Recovery of Magnetite from Leached Laterite-residue by Magnetic Separation

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In order to improve the grade of iron, upgrading of laterite ore was conducted using wet low intensity magnetic separator. The ore was treated through selective reduction followed by sulphuric acid leaching to recover nickel while iron remained in residual solid. The Vibrating Sample Magnetometer measured the magnetic properties of the ore, as a fundamental of magnetic separation. Magnetic separation was carried out using a Davis Tube Tester. The effect of pretreatments on the magnetization and magnetic separation were investigated.

The results showed that the ore has similar magnetic property with goethite. The heating of the ore at 673 K did not improve significantly on its properties whether goethite changes to magnetite. However, the reduction treatment increased the magnetic properties of the ore due to the formation of magnetite. The magnetic susceptibilities of the original, heated and reduction treated laterite ores were $2.36 \times 10^{-5}$, $2.18 \times 10^{-5}$ and $2.357 \times 10^{-5}$ emu/g, respectively. The correlation between magnetite content and magnetization of the magnetic concentrate was showed in a linier equation, which could be used for the prediction of magnetite content in the sample based on its magnetization. Magnetic separation was applied only to recover iron from the laterite ore after being treated by the selective reduction in which magnetite was produced. About 93.9 % of magnetite was upgraded from the laterite ore with 90 % of recovery was obtained. The relatively high iron content in the magnetic concentrate indicated a potential use as raw material for iron making.

KEY WORDS: laterite ore; reduction; magnetization; magnetic separation; ironmaking.

1. Introduction

Since the laterite ore has been used widely as nickel resources, this application is limited for the ore with high nickel content. High iron content instead of less nickel is a reason to reject the ore for the nickel extraction because of its economic disadvantage. The ore possesses high silica, alumina and chromium in association with iron mineral which is mostly as goethite. As being defined that iron ores are iron-bearing minerals associated with proportion of waste or gangue materials which generally contain silica, alumina, lime and magnesia as well as very small amount (usually under 1 %) of other constituents like compounds of Zn, Cu, Ti, Cr, Mn, Ni, S, P, etc., the high grade iron containing laterite ore should be included in the iron ore group. Therefore, the laterite ore can be an alternative of iron resource based on its high iron content when a processing technique is applied economically. Beneficiation of laterite ore for the production of iron and steel has some problems such as high content of impurities mostly as silica, alumina and chromium oxide as well as nickel and cobalt. A process is proposed with the purpose to separate the impurities of laterite ore by a combination process of selective reduction, leaching and magnetic separation. The selective reduction of the laterite ore by CO/CO$_2$ (30/70 vol%) mixed gas produces in metallic nickel and cobalt, together with change of hematite to magnetite. The nickel will be extracted by leaching from selectively reduced laterite ore without insoluble iron, based on the difference affinity between metallic nickel and other metal oxides to acid. There will be a residue containing iron in the form of magnetite and other metal oxides. The residual solid after the extraction of nickel can be further treated by magnetic separation to recover the iron. Finally, the products of this process will be high iron content of magnetic concentrate that can be further processed as raw material for iron making.

Magnetic separation technology has been widely applied in the mineral processing especially in the concentration of iron ore. There are several reports considering a possibility of magnetic separation applied to ferrous and non-ferrous materials. A magnetic separation for processing iron from fly ash as reported by Prakash successes to remove around 92 % iron using magnetic coating at up to 11.8 kG. Youssef reports the magnetic separation of low-grade iron ore by reduction treatment. The iron recovery of 90 % was obtained by using wet low intensity magnetic separator and
assaying about 55% Fe from 45% in original ore. An application of magnetic separation in non-ferrous material has been reported by Geldenhuis to recover nickel from flue dust using wet low intensity magnetic separator.5) The last two studies above show that nickel and iron can be easily recovered by using low intensity magnetic separator, indicating that both elements have high magnetic properties. Therefore, this method cannot be applied directly to recover the iron from laterite ore without nickel included.

