Effect of Superfloc on the Flocculation of Ores from Different Mines in Ghana

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Abstract

Thickeners are used to recycle larger volumes of water used in Gold Mining Process Plants in order to reduce the consumption of and demand on fresh water. The separation process is stimulated by the addition of flocculants, which aggregate fine particles into flocs for easier settling. Depending on the type of flocculant used, the thickener after flocculation, sometimes produces cloudy overflow which creates problems when recycled. This work therefore sought to study the effect of a new flocculant on the market, superfloc (C 491 HMW), in the flocculation of different types of ores in Ghana so as to ascertain the effective required concentration of flocculant to be used for flocculation. Settling tests were conducted for ore samples from three Mines in the southern half of the Ashanti gold belt, tagged Mine 1, Mine 2 and Mine 3. Each ore had 5 setups; a control, setup conditioned with lime, and setups dosed with lime and 1%, 2% and 3% vol/vol concentration of flocculant (0.05% stock solution). The results showed an upturn in settling velocity with increase in flocculant concentration. All the setups dosed with various concentrations of flocculants also produced clear overflow solution. The best concentration of Superfloc consumed for effective settling of the ores from Mines 1, 2 and 3 were 3%, 2%, and 3% vol/vol respectively. Among the ore types, the ore from Mine 2 responded the best to the Superfloc (C 491 HMW), with settling rate of 1.06 cm/min as against an average of 0.95 cm/min for Mine 1 and 3.

Keywords: Flocculation, Superfloc Flocculant, Settling Rate, Gold Ores, Thickener

1 Introduction

The conventional beneficiation route of gold on large scale involves mining, comminution, leaching, adsorption, elution, electrowinning and smelting. One major commodity used in the extraction of gold is water. Water is used for grinding and classification of the ground material to aid in dilution and transportation. Water is also used in leaching, elution, reagent mixing and heat exchangers. Water used in these processes is usually fresh water from the environment or processed water in the mine. Due to environmental regulations, high cost of fresh water, and competition for fresh water for domestic uses and farming, there is always the need to recycle large volumes of water used in the mine in order to reduce the consumption of fresh water (França *et al*, 2017).

Solid-liquid separation is normally used to retrieve recycled water from slurry, and one major facility used is the thickener. The thickener settles materials based on differences in particle size and densities (Gladman *et al*, 2006). Depending on the process route of various plants, the slurry from some plants may be diluted and sent to a thickener for thickening before the thickened slurry is pumped into the leaching tanks (Stange, 1999). This pre-leaching thickener helps to concentrate the slurry before the leaching process begins. Thickening may also be done after leaching (post-leaching thickener) to dewater the slurry before final disposal into the tailings dam.

In the gold processing industry, water suspensions usually contain particles of very small sizes which usually behave as colloidal particles. Particles in these suspensions normally contain functional groups which readily ionise, hence creating surface charges which cause stability in the colloidal system (Bratby, 2016). In basic and slightly acidic media, the particles in the suspension usually have negative charges. Like the magnetic law, the particles having like charges will repel against each other, hence preventing the collision of particles to form flocs. The stability of colloidal suspensions can be reduced by the addition of coagulants or flocculants (Vergouw *et al*., 1998)

The solid liquid separation process in the thickener is usually stimulated by the addition of flocculants, which are organic polymers with high molecular weight, which speeds up the settling rate (Stange, 1999). The flocculant acts as a bridge between fine suspended particles, aggregating them into coarser particles (Vergouw *et al*., 1998). The coarser particles, known as flocs, can then settle relatively easier (Wills and Napier-Munn, 2006; Svarovsky, 2000). In gold mining companies, flocculation is done because the rock particles which are generally finer than 106 µm will not settle naturally due to surface properties and size of particles (França *et al*, 2017). Depending on the mineralogy of the ores, the settling rate of the ore may vary. Ore materials containing large volumes of weathered materials have lower settling rate whiles ore materials containing large volumes of fresh rocks settle faster. Various ore particles respond differently to different kinds of flocculants, which may be classified into cationic, anionic and nonionic flocculants (Pillai, 1997).

