The Influence of Integrated Gravity Circuit on the Efficiency of Gold Extraction at a Carbon-in-Leach Plant*

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Abstract

In gold ores, the precious metal particles may occur as nuggets (> 0.5 mm) and down to sub-microscopic particles. Coarse particles are generally recovered by gravity concentration before leaching the bulk material with sodium cyanide to enhance leaching efficiency. A mine in West Africa operates a carbon-in-leach (CIL) plant where a gravity circuit has recently been installed. The purpose of this study was to investigate the effect of the gravity-integrated circuit on the overall efficiency of metallurgical operations in the CIL plant. In this investigation, a quantitative research approach was selected to determine the variables in analysing the influence of the integrated gravity circuit on the efficiency of gold extraction. The general plant efficiencies before and after the installation of the Gravity Recoverable Gold (GRG) circuit were investigated, with a focus on the milling circuit, CIL circuit, and reagent consumption in the various circuits. A model was constructed using multiple linear regression analysis, and the relationship between the variables was determined. From the results, the mill's throughput increased from 13.5 million tonnes per year to 13.9 million tonnes per year after the installation of the GRG circuit. In models 1 and 2, all coefficient p-values were less than the 5% significance level chosen for the study. Cost-benefit analysis of reagent use before and after gravity installation showed that the plant consumption of reagents decreased from 43 264 – 36 481 tonnes, 13 144 – 10 141 tonnes, 1 779 – 1 538 tonnes, 3 208 – 1 551 tonnes, 9 274 – 8 045 tonnes for lime, sodium cyanide, activated carbon, hydrochloric acid and caustic soda respectively. Again, the GRG circuit dramatically reduced the gold loadings onto activated carbon with an overall reduction in tailing grade and increased the gold recovery rate and purity by 1% and 2%, respectively. Overall, the mine's annual ore processing capacity increased by 2.34 %. Therefore, installing additional Knelson concentrators (gravity units) can be key to addressing the excess gravity-recoverable gold suspected to exist in the circuit with continuous checks and balances performed.

Keywords: Gold extraction, Gravity recovery, CIL, Reagent consumption

1 Introduction

Gold is known for its high value and may be the first metal used by humans for ornamental purposes, which is still in use (Asamoah *et al.*, 2014; Marsden and House, 2006; Amankwah and Ofori-Sarpong, 2014). The mineralogical study of gold has shown that gold ores may be classified in many ways: placer deposits (alluvial, eluvial, colluvial, and paleo-placer) (Marsden and House, 2006). These mineralogical characteristics of gold ores provide an understanding of the ore composition, optical properties, and textural properties and are thus critical in the determination of the processing route, process flowsheet design, process economics and a well-structured environmentally friendly treatment plant (Asamoah *et al.*, 2014; El-Sayed *et al.*, 2020; Marsden and House, 2006). Gold can be extracted from its ores using a number of techniques, including gravity concentration, flotation, amalgamation, and cyanidation. Among these technologies, the most popular method for extracting gold from its ores is cyanidation or cyanide leaching.

Gravity concentration methods usually separate coarse gold particles before cyanidation (Ernawati *et al.*, 2018; Marsden and House, 2006; Ofori-Sarpong *et al.*, 2019). Gold particles coarser than 75 µm require more than 24 hours to leach by cyanidation. Thus, gravity separation before cyanidation is necessary for mineral deposits where the ore contains coarse gold particles. The integration of gravity concentration helps to cut down the cost of chemicals or reagents and reduce gold loss to tails and spillage, hence improving the efficiency of the metallurgical plant. The gravity circuit lowers operating costs as primary or coarse grinding leads to cost savings on power, balls, liners, and classifying equipment (Watson and Steward, 2002; Wills and Finch, 1992). The gravity concentration circuit thus influences reagent consumption, gold in the process, and the efficiency of gold extraction in a mine (Urban *et al.*, 1973; Siame *et al*., 2014).

A mine in West Africa operates a carbon-in-leach (CIL) plant, which functioned without a gravity circuit for many years. Thus, cyclone overflow material was forwarded for leaching while underflow was milled further. During operations, the plant reported high gold in the process, a high ratio of cyclone underflow to overflow grades and high gold in tailings. It was hypothesised that the coarse gold caused the problems and that when gravity concentration is done before leaching in processing facilities, the amount of gold processed in the leaching circuit is decreased. Gravity concentration's removal of coarse gold particles reduces cyanide consumption, leaching time, gold losses due to solution leakage, and gold variability.

