Study of the optimization of gold ore concentration using gravity separator (shaking table): case study for LS epithermal gold deposit in Artisanal Small scale Gold Mining (ASGM) Paningkaban, Banyumas, Central Java

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Abstract. Aiming to increase the concentration of gold ore from LS epithermal gold deposit Paningkaban, Banyumas, Central Java related to its characteristic, shaking table has been applied in the development of non-amalgamation technique for artisanal miners. Many parameters affect the results of processing the gold concentration using a shaking table. The parameters studied in this research are gold grain size fraction, water flow rate, and shaking table speed. With an objective to determine the optimum condition, this study was designed using statistical approach Response Surface Method (RSM) at which all of the variables were varied altogether. The research method is to process the gold using shaking table with three levels approach, so that in total there were 27 concentrates to analyze using Fire Assay (FA) and further assessed using RSM to distinguish the interaction among parameters and the optimum condition. For the gold ore deposit from Artisanal Small scale Gold Mining (ASGM) in Paningkaban, Banyumas, Central Java with the formation of low sulfidation epithermal, the results showed that the highest gold was 3688 ppm with operating conditions ie gold grain size fraction of \(-100 + 200\) mesh (-149 + 74 micron), water flow rate of 18 l/min and shaking speed of 100 rpm. From the RSM assessment it was obtained that optimum operating conditions is on gold grain size of \(-100+ 200\) mesh (87,2576 micron), water flow rate of 9 l/min and shaking speed of 100 rpm. Thus, shaking table could be an alternative non-amalgamation technique to process LS epithermal gold ore in Paningkaban creating a sustainable ASGM.

1. Introduction
The gold processing carried out by Artisanal Small scale Gold Mining (ASGM) generally uses the amalgamation method, which is the process of extracting gold particles by mercury and forming amalgam (Au - Hg). Amalgam is the simplest and most inexpensive gold extraction process, but this process is effective in fully or partially liberated gold in particle sizes of 0.07 mm - 1.5 mm [6] and forms free pure gold (free native gold) with a maximum recovery capability of 30% [11]. ASGM in
poor and developing countries is one of the biggest causes of environmental pollution due to mercury being discharged into the environment, because almost all mercury is discharged into the environment [2]. The ASGM sector is the largest sector in the use of mercury in the world [12]. Indonesia is the 3rd highest mercury polluted country in the world, after China and the Philippines [2]. The use of mercury as a heavy metal in gold processing is very dangerous for the environment. One method of processing gold that does not use heavy metals is gravity concentration, which separates valuable minerals with their impurities or associated minerals based on their specific gravity and grain size. Many methods in this concentration of gravity, one of which is a shaking table. Recovery gold using a shaking table can reach > 90% in grain sizes 3 mm-70 μm and it can still reach > 70% in 50 μm gold grains [3]. Based on the results of the mineragraphy analysis in this study, Paningkaban epithermal gold deposits have a gold grain size between 10-100 μm. The purpose of this study was to determine the optimization of gold grade in gravity concentrations using a shaking table with grain size parameters, water flow velocity and shake table speed. So that optimization of gold grade can be achieved in these parameters.

2. Methods

2.1. Study Area
Paningkaban epithermal gold deposits originated from ASGM located in Paningkaban Village, Gumelar District, Banyumas Regency, Central Java. The location of this research is located at coordinates S 07° 24'48" - 07° 24'55", E 108° 59'48" - 108° 59'59" (Figure 1.).

![Figure 1. Study area map of Paningkaban.](image)

2.2. Research stage
Stages in the optimization of grade begins with processing Paningkaban epithermal gold deposits, namely:
- Reducing the size of deposits (comminution) by destroying rocks using a crusher to the size of ± 0.5 cm
Grinding which aims to liberate or release valuable minerals from gangue minerals by using a 2-hour milling tool and 7 rods (based on previous research).

Sieving milling samples with sieve size of 100 mesh, 200 mesh and 270 mesh so that there are 3 grain size fractions namely -100 + 200 mesh, -200 + 270 mesh and -270 mesh.

Gravity concentration using a shaking table with a test parameters combination, namely the fraction of the grain size (mesh), water flow velocity (l/minute) and shaking table speed (rpm), each of which has 3 levels (Table 1). Of the three parameters, 27 test combinations were obtained (Table 2), thus requiring 27 samples weighing 300 grams each.

Conducting gold grade tests before and after gravity concentration using Fire Assay (FA) analysis conducted at the Geoservices Laboratory in Jakarta.

Optimization of gold grade from gravity concentration using the software Minitab 17.