One major flocculation agent used in gold mining industries in Ghana is superfloc, which is a cationic flocculant. Even though the thickener is supposed to produce thickened slurry and clarified overflow with the addition of flocculants, the overflow is sometimes laden with suspended particles which creates problems when recycled. This work therefore sought to study the response of different types of gold ores in Ghana to flocculation using a new flocculant on the market, superfloc (C 491 HMW), so as to ascertain the required concentration of flocculant to be used for effective flocculation.

2 Materials and Methods

2.1 Materials

Ore samples, weighing 2 kg each and having particle size distribution of 80% passing 106 µm, were obtained from Mine 1 (sulfidic ore), Mines 2 and 3 (oxide ores). Superfloc (C 491 HMW) was obtained from the UMaT Minerals Laboratory.

2.2 Methods Used

2.2.1 Sample Preparation

A one-litre measuring cylinder was graduated to centimetres in order to measure mudline height. The specific gravity of the various samples was obtained using the water displacement method. In order to obtain a 1-litre volume of slurry with 20% solids each, the mass of the ore samples (in kg) to be mixed with a volume of water (in L) were calculated using Equations 1 and 2. Stock solution of 0.05% superfloc (which is a cationic polyacrylamide having high molecular weight) was prepared. This was done by uniformly mixing 0.05 g of superfloc with 100 ml of water.

$$M_s = \frac{V_T * SG}{(1 + \frac{SG}{D})} \quad (1)$$

$$V_{H_2O} = \frac{M_S}{D} \quad (2)$$

Where, M_S- Mass of solids used

V_T- Total volume of slurry

SG- Specific gravity of ore

D- % solids of slurry

V_{H_2O}- volume of water added

2.2.2 Settling analysis

The calculated mass and volume of Mine 1 sample and water were mixed in the graduated measuring cylinder and stirred vigorously for a uniform mixture. The settling of the material was observed for 3 hours by recording the mudline height at stipulated times. About 3 g of lime was added to the solution to condition the pulp to leach pH (> 10.5), and the solution was stirred vigorously to ensure uniformity. The height of the mudline at stipulated times was recorded in the space of three hours. A ratio of 1% vol/vol of the flocculant solution was pipetted into the sample, stirred vigorously, and the mudline height at various times were noted in the space of three hours.

Two different 1-L samples of Mine 1 material at pH above 10.5 were prepared using the method stated above, after which 2% vol/vol on one hand and 3% vol/vol on the other were added to the two solutions. The settling of the materials was observed for 3 hours by recording the mudline height at stipulated times.

This procedure was repeated for samples from Mines 2 and 3. The setup is shown in Figure 1, where sample A and B show the settled slurry from Mine 1 in the graduated measuring cylinder after flocculation.

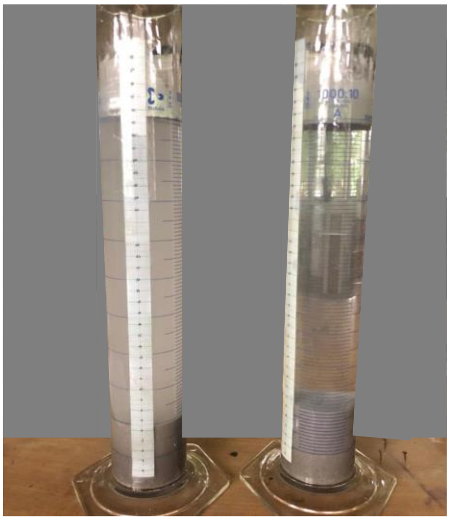

Figure 1 Settled Slurries in Setup A (conditioned with lime) and B (conditioned with Lime and 0.1% vol/vol Flocculant) from Mine 1

2.2.3 Determination of Settling Rate

A graph of mudline height against time was plotted in order to determine the settling rate. In estimating the settling rate, tangent to any point of the curve was constructed and the gradient of tangent was calculated. The estimated settling rate corresponds to the gradient of the tangent (Wills and Napier-Munn, 2006).

