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Centrifugal Concentration of Mandailing Natal North Sumatera Gold Ores Using Knelson Concentrator

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ABSTRACT

Gravity concentration is the type of separation process of minerals based upon the difference in density. This technique has been known for centuries. It has the ability to separate the valuable minerals with relatively low production cost and little environmental impact, such as gold ores. Separation of gold from gangue minerals by using gravity concentration has been used for decades. In fact, it has the limitation to process fine particles. In attempt to recover fine particles using gravity concentration methods, the technique has been developed by combining centrifugal force. One of well-known devices, Knelson Concentrator, was used to separate gravity recoverable golds (GRG) from the gangue minerals of Mandailing Natal (North Sumatera) sulfide complex gold ores with -200# of particle size. The head grade of ores was 5 g/t of gold. The ores were separated by using Knelson Concentrator with variation of pulp density, feeding rate, and water fluidization pressure. The results have proved that these three variables have particular impacts on gold recovery. The recovery of gold was increased by the increasing of pulp density until it reached the optimum level in 25% of solid with 86.9% of gold recovered, and then decresed by increasing of pulp density into 84.88% of gold with 30% of solid in pulp. It has the same trends in variation of feeding rate and water fluidization pressure. The highest point with 87.08% of recovery and 17.88 g/t of concentrate grade was anchieved at 25% of solid, 0.7 kg/minutes of feeding rate, and 2.7 kg/cm^2 of water fluidization pressure.

Keywords: *centrifugal separation, gold, knelson concentrator, recovery*

1. INTRODUCTION

Gravity separation is the oldest among all mineral processing technology based upon the difference of settling rate in a fluid medium. This separation method is considered as the most economically and environmentally friendly process as it has the lowest capital cost, high capacity, and lacks of chemical utilization (Chen et al. 2020). However, along with the invention of flotation process, there was time when the used of gravity concentration decreased. Until the early of 1980's by the development of enhanced gravity separators and environmental concern, the used of gravity concentration were raising again (Burt 1999). Enhanced gravity separation are developed by the adding the centrifugal force into the process, enhancing the sedimentation velocity up to 60 times compared to the initial gravity separation method (Napier-Munn and Wills 2005). This phenomenon made even fine particles up to 10 μm to be able to process by gravity concentration. One of the widely used centrifugal concentration is known as Knelson Concentrator (KC). KC is currently widely used to recover gold and other precious minerals because of its excellent separation performance. It can achieve extensively high recoveries of gold from alluvial and primary ore deposits over a wide range of particle size (Koppalkar 2009).

The principle of a KC separation is based on the difference in the settling rate of minerals in the centrifugal field under the action of opposite direction of fluidization water. As soon as the slurry enters the conical bowl and descends onto the base plate at the bottom of the rotating conical bowl through the central feed pipe, the particles move immediately toward the conical wall of the concentrate bed at different rates depending on their sizes and specific gravities. At the same time, fluidization water at high pressure is tangentially injected opposite to the bowl rotation direction, creating a fluidized concentrate bed. Under the effect of the centrifugal force and water fluidization, particles with higher settling rates settle in the rings on conical bowl as a concentrate, while the lighter particles of gangue minerals are moved out of the bowl by the upward flow slurry as tailings (Chen et al. 2020).

Indonesia is famous of its primary and alluvial gold ore. One the primary gold ore deposit is located at Kotanopan, Mandailing Natal Districts, North Sumatera Province. Primary ore is characteristically available in fine particle size (-75μm) associated with quartz or complex sulfide ores. However, the concentration of Mandailing Natal gold ore by using enhanced gravity separation, specifically Knelson Concentrator have not yet been investigated over -200# of particle size.

2. METHODS

2.1 Preparation

The sample was taken from Mandailing Natal deposit (North Sumatera). In order to be able to process by mineral dressing, the particle size of ores were reduced in two-stage crushing using laboratory jaw and double roll crusher until -10μm. After that, the samples were prepared via grinding in a laboratory ball mill to get the desired size (P_{80} 75 μm). Some of the grind particles were split into 27 bags to get the homogenous sample and then taken into mineralogy analysis using microscope as well as composition analysis using fire assay method.

