iStockphoto/RobertKacpura

A new direction for nickel

BY **DAVE SAMMUT**

A small Australian technology company is working to solve a looming problem in the world's nickel supply.

Metallurgy is a field of science that I love – incredibly diverse and elegantly simple. Scientists are searching for cheaper, cleaner and more thorough ways of extracting, recovering or recycling the vital metals that underpin advanced civilisation. One company at this cutting edge is Direct Nickel Limited.

A reluctant resource

Until recently, most of the world's nickel supply came from sulfide resources. However, economically exploitable sulfidic nickel resources are dwindling, so we are moving to the more metallurgically complex laterite ores, which constitute over 70% of known land-based resources.

Unlike sulfides, most laterites cannot be readily upgraded to high-grade concentrates (10–25% Ni) via froth flotation or other simple beneficiation techniques. So the efficient extraction and recovery of the nickel is necessarily more complex, and costs more per tonne of metal produced.

As with many mineral resources, nickel laterite deposits are usually layered, with an iron-rich limonite layer dominated by goethite (FeOOH), and an underlying saprolite layer that is magnesium rich. And a major problem is that the existing processes are

usually much better at treating one layer or the other, but not both.

The dominant pyrometallurgical process (smelting) works best for saprolites, usually by drying, calcining/reduction and electric furnace smelting. These processes usually produce either ferro-nickel (Fe–Ni metal for stainless steel production) or nickel sulfide matte, which is further processed and refined to produce pure metal. However, smelting requires high-grade ores and has substantial energy requirements.

Hydrometallurgy and the DNi process

Hydrometallurgy feels to me like truly classic chemistry, and I savour the ingenuity inherent to this field. Take as an example the brilliant deception of the Nazis by Hungarian chemist George de Hevesy. To prevent the Nazis stealing the gold Nobel Prizes of Max von Laue and James Franck, de Hevesy dissolved the gold medals in aqua regia, preserving the solution in a bottle left on his shelf at the Neils Bohr Institute in Denmark throughout the Second World War, and afterwards recovering the gold for re-smelting of the medals.

The principles in hydrometallurgy have a wonderful simplicity. Atmospheric leaching starts with equipment as straightforward as a tank with an agitator. Toss in the electrolyte, the ore or concentrate and some acid, and wait for the witch's brew to stew.

In nickel hydrometallurgy, the acid is the key – both for performance and economics. Previous attempts at commercial laterite processing have failed because of uneconomic consumption of acid, particularly as the sulfuric acid used by most technologies is not regenerated or recycled. The high magnesium content in saprolite laterites results in high sulfuric acid consumption – up to 500 kilograms per tonne of ore.

The elegance of Direct Nickel's DNi process is the use of nitric acid – it is much more aggressive than sulfuric, so it eliminates long leach times or high temperatures and pressures. And it is almost wholly recyclable – net nitric acid consumption rates are as low as 40 kilograms per tonne of ore (albeit at three times the price of sulfuric). Based on its current flowsheet, Direct Nickel's early estimates of capital and operating costs suggest figures in the bottom quartile of the nickel laterite processing industry.

Using nitric acid, the DNi process can leach both the saprolite and limonite, and the feedstocks can be either separate or mixed. The nickel (and cobalt) having been extracted into solution, the waste residue is then filtered, washed and disposed. Co-dissolved iron is then directly hydrolysed to hematite, which is an advantage over jarosite-producing processes, because hematite is pretty much as environmentally stable as any iron residue can get.

The pH of the 'pregnant' electrolyte is then raised using recycled MgO, first to precipitate contaminant aluminium that has co-leached with the iron and nickel, and then to recover a nickel–cobalt mixed hydroxide precipitate as an industry-standard intermediate product for sale.

The barren magnesium nitrate solution is evaporated to a monohydrate solid, which is then thermally decomposed from molten salt to produce MgO (mostly for sale, with some being recycled) and nitric acid/NO_x vapours are sent to a series of absorbers and scrubbers for recovery of nitric acid.

The devil is in the detail

Of course, simple schematics are usually quite a long way from the reality of a plant as built. One of the key challenges in commercialising new hydrometallurgical technologies over the last few decades has been the complexity of the various systems that need to be applied around the core chemical process.

Put simply, leaching is often the easy part. But the stronger the lixiviant (liquid used to extract the desired metal), the less selective the leaching process, and the larger and more complex the systems required for handling co-leached contaminants.

Stronger lixiviants, higher temperatures and higher pressures also require more advanced materials of construction. For the DNi process, the atmospheric leaching and comparatively low temperature (about 100°C) mean that 304 and 316 stainless steel should be sufficient. However, nitric acid is more corrosive than sulfuric. While the steel should be passivated (made less vulnerable to environmental factors) by nitric acid, the long-term performance of materials is not as well proven as for the more ubiquitous sulfuric processes.

As an aside, chloride hydrometallurgical systems are more aggressive still, and it is sometimes joked that 316 stainless is so named because that is how many seconds it would last in a chloride leach.

