Study on Sumbawa gold ore liberation using rod mill: effect of rod-number and rotational speed on particle size distribution

A Prasetya, A Mawadati, A M R Putri and H T B M Petrus

Center of Advanced Material and Sustainable Mineral Processing
Department of Chemical Engineering, Universitas Gadjah Mada,
Jl. Grafika 2 Yogyakarta 55281, Indonesia

E-mail: bayupetrus@ugm.ac.id

Abstract. Comminution is one of crucial steps in gold ore processing used to liberate the valuable minerals from gauage mineral. This research is done to find the particle size distribution of gold ore after it has been treated through the comminution process in a rod mill with various number of rod and rotational speed that will results in one optimum milling condition. For the initial step, Sumbawa gold ore was crushed and then sieved to pass the 2.5 mesh and retained on the 5 mesh (this condition was taken to mimic real application in artisanal gold mining). Inserting the prepared sample into the rod mill, the observation on effect of rod-number and rotational speed was then conducted by variating the rod number of 7 and 10 while the rotational speed was varied from 60, 85, and 110 rpm. In order to be able to provide estimation on particle distribution of every condition, the comminution kinetic was applied by taking sample at 15, 30, 60, and 120 minutes for size distribution analysis. The change of particle distribution of top and bottom product as time series was then treated using Rosin-Rammler distribution equation. The result shows that the homogenity of particle size and particle size distribution is affected by rod-number and rotational speed. The particle size distribution is more homogeneous by increasing of milling time, regardless of rod-number and rotational speed. Mean size of particles do not change significantly after 60 minutes milling time. Experimental results showed that the optimum condition was achieved at rotational speed of 85 rpm, using rod-number of 7.

1. Introduction

Indonesia is a country rich in natural resources. One of those resources is gold. Production of gold in Indonesia reaches 100 ton/year (https://www.orori.com/). In nature, gold is not found in its pure form, this exists in rocks which is called ore. Purification process of rock containing gold is commonly done in Indonesia, both traditionally in small scale and production of bigger scale with modern technologies [1]. Gold processing by traditional method known as amalgamation method. The principle of this method is to bind the gold contained in the rock by using mercury. Amalgamation method consists of several processes, such as size reduction process, mixing process, collecting and settling process, panning and washing process, and heating process [2, 3]. Gold purification method by amalgamation is harmful to the environment. Panning and washing process are usually done in the river where the remaining mercury will be carried by the water flow and thus contaminate the river [4]. Meanwhile, the mercury that evaporates during the heating process will be carried by the air. This will harm the health of the surrounding community. Based on that fact, gold purification method of amalgamation needs to be replaced by other methods which are more environmentally friendly.
An example of an environmentally friendly gold purification method is the gravity method. This method separates gold from its impurities by using gravitational force. This process utilized a tool called sluice box. The working principle of this tool is to drain the water on the crushed slurry ore where the other minerals with the lower density than gold will be carried by the water while the gold itself will be left and settled. This separation process will work well if the particles (non gold particles) have uniform size (homogeneous) [5-7].

In order to obtain particles of small size and homogeneous, the ore will go through comminution stage by grinding process (milling). In the mining world, this comminution process plays a role in liberating precious minerals (gold) from the impurities. In this research, the selected milling process is the process done by rod mill. Rod mill is a grinding process using a rotating cylindrical spindle. The grinding media is usually made of steel and arranged parallel to the mill. The result of this grinding process using rod mill is flat rock with flat surface. This flat surface of gold is desirable, as it will increase its effective size during sieving process and ease the separation process by gravity method.

This study uses variations in the number and the speed of rotary rod mill to see which milling process results in the most homogenous particle size distribution. From this study, the most optimum milling process for gold purification using gravity method will be obtained.

2. Methodology

The ore tested in this study is gold ore from Sumbawa, West Nusa Tenggara, Indonesia. Gold ore were crushed using hammer and then screened to get desired size (-2.5/+5 mesh). This condition was taken to mimic real application in artisanal gold mining. The diameter and length of the rod mill are measured using a roll meter. Then the critical speed of rod mill can be calculated by using the critical velocity equation by B.A.Wills. The speed variations used in this study were 60 rpm, 85 rpm, and 110 rpm.

\[
N_c = \frac{42.3}{\sqrt{D-d}} \text{rpm}
\]

\(N_c\) : critical speed, rpm  
D : inner diameter, meter  
d : rod diameter, meter

The observation on effect of rod-number and rotational speed on comminution by using rod mill was conducted by varying the rod number of 7 and 10. The comminution kinetic was applied by taking 1.5 kg sample at 15, 30, 60, and 120 minutes for size distribution analysis. Particle results of each experiment for each rotational speed and each interval of time put into the sieve shaker with sieve size 70, 100, 115, 140, 170, 200, 230 and 270 mesh. The results of the top and bottom of each sieve are weighed using a digital analytical scale. Then by using the data of weighing results at any time could be made a cumulative distribution graph. The change of particle distribution of top and bottom product as time series was then treated using Rosin-Rammler distribution equation.

