The Effect Of Local Coal And Smelting Sponge Iron On Iron Content Of Pig Iron

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Abstract. The new regulation on mineral resources was announced by Ministry of Energy and Mineral resources (ESDM) of Indonesia at 2014 which it called Permen ESDM No 1/2014. Therefore, this research was conducted to add the value of local iron ores by using smelting technology. The objective of the research is to produce pig iron that meet the requirement of the new regulation of mineral resources such as 90% Fe. First, iron ores and coal mixed together with lime as a flux, then smelted in a Electric Arc Furnace at 1800°C. The process variables are (1; 1.25; 1.5 ; 1.75 ; 2.0) and the composition of coal (0.8%, 1.6%, 3.0%). The type of coal that used in this research was bituminous coal from Kalimantan and also the iron ores from Kalimantan. The products of the smelting technology are Pig iron and slag. Both pig iron and slag then analyzed by SEM-EDS to measure the iron content. The result shows that the maximum iron content on pig iron is about 95.04% meanwhile the minimum iron content on slag is about 3.66%. This result achieved at 1.6% coal and 2.0.

Keywords: Mineral Resources, Pig Iron, Slag, Smelting Technology

1. Introduction
Since 2014, mining products such as minerals or ores cannot be exported directly but must be processed first in the Indonesia. This is a Government Regulation (PP) No. 1 of 2014 and the Regulation of the minister of energy and mineral resources No. 1 in 2014, which is derived from the Law of Mineral and Coal Mining No. 4 in 2009. One of the objectives of the government regulation is to give value adding to the minerals and to support the industrial development program which is being launched by the government. According to the regulation of minister of energy and mineral resources No. 1 of 2014 pig iron produced from iron ore processing must contain a minimum iron content of 90% (Permen ESDN, 2014).

In general, reducing agent used to produce pig iron is natural gas. However, nowadays, the natural gas is becoming increasingly scarce and expensive (7-8 dollars per MMBtu) [2] Therefore, in this research coal is used as an alternative reductant to replace natural gas. Utilization of local iron ore and coal as raw material for steel making to produce pig iron is expected to provide the added value of local mineral resources and meet the provisions of the regulation of minister of energy and mineral resources No. 1 of 2014 such as equal and more than 90% Fe. In this research, hematite iron ore and sub-bituminous coal
from Kalimantan with reserves 562.98 million tons (Statistil Geologi dan ESDM, 2013) and 55.363 trillion tons (PSDG, 2013), respectively, were used.

Manufacture of pig iron from the raw material such as iron sponge, flux (CaO) and coal carried in Electric Arc Furnace at a temperature of 1800 °C. This process names smelting of iron ores and basicity is one of the main problems in the processing of pig iron. Basicity is a ratio of a mineral formed from alkaline oxides and a mineral formed from acidic. Flux is used to collect impurities from the raw materials and form a slag phase. The slag phase affects the iron content of pig iron. Therefore, the basicity must be maintained and controlled to achieve the highest iron content of pig iron. In addition, basicity also can affect the viscosity of slag such as basicity increases, the viscosity decreases. If the viscosity decreases, the diffusion of atoms in the slag toward the metal phase will be easier as a result the iron content of pig iron increases. On the other hand, coal is used as a reducing agent for reducing iron oxide from iron ores. The reduced iron is formed metal phase separately with slag phase (Suharto, 2013).

This research is a development of previous research. In previous research, iron ore hematite from Merangin Jambi was used. The value of basicity in previous research was low (0.24 ; 0.3 : 0.36) the result shows that the basicity affected the iron content of pig iron such as basicity increases, iron content of pig iron increases too. Therefore, in this research the value of the is higher ( 1 ; 1.25 ; 1.5 ; 1.75 ; 2 ) than previous research. Furthermore, according to ternary diagram of CaO-SiO₂-FeO if the value of basicity between 1-2, the affinity of SiO₂ and CaO is expected higher than the affinity of SiO₂ and FeO. In a result, SiO₂ and CaO will form slag phase but FeO remains in metal phase.

