Processing and Economics of Nickel Laterites

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Abstract

With world demand for nickel expected to be bullish in the next ten years there has been renewed interests in nickel production. As such, this paper describes nickel laterite ores, the predominant nickel deposit in the Philippines, together with its current viable processes. A comparison of the economics of smelting and High Pressure Acid Leaching (HPAL) is also presented.

Keywords: Processing and economics, nickel laterites, smetting, high pressure acid leaching

I. Introduction

Nickel derived its name from the term "Kupfer Nickel" or Devil's copper as called by the Saxon miners who discovered the copper red/brown mineral in the Middle Ages, and found to their disgust, that they were unable to extract the metal from the ore. Nickel is outstanding among the metallic elements, next to copper and iron, since they have contributed to the advance of civilization through the ages. [1]

The chemical symbol for Nickel is Ni and its atomic number is 28. It has a specific gravity of 8.9 and a relatively high melting point of 1453°C. The electronic configuration of nickel is $1s^2 2s^2 2p^6 3s^2 3p^6 3d^8 4s^2$. [2]

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Nickel is a hard, silvery white metal with a similar hardness and strength to iron, but is more ductile and easier to work and machine. It has the ability to impart special features and desired physical properties to other metals. When alloyed with other elements, nickel imparts hardness, strength, toughness, corrosion resistance over a wide temperature range, and various other electrical, magnetic, and heat resistant properties. [2]

At least 3,000 nickel alloys have been identified and these are widely used in the chemical industry, pipelines to carry seawater and in the highly stressed components for cars. In addition, nickel alloy steels are vital in modern weapons of war, and nickel-base super alloys which provide strength in the high-temperature jets that propel rockets into space. About 60% of the world nickel output is used in the manufacture of stainless steels. [3]

II. Objectives

The objectives of this paper are:

1. to present the market potential of nickel which has presumably attracted pipeline nickel projects in the Philippines
2. to describe nickel laterite which is the predominant nickel deposit in the Philippines
3. to describe the economically viable processes for laterite deposits
4. to discuss the economics of smelting and HPAL nickel processes

III. Scope and Limitation

This paper shall be limited to nickel laterites comprising of limonitic and silicate nickel ores which occur most frequently in tropical climates like the Philippines. The variety of flowsheets used to process these laterite ores generally fall into two categories:[4]

1. pyrometallurgical processes
2. hydrometallurgical processes

Majority of these pyrometallurgical processes use conventional flowsheet involving drying, calcining/reduction and electric furnace smelting while the two principal hydrometallurgical processes utilize the

HPAL and Caron processes. As per benchmarking by Dalvi, et. al. [4], the Caron process is not competitive with the smelting and HPAL processes due to low nickel and cobalt recoveries on top of high energy and reagent costs making the Caron process not attractive to new laterite projects. While existing plants utilizing the Caron process would continue or resume to operate since the capital investment is deemed "sunk", they are expected to carry out debottlenecking to increase process efficiencies and reduce costs to be competitive. As such, this paper shall also be limited to the conventional smelting and HPAL processes.

IV. Market Potential

Presented in Table 1 is the World Primary Nickel Demand and Production for years 2002-2003.[5] While production more or less satisfied demand in 2002 (production slightly exceeded demand by 5,000 tons),

Table 1

World Primary Nickel Demand ('000 tonnes)	2002 year	2003 year
Americas	159	160
Asia	404	423
Europe	435	430
Other West	38	48
Former Eastern Bloc	142	173
World Total	1177	1233

World Primary Nickel Demand ('000 tonnes)	2002 year	2003 year
Africa	50	54
Americas	251	241
Asia	167	174
Europe	190	184
Oceania	181	179
Former Eastern Bloc	337	370
World Total	1182	1201

a reversal did occur in 2003 with a demand-supply gap of 32 metric tons. At present, world nickel demand is increasing at a rate greater than 4% per annum and is expected to be bullish for the next ten years. China accounts for 70% of the increase in nickel demand due to the expansion of its stainless steel production. The expected 2004-2007 worldwide capacity additions will not satisfy the growth in over-all nickel demand due to above mentioned additional stainless steel capacity in China, demand for aerospace alloys and for battery grade nickel.[4]

In view of the above market trend, a number of companies have signified interests to venture into nickel production in the Philippines as shown in Table 2. [6] It should be worth mentioning Coral Bay Project of Sumitomo in Palawan which has already started operations.

