Journal of Metallurgical Engineering and Processing Technology, Vol. 5, No. 2
February, 2025
P-ISSN: 2723-6854, E-ISSN: 2798-1037, page 143-155
DOI: https://doi.org/10.31315/jmept

Study of Laterite Iron Ore Extraction by Smelting Method using Electric Arc Furnace

Luluk Nofitasari Wijayanti[1*], Aura Shafa Choirunnisa[1], Matrix Faqih Azizi[1]
[1]Universitas Pembangunan Nasional "Veteran" Yogyakarta, Indonesia
*Corresponding author: 116210017@student.upnyk.ac.id

Received 02/12/2024; Revised 31/01/2025; Published 15/02/2025

Abstract

Laterite iron ore is the main material for iron and steel production in Indonesia, with reserves estimated at 1,391 million MT and Fe content between 40% and 56%. However, iron ore processing has not been optimally utilized. For this reason, a study was conducted with the aim of determining the effect of variations in calcine and coke composition on the content of product elements in pig iron, the effect of variations in calcine and coke composition on Fe recovery in pig iron. In this study, iron ore processing was carried out using a pyrometallurgical route using an electric arc furnace on a laboratory scale at the Mineral and Coal Testing Center. The results showed that in sample 2-1A with a composition of 30.4 kg of calcine and 6 kg of coke contained 93.58% Fe and in sample 2-2/A with a composition of 30.07 kg of calcine and 6 kg of coke contained 93.28% Fe and the largest Fe recovery was obtained in the sample variation with code 2-1/A of 65.86%. It can be concluded that the Fe content in pig iron increases when compared to the Fe content in the sintering process results, this is because the reduction process of the iron oxide phase in the sinter has occurred during the melting process with the addition of coke as a reducing agent so that CO gas is produced for the iron oxide reduction process.

Keywords: Composition Sample; Electric Arc Furnace; Laterite Iron Ore

Introduction

Ultramafic rocks are igneous rocks with a quartz percentage of less than 45%. Ultramafic rocks are classified based on the content of olivine, pyroxene and horblendite minerals into dunite, peridotite, horblendite, pyroxenite and serpentinite. Cepennites are rocks with a high serpentine mineral composition. Serpentine minerals are formed due to changes in ferromagnesian minerals such as olivine, pyroxene and amphibole (Pardiarto & Wahyu Widodo, 2024). Ultramafic rocks are found widely exposed as carriers of laterite deposits. Weathering of ultramafic rocks will become laterite deposits (Sunarya, 2017). Laterite is a residual product of chemical weathering on the earth's surface, there are original or primary minerals that experience instability by water, then dissolve or

Journal of Metallurgical Engineering and Processing Technology, Vol. 5, No. 2
February, 2025
P-ISSN: 2723-6854, E-ISSN: 2798-1037, page 143-155
DOI: https://doi.org/10.31315/jmept

break to form new, more stable minerals. In laterite there are ore minerals that have economic value such as nickel, chromite, platinum, and iron (Evans, 1993).

Iron ore is a very abundant mining material in Indonesia. Based on the properties of iron ore, this material has been widely used for various research purposes and industrial product materials. Iron ore is a residual product of chemical weathering of ultramafic rocks. This process takes place for millions of years starting when ultramafic rocks are exposed on the earth's surface (Bahfie et al., 2021). There are 4 types of iron ore, namely iron sulfide ore, iron oxide ore, iron carbonate ore and laterite iron ore. Iron sulfide ore is a type of iron ore that contains sulfur, for example pyrite (FeS_2). Iron oxide ore is iron ore that contains oxides in it, such as Magnetite (Fe_3O_4), Hematite (α-Fe_2O_3), and Maghemite (γ-Fe_2O_3). Iron carbonate ore is a type of iron ore that contains carbonate compounds in it, for example siderite ($FeCO_3$). While laterite iron ore is formed from the weathering of mineral-rich rocks in tropical areas, usually containing minerals such as limonite and goethite (Agung, 2014).

