CONCENTRATION OF AN OXIDIZED GOLD ORE BY THE KNELSON CONCENTRATOR

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A B S T R A C T

In this work, the concentration of an oxidized gold ore was investigated using a Knelson concentrator. The effects of Knelson concentrator parameters such as centrifugal force, feed rate, wash water, and solid content on the separation performance were investigated by a set of tests. As a result of test studies, feed rate and wash water were determined to be the most effective parameters for Au recovery and grade. By prioritizing Au grade, optimal parameters were found to be 60 g, 250 rpm, 3 l/min, and 40% for GF, WW, FR, and SR, respectively. A concentrate having a 44.4 g/t Au grade and 70.8% Au recovery was obtained under the optimal conditions. In addition, bottle roll tests were conducted on fresh ore and KC tailings obtained under determined conditions. As a result of bottle roll tests, it was found that gravity concentration prior to leaching lowered both retention time and cyanide consumption from 48 hours to 10 hours and 0.76 kg/mt to 0.50 kg/mt, respectively.

***Key words**: Oxidized gold ore, Knelson Concentrator, cyanide leaching*

1. INTRODUCTION

Gold has been one of the most popular metals throughout human history due to its nobleness, brightness, and workability (Adams, 2016). It also has unique physical and chemical properties, such as thermal and electrical conductivity, corrosion, and wear resistance. Therefore, besides its financial value, gold has become an essential raw material in today's world of advancing technology (Craig and Rimstidt, 1998).

Selection of the proper processing method for gold ores is strongly dependent on ore mineralogy (Klimpel, 1999). Gold mainly occurs as native gold with a wide variety of minerals, while it can be found as alloys of many other metals such as silver, copper, bismuth, antimony, etc. (Allan and Woodcock, 2001). Cyanide leaching is the most common method of beneficiation of gold ores with suitable mineralogy (Marsden and House, 2006). In addition to cyanide leaching, gravity separation and flotation methods can also be applied directly or as a complement to each other (Allan and Woodcock, 2001). The specific gravity of gold is significantly higher than gangue minerals (Chryssoulis and McMullen, 2016). Gravity separation is especially suitable for high-grade gold ores containing free gold, such as placers.

The beneficiation of gold by gravity methods is traditionally carried out by spirals, tables, jigs, and chutes, which have limited operation fineness (Kökkılıç, 2011). As it is known, centrifugal force enhances the relative settling velocity of the particles and improves separation (Greenwood et al., 2013). Following the development of centrifugal gravity devices, such as the Knelson concentrator (KC), the beneficiation of fine gold particles by gravity separation and tailings has improved significantly (Marion et al., 2019). There are several studies in the literature on the beneficiation of gold ores by using KC (Huang, 1996; Klein et al., 2010; Koppalkar et al., 2011; Gul et al., 2012; Altun et al., 2015; Marion et al., 2019).

The first introduction of the KC was in 1978 by Byron Knelson as a semi-batch device, initially developed for gold beneficiation (Chen, Yang, Tong, Niu, et al., 2020). A continuous version was later introduced after successive improvements (Marion et al., 2019). In the device, high-speed rotation of the vertically oriented conical bowl concentrates minerals in a fluidized bed by the use of centrifugal force (Figure 11). Concentration performance of the KC depends on a number of operational parameters, such as centrifugal force (bowl speed), feed rate, and water flow rate (Chen, Yang, Tong, Liu, et al., 2020).

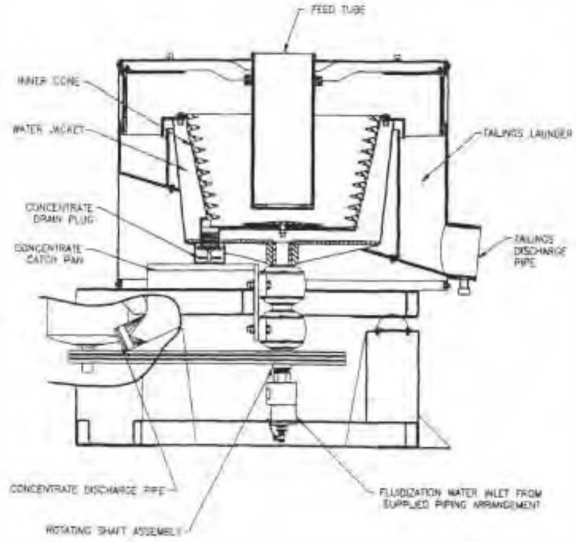


Figure 1. Schematics of the Knelson concentrator (Knelson and Jones, 1994)

