Ni-Co 2013
Edited by: Thomas Battle, Michael Moats, Violina Cocalia, Harald Oosterhof, Shafiq Alam, Antoine Allanore, Rodney Jones, Nathan Stubina, Corby Anderson, and Shijie Wang
TMS (The Minerals, Metals & Materials Society), 2013

LATERITES – STILL A FRONTIER OF NICKEL PROCESS DEVELOPMENT

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INTRODUCTION

- Nickel production has been historically based on sulphide resources & high grade saprolitic laterites.
- Based on currently known resources, future production will increasingly have to come from low grade limonitic & saprolitic laterites with <1.5% Ni.
- Commercially applied processes for low grade laterites are:
  - Caron Process: reduction roast – ammonia leach)
  - PAL (or HPAL) Process: high pressure sulphuric acid leaching
  - EPAL Process: enhanced pressure acid leaching

INTRODUCTION

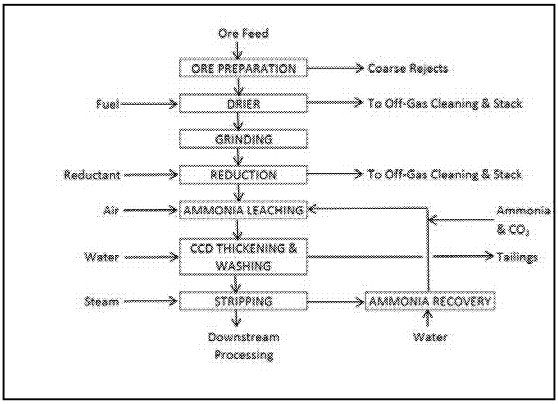
Note: There is a also single known application of ferronickel smelting operated by LARCO, Greece.

However, ferronickel smelting is generally considered to be uneconomic for low grade laterites.

CARON PROCESS

- It is not a new process and was first proposed by Professor Caron, Delft Univ. Netherlands, in the 1920s.
- It was pioneered commercially by Freeport at Nicaro, Cuba, in 1944, then taken over by the Cuban Government in 1960. It is still in operation.
- A further five plants were constructed in the 1970s-1990s, one of which was closed (Nonoc in the Philippines) and one never completed (Los Camariocas in Cuba).

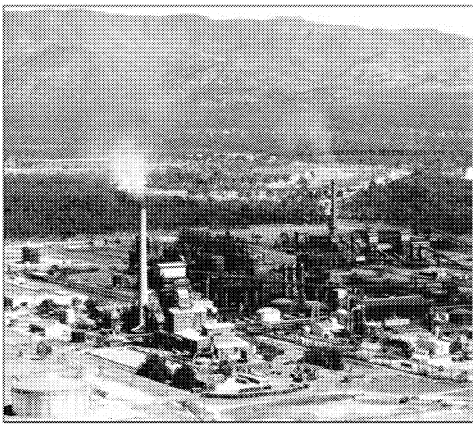
TYPICAL CARON FLOWSHEET



CURRENT CARON INSTALLATIONS

Plant	Start-up Date	Builder	Location
Nicaro	1944	Freeport	Cuba
Yabulu	1974	Freeport	Qld, Australia
Tocantins	1982	Votorantim	Brazil
Punta Gorda	1986	Cuban-Russian	Cuba

YABULU OPERATION, AUSTRALIA



ISSUES WITH CARON FLOWSHEET

- It has s high energy consumption for the initial ore drying step.
- Nickel recovery is only moderately high.
- Cobalt recovery is relatively low.
- It is generally limited to limonite and mixed ores with >35% Fe.
- Recovery falls off with saprolite ores.
- It is sensitive to mineral composition and requires careful mining and blending.

PAL PROCESS

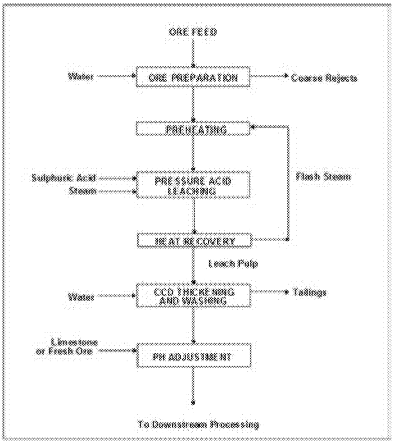
- The process is also not new. The first plant was commissioned by Freeport at Moa Nay, Cuba, in 1959. It was also taken over by the Cuban Government in 1960 and remains in operation today.
- The next major action was not until the development of the AMAX and Nical Processes in the 1970s and 1980s for the Prony Project in New Caledonia and the Gasquet Project in Northern California respectively. Neither reached commercialization due mainly to low nickel price.
- In fact there were no further commercial PAL operations till the 1990s when 3 plants were built in Western Australia, namely Bulong, Cawse & Murrin Murrin (Bulong & Cawse are now closed).

