BENEFICIATION PROCESSING OF MAGNETITE ORE FROM LAMPUNG AS DENSE MEDIA FOR DENSE MEDIUM SEPARATOR IN COAL WASHING PLANT

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Abstract – Until recently, coal washing plants in Indonesia are still using imported magnetite from Australia as dense media for dense medium separator units. To be effectively utilized as a dense media, magnetite ore needs to be concentrated to remove gangue minerals so that the final product will have more than 95% magnetic content, 95% weight passing 53 microns, and relative density ranging from 4.9 – 5.2 g/cm^3. Experimental studies have been performed at the Department of Metallurgical Engineering ITB to concentrate fine magnetite ores from Lampung Province. Two process routes were chosen: grinding-magnetic separation and magnetic separation-grinding. Products from the two routes were sieve size analyzed, assayed and characterized. Magnetism characteristic was analyzed with VSM and relative density was measured with pycnometer. The first process route products have maximum magnetic content of 99.1% and particle weight passing 53 microns of 95.7%, while the second route have magnetic content of 95.2% and particle passing 53 microns of 97.1%. Concentrates from both routes have the same relative density of 4.5 g/cm^3. Characterization by XRF and AAS gives Fe content of 46.6% and 48.8% for the first route product, and 52.1% and 52.9% for the second route. Lampung magnetite ore gives lower magnetism characteristic compare to Australian magnetite ore. Finer particle size gave lower magnetic saturation value, hence lower magnetism.

Keywords: magnetite, dense media, dense medium separator, magnetic separation, grinding

1. Introduction

According to Indonesia Geology Resource Centre (PSDG), iron lateritic ores resource is approximated at 2.44 million ton [1], and Lampung magnetite ore deposits have been identified as a potential industrial resources [2]. Magnetite ore is commonly extracted from earth as the primary raw material to produce sponges iron or iron pellets for steelmaking industry. However, most Indonesian magnetite ore deposits are either not big enough or/and low grade, which makes them not economic to mine to supply for steel industry which required continuously large demand with high grade of iron. An alternative to utilize magnetite is as heavy media for dense medium separators in coal washing plants.

One of primary coal producer in Indonesia, PT Kaltim Prima Coal (KPC), has been importing magnetite concentrate from Australia as dense media for their coal washing units. Finding a local magnetite concentrate source as an alternative for dense media will contribute to plant cost efficiency. However, dense media has a certain characteristic requirement to be working effectively in dense medium separator units. Specification of general dense media by British Coal Mining Industry Standard are [3]:

1. Particle size distribution: maximum 5%wt. larger than 45 microns or more than 95%wt finer than 53 microns.
2. Relative density of 4.9 – 5.2 g/cm^3.
3. Magnetic content of minimum 95%wt.

Some alternative methods used in determining heavy media characteristics are proposed by Mikhail and Osborne [3], but magnetic susceptibility measurement by Vibrating-sample Magnetometer (VSM) had not been commercially developed at that time. With current developed technology, this measurement technique can be used to provide some magnetization measurement values including magnetic saturation, magnetic remanence and magnetic coercivity. These values are very useful to compare the magnetic characteristic of magnetite samples used in this study.

Therefore, a laboratory concentration study has been done at the Metallurgical Engineering Department Bandung Institute of Technology (ITB) to see a possible alternate process to produce magnetite concentrate from Lampung magnetite ore that could meet the preferred specific criteria with some of methods mentioned above. Characteristics comparison between magnetite from Lampung and from Australia has also been studied.

2. Experimental Method

2. 1. Sample Preparation and Characterization

Most experimental works take place at the Mineral Processing Laboratory and Coal Utilization Laboratory ITB. Magnetite ore samples in the fine grain size were supplied by the Indonesian Institute of Science (LIPI) Lampung, while sample of Australian magnetite concentrate is supplied by PT KPC. The magnetite ore from Lampung was crushed at the LIPI Lampung so all the sample used in this experiment is are initially smaller than 260 microns.

