



## Literature Review: Comparison of Caron Process and RKEF on the Processing of Nickel Laterite Ore For Battery

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### ABSTRAK

Indonesia memiliki sumber daya yang melimpah, terutama dalam sumber daya alam (SDA), salah satunya adalah nikel. Nikel merupakan logam yang sangat digandrungi banyak orang karena pengembangan teknologi sangat pesat dalam penciptaan transportasi listrik khususnya, aplikasi nikel ini adalah salah satunya pada baterai. Sumberdaya Nikel di dunia tersedia dalam bentuk Nikel Oksida sebanyak 60% dan 40% sisanya tersedia dalam bentuk endapan sulfida. Saat ini terdapat 2 metode ekstraksi, yaitu hidrometalurgi (*Caron Process*) dan pirometalurgi (*Rotary Kiln Electric Furnace*). Hidrometalurgi merupakan proses yang digunakan untuk bijih nikel yang memiliki kadar < 1,5 % sedangkan pirometalurgi tetap digunakan untuk bijih nikel yang memiliki kadar Ni < 3%. Pada saat ini proses hidrometalurgi paling umum diterapkan untuk bijih nikel limonit. Sedangkan proses ekstraksi pada pirometalurgi menggunakan bijih nikel saprolite. Pengolahan logam Nikel, saat ini yang terbaik dan termurah dari biaya produksi adalah proses hidrometalurgi yang dilanjutkan dengan proses pirometalurgi. Pada faktanya, pemakaian nikel dengan kadar rendah lebih sesuai digunakan untuk fabrikasi pembuatan baterai. Dengan alasan cadangan Nikel Limonit lebih banyak serta dapat menambah nilai jual pada bijih nikel tersebut. Dengan demikian, perlu adanya perhatian mengenai pengembangan dalam proses pengolahan untuk dapat meningkatkan kemurnian logam nikel itu sendiri.

**Kata Kunci:** Ekstraksi Nikel, Limonite, Saprolite, Proses Caron, RKEF, Baterai

### ABSTRACT

*Indonesia has abundant resources, especially in natural resources (SDA), one of which is nickel. Nickel is a metal that is loved by many people because of the rapid development of technology in creating electric transportation, in particular, the application of nickel is one of the batteries. Nickel resources in the world are available in the form of Nickel Oxide as much as 60% and the remaining 40% is available in the form of sulfide reserves. Currently, there are 2 extraction methods, namely hydrometallurgy (Caron Process) and pyrometallurgy (Rotary Kiln Electric Furnace). Hydrometallurgy is a process used for nickel ore that has a grade of < 1.5%, while pyrometallurgy is still used for nickel ore that has a Ni content of < 3%. At present, the most common hydrometallurgical process is applied to limonite nickel ore. While the extraction process in pyrometallurgy uses saprolite nickel ore. Nickel metal processing, currently the best and the cheapest in terms of production costs is the hydrometallurgical process followed by the pyrometallurgical process. Using low-grade nickel is more suitable for manufacturing battery manufacture. The reason is that the Limonite Nickel reserves are more and can increase the selling value of the nickel ore. Thus, it is necessary to pay attention to the development in the processing process to increase the purity of the nickel-metal itself.*

**Keywords:** Nickel Extraction, Limonite, Saprolite, Caron Process, RKEF, Battery

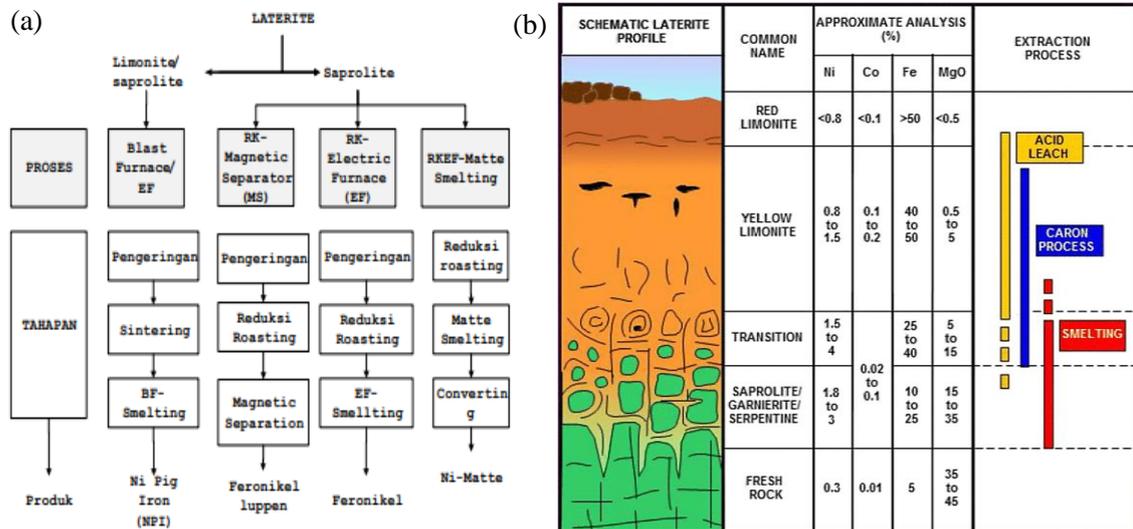
## I. INTRODUCTION

Indonesia is blessed with abundant resources, including nickel. According to data from the Ministry of Energy and Mineral Resources in 2020, Indonesia has nickel ore resources of 11,887 million tons and ore reserves of 4,346 million tons. Meanwhile, the total metal resources reached 174 million tons and metal reserves reached 68 million tons. (Eko B, 2020)

