Optimisation of The Agglomeration Conditions of Vat Leaching of Gold Ores

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***Abstract*—**Agglomeration as a pre-treatment stage prior to the leaching of gold or other metals is very important, yet has not been treated as such and that has robbed the process of the research attention it deserves. The process has been widely considered falling, largely in the space of practice and experience, which to a greater extent contributed to numerous problems faced in various leaching processes emanating from poorly agglomerated ores. To that end, an investigation was undertaken through experiments to determine the optimal agglomeration conditions of moisture content, binder dosage, residence time and the speed of the agglomeration drum, which maximizes gold recovery in the leaching process. From the study, the optimum agglomeration conditions which maximised the gold leaching recovery for the gold ore used in the investigation were determined, thus contributing towards the understanding of the agglomeration process.

***Keywords*—** agglomeration, binder dosage, gold cyanidation, moisture content, residence time, sodium cyanide

I. Introduction

THE gold ore undergoes size reduction before the gold is extracted through processing techniques, such as leaching. It is important to have the knowledge of how gold exists in the targeted ore in order to identify the most suitable processing method to extract it. From different published works, Bare *et al*. [1] gathered that the precious metal exists in compounds, and alloys, as native and invisibly associated with other mineral phases. The invisible gold which usually associates with iron oxides and sulphide minerals is also known as sub-microscopic gold, whereas that which is visible to the naked eye is microscopic gold. Although gold is recovered through the application of cyanide or non-cyanide solvents [2], the common method used to extract gold is cyanide leaching. The depletion of high-grade ores with free-milling gold ores that are easily extracted by cyanide or non-cyanide solvents has forced gold processors to search for the mineral from the low-grade gold ores and tailing dumps. Those sources have several issues, which include a high content of refractory gold ore.

The refractory gold ores have minerals associated with the targeted gold, competing for the cyanide and oxygen [3], which increase the gold recovery cost and make the extraction process uneconomic. Thus, to improve the gold recovery, pre-treatment methods such as roasting, bio-oxidation, nitrox, pressure oxidation and agglomeration, among other pre-treatment methods, were used prior to leaching the gold ore. The rise of energy costs, global warming effects and the incomplete migration and liberation of gold from sulphide matrix, among other challenges, have discouraged the use of pre-treatment methods, such as roasting.

Low-grade ore requires fine grinds to liberate the desired minerals. However, the presence of fines in the product size distribution affects the leaching rate due to their negative influence on the percolation of the lixiviant when employing vat leaching. One pre-treatment method found to effectively address that problem is the agglomeration method. The agglomeration treatment promotes particle adhesion, minimises channelling, improves permeability, and shortens leach cycles [4]. The liquid retention of the agglomerates has well-developed intra-particle pores, which promote mass transfer and accelerate leach reactions [5]. The intra-particle forces are formed by the chemical reaction cementation coupled with the van der Waals forces. In the agglomerated ore, the potential flow paths are more developed as observed by Nosrati *et al*. [6] and the immigration of fine powders is prevented which consequently improves the intra-particle porosity of agglomerated ore and prevents the undesirable clogging of flow paths, particle stratification and segregation [5]. The pore structure of the agglomerated ore, which is well developed, helps to delay the preferential flow path formation.

The agglomeration process is usually used in the heap-leaching operations of precious metals such as gold and silver as well as base metals such as nickel and copper. When the ore has excess fines under 75 µm and high content of clays, agglomeration is employed in the agglomerators or tumbling

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drums to promote the adherence of fines onto larger particles, forming rim agglomerates or onto each other, forming nucleated/conglomerates. This improves the porousness of the ore and uniform distribution of the solution, thus percolation of the leaching agent. As observed by Nosrati et al. [6], the agglomeration procedure is influenced by mineralogy, which affects the agglomeration drum parameters and chemical additives, among other factors. There is also a need to control the particle size distribution of the feed since it affects the dual-pore porosity, potential fines immigration behaviour, compressive strength and agglomeration diameter [5]. Binders such as Portland cement and acid-proof cement as suggested by Yin et al. [7] play an important role in promoting an ideal adhesion and cohesion condition in agglomerated ore by effecting the prompt formation of solid and liquid bridges as well as liquid films.

