Journal of Metallurgical Engineering and Processing Technology, Vol. 5, No. 1
August, 2024
P-ISSN: 2723-6854, E-ISSN: 2798-1037, page 52-64
DOI: https://doi.org/10.31315/jmept

Analysis Effect of the Nickel Ore Reduction Process on Sulfur Fixation in Reduction Kiln #5 at PT Vale Indonesia Tbk Using Factsage Simulation

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Received 23/04/2024; Revised 13/07/2024; Published 05/08/2024

Abstract

The pyrometallurgical process which produces a product in the form of matte nickel is a nickel product that contains high sulfur so it is necessary to carry out a calcination process with the addition of sulfur and coal in the process using a reduction kiln. In order to increase the effectiveness of the process, PT Vale Indonesia Tbk's reduction kiln operations underwent several improvisations regarding the parameters used in the reduction kiln to adapt to the ore and changes to the equipment. This research aims to obtain optimal conditions for the reduction and sulfidation process to produce nickel in a reduction kiln with low fuel consumption. This research stage was carried out by making direct observations in the field as material for assessing actual conditions, then carrying out simulations using Factage software to obtain ideal conditions. Factage simulation results show an optimal calcine composition with 1.95% Ni; 25.86% Fe; 5.03%C; 63.28% $Mg_2Si_2O_6$; and 3.03% Mg_2SiO_4 with a good calcine temperature of 717^oC and federate at a kiln reduction of 767 DMT and the maximum sulfur fixation value obtained was 1.3 because sulfur and coal were added at the ideal dose, namely 9 kg/t and 35 kg/t.

Keywords: Reduction Kiln, Reduction, Extraction Nickel, Factsage Simulation, Sulfur.

Introduction

Indonesia is a country rich in natural resources, one of which is the abundant mineral, namely Nickel (Ni). According to the Ministry of Energy and Mineral Resources, 2019 world nickel reserves are around 23.7% in Indonesia, most of which are spread across South Sulawesi, Southeast Sulawesi and North Maluku. Nickel (Ni) is a mineral that has high economic value when processed, so it must be utilized optimally but still responsibly (Azhim et al., 2022).

Currently there are two types of nickel metal extraction technology in the world, namely pyrometallurgy and hydrometallurgy. In general, pyrometallurgy is used for nickel deposits that have levels above 1.7%, while hydrometallurgy is more suitable for nickel levels below 1.5% (Nick, 1984). The reason saprolite ore with a higher nickel

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content uses a smelting process is because saprolite ore contains low iron content (15%) so it will produce ferronickel with a high nickel content and saprolite containing quite high MgO (20%) is not suitable for processing. using a leaching process, because MgO itself will react with the solvent excessively and prevent nickel from reacting with the solvent so that the process does not run perfectly (Tanjung et al., 2022).

PT Vale Indonesia Tbk produces the final product in the form of matte nickel, namely nickel with a high sulfur content, so to increase the effectiveness of the smelting process, it is necessary to inject sulfur in the form of liquid sulfur before entering the furnace for the sulfidation process so that the separation between matte and slag will be better. Using a reduction kiln to produce calcine is considered effective because it can increase the nickel content of the product (Prasetyo & Prasetyo, 2015). Therefore, based on the needs of this process, it requires a special design that is more optimal and requires special assessments to analyze the process parameters.

The reduction kiln process aims to produce high quality calcine to be continued to the smelting process. High quality calcine is indicated by several parameters, namely; has a temperature above 700°C, has a chemical content of xH_2O less than 1%, carbon 1.6 – 1.8% and reduced nickel greater than 35% (Dalvi (Chapter 2), 1987). The reduction process aims to form free Ni and Fe separated from their oxide compounds and is followed by a sulfidation process to bind the free metal into metal sulfide. To date, PT Vale Indonesia Tbk has operated 5 reduction kilns. To obtain a suitable temperature profile, air supply is established, and five blowers are placed around the kiln at equal distances to inject air. Raw materials are filled from the kiln tail in a predetermined ratio and heated by hot flue gas flowing in the reverse direction. At the beginning of the reduction, NiO and CoO will be reduced first, then FeO (Liu et al., 2016). Reduction dryer products consisting of West Block and East Block ore types are mixed in a certain ratio and then fed to the reduction kiln. This comparison is based on the silica and magnesia content contained in the two blocks. The silica-magnesia ratio has a big influence on the electric furnace process (Crundwell et al., 1961).