As much as 15 kg of magnetite ore from Lampung was heated to dry in oven for a day to ensure all entrapped moisture has left the ore. The ore was then homogenized manually with a shovel and coning quartering sampling procedure is performed to get smaller size of representative samples. The samples were then divided with Riffle splitter into representative 400 g samples. A further sample division was performed to prepare 10 g samples for characterization purposes which include mineralogy microscopy, X-Ray Diffraction (XRD), X-Ray Fluorescence (XRF), Vibrating-Sample Magnetometer (VSM) and Atomic Absorption Spectroscopy (AAS) methods. Sampling and characterization are also performed on all beneficiation products as well as Australia magnetite for final comparison.

2. 2. Beneficiation Process

Beneficiation for the Lampung magnetite ore in this study consists of two processes: comminution and concentration. Two route processes are used and compared in this study:

- Route 1) The first route is performing comminution by grinding in a jar mill and later followed by magnetic separator technique to remove gangue minerals.
- Route 2) The second route is by performing magnetic separation first followed by grinding. The second route was considered because of already fine size particles of the magnetite ore.

Comminution was done with a jar mill with steel ball medium. Grinding time was varied from 90, 105 and 120 minutes. Grinding rotational speed is also varied to 40, 50 and 60 rpm. After each grinding, size analysis was performed with sieves shaker.

Magnetic separation was performed with a dry type laboratory scale magnetic separator with automatic feeder. The operating variables are electric currect which translates into magnetic force and the magnet rotor rotational speed. Feeding rate was set constant. Electric current was set to 0.2, 0.5 and 0.8 A, while rotor rotational speed was 15, 20 and 25 rpm. Feeding rate was constant for all experiment. Concentrate and tailing product weight was measured

For each route, the most optimum variables from the first process (either comminution or concentration) that produce the highest magnetic content will be used for the second process.

2. 3. Relative Density Measurement

Relative density measurement was performed to each process route product as well as Australian magnetite. It was measured with a 100 mL pycnometer and following the procedure of ISO 8833. As much as 10 g representative sample was taken. The 100 mL pycnometer flask was filled with solution of distilled water and 0.5%wt. *Teepol*™ as a surfactant agent to optimize wetting of sample. Vacuum and desiccator were used to remove any trapped gas inside the flask. The weight of empty flask, flask with solution, and flask with solution and sample were recorded for calculation.

3. Results and Discussion

3. 1. Lampung Magnetite Ore Characterizations

Mineralogy microscopy pictures of Lampung magnetite ore is given by Figure 1. Mineragraphy analysis shows that magnetite presents both as individual grains or bounding with non-metallic minerals. A few magnetite altered into hematite and forming lamellar replacement texture and intergrowth with ilmenite. The non-metallic minerals present in the sample is most probably illite ($(K,H_3O)Al_2Si_3AlO_{10}(OH)_2$) and albite ($NaAlSi_3O_8$) , as indicated by XRD result (Figure 2).

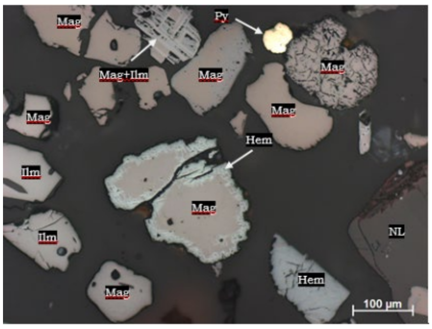

Figure 1: Polished section photomicrograph with nicol prism of Lampung magnetite ore sample (Mag: magnetite; Hem: hematite; Ilm: ilmenite; NL: non-metallic minerals; Py: pyirite)

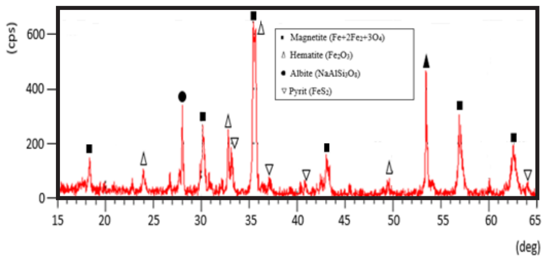

Figure 2: XRD analysis results of Lampung magnetite ore

Table 1: XRF analysis results of Lampung magnetite ore

Senyawa	%	Unsur	%
Fe2O3	69,34	Fe	48,05
TiO2	9,58	Ti	5,75
SiO2	9,2	Si	4,3
MgO	4,65	Mg	2,8
Al2O3	4,06	Al	2,15

The AAS analysis on Lampung magnetite ore gives Fe content of 50.93%. The small difference between XRF (Table 1) and AAS results show that Fe content in the ore is around 50%, while the error is probably due to the existence of other Fe-bearing mineral such as hematite.