The importance of agglomeration as a pre-treatment stage prior to the leaching of gold or other metals has been given very little importance [8]. This leaves the literature void of fundamental knowledge about the agglomeration practice [9], which in turn made the practice fall largely into the space of practice and experience [10]. Poorly agglomerated ore results in too many fine particles/clay in the ore, which leads to numerous problems. Unfortunately, the quality of agglomeration has often been ignored when troubleshooting quality-related issues experienced during the leaching process yet emanated from the agglomeration procedure [8]. To contribute towards solving this problem, this work thus investigates the effect of water content, binder dosage, residence time and the agglomeration speed on the agglomerates, and eventually assesses the leaching efficiency of the agglomerated and unagglomerated gold ore. As noted by Dhawan *et al*. [9], different ores have different agglomeration behaviours which make the study of parameters for this particular gold ore a notable contribution to the knowledge fraternity especially considering the poorly understood process.

II. Methodology

To find the optimal water content, binder dose, residence time, and agglomeration speed, the agglomeration process was carried out under various conditions. A 250 mm by 810 mm drum agglomerator was used during the experiments to create the agglomerates.

A. Agglomeration test

A homogenised 80kg sample was collected from the dumps and further divided into 40 by 2 kg samples using a riffler. Each 2 kg sample was charged into the drum agglomerator along with a 0.02% cyanide solution in order to form pellets. A cement binder was also added to promote pellet growth and stability. After that, the samples were left to cure for 72 hours. This experiment was repeated several times whilst varying water content, binder dose, residence time, and agglomeration speed and the products were subjected to agglomerate quality tests.

B. Soak test

In order to determine how well the agglomerates were held together after carrying out the agglomeration procedure at various conditions with Portland cement as binders, a soak test was performed to determine the quality of the agglomerates. The agglomerate quality tests involved sampling a 1kg sample from the agglomerates and placing it onto a 2mm screen and leaving it to dry naturally. The screen was then immersed in a cyanide solution simulating the environment that would be experienced during vat leaching. After 30 minutes in the solution, the cyanide solution was decanted and the fine material which passed through the mesh was collected, dried and then weighed to determine the fines migration percentage. The undersized material that passed through the screen was collected, dried, and measured. This thus enabled the determination of the percentage of the fines which migrated.

III. Results and discussion

The success of any leaching process depends on how well the leach solution percolates through the run-of-mine in the vat tanks when irrigated with the leach solution. As mentioned in the foregoing, the permeability of the leach pad has often been found to be hindered by the migration of fines in the ore. The fines migration clogs the natural flow channels by forming impermeable sections within the ore which in turn affects the leach response of the ore [11], hence the need for agglomeration of the gold ore. The agglomeration, on the one hand, initiates the leaching process and improves the kinetic response of diluted ore values. On the other hand, it promotes capillary adhesion of fines to coarse particles by forming liquid bridges that create permeability and uniform lixiviant heaps [12]. To ensure that the agglomerates are strong enough to address the fines migration, the agglomeration parameters were optimised, and the results are discussed in the subsequent sections.

A. Effects of the water content on agglomeration

In producing agglomerates, it is important to control the water content since the moisture content determines the stability of the heap and the production. Excessive moisture content results in the production of muck and unstable agglomerates. The inadequate dosage of moisture results in the formation of poor-quality agglomerates and size segregation during stacking with permeability deterioration eventually [8]. On the range of moisture content values investigated, the 12% moisture content was found to be optimal and minimised the migration of fines through a 2mm sieve as shown in Figure 1. This value agrees with the one found by [13] as producing the best agglomeration results for copper ore. At 10% water content, the moisture was not enough to bind the fines to larger particles or onto themselves resulting in the production of unstable pellets. As the moisture content improved, the strength of the pellets improved to 12%.

Beyond that moisture content, the strength decreases as indicated by the migration of fines due to excess water content, as weak agglomerates which tend to deform easily were formed.