3 Results and Discussions

This work aimed at assessing the settling effect of superfloc on different types of gold ores. Settling tests were performed on ore samples from three mines in the southern half of the Ashanti gold belt.

3.1 Settling Velocity of Three Types of Ores for Various Setups

The estimated settling velocities in cm/min of the various setups are shown in Figure 2. The highest settling velocities for the various types of ores were obtained at 3 % vol/vol concentration of flocculant. The settling velocity was noticed to increase with the addition of lime, and further increased as the flocculant concentration increased.

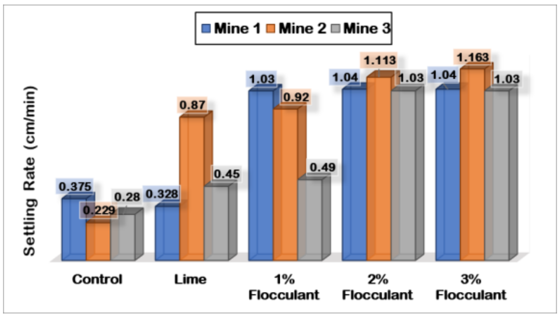

Figure 2 Settling Velocities of Various Setups

It is usually expected that on the addition of lime, the settling rate increases due to the fact that lime is a coagulant. This was observed in the ores from Mine 2 and Mine 3 which were both oxides. The settling velocity of the Mine 1 ore, which is sulphidic, however, reduced on the addition of lime. In a work done by Vergouw *et al*. (1998) in order to study the agglomeration of sulphide minerals using zeta-potential and settling rate, the settling rate and zeta potential for pyrite and galena were measured in the presence of Ca, Pb and Fe(II) ions, and in the presence of each other. It was reported that the settling rate of pyrite was reduced in the presence of calcium and also in the presence of Fe(II) ions.

Zanin *et al.* (2019) also reported that the one effect of the use of lime in sulphidic ores is the adsorption of Ca^{2+} and $CaOH^{+}$ ions on the surface of the mineral. This causes the formation of lime coating on the mineral surface. According to Wills and Napier-Munn (2006), slimes poorly respond to conventional treatment methods. The reduction in the settling rate of the Mine 1 ore may therefore be due to the reaction between Ca ions and the mineral surface or the presence of other ions such as Fe(II) in the sample.

3.2 Observation of Settling

3.2.1 Settling Behaviour of Mine 1 Ore

Figure 3 shows a settling curve of Mine 1 ore. It can be observed from the control curve that zone settling occurred in the initial 8 min, recording a mudline height of 11.5 cm. Transition settling took place in the next 12 min with a height of 7.5 cm.

Compression settling followed for 40 min and the final mudline height recorded was 6.6 cm. The final mudline was recorded after 60 min of settling. A muddy solution was retained on the surface of the settled slurry, implying poor settleability of the material.

For the lime curve as shown in Figure 3 however, zone settling occurred within the initial 6 min, with a mudline height of 16.3 cm. This was followed by 19 min of transition settling, with mudline height reducing further to 8.2 cm. Compression settling occurred in the next 25 min and the final mudline height recorded was 7.2 cm. The final mudline was recorded after 50 min of settling. The clarified solution was observed to be cloudy.