Table 2

Project		
Palawan HPP Project	High pressure acid leaching (HPAL)	11.5 million WMT 2.3% Ni
Adlay-Cadianao Taulawa (ACT) Project	Nickel ore (laterite)	8.9 million MT 1.53% Ni, 0.144% Co, 36.9% Fe
Pujada Nickel Project	Nickel	200 million MT 1.3% Ni
Mindoro Nickel Project	Nickel, Cobalt	100 million MT 0.94% Ni, 0.07% Co
Nonoc Nickel Project	Nickel, Cobalt	

V. Description of Laterite Ores

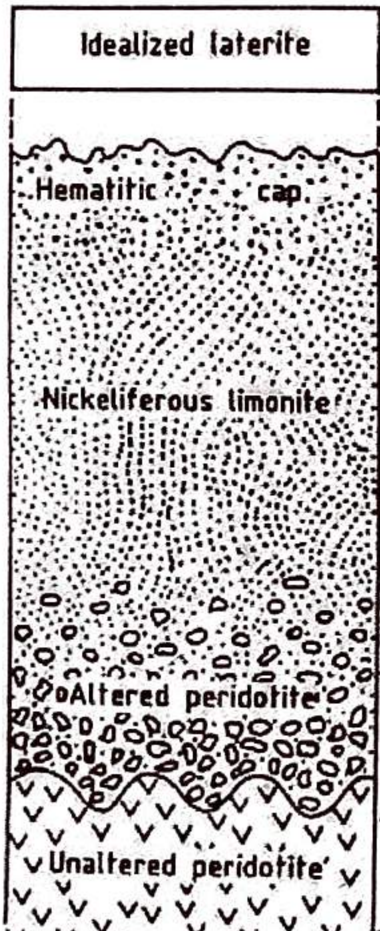
Nickel ranks twenty-fourth in the order of abundance of elements in the earth's crust with an average content of 0.008%. Although nickel is more abundant than copper, zinc and lead there are relatively few ore bodies of commercial significance.

The economically important ores can be divided into two types, sulfide and laterite (oxide or silicate). Nickel does not occur as a native metal. Of the estimated at 58 x 10^6 metric tons world reserves of nickel, about 80% is in laterite ore bodies which is widely distributed throughout the tropics and only 20% in sulfide deposits. Growth in nickel production in the future is expected to come from laterite ores of nickel.

Laterite ores, occur in two main forms, oxides and silicates. In the oxide form, the nickel is dispersed through a limonite, a hydrated form of iron oxide, while the silicate form nickel partially replaces magnesium in the lattice of a hydrated magnesium silicate. The nickel grade of lateritic ores ranges from 1-2%.[7]

The oxidic ores of nickel are formed by a chemical concentration process that occurs as a result of the lateritic weathering of peridotite rock. Peridotite consists mainly of olivine, a magnesium iron silicate containing up to 0.3% nickel. In many rocks, the peridotite has been altered to serpentine, a hydrated magnesium silicate, prior to exposure to weathering. Olivine and serpentine are decomposed by groundwater containing carbon dioxide to form soluble magnesium, iron, nickel, and colloidal silica. The iron rapidly oxidizes in contact with air and precipitates by hydrolysis to form goethite and hematite, which remain near the surface of the deposit. The dissolved nickel and magnesium and the colloidal silica, percolate downwards in the laterite deposit, remaining in solution so long as the solution is acidic. When the solution is neutralized by reaction with rock and soil, nickel, silica and some of the magnesium precipitate as hydrated silicates. This process is shown in the Figure 1 :[7]

Complete separation of iron and nickel into distinct zones is never achieved. Some or even most of the nickel may in fact remain in the upper layer, which is thus enriched in iron and nickel, but depleted in magnesium and silica. Such material, consisting mainly of ferric oxide minerals, is described as limonitic. This type of ore is typically relatively rich in cobalt and chromium. By contrast, in the silicate minerals, the separation of iron and nickel is more complete, and the nickel is presen in silicate minerals with a high magnesia content. Both types of materia are almost always found in a laterite deposit.[7]



Approximate analysis, %					Extractive procedure
Ni	Co	Fe	Cr_2O_3	MgO	
<0.8	<0.1	>50	>1	<0.5	Overburden to stockpile
0.8 to 1.5	0.1 to 0.2	40 to 50	2 to 5	0.5 to 5	Hydrometallurgy
1.5 to 1.8	0.02 to 0.1	25 to 40	1 to 2	5 to 15	Hydrometallurgy or pyrometallurgy
1.8 to 3		10 to 25		15 to 35	Pyrometallurgy
0.25	0.01 to 0.02	5	0.2 to 1	35 to 45	Left in situ

Figure 1. Typical Section in a Laterite Deposit.

The type of weathering which dissolves silica and metallic elements from rock to produce limonitic and silicate nickel ores occur most frequently in tropical climates with high rainfall and with decomposing vegetation to provide organic acids and carbon dioxide in groundwater. Thus, nickel from laterite ores is the predominant type of nickel deposit in the Philippines.