PT Vale Indonesia Tbk's reduction kiln operations have undergone several importations regarding the parameters used in the reduction kiln, adapting to ore availability and changes in equipment, so it is necessary to evaluate the processes that occur in the kiln to obtain optimal conditions, namely when the reduction kiln can be run with the highest reduction and sulfidation conditions and the lowest fuel consumption. After the nickel is calcined in the initial stage, a reduction process is carried out from the metal oxides Fe, Ni and Co and to bind and fix the sulfur in the calcine by adding liquid sulfur (sulfidation). Reduction occurs due to reactions with CO and H_2, which come from incomplete combustion and coal which also enters as feed for the reduction process (Kritzinger & Kingsley, 2015).

The reduction and sulfidation conditions in a reduction kiln can be greatly influenced by the operating temperature. High temperatures cause molecules to move faster and have a higher chance of colliding with each other, thereby increasing the reaction rate. The higher the temperature of the material, which in this case will be calcined, the better the reaction process, including reduction, calcination and further drying, that will occur in the reduction kiln (Sufriadin et al., 2012). The reduction kiln simulation carried out on Factsage uses optimal condition parameters with a temperature of 717^oC. The determination of this temperature is based on literature studies which state that at this temperature calcine conditions are obtained with reduced nickel and high sulfur content and the reduction reaction occurs well if the ore temperature is at least 700^oC (Prasetyo & Prasetyo, 2015).

The sulfidization process is highly dependent on the reduction conditions. Sulfur primarily reacts with iron and nickel metals (Yusfaldin, 2017). The sulfur binding process occurs in a very short time interval, or in other words, very spontaneous. In the combustion chamber in the discharge end area which has very high temperatures, the sulfidization or sulfur fixation process really depends on how much unstable positively charged iron and nickel metal there is, how much oxygen content is in the combustion chamber (Jiang et al., 2013). There are two big possibilities that can happen, namely the first, sulfur bonds with Fe and Ni to form FeS and NiS, while O bonds with C to form CO and CO_2, the second, sulfur bonds with O to form SO_2 and Fe Ni re-bonds with O to form metal oxide. This second possibility is avoided because the SO_2 that is formed is released into the atmosphere to become SO_2 emissions, and the metal oxide that is formed will become EFF (electric furnace feed) and be carried to the electric furnace which increases the possibility of an explosion. SO_2 and metal oxides in EFF are two conditions that must be minimized, even avoided because they increase the level of danger to the continuity of factory operations (Quintero-Coronel et al., 2022).

Sulfur fixation in extraction refers to the process in which sulfur is fixed or retained in certain chemical forms, such as sulfides or sulfates, in certain substrates. Sulfur fixation in calcine mainly occurs through the combination of sulfur with Fe and Ni metals to form sulfide through a sulfidation reaction. Sulfur has very little tendency to react with nickel and iron oxides (Nurjaman et al., 2018). Therefore, the sulfur content in calcine is proportional to the Ni reduction in calcine.

This research was carried out by making direct observations in the field and accumulating operational data, then analyzing it using simulations with factsage software with input data from the most optimal operating conditions so that operational conditions can be obtained that influence the sulfur fixation value. FactSage is one of the largest integrated database computing systems in chemical thermodynamics in the world (Bale et al., 2016). This research uses Factsage as a tool for process simulations in reduction kilns so that it can represent the most optimal design conditions based on the input data.

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Research Methods

The main objective of this research is to determine the effect of the reduction process in the reduction kiln on the sulfur fixation value used with the help of simulations with factsage software.

The factsage used in this research is version 6.2 which can only be accessed from PT Vale Indonesia Tbk. In Factsage, the databases chosen are FactPS, FToxid, FTsulf and FTmisc to obtain the desired phase product, then the results of the thermodynamic calculations are made in the form of a graph plot (Harvey et al., 2020).

Data Collection The research subject was reduction kiln #5 at the PT Vale Indonesia Process Plant. The main data required and derived from company data includes process data and operational data, including:

a. Input rate of material to the kiln
b. Composition of Reduction Kiln Feed
c. Composition of Electric Furnace Feed
d. Metal Reduction
e. Temperature of Thermocouple
f. Fuel consumption on the burner
g. Data on the addition of sulfur and coal

Mass balance calculations were carried out in this research to compare actual conditions in the field with the results of the factsage simulation. The basis for the mass balance calculation is based on the average reduction kiln feed rate in reduction kiln #5. The results of this mass balance calculation are presented in the form of a mass balance simulation using Ms. Excel so that you can find out which minerals or elements enter as input and which come out as output (Zahidin & Rubianto, 2023).