One of the most significant factors in the application of laterite ore into iron making is the increase of iron content and reduction of its impurities as low as described above. In this work, a wet low intensity magnetic separator will be applied to upgrade low-grade iron of laterite ore after several treatments to recover nickel and to increase its magnetic property, based on differences magnetic properties of its minerals. The effects of pretreatment on magnetization and operating parameters of magnetic separation are mainly investigated.

2. Experiment

2.1. Sample Preparation

The original laterite ore from Indonesia (Sebuku Island) was treated by heating at 673 K and reduced by CO/CO$_2$ (30/70 vol%) mixed gas in a tube reactor at 973 K for 90 min. The size distribution of original ore after grinding is given in Table 1. Figure 1 shows change in the extent of reduction of hematite to magnetite with time for 30 mol% CO reduction treatment, which was calculated from the weight change. The reduction degree was obtained over 95% after reduction at 973 K for 5 ks. The reduction rate was larger for the higher temperature.

Figure 2 compares X-ray diffraction patterns for laterite samples before and after reduction. The pattern (a) is for the original laterite, (b) and (c) are for those after heating at 673 K and reduction by 30 mol% CO at 973 K. From the pattern (a), it is apparent that the iron exists mainly as goethite in the original laterite sample. In contrast, the peaks arising from goethite are not found in the pattern (b), and instead, clear peaks attributed to hematite appear. The peaks from goethite are also not detected in the X-ray diffraction pattern (c), but the strong peaks arising from magnetite are clearly seen. These results apparently indicate that the dehydration of combined water and reduction reaction completely proceed in laterite under the heating and reduction conditions following the reactions below:

\[
\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O} \rightarrow \text{Fe}_2\text{O}_3 + \text{H}_2\text{O} \quad \ldots ... \quad (1) \\
\text{Fe}_2\text{O}_3 + \text{CO} \rightarrow \text{Fe}_3\text{O}_4 + \text{CO}_2 \quad \ldots ... \quad (2)
\]

The reduced ore was ground to obtain the particle size of under 44 mm then subjected for leaching with sulphuric acid to recover nickel and cobalt. A residual solid from leaching was washed using hot water to release the sulphuric acid from solid particles, followed by drying at atmospheric condition. As the results, the present of magnetite in the sample did not change to other iron oxide during leaching treatment, therefore the sample used in this experiment was the residual solid containing magnetite.2) The chemical composition of leached laterite-residue is given in Table 2. It should be noted that the present of iron does not only associate with magnetite but also with chromium/aluminum in the form of chromites. The later will be explained by X-ray diffractometry. Mineralogy of the sample that is reported in the previous study shows that impurities such silica can be easily separated but difficult for aluminum and chromium because of their liberation mostly at smaller than 40 mm. Therefore, reduction particle size under 44 mm is necessary in this experiment. Magnetization of laterite ore is measured by using Vibrating Sample Magnetometer (VSM). Magnetic moment and susceptibility can be measured as a function of

![Fig. 1. Reduction rate of laterite ore.](image1)

![Fig. 2. X-ray patterns of laterite ores.](image2)

![Table 1. Particle size distribution of original ore after grinding.](table1)

| Constituent | ~44 | 44~74 | 74~149 | 149~250 | 250~ |
|-------------|-----|-------|--------|---------|-------|
| Weight, mass% | 60.9 | 11.8  | 24.9   | 0.0     | 0.1   |

![Table 2. Chemical composition of leached laterite-residue.](table2)

| Constituent | Fe$_{20}$ | Al$_2$O$_3$ | SiO$_2$ | Cr$_2$O$_3$ | NiO  |
|-------------|-----------|------------|--------|-------------|------|
| Weight, mass% | 51.85     | 7.88       | 9.41   | 4.12        | 0.01 |
magnetic field from the magnetization curves. The measurements of magnetization are conducted at the room temperature under a maximal magnetic field of 10 kOe.