### Table 1. Parameters of shaking table.

|                | 1             | 2             | 3             |
|----------------|---------------|---------------|---------------|
| Fraction of gold (mesh) | A -100+200    | -200+270      | -270          |
| Flow rate water (l/minute) | B 9           | 18            | 24            |
| Shaking table speed (rpm)  | C 100         | 150           | 200           |

### Table 2. Parameter combination of sample.

|                | B1 | B2 | B3 |
|----------------|----|----|----|
| Fraction A1 (-100+200 mesh) | C1  | A1B1C1 | A1B2C1 | A1B3C1 |
|                | C2  | A1B1C2 | A1B2C2 | A1B3C2 |
|                | C3  | A1B1C3 | A1B2C3 | A1B3C3 |
| Fraction A2 (-200+270 mesh) | C1  | A2B1C1 | A2B2C1 | A2B3C1 |
|                | C2  | A2B1C2 | A2B2C2 | A2B3C2 |
|                | C3  | A2B1C3 | A2B2C3 | A2B3C3 |
| Fraction A3 (-270 mesh) | C1  | A3B1C1 | A3B2C1 | A3B3C1 |
|                | C2  | A3B1C2 | A3B2C2 | A3B3C2 |
|                | C3  | A3B1C3 | A3B2C3 | A3B3C3 |

### 3. Result

Based on the results of laboratory analysis using the FA that the gold grade before gravity concentration on each grain size fraction can be seen in table 3, while the gold grade after gravity concentration with the above test parameters can be seen in table 4.

### Table 3. Grade of Au before concentration gravitation.

| Grade of Au (ppm)        |
|--------------------------|
| A1 (-100+200 mesh/-149+74 micron) | 9,59 |
| A2 (-200+270 mesh/-74+53 micron)   | 1,72 |
| A3 (-270 mesh/-53 micron)              | 1,25 |
Table 4. Grade of Au after concentration gravitation.

| Sample A1 | Grade of Au (ppm) | Sample A2 | Grade of Au (ppm) | Sample A3 | Grade of Au (ppm) |
|-----------|-------------------|-----------|-------------------|-----------|------------------|
| A1B1C1    | 224               | A2B1C1    | 2104              | A3B1C1    | 444              |
| A1B1C2    | 703               | A2B1C2    | 1641              | A3B1C2    | 435              |
| A1B1C3    | 955               | A2B1C3    | 311               | A3B1C3    | 833              |
| A1B2C1    | 3688              | A2B2C1    | 122               | A3B2C1    | 25               |
| A1B2C2    | 318               | A2B2C2    | 57                | A3B2C2    | 41               |
| A1B2C3    | 302               | A2B2C3    | 28                | A3B2C3    | 12               |
| A1B3C1    | 240               | A2B3C1    | 160               | A3B3C1    | 31               |
| A1B3C2    | 496               | A2B3C2    | 73                | A3B3C2    | 47               |
| A1B3C3    | 323               | A2B3C3    | 44                | A3B3C3    | 47               |

After the results of concentration concentration analysis were obtained, optimization analysis was performed using the Response Surface Method (RSM). The optimization results can be seen in Figure 2., Figure 3, and Figure 4.:

**Figure 2.** Au (ppm) vs Flow rate of l/ minute; Fraction (micron). Figure (A) is a description of the results of concentration analysis in 2 dimensions and image (B) is a description of the results of concentration analysis in 3 dimensions.

The 2-dimensional image in Figure 2 explains that Au levels > 1000 ppm will be achieved (dark green) in grain size fractions of about 96 microns, flow rate of about 14 l/min, and shaking table speed of 150 rpm. The value of Au content will be clear when viewed in 3-dimensional figure (B).
Figure 3. Au (ppm) vs Flow rate of l/minute; Shaking Table Speed (rpm). Figure (A) is a description of the results of concentration analysis in 2 dimensions and image (B) is a description of the results of concentration analysis in 3 dimensions.

The 2-dimensional image in Figure 3 (A) explains that Au levels will reach 1600 ppm (dark green) on the combination of parameters between the shaking table speed of about 100 rpm, water flow of 9 l/min and grain size fraction of 82.75 microns. This value will be clearly seen in 3-dimensional image (B).

Figure 4. Au (ppm) vs. fraction (micron) levels; Shaking Table Speed (rpm). Figure (A) is a description of the results of concentration analysis in 2 dimensions and image (B) is a description of the results of concentration analysis in 3 dimensions.

The 2-dimensional image in Figure 4. explains that Au levels will reach 1000 ppm (dark green) on the parameter combination between 120 rpm shaking table speed, grain size fraction of about 93 microns and water flow of 16.5 l/min. The value of Au will be clearly seen in Figure 3 (B).

The three combinations of the results of RSM analysis above, it obtain the gold grade optimization as in Figure 5. below:
Figure 5. Optimization operation conditions of the Au Paningkaban deposits.