2. Methodology/ Experimental

Methodology of this research was motivated by the regulation of minister of energy and mineral resources on added value of local resources and the result of previous research that mentioned in introduction section. There are two type resource of iron such as iron ores which calls lateritic ores and iron sands. Lateritic ores can be divided into two type i.e. hematite and magnetite. Generally iron ores contain 40-65%Fe and the value must be added by using preparation process such as mineral dressing (comminution, sizing and concentration process) or others process such as agglomeration, roasting and calcinations. The result of preparation process usually contains 65% Fe that suitable for ironmaking process.

In this research, the preparation processes include ore beneficiation (crushing, grinding, sizing and magnetic concentration) and direct reduction of ores was used. Firstly, the iron ores from mining was crushed and grounded. Then, the product was screened to achieve the suitable size and it added the value by using magnetic concentrator. The product of magnetic concentrator names a concentrate which usually content 65% Fe. The concentrate then mixed with coal and binder to form a pellet.

Secondly, direct reduction of pellet is done after ore beneficiation conducted. The product of direct reduction is called sponge iron and became the raw material of this research. Before the research started, the composition of sponge iron, flux and coal were analyzed by using the proper testing such as XRF (for sponge iron and flux), proximate and ultimate analysis for coals. Figure1 and Figure2 show the sponge iron and sub-bituminous coal used in this research respectively.

This research was conducted in laboratory scale. The objective of the research is to produce pig iron that meet the requirement of the new regulation of mineral resources such as 90% Fe. Basicity is very important factor in the smelting process because it can affect iron content of pig iron. To obtain the desired basicity, it need the addition of CaO (lime). The variation values of basicity in this research were 1 ; 1.25 ; 1.5 ; 1.75 ; and 2. In addition, the variation values of coal were 0.8 %, 1.6 % and 2.4 %.
Meanwhile, the smelting temperature is fixed (1800°C) and Electric Arc Furnace used is in laboratory scale. The product of smelting name is pig iron then analyzed by using SEM-EDS to determine the chemical composition and microstructure of pig iron. Figure 3, 4 and 5 show the Electric Arc Furnace as a laboratory scale, pig iron and slag that produced in this research, respectively.
### 3. Results and Discussion

Tables 1, 2 and 3 show the composition of limestone, coal and sponge iron, respectively, as a raw materials that used in this research.

**Table 1. Composition Of Limestone (CaO)**

| Substitute | %  |
|------------|----|
| CaO        | 53.20 |
| MgO        | 0.28  |
| SiO<sub>2</sub> | 0.70  |
| LOI        | 41.80 |

**Table 2. Proximate Analysis Of Coal**

| Substitute | Fixed Carbon | Moisture | Volatile Matter | Ash |
|------------|--------------|----------|-----------------|-----|
| %          | 37.98        | 7.70     | 41.95           | 12.37 |

**Table 3. Chemical Composition of Sponge Iron**

| Substitute | %  |
|------------|----|
| Fe total   | 72.80 |
| Fe Metal   | 65.60 |
| Al<sub>2</sub>O<sub>3</sub> | 1.03 |
| SiO<sub>2</sub>     | 4.60 |
| MgO        | 0.36  |
| CaO        | 0.14  |

### 3.1. Effect Of Basicity On Iron Content Of Pig Iron

Figure 6 shows the influence of basicity on iron content of pig iron. It could be seen that basicity affects the iron content of pig iron but the effect varies with the variation value of coal addition. At 0.8% coal, the highest value of iron content (90.73% Fe) is achieved at basicity equals to one but the iron content decrease slightly when the basicity increase. We can see that the iron content become 89.85% when the basicity increase to two. According to the previous research that conduct by Budi Syafari, if the basicity too high, it could increase the viscosity of the slag (Syafari, Budi, 2009). Therefore, the iron content of pig iron decreases slightly because diffusion of atom at interphase between slag and metal phase is inhibited. As equation (1) mentioned below, diffusion of atom will decrease if the viscosity increase.

\[
D = \frac{Kb \cdot T}{6\pi \eta} \tag{1}
\]

D: coefficient of diffusion, Kb: Boltzmann constant \(91.38 \times 10^{-23} \) J/mol.K, T: temperature (K), R: radius of particle (cm) and η: viscosity (poise).