In this study, the concentration of an oxidized gold ore was investigated using a KC. The effects of KC parameters, namely centrifugal force, feed rate, wash water, and percent solid, on the separation performance were investigated by a set of tests. In addition, bottle roll tests (BRT) were conducted on fresh ore and KC tailings obtained under optimized conditions. Results are evaluated comparatively based upon the overall Au recoveries.

2. MATERIALS AND METHOD

2.1. Material

A bulk sample of oxidized gold ore was utilized. The ore was crushed below 8 mm and 3 mm by using jaw and roll crushers, respectively. Crushed ore was then split into 500 g pieces as representative samples and stored in the freezer till being used. Samples were dry ground to a P_{80} size of 77.8 µm prior to test work by using a laboratory-sized rod mill with a diameter of 305 mm and 360 mm in length. Stainless steel rods were used as grinding media, weighing 27360 g. The particle size distribution of the sample was determined by Malvern Mastersizer Hydro 2000-MU and is represented in Figure2.

The head sample and test work products were analyzed by the Perkin Elmer AAS Instrument for Au and Ag. The Agilent ICP-OES was utilized for other metals, and S was analyzed by the Leco Carbon & Sulfur Analyzer. Head assays of the sample and size by size Au grades were summarized in Table 1 and Table2, respectively.

Table 1. Head assays of the sample

Au (g/t)	Ag (g/t)	Cu (g/t)	Pb (g/t)	Zn (g/t)	Fe (%)	S (%)
4.57	1.38	29.96	79.23	13.8	1.21	0.22

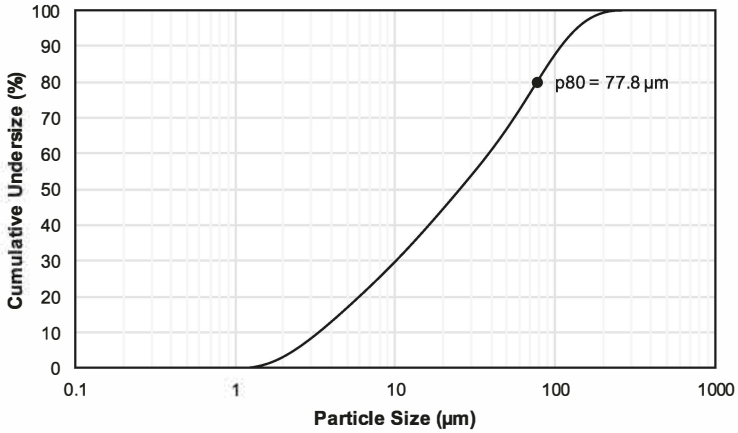


Figure 2. Particle size distribution of the sample

Table 2. Size by size Au grades

Sieve Size (µm)	Weight (%)	Au (g/t)
+106	4.43	1.68
-106+75	14.03	1.69
-75+53	8.62	2.60
-53+38	4.86	5.11
-38	68.07	5.32

In Figure3, XRD analysis of the sample was shown. According to the mineralogical analysis, the ore mineralogy is dominated by quartz and mica, with moderate amounts of carbonates and feldspar. Magnesium silicates and clay were also present, with minor amounts of sulfides. EDX analysis of a panned sample revealed that pyrite is the most abundant sulfide mineral, with trace amounts of chalcopyrite and galena (Figure 4). Gold is primarily in the form of free native gold. Therefore, the ore can be described as an oxidized gold ore with a low sulfide content.