Grade optimization of the Paningkaban deposits can be expressed by the following equation:
Grade of Au (ppm) = 2274 – 26.9 Shaking table speed (rpm) + 59 Fraction (micron) - 202 Flow rate (l/min) + 0.002 Shaking table speed (rpm) * Shaking table speed (rpm) - 0.414 Fraction (micron) * Fraction (micron) + 1.48 Flow rate (l/min) * Flow rate (l/min) + 0.114 Shaking table speed (rpm) * Fraction (micron) + 0.684 Shaking table speed (rpm) * Flow rate (l/min) + 0.259 Fraction (micron) * Flow rate (l/min)

4. Discussion
The type of gold deposits in ASGM in Paningkaban is epithermal gold deposits. Epithermal gold deposits are gold mineralization formed at shallow depths, which are the parent rocks of Au, Ag, and base metals, as well as Hg, Sb, S, kaolinite, alunite and silica [8]. Epithermal deposits are deposits resulting from hydrothermal activity associated with volcanism at shallow depths and low temperatures. Precipitation occurs approximately 1 km from the surface at temperatures between 50 °C - 200 °C, although the commonly known temperature is 300 °C [4].

The minerals found in Paningkaban epithermal gold deposits are quartz, sericite, chlorite, pyrite, calcite, kaolinite and carbonate minerals. Quartz and carbonate minerals are the minerals that dominate these deposits up to 50%. Detection of calcite shows that Paningkaban epithermal deposits are carbonated, which is a type of low sulfidation epithermal gold deposit with Carbonate base metal type [7]. From the minerals found above, the alteration that occurs is phyllic alteration characterized by the presence of sericite-quartz-pyrite ± carbonate ± chlorite and argillic alteration, characterized by the abundance of clay minerals.

The ore minerals found are sphalerite, pyrite, chalcopyrite, galena, gold, and electrum. In observing the polish section, the presence of pyrite, chalcopyrite, sphalerite and galena is very abundant. While arsenopyrite was not found, so the As metal contained in minerals was estimated as arsenian pyrite.

Based on the chemical analysis of gold using SEM-EDS that the Paningkaban gold region has an Ag content > 20%, even up to 58%. Gold ores containing 20% -40% Ag, the type of gold mineral is called electrum, whereas if Ag > 40%, then the type of gold mineral is silver containing gold (aurian silver)[5]. According to [9] stated that the Ag content in electrum is 25% -55%. In general, the type of gold mineral in Paningkaban is electrum.

Gold in Paningkaban deposits has grain sizes between 10-100 microns (from microscopic observations of ore and SEM_EDS), which are categorized as very fine grain size of gold [3]. The size
of gold grains> 0.1-100 microns is categorized as microscopic size because they can still be observed using a microscope [5].

Gangue minerals in Paningkaban deposits are quartz (Qz), sericite (Ser), chlorite (Chl), pyrite (Py), calcite (Cal), kaolinite (Kln), and carbonate minerals (Cb). Mineralogy of associated minerals is very important in the process of gold processing, especially in the grinding process and determine the effectiveness of the right method in obtaining gold metal.

Mineralogy is the main factor influencing gold processing using gravity methods in general are liberation, gold grain size, gold mineral association, surface chemistry, and coating and rimming [1].

The size of gold grains and impurity minerals are characteristics of gold deposits which affect the process of gravity concentration. The impurity minerals in Paningkaban gold deposits are generally dominated by calcite, pyrite and quartz which each have a density of 2.71; 5 and 2.65; while the density of gold is 15.6 -19.3. Based on the calculation of the Concentration Criterion (CC) value to determine the effectiveness of gravity separation, the CC value is> 2.5 which means that gravity separation is easy to do. However, this gravity separation is easy to do if the gold metal has been liberated properly from its impurity minerals, so liberation is an important factor in the process of mineral separation by gravity.

One of the gravity concentration tools is the shaking table. There are many factors that must be considered in the gravity shaking table method, namely the particle size of gold particles, the shape of the grain (flatness), grain surface texture, the presence of other minerals attached to gold, other types of particles, dilution of the feed, and smoothness of the feed. Gravity concentration is not or less effective if the grain is flatness, small grain size or attached to quartz [3].

The size of Paningkaban gold deposits grains includes an effective size range when gravity concentration is carried out using a shaking table of 3 mm - 15 µm [10]. The degree of liberation will affect the recovery of gold, the effectiveness of the gravity concentration will be achieved if the mineral has been liberated properly. Gold recovery using a shaking table can reach> 90% if the size of the gold grains is 3 mm - 70 µm, and can still reach> 70% in the size of 50 µm gold grains [3]. Gravity concentration uses a shaking table on the size of gold grains> 40 µm so that the gold can reach 90%, whereas if the size of the gold grain is 20-40 µm then the gold recovery is only 20% and if the size of the gold grain < 50 µm is only the most efficient chemical method [13].

