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Beneficiation of the gold bearing ore by gravity and flotation

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Abstract: Gold concentration usually consists of gravity separation, flotation, cyanidation, or the combination of these processes. The choice among these processes depends on the mineralogical characterization and gold content of the ore. Recently, the recovery of gold using gravity methods has gained attention because of low cost and environmentally friendly operations. In this study, gold pre-concentrates were produced by the stepwise gravity separation and flotation techniques. The Knelson concentrator and conventional flotation were employed for the recovery of gold. Gold bearing ore samples were taken from Gümüşhane Region, northern east part of Turkey. As a result of stepwise Knelson concentration experiments, a gold concentrate assaying around 620 g/t is produced with 41.4wt% recovery. On the other hand, a gold concentrate about 82 g/t is obtained with 89.9wt% recovery from a gold ore assaying 6 g/t Au by direct flotation.

Keywords: gold ore treatment; beneficiation; gold; gravity separation; flotation

1. Introduction

Gold bearing ores can be classified as placers, free milling, oxidized, silver-rich, iron sulphides, arsenic sulphides, copper sulphides, antimony sulphides, tellurides, and carbonaceous ores depending on their mineralogical characteristics.

Gold concentration usually consists of gravity separation, flotation, cyanidation, or the combination of these processes. The choice among these processes depends on the mineralogical characterization and gold content of the ore. Thanks to the development of new gravitational techniques for the processing of precious metals such as gold, silver, and platinum-group metals (PGMs), the concentration efficiencies for gold recovery based on density differences have significantly increased over the last twenty five years. They include the Knelson, Falcon, and Knudsen gravity concentrators and the Mozley gravity separators. While the Mozley gravity separator has been used for the recovery of gold since the 1980s, the Knelson and Falcon concentrators have only been developed and used for recovering the precious metals since the 1990's, which are primarily used in the gold industry as gravity concentration devices because of their ability to recover the coarse and fine gold from both the alluvial and primary deposits [1]. Coetzee *et al.* [2] studied a comparison of Falcon and Knelson concentrators with heavy liquid separation (HLS). The results of gravity tests performed with Falcon and Knelson concentrators were compared well with the HLS results. Gold recoveries by gravity were a slightly better than those of HLS. The total gold recovery by gravity concentration varied between 17wt% and 44wt% [2].

A lot of researchers and companies have carried out a number of studies on the different kinds of ores using the gravity separators. Meza *et al.* [3] studied the alluvial gold containing sands from Bajo Cauca and El Bagre, Colombia, with the Knelson concentrator. They recovered over 98wt% of gold at the end of three stage tests. In the Golden Giant Mine in Canada, carbon in pulp (CIP) tailings were treated in a Knelson concentrator. Au concentrates grading 3wt%-8wt% were produced from CIP tailings grading 0.4-0.5 g/t Au. The concentrate from the Knelson was further treated on a Gemini shaking table to produce a final concentrate assaying 75wt%-80wt% Au [4]. The Knelson concentrator is used by the Bimak Company in Bulgaria, where a gold concentrate grading assaying 4wt%-6wt% Au

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is produced from run-of-mine ore containing 3.45 g/t Au. A test was also developed for the gravity recoverable gold by Laplante, which involved a three-stage sequential liberation and recovery of gold with a Knelson concentrator. At the final stage, about 80% of ore was ground to passing 75 μm, and as much as 97% gold was recovered [1]. Wotruba and Müller [5] used a Falcon concentrator to treat the tailings of Nicaraguan gold ore with particle sizes below 20 μm and assaying 31.2 g/t Au. As a result of Falcon concentration, a gold concentrate containing 509.5 g/t Au was produced with 59.4wt% recovery.