Nickel is one of the most widely used metal elements due to its excellent corrosion resistance, easy molding, strong resistance, and an excellent conductor. About 60% of the world's nickel resources are available in the form of nickel oxide and the remaining 40% is available in the form of sulfide deposits. Laterite ores are generally classified into two types (limonite and saprolite). The nickel content of saprolite ore is 1.8-3.0% while for limonite ore, it < 1.5% which is shown in Figure 1. below. Nickel laterite (NiO) is generally interpreted as depression formed from ultramafic rocks

(peridotite, dunite, and serpentine) containing high levels of Ni (Nurjaman F, 2019). Meanwhile, nickel sulfide ore is depleting, so laterite nickel ore processing is further improved (Pournaderi et al., 2014).

At present, the most common hydrometallurgical process is applied to limonite nickel ore. While the pyrometallurgical extraction process uses saprolite nickel ore with nickel products in the form of ferronickel (FeNi), nickel pig iron, and nickel sulfide matte as seen in Figure 1. below



**Gambar 1. Laterite Nickel Extraction Schematic, (a) Flowchart, and (b) Nickel Ore Sediment**

Source: Iwan S, 2016 & Elias, 2002

The development of electric cars has also shown great potential as the right solution to global problems facing the world today regarding energy use, safety, and its impact on environmental pollution. However, its application is still very limited due to the small number of vehicles, short distances and the filling process is still inadequate (Dedy Ramdhani, 2017). One of the studies that are often carried out related to this problem is to increase the optimization of nickel processing used in electric cars, especially electric cars whose power source is generated from Nickel Metal Hydride (NiMH) batteries. Nickel Metal Hydride (NiMH) batteries are generally used because they have better resistance than other types of batteries such as Nickel-Cadmium (Ni-Cd) and Lithium-Ion (Li-On). This study aims to compare the processing of nickel laterite ore into Ferronickel or Ni-Matte which are suitable for use as raw materials before the creation of NiMH, Ni-Cd for batteries.

**II. METHODS**

In this study, observations were made based on literature studies sourced from journals and books related to previous research. In the purer nickel ore beneficiation process, it is carried out by integrated metallurgical extraction, or in other words either pyrometallurgy, hydrometallurgy, or electrometallurgy (Zulhan Z, 2020).

**2.1. Genesis Laterite Nickel Ore**

The parent rock of nickel ore is peridotite. There are three main primary sources of nickel from mines, namely magmatic sulfide ores, lateritic oxide ores, and sea nodules. Nickel laterite is an important source of nickel and ferronickel where these deposits are the result of weathering of Ni-silicate-bearing ultramafic rocks and are generally found in equatorial regions (Lintjewas L, 2019). From weathering of ultramafic rocks, the main nickel minerals produced are gautite ( $H_4Ni_2Mg_2(SiO_4)_3 \cdot 4H_2O$ ), konarite ( $H_2Ni_2Si_3O_{10}$ ), garnierite ( $(Mg, Ni) SiO_3 + nH_2O$ ). Of the three minerals, garnierite contains up to 32.52% nickel oxide. (Mirna M, 2018).

Figure 3. below is an analysis of the Synchrotron X-Ray Powder Diffraction (SXRD) mixture of limonite-saprolite ore. This ore was identified as goethite (Fe, Ni)O(OH), serpentine-lizardite  $(Mg, Fe, Ni)_3Si_2O_5(OH)_4$ , quartz  $SiO_2$ , and spinel Fe-chromite  $(Fe, Mg)O \cdot (Cr, Al, Fe)_2O_3$ . After reduction, olivine  $(Mg, Fe, Ni)_2SiO_4$ , magnetite  $(Fe, Ni)O \cdot Fe_2O_3$ , quartz, and spinel Fe-chromite were observed. Apart from these phases, peaks of taenite alloys (Fe, Ni) are also observed in the spectrum. These nickel minerals are usually associated with sulfide minerals such as pyrrhotite, pyrite, and chalcopyrite.

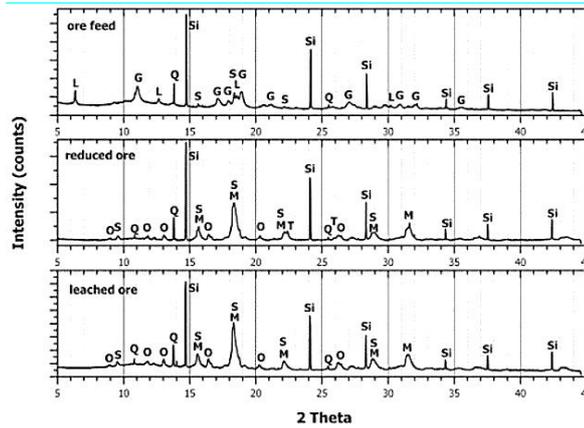


Figure 3. SXR D Spectrum Data ( $\lambda$ : 0.8Å) Laterite Nickel Ore With Minerals L: cadalite (serpentine), G: goethite, Q: quartz, Si: silicon standard, O: olivine, M: magnetite, S: spinel Fe -chromite, T: taenite (Fe-Ni alloy)  
 Source: Rhamdhani, 2008

