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Why heap leach nickel laterites?

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ABSTRACT

With the majority of nickel naturally occurring in laterite ores but the majority of production still in sulphides, it is high time there was a standalone commercial nickel laterite heap leach operation. The broad success of heap leaching of other metals has allowed hitherto uneconomic deposits to undergo successful economic exploitation, and heap leaching now accounts for at least one third of global copper and gold production. Nickel laterites are no different, every major and several junior nickel miners have evaluated nickel laterite heap leaching over the past decade and shown projects to have robust economics, with much lower capital costs than alternative hydrometallurgical options which have in general been dismal failures, both technically and commercially.

Nickel Laterite Heap leaching is simple and flexible, and can be applied to the many laterite deposits that currently have no realistic path to production.

This paper aims to review the current state of nickel laterite processing and aims to show that heap leaching of nickel laterites is a viable and economically attractive alternative.

1. Introduction – Global nickel laterite production

The world's resources of nickel are either sulphides or laterites and while almost ¾ of the world's resources of nickel are found as laterites, until 2009 less than half of the primary nickel production came from laterite sources as illustrated in Fig. 1.1 (Dalvi et al., 2004). This figure has been updated to 2009 production using data from Wood Mackenzie reviews.

Total production of nickel has increased more than 10-fold since 1950, when sulphides accounted for as much as 90% of the world's nickel, in 2009 laterites exceeded the 50% mark for the first time and in 2015 they are expected to account for two thirds of word production. According to Wood Mackenzie (2013) predictions 72% of world nickel will be from laterites by 2022 (see Fig. 1.2).

Laterite ores are divided into three main ore types which until now have largely been treated separately to recover the nickel within. It is however the conclusion of Alyssum Ventures Limited (AVL) and Brazilian Nickel Limited (BRN) after significant amounts of test work at different scales that all ore types could be treated without the need for any selective mining, by heap leaching. Fig. 1.3 was published by Brand et al. (1998) without the heap leach addition.

2. Recent nickel laterite projects

2.1. Existing state-of-the-art

Nickel laterites are currently processed with the exception of the hybrid Caron process by either a Pyrometallurgical or a Hydrometallurgical route.

Most pyrometallurgical routes (ferronickel and matte smelting) use a conventional flow sheet which includes steps for upgrading in the mine, drying, further upgrading, calcining/reduction and electric furnace smelting followed by either refining to produce a ferronickel product or converting to a low iron-containing matte.

Outside of China where there are 2 atmospheric leach project and a small heap leach the only operational hydrometallurgical processes are High Pressure Acid Leaching (HPAL).

2.2. Pyrometallurgical

For all pyrometallurgical nickel laterite operations the ore must meet quite specific criteria to result in a commercially attractive project.

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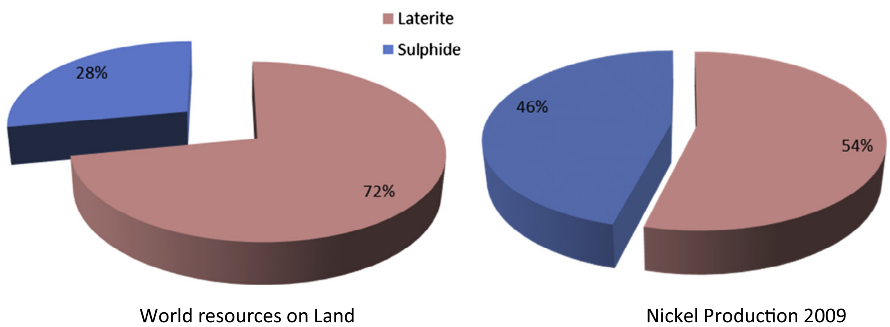

Fig. 1.1. Nickel resources and production; sulphide and laterite.

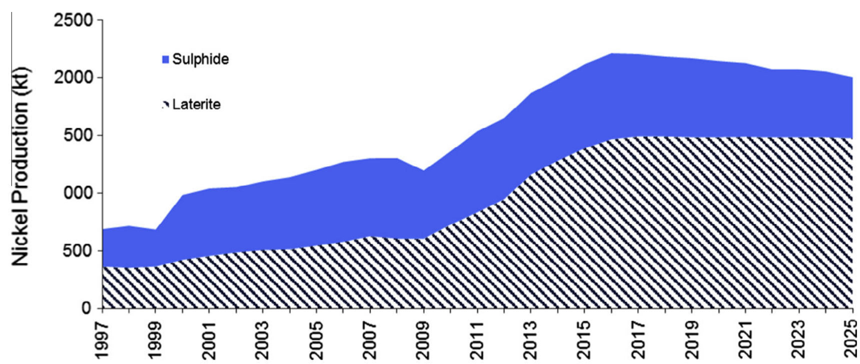

Fig. 1.2. Nickel production past and future predictions (Wood Mackenzie, 2013).

