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► SUMMARY

POX – The green way forward for Base Metals? Part 2

The mining industry is facing many challenges – rapidly declining grades, increasing geological complexities, and concerns about green metal production are just a few of them. With the recent push to decarbonise the world creating enduring demand for base metals, the industry needs to look for more efficient and sustainable treatment processes in order to remain competitive in a more environmentally conscious world. Technological advancements in hydrometallurgy have allowed for the processing route to extract and recover valuable metals economically and in an environmentally friendly way. Pressure leaching/oxidation (POX), in particular, has many great benefits as it can treat large throughputs of complex ores while releasing little to no toxic pollutants into the environment.

In the previous insight series Part 1, we looked into the origins of the POX process. In Part 2, we will discuss how POX is used and opportunities in the base metals industry.

Is POX the solution for increasingly complex copper ores?

In the copper industry, pressure oxidation approaches have been mainly explored for primary sulphides such as chalcopyrite to treat concentrate products, especially when the copper grade is too low or too variable for pyrometallurgical processes, or when deleterious elements (i.e., arsenic) make concentrates unmarketable.

While over the last decades there have been few cases of POX in copper, they were mostly done under similar conditions to those in gold (~3 MPa, 200-250°C). Current examples are the POX facilities at Kansanshi (30 kt/y Cu), and the treatment of copper-containing pyrite concentrate at Sepon (80 kt/y Cu).

Recent developments are mainly looking at POX for dealing with high arsenic concentrates. Ecometales, a subsidiary of Codelco, started developing a copper concentrate leaching project (PLCC) seeking to utilise idle capacity of SXEW facilities at Codelco's Distrito Norte to recover copper from concentrates with high levels of arsenic.

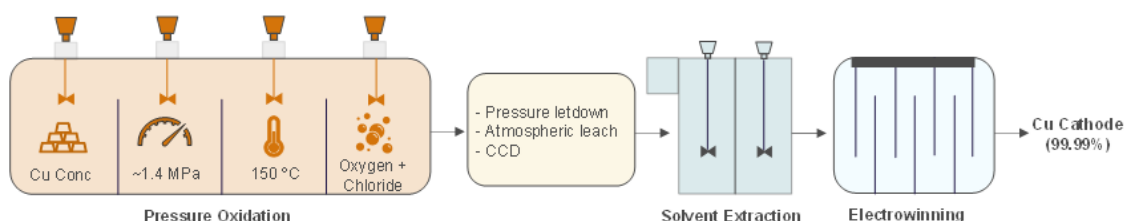
Ecometales' process has low water consumption and emits no arsenic or sulphur dioxide emissions. Arsenic residue is processed to a stable form (scorodite) while the acid generated can be used for heap leaching. The technology relies on a high pressure and temperature autoclave (2.8 MPa and 220 °C) as well as a thickener for separating the copper-rich solution from the solid arsenic-rich component. In the second stage of development, the technology will also allow for the recovery of gold and silver. Codelco expects to revert its deficit in treatment capacity of high-impurity concentrates, with estimated 200,000 t/y processing capacity, >95% recoveries, and around 60,000 tonnes per year of additional copper production. The project has an estimated Capex of \$324 M.

Although commercial developments for copper are largely of high pressure and temperature, medium pressure and temperature processes (~1.2 MPa, ~150° C) have also been applied in operations like Freeport's Bagdad and Morenci.

Currently, one of the most developed technologies in this area is Teck's CESL Copper Process. The process follows the typical POX route through medium pressure and temperature (1.4 MPa, 150° C) to leach sulphide concentrates in the presence of chloride and oxygen. The use of chloride in the autoclave helps to increase the reaction rate and reduce the oxidation of sulphur, which decreases operating costs. The pregnant leach solution (PLS) resulting from the pressure oxidation and subsequent stages is then passed through conventional SXEW treatment to produce LME Grade A copper cathode (99.99% Cu).

The technology was tested between 2008 and 2010 by Vale in Carajas, Brazil, where a 10 kt/y industrial scale leach plant was constructed to process local copper concentrates. No real difficulties or major design changes were identified during the operation.