3. 2. Results of Grinding-Magnetic Separation Route

Effects of grinding time and mill rotational speed

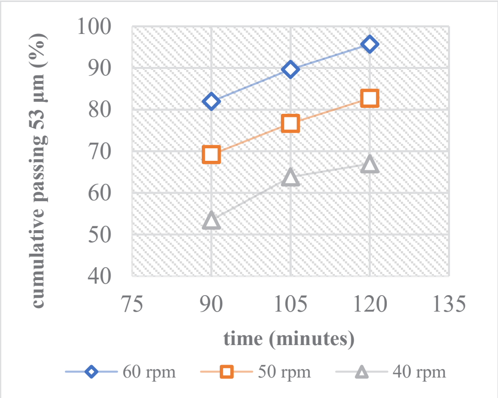

Figure 3: Milling time effect on cumulative passing 53 microns for 40, 50 and 60 rpm rotational speed for route 1

Figure 3 shows that longer milling time will produce more particles smaller than 53 microns size fraction. This is expected because total energy produced to induce breakage will gets higher with longer grinding time. Higher rotational speed will also increase breakage energy up to its milling critical speed before it drops [4]. Preferable grinding with both cataracting and cascading trajectory is achieved at rotational speed near critical speed of mill. The slopes are almost linear for all rotational speed, which showing breakage rate are identical for all rotational speed, except slightly slower rate is shown at 40 rpm after 105 minutes. This is probably because milling energy generated at lower rotational speed (more cascading rather than cataracting) is not enough to break particles as efficient due to smaller size particles. Operation at 60 rpm after 120 minutes successfully produces 95.69%wt. below 53 microns. Therefore, the product will be selected to be processed in magnetic separation.

Effects of magnetic roll rotation speed and electrical current

Two operational parameters are varied for magnetic separation stage: magnetic roll speed and electrical current that enforced the magnetic field. Their effects on magnetic content concentration is given by Figure 4. At the current level of 0.2 A, higher magnetic content of 92.32% comes at 15 rpm magnetic roll speed rather than 20 and 25 rpm. This is also similarly happened for 0.5 and 0.8 A electric current. This results are in accordance with previous study by Saifelnassr [5]. Lower rotational speed will improve the probability of paramagnetic particles to be attached properly. The graph also illustrate higher electrical current will improve magnetite content in the product. This agrees with Sitepu [6]. Concentrate with the highest magnetic content of 99.13% is achieved at 15 rpm magnetic roll speed and 0.8 A. Generally, slightly lower magnetite contents are achieved with higher roll speed for each electric current level.

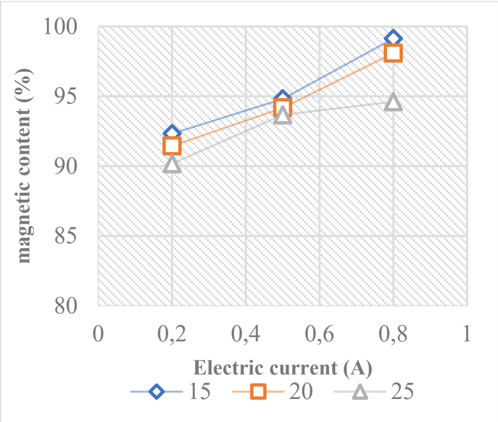

Figure 4: Magnetic content responses under influence of different electrical currents at 15, 20 and 25 rpm magnetic roll speed for route 1

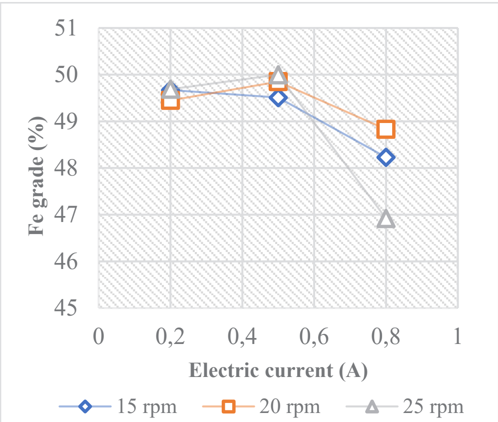

Figure 5: Fe grade responses under influence of different electrical currents at 15, 20 and 25 rpm magnetic roll speed for route 1

Although highest magnetic content can be achieved at 0.8 A current levels, the concentrations of iron (Fe) drop for all magnetic roll speed. Higher electrical current will increase the probability of gangue minerals that have weak positive susceptibility to magnetic fields, thus reducing the purity of Fe-bearing magnetite [6]. Efficient separation through rotational separation and magnetic attraction can be achieved at lower electrical current and high rotational speed [7] is also implied from this result.