\[
Y_d = \exp(-A \ (d/d_{avg})^n)
\]

\(Y_d\) : mass fraction of the particles retained in the sieve of size d  
d : sieve size, mm  
d_{avg} : average diameter, mm  
n : size distribution parameters  
A : size distribution parameters

3. Result and Discussion
3.1 The Effect of rod mill rotary speed on particle size distribution of Sumbawa gold ore particle size distribution analysis with Rosin-Rammler equations: Rosin Rammler’s $A$ parameters

Experiment conducted by using rod mill with rod number of 7 on rotational speed of 60, 85, and 110 rpm. The value of $A$ is a parameter in the Rosin-Rammler equation which serves to align the retained mass fraction curve of the experimental results to the outcome of the equation and does not significantly affect to the shape of the curve which describes the homogeneity of the particle size distribution. Based on Figure 1, the value of $A$ is only slightly affected by milling time and is not influenced by the rotational speed of the rod mill. Its value does not significantly affect the homogeneity of the particle size distribution. Based on this experiment, obtained that the value of $A$ is getting bigger with the increasing time of milling. It can be seen on Figure 1 that on the same milling time, the value of $A$ at each rotational speed tends to be same. Therefore it can be concluded that the value of $A$ is not influenced by the size of the rotation speed of the rod mill.

![Figure 1. Time relation chart of value A with number of rod 7 at various rotational speed](image)

3.2 Particle size distribution analysis with Rosin-Rammler equations: Rosin Rammler’s $n$ parameters

The value of $n$ is a parameter in the Rosin-Rammler equation which describes the homogeneity of the particle size distribution. It is affect on cumulative distribution curve. Based on Figure 2, value of $n$ is affected by the milling time and the rotational speed of the rod mill, so that the value of $n$ affects the homogeneity of the particle size distribution.

Based on the experiments, obtained that the value of $n$ is getting smaller as the milling time increases. On the same milling time, there are different values of $n$ at each rotation speed of the rod mill. However, at milling time of 120 min, $n$ values tend to be the same at every rotational speed. Therefore it can be concluded that the value of $n$ is influenced by the rotational speed, but the effect of rotational speed on the value of $n$ decreases with increasing milling time. It can be seen at milling time 120 minutes, the value of $n$ at each rotation speed tend to be the same.

The smaller value of $n$ will result in an increasingly non-homogeneous distribution of particle sizes, so the cumulative distribution curve generated is getting wider. In Figure 2 shows that at almost any point of time, the smallest $n$ value is obtained at a rotational speed of 85 rpm, so that at a rotation speed of 85 rpm is obtained the best particle size distribution, since it is spread in various sizes or not homogeneous.
3.3 Particle size distribution analysis with Rosin-Rammler equations: diameter average

In the experiment using rod number of 7, it indicate that the increasing milling time effect on the smaller diameter average value. The particle size is getting smaller as the milling time increases. In the graph above shows that at the same time milling, \( d_{\text{avg}} \) values obtained at each rotation speed is not much different. The particle size is influenced not significantly by the rotational speed.

Figure 3 shows that at almost any point of time, the smallest \( d_{\text{avg}} \) value is obtained at 85 rpm rotational speed. It can be conclude that the comminution process is fastest at rotational speed of 85 rpm than the two other rotational speeds.

Figure 4 shows at speeds of 60, 85, and 110 rpm with the number of rod 7, as milling time increase, the \( d / d_{\text{avg}} \) value is greater. This is due to the longer milling time, the particle diameter of the milling results will be even smaller, so the diameter average (\( d_{\text{avg}} \)) value will be even smaller. Because the smaller the value of \( d_{\text{avg}} \), the greater the value of \( d / d_{\text{avg}} \). Thus experiments at speeds of 60, 85, and 110 rpm are in accordance with the theory.

At 60, 85, and 110 rpm rotational speeds, the fractional data of the experimental mass (Yd experiments) on the 15 and 30 minutes much less deviate from the mass fractional data of equation (Yd equation), this is probably due to the milling process which has not been stable in the early time. Meanwhile, in the 60 and 120 Yd data the experiment can be said to be in accordance with the data Yd equation.

As the milling time increases, the curve widened as seen on the larger \( d/d_{\text{avg}} \) value. It shows that the particle size distribution is increasingly dispersed (not homogeneous). This increasingly distributed
size distribution is influenced by the smaller value of \( n \) as the milling time increases as shown in Figure 4.