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Due to the absence of a gravity concentrator before cyanidation, coarse gold in the Carbon-in-Leach (CIL) feed led to increased cyanide consumption, high undissolved gold losses, and lower metal recoveries. These challenges led to installing a gravity circuit on the CIL plant to remove coarse gold before leaching. The application of the gravity separation circuit on this mine is thus considered and examined in this study, paying attention to its effect on metallurgical plant performance.

2 Resources and Methods Used

2.1 Research Design

Due to the nature of the study, secondary metallurgical plant data for six operational years (2015-2021) was collected from the mine. A quantitative research approach was utilised to determine the variables in analysing the influence of the integrated gravity circuit on the efficiency of gold extraction. The study focused on three areas: the milling circuit, Carbon-In-Leach (CIL) circuit, and reagent consumption in the various circuits; to find out if there was a significant change in the general plant efficiencies before (January 2015 to August 2018) and after (September 2018 to December 2021) the installation of the Gravity Recoverable Gold (GRG) circuit.

2.2 Model Specification

In every metallurgical or gold processing plant, tonnage and grade estimate gold production. Therefore, evaluation of the efficiency of the production of every mine is mainly centred on the grade of the deposit and the tonnes available for production in a time frame. However, each variable is independent of the other. In effect, forecasted gold production can be attained by adjusting either of these variables. This study was based on gold production as the dependent variable, whereas head grade, tonnes milled, or throughput served as the independent variables. The study used multiple linear regression to model the linear relationship between the variables of the explanatory (independent) and response (dependent). Fig. 1 shows the procedures for the analysis. This regression is modelled as follows;

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \cdots \beta_p x_{ip} + \epsilon$$

where
$i = n$ observations:
y_i = dependent variable
x_i = explanatory variables
β_0 = y-intercept (constant term)
β_p = slope coefficients for each explanatory variable
ϵ = the model's error term (also known as the residuals)

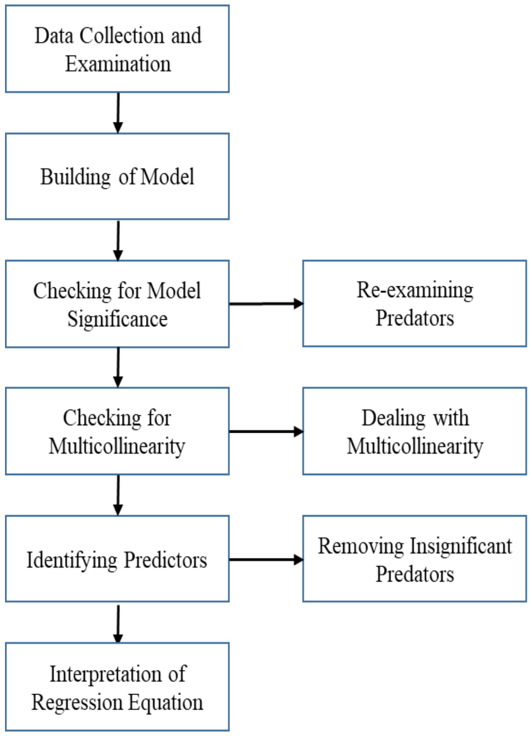

Fig. 1 Analysis Procedure

2.3 Cost-benefit Analysis

Cost-saving measures include everything from increasing efficiency to negotiating reduced supply purchasing prices. The cost savings for the following reagents were calculated; Sodium Cyanide, Lime, Activated Carbon, Caustic Soda, and Hydrochloric Acid.

3 Results and Discussion

3.1 Impact of the Gravity Circuit on Milling

The tonnes milled post the GRG circuit commission was higher than the previous years, as seen in Fig. 2. An average of 13.5 million tonnes were milled per year before the installation of the GRG circuit, which consequently increased the throughput of the mill to about 13.9 million following the installation process in the subsequent years. It can be observed from Fig. 2 that the mine experienced a 2.34% increment in the tonnes of ore milled per year post-GRG circuit installation. Gold grades were decreasing with time, making this increased tonnage vital to the sustainability of mining operations.