A test program was conducted by Klein *et al.* [6] to study a hybrid flotation-gravity concentration process where a Knelson concentrator was used to scavenge the coarse gold bearing sulphide particles as middlings. In the process, the Knelson concentrate was recycled in the grinding circuit to reduce the particle size and improve the liberation prior to flotation. Batch and pilot scale experiments as well as the plant trials indicated that the Knelson unit was effective in recovering gold from flotation tailings. Plant trials proved that Knelson scavenging and flotation of the reground Knelson concentrate provided a significant upgrading and additional Au recovery. At the final stage, a flotation concentrate assaying 60 g/t of gold could be produced with 92wt% recovery.

Flotation has been applied on the native and free gold particles for many years. The floatability of gold particles depends on the modifiers and collectors. Some researchers have investigated the effects of modifiers and collectors on the gold recovery from the different types of ores. When the native gold has the natural floatability, collectorless flotation can be applied using only frothers. Heyes and Trahar [7] studied the collectorless flotation of gold from chalcopyrite. They reported that the pH values and oxidation-reduction potential should be carefully controlled for the success of separation process. Aksoy and Yarar [8] found that the ferric ions in the form of hydrated oxides and humic acid acted as physical barriers between air bubbles and gold surfaces during flotation. Another selective gold separation study was performed by Yan and Hariyasa [9]. They investigated the different types of collectors on the separation of gold tellurides from pyrites, and found that the tellurides floated easily at natural pH values. The addition of xanthate and mercaptobenzothiazole improved the flotation recovery and gold content. Xanthate and dithiophosphate can attach to gold surfaces similarly by chemisorption during flotation; therefore, these kinds of reagents can be used either individually or in conjunction. Two months of industrial trials at Liumei Plant (Guangxi, China) showed that 90.8wt% recovery could be achieved with a grade of 81.1 g/t Au from a feed assaying 2.9 g/t Au at pH 8-8.5, where tertiary dodecyl mercaptan and sodium butyl xanthate were used as collectors [10]. Yalcin and Kelebek [11] studied an auriferous ore originating from the Barry Region in Northwestern Quebec, Canada. Soda ash was used in the grinding circuit as the pH regulator with a single dosage. The collector employed in flotation tests was a mixture of potassium amyl xanthate and sodium isopropyl xanthate. At the end of flotation studies, the gold recoveries were found to increase from 91.8wt% to 95.8wt% as the particles size decreased from 205 μm to 53 μm.

Flotation provides a number of process alternatives for gold ores, containing the readily floatable minerals as following: the flotation of free gold and gold bearing sulphides to produce a gold-rich concentrate followed by cyanidation, regrinding and cyanidation, intensive cyanidation, oxidative pretreatment and cyanidation, or direct smelting; the flotation of free gold sulphides to produce a sulphide-free tail for cyanidation; the flotation of carbonaceous material, carbonates, or other material that may interfere with processing; the differential flotation, *e.g.* separation of gold, gold bearing pyrite and arsenopyrite.

Free metallic gold can be recovered very effectively by flotation, although it is more commonly recovered together with sulphide minerals, where gold is intimately associated with sulphides as fine unliberated grains (solid solutions or inclusions), or with barren and hydrophobic sulphides. The most commonly known gold bearing sulphides are the pyrite, arsenopyrite, and pyrrhotite, to a lesser extent [12].

As oxides and silicates are the major gangue minerals associated, a strong collector should be used to maximize the gold recovery with little concern of sulphides for the co-recovery. This type of flotation is rare but has been proposed for low grade ores where gold is too fine to be recovered by gravity concentration. Thus, the conditions can be adjusted solely for gold recovery, regardless of selectivity with respect to the sulphide mineral.

The objective of this study was to obtain a pre-concentrate of gold minerals in Mastra by flotation and multi-stage gravity separation methods.

2. Materials and methods

The gold bearing ore used in this study is taken from Mastra, located in the Gümüşhane region, Northeast of

Turkey. The ore body contains 8 g/t Au on average [13]. It was observed that quartz was the major gangue mineral in the ore sample. Pyrite, chalcopyrite, sphalerite, and galena as sulphide minerals were also observed. Gold was identified in its native form as well as associated with quartz and sulphides as inclusions, growing within grain boundaries [13]. A mineralogical cross section for the Mastra ore sample is shown in Fig. 1, the association of gold with sphalerite and galena is seen. The representative ore sample subjected to experimental studies was assayed about 6 g/t Au.