PAL PROCESS

- Since then, 5 PAL plants (not including the Ravensthorpe EPAL plant) have been constructed and are either operating or in commissioning; a further two are under construction.
- The main driving forces for the PAL projects include:

  - Increased nickel demand and higher price
  - Availability of numerous low grade laterite deposits
  - Higher energy efficiency and higher nickel and cobalt recoveries than the Caron Process
  - Longevity of the Moa Bay operation.
  - Successful commercial application of horizontal autoclaves and related facilities for pressure leaching of other ores such as gold and zinc.

TYPICAL PAL FLOWSHEET



CURRENT PAL INSTALLATIONS (EXCLUDING RAVENSTHORPE EPAL PLANT)

Plant	Country	Nickel (t/y)	Status
Moa Bay	Cuba	33,000	Operating
Murrin Murrin	Australia	40,000	Operating
Coral Bay	Philippines	20,000	Operating
Goro	New Caledonia	60,000	Operating
Ambatovy	Madagascar	60,000	Commissioning
Ramu	PNG	31,000	Commissioning
Taganito	Philippines	30,000	Construction
Gordes	Turkey	10,000	Construction

MURRIN MURRIN OPERATION, AUSTRALIA

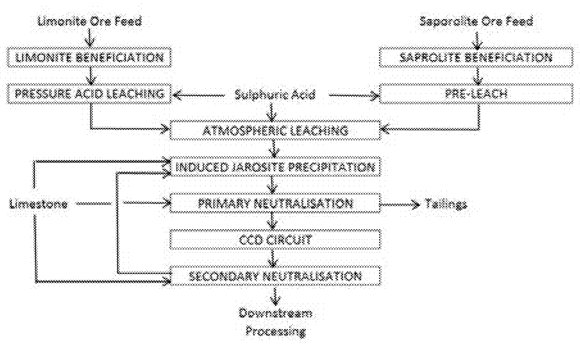
ISSUES WITH PAL PROCESS

- The capital cost is high.
- It has a high acid consumption for saprolitic ores with high magnesium content.
- The process conditions are highly corrosive.
- The maintenance cost is relatively high.
- Autoclave descaling and maintenance involves significant pant downtime.
- Sophisticated control/safety systems are needed.
- Downstream processing is complex.
- There has been a lengthy ramp-up time for the majority of projects.

EPAL PROCESS

- It was developed by BHP Billiton and installed at Ravensthorpe, Western Australia. Commissioning commenced in late 2007, and operation was suspended in early 2009, attributed to a fall in nickel price.
- It was acquired by First Quantum in Dec. 2009 and restarted after modifications, with commercial production achieved in late 2011.
- Limonite ore is treated by PAL and saprolite ore by atmospheric tank leaching.

EPAL PROCESS FLOWSHEET
(Ref: Ravensthorpe Presentation at ALTA 2005)



ISSUES WITH EPAL PROCESS

- It retains the disadvantages of PAL for the limonite ore portion of the flowsheet.
- It is relatively complex, with two different leach processes.

DEVELOPING PROCESSES USING SULPURIC ACID

- Pressure acid leaching (PAL) combined with atmospheric pressure agitated tank leaching (AL).
- Stand-alone atmospheric pressure agitated leaching tank (AL).
- Heap leaching (HL)

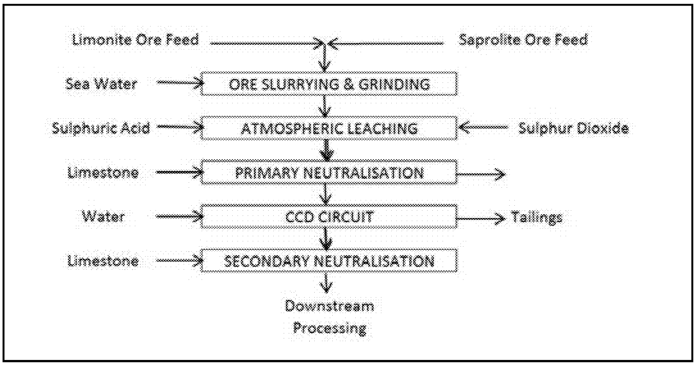
PAL COMBINED WITH AL

- These combine PAL for limonite with AL for saprolite in a parallel circuit and/or use saprolite to neutralize the residual acid from PAL.
- Objectives include:
  - treating the whole orebody
  - reducing the net acid consumption for saprolite
  - eliminating or reducing the limestone needed to neutralize residual acid from limonite PAL
  - reducing capital cost.
- It has been piloted by a number of companies as far back as AMAX and Nical in the 1970s, but not yet commercialized with the exception of EPAL.