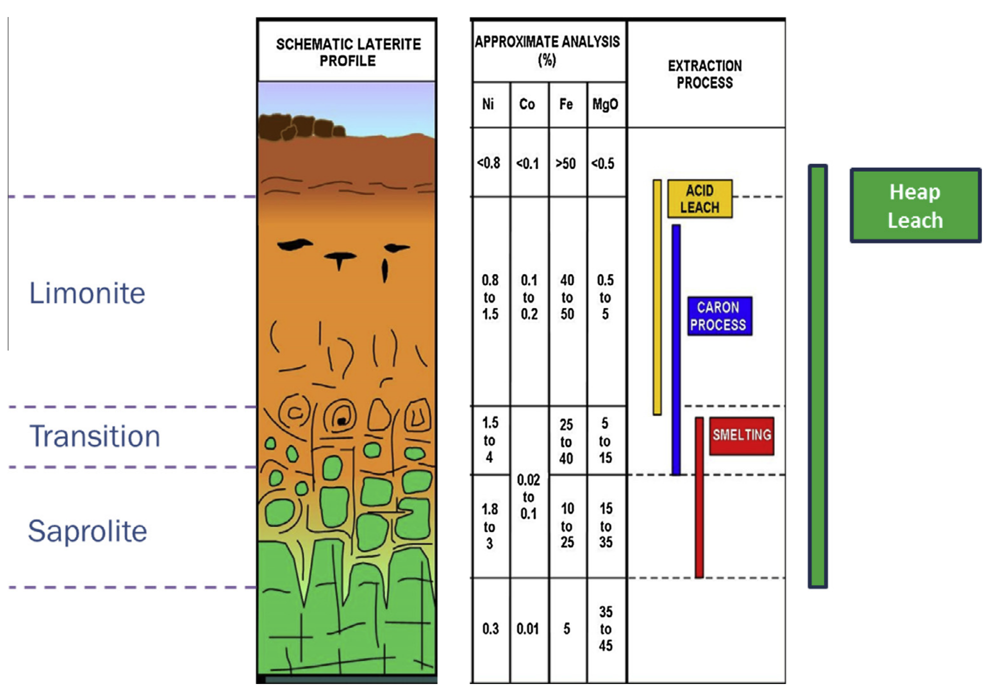

Fig. 1.3. Processing options for nickel laterites (Brand et al., 1998).

For both FeNi Pig Iron (NPI) and Ni matte smelters the ore must meet fixed requirements in terms of their Ni grade, Fe/Ni, Ni/Co and SiO_2/MgO ratios. These are typically a Fe/Ni ratio of 12, a Ni/Co ratio of 40 and a SiO_2/MgO ratio of 1.9 if these criteria are met then good recovery and good product grade can be obtained. These ratios can be extended but then the recovery and the product grade are much lower at similar operating costs resulting in non-profitable operations.

Ferro nickel smelters require Ni grades of typically over 1.8%, with initial grades >2% required for up to 5 years to enable capital payback. They also require Fe/Ni, Ni/Co and SiO_2/MgO ratios of <12, >30 and <1.9 respectively in order to be a commercially successful operation.

2.2.1. New ferro nickel smelters

In recent years there have been 3 major new Ferro-Nickel smelters. These projects have all experienced long delays in start-up and major cost overruns, these are illustrated in Figs. 2.1 and 2.2.

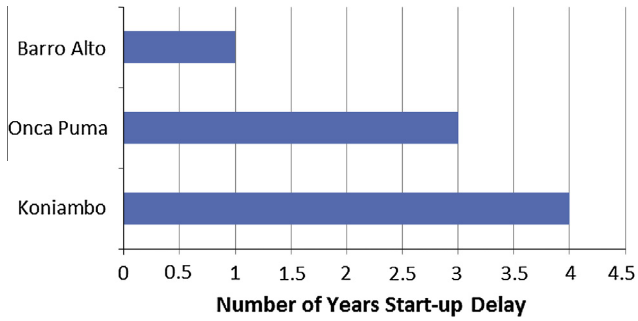

Fig. 2.1. Ferro nickel smelter start-up delays (source Wood Mackenzie).

