High pressure acid leaching: a newly introduced technology in Indonesia

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Abstract. PT Halmahera Persada Lygend (PTHPL) plans to construct new technology for nickel laterite ore processing in Obi Island, North Maluku Province. The facility is expected to produce 247,000 tonnes of NiSO4.7H2O and 32,000 tonnes of CoSO4.7H2O to be sold for the raw material of electric vehicle battery. Indonesia is one of world largest nickel laterite resources and currently only nickel ore saprolite has been exploited while nickel limonite is abandoned as waste due to the lack of technology. In the last decade, nickel smelter is booming in Indonesia to process nickel saprolite to become Ferro Nickel, Nickel Pig Iron, Nickel Matte. This study is aimed to assess the potential implementation of High-Pressure Acid Leaching (HPAL). HPAL is a proven technology but not utilized in Indonesia due to the high investment, and it requires a large media for waste disposal. Nickel limonite ore with grade 1.1 – 1.4 % can be processed using HPAL technology to produce more than 37% nickel and another beneficial product, which is cobalt. Nickel world demand shifts to support electric vehicle battery even though stainless steel demand is still high. The Government of Indonesia is currently starting to support the electric vehicle market program. Therefore HPAL project in Indonesia is a high opportunity and a good investment for investors.

1. Introduction
The Indonesian government has issued a policy to increase added value from mining minerals by processing domestic mineral ore and has also banned the export of raw ore minerals since Year 2014. Harita Group, especially the subsidiary engaged in the development of nickel mines, strongly supports the policy. Harita Group nickel mines with PT.Halmahera Persada Lygend (PTHPL) plans to build a nickel processing plant at North Maluku -Halmahera in Obi Island, Indonesia. It has processed high-grade nickel saprolite to produce ferronickel by smelter rotary kiln electric furnace. Today, PTHPL plan to process nickel ore limonitic to produce nickel sulfate and cobalt sulfate through nickel ore leaching by hydrometallurgy high-pressure acid leach technology. Limonitic ore consists of nickel oxide and cobalt oxide. Nickel and Cobalt in sulfate form are material sources for electric car battery. Therefore, the project will support the Indonesian government program in electric vehicle development.

The Indonesian government has stated that fuel oil and air pollution can be reduced by increasing the use of electric cars. The supply of renewable energy becomes wider while fossil energy becomes smaller and in the next few years ignition combusting engine (ICE) will shift to renewable energy i.e. hybrid cell, fuel cell, and electric cell. The Automotion needs a product transformation to fuel-efficient vehicle to cope with global energy supply and oil limitation. Fossil fuel (oil, gas, and coal) supply in
Figure 1 shows a deficit. As the impact of fossil fuel supply deficit to ICE there will be a shift to electric vehicles, Figure 2. The Indonesia automotive sales growth average is 6% while production growth average is 7.5% and economic growth is 5.7% in 2018. Therefore, this study is aimed to assess the opportunity for HPAL development in the PTHPL project site.

2. Method
In order to achieve the study goal, some methods were applied including literature review and comparative study. Those methods were focused on collecting and obtaining information and data associated with nickel production and HPAL technology.

The opportunity for HPAL development in Indonesia and the application of HPAL worldwide are being discussed and presented as part of nickel mine activity.

3. Result and Discussion

3.1 High-Pressure Acid Leach Technology in Indonesia
Nickel laterite ore can be found in Indonesia in the ultramafic rocks distributed in Sulawesi, Maluku, and Papua Islands (Figure 3). Indonesia is a tropical region and the nickel laterite ores can be found are nickel and cobalt [3]. The limonite layer consists of mixture of minerals of high iron oxide and low magnesium. Nickel ore profile and character leaching type are provided in Figure 4.
Nickel and cobalt extraction from limonite ore will be leached with high-pressure sulfuric acid. Leaching limonite ore with sulfuric acid is selective in temperature and high pressure. The first plant for high-pressure acid leaching (HPAL) of laterite ores was built in Moa Bay, Cuba. Since then, it was not until the 1990s, and beyond, new HPAL plants were built that are currently operating in Australia, Philippines, New Caledonia, Papua New Guinea and Turkey [5]. All of these HPAL plants have been operated under typical high-temperature conditions (temperature about 250°C) and pressure conditions (about 4Mpa) in autoclave system [6]. The HPAL technology, which has been used to produce nickel products (see table 1) for a decade has produced 3 generations. It becomes a matured and reliable process. One study of nickel and cobalt extraction by using HPAL from the Gördes region of Manisa in Turkey was presented by [7].