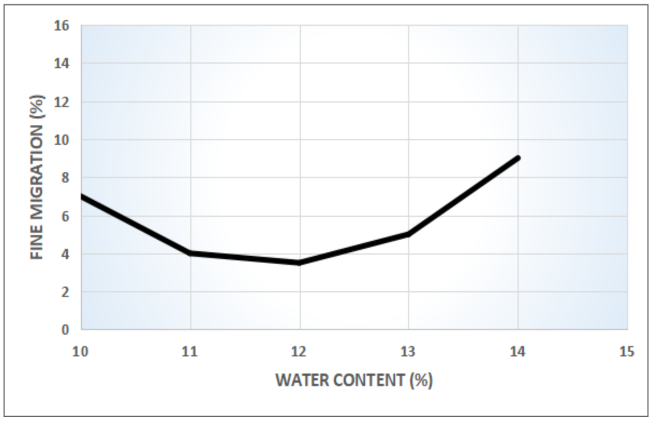

Fig. 1 Effect of water content on the percentage fines migration

B. Effects of binder dosage on agglomeration

Binders play an important role in the agglomeration process by adhering to particles, thus holding agglomerates together and increasing their strength. The bonding mechanism of binders is determined by the adhesion and cohesion forces, attraction forces between solids, solid bridges, surface tension and capillary pressure [14], [15]. Binders have been identified by Dhawan et al. [9] as one of the dominants of the growth mechanism of drum agglomeration. As proposed by Chamberlin [16] binders are usually needed if the ore to be leached has more than 10% of the material below 75 µm. These fines built up in the spaces between larger particles at the expense of permeability. In Figure 2, is shown that the fines migration decreases as the cement binder dosage is increased from 0 to 6kg/ton. This is owing to the increase in adherence of fine particles and or clays to the coarser particles with the consequence of high percolation and permeability of leach solution. This would translate to increased gold recovery rates and a decrease in leach time, which in turn saves energy. As the binder was increased beyond 6kg/ton, there was no further decrease in fines migration observed. This is not different from the results reported by Vethosodsakda [13] for copper recovery, which showed a constant fines migration between 6 and 10kg/ton.

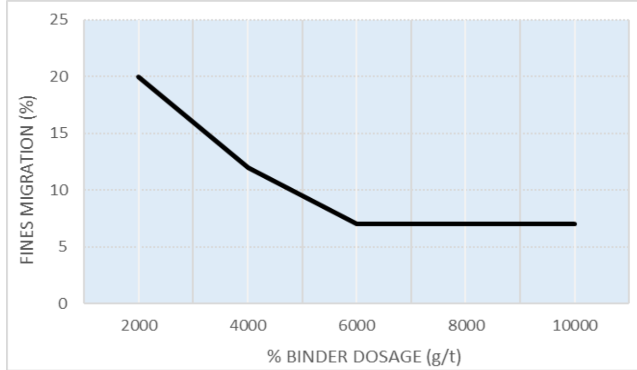

Fig. 2 Effect of the binder dosage on the percentage fines migration

C. Effects of residence time on agglomerates

Residence time is one of the parameters figured to dominate the growth and mechanism of the drum agglomeration process [9]. Figure 3 depicts the reduction in fines migration between 1 - 2 mins residence time, implying that the strength of the pellets was increasing up to the residence time of 2 minutes where it was maximum as indicated by the least fines migration recorded. Beyond 2 minutes, a surge in fines migration is observed because particles tend to get bigger and unstable with longer residence time, hence the deformation. The residence time of 2 minutes confirms the same time proposed by Dhewan *et al.* [9] for a small-scale batch agglomeration of gold ore. Results in Figure 3 also support earlier research findings which suggest that longer residence times promote the growth of agglomerates, albeit with higher breakage rates of agglomerates, which becomes detrimental eventually [17] and [9]. According to Miller [18], solids residence time plays a more important role in the choice of most agglomerates than the degree of agglomeration itself, although Dhewan *et al.* [9] attribute it to the lack of a fundamental understanding of the field.

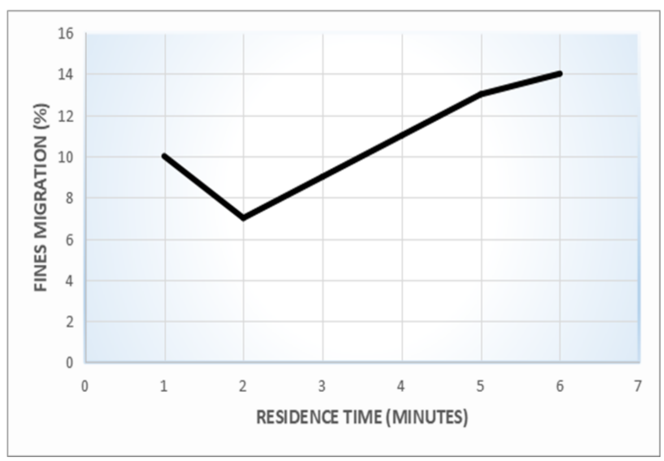

Fig. 3 Effect of residence time on the percentage fines migration

D. Effects of agglomerator speed

The drum speed contributes significantly towards the formation of the desired agglomerates, as observed in previous research [9]. In Figure 4, is shown that the speed of

23% of critical speed led to the formation of the desired agglomerates. Below that speed, the formation of unstable agglomerates which promotes fines migration is attributed to the rolling effect of the pallets at a low drum rotation speed. At 23% of critical speed, there is a proper cascading effect that leads to proper pellet formation with reduced fines due to stability. Beyond that speed, the agglomerates formed promote the migration of fines because excess speed causes the particles to stick to the agglomerator walls due to centrifugal forces [13]. Higher drum speeds, though when coupled with lower moisture content, were found to promote more adherence of more loose fines to existing charge due to the increased tumbling action of the drum [9]. This thus calls for further enquiry into the relationship between the drum speed and moisture content.