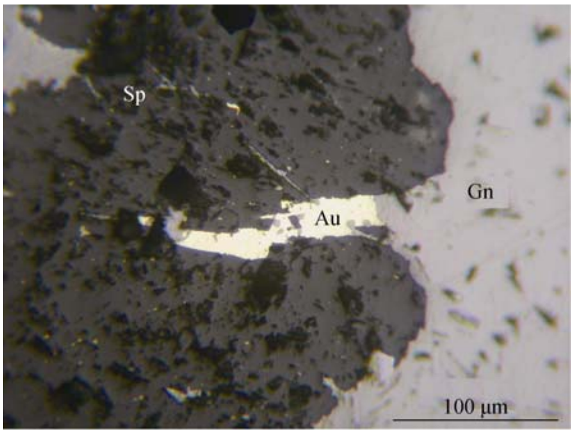

Fig. 1. Gold particles (Au) associated with sphalerite (Sp) and galena (Gn) in the Mastra ore [13].

In a previous study, it was reported that 85% of gold particles were liberated under 50 μm [13]. Hence, the Mastra ore sample was ground under 100 μm prior to Knelson and flotation experiments.

The Knelson gravity concentrator is an advanced gravity recovery system. It is often used as a reliable and accurate method to reduce the volume of heavy mineral samples into small enriched concentrates quickly [3-4]. For experimental studies, a laboratory type KC-MD3-G4 Knelson gravity concentrator with a maximum feed capacity of 45 kg/h was used. Flotation studies were performed with a Denver-type flotation cell having a 1300-r/min agitation rate. In the flotation tests, Aerophine 3418-A and Aero 208 were used as collectors, H_2SO_4 as a pH regulator, Na_2SiO_3 as a depressant, and methyl isobutyl carbinol (MIBC) as a frother.

3. Results and discussion

Knelson gravity concentration experiments were performed for 100-μm particle size. The solid was fed into the concentrator at 20 kg/h, and the water pressure was kept at 3 MPa. All heavy particles were accumulated in the inner cone of the concentrator as concentrates, while lighter particles overflowed from the tailings outlet. The experimental results are shown in Table 1.

Table 1. Results of Knelson experiments performed for 100-μm particle size

Products	Content / wt%	Au		Ag	
		Content / $(g\cdot t^{-1})$	Recovery / wt%	Content / $(g\cdot t^{-1})$	Recovery / wt%
Concentrate	0.4	618.3	41.4	150	12.7
Middlings-1	1.1	30.5	5.6	13	3.0
Middlings-2	4.3	4.6	3.4	3	2.8
Tailings	94.2	3.1	49.6	4	81.5
Total	100.0	5.83	100.0	4.62	100.0

As seen from Table 1, a concentrate assaying 618.30 g/t Au and 150 g/t Ag is obtained with 41.4wt% and 12.7wt% recoveries, respectively. Since a great deal of gold is associated with quartz, the tailings contain considerable amounts of gold. Therefore, the tailings of the experiment was ground below 38 μm and then treated by the Knelson and flotation experiments separately. In the flotation tests, a 25% solids ratio by weight was adopted. The flotation conditions were as following: Aerophine 3418A+Aero 208, 50+50 g/t; MIBC, 40 g/t; Na_2SiO_3, 1000 g/t; pH 5.0.

The second stage of Knelson experiment results are shown in Table 2 and the flotation results are given in Table 3. In the case of the second stage Knelson tests, the tailings assayed as low as 2.6 g/t Au and 4 g/t Ag. However, when flotation was applied, Au and Ag contents in the tailings were 0.5 and 2.4 g/t, respectively. It is clear that the flotation of tailings provided better results compared to two stages of Knelson concentration.

