

## **TMS 2013: Ni-Co 2013**

### **Extraction of Nickel, Cobalt and Iron from Laterite Ores**

#### **by Mixed Chloride Leach Process**

V.I. Lakshmanan, R. Sridhar, R. deLaat, J. Chen, M.A. Halim and R. Roy\*

*Process Research Ortech Inc.  
2350 Sheridan Park Drive  
Mississauga, ON L5K 2T4*

(\*Corresponding author: rroy@processortech.com)

#### **ABSTRACT**

Primary nickel is produced from both lateritic and sulfidic ores. Lateritic ores are formed by prolonged weathering of ultramafic rocks. The laterite deposits exhibit graded layers of ore, with high iron, low nickel ore on top and low iron, high nickel ore below. The low iron (< 15 % Fe) ores containing 1.7- 2.3% Ni are treated by pyrometallurgical processes to produce ferronickel or matte. High iron (> 35 % Fe) limonitic ores can be treated by high pressure leach using sulphuric acid. An alternative process for the production of base metals (Ni, Co and Fe) from both high and low iron laterite ores is being developed by Process Research ORTECH Inc. (PRO), a world leader in the development of chloride metallurgy. The process flowsheet developed by PRO is efficient and environmentally friendly. Novel leaching and solvent extraction separation steps have been developed to make this alternative more economically attractive in the current market conditions.

## **INTRODUCTION**

Primary nickel is produced from both lateritic and sulfidic ores. Although currently majority of nickel is produced from sulfidic ores, the production of nickel from lateritic ores is increasing and may overtake nickel production from sulfidic ores [1]. Lateritic ores are formed by prolonged weathering of ultramafic rocks. Typical mineralogical profile of nickel laterite ore bodies is as follows [2, 3]:

1. Overburden with low nickel values of  $< 0.8\%$  Ni, which is discarded.
2. Limonitic ore zone with 1.2-1.7% Ni, ~ 40 % Fe and 1-4% MgO. These zones are suited for hydrometallurgical processes capable of extracting nickel from limonitic ores. High iron ( $> 35\%$  Fe) limonitic ores can be treated by High Pressure acid Leach (HPAL) process using sulphuric acid.
3. Saprolitic ore zones with 1.7 to 2.3 % Ni and low iron ( $< 15\%$  Fe) are suited for pyrometallurgical smelting processes to produce ferronickel or matte.
4. Base rocks contain  $< 0.5\%$  Ni and are not economic for extracting nickel.

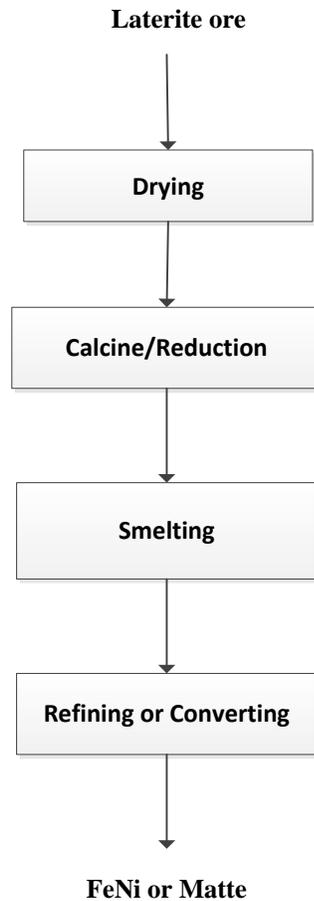
In some of the major laterite projects having the above typical profile, the limonitic ores are stockpiled and are in storage for treatment after exhausting the higher grade saprolitic ores. However there are laterite projects in which the saprolitic ore profile is not present or is minor amount and the limonitic profile has to be treated for nickel recovery.

## **PYROMETALLURGICAL PROCESSING OF LATERITIC ORES**

The ores in the saprolitic zone with high nickel values are commonly treated by pyrometallurgical processing to recover ferronickel and matte with 25 to 75% Ni content. Most of these contain less than 20% Fe and the recovery of nickel from this ore zone exceeds 92% and is about 95% in the best operations. The smelting process continues to be the preferred process for treating this ore zone. The flowsheet for pyrometallurgical processing of lateritic ores is shown in Figure 1 [1]. The flowsheet consists of ore drying followed by calcination/reduction in a rotary kiln. The calcine from the rotary kiln is smelted in an electric furnace with carbon as reductant. This is followed by refining or converting to produce ferro-nickel or matte. The process is energy intensive as it involves drying, calcining and smelting of entire ore body at successively higher temperatures.

