µm. The gangue in this feed is mostly quarz, feldspar, mica,
chlorite, dolomite and etc., and among the gangue, the argillaceous gangue such as dolomite, calcite, sericite, chlorite, clay and kaolinite, accounts for 31.5 % of the total minerals. Attention was paid to the floatation properties and the recovery method of the different gold-carrier minerals. In addition, the processing the large-scale of argillaceous gangue also should be considered.

2. Materials and methods

2.1. Samples
The low-grade refractory ore used in the experiments was obtained from Xiaonangou in Henan province. Approximately 350 Kg ore was homogenized and split into 1-kg representative sub-samples. During the ore preparation, a 100-g sub-sample was taken for head-grade chemical analysis (table1).

Table 1. Multi-element analysis of the head ore

|   | Au  | Ag  | Ca  | Mg  | Pb  | Zn  | Al₂O₃ | SiO₂ | As  | S   | Fe  | Cu  |
|---|-----|-----|-----|-----|-----|-----|-------|------|-----|-----|-----|-----|
|   | 1.55| 3.5 | 0.56| 0.84| 0.020| 0.062| 13.26 | 63.21| <0.005| 0.84 | 4.67 | 0.004 |

*aThe units of Au and Ag were g.t⁻¹, and the units for the others were wt %.

2.2. Reagents
The flotation tests were conducted with potassium butyl xanthate (PBX) and ammonium dibutyl dithiophosphate (ADD) as collectors, which were acquired from the Jiangxi Copper Corporation. These collectors were all industrial grades and were diluted in water to a concentration of 1%. The regulators containing copper sulfate, sodium silicate, sodium sulphide and sodium carbonate (purchased from Sinopharm Chemical Reagent Beijing Co., Ltd.) were analytical grade. Pine oil (acquired from Jiangxi Copper Corporation), with a monohydric alcohol content of more than 40%, was used in the whole flowsheet as a frother. For leaching tests, the reagents used were NaCN and CaO.

2.3. Methods

2.3.1. Mineralogical study. A mineral liberation analyzer was used to characterize the feed. Mineral liberation analysis (MLA) was performed on different size fractions to examine the mineralogy and mineral liberation.

2.3.2. Flotation and leaching. Samples (1 kg, crushed to –2 mm) was ground in a closed stainless steel Ø240X90 mm XMQ ball mill (Jilin Exploring Machinery Plant, Jilin, China) at a pulp density of 66% by weight. Flotation tests were carried out using an XFD series single flotation cell (Jilin Exploring Machinery Plant, Jilin, China) with volumes of 3 L and 1 L for rougher/scavenger flotation and cleaner flotation of sulfide minerals, respectively. Floatation tests were conducted at a solid content of 30%. Before rougher and scavenger flotation, the chemical reagents were added to the cell and conditioned for several minutes. Leaching tests were carried out using an mechanical agitator () with volumes of 250 ml. Leaching tests were conducted at a solid content of 33.33%. Before the addition of leaching reagents, the CaO should be added to the cell and conditioned for about 2 hours which kept the pH of the pulp was above 12. All the products were thermally dried, weighed, and chemically analyzed. Each test was repeated twice and mean grade and recovery of the products are reported. The errors for the grade and recovery are in the range of ±0.3% and ±3%, respectively.

3. Results and discussion

3.1. Feed mineralogy
The mineralogy study was conducted using feed at 85w% passing 0.075mm (P₈₅=0.075mm).
3.1.1. Mineral composition and size distribution. The mineral composition and size distribution are shown in Table 2 and 3.

Table 2. Distribution of major feed minerals from MLA.

| Minerals        | Mass fraction/% | Minerals                        | Mass fraction/% |
|-----------------|-----------------|---------------------------------|-----------------|
| Gold            | trace           | Chalcopyrite                    | 0.01            |
| Pyrite          | 1.70            | Feldspar (and its altered mineral) | 42.50           |
| Limonite        | 0.75            | Chlorite                        | 6.0             |
| Magnetite       | 0.10            | Calcite and dolomite            | 4.0             |
| Haematite       | 0.05            | Spathic iron                    | 3.5             |
| Iliomite        | 0.01            | Sericite                        | 12.0            |
| Kaolinite       | 4.5             | Clay                            | 5.0             |
| Others          | 1.25            | Total                           | 100.00          |

Table 3. Gold distributions in the ore sample.

| Size/mm       | Mass fraction/% | Gold assay/g.t$^1$ | Distribution/% |
|---------------|-----------------|--------------------|----------------|
| +0.074        | 15.02           | 1.38               | 13.40          |
| -0.074 ~ +0.045 | 20.28          | 1.21               | 15.87          |
| -0.045 ~ +0.038 | 17.85          | 1.57               | 18.12          |
| -0.038 ~ +0.019 | 3.65           | 0.98               | 2.31           |
| -0.019        | 43.20           | 1.80               | 50.29          |
| total         | 100.00          | 1.55               | 100.00         |

3.1.2. Mineral dissemination characteristics and associations. Microscopy and MLA analysis were conducted on the Head ore. The MLA results show that gold minerals were present as liberated kustelite, electrum and native gold. For the grain distribution of the gold and the gold association distribution, see table 4 and 5.