Iron ore is the main ingredient in making steel. According to Nurhakim, national steel consumption is currently estimated to have reached 6.3 million tons, while production is only 3.8 million tons, where the shortfall of 2.5 million tons is still supplied from imports. This condition causes steel production in Indonesia to require raw materials and supporting materials, most of which are still imported. Materials whose procurement still depend on imports are iron ore pellets, while scrap, lump ore and coarse fine iron ore can still be partially supplied domestically, for example for lump iron ore with an Fe content of 57% and coarse fine iron ore with an Fe content of 56%. In order to support the increasing needs of the iron and steel industry in the future, Indonesia has a large potential for iron ore resources, in the form of primary iron ore with estimated reserves of 320 million MT and a content of 25 ± 62% Fe, laterite iron ore with estimated reserves of 1,391 million MT and a content of 40 ± 56% Fe and iron sand with estimated reserves of 600 million MT and a content of 25 ± 40% Fe (Nurhakim et al., 2011).

The ore used in this extraction process is laterite iron ore. The iron ore used has an Fe content of around 45-50%. With the type of tool used is an electric arc furnace (EAF). EAF is used because it has advantages in lower energy consumption and the availability of more diverse raw materials. In addition, EAF also has advantages in the ability to produce high quality products, good environmental control, reduction and optimization of electrical energy consumption, low impurities produced and fully sophisticated process control (Saboohi et al., 2019). In the process, this laterite iron ore is dried first, then crushed. followed by homogenization and pelletizing processes. These pellets are then fed to the sinter maker to form sinter and this sinter is fed to the smelting process. From this smelting process, pig iron and slag will be obtained and XRD and XRF tests will be carried out to determine whether the results of this process have occurred optimally or not (Cavaliere, 2019; König et al., 2017; Zhou et al., 2020).

Journal of Metallurgical Engineering and Processing Technology, Vol. 5, No. 2
February, 2025
P-ISSN: 2723-6854, E-ISSN: 2798-1037, page 143-155
DOI: https://doi.org/10.31315/jmept

This study focuses on testing a certain composition of laterite iron pyrometallurgy to obtain the best product. This study was conducted on a pilot scale at the Mineral and Coal Testing Center. This study aims to determine the effect of variations in calcine and coke composition on the content of product elements in pig iron, the effect of variations in calcine and coke composition on Fe recovery in pig iron.

Research Methods

In this pyrometallurgical process, laterite iron ore is used (Liang et al., 2019). Its composition can be seen in the following table 2.1.

Table 2.1 Composition of Laterit Ore

Element	Ni	Co	Fe	SiO_2	MgO	Cr_2O_3	Al_2O_3	MnO	CaO
Percentage	0,852	0,127	48,33	3,51	0,88	3,20	8,04	1,10	0,02

In this process, BCI semi coke is also used. BCI semi coke functions as a reducer and energy source (Tyassena et al., 2022). The composition of BCI semi coke is presented in the table 2.2 as follows.

Table 2.2 Composition BCI Semi Coke

Element	C	Ash	WM	S	P	Particle Size
Percentage	~80	-	-	-	-	≤8mm

In this process, lime is also used to help bind the impurity minerals into the slag (Syguła et al., 2023). The composition of lime can be seen in Table 2.3 below.

Table 2.3 Composition of Lime

Element	SiO_2	CaO	Al_2O_3	MgO	P_2O_3	Fe_2O_3	S	Particle Size
Percentage	3,61	90,06	1,0	3,73	0,00	0,047	0,075	≤8mm

Then for the pyrometallurgy process of laterite iron ore includes several processes, namely:

a. Drying

This pyrometallurgy extraction method begins with a pre-treatment process that aims to reduce the moisture content in the ore by 45%. Furthermore, drying is carried out in an oven or furnace using temperatures up to 250° C. This process produces ore with a moisture content of 15% to 20% (Mohanty et al., 2009). The drying process can be seen in the following Figure 2.1.