More recently the upper iron zone near the saprolitic zone is treated by mini blast furnaces converted from iron producing operations in China [4] to recover lower grade

ferronickel (< 20% Ni). They will continue to have the pollution problems encountered in the iron making process for which they are now banned in China and will be economical in periods of high nickel prices (> \$6/lb Ni).

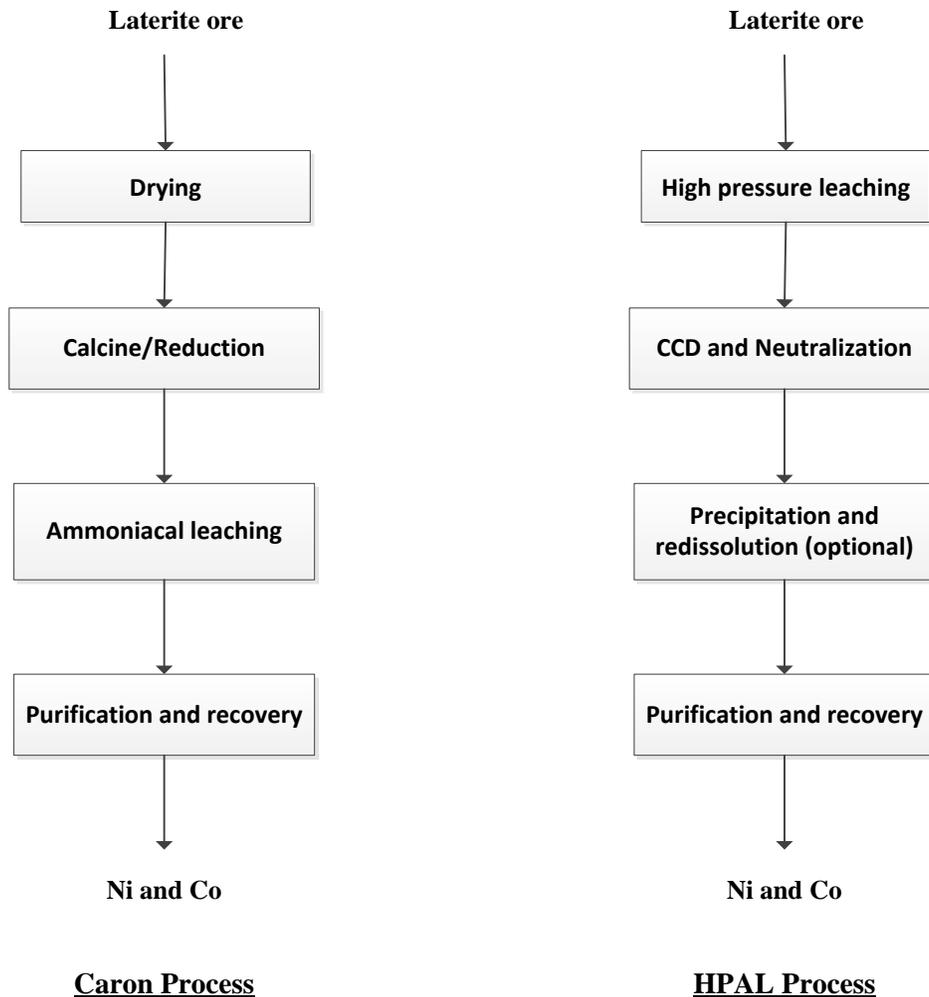


**Figure 1: Pyrometallurgical Processing of Lateritic Ores**

## **HYDROMETALLURGICAL PROCESSING OF LATERITIC ORES**

There are two major processes for the hydrometallurgical processing of lateritic ores: Caron process and High Pressure acid Leach (HPAL) process. The flowsheets for these two processes are shown in Figure 2 [1]. The Caron process involves ore drying followed by selective reduction of nickel. This is followed by leaching in an ammoniacal solution to bring metals in solution. Leaching is followed by precipitation of basic nickel carbonate, which is then decomposed to form nickel oxide. Nickel oxide is reduced to form nickel metal. The Caron process is used either for limonitic ores or for a mixture of limonitic and saprolitic ores.