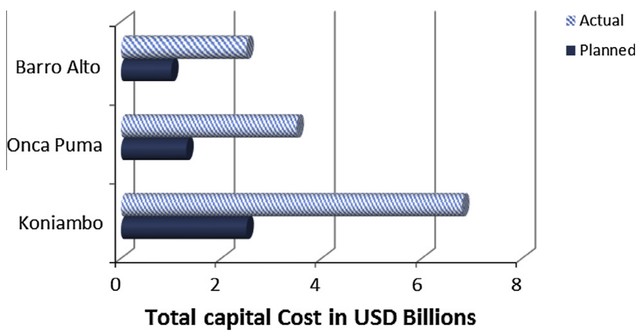

Fig. 2.2. Ferro nickel smelter planned and actual costs (source Wood Mackenzie and BRN).

2.2.1.1. Onca Puma. Vale's Onca Puma project is a 2 train RKEF ferro nickel smelter which began production in 2011 some 3 years later than originally planned. Within less than 9 months catastrophic failure of both furnaces resulted in a cessation of production at Onca Puma.

Vale decided to only rebuild one furnace thereby reducing the capacity of the operation to approximately 25,000 tonnes per annum. The single line re-opened in November 2013 and production in 2014 rose to 21.4 kt (Vale Annual Report, 2014).

Currently there are no plans to rebuild the 2nd train.

Total capex for the project including the rebuilding of one furnace was around USD 3.5 billion more than double that originally planned.

2.2.1.2. Barro Alto. Anglo American's Barro Alto project is also a 2 train RKEF ferro nickel smelter in Brazil. This project also began production in 2011, sadly the similarities to Onca Puma do not end here. As with Onca Puma both furnaces needed to undergo full rebuilds. The first furnace has completed its rebuild and is now operating again and work on line 2 commenced in October 2014.

Production in 2013 was 25.1 kt and in 2014 28.3 kt. Barro Alto suffered only a 1 year delay to initial start-up with the capex doubling to that originally planned (Anglo, 2014).

Full production will not be possible until 2016 at the earliest.

2.2.1.3. Koniambo. Glencore Xtrastra's Koniambo project (see Fig. 2.3) in New Caledonia commenced production in 2007 and it was 6 years later before the first metal tap was carried out. The first commercial grade FeNi was tapped just after this in April 2013 some 4 years later than planned.

This ferro nickel smelter uses innovative technology; the use of flash drying followed by fluid bed reduction and direct feed to a DC electric arc furnace has not been used in nickel production on a commercial scale previously and as such the commissioning process has been very slow.

Nickel production to date has been 1.4 kt in 2013 and 12.6 kt in 2014 (Glencore Production Report, 2014). 2014 figures are approximately half that planned in 2013. Full production of Koniambo is 60,000 tonnes but after Line 1 was closed down in December 2014 due to a metal leak and work continues to repair the line and with Line 2 having only just commenced commissioning in January 2015, the name plate capacity could be several years away yet.

Capex for project is now estimated well in excess of 6 Billion USD, which includes sustaining capex of 1.85 Billion over the last 2 years this is again more than double that planned.

2.3. Hydrometallurgical

2.3.1. High pressure acid leaching (HPAL)

With the exception of China to date the only commercially operating hydrometallurgical process is the HPAL.

In recent years 4 new HPAL projects have come into operation with varying degrees of success.

2.3.1.1. Ravensthorpe. Ravensthorpe in Western Australia was the first of the 4 planned operations to come online in 2008 but due to upgrading issues and the global economic crisis onset BHPBilliton decided to mothball the project after just 12 months. The project was sold to First Quantum (FQM) for just A$ 340 M and after spending a further A$ 370 M the project re-opened in 2011.

The plant has on the whole operated relatively successfully under First Quantum with production in 2014 of 37 kt (FQM Annual Report, 2014). In December 2014 there was a structural failure in one of the atmospheric leach tanks, repair of this is still ongoing resulting in a reduced production plan for 2015.

2.3.1.2. VNC Goro. Vale's Goro project – now Vale New Caledonia (VNC) should have originally commenced production long before Ravensthorpe but this was a project dogged by issues and construction was finally completed in 2010 some 6 years later than planned.

The project has undergone many more setbacks post production start, all of which are very well documented in the non-scientific press (SX pulse column failure, acid plant failure, circuit redesign and recent environmental spills) that have meant that this project has had a very poor ramp up with continuous production still very far from being stable.

