Effect of Particle Size and Shaking Speed on Enhancing Concentration of Manganese using Shaking Table

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Abstract. Increased levels of elements or minerals from ore are usually always done in the metallurgical industry. In the present investigation, low grade manganese ores from Kulonprogo, Yogyakarta has investigated by gravity methods using shaking table. In this context, the effect of different process variables such as particle size (-60 + 100 mesh; -100 + 200 mesh and -200 + 270 mesh) and shaking speed (80 rpm, 100 rpm and 120 rpm) was analysed. The table slope and wash water flow rate are a constant variable, which are at 11° and 13 dm³/minute. The interactional effects between different process variables were analysed using contour plot. It was founded that enhancement of the concentration of Mn is more than 5% with the shaking speed condition of 100-120 rpm and the particle size of 0.17 mm. Second order quadratic equations have developed to predict enhancement of Mn concentration using shaking table.

1. Introduction
Manganese is one of the metals that has an important role in many industrial and other. Manganese is used as food additives, fertilizer additives, battery dry cells, paint materials, iron steel industries and various other chemicals [1]. Global consumption of manganese metal has reached more than 1.3 million tons per year and is predicted to increase in the future [2]. Manganese resources are found in high grade manganese ore (> 45% Mn) and low grade manganese ore. In the past few decades, the availability of high grade ore has dramatically dropped and resulted to explore and develop manganese processes from low grade ore [3,4]. Kulon Progo, one of the regions in Indonesia, has the low grade manganese ore deposits with 5-10% manganese content in which considerable potential to explore.

Ores processing after mining is mineral processing. It is a process of ore preparation, milling and ore beneficiation. Ore beneficiation is a separate process that is based on the physical properties of minerals. Minerals will be more easily separated by gangue if it has a large difference in physical properties [5,6,7,8,9,10,11,12]. Therefore, this study will focus on the method for increasing the manganese fraction in low grade manganese ore by utilizing one of the physical properties of minerals, specifically density through gravitational separation using shaking table.
The purpose of this study was to determine the effect of particle size and shaking speed to increase the concentration of manganese using shaking table.

2. Materials and methods

2.1. Materials

Low grade manganese ore was mined from Kulon Progo, Yogyakarta Province, Indonesia and was associated with limestone. The chemical components of the different size fractions were carried out and given in the Table 1. It can be seen from Table 1, manganese ore from Kulon Progo is classified as low grade manganese ore (<40%) because it only contains about 4-5% manganese.

**Table 1. Chemical analysis of low grade manganese ore from Kulon Progo**

| Content       | -60+100 mesh | -100+200 mesh | -200+270 mesh |
|---------------|--------------|--------------|--------------|
| Ca (%)        | 32.00        | 34.20        | 36.00        |
| Mn (%)        | 4.92         | 4.80         | 3.77         |
| Fe (%)        | 0.27         | 0.30         | 0.27         |
| Cu (ppm)      | 13.1         | 14.8         | 12.30        |

2.2. Experimental design

Sample puts into the oven at 70-80°C to reduce the water content to facilitate the crushing process. There were three main steps in this research, that are comminution, sieve, and separation using shaking table. In this study, -60+100 mesh; -100+200 mesh and -200+270 mesh particle size were used as feeder of the shaking table. The sample is introduced at the upslope corner of the table (Figure 1). The shaking table was set on a constant table slope and water flowrate, which are at 11° and 13 dm³/minute. The shaking speed variable has been done in three variations, there are at 80 rpm, 100 rpm and 120 rpm. After the separate process, the results of the shaking table are analyzed using XRF to find out the quantitative amount.

![Figure 1. Shaking table scheme](image)

3. Results and discussion

The experiment was conducted using three variations of particle size and three variations of shaking speed to determine the effect of each variable on increasing manganese concentration in ore. The particle size of variations were used at -60 +100 mesh, -100 +200 mesh and -200 +270 mesh. Whereas, the shaking speed of variations carried out at 80 rpm, 100 rpm and 120 rpm. After
conducting the experiment, the results of the shaking table were analyzed using XRF. Increased concentration of manganese in low grade manganese ore can be seen in Table 2.

