Beneficiation of Lateritic Iron Ore from Malili Area, South Sulawesi, Indonesia Using Magnetic Separator

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Abstract. The increasing demand of sponge iron as raw materials in steel industry nowdays has led to increase the effort in obtaining such materials from various sources. This study aims to characterize and beneficiate of a lateritic iron ore sample from Malili area of South Sulawesi. Mineralogy of the ore was investigated by means of X-ray diffractometry (XRD) and microscopy techniques; whereas chemical composition of the sample was determined by using X-ray fluorescence (XRF) spectroscopy. Result of mineralogical analysis indicated that ore sample consists of goethite, magnetite and chromite. The ore shows fine grained size with accicular texture. Chemical analysis reveals that sample is composed of Fe$_2$O$_3$ 32.8%, Al$_2$O$_3$ 35.5%, SiO$_2$ 21.0%, Cr$_2$O$_3$ 7.2%, MnO 1.5%, and NiO 1.2%. Sieving of 20 kg iron ore sample was carried out to separate into five size fractions: (+212)μm, (-212+180)μm, (-180+150)μm, (-150+90)μm and (-90)μm with mass distribution of 12.0kg; 2.8kg; 0.9kg; 1.8kg and 1.6kg respectively. Each feed fraction was further treated by using dry low-intensity drum magnetic separator to produce concentrate. Result of each fraction having the mass percentage of 15.5%; 31.7%; 30.7%; 32.0%; and 40.0% with the respective iron content (Fe$_2$O$_3$) of 45.0%; 47.9%; 43.9%; 46.7% and 47.2%. The Fe$_2$O$_3$ grade of concentrate in all fractions have narrow range values, but the mass percentage of concentrate increase significantly with finer grain size fraction. The highest Fe$_2$O$_3$ recovery was found to be 89.82% with -90 μm size fraction.

Keywords: iron ore, beneficiation, magnetic separator, goethite, concentrate.

1. Introduction

Lateritic ore is usually formed by chemical weathering containing oxides and hydroxides of iron and aluminum which found in the tropical regions [1]. The estimated resources of lateritic iron ore in Indonesia in measured resource category may reach up to 1.307 billion tons, while its proved reserve is about 297.25 million tons [2]. This kind of ore is dispersed in Lampung, West Java, South Kalimantan, South Sulawesi, Southeast Sulawesi, North Maluku, and Papua. In addition, there are also resources of iron sand, primary iron, and sedimentary iron. One of the lateritic iron deposit in South Sulawesi is located in Malili Area of East Luwu Regency. This deposit is predicted to have about 20 million tons of resource which has been mined by PT Panca Digital Solution in 2010 with the grade of 0.62-0.94 % Ni and 36.2-41.36 % Fe [3].

The iron ore which was formerly economic to be mined has a grade of 60 % Fe. Nonetheless, it has not been longer viable since the 2000s. Nowadays by using the new and simple technology, an iron ore with the grade of 30 % Fe has sufficient for iron ore to be economic mined. In China and India, iron ore...
is processed using simple technology, such as magnetic separator, gravity concentration and blast furnace for iron producing which has already been used by manufacturing industry [4].

Processing of minerals is strongly influenced by its properties, both physical characteristics such as mineralogy, specific gravity, electrostatic, magnetism, and chemical nature of the ore [5]. Consequently, selection of appropriate methods depend on the properties of the. For example, ore with high content in goethite (FeOOH) should be heat-treatment to transform into magnetite before the application of magnetic separation [6-7]. This research aim to examine the mineralogical and chemical composition of lateritic iron ore sample from Malili area and beneficiation of such ore using magnetic separator.

2. Sample and Methods
This research consists of two main stages, there are field and laboratory activity. However, it begun with a literature review on the Malili area, followed by lateritic iron ore sampling in Malili, East Luwu Regency, South Sulawesi Province, exactly in Lamplia Village with coordinate locality lies at 2º44'25.6'' latitude south and 121º05'16.9'' longitude east. Sampling was conducted by scraping method. Sample was taken from lateritic soil profile which has indication of iron-rich material. Sample preparation was begun with air-drying floor or indoor drying method at room temperature for two weeks until the surface water content decreases.

Initial sample of lateritic iron ore was characterized by mineralogical analysis using X-Ray Diffraction (Shimadzu X-7000). Sample preparation was started with grinding using agate mortar until particles passed 200 mesh sieve. Powder sample was pressed to find flat surface on the holder to be tested with X-ray fluorescence (XRF) spectrometer for chemical determination.

In supporting the mineralogical data, microscopic analysis was carried out using a polarized microscope (Nikon Eclipse LV100). For this purpose, sample was prepared by mixing with powder resin and then it was heated and pressed with a mounting press at a certain temperature and pressure. Polishing was done until the sample surface was found to be flat and then it was observed under a microscope. The chemical analysis was conducted with X-Ray Fluorescence (Shimadzu) whereby the sample was prepared first into pellets. It is a kind of sample specimen in the form of a pressed powder by a PVC ring until it solidified.

