Effect of basicity and reductant amount in the nickel pig iron (NPI) production from Indonesian limonite ore in submerged electric arc furnace (SAF)

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Abstract. The effect of basicity and reductant amount on the nickel and iron recovery of the nickel pig iron (NPI) production from Indonesian limonite ore was investigated in the experimental study using submerged electric arc furnace (SAF). Indonesian limonite ore used in this study originated from Sulawesi Island with the composition of Ni (1.26%) and Fe (43%). Metallurgical coke was applied as the reductant. This study showed that the highest nickel and iron recovery as well as metal yield can be resulted from the basicity of 0.8 and reductant amount of 0.23 kg coke/kg limonite ore. Nickel content in the NPI produced was around 3 – 4%. It was concluded that this experiment can produce medium grade NPI.

1. Introduction
Nickel is an important metal used in the production of stainless steel and alloys [1]. Approximately 65% and 12% of the overall nickel consumption worldwide are primarily consumed for stainless steel production and for super alloy or nonferrous alloy manufacturing, respectively [2]. Nickel laterite ores, which comprise 73% of the world’s proven nickel reserves (approximately 160 million tons), are the dominant source of nickel [3]. Indonesia is one of the largest producers of nickel ore in the world and it has approximately 16% of total global nickel resources in the form of lateritic ores. They are widely distributed and spread among the islands of Kalimantan, Sulawesi, Halmahera, and Papua [4].

Nickel laterite ores are difficult to beneficiate by physical methods because of their complex mineralogy [5]. Thus, metallurgical technology is usually applied to extracting nickel from nickel laterite ores. In recent years, the rapid growth in stainless steel demand has dramatically increased the recovery of nickel metal by approximately 4.7% per year. Therefore, the recovery of nickel from laterite ores using pyrometallurgy has been extensively investigated.

In this study, the production of nickel pig iron (NPI) from an Indonesian low-grade nickel limonite ore was performed in submerged electric arc furnace (SAF) using metallurgical coke as a reductant. The effects of basicity and reductant amount on the metal yield and recovery of nickel and iron were investigated. The present study aims to provide a basis for the utilization of nickel laterite ores to produce nickel pig iron (NPI) by pyrometallurgical method.

2. Materials and Method
2.1. Materials
The low-grade limonite ore used in this study was collected from Sulawesi Island, Indonesia. The chemical composition of the limonite ore that is analyzed by X-ray fluorescence (XRF) and X-ray diffraction (XRD) pattern is given in Table 1 and Figure 1, respectively. Metallurgical coke was
employed as a solid reductant in the smelting process. The proximate analysis of the coke is listed in Table 2. The coke is a good reductant because of its high fixed carbon and volatile matter, low ash, and relatively low harmful element (S, P) content. The ore and coke were ground to 100% passing screen aperture of 74 μm to increase the contact between them before they were mixed and agglomerated into pellets with diameter 10-20 mm. Limestone was used as a flux to adjust the basicity of material during the smelting process of lateritic nickel ore.

2.2. Experimental Method

Reduction and melting process of low-grade limonite ore to produce nickel pig iron (NPI) were conducted in SAF with capacity of 30 kg/heat. The effect of basicity on the recovery of nickel and iron was conducted by adjusting the composition of limestone in the raw material with the basicity used in this experiment is 0.8; 1; and 1.4. The effect of reductant amount was also studied by varying of coke amount in the raw material. The composition of raw material in this smelting process is listed in Table 3. The pouring temperature of slag and hot metal was 1246-1578 °C. Metal that produced from the experiments were analyzed using optical emission spectrometry (OES) to get their chemical composition. Recovery of metal particularly iron (Fe) and nickel (Ni) as well as the yield of metal can be calculated from the iron and nickel content in the nickel pig iron produced.

| Parameter | Ni | Fe | Si | Mg | Ca | Al |
|-----------|----|----|----|----|----|----|
| wt. %     | 1.26 | 43.10 | 3.23 | 6.29 | 0.34 | 2.83 |