2.2 Concentration

A laboratory–scale Knelson Concentrator was used for performing the experiments. The variable used in this experiments consists of pulp density variations (20, 25, and 30% of solid), feeding rate (0.5; 0.7; and 0.9 kg/minutes), and also the variations of water fluidization pressure (2.4; 2.7; and 3 kg/cm^2). Both concentrate and tailing produces from the KC were filtered to separate the solid and liquid using filter press machine. The solid were taken into fire assay method to analyze the gold contained in the concentrate.

In order to simplify the naming of samples, A symbols was used as pulp density variable, B for feeding rate variables, and C for water fluidization pressure. The details of sample codes can be seen in Table 1. For example, sample code A1B1C1 means the sample was gravitationally concentrated using Knelson with 20% of pulp density, 0.5 kg/min of feeding rate, and 2.4 kg/cm^2 of water fluidization pressure.

Table 1. Sample Code

(a)

B \ A	**20 %**	**25 %**	**30 %**
0.5 kg/menit	A1B1	A2B1	A3B1
0.7 kg/menit	A1B2	A2B2	A3B2
0.9 kg/menit	A1B3	A2B3	A3B3

(b)

AB \ C	**2.4 kg/cm^2**	**2.7 kg/cm^2**	**3.0 kg/cm^2**
A1B1	A1B1C1	A1B1C2	A1B1C3
A2B1	A2B1C1	A2B1C2	A2B1C3
A3B1	A3B1C1	A3B1C2	A3B1C3
A1B2	A1B2C1	A1B2C2	A1B2C3
A2B2	A2B2C1	A2B2C2	A2B2C3
A3B2	A3B2C1	A3B2C2	A3B2C3
A1B3	A1B3C1	A1B3C2	A1B3C3
A2B3	A2B3C1	A2B3C2	A2B3C3
A3B3	A3B3C1	A3B3C2	A3B3C3

3. RESULTS AND DISCUSSION

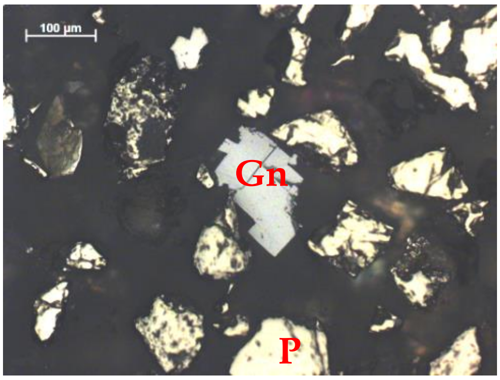
3.1 Ore Analysis

As the result of fire assay analysis of primary ore, the head grade was known having 5 g/t of gold and 7 g/t of silver. Mineralogy analysis was also conducted to find out the mineral composed and also the degree of liberation of the minerals. The minerals compound in Mandailing Natal ore were shown in Table 2 as follow:

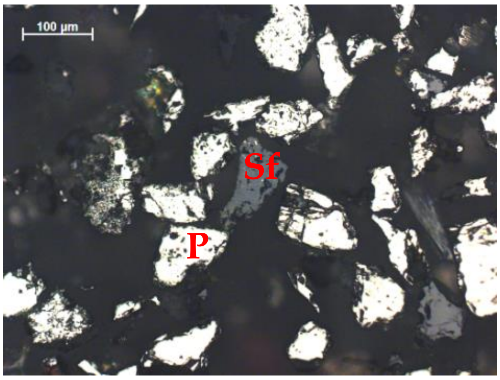
Table 2. Mineralogy analysis

Mineral	Formula	Specific Gravity	Notation
Pyrite	FeS_2	4.9-5.2	P
Sphalerite	ZnS	3.9-4.1	Sf
Galena	Pbs	7.4-7.6	Gn
Chalcopyrite	$CuFeS_2$	4.1-4.3	Cp
Covelite	CuS	4.6	Cv
Magnetite	Fe_3O_4	5.5-6	Mag
Hematite	Fe_2O_3	5-6	Hem

The morphology of minerals was identified using microscope as the results shown in Fig.1 below:



(a)