Table 1. The HPAL technology to produce nickel products for a decade

| Generation | Country          | Project | Product           | Capacity (ton) | Operation Time |
|------------|------------------|---------|-------------------|----------------|----------------|
| 1<sup>st</sup> | Cuba            | MOA     | Ni & Co sulfide   | 32,000 Ni, 2,000 Co | 1959          |
| 2<sup>nd</sup> | Australia       | Bulong  | Ni & Co cathode   | 9,000 Ni, 700 Co  | 1998          |
| 2<sup>nd</sup> | Australia       | Cawse   | Ni & Co sulfide   | 9,000 Ni, 1,300 Co | 2000          |
| 2<sup>nd</sup> | Australia       | Murin Murin | Ni & Co Briquette | 45,000 Ni, 3,000 Co | 1998          |
| 2<sup>nd</sup> | Philippine      | Coral Bay | Ni & Co sulfide  | 18,000 Ni, 1,500 Co | 2005          |
| 3<sup>rd</sup> | Australia       | Ravensthorpe | Ni & Co hydroxide | 50,000 Ni, 1,400 Co | 2008          |
| 3<sup>rd</sup> | New Caledonia   | Goro    | Ni & Co hydroxide | 60,000 Ni, 5,000 Co | 2009          |
| 3<sup>rd</sup> | Papua New Guinea | Ramu    | Ni & Co hydroxide | 30,000 Ni, 3,000 Co | 2012          |
| 3<sup>rd</sup> | Madagascar      | Ambatovy | Ni & Co Briquette | 60,000 Ni, 5,000 Co | 2012          |
| 3<sup>rd</sup> | Philippine      | Taganito | Ni & Co sulfide  | 30,000 Ni, 2,600 Co | 2013          |

3.2 Separation and Purification of Nickel/Cobalt from Pregnant Leach Solution

PTHPL will process nickel ore by HPAL technology under the temperature of 240°C~270°C and Pressure of 3,400kPa~5,600kPa. The composition of raw material ore composition including limonite and saprolite from HPL mine is presented in Table 2 and Table 3. Mineralogy nickel laterite, the metallic elements mainly exist in the form of metallic oxides in ores: NiO, CoO, Co2O3, CaO, FeO, FeO(OH),MgO, MnO, ZnO and SiO2 [8].

Table 2. Limonite nickel ore composition (in %)

| Compositions | Ni | Co | Al | Cr | Ca | Mn | Cu | Fe | Mg | SiO2 | S | Zn |
|--------------|----|----|----|----|----|----|----|----|----|------|---|----|
| Limonite     | 1.35 | 0.17 | 3.00 | 1.00 | 0.02 | 0.97 | 0.01 | 41.15 | 1.6 | 15.22 | 0.00 | 0.04 |

Table 3. Limonite nickel ore composition (in %)

| Compositions | Ni | Co | Fe | SiO2 | MgO | Ca | H2O |
|--------------|----|----|----|------|-----|----|-----|
| Limonite     | 1.7 | 0.08 | 16.08 | 32.94 | 26.51 | 0.12 | 35  |
Oxides of most metallic elements, such as Me (Ni, Co, Mg, Mn, Zn, and Cu) will react with sulfuric acid. They could be extracted into pregnant leach solution (PLS) in liquid sulfate (MeSO₄). The equation is as follows:

$$\text{Me}_2\text{On(s)} + 2n\text{H}^+ \rightarrow 2\text{Me}^{n+} + n\text{H}_2\text{O}$$

Where Me: Ni, Co, Mn, n: metal ionic compound

Metallic element gangue in PLS will be separated by precipitation of alkaline ferric sulfate and alumina by pH setting. Iron/aluminum removal through pH setting is mainly to remove impurity elements such as iron, aluminum and silicon in CCD overflow. Limestone slurry will be used as neutralizer and air will be introduced into the solution to oxidize ferrous element. The pH value at terminal will be controlled at 3~5 for two stages of iron/aluminum removal to achieve hydrolytic precipitation, and iron and aluminum removal together with silicon dioxide. Main reaction equations are as follows (M=Al, Fe):