Sulfur fixation in extraction refers to the process in which sulfur is fixed or retained in certain chemical forms, such as sulfides or sulfates, in certain substrates. The variation value of sulfur fixation in calcine can be calculated using the formula.

$$\%S\ (calcine) = C \times (\%Ni\ reduction/100)$$

Where C is a constant with each Caverage value = 1.64; Cmax = 2.25; and Cmin = 1.25

The results of sulfur fixation calculations based on the formula above will be presented in boxplot form. Boxplot is a summary of the sample distribution presented graphically which can describe the shape of the data distribution (skewness), a measure of central tendency and a measure of the spread (diversity) of observational data so that you can see the best distribution of data compared to other data (Napier-Munn, 2014).

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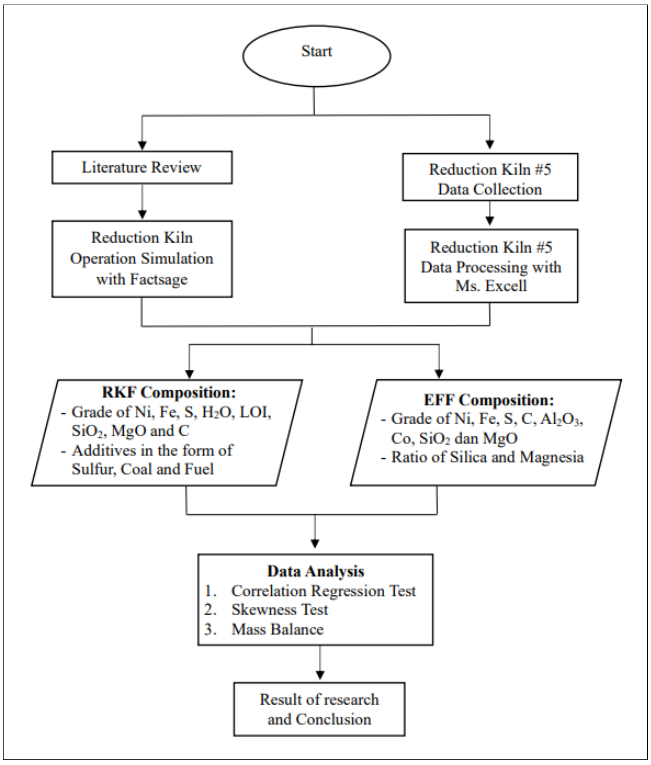

Figure 1 Research flow diagram

Result and Discussion

Results of Research

1. Data Composition of Reduction Kiln

The nickel ore product from the dryer is stored in dry ore storage 1 and 2 then before entering the reduction kiln as process feed, the Reduction Kiln Feed is sampled every 2 hours so that 12 samples are tested in a day. The resulting RKF data will be averaged to represent production in the reduction kiln in one day. RKF composition data for December 2023 can be seen in the table 1.

Table 1. Composition of Reduction Kiln Feed

Composition (ton)	Min	Max	Av
OIL	130,9	191,7	179,5
COAL	70	141,8	103,9
S	0,0227	0,0348	0,0318
LOI	234,5	453,8	368,5
Ni	59,4	75,6	67,1
Fe	705,3	909,3	812,6
H_2O	638,9	832,1	733,6

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The product resulting from the reduction kiln process is calcine with a lower water content, which will then be fed into the furnace as electric furnace feed. Before entering the Electric Furnace, EFF sampling is carried out every 2 hours so that 12 samples are tested in a day. The resulting EFF data will be calculated on average to represent the composition of calcine in one day. EFF composition data for December 2023 can be seen in the table 2.