## 2.2. Hydrometallurgical of Nikel Laterite: Caron Process

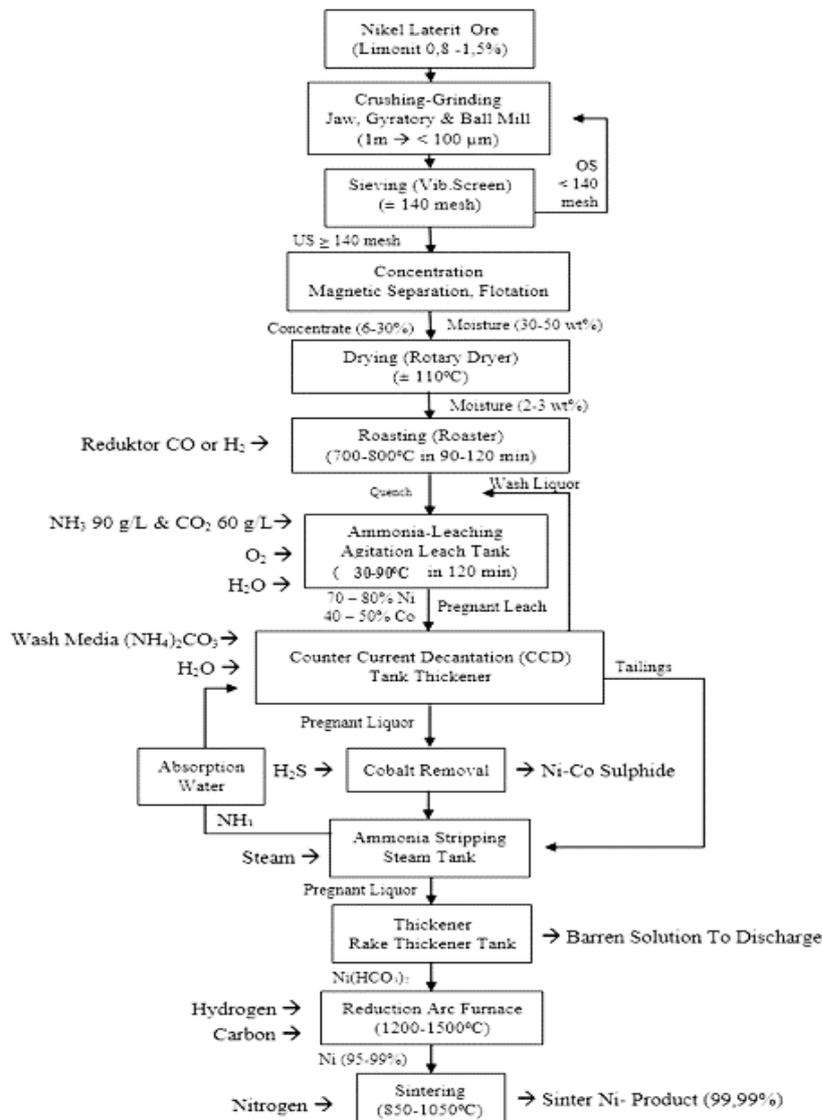


Figure 4. Caron Process Flowchart

In the process of processing nickel laterite with limonite type, using the process flow provided in Figure 4. above.

### 1. Ore Preparation

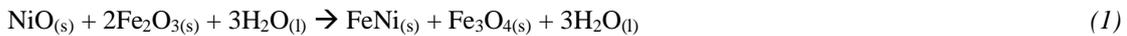
In the nickel hydrometallurgical process, the feed used is limonite laterite ore. Nickel ore is comminuted using a crusher (jaw crusher and gyratory crusher) to a size of < 0.5 cm. Then grinding using a ball mill and sieving using a vibrating screen up to a grain size of < 100 μm or ±140 mesh (Ardra, 2019).

### 2. Ore Concentration

The stage of nickel ore concentration is usually carried out by a flotation process and a magnetic separator. Nickel Sulfide ore is carried out by a flotation process which initially has a grade of 1-2% to concentrate with a grade of 6-20% (Ardra, 2019). For nickel oxide ore, a magnetic separator process is carried out to remove impurity (non-magnetic) minerals from the ore which initially had a grade of 0.8-1.5% to 20-30% (Nurjaman F, 2020). With this concentration process, it is hoped that nickel minerals will be separated from impurities as well as minerals, lead, and non-sulfides. Concentrates resulting from the concentration process usually still contain high levels of iron, because limonite ore consists of a mixture of hydrated iron(III)oxide-hydroxides in various compositions. Likewise associated minerals such as hematite (Fe<sub>2</sub>O<sub>3</sub>) pyrite (FeS<sub>2</sub>) and chalcopyrite (CuFeS<sub>2</sub>) indicates a lot of Fe formation in Limonite Nickel ore).