Fig. 2.3. Koniambo ferro nickel smelter New Caledonia.

Table 2.1
AL projects.

Project	Location	Owner/partners	Remarks
Dutwa	Tanzania	African Eagle	Project shelved
Weda Bay	Halmahera Indonesia	Eramet	Investment decision postponed
Acoje	Philippines	ENK/DMCI	Stopped/shipping ore
Yerilla	Australia	Heron resources	Project on hold
Agata	Philipines	Mindoro resources	Project on hold/shipping ore

Total production in 2014 was 18.7 kt in an intermediate product (Vale, 2014). This is less than one third of the 58 ktpa name plate capacity.

2.3.1.3. Ambatovy. Sherritt International's Joint Ventures project Ambatovy commenced production in 2012 and seems to be having a smooth ramp up with 2014 production of 37 kt (Sherritt, 2014).

General consensus is that the ramp will continue with near name plate capacity being achieved within 4 years.

While production start was delayed by 2 years and capital costs have more than doubled Ambatovy appears now to be on track (see Table 2.1).

2.3.1.4. Ramu. Highland Pacific's joint venture with Chinese Metallurgical Group Corporation, Ramu, in Papua New Guinea began production in 2012 and the slow ramp up has been continuing with 2014 production reaching 20.9 kt (Highland Pacific, 2014), this is two-thirds of nameplate capacity. Ramu also had a significant delay in start-up and a capital double that originally forecasted.

2.3.2. Atmospheric tank leaching (AL)

The atmospheric tank leaching process takes saprolite or limonite ore which is then leached in a tank at elevated temperatures but at atmospheric pressure.

China now has 2 operating atmospheric tank leaching operations at Jianxi Lithium which currently produces 20 ktpa nickel and Yulin Wei which produces 10 ktpa nickel (Wood Mackenzie, 2013).

Outside of China there have been several studies conducted but as yet no commercial operations.

There have been many reviews of Hydrometallurgical process routes including those of Reid (2002), Taylor (2007, 2014), and Dry (2014, 2015).

All of the above projects both pyrometallurgical and hydrometallurgical have in common that they:

- Are highly complex.
- Have suffered long delays to the original schedules.
- Are long and slow to ramp up, often undergoing significant commissioning and ramp-up issues.
- Have capital costs significantly (more than double) higher than originally planned.

3. Heap leaching

In comparison to the above high complexity processes heap leaching is a simple delinked process that has a straight forward ramp up to steady state production.

Heap leaching is well established process used for the treatment of copper, gold and uranium and it is now being used in varying degrees by established companies such as Glencore (Minara and Xstrata), Vale, BHPB and Anglo American for nickel laterites.

The heap leach process has the potential to be the lowest capital cost and most environmentally friendly of the processes to recover nickel from laterite ores.

Nickel laterite heap leaching has been demonstrated over the past 10–20 years on a large scale by almost all major mining companies and several juniors.

- European Nickel (ENK) at its Çaldağ project leached >15,000 t ore.
- ENK at the Acoje project in the Philippines leached >5000 t ore.
- BHP Billiton at Cerro Matoso leached >20,000 t ore.
- Both Vale, Anglo American and Xstrata have conducted various testing with respect to heap leaching.

There are also two commercial operations

1. Glencore's Murrin Murrin where over 1.5 million tonnes of ore has been successfully leached in integration with the HPAL. The Heap leach is used a flexible add-on when part of the HPAL is undergoing maintenance or there are issues with the circuit.
2. Yuanjiang China which is a small standalone nickel heap leach which commenced production in 2007 and until the end of 2014 has produced approximately 10,000 tonnes of nickel contained in product.

Additionally the following (Table 3.1) stand-alone and integrated heap leach projects have been looked at in the past or are currently under study.

There is no requirement for specific ore characteristics to enable a successful leach, if the ore contains nickel at above cut-off grade then it can be stacked on the heap and leached.

4. Costs

Costs for nickel laterite heap leach projects from BRN's data base have been used to compare with recently completed industry projects. Table 4.1 summarizes the typical ranges of capital and operating costs for the 2 main operational process technologies and compares them with those for heap leaching.

The cost data for the none heap leach projects has been collated by BRN using published costs from both major nickel mining company annual reports and purchased industry studies.

Table 3.1
HL projects.