In addition, the consequent increase in tonnage caused a replicating increase in the SAG mill power draw. Fig. 3 depicts the post-installation of the GRG circuit. However, no significant change in power draw was recorded for the Ball mill as the material hardness is expected to be more pronounced at the grain level of the ore. Therefore, the GRG circuit is projected to reduce the circulation load since it feeds from the ball mill discharge or the circulation load to mill residence time.

The increased throughput affected both mills' steel ball consumption. As a result, the average consumption of 60 mm and 125 mm steel balls increased by 10.40% and 33.35%, respectively. On the other hand, the average consumption of 50 mm and 100 mm steel balls decreased by 29.60% and 27.59%, respectively. Generally, a 13.44% reduction in steel ball was attained, amounting to a $2.7 million cost savings after the installation of the GRG circuit.

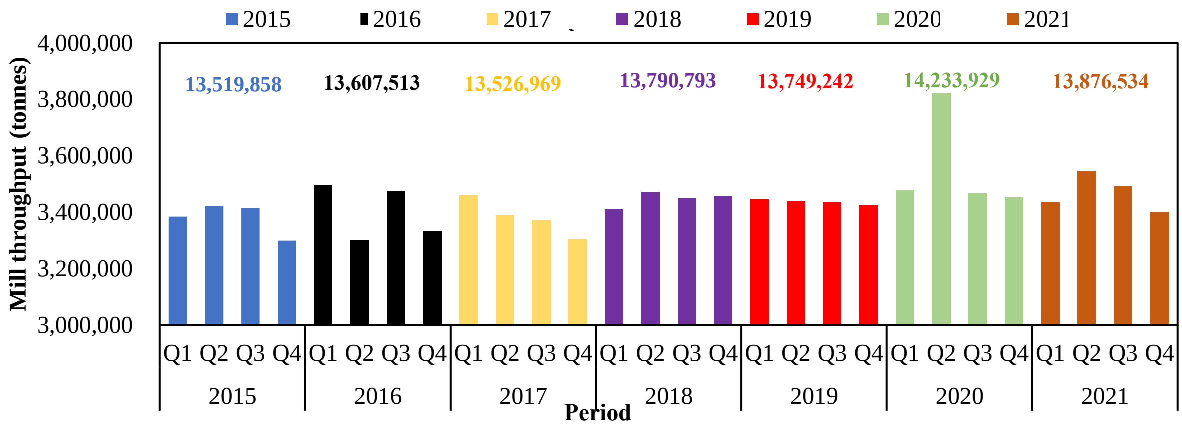

Fig. 2 Mill Throughput

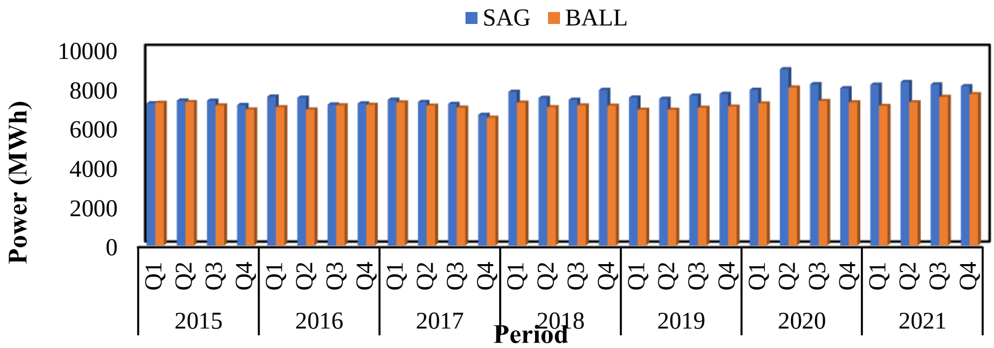

Fig. 3 Mill Power Usage

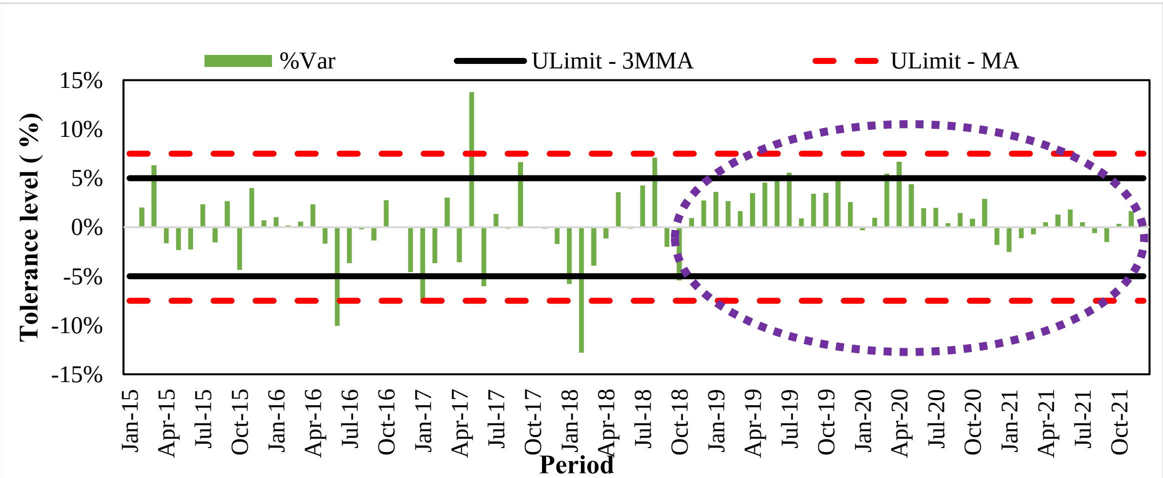

Fig. 3 Average Monthly Reconciliation Variance

3.2 Impact of Gravity Circuit on CIL Efficiency

One-month average (MA) variances were also generated, as illustrated graphically in Fig. 4. These variances were analysed per the tolerance level of metal accounting standards and protocols, where the monthly (MA) reconciliation variance is expected to be within ±7.5 %. Three-month moving average (3 MMA) reconciliation variance is expected to be within ±5.0 %, and the twelve-month moving average (12 MMA) reconciliation variance is expected to be within ±2.5 %.

It was observed that a tolerance level of ±7.5 % was achieved after the gravity circuit's commissioning. Moreover, a consistently positive reconciled plant head grade variance yielding an improved tolerance of less than +5.0 % was also realised post the establishment and operation of the gravity circuit. Gravity circuit installation has improved on monthly and quarterly head grade measurement balances and reconciliation variance; hence its tolerance was conforming to the mine’s metallurgical accounting standards and protocols.