To treat the high iron laterite ores, High Pressure Acid Leach (HPAL) processes have been developed by many companies and are in the planning or execution stage [5]. The acid requirement for these ore bodies depends on the MgO content and is typically about 30 to 40 weight percent of the ore weight [6]. As shown in Figure 2, the HPAL process involves high pressure leaching followed by counter-current decantation (CCD) and neutralization. There are different options for purifying nickel containing solution and separation of nickel and cobalt. Purification can be done by solvent extraction, followed by electrowinning of nickel. Historically sulphur has been available in abundance and therefore sulphuric acid was available for such processes at a cost of about \$100 per ton. When recovering 30 lbs of nickel with market price of about \$6/lb Ni, the plants could afford \$30 to \$40 per ton of ore for acid cost.

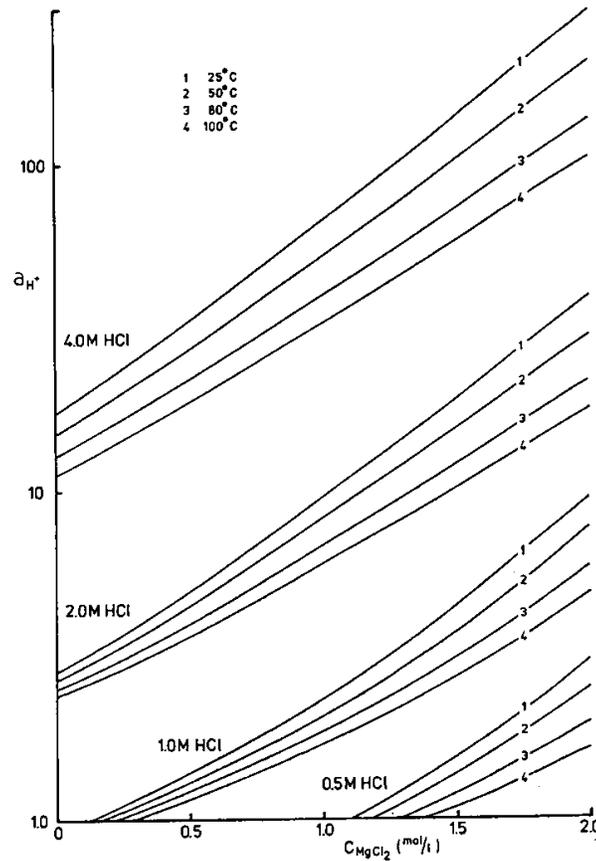


**Figure 2: Hydrometallurgical Processing of Lateritic Ores**

Few years ago the sulphur and acid prices saw a peak of about \$200 per ton in many parts of the world. At these prices the economics of the new plants became questionable. The market has however corrected itself. Nevertheless, when growth in the developing world is considered along with the requirement for fertilizer for their food security, it is projected that there will be corrections in the coming years for the acid price. Therefore it was of interest to develop an alternate process that depends less on sulphuric acid, the demand of which is expected to increase in the developing economies. This new innovative process is based on Chloride hydrometallurgy, which will be described in the next section. This process is applicable for both high and low iron laterite ores.

### CHLORIDE HYDROMETALLURGY

Chloride chemistry is complex and quite different from corresponding sulphate systems. In concentrated magnesium chloride salt solutions, the activity of water is  $\ll 1$ , and the activity of the hydrogen ion,  $H^+$  (or  $H_3O^+$ ) increases rapidly with chloride concentration as shown in Figure 3 [7].



**Figure 3: Effect of  $MgCl_2$  Concentration on the Activity of  $H^+$  in HCl Solutions [7]**

In addition, many metal chlorides are considerably more soluble than their corresponding sulphate salts, thus allowing the use of more concentrated solutions [8]. The solubility of  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ , for example, is about one fifth that of  $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ , and both nickel and ferrous chlorides are also more soluble than their sulphate counterparts.