### 3. Drying and Roasting Process

Limonite ore does contain a lot of moisture (moisture) which is usually 30-50 wt% water content in limonite ore. So it is necessary to dry before proceeding to the next process. At the drying stage, it can be done using a rotary dryer so that the water content in the ore reaches 2-3 wt%. Then the roasting stage is carried out to reduce Nickel Oxide (NiO) compounds to Nickel Metallic which aims to minimize the reduction of Fe in Limonite Ore. The reaction that occurs in equation 1 of the Roasting process, namely:



At this roasting stage, it is necessary to pay attention to the pressure of O<sub>2</sub> and SO<sub>2</sub> needed to get the Fe-Ni or Fe<sub>3</sub>O<sub>4</sub> formed. The pressure of O<sub>2</sub> and SO<sub>2</sub> on Ni (Nickel) is shown in Figure 5. While Fe (Iron) is shown in Figure 6. This roasting stage is carried out at temperatures < T<sub>melt</sub> to remove oxide compounds, this reduction process is carried out at a temperature of 700-800°C for 90-120 minutes. Kellogg diagram of solid phases such as oxides, sulfates, sulfides, and metals with consideration of 4 temperature characteristics, namely (25°C, 500°C, 650°C, and 800°C).

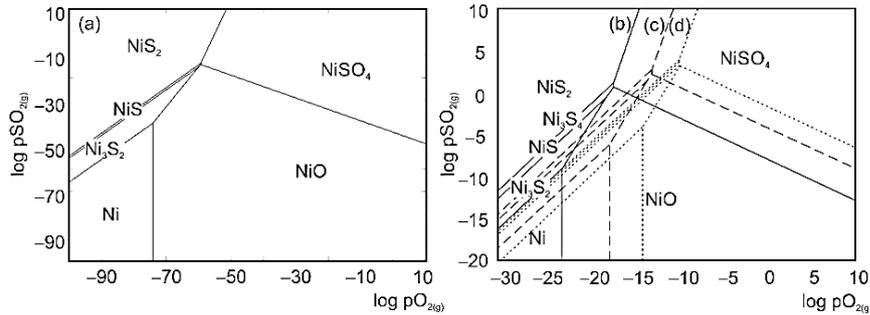


Figure 5. Kellogg Diagram Of Ni-S-O System With Temperature (a) 25°C, (b) 500°C, (c) 650°C, and (d) 800°C

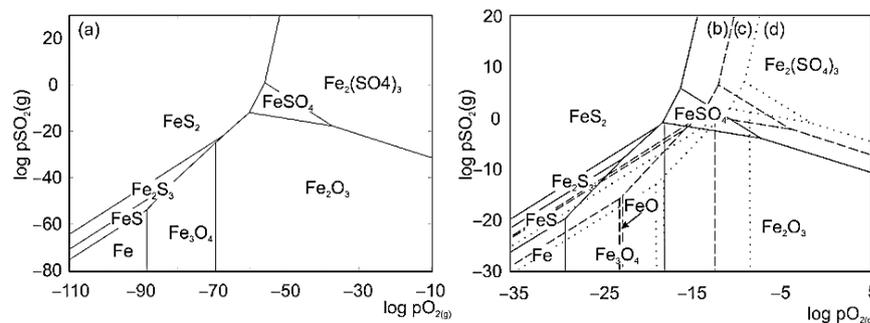


Figure 6. Kellogg Diagram of Fe-S-O System With Temperature (a) 25°C, (b) 500°C, (c) 650°C, and (d) 800°C

To make it easier to make diagrams, Chemistry Software (9.0 Outotec) is used in HSC (Roine, 2016 and Shamsuddin, 2016). To get a reduction reaction, it is necessary to have a reducing agent as a source of oxygen and a substance that is being reduced. The reducing agent used is CO and H<sub>2</sub> gas. This reductant serves to break the oxygen bond with carbon or with the metal itself. (Aris K W, 2017)

#### 4. Agitation Leach: Ammonia Leaching

In the next stage, the Ammonia-Leaching process which has been roasted is carried out by cooling using rinse water resulting from the CCD process as shown in Figure 4. This quenching serves to stabilize the temperature or heat of the ore after the roasting process to proceed to the leaching process using H<sub>2</sub>O solution added with NH<sub>3</sub>. The leaching process is assisted by agitation which is added by exhaling O<sub>2</sub> (Oxygen) as an oxidizer and decomposer of Fe-Ni alloys from roasting products. To optimize the extraction conditions for nickel and cobalt from limonite ore, a liquid-solid ratio of 4:1 (mL/g), a leaching temperature of 40°C, a leaching time of 120 minutes, and a concentration ratio of 90 g/L and CO<sub>2</sub> of 60 g/L were used (Fathan, 2021).