Project	Country	Owner	Estimated cost US$ millions	Planned nickel production kilo tonnes per annum (ktpa)	Capital intensity US $/lb Ni
Piauí	Brazil	Brazilian Nickel	450	22	9.28
NiWest	Australia	GME	400	14	12.75
Cerro Matoso	Colombia	BHPB	750	20	17.01
Çaldağ	Turkey	ENK	450	20	10.30
	Guatemala	BHPB	2550	79.5	14.55
Pearl	Indonesia	BHPB	800	32	11.11
Gag Island	Indonesia	BHPB	800	27.3	13.47
Cleopatra	USA	RFN	475	21.5	10.02
Acoje	Philippines	ENK	498	24.5	9.22

Table 4.1
Capital and operating costs.

Process technology	Typical capacity ktpa of Ni	CapEx US$/lb annual Ni capacity	OpEx US$/lb Ni
Smelting	18–60	24–45	2.20–4.00
HPAL/AL	10–60	21–70+	2.70–11.00
Heap Leach	10–60	9–15	2.20–3.00

The chart shown in Fig. 4.1 illustrates the order of magnitude less in capital intensity for a nickel heap leach project.

5. Sceptics perceived issues

For some reason there is some scepticism to nickel laterite heap leaching. The main areas of discussion are:

- New technology.
- No commercial operations.
- Laterites don't percolate/Laterites and clay.
- Low recovery.

The following section shall address each of these in turn.

5.1. New technology

The application of heap leaching technology to nickel laterites is often foreseen as a completely new technology whereas in practice it is simply the combination of well-known industry unit operations in turn using standard equipment and standard construction materials.

A standard block flow sheet of the process steps in a nickel laterite heap leach operation can be seen in Fig. 5.1.

5.1.1. Crushing

The purpose of the ore preparation area or crushing circuit is to receive, crush and stockpile the ore.

Knowhow is directly transferable from both other laterite operations and copper heap leach operations.

5.1.2. Agglomeration

Agglomeration aids but is not always essential to heap percolation and permeability throughout the life cycle of the heap cell.

Optimized agglomeration enhances leach cycle, improves initial leach characteristics, allows for taller heaps and helps to achieve higher extraction of nickel and other value metals.

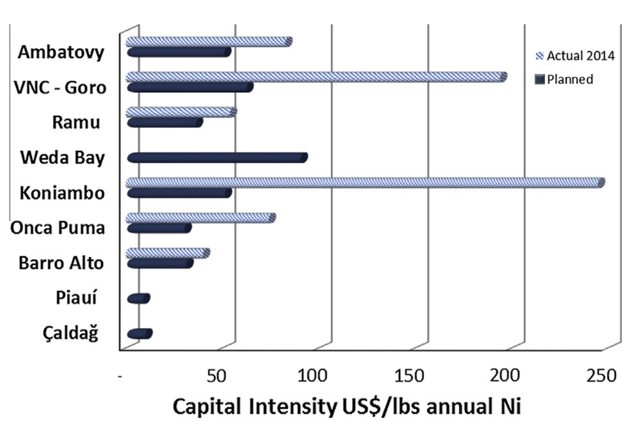

Fig. 4.1. Capital intensity of nickel laterite projects.

Know-how is transferable from other heap leach operations for copper, gold and uranium. Specific methods for the agglomeration of very fine laterites, e.g. those found in the Philippines is an industry best practice found during the extended periods of demonstration test work undertaken over the past decade.

5.1.3. Heap pad design and stacking

Heap leaching is a widely used process in copper, gold and uranium for the pad, heap and stacking design and is directly transferrable to nickel.

Selection of the most suitable heap method, heap design (stacking height, pad inclination, lining and compaction testing) and method of stacking and reclaiming is done on a project by project basis but using standard technologies. There are many similarities between the physical properties of nickel laterites and other copper and gold ores which allows the transfer of these technologies.

5.1.4. Irrigation

Irrigation systems are used in copper, gold and uranium and the design of these systems is directly transferrable to nickel. Little new know-how is required to operate the irrigation system for a nickel laterite heap leach. The irrigation rate is however key to a successful nickel laterite heap leach.

5.1.5. Leaching

Leaching is similar to other operations in copper and uranium but the know-how here is key to optimize the operation for a nickel laterite operation.

Correct selection of application rate and lixiviant acid strength allow selective leaching of nickel over iron and reduce acid consumption.

Correct selection of heap height results in good reaction kinetics, appropriate selectivity in the leach, suitable neutralisation capacity and effective permeability leading to the required longevity of the heap.