Figure 4: The CESL process uses medium pressure-temperature to leach sulphide concs



DATA: CRU, Teck Resources

Despite the promising results of POX in the copper industry, this technology is also competing against other emerging large-scale primary sulphides leaching processes.

Antofagasta is developing a technology, Cuprochlor-T, which uses chloride leaching. The ore is agglomerated through the use of a leach solution containing chloride salts and sulphuric acid, which forms a paste that can be heap leached. By raising the temperature of the heap to 30 °C, the technology can recover copper from primary sulphides such as chalcopyrite. Cuprochlor-T is currently being tested at Centinela, Chile, through a 40,000-tonne heap of primary sulphides, where results are showing >70% recovery after ~200 days of leaching.

Meanwhile, Jetti Resources is working on a novel catalytic approach that can break the sulphur metal bonds in low-grade primary sulphides through the use of bio leaching in heaps and stockpiles. The technology has received funding amounting to more than \$50 M from some of the majors including Freeport and BHP. It also recently started being evaluated in Teck's copper assets, where if successful, it could start being implemented commercially. The approach is said to have low Capex and Opex, along with lower water usage and lower emissions, and it can be easily integrated within existing plants.

Antofagasta's Cuprochlor-T and Jetti Resources' technology are moving ahead in what appears to be a ground-breaking event for copper beneficiation – obtaining cathodes directly from chalcopyrite and bornite, which would otherwise require costlier, energy intensive, and more pollutant pyrometallurgical treatments.

It is clear, however, that POX may be a competing alternative to pyrometallurgical routes for handling complex copper concentrates. Among its many advantages, POX can:

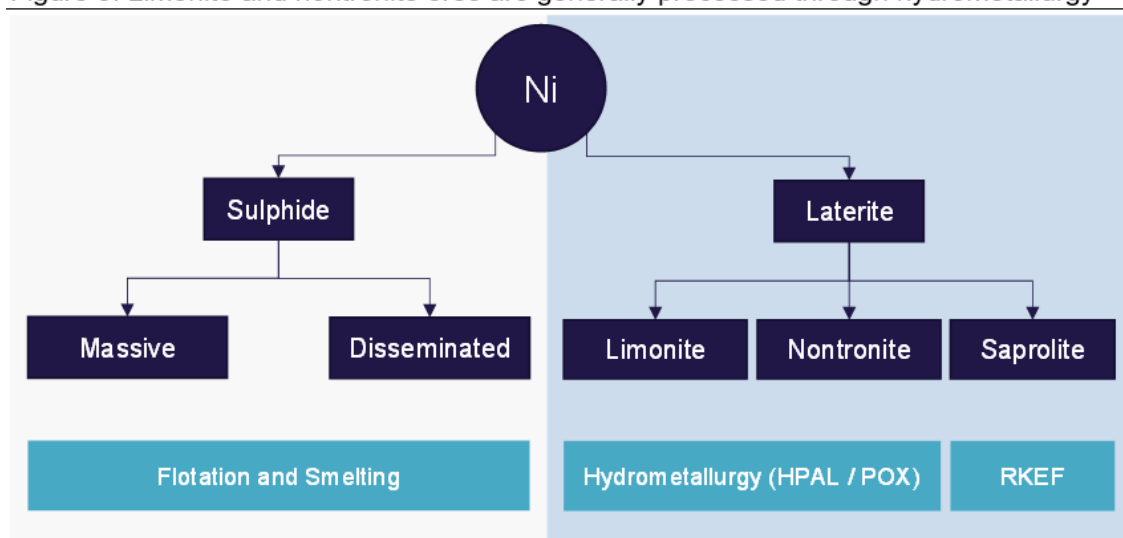
- Offer an on-site solution to produce copper cathodes, lowering freight costs and by-passing the marketing stage of the concentrate value chain
- Lower water usage and avoid dispersion of toxic contaminants as they are produced in solution, compared to polluting gases produced in traditional smelting and refining
- Reduce the cost of purchasing sulphuric acid, as it is produced in solution and can then be sold as a by-product, or used for heap leaching if it is part of the flowsheet

Nevertheless, for hydrometallurgical alternatives to be considered viable and challenge the conventional pyrometallurgical processes, they not only need to be cost competitive (by successfully recovering high purity copper from concentrates, as well as by-products), but they also need to be implemented using environmentally-friendly modern separation techniques, including the safe treatment of deleterious elements.