Journal of Metallurgical Engineering and Processing Technology, Vol. 5, No. 2
February, 2025
P-ISSN: 2723-6854, E-ISSN: 2798-1037, page 143-155
DOI: https://doi.org/10.31315/jmept

Figure 2.1 Drying Process

b. Crushing

This process aims to reduce the size of the material by crushing using a roller crusher. The dried ore is crushed to a size of <25mm (Yin et al., 2024). The crushing process can be seen in Figure 2.2 below.

Figure 2.2 Crushing process by using roller crusher

c. Mixing Process (Two-Stage Mixing)

This mixing process is carried out by mixing the sample with coke and lime. The purpose of adding coke is for fuel and reducing agent in the refining process, while lime functions as a flux to bind impurities and form slag (Ahmed et al., 2014). This mixing aims to maximize the efficiency of laterite iron ore reduction. In this mixing process, two stages are carried out, namely as follows.

- Mixing Stage 1: Homogenization

In this stage, iron ore with a moisture content of 20%, lime powder, and fuel (semi coke powder) are first mixed to homogenize (mix well). The homogenization process can be seen in Figure 2.3 below.

Journal of Metallurgical Engineering and Processing Technology, Vol. 5, No. 2
February, 2025
P-ISSN: 2723-6854, E-ISSN: 2798-1037, page 143-155
DOI: https://doi.org/10.31315/jmept

Figure 2.3 Homogenization Process

- Mixing Stage 2: Pellet Formation

Iron ore that has been enhanced in Fe content will be processed into pellets. The mixture of iron ore and additional materials is then formed into small balls (pellets) using tools such as drum pelletizing or disk pelletizing. The pellet size is usually between 6-16 mm (Casagrande et al., 2017). The process can be seen in Figure 2.4 below.

Figure 2.4 Pelletizing process

d. Sintering

The pellet material is directly fed from the mixing process into the sintering machine. The sintered material becomes thick and is fed into the crusher to reduce the particle size with a target of 10-45 mm. This sintering process is carried out at a temperature of 1100 ^{o}C. The powder content (<10 mm) of the sintered product is controlled at <30%; Therefore, the crushed sinter needs to be classified. The temperature of the sintered ore as feed for EAF is controlled at 500 ^{o}C. Thus, the sintered ore needs to be reheated after the crushing process (Fernández-González et al., 2017a). The sintering process can be seen in Figure 2.5 below.

Journal of Metallurgical Engineering and Processing Technology, Vol. 5, No. 2
February, 2025
P-ISSN: 2723-6854, E-ISSN: 2798-1037, page 143-155
DOI: https://doi.org/10.31315/jmept


Figure 2.5 Sintering Process

e. Reheating

This process is carried out to change the chemical structure and improve the quality of the final product. The temperature used is around 500 °C. The reheating process can be seen in Figure 2.6 below.


Figure 2.6 Reheating Process

f. Smelting

Smelting process is a process of reducing ore so that it becomes elemental metals that can be used in various substances such as carbide, hydrogen, active metals or by electrolysis (Kovačič et al., 2019). The sintered ore feed temperature is controlled at 500 °C after the reheating process. The hot sintered ore is directly fed to the EAF. The pressure in the furnace is controlled at +20Pa. The furnace is closed and sealed. For this smelting process the temperature is 1500 °C. The EAF smelting process can be seen in Figure 2.7 below.

Journal of Metallurgical Engineering and Processing Technology, Vol. 5, No. 2
February, 2025
P-ISSN: 2723-6854, E-ISSN: 2798-1037, page 143-155
DOI: https://doi.org/10.31315/jmept

Figure 2.7 Smelting Process

This EAF smelting process produces molten iron and molten slag. Molten iron is molded and cooled, while molten slag is only cooled. For molten iron can be seen in Figure 2.8 and molten slag can be seen in Figure 2.9.