The know-how to optimize the leach has been derived from the extensive demonstration plant level test work completed by the BRN team.

5.1.6. Solution management

The knowledge base here is transferable from other heap leach operations in copper, gold and uranium and as a result of the demo work in nickel laterites. The key criteria is to be able to transfer solution from any heap cell to any pond to improve the flexibility of the operation.

5.1.7. Spent ore

Nickel laterite heap leaching is a destructive process and as such the most suitable method of heap leaching is via a dynamic (on/off) pad. Spent ore is simply removed as per other operational heap leaches and disposed of in the residue disposal area, in a nickel laterite heap leach most often it is co-disposed with the iron filter cake.

5.1.8. Downstream processing

The PLS is treated in a simple precipitation circuit. The equipment used is a series of standard agitated tanks, followed solid–liquid separation in thickeners and with products and waste products filtered and the final overflow returning to the heap leach circuit as process water make up.

All wastes for disposal are solid, with solutions being re-used.

5.1.9. Acid plant

Acid consumption in a nickel laterite heap leach is much higher than that seen in copper or uranium acid leaching. While this can be seen as a disadvantage by some the acid consumption in heap

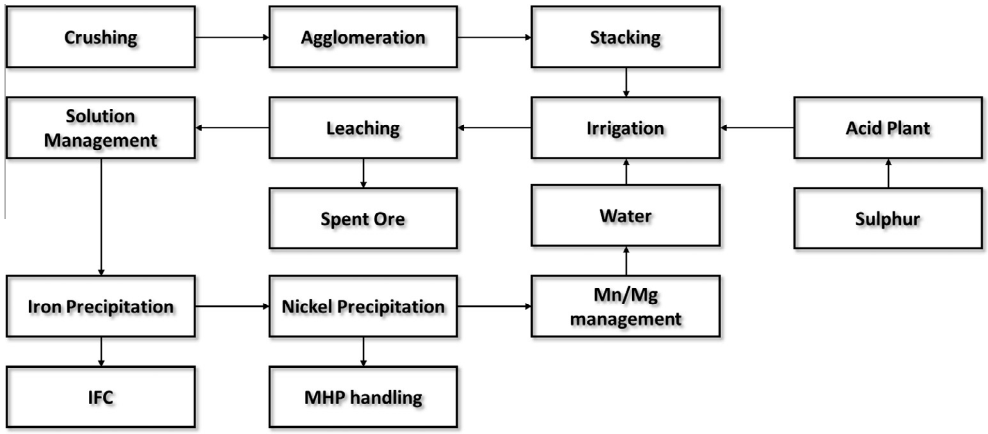

Fig. 5.1. Block flow sheet nickel laterite heap leach.

leaching, if the parameters are correctly managed, should be significantly less than AL and equal to or less than HPAL.

The higher acid consumption also leads to the construction of an on-site acid plant as part of the operation. This allows the transport of sulphur rather than acid in large quantities over often very large distances. Further the sulphur burning acid plant co-generates more than enough electricity to operate the HL operation and usually allows some sale of power back to the country grid. In remote areas where nickel laterites are often found this is an advantage both to the operation, giving it, at no additional cost, carbon free power and to the community which can have access to power that it may not previously have had.

5.2. No commercial operation

The integrated commercial heap leach operation at Murrin Murrin began as a demonstration heap in 2009 and has since been expanded to provide significant nickel. The heaps leached have consistently had recoveries in the region of 75% and performed beyond expectation. The capital required to expand the HL is significantly less than for any HPAL expansion for the same nickel output.

Further there is a small standalone Chinese nickel heap leach which began in 2007 in Yuanjiang operated by the Yunnan Tin Group. There is no public information available on this operation, but it produces 1000–2000 t of nickel a year (Wood Mackenzie, 2013).

It must also be noted that there are some 200+ other non-nickel heap leach operations worldwide that successfully operate.

5.3. Laterites don't percolate

All natural materials percolate to some extent.

The natural permeability of nickel laterite ores is similar or better than many copper heap leach projects and most nickel laterite ores have lower clay mineral content than other ores where heap leaching is successful.

Particularly difficult copper ores that are part of successful heap leach projects are BHPB's Spence project, Antofagasta's Michilla and El Tesoro projects and Ivan-Zar all in Chile, along with Tintaya and Cerro Verde in Peru.

Table 5.1 lists the number of tests undertaken and the results for the natural permeability of various heap leach ores and clearly shows that the average of nickel laterite tests completed has better permeability than reported in both copper and gold ores.