![Figure 4](image)

Figure 4. \( d / d_{avg} \) relation chart with \( Y_d \) at various rotational speed with number of rod 7

3.4 The effect of number of rod on Sumbawa gold particle size distribution

Sumbawa gold particle size distribution analysis with Rosin-Rammler equations: Rosin Rammler’s \( A \) parameters

The experiment using rod mill with number of rod 7 and 10 with a rotational speed of 85 rpm obtain the value of \( A \) which increases with the addition of milling time. However, increasing the value of \( A \) is not significant with increasing milling time. So it can be concluded that the value of \( A \) is slightly influenced by milling time. It can be seen on Figure 5 that with the same milling time, the value of \( A \) on each number of rods tend to be the same. However, at minute 120, a significant difference of value \( A \) of each number of rods is obtained. Therefore it can be deduced that the value of \( A \) is not influenced by the number of rods, but the effect of the number of rods against this \( A \) value will increase with increasing milling time.
Figure 5. Time relation graph of value A with number of rod 7 and 10 at rotational speed 85 rpm

3.5 Particle size distribution analysis with Rosin-Rammler equations: Rosin Rammler’s n parameters
In the experiments with the number of rods 7 and 10 at a rotational speed of 85 rpm obtained the value of n is getting smaller as the milling time increases. Meanwhile, with the same milling time, we get different values of n on each number of rods. However, at milling time of 120 min, we get n values which tend to be the same in both rod numbers. Therefore it can be concluded that the magnitude of the value of n is influenced by the number of rods, but the effect of the number of rods on the value of n decreases with increasing milling time and the smaller particle size, it is seen at milling time 120 min. Already tend to be the same.

Figure 3 shows that at all time points, the smallest n value is obtained on the number of rods of 10 pieces but only slightly different with number of Rod 7 with increasing time of milling process. The number of rods of 10 is obtained the best particle size distribution, because it is spread in various sizes or not homogeneous but the number of rods 7 become more effective compare to number of rod 10.

Figure 6. Time relation chart of value n with number of rods 7 and 10 fruits at rotational speed 85 rpm

3.6 Particle size distribution analysis with Rosin-Rammler equations: diameter average (d_{avg})
The experiments with rotational speed of 85 rpm, indicate that the increasing milling time effect on the smaller the d_{avg} value. This indicates that the particle size is getting smaller as the milling time
increases. At the same milling time, the $d_{\text{avg}}$ value obtained at each rod number is not much different, but with the increasing milling time, the difference in $d_{\text{avg}}$ value is more significant. It can be concluded that the particle size is influenced by the number of rods, and the influence of the number of rods is getting bigger along with the increasing time of milling.

Figure 7 shows that at all time point, the smallest $d_{\text{avg}}$ value is obtained on the number of rods of 10 pieces. It can be concluded that comminution process on the number of rod 10 effects on the smaller $d_{\text{avg}}$ value than the number of rod 7 but the differences is not too significant.

![Graph showing time milling relation chart (t) with average diameter (d_{\text{avg}}).](image)

**Figure 7.** Time milling relation chart (t) with average diameter ($d_{\text{avg}}$)

The experiments with a rotational speed of 85 rpm with the number of rod 7, the longer milling time effect on the greater of $d / d_{\text{avg}}$ value. It is because the longer milling time, the diameter particles will be smaller so the value $d / d_{\text{avg}}$ will be greater. In both graphs on Figure 7, the mass fractional data retained by the experimental results (Yd experiments) on the 15 and 30 minutes are much too distorted from the mass fractioned data of the equation (Yd equation), similar to the previous experiments, probably due to unstable milling processes at the beginning of the time. Meanwhile, in the 60 and 120 minutes, Yd data the experiment is in accordance with the data of Yd equation. Figure 7 show that as the milling time increases, the curve widened as seen on the larger $d / d_{\text{avg}}$ value. The widening curve illustrates the increasingly dispersed (not homogeneous) particle size distribution. This increasingly distributed size distribution is influenced by the smaller value of n as the milling time increases as shown in Figure 8.
4. Conclusions
From this experiment, it can be concluded that the longer the milling time, the less homogeneous the particle size distribution. The higher the rotational speed and the more number of rod will provide higher size reduction. The homogeneous distribution can be obtained in a condition at which the rotational speed is 85 rpm and the number of rods is 10 rods. While Rosin-Rammler could fit and predict the phenomenon occured in this comminution experiment.

References
[1] Aye M T, Pramumijoyo S, Idrus A, Setijadji L D, Imai A, Araki N, Arif J 2011 J. SE Asian Appl. Geol. 3 12-22
[2] Kelly E G, Spottiswood D J 1982 Introduction to Mineral Processing Michigan: John Wiley and Sons pp 132-62
[3] Mular A L, Halbe D N, Barrat D J 2002 Mineral Processing Plant Design, Practice, and Control Littleton: Society for Mining, Metallurgy, and Exploration Inc. 1 p 712
[4] Eugene W W L, Mujumdar A S 2009 Gold Extraction and Recovery Processes Singapore: National University of Singapore pp 5-7
[5] Wills B A 1985 Mineral Processing Technology Cornwall: Camborne School of Mines pp 14-20
[6] Zhou J, Jago B, Martin C 2004 SGS Mineral 3 1-3
[7] Pedersen H K, Andersen A 2007 Geoviden 2 5-6