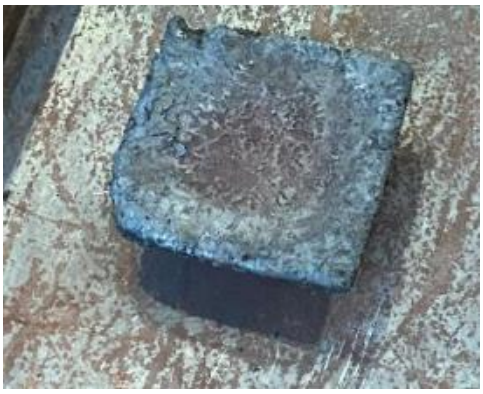

Figure 2.8 Molten iron that has been molded and cooled

Figure 2.9 Cooled molten slag

Journal of Metallurgical Engineering and Processing Technology, Vol. 5, No. 2
February, 2025
P-ISSN: 2723-6854, E-ISSN: 2798-1037, page 143-155
DOI: https://doi.org/10.31315/jmept

After the refining process is complete, molten iron and molten slag are tested in the laboratory to determine the content and content of the laterite iron ore that has been refined, Fe recovery, percent metallization and so on can be determined. The laboratory testing process used is XRF and XRD. Usually before the laboratory test is carried out, molten iron and molten slag are cooled and crushed using a swing jaw crusher to facilitate the laboratory testing process (Abd Halim et al., 2023).

The Effect of Variation in Calcine and Coke Composition on the Elemental Content of Pig Iron Products

In the process of smelting laterite iron ore, flux functions as a binder of impurities or slag so that the results of the smelting process contain a small amount of impurities. Variations in the weight composition of the flux used in this experiment will affect the final Fe content in the pig iron resulting from the smelting process. To determine the appropriate weight composition of the flux, a study was conducted by varying several weight compositions of the flux in the process of making pig iron from the smelting process. Identification of pig iron which is the result of the smelting process is carried out by identifying elements with XRF testing (Liu et al., 2017). From the test results, the composition of the elements contained in pig iron with various variations of flux is obtained as shown in Table 3.1.

Table 3.1 Elemental Composition of Iron Ore Smelting Results

Code	Element												
	Fe	Ni	Co	Cr	Si	C	Al	Mg	Mn	Ti	P	S	Zn
2-1/A	93,58	1,66	-	0,95	0,05	3,16	0,00	-	0,05	0,00	0,02	0,64	-
2-1/B	94,43	1,75	-	0,47	0,00	2,55	0,00	-	0,02	0,00	0,02	0,88	-
2-2/A	93,28	1,83	-	0,70	0,00	3,43	0,00	-	0,05	0,00	0,02	0,73	-
2-2/B	93,74	1,91	-	0,43	0,03	3,18	0,00	-	0,04	0,00	0,02	0,73	-

Based on the results of the XRF test, a pig iron sample with code 2-1/A with a calcine weight of 30.4 kg and 6 kg of coke contained 93.58% Fe, 1.66% Ni, 0.95% Cr, 0.05% Si, 3.16% C, 0.05% Mn, 0.02% P, and 0.64% S. In the pig iron sample with code 2-1/B with a calcine weight of 30 kg and 6 kg of coke contained 94.43% Fe, 1.75% Ni, 0.47% Cr, 2.55% C, 0.02% Mn, 0.02% P, 0.88% S. While in the pig iron sample with a calcine weight of 30.07 kg and 6 kg of coke with code 2-2/A contained 93.28% Fe, 1.83% Ni, 0.70% Cr, 3.43% C, 0.05% Mn, 0.02% P, 0.73% S. Then for the pig iron sample with code 2-2/B with a calcine weight of 30 kg and 5.4 kg of coke contains 93.74% Fe, 1.91% Ni, 0.43% Cr, 0.03% Si, 3.18% C, 0.04% Mn, 0.02% P, 0.73% S.

It can be seen that the Fe content in pig iron increases when compared to the Fe content in the sintering process results, this is because the reduction process of the iron oxide phase in the sinter has occurred during the melting process with the addition of coke as a

P-ISSN: 2723-6854, E-ISSN: 2798-1037, page 143-155
DOI: https://doi.org/10.31315/jmept

reducing agent so that CO gas is produced for the iron oxide reduction process (Fernández-González et al., 2017b).