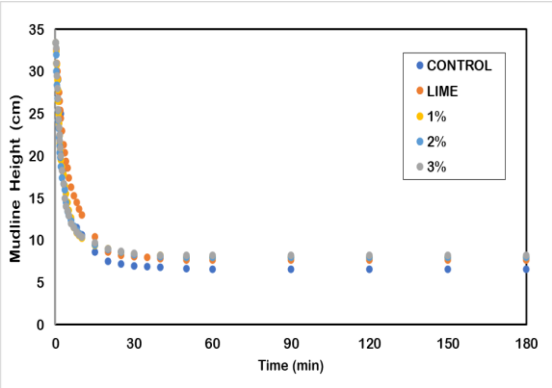

Figure 3 Graph of Mudline Height against Time for Mine 1 Setup

For all Mine 1 setups containing flocculant, however, zone settling was observed within the initial 3 min with mudline heights of 17.8, 16.7 and 16.7 cm for 1%, 2% and 3% vol/vol of flocculant concentration respectively. Transition settling also followed for the next 7 min for each setup with 1%, 2% and 3% vol/vol of flocculant concentration with mudline heights reducing further to 10.3, 10.4 and 10.4 cm respectively. Compression settling followed for the next 40 min for setups with 1% and 2% vol/vol flocculant concentration and 30 min for 3% vol/vol concentration of flocculant. A final mudline height of 8 cm was recorded after 50 min of settling for setups with 1% and 2% vol/vol flocculant concentration, while 8.4 cm was also recorded after 40 min for the setup with 3% vol/vol concentration of flocculant. The clarified solution for all setups containing flocculant of various concentrations were observed to be clear.

The best flocculant concentration for Mine 1 ore was therefore 3% vol/vol.

3.2.2 Settling Behaviour of Mine 2 Ore

The settling curve for Mine 2 ore is displayed in Figure 4. The zone settling time for the control setup took comparatively a longer period of 20 minutes and recorded a mudline height of 12 cm. Transition settling also took place in the next 20 min with a decreased in height to 7.2 cm. Compression settling occurred for 20 min and the final mudline height of 6.3 cm recorded; after 60 min of settling. The clarified solution on the surface of the slurry was observed to be cloudy.

Addition of lime as shown in Figure 4, however, shortened the zone settling time to 3.5 min, and a mudline height of 14.4 cm was recorded. This was followed by 6.5 min of transition settling, with a mudline height reduction to 8.7 cm. The final mudline height of 7.4 cm was recorded after 40 min of settling. The clarified solution was observed to be relatively clear.

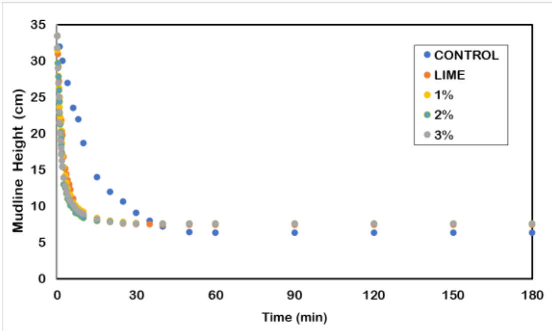

Figure 4 Graph of Mudline Height against Time for Mine 2 Setup

All Mine 2 setups dosed with flocculant however, observed zone settling in the initial 3 min with mudline heights of 14.2, 13 and 13.9 cm for 1%, 2% and 3% vol/vol of flocculant concentration respectively. Transition settling also followed for the next 5 min for setups with 1%, 2% and 3% vol/vol of flocculant concentration reducing the mudline heights to 9.7, 8.9 and 9.3 cm respectively. Compression settling followed for next 32 min for setups with 1% vol/vol flocculant concentration and 22 min for both 2% and 3% vol/vol concentration of flocculant. A final mudline height of 7.6 cm was recorded after 40 min of settling for setups with 1% vol/vol flocculant concentration. The same height was recorded after 30 min for the setups with 2% and 3% vol/vol concentration of flocculant. The solution on the surface of the settled slurry of all setups containing flocculant of various concentrations were clear. The Mine 2 ore settled best with flocculant concentration of 2% vol/vol.

3.2.1 Settling Behaviour of Mine 3 Ore

Figure 5 shows the settling curve for the Mine 3 ore. Zone settling occurred in the initial 10 min, recording a mudline height of 18.1 cm. Transition settling followed in the next 20 min with the mudline height decreasing to 8.4 cm. Compression took place for 10 min and recorded a final mudline height of 6.8 cm. The final mudline was recorded after 40 min of settling. The clarified solution on the surface of the slurry was observed to be muddy.

Zone settling occurred within the initial 3 min on the addition of lime, and a mudline height of 19.4 cm was recorded. Transition settling followed in the next 17 min, with the mudline height decreasing to 9 cm. Compression occurred in the next 20 min and the final mudline height recorded was 7.8 cm. A consistent mudline was achieved after 40 min of settling. The clarified solution was observed to be cloudy.