3. 3. Results of Magnetic Separation-Grinding Route

Effects of magnetic roll rotation speed and electrical current

Profile of magnetic content and iron grade under the influence of different electric current and magnetic roll rotation speed is given by Figure 6. The result shows increasing magnetic content percentage with increase of electric current. At low current level, only particles that have strong positive magnetic susceptibility that will be attracted by magnetic field generated from rotating rotor, resulting higher magnetic content. As indicated with ore characterization results in section 3.1., there are several minerals apart of magnetite that present together with magnetite such as hematite, pyrite and non-metallic minerals. When stronger electric current is applied, stronger magnetic field will probably also pull fractions of magnetite that are not fully liberated from those gangue minerals. Thus, magnetic in the product content increase. As consequence, this will also reduce concentration of iron as shown by Figure 7.

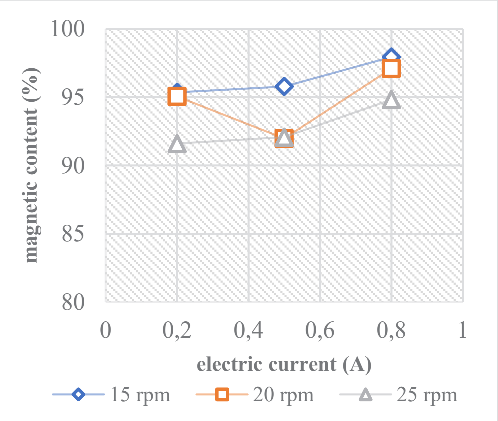

Figure 6: Fe grade responses under influence of different electrical currents at 15, 20 and 25 rpm magnetic roll speed for route 2

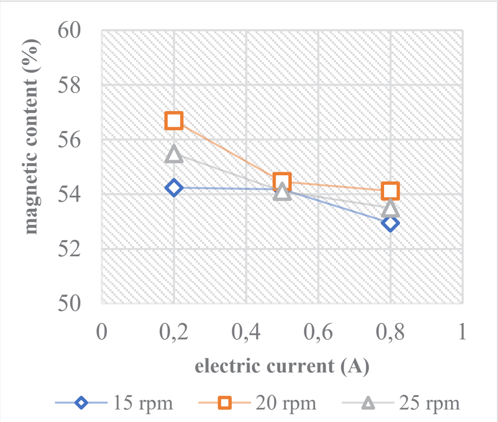

Figure 7: Fe grade responses under influence of different electrical currents at 15, 20 and 25 rpm magnetic roll speed for route 2

The highest magnetic content, 97.95%, is resulted from magnetic separation as the first stage process is achieved at 0.8 A electric current level with 15 rpm rotor speed. The concentrate product from optimum parameters will be ground to the preferred product size.

Effects of grinding time and mill rotational speed

Similar with grinding experiment in route 1, two variables are studied in this experiment: mill rotation speed and grinding time. Grinding time affects the total energy applied to particles. At optimum mill rotation speed, the longer the grinding time, the finer the product will be. If this is happening continuously, effective grinding mechanism which includes impact and abrasion actions are still taking place. The experimental results in Figure 8 agree with this theory.