The use of coke as flux can increase the Fe content because the coke used acts as a reducing agent. Coke will undergo reduction with iron oxide (Fe_2O_3) in the electric arc furnace, then change the iron oxide into liquid iron (Fe) and carbon dioxide gas (CO_2) with the following reaction:

$$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$$

In addition, coke can also remove oxygen from iron oxide, thereby increasing the pure iron (Fe) content in the smelting process. Coke can also help maintain and optimize the temperature during the melting process, so that higher Fe levels can be produced (Ghosh et al., 2008).

The Effect of Variation in Calcine and Coke Composition on Fe Recovery in Pig Iron

In the laterite iron ore smelting process, flux functions as a binder of impurities or slag so that the results of the smelting process contain a small amount of impurities. Variations in sample composition and calculation of the initial mass of Fe and the smelting results can be seen in Table 3.2.

Table 3.2 Calculation of Mass and Recovery of Fe in Pig Iron

Sample Code	Initial mass (gr)	Initial Fe grade (%)	Final Fe grade (%)	Fe Recovery (%)
2-1/A	30.400	49,07	93,58	65,86
2-2/B	30.000	49,07	94,43	63,6
2-1/A	30.070	49,07	93,28	59,8
2-1/B	30.000	49,07	93,74	62,15

Based on Table 3.2, it can be seen that the largest Fe recovery was obtained in the sample variation with code 2-1/A, which is 65.86%, this can be caused by the use of a larger calcine weight compared to the other three sample codes when viewed from the amount of calcine mass used. The final mass results for the sample code are also greater, namely 10,500 grams of metal.

Meanwhile, when viewed in terms of increasing the final Fe content, it can be seen that in samples with code 2-1/B the final Fe content is greater when compared to other sample codes. This can be caused by the influence of the composition of the use of the right and optimal weight of calcine and coke so that it can produce a significant increase in the final Fe content. Variations in the composition of calcine can affect the temperature and time of the melting process. The right limestone can help achieve the

Journal of Metallurgical Engineering and Processing Technology, Vol. 5, No. 2
February, 2025
P-ISSN: 2723-6854, E-ISSN: 2798-1037, page 143-155
DOI: https://doi.org/10.31315/jmept

optimal temperature for an effective chemical reaction, so that the Fe content in the final product can increase.

The mass of calcine used during the melting process can affect the efficiency of this process. If the mass of calcine used is too little, the melting process will not run optimally and impure iron oxide will be formed. Meanwhile, if too much mass of calcine is used, unwanted slag formation can occur. The mass of coke used is also very important because it can affect the amount of carbon available for the reduction process. If too little coke is used, the reduction process will not run optimally and impure liquid iron will be produced. However, if too much coke is used, it will cause the formation of unwanted carbon monoxide (CO) (Gupta et al., 2008).

Similarly, the smelting process requires strict control of the composition of calcine and coke and the melting temperature to produce high-quality pig iron. In addition, the mass of calcine and coke used previously can affect the properties of the pig iron produced, such as carbon (C), manganese (Mn), and silicon (Si) content (Gupta et al., 2008; Tyassena et al., 2022).

Conclusion

The conclusion obtained from the process of extracting laterite iron ore into pig iron using the electric arc furnace method is:

1. The process carried out to extract laterite iron ore into pig iron using the electric arc furnace method is drying, crushing, mixing, pelletizing, sintering, reheating and smelting.
2. The Fe content in pig iron increases when compared to the Fe content in the sintering process results, this is because the reduction process of the iron oxide phase in the sinter has occurred during the melting process with the addition of coke as a reducing agent so that CO gas is produced for the iron oxide reduction process.
3. By carrying out all the process sequences correctly and the right material composition will produce pig iron with a high Fe content. The highest content obtained from the series of processes that have been carried out is 94.43%.
4. This iron ore extraction process is greatly influenced by several factors including temperature, composition of additives, melting time.

Acknowledgements

The author would like to thank the Center for Mineral and Coal Testing tekMIRA and the Department of Minerals and Energy Technology for providing the opportunity to use the company's facilities in completing this research. Metallurgy Study Program UPN "Veteran" Yogyakarta.