Table 4. The grain distribution of the gold.

| Grain size/ mm | -0.001 -0.002 | +0.002 -0.003 | +0.003 -0.008 | +0.008 -0.016 | +0.016 |
|----------------|---------------|---------------|---------------|---------------|--------|
| Distribution/% | 14.81         | 37.04         | 22.22         | 18.52         | 7.41   |
| Cumulative mass distribution/% | 14.81 | 51.85 | 74.07 | 92.59 | 100.00 |

Table 5. The gold association distribution.

| Phase                          | Liberated gold, fissure gold and intergrown gold | Gold in carbonate | Gold in metal oxides | Gold in pyrite | Gold in pyrite replaced by limonite | Gold in silicate | Total |
|--------------------------------|-------------------------------------------------|-------------------|---------------------|---------------|-----------------------------------|-----------------|-------|
| Content/g.t$^1$                | 1.020                                           | 0.110             | 0.040               | 0.162         | 0.163                             | 0.055           | 1.55  |
| Distribution/%                 | 65.81                                           | 7.10              | 2.58                | 10.45         | 10.52                             | 3.55            | 100.00|

3.2. Strategies to recover gold
Several different tests were conducted to examine strategies to recover gold from the ore. For the results, see table 6. The result of table 6 shows that the Two-step floatation-tailing leaching can obtain the high quality gold concentrate and the high total recovery.

Table 6. The results of different gold recovering strategies.

| Strategies                                      | Gold concentrate assay (g/t) | Leaching rate (%) | Total recovery (%) |
|------------------------------------------------|----------------------------|------------------|-------------------|
| All slime cyanide leaching process             | /                          | 65.81            | 65.81             |
| Combination process of gravity-floatation      | 26.71                      | 68.38            | 68.38             |
| Combination process of gravity-leaching        | 40.12                      | 62.25            | 62.47             |
| Floatation process                            | 28.82                      | 62.47            | 62.47             |
| One step floatation-tailing leaching           | 46.22                      | 44.47            | 77.13             |
| Two-step floatation-tailing leaching           | 44.52                      | 18.93            | 83.59             |

3.3. The comparison of one-step and two-step floatation

The flowsheets of one-step and two-step floatation were shown in figure 1 and 2, and the results were shown in table 7. The results show that two-step floatation process has obvious advantages.

Figure 1. One-step floatation flowsheet.

Figure 2. Two-step floatation flowsheet.

Table 7. The comparison results of one-step and two-step floatation.

| Process                  | Products      | yield (%) | Au assay (g/t) | floatation recovery (%) |
|--------------------------|---------------|-----------|----------------|-------------------------|
| One-step floatation      | Gold concentrate | 2.55     | 32.89          | 54.11                   |
|                          | tailing       | 97.45    | 0.73           | 45.89                   |
|                          | Head ore      | 100.00   | 1.55           | 100.00                  |
| One-step floatation (1+2)| Gold concentrate | 2.25     | 44.52          | 64.66                   |
|                          | tailing       | 97.75    | 0.56           | 35.34                   |
|                          | Head ore      | 100.00   | 1.55           | 100.00                  |

3.4. The open-circuit and closed-circuit floatation test
After detailed conditional experimental tests, the open-circuit and closed-circuit flowsheet and results were shown in Figure 3, 4 and table 8. The results in table 8 shows that the gold assay in final Au concentrate of the closed-circuit decrease sharply but the recovery were merely the same with the open-circuit gold concentrate. From the mineralogy results of the middling 2 and 3, it shows that there’s limited liberated pyrite and there’re substantive argillaceous gangue such as dolomite, calcite, sericite, chlorite, clay and kaolinite in middling 2 and 3, which has the homogeneity with the head ore mineralogy study results.

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### Figure 3. The open-circuit flowsheet.

| Flowsheet       | Products                  | yield (%) | Au assay (g/t) | Au flotation recovery (%) |
|-----------------|---------------------------|-----------|----------------|----------------------------|
| The closed-circuit | Gold concentrate 1       | 0.73      | 59.23          | 27.81                      |
|                 | Gold concentrate 2       | 2.53      | 25.63          | 41.70                      |
|                 | Gold concentrate 1+2     | 3.26      | 33.15          | 69.51                      |
|                 | (Final gold concentrate) |           |                |                            |
|                 | Tailing                  | 96.74     | 0.49           | 30.49                      |
|                 | Head ore                 | 100.00    | 1.56           | 100.00                     |
|                 | Gold concentrate 1       | 0.73      | 59.23          | 28.04                      |
| The open-circuit | Gold concentrate 2       | 1.59      | 38.66          | 39.87                      |
|                 | Gold concentrate 1+2     | 2.32      | 45.13          | 67.91                      |

Since easy-to-float gangue and clay minerals such as mica, calcite and etc. can be enriched in the rough concentrate during the flotation process of gold-carrier minerals, this certainly will affect the quality of the gold concentrate products if all the middlings were returned. In the experiment, the middling of the first cleaning and the second cleaning were gathered together to return to the tailing for gold leaching.

### 3.5. The whole process route test
According to the tests above, two-step floatation-part of the middling discarded to the floatation tailing-tailing leaching flowsheet was recommended to process this ore. For the processing route and results, see figure 5.

![Floatation-leaching recovery](image)

Figure 5. The whole process route test.

4. Conclusions
The feed in this study containd low grade gold which are in the form of pyrite-encapsulating gold, pyrite replaced by limonite-encapsulating gold, gangue-encapsulating gold, liberated native gold and fissure gold. Under an optical microscope, the gold size mostly distributes in the range of 1-10μm. The gangue in this feed is mostly quartz, feldspar, mica, chlorite, dolomite and etc., and among the gangue, the argillaceous gangue such as dolomite, calcite, sericite, chlorite, clay and kaolinite, accounts for 31.5 % of the total minerals.

Two-step floatation-part of the middling discarded to the floatation tailing-tailing leaching flowsheet was recommended to process this ore. The first step: rapid floatation, the object minerals were the liberated gold and the pyrite-carried gold; the second step: reinforcement floatation, the object minerals were rich intergrown gold, the gold in pyrite replaced by limonite; the third step: leaching, fissure gold and the poor intergrown gold.

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