Table 2. Proximate analysis of metallurgical coke

| Parameter       | Moisture | Volatile matter | Ash | Fixed carbon |
|-----------------|----------|-----------------|-----|--------------|
| wt. %           | 0.20     | 9.65            | 27.18 | 62.97        |

Table 3. The composition of raw material

| Trial | Laterite ore | Coke (kg)  | Limestone (kg) | Basicity |
|-------|--------------|------------|----------------|----------|
| 1     | 30           | 7 (stoichiometry) | -             | 0.8      |
| 2     | 30           | 7 (stoichiometry) | 0.90          | 1        |
| 3     | 30           | 7 (stoichiometry) | 3.12          | 1.4      |
| 4     | 30           | 10.5 (excess + 50%) | -             | 0.8      |
| 5     | 30           | 5.6 (lean - 25%) | -             | 0.8      |

Figure 1. X-ray diffraction pattern of limonite ore
3. Result and Discussion

As listed in Table 2, the nickel laterite ore has high in Fe content and it was in form of goethite, as shown in Figure 1. Quartz (SiO₂), and proto-enstatite (MgSiO₃) also found in this lateritic ore. From the Rietveld analysis, as listed in Table 4, it was 76.5%, 7.9%, and 15.6% for goethite, quartz, and enstatite, respectively.

3.1. Effect of Basicity

The quaternary basicity, which is calculated as the ratio of CaO and MgO to SiO₂ and Al₂O₃, as expressed in Equation 1, is used in this experiment to investigate its effect on metal yield and metal recovery. From the Figure 2 and Figure 3, the 0.8 basicity showed the optimum metal yield and metal recovery, both for Ni and Fe recovery. The metal yield and recovery tend to decrease when it was 1.0 basicity and it tend to increase at 1.4 basicity.

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B = \frac{CaO + MgO}{SiO₂ + Al₂O₃}
\] (1)

From other research, as reported by Li et al., the optimum basicity for smelting the nickel laterite ore was 1.0 [6]. Zhu et al., also reported the optimum basicity was 1.0, nevertheless the basicity was calculated from binary basicity as the ratio of MgO to Al₂O₃ [7]. The lower basicity in this experiment probably due to the higher Fe content, i.e. 43.1%, than the previous research.

3.2. Effect of Reductant Amount

From Figure 4 and Figure 5, the optimum metal yield and metal recovery was obtained by the addition 7 kg of coke as stoichiometry calculation. Nickel oxide and ferrous oxide needs carbon as reductant to transform into metal, Ni and Fe. The less amount of coke than stoichiometry resulted in low metal yield and recovery. It means there was no-sufficient coke to reduce the metal oxides. Nevertheless, the same result was also found in excess coke of stoichiometry. The metal yield and metal recovery was lower than stoichiometry. Coke contains S and P. More coke means in more harmful element in smelting process. S and P inhibit the reduction of oxides in smelting process, thus it lowering the recovery of metal.

![Figure 2. The effect of basicity on the metal yield](image-url)
Figure 3. The effect of coke amount on the nickel and iron recovery

Table 5. Smelting process result

| Trial No. | NPI Composition (wt.%) | Pouring Temperature (C) | Metal yield (wt.%) | recovery Ni (wt.%) | recovery Fe (wt.%) |
|-----------|------------------------|-------------------------|-------------------|-------------------|-------------------|
|           | Fe  | Ni   |                |                   |                   |                   |
| 1         | 82,81 | 3,64 | 1480            | 28,67             | 82,81             | 55,21             |
| 2         | 88,9 | 3,91 | 1485            | 21,00             | 65,17             | 43,42             |
| 3         | 87,3 | 3,86 | 1246            | 26,00             | 79,65             | 52,79             |
| 4         | 87,1 | 3,19 | 1435            | 21,67             | 54,85             | 43,89             |
| 5         | 90,7 | 3,31 | 1578            | 20,33             | 53,42             | 42,89             |

4. Conclusion
This study showed that the highest nickel and iron recovery as well as metal yield can be resulted from the basicity of 0.8 and reductant amount of 7 kg of coke as stoichiometry calculation. Nickel content in the NPI produced was around 3 – 4%. It was concluded that this experiment can produce medium grade NPI.

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