Processing of Nickel Ores & Concentrates '10
Falmouth Beach Hotel, Falmouth, UK, June 17-18, 2010

Sponsored by:

Thursday 17th June

09.15 *Opening Remarks*
J. Wills (MEI, UK) and N.O. Lotter (Xstrata Process Support, Canada)

09.30 *Technical Session 1*
Chairmen: T. Norgate (CSIRO, Australia) and İ. Girgin (Hacettepe University,Turkey)

09.30 **Reductive dissolution of ferric iron minerals: a new approach for bioprocessing nickel laterites**
K.B. Hallberg, B.M. Grail, D.B. Johnson (Bangor University, UK) and C. du Plessis (BHP Billiton, Australia)

Oxidative bioprocessing of sulfidic ores and concentrates to recover metals has developed into a thriving area of biotechnology, known generically as "biomining". Significant reserves of some metals also occur in oxidized (ferric iron) ores, such as nickel laterites. We have used bacteria to catalyse the reductive dissolution of goethite (the major nickel host mineral in ferric iron limonitic laterites) and thereby liberate the associated nickel. *Acidithiobacillus ferrooxidans*, which can grow in the absence of oxygen using elemental sulphur as electron donor and ferric iron as electron acceptor, was used to bioprocess representative ore in an anaerobic bioreactor under conditions of controlled pH and temperature. Over 70% of the nickel present in the ore was solubilised within 14 days from <6 mm crushed ore limonite with a low nickel grade of 0.5%. The acidic (pH 1.7) conditions at which tests were carried out caused the nickel to remain in solution. The results suggest that biological processing of nickel laterites is technically feasible and, more generically, that reductive dissolution can be used to bioprocess oxidized mineral ores.

10.00 **Selective reduction and sulphidation of nickeliferous laterites**
C. Harris, J. Peacey and C.A. Pickles (Queen's University, Canada)

Processing of nickeliferous laterites to produce nickel metal is process and energy intensive. Since most laterites are found in less developed regions, capital costs for infrastructure can exceed those for the process. The low temperature sulphidation of lateritic ores to produce an intermediate nickel concentrate for further processing offers a potentially lower energy and simpler alternative. The sulphidation of nickeliferous lateritic ores was investigated over a range of temperatures and conditions. A DTA/TGA with mass spectrometer was used to elucidate reaction mechanisms and determine reaction kinetics, and a combination of electron microprobe and high resolution scanning electron microscope were used to characterize the reaction products.

10.30 Coffee

11.15 **Assessing the sustainability of nickel laterite processing**
T. Norgate and S. Jahanshahi (Minerals Down Under National Research Flagship, CSIRO, Australia)

While currently accounting for only about 40% of world nickel production, laterite processing is expected to grow significantly in the future in order to balance the long-term supply of nickel as production from sulphide ores falls off.

Given this anticipated expansion in nickel laterite processing, it is important that the various processing routes for nickel laterite ores, both existing and proposed, be assessed from a sustainability point of view. To this end, a number of hydrometallurgical and pyrometallurgical processing routes for nickel laterite ores were assessed using life cycle assessment (LCA) methodology, focussing in the first instance on energy consumption and greenhouse gas emissions.

The processing routes assessed were:

- hydrometallurgical – high pressure acid leach, enhanced pressure acid leach, atmospheric leach, heap leach;
- pyrometallurgical – ferronickel process;
- combined hydrometallurgical/pyrometallurgical – Caron process.

The results of this study are presented in the paper, including a comparison of the various processing routes.

11.45 **Reductive leaching of nickel laterite**
G. Senanayake, J. Childs and A. Winn (Parker Centre, Murdoch University, Australia)

The reductive leaching of nickel laterite has attracted renewed interest of many researchers due to the enhanced leaching kinetics of nickel and cobalt in the presence of acids and reducing agents and the application of reducing agents in atmospheric, pressure or heap leaching processes. Systematic studies based on chemical species, potential-pH diagrams and measured rate data based on synthetic oxides and natural ores can shed light on the reaction mechanism which leads to investigate beneficial reagents for further studies. This paper describes a comparative study of metal leaching from synthetic goethite and laterite ores to shed light on the role of reducing agents in acid or alkaline media. Results are rationalised on the basis of the effect of speciation, chemical reactivity of mixed oxide systems and heterogeneous kinetic models.

12.15 **Rheological behaviour of nickel laterite smectite ore slurries**
G.K. Das, N. Kelly and D.M. Muir (CSIRO Process Science and Engineering (Minerals), Australia)

The characterisation and rheology of several nickel laterite (nontronite-rich) smectite ores and pure minerals are compared to assess the effect of mineralogy and particle size on the rheology of the pulps. Studies have been carried out with smectite ores in the presence of pure goethite, maghemite, hematite, talc, kaolin and magnesite. A vane viscometer was used to determine the pulp density that gave an optimum yield stress of 100 Pa for pumping slurries. In general, smectite ores exhibit poor rheological behaviour in comparison with goethite < kaolin < talc < hematite < maghemite < magnesite and the finer fractions were more viscous than the coarser fractions. Blending smectite ores with other minerals improves the optimum yield stress by up to 5% w/w.