Beneficiation process for a 20 kg sample of lateritic iron ore was ground using ball mill then it was sieved into five grain size fractions: (+212)μm; (-212+180)μm; (-180+150)μm; (-150+90)μm; and (-90)μm. Each fraction was screened and weighed to determine the grain size distribution and mass of the feed respectively. The feed of each size fraction was beneficiated using magnetic separator. Drum-type magnetic separator is the most widely applied as compared to other types, such as magnetic pulley, plate magnet, grate magnet, and suspended magnet [8]. In this study, we use drum magnetic separator with low intensity. The product of concentrate (magnetic rich material) and tailing (magnetic poor material) resulting from beneficiation were further weighed and chemically analyzed in order to find out recovery.

Figure 1. XRD pattern of a lateritic iron ore sample from Malili (A); Microscopic appearance (Goe: goethite, Hem: hematite, Chr: chromite, Mag: magnetite, Sp: spinel), (B).
3. Results and Discussions

The result of mineralogical analysis using the XRD method exhibit that initial sample of lateritic iron ore is mainly composed by goethite (FeO.OH). It is indicated with the presence of reflection intensity with d-spacing of 4.18 Å and 2.69 Å. Spinel group mineral such as spinel (Al_{0.39}Cr_{1.58}Mg_{0.5}O_{4}) itself, magnetite (Fe_{3}O_{4}) and hercynite (Al_{2.1}Fe_{0.1}O_{4}) are also present in minor quantity, whereas hematite (Fe_{2}O_{3}) and quartz (SiO_{2}) are two oxide minerals which occur in the sample in small amount. Figure 1-A shows the diffractogram of a lateritic iron ore sample.

X-ray diffraction is a reliable and fast method for identifying minerals. The result of mineralogical analysis also showed that mineralogy of the lateritic iron ore has generally poor crystallinity, which is represented by a widening peak shape. The degree of crystallinity of a mineral is equivalent to the 2-theta degree [9]. This is supported by microscopic observation such as shown by goethite (FeO.OH) with fine crystalline size and acicular texture. Spinel group minerals (Al_{0.39}Cr_{1.58}Mg_{0.5}O_{4}), magnetite (Fe_{3}O_{4}) and hematite (Fe_{2}O_{3}) were detected to be associated with goethite. Goethite is formed by weathering process in which iron oxide is converted to iron hydroxide [10].

Figure 1-B shows the microscopic appearance of lateritic iron ore. Goethite show unhedral with acicular texture; whereas spinel exhibits euhedral to subhedral with grain size ranging between 100 and 300 microns. Result of chemical analysis using X-ray fluorescence method is given in Table 1. It is shown that iron, aluminum and silicon are the three elements dominant with >90 wt% in total.

Table 1. Chemical composition of lateritic iron ore feed

| Major Oxide | Composition (wt%) |
|-------------|------------------|
| Fe_{2}O_{3} | 32.845           |
| Al_{2}O_{3} | 35.596           |
| SiO_{2}     | 21.133           |
| Cr_{2}O_{3} | 7.202            |

The concentration Fe_{2}O_{3} can be derived from minerals such as goethite, magnetite, hematite, hercynite, and other minerals that have iron element composition. The availability of Al_{2}O_{3} could be derived from the spinel group minerals and some of them are likely associated with goethite.

Beneficiation process was started with classifying the initial sample (feed) based on grain size using a multilevel sieve. The sieving result of the dominance of coarse grain size is shown in Figure 2. There is 60% lateritic iron ore sample from Malili area was included in the size of +212 µm.
The beneficiation process using magnetic separator produces a concentrate that increases with the smoothness of the grain size of the fraction. The smaller the size of the feed particles indicate the easier of magnet attracts to them. This also proves that the finer grain size of the feed, showing the higher degree of mineral liberation. The degree of liberation is the amount of weight of a valuable mineral that is completely free, commonly stated in percent, compared to the amount of all minerals contained in the ore, either free or still bind. The magnetic separation result is presented in Figure 2B.

The color of a concentrate is darker than a tailing product. Based on mineralogical analysis on the sample of concentrate and tailing, there are diffractogram differences indicated the variation of the minerals composition. Figure 3 shows the comparison of diffractograms which were obtained from mineralogical analysis using X-Ray Diffraction method.

Based on the diffractogram, it can be interpreted that the magnetic minerals are the minerals within the poor crystallinity, meanwhile the non-magnetic minerals has a good crystallinity. This was shown on the widened peak shape until no peak shaped, such as at the angle of $2\theta = 65^\circ$, $58^\circ$, $36^\circ$, $30^\circ$, and others.