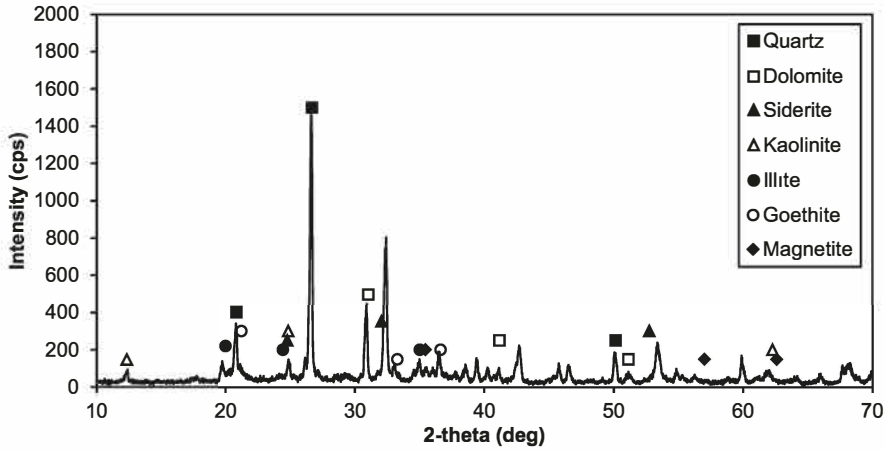


Figure 3. XRD pattern of the sample

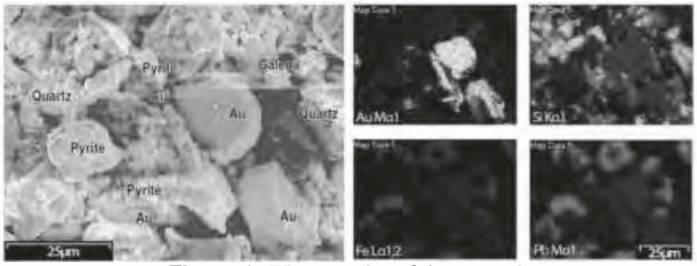


Figure 4. EDX results of the sample

2.2. Method

Gravity separation tests were carried out by the Knelson MD-3 laboratory-type concentrator. Each batch test is performed using 850 grams of sample. Continuously stirred ore slurry was fed into KC by using a peristaltic pump. In the test work, operational parameters of KC, namely G-force (GF), wash water (WW), feed rate (FR), and solid ratio (SR), were optimized using the one factor at a time method. The studied levels of the parameters are summarized in Table 3.

Table 3. Studied parameters and their corresponding levels

Parameters	**Levels**
G-force (g)	60, 80, 100
Wash water (l/min)	1, 2, 3
Feed rate (g/min)	150, 250, 350 (300, 475, 650)
Solid ratio (%)	20, 40, 60

Bottle roll tests (BRT) were carried out in order to determine leach recoverable gold content of the ore before and after gravity concentration. Tests were conducted at 45% solids with a 500 g sample, using 500 ppm sodium cyanide for 48 hours while pulp pH was adjusted to 10.5-11.0 using lime. During the leaching process, samples were taken from the solution at 2, 4, 8, 24, and 32 hours, and gold recoveries were determined for the corresponding times.

3. RESULTS AND DISCUSSION

The effect of GF on Au recovery and grade is given in Figure 5. As can be seen with increasing GF values, recovery slightly increases while grade decreases. The highest Au recovery obtained was 76.9% at 100 g, while it was 73.3% at 60 g. The GF value of 60 g was selected due to the fact that the highest grade value of 41.9 g/t was obtained at this value, compared to 33.9 g/t at 100 g.