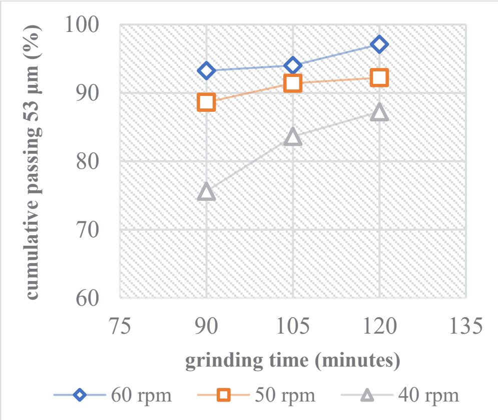

Figure 8: Milling time effect on cumulative passing 53 microns for 40, 50 and 60 rpm rotational speed for route 2

The result reveals a significant increase of fine size formation at 40 rpm mill speed when grinding time is added from 90 to 105 minutes. Less significant increase is shown after 120 minutes. This is expected because at lower mill rotation, attrition-induced breakage from cascading trajectory is more dominant at lower milling speed [4, 8]. Trends for all mill rotational speed are similar, with increasing cumulative particle passing 53 microns with the longer grinding time. The maximum cumulative passing 53 microns is achieved at 60 rpm after 2 hours of grinding, which is 97.11%.

3. 4. Comparisons of Lampung Magnetite Concentrate and Australian Magnetite Concentrate

Final concentrate products of Lampung magnetite from route 1 and route 2 are compared with magnetite from Australia and with standard specification of general dense media by British Coal Mining Industry Standard (BCMIS). The summary is tabulated and presented in Table 2.

Table 2:Characteristic of Lampung magnetite concentrate, Australian magnetite concentrate and British Coal Mining Industry Standard

Property	Measurement technique	Lampung magnetite concentrate			Australian magnetite concentrate	Dense media standard specification (BCMIS)
		Ore sample	Route 1 (Grinding-Magnetic Separation)	Route 2 (Magnetic Separation-Grinding)		
Fe grade (%)	*XRF*	48.05	46.56	52.15	61.05	-
	AAS	50.93	48.83	52.95	61.92	-
Relative density (gr/cm^3)	*Pycno-meter*	-	4.48	4.53	4.75	4.9-5.2
Ms (T)	*VMS*	0.0074	0.0073		0.0149	-
Mr (T)		0.0006	0.001		0.0016	-
jHc (kA/m)		7.5	10		10.8	-
Magnetic content (%)	*Magnetic separation*		99.13	95.18	>96	>95%
cumulative passing 53 µm (%)	*sieves analysis*		95.69	97.11	90-95	>95%

According to Table 2, iron content in magnetite concentrate from Australia is more than 10% higher than iron content in Lampung magnetite concentrates. Iron grade is only slightly improved with beneficiation process. Relative density of concentrate of Australian magnetite is also 0.22 higher. Magnetic saturation was only measured prior to experiment and it is assumed that magnetic properties are not altered by beneficiation process. Australian magnetite shows slightly larger magnetic saturation (Ms) but other than that they are similar. Both beneficiation process routes increase magnetic saturation, magnetic remanence, and coercivity. This indicates that Lampung concentrate product can be more easily magnetized as permanent magnet than the unprocessed ore. With optimum grinding parameters, Lampung magnetite concentrate has more particles finer than 53 microns. According to BCMIS, both particle size and magnetic content has achieved the desirable range. However, relative density is slightly below the requirement. It is suggestive that to achieve the range of 4.9 to 5.2 g/cm^3 relative density, a multiple stage of concentration can be applied. With this current characteristic, Lampung magnetite concentrate is argued to be a good replacement to imported magnetite, even in current properties it can be mixed with imported magnetite to lower operational cost of coal washing plant.

4. Conclusion

Ore characterization with XRD and optical microscope photography results show that Lampung magnetite ore is also compose of several gangue such as magnetite, hematite, albite, illite and pyrite. XRF and AAS results produce similar Fe content in the ore around 48%.

In the first beneficiation route, grinding is operated at first and the preferable size is achieved at 60 rpm after 120 minutes, which successfully produces 95.69%wt. finer than 53 microns. At the following stage, magnetic concentration produces concentrate with the highest magnetic content of 99.13% at 15 rpm rotor speed and 0.8 A electric current level.

Second beneficiation route is started with magnetic concentration, achieving magnetic content of 97.95% at 0.8 A electric current level with 15 rpm rotor speed. The concentrate is then ground in jar mill at the highest mill speed of 60 rpm in 120 minutes grinding time.

Beneficiation of Lampung magnetite ore into concentrate can improve the magnetization parameters (saturation, remanence, and coercivity), but relative density needs to be improved to the desired range. Arguably Lampung magnetite concentrate is quite similar with Australia magnetite and it has potential to be utilized as mixing material to bring down coal washing cost.

5. Acknowledgement

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