2.2. Magnetic Separation

Magnetic separation is carried out using Davis Tube Tester (DTT) as a magnetic separator under various parameters such as water flow rate, magnetic induction and sample rate. The sample is poured into the water-filled glass tube (2.5 cm diameter), set between two magnetic poles at 45 degree of the tube angle. Magnetic induction produced by controlling the amperes current is induced then followed by water flow and agitation for 3 min for each experiment. During the experiments, particle with high magnetic properties will be captured by magnetic poles, however, the non-magnetic sample will pass through the tube into the tailing bucket. At the end of the test, concentrate and tailing are dried for the preparation of chemical analysis. The samples are also subjected to the analysis of magnetite content, magnetization and X-ray diffractometry for the existence of magnetite. For each test, the recovery of magnetite and removal of impurity are defined according to the equation below:

\[
R_c = \frac{W \times C_i}{W_0 \times C_{i0}} \times 100 \quad \text{(1)}
\]

\[
R_m = (100 - R_c) \quad \text{(2)}
\]

where, \( R_c \): recovery (mass%), \( R_m \): removal (mass%), \( W_0 \): weight sample and magnetic concentrate (g), \( C_{i0} \); \( C_i \): element (i) content in the sample and magnetic concentrate (mass%).

3. Results and Discussion

3.1. Magnetization

Figure 3 shows the magnetization curves of laterite ore with different pretreatments obtained by plotting magnetization against the applied magnetic field. The magnetization was defined as magnetic moment per gram sample. According to the magnetization curve, two parameters were derived, namely, maximum magnetization (\( M_{\text{max}} \)) obtained at magnetic field 10 kOe and magnetic susceptibility (\( \chi \)) defined from the high field slope at applied magnetic field up to 2 kOe that reflects the presence of ferromagnetic. However, the slope raised at interval 2 to 10 kOe was mainly from paramagnetic and/or diamagnetic minerals. It could be seen that the magnetization of all samples increased drastically at the magnetic field up to 2 kOe and the gradient became small as seem to be a saturation condition. Generally, the original and heated samples had a trend of similar magnetization, and both values were relatively low compared to the magnetization of laterite residue.

The magnetization data of laterite ores obtained from the magnetization curves are summarized in Table 3. The magnetic susceptibilities of some minerals are also presented as references. Magnetic susceptibility of original and heated laterite ores were 2.36 and 2.18 \( \times 10^{-3} \) emu/g, respectively. The heating of the ore at 673 K had no significant effect to the magnetic susceptibility that could be identified as hematite. It could be explained that the iron in the original laterite existed mostly as goethite with low magnetic properties. The goethite in the original laterite changed into hematite phase by releasing its combined water during heating at moderate temperature. Therefore, the magnetic susceptibilities of the laterite samples were similar to the natural goethite and hematite, which obtained by Pastrana et al. Different from the other two samples, the magnetic susceptibility of residue was obtained about hundred times higher than that of original and heated ores. The reduction treatment before leaching of the ore led to the increasing of magnetization. The selective reduction process changed the existence of iron in a goethite and/or hematite completely into magnetite. Therefore, the artificial magnetite from selective reduced laterite tended to have about the same degree as the susceptibility with natural magnetite. The magnetic susceptibility of laterite residue was measured about 2.357 \( \times 10^{-3} \) emu/g. This value is about half of the magnetic susceptibility of the magnetite 35.98–45.14 \( \times 10^{-3} \) emu/g given by Svoboda. It can be explained that the laterite leached residue contains about 50% of the total iron or only less than 70% of magnetite, while the 30% remaining constitutes other oxides called as an impurity. In comparison, the magnetite content in the natural magnetite is usually over 90%. The lower magnetite content in the laterite sample may decrease its magnetic susceptibility and magnetization.