STAND-ALONE AL

- Stand-alone AL has also been tested by a number organizations. A recent example is Eramet who have adopted AL for the Weda Bay Project in Indonesia.
- The advantage of stand-alone AL is the absence of a PAL circuit which should translate into capital cost savings, reduced down time and lower maintenance costs.
- However, this may be offset by increased sulphuric acid consumption.
- Higher acid consumptions lead to higher iron and other impurities to downstream processing.

PROPOSED WEDA BAY FLOWSHEET
(Ref: Eramet Paper at ALTA 2012)



ISSUES WITH AL

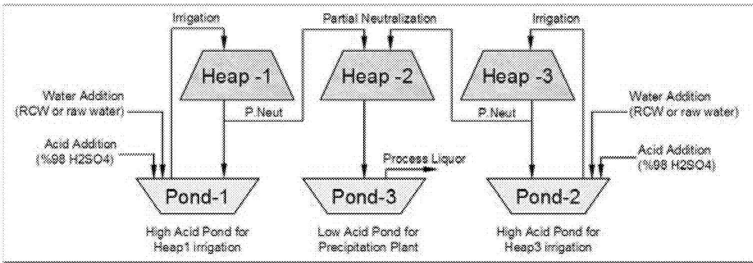
- It generally has a high acid consumption, especially for saprolite ore, leading to higher operating cost which offsets the saving in capital cost versus PAL.
- It produces high levels of iron and other impurities in the leach solution which makes downstream processing more challenging.
- It is generally less effective for leaching limonite ore and sulphur dioxide injection may be needed to achieve high cobalt extraction.
- It typically operates close to 100C so that expensive materials of construction are needed.

HEAP LEACHING

- Development work has been carried out by numerous organizations since the 1990’s, but no stand-alone commercial operation has yet been established.
- A commercial satellite operation treating grinding circuit scats was established in 2007 by Minara at Murrin Murrin in Western Australia. Fresh ore treatment was also successfully demonstrated, but is not currently practiced as it is said to be more profitable to send ore through the existing PAL circuit.
- A stand-alone HL demonstration plant was operated by European Nickel at Caldag in Turkey, in 2004; but the project was held up by permitting issues. It was sold in 2011 and is now owned by VTG Nikel of Turkey who are aiming for commercial operation.

CALDAG HL DEMONSTRATION PLANT
(Ref: European Nickel Paper at ALTA 2006)

CALDAG DEMONSTRATION PLANT HL FLOWSHEET
(Ref: European Nickel Paper at ALTA 2006)



ISSUES WITH HL

- Laterites frequently have a high fines content and agglomeration with a polymer is typically required.
- Heap stability is a problem, especially in high rainfall locations. High rainfall can also cause breakdown of agglomerates and cause dilution of the leach solution.
- It generally has a high acid consumption, especially for saprolite ore, leading to higher operating cost which offsets the saving in capital cost versus PAL.
- It typically produces higher levels of iron and other impurities in the leach solution than PAL, which makes downstream processing more difficult.

ISSUES WITH HL

- Heap leaching of limonite ore typically yields low recoveries.
- Decommissioning can be challenging especially at high rainfall sites.
- Environmental issues can be greater that for PAL or AL.

ADVANTAGES OF SULPHURIC ACID BASED LEACHING PROCESSES

Key advantages of sulphuric acid for leaching laterites include:

- It is the best known and most widely applied leaching reagent in the mining and metallurgical industry.
- it is widely available at moderate cost.
- It is commonly produced in the same industry – eg smelters.
- On-site production yields very useful energy.
- Intermediate products can be produced which significantly reduces cost and simplifies operation.

ISSUES WITH SULPHURIC ACID BASED PROCESSES

- Downstream processing is typically complex and is a major component of overall capital cost, especially if separate nickel and cobalt products are produced at site.
- The leach solution is generally dilute with regard to nickel and cobalt, which adversely affects capital and operating costs.
- The acid not regenerated and recycled.