The shape of the gold grain also affects the process of gold processing using the gravity shaking table method. Flakey gold is a grain of gold that has a shape with a larger surface area so that it can be light and carried on the tailings, as well as hydrophobic gold which is the surface of gold that likes the air so that the density is low and falls as tailings. The smaller the size of gold grains is usually not round (non-spherical) and the type is in pieces or flaky, this is because gold is malleable. This flaky form (flakey gold) causes the particle density to decrease and is like the air (hydrophobic), which causes gold grains to float when gravity is concentrated using a shaking table and will fall on middling or tailings, especially in fine grain. The gold grain surface is often coated by a hydrophobic organic layer or iron oxide and some free impurities (such as silver) are left on the grain surface, all of this causes surface hydrophobic.

Gold metal has a density of 15.6-19.3 so it is very easy to separate gold from its impurities such as pyrite, calcite, quartz, galena, spalerit which have a density of 5; 2.71; 2.65; 7.5; and 4, respectively. But gold metal will be more difficult to be gravitationally concentrated if it has not been fully liberated or still attach to the impurity mineral, which causes the gold density to decrease so that when the concentration process will be carried on the tailings. This happens because even though the weight of the gold metal is large (15.6-19.3) but if it is still attached to quartz with a small specific gravity (quartz 2.65), the gold grains will be concentrated as middling or tailings, especially if the gold form is flat (flakey gold) and small grain size.

The recovery of gold after gravity concentration is very dependent on the characteristics of the initial level and the content of sulfur in a deposits. Gold grade in Paningkaban deposits is 0.265-76 ppm, content of sulfur (S) element based on the analysis results has a value between 4.84% -15.7%. Gold grade before the gravity concentration was carried out at the fraction size of -149 + 74 microns (-
100 + 200 mesh) was 9.59 ppm, and the gold grade after the gravity concentration reached a value of more than 1000 ppm (figure 2), more than 1600 ppm (figure 3) and more than 1000 ppm (figure 4) on the size of the fraction. Figure 2, Figure 3 and Figure 4 shows that the gold grade will be high in the fraction of grain size -100 + 200 mesh (-149 + 74 microns). This means that gold in grain sizes of -149 + 74 microns is a lot of gold metal, some of which has been liberated and some are probably still bound by other minerals, besides that the biggest size of Paningkaban gold grains is around 100 microns. The fraction size of smaller gold grains has a lower gold grade due to several possibilities, generally the smaller the grain size, the more granules that have been liberated (perfectly liberated), but the granular form factor affects the recovery of gold grade, if the spherical grain shape then in the concentration process using a shaking table, minerals with large density will be concentrated as concentrates (not as middling or tailings), while the shape of the flaky grains (flakey gold) causes the particle density to decrease and is like air (hydrophobic) so the density becomes smaller and float so that when there is water flow, there is a possibility that gold metal will be carried by water and concentrated as middling or tailing.

Excessive milling and low liberation can lead to low yields of valuable minerals so it is very important to look for optimum milling operating conditions to obtain the desired degree of liberation [14]. The optimum gold grade of Paningkaban deposit (using the Minitab version 17 program), at its optimum operating conditions is 100 rpm shaking table speed, grain size fraction 87.25 microns and water flow rate of 91 / min, is 1678.62 ppm (Figure 5).

Recovery of gold grade will be optimum in the grain size fraction of 87.25 microns, where the grain size fraction is at -100 + 200 mesh (-149 + 74 microns). This shows that the smaller the grain size fraction does not determine the amount of gold grade, although in general the smaller the size of the gold grain, the gold metal may have been perfectly liberated, but due to the malleable nature of the gold grain, the smaller the size of the gold grain is usually non-round (non-spherical) and the type is in pieces or flaky (flakey gold) so that the specific gravity becomes smaller and causes gold grains to be concentrated as middling or tailing.

5. Conclusion
Recovery of optimum gold grade in the grain size fraction 87.25 microns, where the grain size fraction is at -100 + 200 mesh (-149 + 74 microns). This shows that the smaller the grain size fraction does not determine the amount of gold grade due to the malleable nature of the gold grains, the smaller the size of the gold grains is usually non-spherical and the type is smashed (flakey gold) so specific gravity becomes smaller and causes gold grains to be concentrated as middling or tailing.

Acknowledgment
I would like to express my gratitude to the Ministry of Research, Technology and Higher Education (RistekDIKTI) who have provided Beasiswa Pendidikan Pascasarjana Dalam Negeri (BPPDN) during the doctoral studies.

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