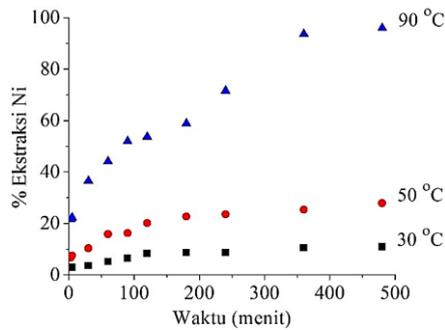
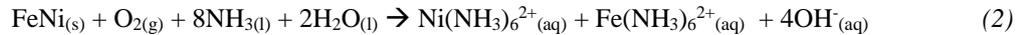
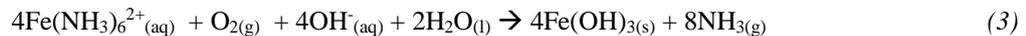


Figure 7. Graph of Temperature Against % Nickel Extraction  
 Source: Febriana, 2018

Figure 7. above explains that an increase in temperature can cause an increase in the % nickel extraction during the leaching process. At 30°C, nickel extraction reached 10.8%, while at 50°C nickel extraction increased to 27.8%. Then at 90°C, there was a fairly high increase, namely as much as 95.9% nickel. In the leaching process, the hydrolysis of nickel and cobalt is prevented by the strong affinity for the breakdown of ammonia (NH<sub>3</sub>), which forms a complex of soluble cobalt and nickel amines. The reaction of the limonite ore leaching process by ammonia carbonate in equation 2 is as follows :



In the above reaction there is iron which will form ferrous amine complexes but is rapidly oxidized to form ferric and then precipitates as iron hydroxide. The following reactions occur in equation 3, namely:

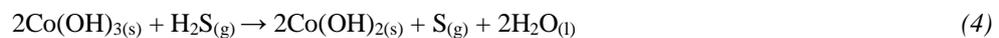


#### 5. Countercurrent Decantation Thickener (CCD)

Then, the Pregnant Leach Solution (PLS) was separated using the precipitation principle. Several influences can cause the speed of deposition, including concentration, particle size, and particle type (density). The Rich solution was separated using a Countercurrent Decantation Thickener (CCD) using ammonia carbonate as the rinsing medium.

#### 6. Recovery Nikel dan Cobalt

To obtain cobalt, pregnant liquor obtained from CCD results was added with H<sub>2</sub>S to obtain cobalt(ii) hydroxide. The following reactions occur in the cobalt separation process, in equation 4, namely:



Meanwhile, to get Ni (Nickel), pregnant liquor is flowed with steam, so that in the reaction below it can be seen that the ammonia evaporates and the nickel precipitates in the form of nickel carbonate as shown in Figure 4.

This happens in the steam tank which is flowed to the thickener to get the Ni(HCO<sub>3</sub>)<sub>2</sub> precipitate. The following reactions that occur in the process can be seen in equation 5. below, namely:



#### 7. Smelting: Reduction Arc Furnace

After the deposition process, the Nickel Carbonate from the CCD process was reduced using an Arc Furnace. In the process, the nickel smelting process is carried out by injection of hydrogen and carbon. This smelting process is carried out to obtain Ni metal with levels around 85-90%. To be able to know the reaction that occurs can be seen in equation 6. below.



After obtaining Nickel Oxide and the formed CO<sub>2</sub> gas, NiO will be reduced with coke or Carbon which is inserted into Ni metal, and CO gas is formed. The following reactions occur when the reduction of metal Ni with C atoms in equation 7, namely:



## 8. Sintering

After getting the Ni metal, it is then molded into Sintered Ni-Product according to the needs of each production. Sintering is a process used to form bonds between particles/powder after the compaction process. In this process, nitrogen gas is also injected to assist the sintering process. This process is carried out by providing heat/heating the sample at a temperature of  $< T_{\text{melt}}$  until the mass transfer occurs on the surface of the powder so that a joint bond is formed between the powders.

### 2.3. Pyrometallurgy of Nickel Laterite: RKEF- Smelting Process

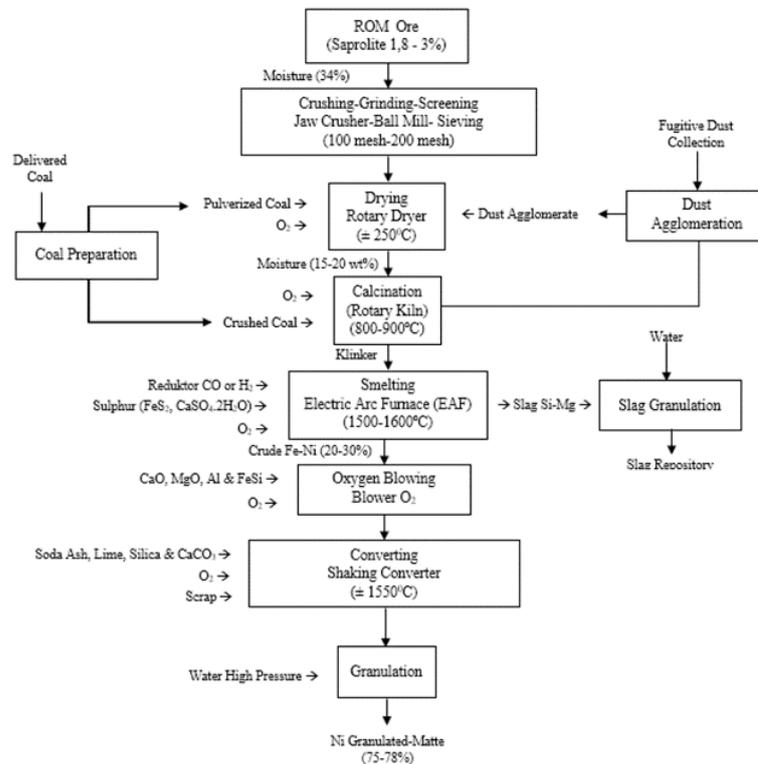


Figure 8. RKEF Process Flowchart

In the process of processing nickel laterite with the type of saprolite, using the process flow in Figure 8. above.