When the natural permeability is low or clay content is higher, agglomeration is use to improve the percolation in the heap.

Table 5.1
Permeability of heap leach ores.

Ore/location (# of tests)	Ave perm (cm/s)
Nickel	
37 samples from 5 sites	2×10^{-3}
Copper (operating heaps)	
Low quality ore, Peru (63)	6×10^{-4}
Good quality ore, Peru (30)	2×10^{-2}
Gold (operating heaps)	
Central America, saprolite (10)	7×10^{-4}
Brazil, saprolite (13)	9×10^{-3}

Various agglomeration agents can be used in this process with the perfect recipe found through test work on a project by project basis.

Fig. 5.2 shows the large agglomeration drum at the Spence Project in Chile which is 3.9 m diameter by 12 m long and has a throughput of 1492 tonnes per hour. Without this agglomeration process the heap leach at Spence would not be successful. The size of this agglomeration circuit demonstrates that even on this large scale successful agglomeration is possible.

5.4. Low recovery

Heap leaching treats the entire ore body, there is no need for specific chemical and/or mineralogical targets to be met. As such there is no selective mining and no blending necessary. Once mined a block is simply ore for the heap or waste, except in very rare circumstances where permeability could be an issue as experienced in some copper heap leach operations.

Typical extractions in the heap are in the range 72–85% with downstream nickel losses at around 5% therefore giving overall recovery of nickel in the range 68–81%.

Smelting and HPAL typically have recoveries of the target ore zone in the range 85–95%; however these process have a very specific target ore zone and therefore total resource recovery is normally in the range of 45–60%; significantly lower than that of a heap leach.

6. The ideal nickel laterite heap leach

While BRN is of the opinion that any nickel laterite is amenable to heap leaching, with the right agglomeration recipe and use of the best know-how in the leach there is of course an ideal nickel laterite for heap leaching.

Fig. 5.2. Agglomeration drum at spence in Chile.

That would have the following characteristics:

- A target resources of more than 50 Mt at >1.0% Ni and, >0.05% Co.
- In heap extraction >65%.
- A preference for a low ratio of limonite to saprolite.
- A local limestone supply.

Mineralogically

- High SiO_2 which in turn results in;
  - better heap stability and equipment support;
  - better permeability, agglomerate quality;
  - faster leach kinetics; and
  - lower acid consumption.
- Low Fe, Mg
  - lower acid consumption;
  - lower residue production;
  - better agglomerate durability; and
  - smaller precipitation and filtration plant.
- Low clay content
  - improved permeability, agglomerate quality;
  - taller heaps; and
  - lower liquid hold-up and therefore lower working capital.

Fig. 6.1 illustrates the difference in extraction and acid consumption when the "ideal" mineralogy is available. BRN's Piauí nickel project in NE Brazil has a high silica, low Mg, low Fe and very little clay and results in excellent recoveries at much lower acid consumption than many other nickel laterites that BRN has studied over the years.

Finally to complete the ideal project the location is crucial with siting factors being very important as for any other heap leach project.

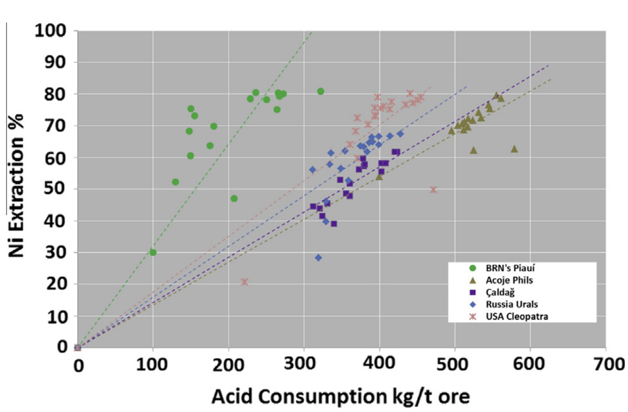

Fig. 6.1. Leach test results for various nickel laterites.

The key factors are:

- Climatic conditions:
  - Low rainfall.
  - No typhoons.
  - Warm.
- Topography:
  - Flat terrain.
  - Ample operational space.
- Environmental and social:
  - Non-sensitive environment.
  - Manageable underground water systems and water bodies in the surroundings.
  - Positive social impact.
  - Stakeholder support.
- Infrastructure:
  - Available choices of water.
  - Transport route choices and in-coming tonnage exceeds outgoing.
  - Port choices.
  - Net power producer after ramp-up.