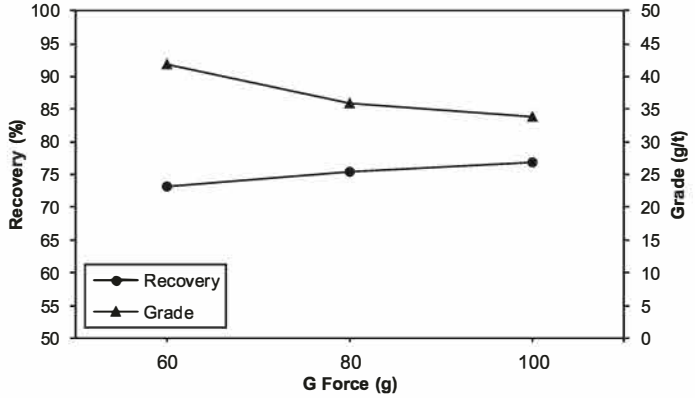


Figure 5. The effect of GF on Au recovery and grade (FR: 250 rpm, WW: 2 l/min, SR: 20%)

The effect of WW on Au recovery and grade is shown in Figure6. Increasing WW resulted in decreasing Au recoveries from 73.3% to 69.3%. The highest grade value of 44.2 g/t was obtained at 3 l/min. Therefore, a WW rate of 3 l/min was selected as the optimal point.

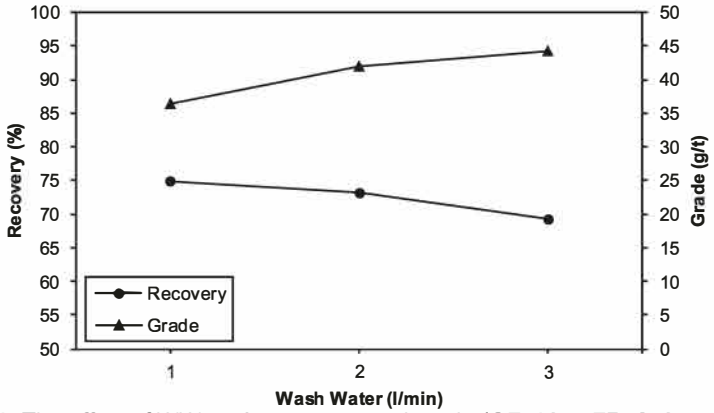


Figure 6. The effect of WW on Au recovery and grade (GF: 60 g, FR: 250 rpm, SR: 20%)

The effect of FR on Au recovery and grade is shown in Figure7. Increasing FR led to decreasing recoveries. The highest recovery value of 71.8% was obtained at 150 rpm, while the lowest was 58.4% at 350 rpm. Since the difference in recovery from 150 rpm to 250 rpm is marginal, but the grade obtained at 250 rpm (44.2 g/t) was higher compared to 150 rpm (40.8 g/t), 250 rpm was chosen as the most suitable condition.

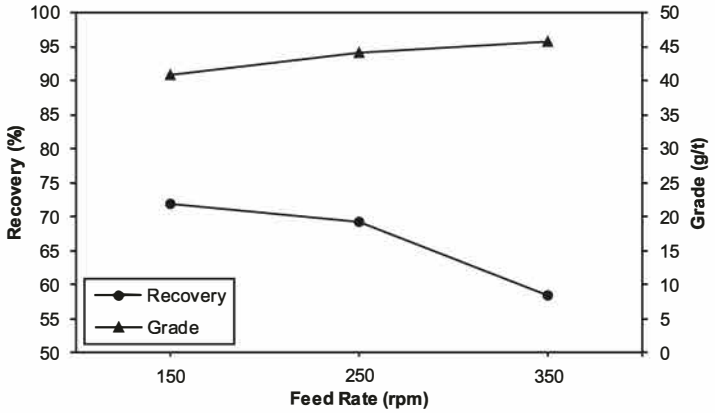


Figure 7. The effect of FR on Au recovery and grade (GF: 60 g, WW: 3 l/min, SR: 20%)

The effect of SR on Au recovery and grade is shown in Figure8. As seen, increasing SR did not significantly affect both Au recoveries and grades. Slightly higher recovery (70.8%) and grade (44.4 g/t) were obtained at 40% SR compared to other levels. Therefore, this level was chosen as the optimal condition.