A good linear correlation was found between the viscosity and the settling density of laterite ores which provides a simple measure of predicting the rheological behaviour of slurries. The variation in the viscosity of laterite ores depends largely on the mineralogy and the particle size distribution. However, the correlation of surface area with rheology was a poor fit.

12.45 Lunch

14.00 *Technical Session 2*
Chairmen: C. Harris (Queen's University, Canada)

14.00 **Dissolution behaviour of a Turkish lateritic nickel ore**
İ. Girgin, A. Obut and A. Üçyildiz (Hacettepe University,Turkey)

The atmospheric pressure sulphuric acid leaching characteristics of Adatepe (Eskişehir-Turkey) laterite ore that has recently been put into operation was investigated. The effects of sulphuric acid concentration (5-95%), temperature (20-95°C) and time (30-240 minutes) on leaching were determined by nickel, iron and arsenic analyses. The amounts of Ni, Fe and As in solution were observed to increase with the increase of temperature from 25°C to 70°C for sulphuric acid concentrations between 5 to 95%. Further increase of temperature to 95°C showed that the dissolution of Ni, Fe and As were increased until 60% sulphuric acid concentration and over 60% a decrease in the dissolution behaviour was observed. Experimental results showed that maximum nickel dissolution of 99.2% at 95°C could be reached in 120 minutes leaching time for a sulphuric acid concentration of 60%. The congruency of Ni dissolution with respect to Fe was investigated and Fe was found to be as congruent over about 25% Ni and 20% Fe dissolution values at 95°C. The causes of the discrepancy in nickel and iron dissolution and the lowering in the dissolution values over sulphuric acid concentrations of 60% at 95°C are being investigated considering the mineralogical composition of the ore and the leaching conditions.

14.30 **An update on the application of MRT to separations of interest in the nickel and cobalt industry**
S.R. Izatt, N.E. Izatt, R.L. Bruening and J.B. Dale (IBC Advanced Technologies, Inc., USA)

IBC Advanced Technologies' Molecular Recognition Technology (MRT) SuperLig® products, selectively and rapidly binds with target metal ions to remove them from solution. The MRT process can produce a high purity separation product of maximum added value at low cost. This paper provides a review of some examples of applications for MRT related to nickel and cobalt processing streams

including recovery of Ni and Co from PAL streams and removal of minor contaminants from cobalt processing streams.

15.00 **Isasmelt™ TSL – applications for nickel**
M.L. Bakker, S. Nikolic, A.S. Burrows (Xstrata Technology, Australia), and P.J. Mackey (PJ Mackey Technology Inc., Canada)

The ISASMELT™ process is top submerged lance (TSL) bath smelting technology which has been developed and optimised over the last 25 years. By the end of 2011, the total installed capacity of the ISASMELT™ technology will exceed 9,000,000 tonnes per year of feed materials in copper and lead smelters around the world. The technology is equally effective for smelting nickel sulfide concentrates, converting nickel mattes, and producing ferronickel from lateritic ores. This paper demonstrates how the features that make ISASMELT™ attractive for copper and lead smelting may be equally applied to nickel smelting and converting operations. Conceptual flowsheets are presented supported by results from recent pilot plant and bench-scale testwork.

15.30 Coffee

Friday 18th June

09.15 *Technical Session 3*
Chairmen: A. Barnes (Xstrata Process Support, Canada) and B. Lumsden (Ausmetec, Australia)

09.15 **The effect of changes in iron endpoint during Peirce-Smith converting on matte mineralization**
E.L. Thyse, G. Akdogan (University of Stellenbosch, South Africa) and J.J. Eksteen (Lonmin, South Africa)

Nickel-copper sulphide matte is blown to an iron endpoint during Pierce-Smith conversion (PSC). The matte is granulated after conversion and the process can be described as fast cooling. The effect of changes in iron endpoint on matte mineralization is poorly understood. It was postulated that small changes in the iron endpoint have significant effects on the relative abundance and mineral chemistry of the constituent mineralized phases in the converter matte. The primary objective was therefore to quantify the mineralogy and basic mineral chemistry (and relate to iron endpoint) directly from actual production samples and a multi-step mass reduction procedure was followed in line with sampling theory. A combination of macro-physical, chemical and mineralogical techniques was applied to study the matte characteristics as a function of iron endpoint.

Representative samples of granulated converter matte of different iron endpoints were mounted in resin, ground and polished to section the matte particles for detailed characterisation using optical microscopy and phase specific analyses by scanning electron microscopy (SEM), transmission electron microscopy (TEM), electron microprobe (EMP) and quantitative X-ray diffractometry (QXRD). Converter matte samples studied for the iron endpoints for 5.17 wt% Fe, 0.99 wt% Fe and 0.15 wt% Fe were dominated by a matrix of the major phases of nickel sulphide (heazlewoodite – Ni_3S_2) and copper sulphide (chalcocite – Cu_2S). The relative abundance of the base metal alloy phase (Ni-Cu alloy) which houses most of the platinum group elements varies significantly from 0.62 wt% to 13.82 wt% for 5.17 wt% Fe and 0.15 wt% Fe endpoints respectively. Scanning electron and transmission electron microscopy also confirmed the sub-ordinate presence of worm-like shaped base metal alloy phases for 5.17% Fe endpoint with a nickel content of 48.1 wt% and 53.3 wt%, Cu content of 6.38 wt% and 5.5 wt%, platinum content of 12.71 wt% and 19.5 wt% respectively.