The need for battery metals has greatly renewed interest of pressure leaching for nickel laterites treatment

When it comes to nickel, the type of ore plays a major role for processing route selection. Nickel is extracted from two types of ore: sulphide and laterite. Laterites can be further split to saprolite, nontronite (smectite), and limonite. The key differences between them are the average content of nickel, iron, and magnesia. Saprolite ores are most commonly treated by pyrometallurgy since the high amounts of acid required to leach the high levels of magnesia (5-35% of magnesium) make hydrometallurgical processes too costly. Therefore, it is low grade limonite and smectite ores that are generally treated through pressure leaching.

Figure 5: Limonite and nontronite ores are generally processed through hydrometallurgy



DATA: CRU, Nickel Institute

High pressure acid leach (HPAL) has massively grown in popularity for the treatment of low grade limonite and smectite nickel ores. There are already a growing number of HPAL plants under construction (GEM at IMIP, Huayou at Weda Bay) or waiting permission to be constructed (PT Vale Pomalaa in Indonesia). First used at Moa Bay in 1961, the technology produces a form of nickel precipitate – in the case of Moa Bay, it is a mixed sulphide precipitate (MSP). These precipitates can be further processed to produce Class 1 nickel and high-grade cobalt. Although both HPAL and POX are hydrometallurgical processes used in nickel, they operate under different conditions and are used for different nickel products:

- HPAL treats low grade laterite ores at ~255° C and 4.5 MPa.
- POX is primarily used to process nickel concentrates from sulphide ores at ~210° C and 2 MPa. However, POX can process other nickel intermediate products, such as matte and mixed precipitates.

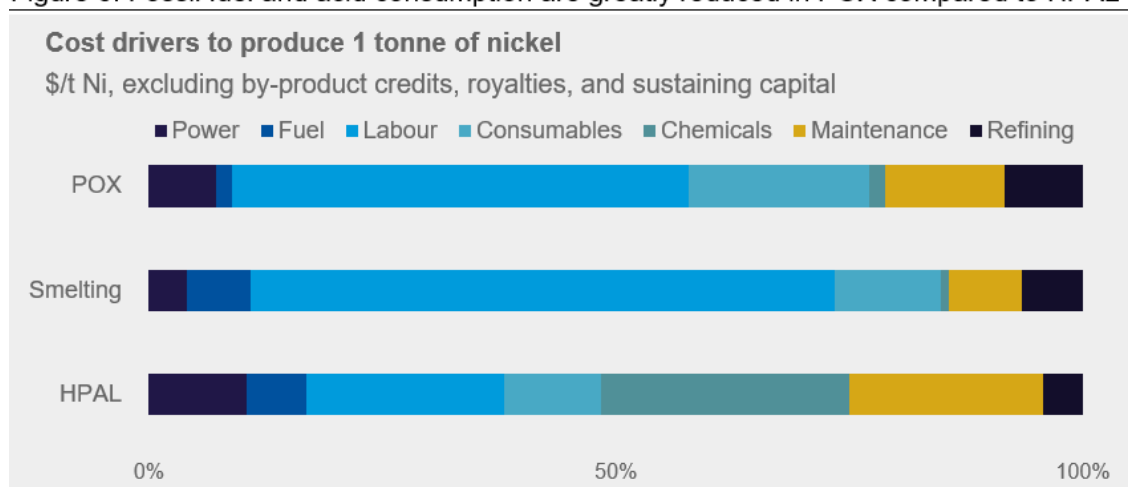
One of the strong advantages of all hydrometallurgical solutions over pyrometallurgy is their lower carbon footprint. Pressure oxidative leach of nickel sulphide concentrates shows more than 30% of carbon reduction when compared to traditional concentrate smelting and refining. The fossil fuel dependency for hydrometallurgy is up to seven times lower than smelting. Meanwhile, fuel consumption required to roast the sulphide concentrates and the coal used to agitate the smelting process have significant carbon footprint, and account for ~50% of total emissions of the pyrometallurgical processing route.