7. Upside potential of process integration for existing facilities

While nickel laterite heap leach projects have low capital and operating costs and have very attractive and robust economics as stand-alone projects there is also significant upside potential for existing pyro and hydrometallurgical operations to improve their own economics by integration with a new heap leach operation.

Murrin Murrin added the HL circuit to compensate for the poor performance for the HPAL circuit. Murrin Murrin still utilises the HL when there are issues of performance with the HPAL, any expansion would most likely be through expansion of the HL rather than the HPAL as the capital is significantly lower for the same nickel output (Wedderburn, 2010).

There have been various FeNi smelter HL studies conducted in recent years including:

- Cerro Matoso, Colombia:
  - Status: Operating smelter, HL in development.
- Guatemala:
  - Status: FeNi/HL & HPAL/HL PFS completed.
- Brazil:
  - Status: FeNi/HL in early study.

An operating FeNi smelter taking an MHP or NHP feed from a heap leach operation would result in increased overall resources utilisation of approximately 30% up to a total of 80–85%.

Further improvements to circuit efficiency would result (Oxley and Barcza, 2012):

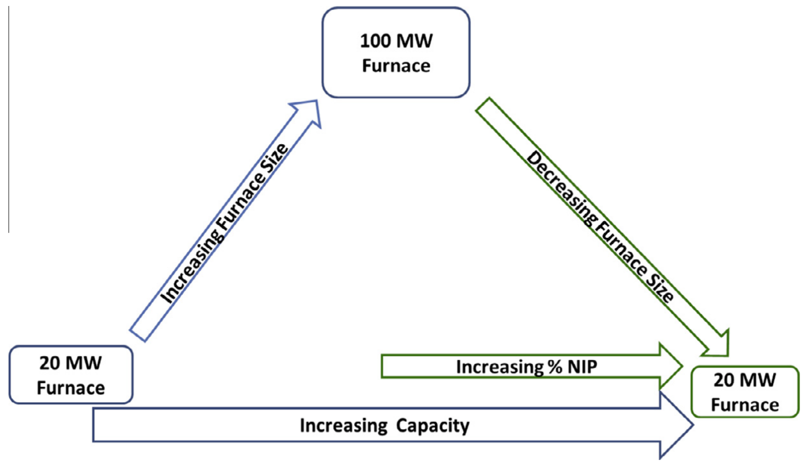

Fig. 7.1. Reduction in Furnace size with a HL intermediate (NIP) feed (Oxley and Barcza, 2012).

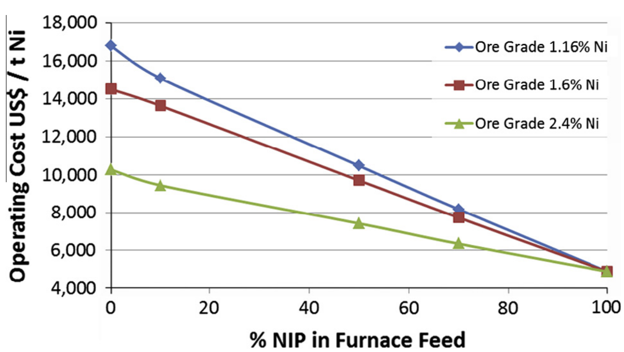

Fig. 7.2. Operating cost per tonne of nickel produced with increasing % NIP (Oxley and Barcza, 2012).

- Increased average grade to and recovery from FeNi or HPAL
  - Increased Ni production for existing plant.
  - Reduced plant cost for greenfield project.
- HL product (NHP) can be added to FeNi furnace:
  - Increases furnace efficiency (Fig. 7.1) and decreases size.
  - Increases NPV of HL circuit (no discount for selling intermediary product).

Additionally in an integrated circuit the economics are improved as follows:

- Reduced operating cost and energy consumption per tonne of Ni produced (Fig. 7.2).
- Increased cobalt production.
- Can reduce reliance on grid power.
- Can increase Ni grade in FeNi product, increasing market value.
- Reduced carbon emissions and reduced overall environmental impacts.
- Allows commercialisation of otherwise uneconomic deposits.

8. Conclusions

The heap leaching of nickel laterites either as a stand-alone project or integrated into an existing facility:

- Has lower costs.
- Has lower risk.
- Increases resource utilisation.
- Increases access to raw materials.
- Allows commercialisation of hitherto uneconomic resources.
- Results in environmental improvements per tonnes of nickel produced.

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