The impurity in the laterite sample mostly consisted of quartz, alumina and chromium oxide composed with iron in the form of chromites. All of the components of the impurity are classified as paramagnetic or diamagnetic that have low magnetic susceptibilities. Resende et al. divided the magnetization of mineral containing ferromagnetic oxide and paramagnetic oxide impurities according to the slopes
It is revealed that the first strong slope was the magnetization of ferromagnetic oxide and the other small slope should be for the paramagnetic one. According to the magnetization curves of laterite ores, the slope appeared over 2 kOe of magnetic field should be noticed as the magnetic susceptibility of the impurities. The values measured from the slopes were obtained in the range 22.0–315.0/emu/g. This values seem to be similar with the magnetic susceptibility of chromites given by Owada and the data obtained by Rao for the magnetic susceptibility of Indian chromites. Thus, to recover the iron from laterite ore by magnetic separator should consider the magnetic properties both of iron oxide and impurity.

3.2. Magnetic Separation

In a magnetic separation, the important property that responds to the separation is the difference of magnetic susceptibility in the particles. Magnetic susceptibility has important role in the magnetic force of magnetic and non-magnetic particles. The magnetic forces for each separated particle are calculated based on the differences of magnetic susceptibility. To evaluate the optimal condition of the magnetic separation, the forces occur during the magnetic separation using Davis Tube tester is simplified by a single particle motion in a laminar water flow. Figure 4 shows the consideration of a spherical particle as magnetic separation object in a wet separator system. A uniform external magnetic field \( H_0 \) is applied to the iron/oxide sphere having radius, \( a \). A uniform magnetization, \( J \) is developed parallel to the \( H_0 \). Since it is difficult to determine the magnetic force on a particle, based on the above simplification, the magnetic force can be derived as follow:

\[
F_m = \chi VH_0 \frac{\partial H_0}{\partial r} \tag{3}
\]

\[
H_0 = \left( H_0 + \frac{8\pi J \rho \sin \theta}{3} \right) \cos \theta \tag{4}
\]

\[
\frac{\partial H_0}{\partial r} = -8\pi J a^3 \frac{\rho \sin \theta}{r^4} \cos \theta \tag{5}
\]

where \( F_m \): magnetic force (dyn), \( \chi \): magnetic susceptibility (-), \( H_0 \): particle volume (cm³), \( H_0 \): external magnetic field (G), \( J \): uniform magnetization = \( H_0 / 4\pi \) (emu/cm³), \( H_r \): magnetic field at distance \( r \) (Oe), \( a \): radius (d/2) (cm), \( r \): distance from the particle center (cm).

From the equations above, it can be seen that the magnetic force on a particle depends on both the applied magnetic field and the gradient of the induced magnetic field. In opposition to the magnetic attraction, several compete forces should be considered in the magnetic separation. The major competing forces that tend to hold the particle in the separator are gravity and drag forces. For a spherical in a laminar flow, the gravitational and drag forces are given by the following equation:

\[
F_g = \frac{\pi}{6} d^3 \left( \rho_s - \rho_f \right) g \sin 45^\circ \tag{6}
\]

\[
F_D = 3\pi \eta d u \tag{7}
\]

where \( F_g \): gravitational force (dyn), \( F_D \): drag force (dyn), \( \rho_s, \rho_f \): density of solid, fluid (g/cm³), \( d \): particle diameter (cm), \( g \): gravitation constant (981 g/cm·s²), \( \eta \): water viscosity (0.01 g·cm·s), \( u \): water flow rate (cm/s).

Figure 5 shows the ratio of magnetic, gravitational and
In this experiment, the particle size of the sample used was limited, and the particle will not be trapped magnetically. For a very fine particle, the drag force will be greater than the magnetic force. Therefore, the separation can occur over a limited range of the particle size diameter. For a very fine particle, the particle size of the sample used was smaller than 44 μm. If most of the sample has particle size larger than 20 μm, the magnetic force work is over 80%, which is still dominant. However, small particle in this sample should be considered during separation process. To get a maximum result, the process parameter plays an important role during magnetic separation. Those controlling the separation of water flow, sample feed and magnetic induction is necessary to minimize the particle loss.