VI. Description of Smelting and HPAL Processes

A generalized block flow diagram for conventional smelting is presented in Figure 2 below:[4]

Figure 2

Laterite Ore – Conventional Smelting

Drying

↓

Calcining/Reduction

↓

Smelting

↓

Refining or Converting

FeNi or Matte

1. Drying – Nickel laterite ores have high moisture contents (typically up to 45%) as well as chemically bound water in the hydroxide form. Dryers, usually direct-fired rotary units operating at about 250°C, reduce the moisture content only to 15-20% to minimize dusting during drying and subsequently smelting.
2. Calcining/Reduction - Calcining to dehydrate the ore and pre-reduction prior to electric furnace smelting are generally carried out in countercurrently fired rotary kilns. Chemically bound water is released above 400°C and reduction of the oxides to metal starts at 500-600°C. The maximum temperature reached in the kiln is

generally limited to 800-900°C because of the tendency of the ore to agglomerae and form accretions on the furnace walls.

Dehydration and pre-reduction of the ore in the kiln prior to smelting optimizes the utilization of energy available from the reductants and fuel, thus reducing energy consumption in the smelting operation.

3. Smelting - In the electric furnace, the calcined ore is smelted with the reductant to form immiscible layers of slag and ferronickel. Virtually all the nickel and 60-70% of the iron in the ore are reduced to metal to yield a ferronickel grading about 20% Ni while the slag contains only 0.1% Ni. The energy consumption in the electric furnace for this mode of operation is 2.0 –2.2 GJ per tonne of dry ore (550-600 kWh/t) with operating temperatures of 1400 - 1650°C.

From the above flow, pyrometallurgical processes are energy intensive since all of the free moisture and combined water has to be removed and all of the material has to be first calcined and then melted to form a slag.

A generalized block flow diagram for the HPAL process is presented in Figure 3 as shown in the next page:[4]

Figure 3

Laterite Ore - HPAL

High Pressure Leaching

↓

CCD & Neutralization

↓

Precipitation and Redissolution (Optional)

↓

Purification & Recovery

Ni & Co

HPAL is currently utilized by the Coral Bay Project of Sumitomo in Palawan. This process requires ores that are predominantly limonitic. Pressure leaching with sulfuric acid is done at a temperature range of 245-270°C to solubilize nickel and cobalt. Solid-liquid separation is carried out by Counter Current Decantation (CCD). The separation of nickel and cobalt from the pregnant solution is carried out by solvent extraction.

VII. Economics of Smelting and HPAL Processes

It has been benchmarked by Dalvi, et. al. [4] that financial viability of laterite projects both conventional smelting and HPAL processes is very sensitive to feed grade. But only a limited upgrading can be done with laterite ores as compared to sulfide processing which is amenable to beneficiation. This means a large tonnage of feed material to be processed and a large tonnage of tailing or slag to be disposed. As such, laterite projects have generally high capital costs and laterite smelters in particular incurring relatively high operational energy costs.

Economics of new laterite smelters is presented in Table 3.[4] Projects are categorized as attractive, marginal and unattractive based on nickel grade and power costs ($/kWh).

Table 3. Economics of Laterite Smelters

Scenario	Grade % Ni	Power Cost Cents/kWh	Capital Capex Charges $/lb Ni	Opex $/lb Ni	Price req'd for justification $/lb Ni	Attractive-ness
High ore grade, or upgradable; large scale; low cost power; existing or low-cost infrastructure	2.5	3	10-12	1.5	3.5	Attractive
Average ore grade and infrastructure; relatively large scale; medium power cost	2	4	12-14	2	4.3	Marginal
Low ore grade; relatively small scale; infrastructure req'd; thermal power at lower fuel cost	1.7 or lower	5+	15	2.4	5	Unattractive

It is but logical that with higher nickel feed grade and lower power cost, a lower price required for justification is expected to earn the acceptable or desired return on investment. From Table 3, laterite smelter projects with low-grade ores and high cost power are not economically viable. The lower limit of nickel grade for a laterite smelter is 1.7% Ni for plants supplied with low cost power. However, high grade laterite ores are dwindling and rarely can we find an undeveloped hydroelectric power capacity existing in the vicinity of a laterite mine.

Apart from nickel feed grade and cost of power, operating expenses of laterite smelters are also highly sensitive to cost of fuel and reductants which account for a great percentage of unit operating expenses ranging from US $ 1.5-2.4/lb Ni of annual capacity.