Gold recovery can start when the leach filtrate (loaded carbon) is transported to the carbon columns for gold desorption. The American-Anglo Research Laboratories (AARL) process is then used to elute the gold from the carbon, leaving behind only the bare carbon. Gold recovery, in comparison, increased to an average of above 97 % monthly after the installation of the gravity circuit, which is about a 1 % increment from the 96 % monthly average before the installation of the gravity circuit, which is consistent with available literature of about 0.5 – 1 % (Wardell-Johnson *et al.*, 2004; Laplante and Xiao, 2001; Bird and Briggs, 2011).

3.3 Effect of Gravity Circuit on Reagent Consumption

3.3.1 CIL

The inevitable use of reagents, including sodium cyanide (NaCN), oxygen, lime, and activated carbon (AC) in gold processing amount to about 15 – 20 % of the total plant production cost. A comparison of the reagents consumed before and post-installation of the GRG circuit revealed that lime consumption in the course reduced from a total of 43 264 tonnes to 36 481 after the commissioning of the GRG circuit, which is about a 15.7% reduction.

Preceding the GRG circuit installation, the yearly average sodium cyanide consumption was 3 697 tonnes, with 2017 recording the highest cyanide consumption of 4 259 tonnes. However, a reduction in sodium cyanide consumption was recorded after installing the GRG circuit, with a yearly average of 3 008 tonnes. Total usage of cyanide before and after the commission of the circuit was 13 144 and 10 141 tonnes, respectively, and about 22.8 % cost savings, as observed. The sodium cyanide concentration required for gold dissolution was reduced, which explains the reduction in NaCN consumption. Likewise, the DO, owing to the removal of coarse gold in the system, required higher concentrations of oxygen and sodium cyanide to achieve optimum recovery before installing the GRG circuit.