Tabel 2. Composition of Electric Furnace Feed

Composition (%)	Min	Max	Average
AL_2O_3	2,66	4,54	3,61
C	0,92	2,97	1,82
Co	0,05	0,1	0,07022
Fe	15,5	24,6	21,6
Ni	1,36	2,24	1,82
S	0,2	1,31	0,71
SiO_2	33,2	47,3	38,9
MGO	14,4	24,6	17,98
SM	1,69	3,28	2,17

2. Simulation Factsage Data

The Factsage simulation for the reduction kiln process begins by inputting the composition of the ore which is used as feed for the process, apart from that additional materials are added in the form of sulfur and coal with an optimal feed rate of 767 DMT. The composition of the ore reacted in the reduction kiln is entered into data based on literature books used as process references at PT Vale Indonesia in the table based on secondary data obtained from the Company, the results of which can be seen in table 3.

Tabel 3. Ore Dry Kiln Composition for Factsage Simulation

Komposisi	Nilai	Temp (^oC)
Fe%	22,9	100
Ni%	1,8	100
Co%	0,01	100
SiO_2%	35,5	100
MgO%	16	100
H_2O	23,8	100
S (Kg/T)	9	120
C (Kg/T)	35	30

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3. Mass Balance

The basis for mass balance calculations is based on the average reduction kiln feed rate data for December. The material charging process in the reduction kiln uses a belt conveyor to the feed bin. Mass balance calculations are carried out based on the mass balance formula whose values are based on field data that has been collected. Depiction of the mass balance simulation for the reduction kiln for December 2023 in the figure 2.

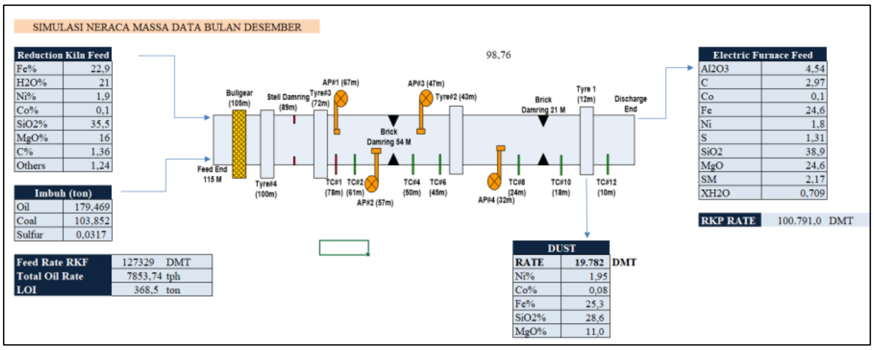

Figure 2. Mass Balance Simulation for December 2023

Discussion

1) Process Analysis from Factsage Simulation Results

The parameters entered to carry out factsage simulations are ore feed composition, calcine temperature and feed rate. The equilibrium results are made in the form of a plot or graph of temperature vs mass % where the graph shows the phase of the compound formed and can be seen in the Figure 3.

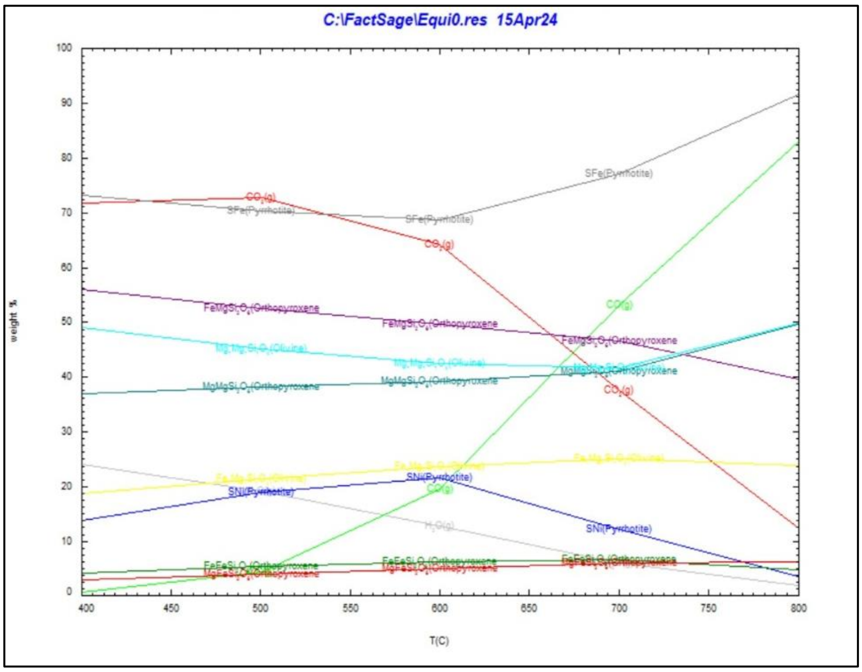

Figure 3. Plot Simulation Results Factsage T(C) vs %weight

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Based on this graph, it can be seen what phases and minerals are formed for reduction kiln products and it can be seen that there are changes in mass for several minerals at certain temperatures. The graph shows that the masses of CO and CO_2 in the kiln material experience inverse changes in mass. This is related to the CO_2 that comes out of the reduction kiln as exhaust gas, while the mass of CO increases because it is used as a metal reducing agent so that the mass of CO is needed in the material for the reduction process.