3.2.1. Effect of Reduction Treatment

The effect of selective reduction on the magnetite recovery was investigated by performing magnetic separation using non-treatment (original) laterite ore and residue under the experimental condition of 6.8 cm/s of water flow and 2 g/cm² of sample rate. Both values of water flow and sample rate were calculated on the basis of the cross section area of the glass tube. The results are given in Fig. 6 for the recovery of magnetite and removal of impurity. Products of the magnetic separation were magnetic concentrate for the particle that was captured by magnetic force and tailing that was passed together with water into a tailing bucket. The recovery and removal were calculated based on the elements content in the concentrate. Impurity was defined as the total of quartz, alumina and chromium oxide or chromites. In general, magnetic separation of original laterite ore resulted in a very low recovery of iron but high removal of impurity. The amount of concentrate resulted from the separation was very small and most of the sample was passed into the tailing. For experiment using residue, the first recovery was very low at low magnetic induction and increases with the increasing magnetic induction up to 3000 G, however there was no change of recovery for original ore.

According to the magnetization curves shown in Fig. 3, it could be seen that the original laterite ore had very low magnetization compared to the residue. The existence iron as goethite in the ore may cause it difficult to be concentrated by magnetic separation especially at low magnetic field. The magnetization grade of impurity in the laterite sample should be considered. The present chromites create difficulties in the separation of iron in the original ore because the difference between magnetic susceptibilities of goethite and chromites is very small. However, to get a good result of magnetic separation, the particles separated should have as high as the gradient of magnetization or magnetic susceptibility. Laterite-residue which was treated by selective reduction, resulted in high magnetization due to the change of goethite/hematite into magnetite phase. High magnetization of magnetite made the sample to be captured by magnetic easily even at low range of magnetic induction. At the experimental condition given above, the magnetic attraction of the sample was strong at above 2000 G. However, this magnetic induction will be changed for different condition of magnetic separator such as water flow rate and sample rate. Here, the reduction treatment before leaching has an important role to change the magnetic properties of laterite ore that will be very useful for the prediction of magnetic separation process.

3.2.2. Effect of Magnetic Induction

To obtain better results from magnetic separation at a given condition, it is necessary to minimize the sample rate and water flow. The other parameter concerning the magnetic separation is its magnetic induction. Several experiments were conducted at constant sample rate and water flow in order to investigate the effect of magnetic induction on the particle captured and recovery of iron as well as removal of impurities. The results are shown in Fig. 7 for magnetic induction up to 3000 G plotted against recovery and removal. The figure shows the removal distribution of elements at each magnetic induction. Removals of Si were greater than the other two impurities of Al and Cr that were almost same in the trends. Unlike Si, the Cr and Al mostly existed together with iron in the form of chromites. As the chromites is paramagnetic mineral, a high magnetic force is probably the reason of the collecting of chromites and de-
crease of its removal. It should be noted that the total iron recovered does not indicate the recovery of magnetite because of the fact that the amount of iron in concentrate also exists in chromites as much as the balance of chromium fraction. Generally, the higher of magnetic induction resulted in high magnetic concentrate and increased the recovery, but at the same time, the removal decreased drastically. The recovery ranging from 1 000 to 3 000 G was far better than the lowest magnetic induction. However at 1 000 G of magnetic induction, iron recovery over 90% was achieved with high grade of iron due to less impurity that was indicated by high removal.