P-ISSN: 2723-6854, E-ISSN: 2798-1037, page 143-155
DOI: https://doi.org/10.31315/jmept

References

Abd Halim, M. H., Mokhtar, N. A. M., Masnan, S. S. K., Talib, N. K., Jusoh, A. F., & Saidin, M. (2023). X-Ray Fluorescence (XRF) analysis of iron ore at ancient Kedah iron smelting site, Sungai Batu archaeological complex, Bujang Valley, Kedah, Malaysia. *Heliyon*, *9*(4). https://doi.org/10.1016/j.heliyon.2023.e14850

Agung, L. N. (2014). Potensi Nilai Tambah Mineral Ikutan Pada Wilayah Bekas Tambang Bijih Besi Laterit Di Kecamatan Mantewe Dan Kecamatan Simpang Empat, Kabupaten Tanah Bumbu, Provinsi Kalimantan Selatan. *Buletin Sumber Daya Geologi*, *9*(3), 44–55. https://doi.org/10.47599/bsdg.v9i3.132

Ahmed, H. M., Viswanathan, N., & Bjorkman, B. (2014). Composite pellets-a potential raw material for iron-making. In *Steel Research International* (Vol. 85, Issue 3, pp. 293–306). https://doi.org/10.1002/srin.201300072

Bahfie, F., Manaf, A., Astuti, W., Nurjaman, F., & Herlina, U. (2021). Tinjauan teknologi proses ekstraksi bijih nikel laterit. *Jurnal Teknologi Mineral Dan Batubara*, *17*(3), 135–152. https://doi.org/10.30556/jtmb.Vol17.No3.2021.1156

Casagrande, C., Alvarenga, T., & Pessanha, S. (2017). Study of Iron Ore Mixtures Behavior in the Grinding Pelletizing Process. In *Mineral Processing and Extractive Metallurgy Review* (Vol. 38, Issue 1, pp. 30–35). Taylor and Francis Inc. https://doi.org/10.1080/08827508.2016.1244058

Cavaliere, P. (2019). Clean Ironmaking and Steelmaking Processes: Efficient Technologies for Greenhouse Emissions Abatement. In *Clean Ironmaking and Steelmaking Processes* (pp. 1–37). Springer International Publishing. https://doi.org/10.1007/978-3-030-21209-4_1

Evans, A. M. (1993). *Ore Geology Industrial Minerals: An Introduction* (Third). Blackwell Publishing.

Fernández-González, D., Ruiz-Bustinza, I., Mochón, J., González-Gasca, C., & Verdeja, L. F. (2017a). Iron Ore Sintering: Process. In *Mineral Processing and Extractive Metallurgy Review* (Vol. 38, Issue 4, pp. 215–227). Taylor and Francis Inc. https://doi.org/10.1080/08827508.2017.1288115

Fernández-González, D., Ruiz-Bustinza, I., Mochón, J., González-Gasca, C., & Verdeja, L. F. (2017b). Iron Ore Sintering: Raw Materials and Granulation. In *Mineral Processing and Extractive Metallurgy Review* (Vol. 38, Issue 1, pp. 36–46). Taylor and Francis Inc. https://doi.org/10.1080/08827508.2016.1244059

Ghosh, Ahindra, Chatterjee, & Amit. (2008). *Iron Making and Steelmaking : Theory And Practice* (Second). PHI Learning Private Limited.

Gupta, S., French, D., Sakurovs, R., Grigore, M., Sun, H., Cham, T., Hilding, T., Hallin, M., Lindblom, B., & Sahajwalla, V. (2008). Minerals and iron-making reactions in blast furnaces. In *Progress in Energy and Combustion Science* (Vol. 34, Issue 2, pp. 155–197). https://doi.org/10.1016/j.pecs.2007.04.001

König, U., Norberg, N., & Gobbo, L. (2017). *FROM IRON ORE TO IRON SINTER – PROCESS CONTROL USING X-RAY DIFFRACTION (XRD)*. 146–153. https://doi.org/10.5151/2594-357x-26276