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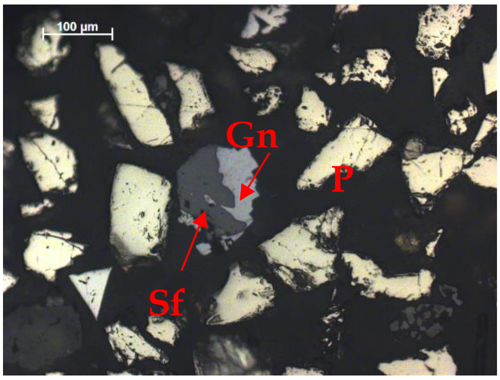

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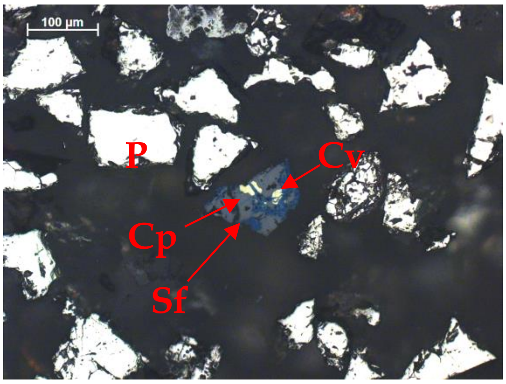

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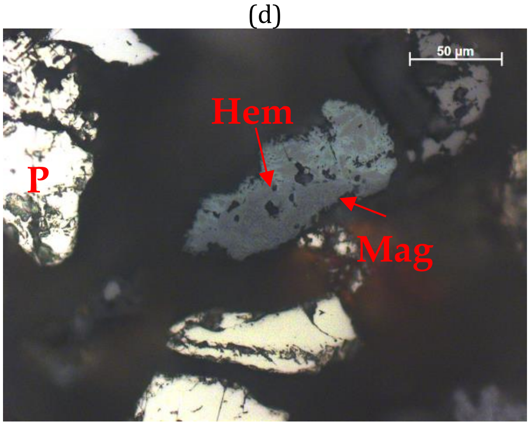

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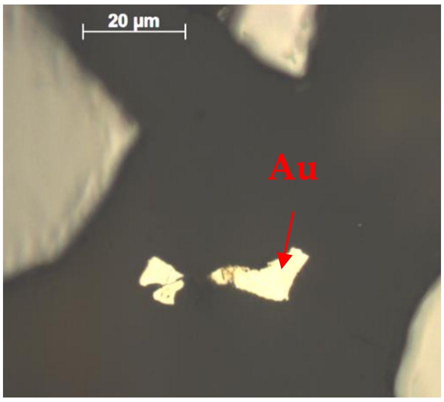


(g)

Fig. 1. Morphology of Mandailing Natal ore

As the result of mineralogy analysis, Mandailing Natal Ores was classified as complex sulfide ore as the present of pyrite, sphalerite, galena, chalcopyrite, and covelite as shown in Table 2. Sieve analysis was also conducted to consider the particle size distribution. Each of the sieve particles was observed under microscope to evaluate the degree of liberation of gold. The result can be seen in Fig. 2 below:

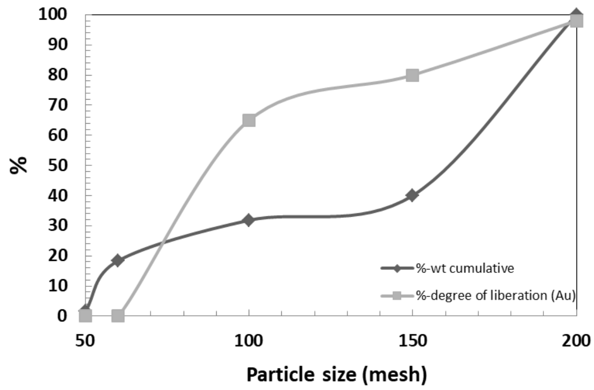


Fig. 2. Sieve and degree of liberation analysis

As the result shown int Fig 2, 98% of gold was liberated when the particle size passing 200 mesh. The degree of liberation refers to the percentage of the mineral occurring as the free particles in the broken ore in relation to the total mineral content in locked and free particles (Wills). The higher the degree of liberation, the higher the chance for gold to be separated in mineral dressing as the surface area increased.