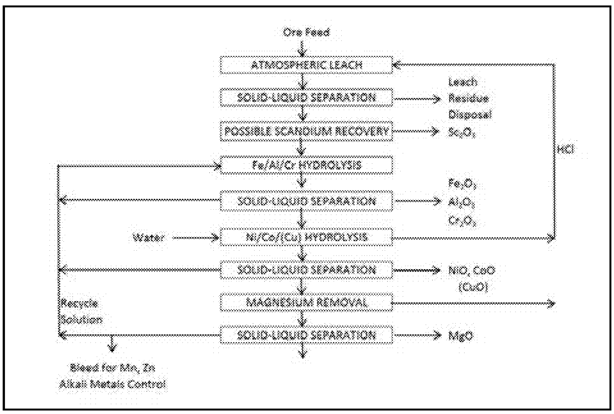
DEVELOPING PROCESSES USING CHLORIDE LEACHING SYSTEMS

- Chloride leaching processes for laterites have been tested by a number of organizations.
- Recent examples include Neomet in Canada, Anglo Research in South Africa, Nichromet in Canada, Process Research Ortech in Canada and SMS Siemag in Austria.
- There are no commercial plants for laterites as yet; however, there are a number of long established commercial operations refining nickel matte in chloride conditions.

POTENTIAL ADVANTAGES OF CHLORIDE LEACHING OF LATERITES

- It is an agitated tank leach at atmospheric pressure.
- It is applicable to both limonite and saprolite ores.
- It has lower capital and operating costs than PAL.
- Nickel and cobalt recoveries are high.
- The lixiviant is regenerated and recycled.
- Separation and recovery of nickel and cobalt products is comparatively straightforward and commercially proven methods are available.
- Secondary neutralization to remove residual iron is not needed.
- Solid/separation properties are superior to sulphuric acid processes.
- There are opportunities to recover saleable by-products.

NEOMET PROCESS FLOWSHEET
(Ref: Neomet Paper at ALTA 2011)



ISSUES WITH CHLORIDE SYSTEMS

- Chloride solutions are highly corrosive, especially at high temperatures.
- The handling of HCl vapours involves personnel safety issues.
- Depending on the overall water balance, there can be environmental problems due to the release of chloride containing solutions.

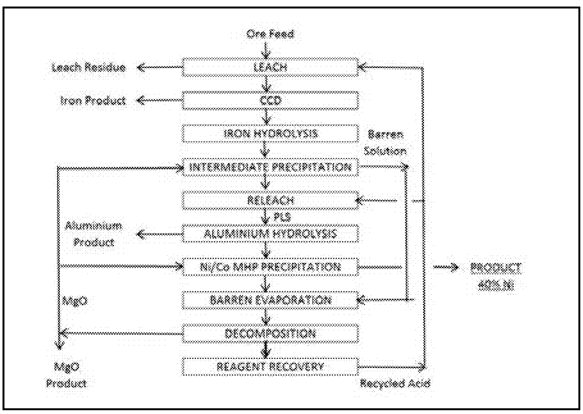
DEVELOPING PROCESSES USING NITRIC LEACHING SYSTEMS

- Nitric leaching systems have attracted limited interest for laterites.
- A recent example is the DNi Process being developed by Direct Nickel in Western Australia.
- There are no commercial plants as yet, however nitric systems have been used for other leaching and refining applications.

POTENTIAL ADVANTAGES OF NITRIC LEACHING OF LATERITES

- It is an agitated tank leach at atmospheric pressure.
- It is applicable to both limonite and saprolite ores.
- Lower capital and operating costs than PAL.
- Nickel and cobalt recoveries ate high.
- The lixiviant is regenerated and recycled .
- The is no secondary neutralization to remove residual iron.
- Solid/liquid separation properties are superior to sulphuric acid processes.
- There are opportunities to recover saleable by-products.

DNi PROCESS FLOWSHEET
(Ref: Direct Nickel Paper at ALTA 2011)



ISSUES WITH NITRIC SYSTEMS

- Nitric acid solutions are highly corrosive, especially at high temperatures.
- The handling of vapours involves personnel safety issues.
- Depending on the overall water balance, there can be environmental problems due to the release of chloride containing solutions.

SUMMARY OF PRESENT STATUS FOR PROCESSING OF LOW GRADE LATERITES

- PAL dominates for recent projects. No recent Caron plants have been built.
- AL is being pursued for a number of projects, but there are no stand-alone operations as yet.
- HL is still being pursued , though Interest has waned, and there are no stand-alone operations as yet.
- A number of chloride leaching processes are being developed, but there are no operations as yet.
- A nitric acid leaching system is being developed by Direct Nickel, but there is no commercial plant as yet.

THE IDEAL LATERITE PROCESS

- High recoveries of nickel and cobalt.
- Lower capex and opex than existing processes
- No initial drying and low overall energy requirement.
- Atmospheric pressure operation.
- Low net reagent consumption.
- Straight forward downstream processing.
- Ability to provide separate nickel and cobalt products.
- Potential for saleable by-products.
- Suitable for large and small projects.
- Low to moderate corrosivity.
- Low short and long term environmental impact.

The field is still wide open

There is <u>no clear winner</u> as yet

<u>Laterites are still a very much a frontier of nickel process development</u>

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