While filtering and washing solid–liquid slurries is easy enough in the

The elegance of Direct Nickel's DNi process is the use of nitric acid – it is much more aggressive than sulfuric, so it eliminates long leach times or high temperatures and pressures.

lab, the loss of entrained electrolyte with waste residues can be a big-ticket item in minerals processing, from both an economic and an environmental perspective. As it scales up its process, Direct Nickel has been paying due attention to the potential loss of nitrates with its residues at the end of the leach.

On top of that, the DNi Process requires high temperature and gas systems for the $MgNO_3$ decomposition and conversion of NO_x back to nitric acid. This will increase complexity against simpler atmospheric leaching processes and introduce specific safety issues that need to be addressed. None of these problems is by any means intractable, but they all require specific engineering focus, and they all add to the cost of a developing project.

The production of an intermediate mixed hydroxide generates appreciably less value per tonne of nickel in product than metal, but has the advantage of limiting the complexity in the system. Perceived technical risk is a major factor when trying to secure finance for a new technology project, so this is probably a good choice until the DNi Process is more thoroughly proven.

These complexities are at least part of the reason why the road to commercialisation for new minerals processes is so very long ...

Beyond the technology

These complexities are at least part of the reason why the road to commercialisation for new minerals processes is so very long, and why so many concepts that look great on paper fail to make it through to commercial application.

Nickel laterites usually occur in regions where prolonged weathering of ultramafic rocks has occurred; many of the known deposits occur within or close to the tropics. Iron oxides are responsible for the rust red colour typical of most laterites, as seen around this river in New Caledonia. Nickel mining forms a significant sector of New Caledonia's economy.

Implementing a new minerals project takes four major factors: a really good technology, the simpler to execute the better; secure access to a specific feedstock over the full course of time to implement the critical first project (the minerals industry has a tendency to 'rush to be second'); enough finance to develop the technology (DNi has already spent $40 million to get this far) and then to implement a project running into the hundreds of millions of dollars in capital costs; and perhaps just as importantly, the dogged tenacity to hang on through every setback along the way.

Although having started by licensing partially developed technology from Drinkard Metallox in late 2006, and having put in place critical new patents for the nitric acid recycling technology around the same time, Direct Nickel is only now running its first major pilot plant. This is pretty normal for developing hydrometallurgical processes.

Direct Nickel has been intelligent in its approach. It has achieved buy-in from key experts in the field of hydrometallurgy to collaborate in the difficult process of commercialising technology – most notably CSIRO Minerals and Teck Resources, but more recently also PT Antam, Indonesia's largest nickel producer.

The company's one tonne per day pilot plant at CSIRO's Perth facility kicked off over the first quarter of 2013. Direct Nickel announced milestone success in mid-July, with the production of its first marketable nickel–cobalt concentrate from a ten-day continuous campaign treating Indonesian laterite feed containing 25% limonite and 75% saprolite.

Dr Dave Robinson of CSIRO expanded upon this to speak of the success in solid–liquid separation and residue washing results, which help maximise acid recycling efficiency, noting that these results have actually improved on the scale-up from the lab to the pilot plant. Operations at the

The DNi process pilot plant at CSIRO's Perth facility is scheduled to continue operations through to the end of 2013.

plant are scheduled to continue to the end of 2013.

As noted by Richard Carlton, chief operating officer of Direct Nickel, 'nickel and particularly laterites have a stigma to them so anyone claiming to have a solution is viewed with scepticism. This extends to making it difficult to raise funds, made worse by the tough state of global financial markets over the last few years. Partnering with reputable strategic partners including Teck Resources Limited, PT Antam and CSIRO has been an important boost to the credibility of the DNi efforts to introduce this new process.'

Carlton indicated the company's aim to be constructing an associated first plant during 2015, for operation by 2018.

This timing to commercialise new technology points to a major flaw in international intellectual property systems. Development and implementation of any new minerals technology can easily take 20 years, and almost never less than ten. Even if a company has the commitment and resources to bring its new technology to market, by the time it has done so the 20-year protection of its ideas is already nearing its expiry, except to the extent that the company can 'evergreen' the developments in its technology over the course of development.

There is no question that Direct Nickel has a great technology, and that its collaboration with CSIRO significantly enhances its chances of success. But the inertia of industry, the challenge of competing against sunk capital, and the conservatism of finance in the face of huge investment requirements all remain huge hurdles to taking promising technology over the line. I wish the team every success.

Robinson emphasises the wide range of opportunities for hydrometallurgy based on recycled nitric acid, and the additional opportunities for value-adding by upgrading those processes to produce finished products rather than intermediates.

As hydrometallurgists, we share a vision of clean, efficient metals production. And as eternal optimists, for us the bucket is always half full.

Dave Sammut MRACI CChem is Principal at DCS Technical Pty Ltd. DCS Technical has no affiliation with Direct Nickel.