#### 1. Ore Preparation

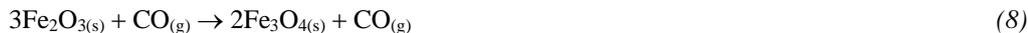
Saprolite ore has a moisture content of 34 wt% in the ore. The saprolite type laterite nickel ore that has been separated will then be crushed, screened to size (100-200 mesh), and blended first to get a mixture according to the desired composition. Furthermore, the feed is fed into the rotary dryer together with the reductant (Pulverized Coal), Oxygen (O<sub>2</sub>), and flux (Dust Agglomerated). This process begins with drying the moisture content through a pretreatment process (Rock E, 2012). In this process, the laterite ore is dried using a rotary dryer at a temperature of 250°C until the moisture content reaches 15-20 wt% as shown in Figure 8.

#### 2. Calcination

The product from the rotary dryer then enters the calcination stage (pre-reduction) using a rotary kiln at a temperature (800-900°C). In the calcination process, O<sub>2</sub> is also injected and there is additional carbon as a reducing agent for oxide

ore. During this process, water crystals are reduced, followed by the reduction of nickel and some of the iron to a metallic state. (Iwan S, 2016) The reaction that takes place in the rotary kiln in equations 8-11, namely:

(a) Reduction of Iron Oxide



(b) Reduction of Nickel Oxide



**Table 1. Thermodynamics of NiO Reduction with CO Gas at Temperature 25-1000°C**

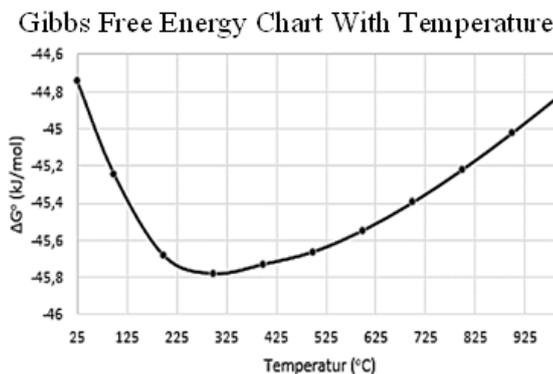
T (°C)	ΔH° (kJ/mol)	ΔS° (J/(mol.K))	ΔG° (kJ/mol)
25	-42,386	7,903	-42,5836
100	-43,09	5,794	-43,6694
200	-44,381	2,762	-44,9334
300	-46,038	-0,447	-45,9039
400	-45,975	-0,362	-45,8302
500	-46,395	-0,946	-45,922
600	-46,732	-1,356	-45,9184
700	-47,009	-1,657	-45,8491
800	-47,241	-1,884	-45,7338
900	-47,438	-2,06	-45,584
1000	-47,607	-2,198	-45,409

Source: Sutawiratmaja, 2009

Based on Table 1. above, it is explained that as the temperature increases, the reaction takes place spontaneously. Figure 9. is a representation of the anomaly when a decrease in the value of ΔG° becomes more negative when the temperature increases at a temperature of (25-300°C), after that it becomes more positive at a temperature of 300-1000°C. The products of the reaction can produce several gas molecules less than the reactants, causing a decrease in entropy. In the reduction process of FeO and NiO pressure also plays a role to determine the equilibrium reaction contained in this reduction process. (Stephany, 2016). The following equation is 12. to be able to calculate the amount of Pressure and Gibbs Free Energy produced

$$P = P^0 + \left( \frac{T\Delta S^0 + \Delta H^0 + RT \ln K}{\Delta V} \right) \& \Delta G^0 = \Delta H^0 - T\Delta S^0 \quad (12)$$

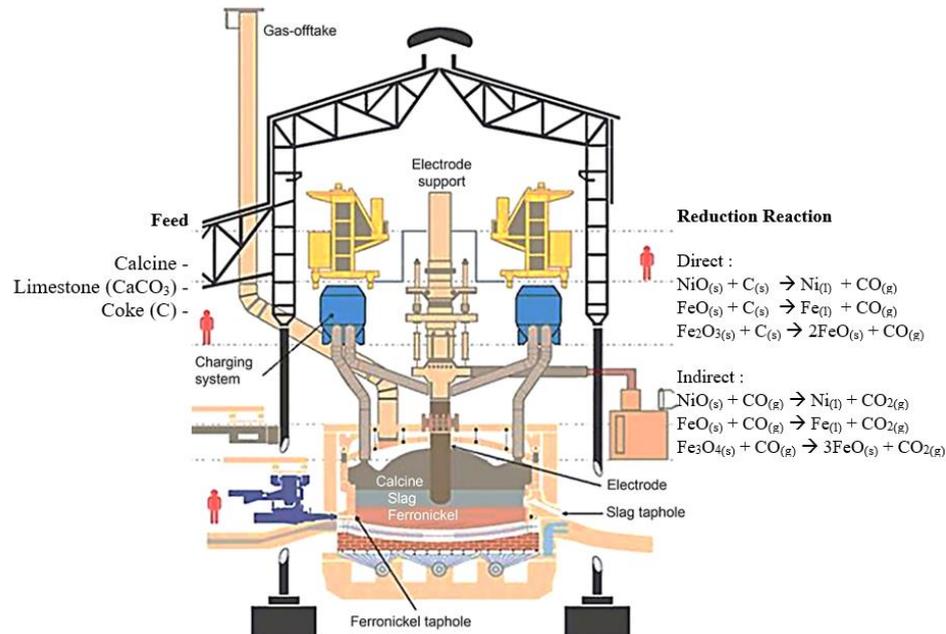
Where P: Pressure (atm), P<sup>0</sup>: Standard Pressure (atm), T: Temperature (K), ΔG<sup>0</sup>: Standard Gibbs Free Energy (kJ/mol), S<sup>0</sup>: Entropy ((J/(mol. K)), ΔH<sup>0</sup>: Standard Enthalpy (kJ/mol), ΔV: Volume Change (L), R: 8.3145 (J/mol.K)