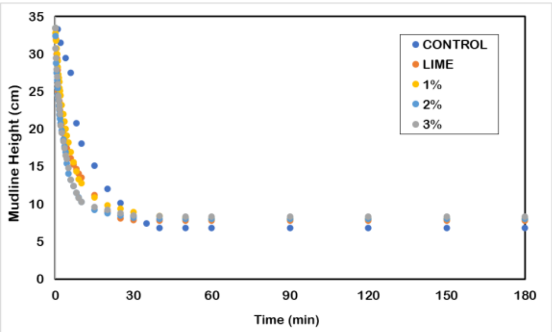

Figure 5 Graph of Mudline Height against Time for Mine 3 Setup

Zone settling was observed within the initial 5 min with mudline heights of 19.4 cm recorded for the Mine 3 setup with 1% vol/vol of flocculant concentration. Setups with 2% and 3% vol/vol of flocculant concentration both observed zone settling within the initial 3 min with mudline heights of 18.6 cm and 18.4 cm respectively recorded. This was followed by transition settling for the next 15 min for 1% vol/vol of flocculant concentration setup, recording a mudline height of 9.8 cm. Setups with 2% and 3% vol/vol of flocculant concentration both observed transition settling after 7 min and both recorded mudline heights of 10.3 cm. Compression settling followed for next 40 min for setups with 1% vol/vol flocculant concentration and 30 min for both 2% and 3% vol/vol concentration of flocculant. A final mudline height of 8 cm was recorded for both setups with 1% 2% vol/vol flocculant concentration after 60 and 40 min of settling respectively. Final mudline height of 8.4 cm was recorded after 40 min for the setup with 3% vol/vol concentration of flocculant. All setups dosed with flocculant at various concentrations were observed to have a clear solution on the surface of the settled slurry. The best flocculant concentration for the Mine 3 ore was therefore 3% vol/vol.

3.3 Comparison of Superfloc Activity on the Three Types of Ores

The control setup for Mine 1 and Mine 3 ore had a muddy solution above the settled slurry implying relatively poor settleability of the ores. The control setup of the Mine 2 ore, however, had a cloudy clarified solution, clearest of all the three ores. The Mine 2 ore settled best on its own. On addition of lime, the clarified water looked cloudy in the Mine 3 and Mine 1 ore, but clearer in the Mine 2 setup. On the addition of 1% vol/vol (and more) of flocculant to the three types of ores, the clarified solution above the settled slurry appeared very clear.

It was also observed generally that, the zone settling time was shortened on the addition of flocculant, and more material was settled in this region; compared to the control and lime setups of the various samples. The Mine 2 ore settled more materials in the zone settling region and had the shortest zone settling time (2.5 min for 2% and 3% vol/vol setups). As expected, it was generally observed that as settling rate increased, zone settling time decreased, however, more materials were settled. Addition of superfloc also relatively shortened the transition region and increased the compression settling zone. Relatively, as settling rate increased, the compression time increased and more materials were settled compared to setups with lower settling rate of the same ore. Effective flocculation was therefore observed to enhance effective hindered settling and effective compression.

The greatest settling velocities were obtained with the Mine 2 ore for the setups containing various concentrations of flocculant. The Mine 2 ore also achieved its final mudline height faster with the least concentration of flocculant.

4 Conclusions and Recommendations

The study showed that the addition of Superfloc (C 491 HMW) at various concentrations produces clear clarified solution on the surface of the thickened slurry. The settling velocity increased as the flocculant concentration increased and were in a range of 0.49 to 0.14 cm/min. Effective flocculation enhanced effective hindered settling and effective compression. The suitable concentration of Superfloc needed for effective settling of the Mines 1, 2 and 3 ores were 3%, 2%, and 3% vol/vol respectively and the ore type that worked best with Superfloc (C 491 HMW) was the Mine 2 ore.

It is recommended that this work is repeated using process water in order to ascertain its effect on flocculation. The effect of ore mineralogy on the settling velocity of an ore should also be explored to enhance effective flocculation.

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