Separation at 500 G of magnetic induction gave less magnetic concentrate and only 40% of iron was recovered while the removal of impurity obtained about 80%. This low magnetic induction gave a weak magnetic force and decreased the forces ratio. Since the ratio of magnetic and drag forces was less then the limited value, the small particle was falling into the tailing. Thus, the only particle with big size was captured at the magnetic poles, since the experiment was conducted for a relatively small particle size. As shown in Eqs. (7) and (3), the increasing of magnetic induction led to the strong magnetic force and resulted the high force ratio. The effect of magnetic induction can be seen in the figure with the increasing of the recovery and removal drastically at 1 000 G. There was a very slight drop in elements removal at over 1 000 G but a very little increasing in the iron recovery.

3.2.3. Effect of Water flow

In order to clarify the effect of water flow on the recovery of magnetite, a series of experiments were conducted at 1 000 G and 0.6 g/cm² of sample rate. Figure 8 shows the recovery and removal for a magnetic induction of 1 000 G plotted against water flow. The recovery was higher for the slower flow at a given magnetic induction at which more particles were captured. Following the recovery, the trend of removal of impurity was similar but the gradient was lower than the recovery at lower flow. In this condition, the forces ratio between \( F_m \) and \( F_D \) obtained from Eqs. (7) and (3) were lower at higher flow rate, which less number of particle was captured and resulted in low recovery. The faster of the water flow caused not only non-magnetic particles pass into the tailing, but also the magnetic particles together with it. This phenomenon indicates the importance of having a high magnetic induction for high water flow. However, it should be sought on the basis of other parameters and ultimately on economics.

Table 4 shows the comparison between \( F_m/F_D \) for magnetite and chromites based on their magnetic properties. The ration seems to be higher at high magnetic induction, both of the two samples. However, the ration for magnetite was obtained about two hundreds at low magnetic induction of 300 G. Comparing with chromites which has ratio of 2.7 or one per hundred smaller than that of magnetite, it shows the possibility to separate the two minerals at low magnetic induction. Accordingly, a separation method has been proposed as shown in Fig. 9. First step of magnetic separation was conducted at 1 000 G. The concentrate produced then was separated by using lower magnetic induction of 500 and 300 G, respectively. The tailing from each step was repeated for separation at the same condition of its step. Finally, the recovery was obtained for each step using experimental condition of 0.2 g/cm² sample and 0.68 cm/s water. Table 4 shows the recovery and magnetite grade of the concentrate of each step. Recovery of magnetite decreased with increasing of magnetic induction, however the magnetic content in the concentrate increased. Highest grade of magnetite was obtained 93.9% at 300 G and about 90% was recovered.

3.3. Relation between Magnetite Content and Magnetization

To evaluate the efficiency of the magnetic separation

\[ \text{Table 4. Comparison between } F_m/F_D \text{ for magnetite and chromites (size: } 44 \mu m; \text{ water: } 1.7 \text{ cm/s).} \]

| Minerals | Guess | Force, 10^4 dynes | F_m | F_D | F_m/F_D |
|----------|-------|------------------|-----|-----|---------|
| Magnetite | 300   | 1.3              | 1433| 204 |
|           | 500   |                  | 3982| 568 |
|           | 1000  |                  | 15927| 2275|
|           | 2000  |                  | 65710| 9101|
|           | 3000  | 1.3              | 343348| 26478|
| Chromite | 300   | 1.2              | 19.1| 2.7 |
|           | 500   |                  | 53.2| 7.6 |
|           | 1000  |                  | 212.8| 30.4|
|           | 2000  |                  | 851.4| 121.6|
|           | 3000  |                  | 1915.7| 273.6|

\[ \text{Fig. 8. Effect of water flow on recovery and removal (sample: } 0.6 \text{ g/cm}^2, 1000 \text{ G).} \]