To see how the sulfur content changes in the product compared to the feed, a mass balance form is presented in table 4. The input in the mass balance used is the composition of ore and added with liquid sulfur and coal, which in the kiln process, coal is added together with the dyer product so that can be mixed homogeneously in the tool, while liquid sulfur will be added to the kiln by spraying it on the part near the main burner.

Table 4. Mass Balance Based on Factsage Simulation

Input (RKF)		**Output (EFF)**		
Senyawa	**Massa**	**Streams Phase**	**Senyawa**	**Massa**
Fe	175,643	Orthopyroxene	$Mg_2Si_2O_6$	439,91
Ni	13,806	fcc	Ni	169,55
Co	0,077	Pyrrhotite	Fe	24,595
SiO_2	272,285	Olivine	Mg_2SiO_4	21,063
MgO	122,720	bcc	Fe	5,0168
S	6,903	Beta Ni_3S_2	S	14
C	26,845	C_graphite	C	35
H_2O	148,7213	Gas ideal		57,8652
Total	767			767

The mass balance table shows that there is an increase in sulfur content in the kiln output of 2% compared to the input. Based on the calculations carried out in Appendix D, the Fe content in the calcine is 26.547%, the Ni content is 1.99% and the Co content is 0.108%. The nickel reduction that occurs has a percentage of 34% and is obtained from comparing the Ni content in the input with the Ni content in the output.

The increase in sulfur content in the calcine can be an optimal reduction process parameter because it is based on the sulfur fixation theory where the higher the sulfur content in the calcine, the higher the nickel reduced.

2) Effect of the Reduction Process on Sulfur Fixation

Based on the theory that high sulfur levels also indicate high nickel levels in calcine. This can happen because the sulfur is injected into the lance close to the discharge end, which is where the main burner is located, so it is at the highest operating temperature (Dan et al., 2017). High temperature environments make sulfur have a tendency to bond with reduced nickel so when the nickel and sulfur levels are high in calcine, it can be a

P-ISSN: 2723-6854, E-ISSN: 2798-1037, page 52-64
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good reduction process parameter in reduction kiln operations.

Assessment of the conditions of the reduction process in a reduction kiln can also be done by comparing the process under design conditions which has been carried out previously using Facsage simulation and the process under field conditions which is carried out by evaluating the heat balance calculation with secondary data. The mass balance calculation will display the variance value which is the percentage value of the difference between the input mass and the output mass to be used as a consideration for assessing the condition of the reduction process in the tool. Mass balance calculations are based on secondary data obtained from the Company, the results of which can be seen in the table 5.

Tabel 5. Company Data Mass Balance Calculation Results

Komposisi	**Input**			**Output**		
	%	**RKF (ton)**	**Imbuh (ton)**	**%**	**EFF (ton)**	**Dust (ton)**
Fe	24,1	21.611		25,3	21.413,7	288,5
H_2O	20,6	18.473				
Ni	1,8	1.614		1,8	1.523,5	21,81
Co	0,1	90		0,1	84,6	0,89
SiO_2	34,83	31.233		42,3	35.802,3	314,6
MgO	16	14.348		24,3	20.567,3	122,7
C	1,2	1.076		1,79	1.515,0	
Al_2O_3				3,69	3.123,2	
S				0,7	592,5	
Sulfur Add			0,028			
Coal			84,283			
Oil			159,853			
Total			88.688,644			85.370,6
Variansi	-3,89%					

The mass balance calculation in table 2 shows a variance value of -3.89%. Several things that can be a loss factor in the reduction kiln process are the presence of chunks, which are feed material that settle on the tool due to temperatures that are too high. Apart from that, it can also be caused by some material being very fine and being wasted as dust. However, the increase in sulfur in the reduction kiln output was 1.7% and the value of reduced nickel was 33% based on test results. Based on the theory that good quality calcine has a sulfur content of more than 2% and a reduced nickel value of above 34% so that the field data is close to good calcine quality. The graph of sulfur fixation based on calcine data can be seen in the Figure 4.