In the second group of tests, the ore was concentrated by flotation only, where the rougher concentrate was cleaned twice. The flotation test conditions are given as: Aerophine 3418A+Aero 208 dosage, 50+50 g/t; MIBC, 50 g/t; Na_2SiO_3, 1000 g/t; pH 5.0. The results are presented in Table 4. As seen from Table 4, a gold concentrate assaying about 82 g/t Au is obtained by direct flotation with a recovery value of 89.9wt% from a gold ore containing 5.02 g/t Au.

Table 2. Results of the second stage Knelson experiments

Products	Content / wt%	Au		Ag	
		Content / $(g \cdot t^{-1})$	Recovery / wt%	Content / $(g \cdot t^{-1})$	Recovery / wt%
Concentrate	0.1	184.6	7.0	47.7	1.4
Middlings-1	1.4	7.1	3.2	2.6	0.9
Middlings-2	0.9	13.3	3.8	5.3	1.1
Middlings-3	1.7	9.3	5.1	2.6	1.1
Tailings	95.9	2.6	80.9	4.0	95.5
Total	100.0	3.1	100.0	4.0	100.0

Table 3. Results of flotation tests performed on the tailings of the Knelson concentrator

Products	Content / wt%	Au		Ag	
		Content / $(g \cdot t^{-1})$	Recovery / wt%	Content / $(g \cdot t^{-1})$	Recovery / wt%
Concentrate	3.7	65.6	78.1	36.7	34.0
Middlings	6.0	3.1	6.0	7.3	11.1
Tailings	90.3	0.5	15.9	2.4	54.9
Total	100.0	3.1	100.0	3.9	100.0

Table 4. Results of flotation tests performed with the original ore sample

Products	Content / wt%	Au		Ag	
		Content / $(g \cdot t^{-1})$	Recovery / wt%	Content / $(g \cdot t^{-1})$	Recovery / wt%
Concentrate	5.5	82.06	89.9	38	51.2
Middlings-1	0.3	4.85	0.3	9	0.7
Middlings-2	8.0	1.21	1.9	3	5.9
Tailings	86.2	0.46	7.9	2	42.2
Total	100.0	5.02	100.0	4.08	100.0

Mineralogical studies show that the gold is associated with sulphide and some extend to quartz. Compared to the associated sulphide and silicate minerals, the specific gravity of gold (19.3 g/cm^3) is markedly high. A small amount of gold contained in a particle may change the specific gravity, so those particles can show up in the concentrate as a heavy fraction in the Knelson concentrator. However, the efficiency of separation depends on the differences of particle specific gravity as well as the particle size. The efficiency of separation gets the worse independent of specific gravity at the small particle sizes. Therefore, the concentrate with high gold content can be obtained using a Knelson concentrator, yet provide a low recovery. Furthermore, compared to sulphide minerals, quartz particles containing a little amount of gold may show up in the tailings owing to the low specific gravity of quartz.

On the other hand, flotation is a physicochemical process, therefore, and all sulphide minerals as well as the free gold can be collected into the froth phase as concentrates using a specific collector. However, since all sulphide minerals are collected, particles without gold can also be present in the concentrate phase; therefore, a comparatively higher recovery may be obtained with low grades by flotation. Some losses in flotation can be attributed to quartz particles containing the locked gold that show up in the tailings.

4. Conclusions

The experiments show that the employing flotation and gravity concentration yield the concentrates with high gold content efficiently. The processes of flotation only or the combination of Knelson concentration and flotation show the highly satisfied results. Particularly in the case of flotation, the clean tailings can be discarded from the ore sample. Compared to the combined processes of Knelson concentration and flotation, relatively high gold recovery values are obtained by directly floating the ore sample.

The flotation process requires the smaller amounts of collector addition into the slurry to enhance the gold recovery, making the method more economically more viable. The results of this investigation seem to be encouraging in obtaining high grade gold concentrates efficiently.

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