**Figure 9. Graph of NiO Reduction with CO Gas at Temperature 25-1000°C**  
 Source: Sutawiratmaja, 2009

### 3. Smelting

The results of the calcination process are then melted in an electric furnace at a temperature of 1500-1600°C to produce ferronickel. In the electric furnace, ferronickel is separated from silica-magnesia slag, nickel oxide and calcine iron oxide are reduced to metallic nickel, and nickel is melted and dissolved in ferronickel.



**Figure 10. Schematic of Smelting Electric Arc Furnace (EAF)**

Source: Michael S & William G, 2014

The feed included consists of materials such as (calcine, limestone, and coal/coke). Nickel Oxide will be reduced by Carbon from coke. While limestone serves as a flux to bind impurities. In the EAF, hot gasses are also flowed to oxidize carbon into CO<sub>2</sub> gas. The reaction is exothermic (releases heat), so the heat released will increase the temperature of the bottom of the furnace until it reaches 1.600°C. Then CO<sub>2</sub> gas moves up and reacts again with coke to become CO. There are 2 Reduction Reactions namely direct reduction and indirect reduction reactions. The direct reduction reaction is the reduction of nickel ore calcine which is carried out by solid carbon directly. Meanwhile, an indirect reduction is a further reduction carried out by CO gas (which is mostly produced from direct reduction reactions)

Melted iron and nickel are formed which will settle to the bottom of the furnace based on differences in specific gravity and then mix to form a ferronickel solution. Meanwhile, in the high-temperature furnace, limestone CaCO<sub>3</sub> decomposes into CaO. The CaO formed will react with acidic impurities present in ferronickel ores, such as silica sand. This reaction produces a compound with a low boiling point called slag. The melted slag will then flow to the bottom of the furnace. The slag melt is above the ferronickel melt because the density of the slag melt is lower than that of the ferronickel melt, so both can be removed from the heating furnace separately. (Stephany, 2016).

### 4. Oxygen Blowing

In the smelting results obtained ferronickel (crude ferronickel) is further purified in the purification process. Crude ferronickel contains 15-25% Ni and contains high impurities such as carbon, silicon, and chromium. Purification is carried out by oxygen blowing to remove carbon, chromium, and silicon as well as adding fluxes in the form of lime, dolomite, fluorspar, aluminum, magnesium, ferrosilicon, etc., to produce slag which allows sulfur to be absorbed during stirring with nitrogen injection (Rock E, 2012).

### 5. Converting

Crude ferronickel contains 20-30% Ni and contains high impurities such as carbon, silicon, and chromium. Purification is carried out by oxygen blowing to remove carbon, chromium, and silicon, also by adding flux in the form of lime, dolomite, fluorspar, aluminum, magnesium, and ferrosilicon. After that the ore is taken to the converter, where the air is blown into the converter, thereby oxidizing the iron. The last process is to purify crude Ferronickel into a salable product as shown in Figure 8. The purification process carried out is removing crude FeNi from an electric furnace into a Ladle, where additives such as soda ash, lime, and calcium carbide are added to crude FeNi to remove impurities. The final concentrate contains 75-78% Ni. In general, nickel in the form of matte is first processed into nickel metal granules or granulated matte before being used in more downstream industries. (Vale, 2020)

### III. RESULTS AND DISCUSSION

Indonesia has the largest nickel reserves in the world, reaching 21 million tons or equivalent to 22% of global nickel reserves after Australia, Brazil, and Russia, which each have nickel reserves of 20 million tons, 16 million tons, and 7 million tons. This encourages the government to increase investment potential in downstream mineral mining, such as nickel derivative products into electric batteries. In some current studies, it can be said that laterite nickel will dominate nickel production shortly. There are 3 reasons for considering the selection of hydrometallurgical and pyrometallurgical processes, among others:

#### 1. Extraction and Purification Cost

Laterite nickel ore with limonite type with content of < 1.5% was extracted using hydrometallurgy. Because costs must be reduced, so the tools and materials used to use the low-temperature principle to reduce the energy costs incurred when extracting the ore. While the pyrometallurgical process is suitable for high-grade ore with the type of saprolite 1.8–3% which is expected to have high yields from the extraction of the ore. However, pyrometallurgy is very expensive in terms of the energy required and the procurement of tools and materials.