3.2 Report of Sieve Analysis and Degree of Liberation

Sieve analysis and degree of liberation are conducted to analyze the weight distribution of each fraction as well as the distribution of gold particle. Sieve analysis was done by using ASTM sieve in wet condition along 40 minutes. The degree of liberation was found out by observing through polarization microscope. The result can be seen in Table 3.

Table 3. Results of sieve analysis and degree of liberation

No	Fraction (*Mesh*)	Retained (gr)	Retained (%)	Cum. (%)	Gold Liberation (%)
1.	+50	1.79	0.37	0.37	-
2.	-50+60	6.23	1.29	1.66	-
3.	-60+100	81.03	16.73	18.39	-
4.	-100+150	65.12	13.44	31.83	65.00
5.	-150+200	39.83	8.22	40.05	80.00
6	-200	290.45	59.95	100	98.00
	Jumlah	484.45	100		

From the Table 3. above, it can be concluded that 98% of gold was free from any impurities at -200 mesh (75 µm) of particle size. Moreover, to be able to separate the gold from impurities in dressing stage, the ore should be ground up to -200 mesh.

3.3 Effect of Pulp Density

The pulp density was varied in 20, 25, and 30 wt-% of solid. The experimental results show that an increase in %-solid also increases recovery up to a certain point and decreases after reaching a dynamic equilibrium point. Figure 3. illustrates an increase in recovery at 25% solid (A2) and decreases when% solid is increased to 30% (A3). This occurs in every change in the conditions of variables B and C. The highest recovery is achieved in the condition of variable A2B2C2, which is equal to 87.08%. The lowest recovery occurred in the experiment with the A1B3C1 variable depicted in Fig. 3 (c), which is 83%.

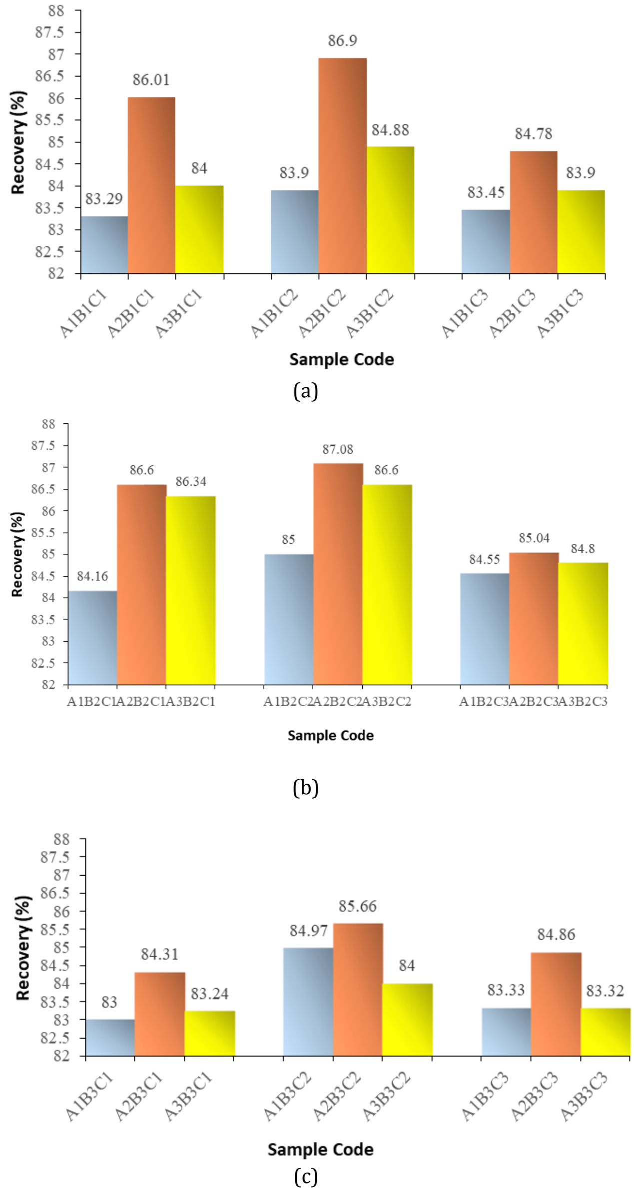
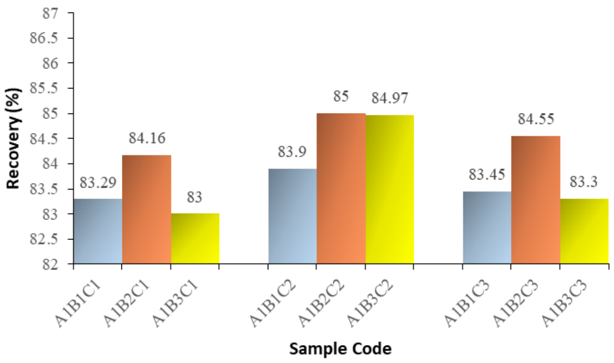


