Optimization of Gravity Recovery of Gold at High Pressure Leach Plant of Kansanshi Mining PLC, Zambia

J. Siame, K. Muchima, D. Chirwa, and P. C. Magawa

Abstract—The study provides optimization data on the work carried out on the Knelson Concentrator KC XD-20 at the High Pressure Leach (HPL) plant at Kansanshi Mining PLC (KMP), Zambia. The concentrate sent to HPL plant contains approximately 8 g/t of gold. This study involved the optimization of various parameters and performance determination of KC XD-20. The parameters investigated include G-force, fluidization water flowrate, cycle time and particle size distribution. The feed flow rate and pulp density were kept constant. A series of optimization tests were carried out at KMP. The results of the tests showed that there was a significant increase in free gold recovery. The optimization tests indicated an improvement of 12 – 25% of gold recovery under the conditions investigated. The optimum parameters obtained were 150 G, fluidization water flowrate of 13 m³/h and cycle time of 30 min.

Keywords—Gold, Gravity recovery, Knelson Concentrator, Optimization.

I. INTRODUCTION

A. Kansanshi Mining PLC

KANSANSHI Mining PLC (KMP), a subsidiary of First Quantum, owns 80% and operates the copper and gold mines while ZCCM’S subsidiary owns the remaining 20%. Gold at KMP copper and gold mine exits in two different forms namely gravity gold (nuggets) and refractory gold, locked up in the pyrite and chalcopyrite matrix. The nugget gold is collected by the use of falcons with feed coming directly from the mills. Gravity Gold (Nuggets) is recovered from course material before any further processing of the ore. The refractory gold is collected using Knelson concentrators at the high pressure leach (HPL) plant after the autoclave leaching liberates it from its complex lock up [1].

B. Knelson Concentrator and its Basic Separation Mechanisms

The first unit of batch Knelson Concentrator was introduced into the mineral processing industry in 1978. Nearly 3 decades of development and modification, different series Knelson Concentrators for different application purposes have been well manufactured and used in precious metals recovery industries all over the world [2], [3], [4], [5]. The following is a summary of the Knelson concentrator XD-20 presently used in industry [5].

B.1. Extended duty series (XD)

The XD series, with its futures of compact design, stainless steel construction and high quality components, is for hard rock milling circuits to withstand severe operating conditions. These features of the design have made the XD series the most demanding application for precious metals recovery industry.

Centrifugal fields can be generated in two different ways. Firstly, a fluid is introduced at a high tangential velocity into a cylinder or conical vessel such as a hydro cyclone. Generally, the larger and heavier particles will be collected near the wall of the separator, while the smaller and lighter ones will be taken off through an outlet near the axis of the vessel. The second way is the use of a centrifuge. In this case, a fluid is introduced into a rotating bowl and it is rapidly accelerated. All the fluid tends to rotate at a constant angular velocity, \( \omega \) and a forced vortex is established. The tangential velocity is directly proportional to the radius at which the fluid is rotating [6].

In most practical cases, when a particle is moving in a fluid under a centrifugal field, gravitational effects will be comparatively small, and can therefore be neglected. The equation for the particles in the centrifugal field will be similar to that for the motion in the gravitational field, except that the gravitational acceleration \( 'g' \) must be replaced by the centrifugal acceleration \( r\omega^2 \) [6]. The centrifugal acceleration is given by:

\[
a = r\omega^2
\]

The main forces acting on a particle inside the Knelson Concentrator are centrifugal force and axial drag force. For the drag force, it is assumed that under laminar flow conditions, the drag force on a spherical particle was entirely due to viscous forces within the fluid (Stock’s equation), and can be described as [7], [8]:

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where \( F_d \): inward drag force, g.cm.s\(^{-2} \); \( V_r \): velocity at radial distance \( r \), cm.s\(^{-1} \); \( \mu \): the viscosity of the fluid medium, 0.01 g.cm\(^{-1}\).s\(^{-1} \) for water at 20 °C.

If the effects of the fluidization water and other forces on the particle are not considered, the particle reaches its terminal settling velocity when \( F_c \) equals \( F_d \). Because we mainly consider the behaviour of fine particles, Stokes equation could be used to approximate the terminal settling velocity in a centrifugal field by substituting \( \rho \) for ‘\( g \)’, as shown in Eq. (3) [6], [9].

\[
V = \frac{d^2(\rho - \rho')}{18\mu} - r\omega^2
\]  

(3)

Why, in the centrifugal force field, can very fine particles be more effectively separated, compared to the gravity field? Eq. (4), answers this question, that is, as the centrifugal acceleration increases, the size of the critical particle (the finest particle that can be recovered) decreases [9].

\[
d_{cv} = K^4 \sqrt{\frac{2^{2}H_\rho}{{aw^2R}}} \]  

(4)

Where, \( K \), \( m \), and \( c \) are coefficients, \( H \) is the thickness of fluid film, and \( R \) is the average radius of the rotation drum. From this equation, it is also easy to understand why the Falcon Concentrator (or Super Bowl) can effectively recover even finer particles than the Knelson Concentrator does, since their centrifugal acceleration can reach 200 gs, compared to 60 gs of a regular Knelson Concentrator [7], [10].

The recovery of gold was calculated using the following equation:

\[
Recovery = \left( \frac{\text{Feed grade - Tails grade}}{\text{Feed grade}} \right) \times 100
\]  

(5)

II. METHODOLOGY

The Knelson Concentrator XD-20 was used for the optimization test works at KMP. The operating variables such as G-Force, Fluidization water flow and cycle time were selected using Knelson proprietary “Independent Control System” (ICS). The pilot test work was carried out over two campaigns. A sample of 500g was collected on each campaign per day from the sampling points as follows: Knelson Concentrator 1 feed and Knelson Concentrator 1 tails; Knelson Concentrator 2 feed and Knelson Concentrator 2 tails as shown in Figure 1, (a) and (b).