High strength magnesium chloride brines offer significant advantages over other leaching media as follows:

- ▶ **High  $\text{H}^+$  activity** – enables only a small amount of acid (HCl) to effect leaching of the value metals. This is because the high hydrogen ion activity provides a very much higher driving force than for equivalent acid strength in more dilute solutions, and in many instances, the amount of acid added is only marginally higher than the stoichiometric amount required for the nickel, cobalt, iron and Mg.
- ▶ **High chloride concentration** – stabilises base metals in solution and leads to increased solubility. The formation of ferric anion complexes such as  $\text{FeCl}_4^-$  facilitates the recovery of iron by solvent extraction.

Based on the above considerations, an innovative process for the production of base metals (Ni, Co and Fe) from laterite ores has been developed by Process Research ORTECH Inc. (PRO), a world leader in the development of chloride metallurgy [8-22]. PRO laterite process is environmentally friendly as the hydrochloric acid is regenerated using pyrohydrolysis and recycled to the leaching process and the tailings generated from leaching is inert. PRO laterite process involves pyrohydrolysis of iron-rich preg strip solution and bleed stream from the magnesium chloride containing raffinate from nickel solvent extraction. Iron oxide and magnesium oxide by-products generated from pyrohydrolysis can be sold in the market. Magnesium oxide can also be used for pH control and precipitation of Ni and Co compounds from respective preg strip solutions. PRO is developing a hydrothermal hydrolysis process that can lower the energy cost for production of  $\text{Fe}_2\text{O}_3$  and regeneration of HCl from brine.

### **PRO LATERITE PROCESS [23]**

The process flowsheet developed by PRO is efficient and environmentally friendly. Novel leaching and solvent extraction separation steps have been developed to make this alternative more economically attractive in the current market conditions. The process flowsheet is shown in Figure 4 below.