Kovačič, M., Stopar, K., Vertnik, R., & Šarler, B. (2019). Comprehensive electric arc furnace electric energy consumption modeling: A pilot study. *Energies*, *12*(11). https://doi.org/10.3390/en12112142

Liang, Z., Yi, L., Huang, Z., Lu, B., Jiang, X., Cai, W., Tian, B., & Jin, Y. (2019). Insight of iron ore-coal composite reduction in a pilot scale rotary kiln: A post-mortem study. *Powder Technology*, *356*, 691–701. https://doi.org/10.1016/j.powtec.2019.08.086

Liu, H., Qian, W., Chen, J., Chen, H., Chastain, M. L., & Notis, M. R. (2017). Cast iron-smelting furnace materials in imperial China: Macro-observation and microscopic study. *Journal of Archaeological Science*, *86*, 50–59. https://doi.org/10.1016/j.jas.2017.09.003

Mohanty, D., Chandra, A., & Chakraborti, N. (2009). Genetic algorithms based multi-objective optimization of an iron making rotary kiln. *Computational Materials Science*, *45*(1), 181–188. https://doi.org/10.1016/j.commatsci.2008.03.056

Nurhakim, Dwiatmoko, M. U., NH, R., & M., A. (2011). Identifikasi Potensi Endapan Bijih Besi Laterit Di Bagian Tengah Pulau Sebuku, Provinsi Kalimantan Selatan. *Info Teknik*, *12*(2), 48–53. https://doi.org/http://dx.doi.org/10.20527/infotek.v12i2.1806.g1578

Pardiarto, B., & Wahyu Widodo. (2024). Keterdapatan Dan Genesa Cebakan Bijih Besi Daerah Kapayang, Kabupaten Tanah Bumbu, Kalimantan Selatan. *Buletin Sumber Daya Geologi*, *19*(1), 11–25. https://doi.org/10.47599/bsdg.v19i1.471

Saboohi, Y., Fathi, A., Skrjanc, I., & Logar, V. (2019). Optimization of the electric arc furnace process. *IEEE Transactions on Industrial Electronics*, *66*(10), 8030–8039. https://doi.org/10.1109/TIE.2018.2883247

Sunarya, W. (2017). IDENTIFIKASI BIJIH BESI (Fe) MENGGUNAKAN METODA GEOLISTRIK RESISTIVITAS KONFIGURASI WENNER-SCHLUMBERGER DI KABUPATEN LUWU. *Jurnal Geocelebes*, *1*(2), 72–81.

Syguła, E., Rasaq, W. A., & Świechowski, K. (2023). Effects of Iron, Lime, and Porous Ceramic Powder Additives on Methane Production from Brewer's Spent Grain in the Anaerobic Digestion Process. *Materials*, *16*(15). https://doi.org/10.3390/ma16155245

Tyassena, F. Y. P., Agus, T. G., Nur, M. A., Prameswara, G., & Amin, I. (2022). Perbandingan Batubara Dan CaSO4 Sebagai Reduktor Dalam Proses Reduksi Bijih Nikel Laterit. *JURNAL TEKNOLOGI KIMIA MINERAL*, *1*(1), 31–35. https://doi.org/10.61844/jtkm.v1i1.25

P-ISSN: 2723-6854, E-ISSN: 2798-1037, page 143-155
DOI: https://doi.org/10.31315/jmept

Yin, Z., Wang, N., & Li, T. (2024). Study on single particle compression crushing characteristics of iron ore with five different particle sizes. *AIP Advances*, *14*(10). https://doi.org/10.1063/5.0229821

Zhou, S., Yuan, Z., Cheng, Q., Weindorf, D. C., Zhang, Z., Yang, J., Zhang, X., Chen, G., & Xie, S. (2020). Quantitative Analysis of Iron and Silicon Concentrations in Iron Ore Concentrate Using Portable X-ray Fluorescence (XRF). *Applied Spectroscopy*, *74*(1), 55–62. https://doi.org/10.1177/0003702819871627