1. $$\text{H}_2\text{SO}_4 + \text{CaCO}_3 + \text{H}_2\text{O} \rightarrow \text{CaSO}_4.2\text{H}_2\text{O} + \text{CO}_2$$
2. $$4\text{FeSO}_4 + 2\text{O}_2 + 2\text{H}_2\text{SO}_4 \rightarrow 2\text{Fe}_2(\text{SO}_4)_2 + 2\text{H}_2\text{O}$$
3. $$\text{M}_2(\text{SO}_4)_3 + 4\text{H}_2\text{O} \rightarrow 2\text{M}^{2+}(\text{OH})_2 + 3\text{H}_2\text{SO}_4$$
4. $$\text{M}_2(\text{SO}_4)_3 + 6\text{H}_2\text{O} \rightarrow 2\text{M}^{2+}(\text{OH})_3 + 3\text{H}_2\text{SO}_4$$
5. $$n\text{H}_2\text{SiO}_4 \rightarrow (\text{SiO}_2)_n + 2n\text{H}_2\text{O}$$

Nickel/cobalt precipitation overflow will be used as CCD scrubbing water. Another part will be used as water for tail gas scrubbing in high-pressure acid leaching, limestone slurry preparation as well as sodium hydroxide dilution. The remaining will be drained out after tailings residues neutralization. Main reaction equations are as follows:

1. $$\text{MSO}_4 + 2\text{NaOH} \rightarrow \text{M(OH)}_2 + \text{Na}_2\text{SO}_4$$
2. $$\text{MSO}_4 + \text{Ca(OH)}_2 \rightarrow \text{M(OH)}_2 + \text{CaSO}_4.2\text{H}_2\text{O}$$

Where: M=Ni, Co, Mn and Mg

Nickel/cobalt precipitation in mix hydroxide precipitate (MHP) by pH setting 7-8 in two stages of pH setting. Nickel/cobalt mixed in hydroxide precipitate are used as intermediate products to be sold before purification in the next step. MHP content of about 39% Ni and 4.8% Co and the main composition are shown in Table 4.

### Table 4. Main compositions of nickel/cobalt hydroxide (%)

| Compositions | Ni  | Co  | Al  | Ca  | Mn  | Cu  | Fe  | Mg  | S   | Zn  |
|--------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| %            | 39.14 | 4.84 | 0.13 | 0.41 | 7.3 | 0.1 | 0.17 | 0.40 | 4.33 | 0.77 |

MHP is further produced to be nickel sulfates and cobalt sulfate with lime milk as precipitator in both stage I and stage II. In the first-stage precipitation processing nickel/cobalt hydroxide, sodium hydroxide or lime milk will be adopted as precipitants to make ~90% nickel/cobalt in solution precipitate. After first-stage precipitation, slurry will be delivered to thickener for liquid-solid separation. First-stage thickener overflow will be delivered to second-stage nickel/cobalt precipitation system and lime milk will be adopted as the precipitant. After precipitation, slurry will go through thickening and separation. Part of the underflow will be used as crystal seeds and the remaining will be returned to recycled leaching procedure to collect nickel, cobalt and other.
valuable metals. Part of second-stage nickel/cobalt precipitation overflow will be used as CCD scrubbing water. Another part will be used as water for tail gas scrubbing in high-pressure acid leaching, limestone slurry preparation as well as sodium hydroxide dilution. The remaining will be drained out after tailings residue neutralization. Nickel and cobalt extraction process flow is available in Figure 5.