Fig. 3. Effect of Pulp Density

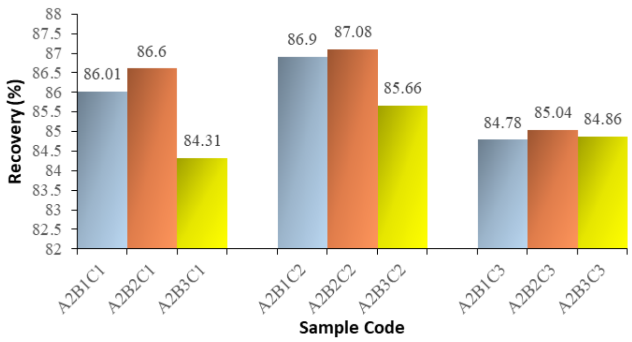
Increasing the %-solid in the separation process resulted in more particles involved in the separation process. As can be seen in Fig. 3, %-solid reached above the optimum dynamic balance caused the drag force generated by the flow of fluidization water being blocked by other particles. The higher the particles would increase inter-particle collisions. Hence, there were a lot of tailings trapped in the concentrate bed as such reducing the gold recovery. Meanwhile, the lower pulp density caused many particles thrown as tailings due to the greater fluid force. In addition, the decreasing of %-solid reduced the number of particles involved in the process as such decreasing inter-particle collisions. The experimental results showed that ascending of pulp density resulted the increasing of gold recovery up to a certain point and then decreasing after reaching a dynamic equilibrium point.

3.4 Effect of Feeding Rate

The relationship between interparticle collisions and gold mineral recovery in the concentrate bed is also controlled by feeding rate. The greater the feed rate is directly proportional to the increase in interparticle collisions. This is due to the fact that many particles enter the Knelson Concentrator bowl, but the increase in interparticle collisions reduces the drag force that causes the trapped mineral gangue to be unable to escape. At the same time when the feed rate is large and the percent solid is large, the recovery obtained is also greater.



(a)



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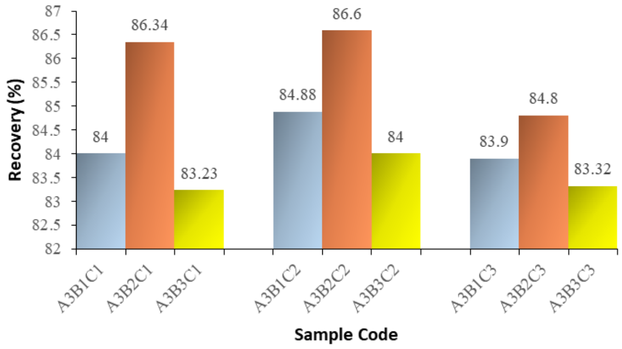


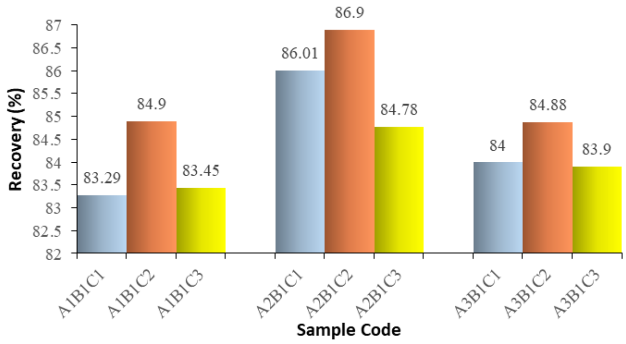
(c)