Samples from the two streams were drawn and filtered using a pressure filter and then dried in the oven at 60 °C for 2 hours. The dried samples were then pulverized. Individual samples of 50 g each were sent for chemical analysis. Gold analysis was performed by KMP in Solwezi, Zambia. Fire analysis of gold solid samples was also carried out. The tests were repeated in triplicates.

For the particle size analysis, 2 kg sample was taken from three sampling points: Autoclave discharge point (before the thickener), Knelson Concentrator 1 feed, Knelson Concentrator 2 tails. The pulverized sample was then split into 1 kg batch each using the riffle splitter. Each portion of each sample was then put on the 150 µm sieve with the 106, 75, 53 and 25 µm sieves arranged in descending order then placed on a sieve shaker. The retained sample on each screen size was then weighed and sent for gold analysis.
**B. Effect of cycle time**

In general, for Knelson Concentrator application in a secondary circuit or in other circuits with high levels of pyrite in the ore, a phenomenon known as “concentrate bed erosion” can occur, whereby gold already recovered on the surface of the concentrating ring is removed due to the effect of high specific gravity particles such as pyrite. As such, short concentrating cycle times are generally of benefit. The test work carried out proved this to be the case in this application. Figure 3 shows more stability with the minimum cycle time giving an experimentally accurate peak for all cycle time (30, 45 and 60 min) investigated. Initially, 60 minute cycles were used, but the results suggested shorter cycles would be of benefit without causing significant dilution of the final copper concentrate. Thus 30 minute cycles were adopted. Figure 3 shows the differences in unit GRG recovery between the 30 and 60 minute concentrating times.

**C. Effect of fluidization water flowrate**

The effect of using different fluidization water flowrate values on the gold recovery was investigated. Laplante et al. [12] reported that the effect of fluidization water pressure was minimal in their findings. Optimum fluidization occurs when the force of the slurry against the cone is comparable to that of the fluidization water flow rate.

Figure 4 shows gold recovery for two tests, one at low fluidization water flow rate and another at high water flow rate to understand the effect of fluidization water flow rate on gold recovery. The tests conducted at low fluidization flow rate (9m\(^3\)/h) produced low recoveries in all sizes with an overall recovery of 64% whereas the test performed at a high fluidization flow rate (13m\(^3\)/h) produced high size by size recoveries and an overall recovery of 71%. The low recoveries are attributed to the combined effect of coarse size, and low fluidization flow rate, 9m\(^3\)/h, which act synergistically to erode the concentrate collected in the riffles. Typically for an operating Knelson, low recoveries have been reported due to the suboptimal fluidization water flow rates [13].

However, the recovery trend is consistent for both high and low fluidization water flow rates. However, as fluidization water flows are increased beyond this range, a loss of recovery of fine GRG is incurred.

**D. Particle Size Analysis**

Table II (see appendix) shows the amount of gold contained on each screen size. It is expected that a higher grade of gold would be on the smaller size fraction as more gold would have been liberated and there would be less gangue material.

![Figure 5. Cumulative % passing and retained as related to screen size for the series test work.](image)
Furthermore, the results showed that gold grade was higher on the 53µ screen and highest on the 25µ screen. The least gold grade was found to be on the 106µ screen followed by the +150µ screen. In Figure 5, the cumulative passing and retained indicated that bulk of the feed material was a bigger size, falling in the range of 150µm and above. This could have been due to gangue material being mostly in the coarser size fractions (+53 µm). This could be due to gangue material being mostly in the coarser size fractions (+53 µm). This could have been due to gangue material being mostly in the coarser size fraction and less in the finer sizes.

According to Grewal and Fullam [14], it is expected that that gold size, falling in the range of 150µm and above.

The optimization results indicated an improvement of 12-25% of gold recovery and this was achieved at 150G-force, 13m³/h fluidization water flowrate and a 30min cycle time. Replicate tests suggest that the G-force giving greater than 150G-force do not offer additional gold recovery for these feed materials.

The particle size distribution was found to be a contributing factor to the overall yield. This was mainly due to either interstitial trickling or composition of gangue material in the overall course material. The recovery was best in the -75µm size fraction. Extending the size analysis to -25µm demonstrated that the Knelson Concentrator is concentrating gold bearing silicate particles down to 25 µm. However, particles finer than 25 µm are beginning to follow the water flow into the tailings.

### IV. CONCLUSION

The objective of the work described in this paper was to determine the optimum parameters and investigate the effects of G-force, fluidization water flowrate, cycle time and particle size distribution on the recovery of very fine gold in leach tailings.

The optimum recovery of gold was achieved at different conditions. The optimization results indicated an improvement of 12-25% of gold recovery and this was achieved at 150G-force, 13m³/h fluidization water flowrate and a 30min cycle time. Replicate tests suggest that the G-force giving greater than 150G-force do not offer additional gold recovery for these feed materials.

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### APPENDIX

#### TABLE II

<table>
<thead>
<tr>
<th>Screen size (µm)</th>
<th>150</th>
<th>106</th>
<th>75</th>
<th>53</th>
<th>25</th>
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<tbody>
<tr>
<td><strong>Sample collection point</strong></td>
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<td>Knelson Feed</td>
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<td>Weight % contained</td>
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<td>Cumulative % retained</td>
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<td>Cumulative % contained</td>
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<td>Weight % contained</td>
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<td>Gold % contained</td>
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#### ACKNOWLEDGMENT

The authors would like to thank the Kansanshi Mining Plc, Solwezi, Zambia and the Copperbelt University, Kitwe, Zambia.

#### REFERENCES