![Figure 3. Comparison of diffractogram patterns of the sample before and after separation.](image)

Based on chemical analysis using X-Ray Fluorescence method, lateritic iron ore experienced an increase in Fe$_2$O$_3$ grade from 32% in the feed to an average of 46% in the concentrate, after passed a magnetic separation process. The increase of Fe$_2$O$_3$ grade per fraction has an identical value with moderately small difference value, between 43% and 47%. The level of magnetism depends on the Fe$^{3+}$ ion content.

| Table 2. Chemical composition of product concentrates (wt%) |
|------------------|-----|------|------|-----|
| Size Fraction (µm) | Fe$_2$O$_3$ | SiO$_2$ | Al$_2$O$_3$ | Cr$_2$O$_3$ |
| Feed | 32.8 | 21.1 | 35.5 | 7.2 |
| (+212) | 45.0 | 31.1 | 18.2 | 2.8 |
| (-212+180) | 47.9 | 17.8 | 24.2 | 7.3 |
| (-180+150) | 43.9 | 16.3 | 28.5 | 8.9 |
| (-150+90) | 46.6 | 16.4 | 26.5 | 8.2 |
| (-90) | 47.2 | 20.3 | 26.1 | 3.9 |

This suggests that goethite (FeO.OH) has a fairly good magnetic susceptibility, consistent with XRD analysis that the concentrate is mainly composed of goethite with poor crystallinity. Goethite is the most dominant mineral found in lateritic iron ore [11]. Whereas the grade of non-magnetic Al$_2$O$_3$, SiO$_2$, and Cr$_2$O$_3$ decreases. For more details, the chemical composition of the concentrate is shown in Table 2.
In tailing products, the percentage of Fe$_2$O$_3$ decreased, with the Fe$_2$O$_3$ grade from 25.4 to 39.0 wt% the lowest was 25.2%. Even as Al$_2$O$_3$ and SiO$_2$ increased due to its non-magnetic. Table 3 shows the transformation of grade in tailing.

The recovery is obtained from the ratio between the concentrate mass multiplied by its grade and the feed mass multiplied by its grade. It is caused of the processing of minerals never goes perfectly (perfect means all the valuable minerals can be obtained) which means that there is some valuable minerals going into the tailing that are eventually discarded. If the recovery is equal to 100% (perfectly) then the weight of the concentrate is probably equal to the weight of the incoming feed, consequently the concentrate must be equal to the feed grade, meaning that no process occurs. The recovery formulation can be written as follows:

$$R = \frac{(C.c)/(F.f)}{*100\%}$$

**Table 3. Chemical composition of product tailing (wt%)**

| Fraction (µm) | Fe$_2$O$_3$ | SiO$_2$ | Al$_2$O$_3$ | Cr$_2$O$_3$ |
|---------------|------------|---------|-------------|-------------|
| (+212)        | 39.0       | 22.2    | 31.1        | 3.3         |
| (-212+180)    | 25.4       | 19.8    | 41.1        | 11.0        |
| (-180+150)    | 25.2       | 16.6    | 43.1        | 12.7        |
| (-150+90)     | 25.4       | 15.5    | 43.4        | 13.6        |
| (-90)         | 39.0       | 21.3    | 30.1        | 7.1         |

Results of calculation of recovery of Fe$_2$O$_3$ along with graph showing the concentrate of grade and recovery against size fraction are presented in Table 4 and Fig. 5 respectively.

**Table 4. Recovery of Fe$_2$O$_3$**

| Fraction (µm) | Concentrate | Feed | RECOVERY (%) |
|---------------|-------------|------|--------------|
|               | Fe$_2$O$_3$ | Mass | Fe$_2$O$_3$ | Mass |              |
| (+212)        | 45.0        | 1821.0 | 32.8        | 12081.3 | 20.6          |
| (-212+180)    | 47.9        | 854.0  | 32.8        | 2785.2  | 44.7          |
| (-180+150)    | 43.9        | 424.8  | 32.8        | 895.1   | 63.5          |
| (-150+90)     | 46.6        | 803.3  | 32.8        | 1880.3  | 60.7          |
| (-90)         | 47.2        | 986.3  | 32.8        | 1579.4  | 89.8          |

4. Conclusion

The lateritic iron ore from Maili area is composed of minerals with poor crystallinity mainly goethite (FeO.OH) which is characteristic of minerals that is formed by weathering. Spinel (Al$_{1.64}$Cr$_{0.244}$Mg$_{1.115}$O$_4$), hematite (Fe$_2$O$_3$), magnetite (Fe$_3$O$_4$), and hercynite (Al$_{2.1}$Fe$_{0.1}$O$_4$) were also identified.

Lateritic iron ore sample from Maili area consists of 33%Fe$_2$O$_3$, 21%SiO$_2$, 35%Al$_2$O$_3$, 7%Cr$_2$O$_3$, 1.5%MnO, and 1.2%NiO. The concentrate product by magnetic separator has an average grade of 46%Fe$_2$O$_3$, 16%SiO$_2$, 24%Al$_2$O$_3$, 6%Cr$_2$O$_3$, 1%MnO, and 1.2%NiO. The tailing product shows an average grade of 25%Fe$_2$O$_3$, 20%SiO$_2$, 38%Al$_2$O$_3$, 9.5%Cr$_2$O$_3$, 1.1%MnO, and 1%NiO.
Result of iron ore beneficiation using magnetic separator indicates an increasing amount of concentrate with the finer fraction of the grain size of the feed. Consequently, the highest Fe$_2$O$_3$ recovery was about 89.83% and it was found at (-90) μm size fraction of the feed.

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