\[ \text{Fig. 9. Flow diagram of magnetic separation.} \]
above the sample of laterite-residue before and after magnetic separation were analyzed by X-ray diffractometry. The effective used of this method has been performed by Fontes to evaluate the qualitative of diamagnetic, paramagnetic and ferromagnetic minerals in soils materials after magnetic separation. The X-ray patterns of laterite samples are shown in Fig. 10. The quartz from the sample was concentrated in the tailing as given by larger peak comparing with sample before separation and only small peak for magnetic concentrate. It indicated that only few quartz remained in the concentrate, as expected. As quartz is a diamagnetic mineral, it is easy to remove as non-magnetic mineral into tailing. It had to be emphasized the existence of some unexpected chromites in the magnetic concentrate and of magnetite in the tailing as shown by peak appeared in the same diffraction angle. Although these were paramagnetic and diamagnetic minerals that should be separated from magnetite during magnetic separation, the association of some minerals with magnetite as locked matrix made it difficult to separate completely. Therefore, the distributions of Al and Cr had similar trend due to their association in chromites. The patterns indicated that the quality of magnetic separation products could be shown by the intensity or peak of these minerals. The magnetite peaks appeared in magnetic concentrate were higher than two other samples, indicating a high grade of magnetite.

Magnetization curves of the laterite samples after magnetic separation compare with sample before separation are shown in Fig. 11. The magnetization of tailing was very low and the maximum magnetization obtains about 9.6 emu/g, lower than that before separation. However, a high magnetization of 40.9 emu/g was obtained for magnetic concentrate, this value was higher than 32.5 emu/g for the sample before separation. As revealed by X-ray diffractometry the magnetite peak for magnetic concentrate was higher than the sample before separation, indicating the increased in magnetite or decreased in impurity contents. The peak of quartz disappeared and was shown in low intensity. However, quartz was dominant in the tailing sample as shown by high intensity peak and lower magnetite peak that appeared. It was clear that the lower impurity and higher magnetite contents in the sample increased the magnetization due to the decreased of diamagnetic and paramagnetic contents in the sample.

The correlation between the measured magnetization and magnetite content in concentrate from magnetic separation are summarized in Fig. 12. The correlation were expressed by the following linier equation:

$$M_c = 1.69 M_{\max} + 15.60$$

where, $M_c$: Magnetite content (mass%) and $M_{\max}$: Maximum magnetization (emu/g). Accordingly, the content of magnetite can be predicted based on the value of magnetization measured. To calculate the total iron containing in the concentrate, the iron associated with chromites should be considered.

Table 6 shows the chemical composition of magnetic. Comparing with sample before separation in Table 2, about
90% of magnetite was recovered with the increased of iron from 51.85 to 68.24%. The results were also compared with several iron ores, which are typically iron ore in present ironmaking industries. Accordingly, most of iron ores contain low alumina and lime which are high in the laterite concentrate, although it is relatively high in iron content. Unlike the Australian and Indian ores that contain lower iron and high combined water, the laterite concentrate contains amount of chromium oxide. Therefore, to use the laterite ore as raw material for ironmaking should consider the presence of the impurities. Further, it is necessary to investigate the characteristics of the ore during reduction process.

4. Conclusions

The measurements of magnetization of original laterite ore show that the ore had similar magnetic property with goethite. The heating of the ore at 673 K did not improve significantly on its properties whether goethite changes to hematite. However, reduction treatment increased the magnetic properties of the ore due to the formation of magnetite. The magnetic susceptibilities of the original, heated and reduce laterite ores were obtained 2.36 × 10^{-5}, 2.18 × 10^{-5} and 2.357.00 × 10^{-5} emu/g, respectively.

The correlation between magnetite content and magnetization of the magnetic concentrate showed in a straight line, which useful for prediction of magnetite content in the sample based on its magnetization.

Magnetic separation was applied only to recover iron from the laterite ore after being treated by selective reduction in which magnetite was produced. About 93.9% of magnetite was upgraded from the laterite ore with 90% of recovery was obtained. The relatively high iron content in the magnetic concentrate indicated a potential use as raw material for iron making.

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