Contrary to these findings, an increase in reagent consumption was expected since tonnage increased from 13.5 – 13.9 million tonnes. This could be attributed to the inclusion of the GRG circuit, which treats about 40 - 45% of the total ore. In addition, the installation of the gravity circuit caused a positive effect on the reagents used at the CIL/Elution circuit and, as such, saved the company in all about $110 424 after the installation of the circuit.

3.3.2 Elution

HCl usage dropped from an average of 863 tonnes to as low as 313 tonnes after the gravity circuit installation. Total consumption of HCL before and after the circuit was 3 208 – 1 551 tonnes and a cost reduction of about 48.35 %. Consistently, the yearly consumption of caustic soda was recorded after the installation of the GRG circuit, with 2 370 tonnes, 2 435 tonnes, and 2 483 tonnes recorded for 2019 - 2021. The caustic soda consumption totalled 9 274 tonnes in the years before the installation of the GRG circuit though the total milled tonnes before the GRG circuit was low. In contrast, a reduced total of 8 045 tonnes representing 13% of caustic soda consumption after the GRG circuit, came into effect even with the high tonnage treated.

3.4 Model Specification

The model was built before and after the installation of the Gravity Recoverable Gold (GRG) circuit and thus January 2015 to August 2018, namely, model one (before Gravity was Installed) and September 2018 to December 2021 representing model two (after Gravity was Installed).

It was observed from models one and two that the p-values for the various coefficients of the variables considered in this study were all less than 5% significant, as chosen in the study. This indicates that the coefficient of the variables in both models is significant. Therefore, both models were adequate because their Durbin-Watson values were greater than 5%. However, the adjusted R^2 value for models one and two were 70.7% and 92.8%, respectively. Thus, it can be deduced that 70.7% of the data fit the regression model in Table 1, and 92.8% fit the regression model in Table 2. Therefore, a higher adjusted R^2 value indicates a better fit for the model.

Hence, there is a clear indication of improvement for the mine after installing the GRG circuit.

Table 1. Model One (No Gravity Circuit Installed)

Variables	T-Statistics	P-Value	F-Value
Constant	-3.99	0.00	52.83
Tonnes Milled	6.17	0.00	38.11
Head Grades	9.80	0.00	96.07
Adjusted R^2 = 70.68 %		**Durbin Watson = 2.09**	

Table 2. Model Two (Gravity Circuit Installed)

Variables	T-Statistics	P-Value	F-Value
Constant	-10.94	0.00	252.93
Tonnes Milled	20.62	0.00	291.69
Head Grades	17.08	0.00	425.07
Adjusted R^2 = 92.82 %		**Durbin Watson = 2.53**	

4 Conclusion

Upon the installation of the GRG circuit, the mine experienced a 2.34% increment in the tonnes of ore milled per year obtained. The consequential increase in tonnage caused a replicating increase in SAG mill power draw post-installation of the GRG circuit. However, no significant change in power draw was recorded for the Ball mill. Generally, a 13.4% reduction in steel ball was attained, amounting to a $2.7 million cost savings after the installation of the GRG circuit. Hence, the introduction of the GRG circuit has proven to be a profitable venture for Gold Fields Tarkwa Mine.

From multiple linear regression analysis, the adjusted R^2 value before and after the installation of the GRG circuit were 70.7% and 92.8%, respectively. Statistically, a higher adjusted R^2 value indicated a better fit for the model. Hence, there is a clear indication of improvement for the mine after installing the GRG circuit. In relation to CIL reagents consumption, a reduction of 22.8%, 15.7%, and 13.6% in cost savings was observed for sodium cyanide, lime, and activated carbon, respectively. Similarly, the reduction was also observed for caustic and hydrochloric acids critical for elution. An increase in tonnage was observed and expected to cause a replicative increase in these reagents.

However, a reduction in consumption of the reagents was rather recorded. Evidently, the installation of the gravity circuit caused a positive effect on the reagents used at the CIL/Elution circuit. It saved the company about $110 424 three years after its operation.

The gold production decreased by 8.60% after the gravity circuit installation, although the milled tonnes increased. This reduction in gold production is largely attributed to the decline in high-grade gold ores. However, the gravity circuit has increased gold recovery to about 1% at the mine. The introduction of the GRG circuit has proven to be a profitable venture.

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