#### 2. Environmental Waste Management

In nickel production using hydrometallurgy, special attention must be paid to the environment, especially residues or residual solutions that are not reused, so that groundwater is not exposed or directly polluted by the chemicals used. Meanwhile, the pyrometallurgical process produces solid and gaseous wastes that can be hazardous in the production process. Air is an important factor to consider is the handling of the resulting off-gas and slag produced in the pyrometallurgical process.

#### 3. Production Capacity

In the refining process using the hydrometallurgical and pyrometallurgical lines, one must still pay attention to the advantages of production, in terms of time, for example. The purification process using hydrometallurgy has a long processing time (days/weeks/months) compared to the pyrometallurgical process (hours). Thus affecting the production capacity of a process, hydrometallurgy has a relatively small production capacity compared to the pyrometallurgical process.

The selection of the method to be used for nickel ore processing is influenced by the characteristics or composition of the laterite nickel deposit. In the hydrometallurgical process, it was chosen to be able to process limonite type laterite nickel ore with levels of Ni: 0.8-1.5%, Co: < 0.2%, Fe: > 40%, MgO: < 5%. While the pyrometallurgical process is intended for laterite nickel ore from the transition zone with levels of Ni: 1.5-2%, Co: 0.02-0.1%, Fe: 25-40%, and MgO: 5-15%, and the saprolite zone. with levels of Ni: 1.8-3%, Co: 0.02- 0.1%, Fe: 15-35% and MgO: 15-35%.

Commercially processing of laterite nickel ore is based on the content of magnesium (Mg) and the ratio of nickel to iron (Ni/Fe). Currently, the most economical methods applied are the hydrometallurgical and pyrometallurgical methods. Nickel ore with high MgO content is not suitable for using the hydrometallurgical method because it can increase acid consumption in the leaching process. This is because magnesium is more dominant to react with Si and NiO. So most of the NiO will not be reduced during the roasting reduction process. Meanwhile, pyrometallurgy is used to treat those containing Ni and MgO in laterite deposits in the limonite zone. Some examples of commercial processes for nickel production from laterite using saprolite-limonite as raw materials, can be seen in Table 2. below, namely :

**Table 2. List Of Nickel Companies And Their Production**

Company	Product			
	<i>Ferronickel Shot or Ingot</i>	<i>Nikel MHP or MSP</i>	<i>Nickel Matte</i>	<i>Nikel Pig Iron</i>
PT. ANTAM Tbk	√			
PT. Vale Indonesia (Inco)			√	
PT. Indonesia Morowali Industrial Park				√
PT. Virtue Dragon Nickel Industry		√		√
PT. Citra Silika Malawa	√		√	√
PT. Kolaka Nickel Industri	√			
PT. Halamahera Persada Lygend		√		
PT. Smelter Nikel Indonesia		√		√
PT Bintang Delapan Indonesia				√
PT. Indoferro Indonesia	√			
PT. Gebe Industri Nikel		√		

Source: CNBC, 2022

The most common process used in the nickel industry is the pyrometallurgical method because the process is considered simpler and can be applied to ores from various locations. Although in reality, the energy consumption is very high and only lower than the Caron process. The pyrometallurgical production of ferronickel and nickel-matte from laterite ore requires higher energy than hydrometallurgy as shown in Table 2. There are still many companies that still use the pyrometallurgical route, so the development of the hydrometallurgical route needs to be further improved.

Hydrometallurgy has several drawbacks, namely, it requires a large processing area and a long processing time so laterite processing is expected to be developed in pyrometallurgy. In addition, Wanta, et al (2018) say that the hydrometallurgical process has the advantage of producing a much purer product than the pyrometallurgical process. Pyrometallurgy is a process line for processing high-grade nickel ore, while hydrometallurgy is chosen for nickel extraction from low-grade laterite nickel ore in general, this is considered uneconomical if nickel with low grade is processed using pyrometallurgy which processes at high temperatures.

#### IV. CONCLUSION

From the description above, it can be concluded that the current best and cheapest nickel-metal processing in terms of production costs is the hydrometallurgical process followed by the pyrometallurgical process. Hydrometallurgy is a process used for nickel ore that has a grade of < 1.5%, while pyrometallurgy is still used for nickel ore that has a Ni content of < 3%. The nickel commonly used by smelter companies today is nickel with a high grade of above 1.8%, while for battery raw materials, nickel ore used is nickel ore with a low grade of below 1.8%.

With the consideration that the government will provide incentives so that this low-grade nickel can be utilized. Moreover, he continued, reserves of low-grade nickel ore are much larger than reserves of high-grade nickel. So that it is necessary to increase the hydrometallurgical route to be able to process nickel ore which will later be able to balance the need for battery supply in the electricity-based automotive industry.

The choice of methods cannot be separated from the content of these minerals and the levels present in the rock and the association of minerals. In the selection of nickel laterite ore processing, it is necessary to pay close attention and it is necessary to renew research on the process path or method used. In further research, it is hoped that there will be an analysis of energy use, availability of reserves, nickel content, and processing of the resulting side-product.

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