FR and WW were found to be the most important parameters in terms of Au recovery and grade. As a result of KC tests performed, the optimal conditions were determined as 60 g, 250 rpm, 3 l/min, and 40% for GF, WW, FR, and SR, respectively. Under these conditions, a concentrate having a 44.4 g/t Au grade was obtained with a recovery of 70.8%. The remaining tailings were subjected to a BRT. Overall Au recoveries in terms of direct leach and KC +

leaching are given in Figure9 comparatively. As can be seen, overall Au recoveries were similar at 48 hours. However, KC + Leach reached a maximum Au recovery at about 10 hours, while with direct leach at about 48 hours. This indicates that obtaining gravity-recoverable gold prior to leaching significantly shortened the leaching time. Cyanide consumption was 0.76 kg/mt ore in the case of direct leaching, while it was 0.50 kg/mt ore in the case of KC + Leach.

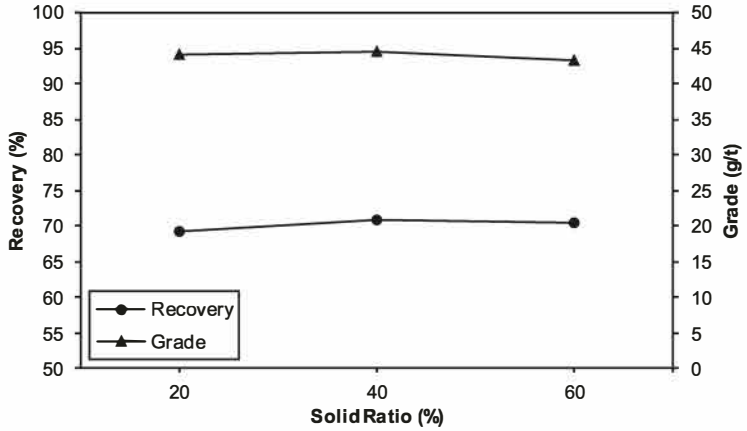


Figure 8. The effect of SR on Au recovery and grade (GF: 60 g, WW:3 l/min, FR: 250 rpm)

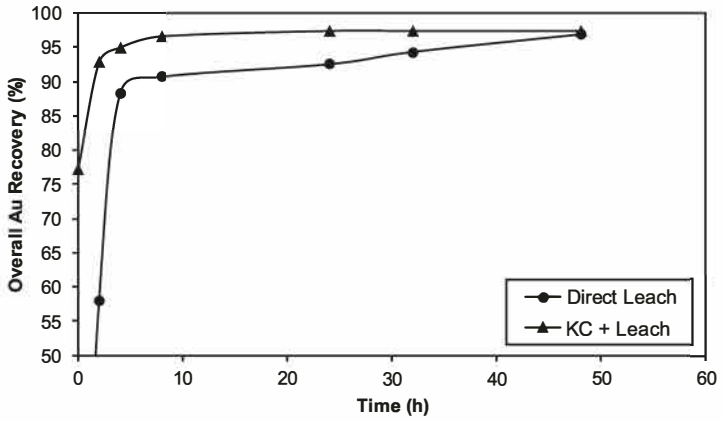


Figure 9. Comparison of Au recoveries in terms of direct leach and KC + Leaching

It should be kept in mind that KC concentrate should also be subjected to leaching as well, which will increase cyanide consumption to a certain extent. Intensive leaching will be the most suitable solution for treating the KC concentrate. It is known that intensive leaching will result in higher overall recovery, lower retention time, lower cyanide, and lower carbon consumption. Therefore, it is expected that the Knelson concentration prior to leaching will still be more cost-effective and operationally advantageous than direct leaching.

4. CONCLUSION

The effects of KC parameters such as CF, FR, WW, and SS were investigated for the concentration of an oxidized gold ore. FR and WW were determined to be the most effective parameters in terms of Au recovery and grade. By prioritizing Au grade, optimal parameters

were found to be 60 g, 250 rpm, 3 l/min, and 40% for GF, WW, FR, and SR, respectively. A concentrate having a 44.4 g/t Au grade and 70.8% Au recovery was obtained under the optimal conditions. In addition, BRTs were conducted on fresh ore and KC tailings obtained under determined conditions. As a result of BRTs, it was found that gravity concentration prior to leaching lowered both retention time and cyanide consumption from 48 hours to 10 hours and 0.76 kg/mt to 0.50 kg/mt, respectively.

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