Capital costs for new laterite smelters vary in the range from US$ 12 to 15/lb Ni of annual capacity. Such is inclusive of capital cost in a power generation facility amounting to US$4.50 to 5.00/lb of Ni. For smelters that do not have their own power plants, power costs are expected to be higher since power firms have also to earn a return on their capital. This benchmark applies to project with an annual capacity of about 40 kt Ni/yr with a feed grade of about 2% Ni. Capital cost is also subject to economies of scale. Larger plants are expected to have lower capital cost per pound nickel of annual capacity.

For existing smelters that are to undergo debottlenecking, capital cost is reduced by about US $ 4/lb Ni of annual capacity due to already built and available facilities and infrastructure which are considered "sunk".

Economics of new laterite projects PAL projects is summarized in Table 4. [4]

Table 4. Economics of PAL Projects

Scenario	Grade % Ni	Capex $/lb Ni	Opex $/lb Ni	Cobalt Credit $/lb Ni	Price req'd for justification $/lb Ni	Attractive-ness
High ore grade, or upgradable ore; large scale; intermediate products with low acid composition	>1.5	12	2.00	1.00	3.10	Attractive
Average ore grade and infrastructure; relatively large scale; finished products or high conversion costs for intermediate	1.4	14	2.20	0.70	4	Marginal
Low grade ore, low cobalt; relatively small scale; high infrastructure cost, or high conversion cost; high acid consumption	1.3 or lower	16+	2.50	0.40	5	Unattractive

Projects are categorized as attractive, marginal and unattractiv based on nickel grade, capital expenditures, operating expenses an cobalt credits.

From Table 4, PAL projects with low nickel grade (< 1.3% Ni) are not economically viable. Cut-off grade is pegged at about 1.4% Ni.

Capital costs for new laterite PAL projects vary in the range of US $ 12-16/lb Ni of annual capacity. Of this figure, capital cost for a power generation facility amounts to only US $ 1-2 /lb Ni of annual capacity. This benchmark applies to projects with an annual capacity of about 40 kt Ni/yr with a feed grade of about 1.4% Ni. Over-all capital cost is also subject to economies of scale with larger plants having lower capital cost per pound nickel of annual capacity.

Cost of reagents also account for the bulk of the unit operating expenses which range from US $ 2-2.50/lb Ni of annual capacity. In particular, an economic advantage is enjoyed by projects with feed that require low acid consumption.

Laterite PAL plants recover cobalt in relatively pure form and realize substantial revenues ranging from US $ 0.40-1.00/lb Ni annual capacity.

Similarly, existing laterite PAL projects undergoing debottlenecking operations would also enjoy an economic advantage since past investment in already built facilities is considered "sunk".

Benchmarking of laterite smelters has been made possible with a reasonable degree of confidence since a relatively large number of smelters have been built since 1950. On the other hand, benchmarking of laterite PAL projects is not as reliable as that of laterite smelters since only a small number of modern PAL plants have been built.[4]

VIII. Conclusion

1. The market potential for nickel is expected to be bullish for the next ten years with demand expected to grow more than 10% per annum. However, with China accounting for 70% of nickel demand worldwide, a slowdown in China's economic activity poses a clear risk to its long term viability.
2. Nickel from laterite ores is the predominant type of nickel deposit in the Philippines. Limonitic and silicate nickel ores occur most frequently in tropical climates with high rainfall and decomposing

vegetation to provide organic acids and carbon dioxide in groundwater to dissolve silica and other metallic elements.

3. Production from nickel laterite ores is projected to fill the bulk of nickel demand. Laterite ores are generally processed using pyrometallurgy in conventional smelting and hydrometallurgy using High Pressure Acid Leacing (HPAL). The other hydrometallurgical process, Caron, has been benchmarked to be not competitive.
4. Capital costs for smelting which is US $ 12-15/lb Ni as compared to PAL which is US $ 12-16/lb Ni of annual capacity are more or less the same. From these figures, US $ 4.50-5/lb Ni for smelting while only US $ 1-2/lb Ni of annual capacity for a PAL process is the capital cost for a power generation facility. Smelting is energy intensive since drying, calcining and melting are required. Modern PAL technology, however, remains unproven and faces technical and engineering challenges. But as more plants are built and experience gained in design, investment in PAL plants may decrease over the long term.
5. PAL nickel projects can treat lower feed grades which are still relatively abundant as compared to high grade laterite smelter ores which are dwindling. Cut-off grades for smelting is 2% Ni while that of PAL process is 1.4% Ni.
6. Most laterite smelters produce ferronickel and do not recover cobalt. In contrast, PAL plants realize substantial revenues from cobalt ranging from US $ 0.40-1.00/lb of Ni annual capacity.

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