### Table 2. Increased manganese concentration in low grade manganese ore

| Particle Size (mesh) | Feed Weight (g) | Shaking Speed (rpm) | Weight Concentrate (g) | Increase of Mn Concentration (%) |
|----------------------|-----------------|---------------------|------------------------|---------------------------------|
| -60+100              | 0.0984          | 80                  | 0.1720                 | 3.68                            |
|                      |                 | 100                 | 0.2000                 | 5.08                            |
|                      |                 | 120                 | 0.2140                 | 5.78                            |
| -100+200             | 0.0960          | 80                  | 0.1572                 | 3.06                            |
|                      |                 | 100                 | 0.1968                 | 5.04                            |
|                      |                 | 120                 | 0.1744                 | 3.92                            |
| -200+270             | 0.0754          | 80                  | 0.1432                 | 3.39                            |
|                      |                 | 100                 | 0.1778                 | 5.12                            |
|                      |                 | 120                 | 0.1386                 | 3.16                            |

**Figure 2.** Relation of particle size and shaking speed to increase of Mn concentration

The data in Table 2 are plotted to find out an overview the effect of variables on increasing manganese concentration. Plotting can be seen in Figure 2. From Figure 2, it can be concluded that the larger particle size, the greater manganese concentration is. This is accordance with the existing theory that the larger particle size, the more difficult it carries the flowing water and is restrained by riffles. In addition, motion of the shaking table will push the particle to the concentrate area. Whereas, a small particles will be more easily carried away by the washing water stream which is called tailing. This happens because the concentration in the concentrate is a quite low concentration [13,14]. In Figure 2, it is also seen that the higher shaking speed, the bigger the manganese concentration is resulted at 80 rpm to 100 rpm but the manganese concentration decreased at 120 rpm.

Interaction studies show the effectiveness of the separation that is indicated by the increasing concentration of Mn. There was influenced by the combination of variables that was seen in Figure 3. Figure 3 shows the contour of the shaking speed vs particle size in increasing the concentration of Mn. In Figure 3 can be seen the area with the increasing concentration of Mn is more than 5.5%, which it
happens with the condition of the shaking speed is 100-120 rpm and the particle size is more than 0.17 mm.

![Contour Plot of Increase of Mn Conc. vs Shaking Speed and Particle Size](image)

**Figure 3.** Contour plot of increase of Mn concentration vs shaking speed and particle size

![Response Surface of Increase of Mn Conc.](image)

**Figure 4.** Response surface of increase Mn concentration function of shaking speed and particle size

As can be observed in Figure 4, the highest increase of Mn concentration (5.78%) is achieved at the highest level of shaking speed and particle size. The lower value of Mn concentration (3%) occurs at the lowest shaking speed and particle size of 0.11 mm. The highest of Mn concentration with particle size in 0.2 mm because it has more Mn content than the others (Table 2).
For predicting the increase Mn concentration of shaking table, second order quadratic models have developed and given as,

$$\text{Increase Mn conc. (\% wt.)} = -23.32 - 48.6x + 0.595y + 52.3x^2 + 0.003121y^2 + 0.419xy$$

Where,
- $x$ is particle size ore (mm)
- $y$ is shaking speed (rpm)

the predicted increase of Mn concentration derived by using the above equation is in good agreement with experimental data ($R^2$ value, the accuracy of the model, is 89.51%).

4. Conclusions

Increasing of the concentration of Mn using the shaking table can be reached up to 5% wt. Shaking speed and particle size significantly affected to increase of Mn concentration. From the contour plot, it can be seen that in the range of shaking speed of 100-120 rpm and particle size of more than 0.17 mm, increase Mn concentration more than 5%. The developed second order quadratic equations can be used for predicting the increased of Mn concentration using shaking table, which $R^2$ value is 89.51%.

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