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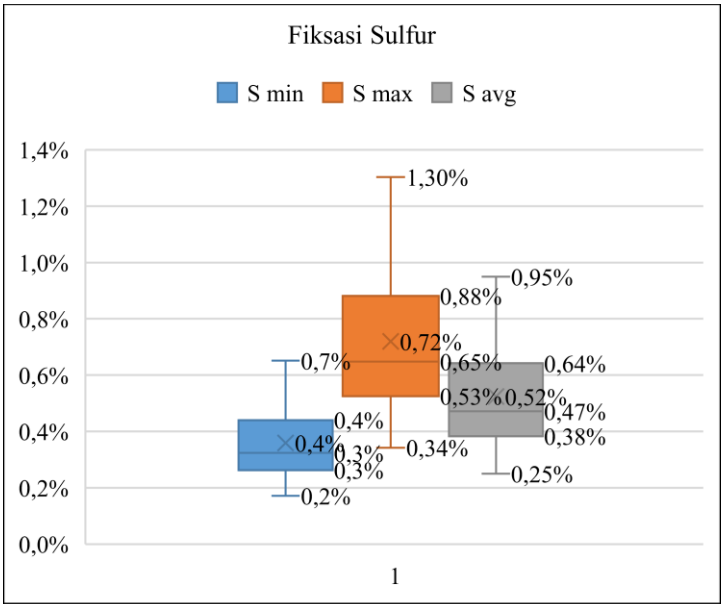

Figure 4. Box Plot Distribution of Sulfur Fixation Data

The calculation for the sulfur fixation value is carried out based on the equation which is used as the basis for the research method. Based on the data distribution plot, the highest sulfur fixation was obtained at 1.3% with the highest data distribution also obtained by Cmax data. There are no outlier data and extreme data in the box plot indicating that there is no data that is more than the whisker length with the max whiskers values at s min, s max and s average being 0.7%, 1.3% and 0.95%.

The addition of sulfur is done because the metal form of nickel and iron is unstable and can return to its oxide form so that when nickel metal and iron metal bond with sulfur it will have a more stable form (Dan et al., 2019). However, adding too much sulfur will increase the resulting SO_2 emissions because sulfur also has the opportunity to bind with oxygen to form SO_2, while adding too little sulfur will reduce the mass of nickel sulfide and iron sulfide in the calcine. Therefore, it is necessary to add sulfur at the optimal dose, namely at a dose of 9 kg/t.

The results of the Factsage simulation have a better fixation value because it uses an optimal sulfur addition dose so that the sulfidation process in the tool also runs optimally. The highest sulfur fixation value was obtained because the nickel reduction value was also high, indicating that the reduction process in the reduction kiln affected the sulfur fixation value.

Conclusion

Through data analysis and results obtained from a series of research that has been carried out, there are several conclusions that can be drawn as follows:

1. Factsage simulation was carried out and optimal results were obtained for the reduction and sulfidation processes in the reduction kiln. Based on the simulation results, the composition of calcine is 1.95% Ni; 25.86% Fe; 5.03% C; 63.28%

P-ISSN: 2723-6854, E-ISSN: 2798-1037, page 52-64
DOI: https://doi.org/10.31315/jmept

$Mg_2Si_2O_6$; and 3.03% Mg_2SiO_4 with a good calcine temperature of 717°C and a feed rate in the reduction kiln of 767 DMT. The doses of sulfur and coal added in this process are 9 kg/t and 35 kg/t respectively.

2. Conditions of the nickel ore reduction process affect sulfur fixation where when the reduced nickel value reaches the maximum value, namely 57.91%, the sulfur fixation value is obtained at 1.3%, while for the optimal reduced nickel value, namely 36.4%, the value will be obtained. sulfur fixation is 0.95% so it can be said that the higher the nickel reduction, the higher the sulfur fixation value produced.

Acknowledgements

The author would like to thank the process engineer of PT Vale Indonesia Tbk for his guidance and direction for this research and thanks also to the leadership of PT Vale Indonesia Tbk who have given permission so that the research runs smoothly.

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Journal of Metallurgical Engineering and Processing Technology, Vol. 5, No. 1
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