**Figure 5. Extraction process flow of nickel and cobalt from nickel ore, PTHPL Province North Maluku, Indonesia**

The total laterite nickel ore consumption is about 8.3 million tons to produce 365,000 tons of Nickel/cobalt mixed hydroxide, 247,000 tons of nickel sulfate and 32,000 tons of cobalt sulfate. In this process, about 780,000 tons of saprolite nickel ore are needed to replace the lime milk for neutralizing. Saprolite consisting high nickel and magnesium are needed to neutralize PLS after HPAL process and to increase recovery. Increase recovery by spike nickel content. Approximately 90-95% of the nickel, cobalt, copper, and zinc are precipitated along with any residual iron, aluminum, and chromium, presented under an operating temperature of >60°C. Chromite as a by-product obtained after the beneficiation process is around 225,000 tons with average Cr content of 30%.

### 3.3 Environmental Issues

Main waste residue is 6.1 million dry metric tons tailings residue and it will be pumped to DSTP (deep sea tailing placement) site in the form of slurry with the tonnage of 51.9 million tons. Land Tailings application for Halmahera tropical region is less suitable. Halmahera tropical region, particularly at Obi island, is an earthquake active area with 3,000 mm/year rainfall, and ±7,000 people living in the village downstream. Due to this condition, the cost of construction and water control will be very high and is not feasible for the project economically. The main composition residue will be pumped to DSTP present in Table 5.

**Table 5. Main compositions of nickel residue before neutralization**

| Compositions | Ni  | Co  | Al  | Ca  | Mn  | Cu  | Fe  | Mg  | S   | Zn  | Cr  | SiO₂ |
|--------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
| %            | 0.114 | 0.014 | 2.97 | 2.86 | 0.76 | 0.002 | 38.6 | 0.74 | 5.38 | 0.01 | 0.94 | 6.6  |
The tailings residue neutralization is configured as one series. The main equipment includes 6 end-solution neutralization tanks arranged in series. The CCD thickener underflow, scrub water of HPAL tail gas scrubbing, 2nd stage Ni/Co hydroxide precipitation thickener overflow and other effluents from the refinery, etc. are put into the tailings residue neutralization tank, where lime milk is added for neutralization treatment. The slurry pH value is adjusted to 8.1~8.5. After neutralization, the slurry is pumped to DSTP site. DSTP system requires approval from the Government of Indonesia. Main reaction equations are as follows:

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\begin{align*}
\text{Fe}_2(\text{SO}_4)_3 + 3\text{Ca(OH)}_2 + 3 \text{H}_2\text{O} & \rightarrow 2\text{Fe(OH)}_3 + \text{CaSO}_4 \cdot 2\text{H}_2\text{O} \\
\text{NiSO}_4 + \text{Ca(OH)}_2 + 2\text{H}_2\text{O} & \rightarrow \text{Ni(OH)}_2 + \text{CaSO}_4 \cdot 2\text{H}_2\text{O} \\
\text{CoSO}_4 + \text{Ca(OH)}_2 + 2\text{H}_2\text{O} & \rightarrow \text{Co(OH)}_2 + \text{CaSO}_4 \cdot 2\text{H}_2\text{O} \\
\text{MgSO}_4 + \text{Ca(OH)}_2 + 2\text{H}_2\text{O} & \rightarrow \text{Mg(OH)}_2 + \text{CaSO}_4 \cdot 2\text{H}_2\text{O}
\end{align*}
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DSTP with 15km onshore and 0.7 km offshore pipelines in 40” diameter from refinery plant to the sea canyon at the depth of > 200 m below sea level. Tailings will flow from pipeline outfall to 1000-2000 m deep of the seabed below sea water level. Series of tests such as toxicity leach p (TCLP), lethal concentration (LC50), up to sub-chronic test were conducted to ensure that tailings cause no harm to the marine environment.

4. Conclusion
Indonesia is one of the countries that has bulk mineral deposits including nickel. Indonesia is also the largest nickel laterite resource in the world. Currently, only nickel ore saprolite is exploited while nickel limonite is abandoned as waste due to lack of technology.

PT Halmahera Persada Lygend (PTHPL) plans to construct new technology for nickel laterite ore processing in Obi Island, North Maluku Province, which is expected to produce 247,000 tonnes of NiSO4.7H2O and 32,000 tonnes of CoSO4.7H2O that to be sold for the raw material of electric vehicle battery. Potential nickel resources in Indonesia open an opportunity for PTHPL to further process the nickel limonite by using HPAL technology. The HPAL is a proven technology and has been applied worldwide.

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