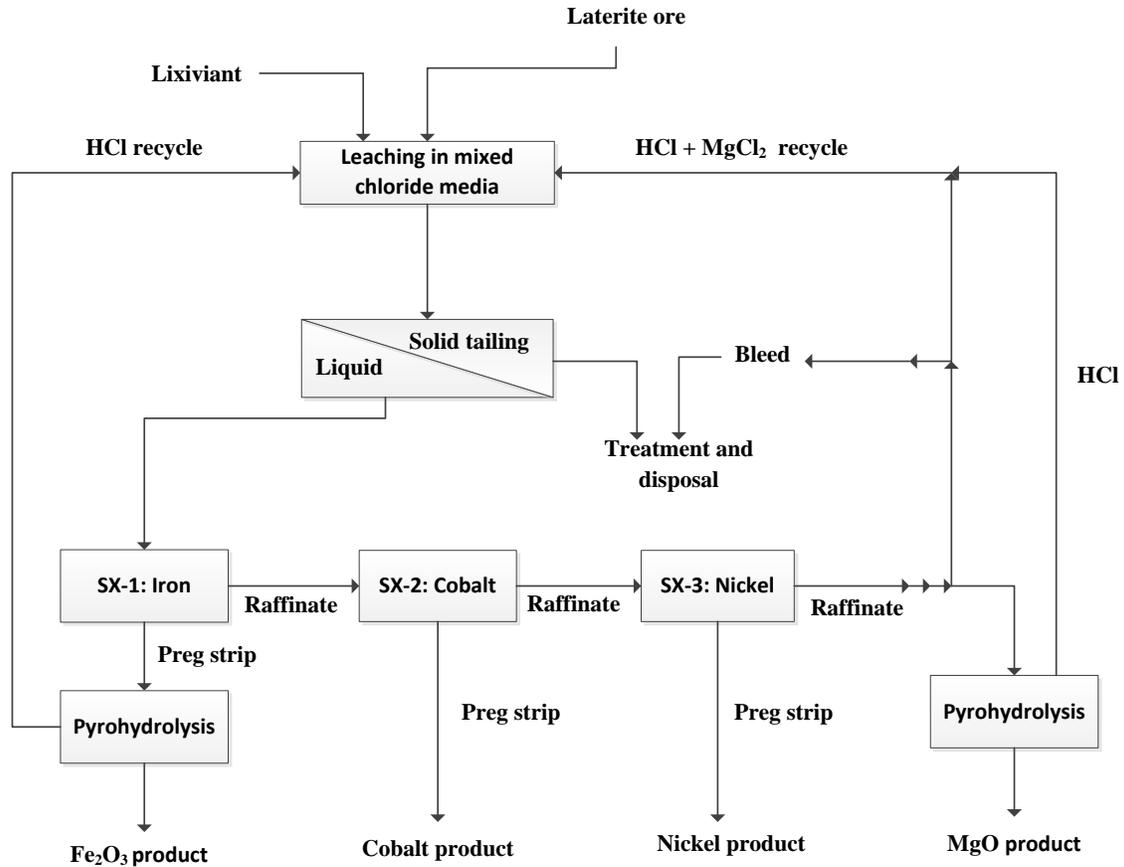


Figure 4: PRO Process for Treatment of Lateritic Ores [23]

The PRO Laterite process employs the following innovative steps:

1. Leaching in mixed chloride media to bring Fe, Ni, Co and Mg in solution.
2. Innovative solvent extraction steps for successive extraction and stripping of Fe, Ni and Co ions to obtain high purity concentrated preg strip solutions of Fe, Ni and Co respectively.
3. Precipitation of high purity Ni and Co products from respective high purity concentrated preg strip solutions of Ni and Co by addition of MgO generated from pyrohydrolysis.
4. Production of  $\text{Fe}_2\text{O}_3$  and regeneration of HCl by pyrohydrolysis of the iron chloride rich preg strip solution.
5. Production of MgO and regeneration of HCl by pyrohydrolysis of bleed stream from the magnesium chloride containing raffinate from nickel solvent extraction stage. This MgO can be used for pH control as well as precipitation of Ni and Co compounds from respective preg strip solutions. Excess MgO produced can be sold.
6. Recycle of HCl generated by pyrohydrolysis as described above.

## COMPARISON OF PRO LATERITE PROCESS WITH COMMERCIAL PROCESSES

A comparison of PRO laterite process with commercial processes is shown in Table 1.

Table 1: A comparison of PRO laterite process with commercial processes

	Pyrometallurgical process	Caron process	HPAL process	PRO Laterite process
Ores that can be treated	Med-high Ni (1.8-2.5 %), low-med Fe (10-20 %) ores	Low Ni (1.2-1.5 %), high iron (>40 %) ores	Low Ni (1.2-1.5 %), high iron (>40 %) ores	Both low Fe and high Fe ores
Ni recovery	~ 95 %	~ 75 %	~ 95%	> 90 %
Co recovery	None	< 50%	~ 95%	> 90 %
Fe recovery	No	No	No	Yes
Mg recovery	No	No	No	Yes
Capital cost	High	Medium	High	Low
Operating cost	High	Medium	High	Medium
Energy requirement	High (due to water removal from ore and high temperature processing)	High (due to water removal from ore and high temperature processing)	Low (no water removal from ore and low temperature process)	Medium (no water removal from ore and low temperature process, however pyrohydrolysis needed for acid regeneration adds energy cost)
Reagents	Not recycled	Not recycled	Not recycled	Recycled
Residue amount	High volume	High volume	High volume	Low volume
Environmental	Slag disposal	Residue disposal containing ammonia	High volume residue disposal	Inert residue
Sulphur price	No effect	No effect	Very dependent	No effect
Fuel price	High effect	Medium effect	Lower effect	Medium effect
By-product credit	None	None	None	Fe <sub>2</sub> O <sub>3</sub> and MgO credit

## CONCLUSION

An innovative process consisting of leaching in mixed chloride media and selective solvent extraction steps has been developed for treating lateritic ores. This process offers significant advantages over existing commercial processes. Atmospheric leaching of the ore in mixed HCl-MgCl<sub>2</sub> lixiviant is highly efficient in metal recovery. Innovative solvent extraction steps are used to generate high purity preg strip solutions of Fe, Ni and

Co individually. Pyrohydrolysis process is used to regenerate the acid and make the process sustainable and environmentally friendly. Magnesium from ore which is leached as magnesium chloride can be recovered as MgO by pyrohydrolysis and the regenerated acid (HCl) can be recycled to the leaching step. The process can treat low grade ores as well as rejects from higher grade ores. The process is also suitable for slags generated from pyrometallurgical operations during the production of Ni, Cu and Co. It has lower capital cost because it involves atmospheric leach as compared to autoclaves for a pressure leach process.

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