Meanwhile, at 1.6% and 2.4% coal, the increasing of iron content depends on the increasing of basicity. As can be seen from reaction (2) that CaO will replace FeO in slag and form calcium silicate. Therefore, if basicity increases, the iron content of pig iron increases too. The smallest values of iron content (90.67 %Fe) is achieved at 1.6% coal while the highest iron content (95.04%) at 2.4% coal.

\[
2\text{FeO}.\text{SiO}_2 + 2\text{CaO} \rightarrow 2\text{CaO}.\text{SiO}_2 + 2\text{FeO} \quad \Delta G_{1923}^0 = -113 \text{ KJ} \tag{2}
\]
3.2. Effect Of Addition Of Coal On Iron content Of Pig Iron

The addition of limestone without accompanied by the addition of coal, the iron content of Fe in pig iron will not rise. Coal is a source of carbon used as a reducing agent for reducing iron oxides to increase the percentage of iron content of iron. In the process of smelting using EAF, limestone as a flux is added to react with impurities in sponge iron such as SiO\textsubscript{2}. Moreover, it is also added coal as a reducing agent. If the content of C increases, the reduction process will increase too but there is an additional restrictions coal because excess coal can affect the viscosity. The reduction reaction of iron oxide by coal which occurs in the melting process can be seen as follows: (Rosenqvist, 1983)

\[ \text{FeO} + \text{C} \rightarrow \text{Fe} + \text{CO} \quad \Delta G_{1823}^0 = -139.86 \text{ KJ} \quad (4) \]

\[ \text{FeO} + \text{C} \rightarrow \text{Fe} + \text{CO} \quad \Delta G_{1823}^0 = -141.46 \text{ KJ} \quad (5) \]

Based on the research that has been done is seen that the additional of coal tends to increase the percentage of iron content of iron but after it reach a maximum point, the percentage of iron content is decreased. For more details can be seen in Figure 7. The decline in iron content caused by excess of coal could increase the viscosity. High viscosity means hot metal becomes condensed therefore atoms difficult to diffuse. Furthermore, the decline of iron content of iron is affected by the content of SiO\textsubscript{2} in coal. Table 4 shows the composition of coal ash by ultimate analysis (Amaliyah et.all, 2011).
Table 4. The Composition of Coal Ash

| Substitute | %    |
|------------|------|
| SiO₂       | 48.96|
| Al₂O₃      | 29.26|
| CaO        | 6.08 |
| MgO        | 1.13 |
| SO₃        | 4.17 |
| Na₂O       | 0.25 |
| Fe₂O₃      | 6.83 |
| TiO₂       | 2.27 |

3.3. Effect of Basicity on percentage of Iron in Slag

Figure 8 shows the effect of basicity on percentage of iron in slag. It can be seen that initially the percentage of iron in slag is high (8%) then is decrease slightly by increasing basicity. It means, CaO replace FeO in forms of fayalite because the affinity of CaO and SiO₂ higher then affinity of CaO and FeO that mention at equation (2). In addition, the additional of coal can also affect the content of iron in slag such as the increasing carbon content in the smelting process, the percentage of iron in slag is decreased.

4. Conclusion

Based on this research, it can be concluded that:

- Basicity affects the iron content of pig iron such as if basicity increases, the iron content increases too. The highest iron content (95.04%) achieved at basicity equals to 2.
- The addition of coal also can affect the iron content of pig iron. The improvement of iron content of pig iron has the same pattern as the effect of basicity i. e. iron content increase if the addition of coal increase as well. The highest iron content (95.04%) achieved at 1.6% of coal.
- Iron content in slag decrease when the basicity and the addition of coal increase. The highest iron content in slag (8.52%) is achieved at 1.5 basicity and 0.8% addition of coal.

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