When it comes to hydrometallurgical treatment of laterites, the main cost drivers are high acid and power consumption, and neutralising agents. Our estimates show that, by stripping off the costs of refining cobalt, the total conversion costs (excluding by-product credits, sustaining capital, and royalties) for producing nickel pyrometallurgically is ~30% higher than the hydrometallurgy treatment.

Additionally, our cost comparison between POX vs HPAL vs Smelting & Refining also showed that, overall, conversion costs of HPAL are the highest. This is due to HPAL typically consuming significantly more sulphuric acid in addition to 3x more power and ~10x more fuel consumption compared to POX. In terms of capital intensity, both HPAL and POX are more expensive than a traditional pyrometallurgical setting. However, we have not seen new nickel sulphide smelters coming online. Instead, old ones being refurbished. For the new potential nickel concentrates coming from North America, POX seems like the right solution and a good trade-off between Capex, Opex, and emissions wins.

For the reasons mentioned above, the emissions footprint of HPAL processing is also the highest of all three routes. However, it is important to mention that the average feedstock of HPAL autoclave is also of much lower nickel grade than a sulphide POX autoclave – 1% Ni for laterites versus 1.7% Ni for sulphides.

Figure 6: Fossil fuel and acid consumption are greatly reduced in POX compared to HPAL



DATA: CRU's Cost Model

But with growing concerns on climate risks, the carbon footprint of 'green metals' has become increasingly relevant for EV producers. Battery makers face growing pressure to take accountability in reducing GHG emissions by sourcing sustainably and responsibly produced metals. Furthermore, with tightening supply on Class 1 nickel and growing robust demand in the battery sector, it might become very popular for battery producers to seek long term sourcing arrangements directly with miners. This would incentivise the integration of their supply chains and mitigate shortage and delay risks.

We are already seeing examples of this. Chinese battery materials manufacturer CNGR engaged itself to make nickel matte in Indonesia to secure its nickel supply. GEM, another Chinese battery metals producer, has signed a contract with Lygend's Obi HPAL plant in Indonesia to guarantee its supply while it also invested in a HPAL plant in Indonesia at Morowali Industrial Park. If the HPAL plants in Indonesia prove to be economically and environmentally viable, we are likely to see a strong supply growth in the technology.

Outside of Indonesia, we see several projects planning to use hydrometallurgical processes for the treatment of sulphide and laterite ores. Interestingly, these projects are estimated to produce on average only ~25% of nickel metal of what a typical NPI project would (25-40 kt Ni vs 150-200 kt Ni).

The main challenge for the nickel market is that ~70% of the world's nickel is estimated to be in laterite reserves. If the world wants to shift away from highly contaminant metal production, renewable powered hydrometallurgical processes might be a solution.

The uptake of pressure leaching lies in four key themes

One of the most profound lessons that the end of the last price supercycle left for the mining industry was cost control, which, while allowing the industry to survive in tough times, also reduced incentives to adopt new technologies.

Stakeholders pressure, higher cash availability, and the rapid deployment of new technologies have opened up the miners' mindset to assess new processes. At the same time, growing geological complexities, concerns about green metal production, and expectations of increased long-term demand for many base metals have driven producers to

modernise their mining and processing practices in order to extract and recover valuable metals economically and sustainably. Although we do not see hydrometallurgy taking over conventional pyrometallurgical processes – at least not in the next few decades – we see it gaining traction in the near future due to its flexibility and environmental benefits.

To keep its competitiveness in a more environmentally aware world, the industry should naturally move towards more efficient and sustainable treatment processes. Given the many attributes that POX has in this regard, we believe that for this technology to increase its adoption in the copper, nickel, and other base metals industries, the following four drivers would be crucial in the medium-term:

Figure 8: More complex ores, vertical integration, and renewables are key for POX adoption



Complex sulphide ores and concentrates with high toxic elements become more prevalent, requiring environmentally-friendly processing to remove impurities.



Pressure for vertical integration increases from battery producers as they seek to reduce their risks along the supply chain and secure key raw material inputs from clean sources.



The push to remain competitive in a more environmentally-demanding world intensifies, allowing for adoption of cleaner alternative onsite processes.



Growth of renewable power surges – further supporting emissions-free metal production from power-intensive hydrometallurgical process.

DATA: CRU

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