Fig. 4. Effect of Feeding Rate

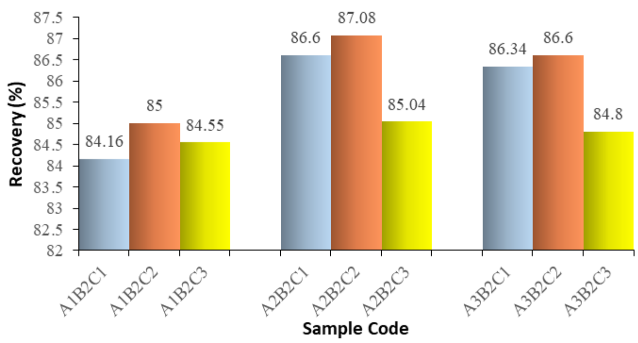
This comparison can be seen between the graphs in Fig. 4(a) and 4(b). Research shows that increasing the feeding rate increases recovery to a dynamic equilibrium point with a feed rate of 0.7 kg/min. Recovery decreased when the feed rate was increased by 0.9 kg/min. At the largest feeding rate, the concentrate bed was filled faster by particle gangue and caused more gold particles to be wasted into the tailings launder. This can be seen in Fig. 4. The highest recovery is achieved in A2B2C2 conditions (A2 = 25% solid; B2 = 0.7 kg/minute; C2 = 2.7 kg/cm2) of 87.08% illustrated in Fig. 4(b) and the lowest recovery was achieved at A1B3C1 (A1 = 20% solid; B3 = 0.9 kg/minute; C1 = 2.4 kg/cm2) of 83% as shown in Fig. 4(c).

3.5 Effect of Water Pressure

The effect of water pressure on recovery can be seen in Fig. 5 below:



(a)



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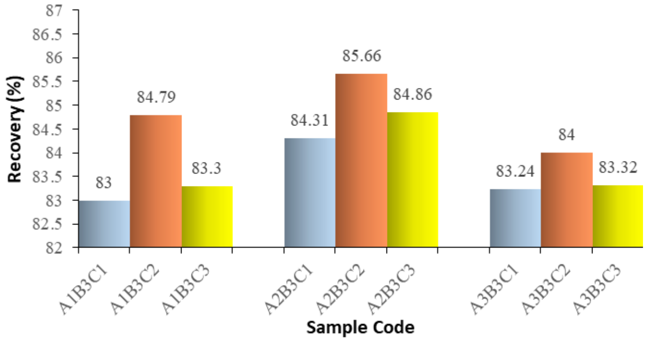

Fig. 5. Effect of Feeding Rate

Fig 5. illustrate the increasing in recovery as the water pressure increased to a point of dynamic equilibrium. The dynamic equilibrium point for the fluidization water pressure was reached when the fluidization water pressure applied to the concentrate bed causes gangue particles that have much lower density than gold to be thrown out as tailings, while gold ore remains in the concentrate bed. The throwing of gangue particles out of concentrate bed is caused by the fluidization water which generates drag force. The large fluidization water pressure generates a large drag force, which will push the gangue particles out of the concentrate bed. This was proved at Fig. 4vof all the experiments carried out, every time the fluidization water increased, the amount of tailings always increased. The highest recovery was achieved at water pressure of 2.7 kg/cm^2, namely 87.08% and the lowest recovery occurred at A1B3C1 at 83%. Recovery decreased when water pressure was increased to 3.0 kg/m^2. The higher the water pressure increased the drag force of the particles out of the concentrate bed. As the result, not only the gangue particles are thrown out, but also the very fine gold particles are wasted along with the tailings due to the large pressure of the water applied.

4. CONCLUSION

Based on this research, it can be concluded that solid percentage, feed rate, and fluidization water pressure affect the concentration process of Mandailing Natal North Sumatra gold ore using Knelson Concentrator. The experimental results show an increase in %-solid, feed rate, and fluidization water pressure can increase recovery to the point of optimal dynamic equilibrium, then recovery will decrease as the percentage of solid, feed rate, and fluidization water pressure increased above the optimal dynamic balance. Furthermore, the optimum variable is achieved at% solid 25% (A2), feed rate 0.7 kg/minute (B2), and water pressure 2.7 kg/cm^2 (C2). The maximum recovery achieved was 87.08% with and grade 17.88 g/t of gold recovered.

5. ACKNOWLEDGMENTS

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