Effect of Sodium Carbonate on the Reduction Process of Nickel Slag from Sulawesi

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Abstract. Nickel slag is one of the results of the nickel ore smelting process which is still a waste and has not been used optimally. Considering the amount of nickel slag waste in Indonesia, the effort to utilize it into a more valuable product becomes very important. Therefore, in order to extract the precious metal content in nickel slag, this study aims to analyze the effect of adding sodium carbonate in the reduction process of nickel slag. In this study, the reduction process is carried out using coal as a reducing agent, where the variation of the reduction temperature is 800, 900, and 1000 °C; while the variation of the ratio between nickel slag and additives is 1:1, 1:2, and 2:1. The XRD analysis results show that the temperature rise up to 1000 °C and the addition of sodium carbonate will increase the amount of sodium magnesiosilicate up to 29.4% and also hematite up to 25.1%. The same thing happened in samples with a ratio of 1:1 and 1:2 where the amount of sodium magnesiosilicate increased from 29.4% to 30.0% and hematite from 25.1% to 28.8%.

Keywords: Additive, Nickel slag, Reduction, Sodium carbonate, Waste

1. Introduction
The production of ferro-nickel in Indonesia mostly comes from processing laterite ore, where some researchers have succeeded in increasing the concentration of nickel through a reduction process[1–3]. In addition to nickel, nickel ore processing also produces a side product called nickel slag which still contains other valuable metals such as lanthanum and yttrium[4]. Nickel sulphide ore smelting firstly recovered by increasing sulphur product called as matte [5-6]. Sulphide iron in the initial ore is oxidized in two stages that are calcination and oxygen flash smelting which then followed by the conversion of sulphide iron to iron oxide and SO₂. Iron oxide then fluxed with silica and other combination of oxide mineral that ends with the produce of byproducts called as slag[7]. This causes the high silica content on slag nickel where it usually contain 20% silica in the form of amorphous silica or metal silicates and fayalite[4]. Unfortunately, the precious metals in fayalite are strongly bonded in the silica iron matrix and difficult to separate. Therefore, in this study sodium
carbonate is added to break the silica iron matrix bond and separating silica so that the precious metals content in the nickel slag will increase.

2. Experimental method

2.1 Materials
The nickel slag sample used in this study originated from Sulawesi and was characterized in previous studies [8], where the Si oxide content was 25.02% (based on XRF) and in the form of forsterite, olivine, quartz, and fayalite as seen in the XRD pattern, Figure 1.

![XRD results of initial sample (nickel slag) [8].](image)

2.2 Experiment
To determine the effect of temperature, three samples each containing a mixture of 20gr nickel slag, coal 2gr, and sodium carbonate 20gr were reduced for one hour at different temperatures namely 800, 900, and 1000°C, respectively. Meanwhile, three other samples carried out variations in the weight ratio of nickel slag with sodium carbonate, namely 1: 1, 1: 2, and 2: 1, and heated at a temperature of 1000°C for 1 hour. After the reduction process, the samples were taken to BATAN for XRD testing and the results were analyzed using the highscore plus software.

3. Results and discussion
The result of XRD pattern analysis can be seen on Figure 2, and its semi-quantitative analysis is separated to Figure 3 until Figure 5. Figure 2a and Figure 3 show that the percentage of quartz tends to increase with increasing temperature, while a percentage of forsterite tends to decrease. This indicates the possibility of the decomposition of forsterite into quartz due to the presence of the reducing agent. In this reduction without sodium carbonate, the optimum decomposition of forsterite into quartz occurs at the highest experimental temperature of 1000°C.
Figure 2. XRD patterns of nickel slag after reduction (a) without sodium carbonate at various temperatures; (b) with sodium carbonate (ratio 1:1) at various temperatures; (c) in various sodium carbonate ratios at 1000°C.

In Figure 2a there is also no significant change in compound. This is presumably due to the strong bond of iron silicate compounds from nickel slag so that they cannot be reduced directly by using coal only. This assumption is strengthened from the results of experiments using sodium carbonate as an additive as seen in the XRD results in Figure 2b and Figure 4. Figure 2b shows the presence of other dominant compounds namely Magnesiosilicate (Na$_2$MgSiO$_4$) and hematite, although the iron silicate compounds are still present. This can also be seen in Figure 2c that as the addition of sodium carbonate increases, more hematites are formed. According to the semi-quantitative results in Figure 5, Fe-rich forsterite is reduced from 18.5% to 14.9% by reducing the amount of carbonate sodium, i.e., from 1:1 ratio of nickel / sodium carbonate to 2:1.

Based on semi-quant result of XRD as shown in Table 7, it can be seen where at 800°C, the most dominant phase is Forsterite (Mg$_2$SiO$_4$) with the content of 25.9%. In the increase of temperature, it is seen that the Hematite began to form. Temperature of 900°C and 1000°C shows the presence of Hematite and Sodium Magnesiosilicate with the value of 10.6%, 25.1% and 36.2% and 29.4% respectively.
Figure 3. XRD semi-quantitative analysis of nickel slag after reduction without sodium carbonate at various temperatures.

| Temperature | Fe-rich Forsterite | Olivine | Forsterite | Quartz | Fayalite |
|-------------|--------------------|---------|------------|--------|----------|
| 800°C       | 71                 | 9.2     | 7.6        | 1.4    | 11       |
| 900°C       | 67.8               | 8.1     | 7.2        | 6.4    | 10.5     |
| 1000°C      | 55.7               | 8.2     | 6.8        | 19.7   | 9.7      |

Figure 4. XRD semi-quantitative analysis of nickel slag after reduction with sodium carbonate (ratio 1:1) at various temperatures.

| Temperature | Fe-rich Forsterite | Olivine | Forsterite | Quartz | Fayalite | Sodium Magnesiosilicate | Magnesium Oksida | Hematit |
|-------------|--------------------|---------|------------|--------|----------|-------------------------|------------------|---------|
| 800°C + Na2CO3 | 20.4             | 12      | 25.9       | 1.3    | 16.8     | 22.8                    | 0.8              | 0       |
| 900°C + Na2CO3 | 6.3              | 6.8     | 12.3       | 18.2   | 9.2      | 36.2                    | 0.4              | 10.6    |
| 1000°C + Na2CO3 | 18.5             | 0       | 23.2       | 2.7    | 0        | 29.4                    | 1.1              | 25.1    |
Figure 5. XRD semi-quantitative analysis of nickel slag after reduction in various sodium carbonate ratios at 1000°C.

Figure 5 shows the semi-quant XRD result of slag nickel that had been added by Na$_2$CO$_3$ in different weight ratio of nickel slag and Na$_2$CO$_3$. In 2:1 ratio shows that there is still fayalite and hematite with the value of 12.7% and 15.1% respectively. On the other side, with the increase of Na$_2$CO$_3$ content in the ratio to 1:2 it can be seen there is no fayalite found. Figure 5 also informs that the higher the weight ratio between nickel slag and Na$_2$CO$_3$, the higher the hematite content that is 25.1% and 28.8% respectively.

4. Conclusion
Nickel slag used in this study is an amorphous compound in which silicate compounds dominate and become a barrier to the separation of precious metals.
Sodium carbonate added in the tin slag reduction process can accelerate the decomposition of Fe-rich forsterite (FeMgSiO$_3$) into Sodium Magnesiosilicate (Na$_2$MgSiO$_4$), Magnesium Oxide (MgO), and Hematite (Fe$_2$O$_3$).

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