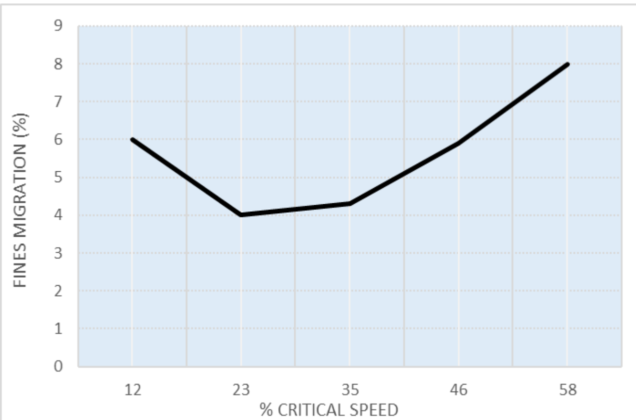

Fig. 4 Effect of the drum speed on the percentage fines migration

E. Leaching efficiency

Agglomeration undoubtfully improves the leaching efficiency, as can be seen in Figure 5. The process helps to create uniform-sized agglomerates, which minimizes segregation and improves percolation and uniform solution distribution [9]. This becomes imperative, especially in the wake of low-grade ore processing necessitated by fast-depleting high-grade ores, which are almost exhausted [19]. Results of the unagglomerated ore show a leaching efficiency of 56% after a 12days leach cycle. This is due to poor percolation caused by fines migration and the blocking of solution channels, forming dead zones which are impermeable within the heap. Conversely, in just 6 days, the agglomerated sample shows an increase in overall efficiency to 88%. This was achieved through improved permeability as evidenced by the high leaching efficiency in just a few days leach. The agglomeration process was done using the optimal conditions of 10% moisture content, 6kg/ton binder dosage, 2 minutes residence time and the drum rotating speed at 23% of critical speed.

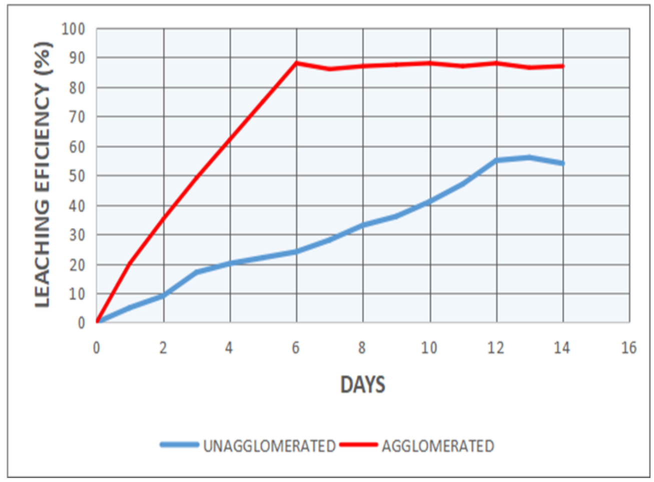

Fig. 5 Effect of agglomeration on the leaching efficiency

IV. Conclusion

The agglomeration process is still not well known, thus the study of different parameters affecting the agglomeration process makes a notable contribution to the literature. This is owing to the existence of significant variability in the agglomeration behaviour of different ores in industrial operations. The agglomeration parameters of gold investigated in this work exhibited behaviour not significantly different from those reported in previous work, considering the aforementioned fact that different ores have different agglomeration behaviour. For this ore, the optimum operating conditions for producing the desired agglomerates which maximise the recovery of gold during leaching were moisture content of 10%, binder dosage of 6kg/ton, a residence time of 2 minutes and a drum rotating speed of 23% critical speed. The agglomerated ore resulted in 88% leaching efficiency in just six days compared to the 16 days needed to leach unagglomerated ore with a leaching efficiency of just 56%. Although these results are insightful, the subject still deserves more attention to fully explore all the avenues that help researchers to fully understand the process.

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