09.45 **Endpoint control in PGM-containing nickel matte converting using flame emission spectroscopy**
G.A. Bezuidenhout, J.J. Eksteen (Lonmin, South Africa) and W. Wendt (SemTech Metallurgy AB, Sweden)

Flame emission spectroscopy has been shown to be feasible for endpoint control during the converting of copper mattes. This paper investigates the role of the endpoint in nickel matte converting in the platinum group metals (PGM) industry with respect to downstream processing. A number of economic factors are associated with the choice of endpoint. Moreover, the performance of a SemTech ® optical spectroscopy sensor in detecting leading indicator trace species is evaluated to infer the Peirce Smith converter endpoint. The particular implementation challenges in a nickel matte converting environment are discussed, where the desired endpoint is difficult to detect compared to copper matte converting. An evaluation of the impact of the endpoint on the Base Metal Refinery (BMR) was done. Theoretical modelling of the thermochemistry and phase equilibria was performed using the FactSage ® thermodynamic equilibrium modeling software. The data was validated with actual plant data. The impacts on the quality of the matte (from a BMR perspective), environmental and safety aspects and smelter economics were also investigated.

10.15 **Modelling matte droplet formation in Ni-Cu matte smelting furnaces from chromite rich concentrates and slag-matte heat transfer**
J.J. Eksteen (Lonmin, South Africa)

The formation, coalescence and growth of matte droplets in a concentate bed and through a laminar stirred slag layer are still very poorly understood. This paper attempts to develop a phenomenological model to predict average matte droplet sizes and matte hold-up in the slag volume in Ni-Cu smelting furnaces. The matte settling and heat transfer from slag to matte are subsequently modelled for the predicted matte droplet sizes in order to predict matte temperatures. It has been found that predicted matte temperatures fall within the range of temperatures the initial and final matte tapped during a single tap. The predicted matte hold-up corresponds with published results. While this model does not yet take into consideration all the heat transfer phenomena in the concentrate bed and the role micro-arcing on matte temperatures at deep immersions, it does provide a proper foundation for further modelling of droplet formation and heat transfer.

High matte temperatures are often experienced and are particularly problematic in the smelting of Cr_2O_3-rich concentrates found in the South African PGM industry. The slag temperatures are

significantly higher than in traditional Ni-Cu matte smelting (1600 - 1650 °C) and matte temperatures exceeding 1500 °C and up to 1600 °C are experienced in the industry. At these temperatures matte becomes extremely aggressive towards slag freeze linings and refractory tap blocks due to its high heat transfer rates and its ability to sulphidise some refractories above 1500 °C.

It has been found that the %matte fall, the true oxide FeO / Fe_2O_3 content of the feed blend to the furnace, the slag depth and flux additions all have significant impacts on matte droplet sizes, matte temperatures, and matte hold-up in slag, via the impacts on physical properties, in particular interfacial tension and viscosity. The role of concentrate chemistry and mineralogy is therefore crucial to maintain furnace integrity and availability.

10.45 Coffee

11.30 **CFD modelling of the role of electrode immersion and hearth power density on the flow and thermal profiles and particle suspension in a round AC 3-electrode furnaces for Ni-Cu matte smelting in the PGM industry**

S. Ritchie, J. Nell (Hatch Africa, South Africa) and J.J. Eksteen (Lonmin, South Africa)

The thermal profiles inside alternating current 3 electrode round furnaces are of paramount importance in establishing heat fluxes to the slag freeze linings and intensive copper coolers, the concentrate layer and the matte pool. Of equal significance are the flow profiles (the distribution of 3 D velocity vectors) within the 3 dimensional slag volume, to understand the quality of mixing in various zones within the slag and to establish the percentage dead volume in the slag layer. The slag velocities in the dead volume region is not sufficient to fluidise / suspend insoluble solids in the slag layer, such as chromite spinel minerals found in the South African platinum group metals (PGM) containing concentrate derived from the UG2 chromatite reef. The UG2 reef has replaced the Merensky reef as the most predominant PGM rich reef to be processed in South Africa. While the chromite solubility in smelting slags depends on slag chemistry, these spinels typically reach a solubility limit in slag at 1600 °C when the Cr_2O_3 concentration in concentrates exceeds circa 1.8%. The only way to efficiently smelt high chromite concentrates, other than reductive smelting or reducing the Cr_2O_3 at the concentrator, is to provide sufficient stirring in the slag volume. This will prevent settling and consolidation of the chromite particles, so that the chromites can be removed at the same rate with slag tapping as it enters the furnace via the concentrate bed.

This paper investigates the role of hearth power density (in kW/m^2) and electrode immersion on the flow and thermal profiles and show that certain immersion and hearth power density combinations lead to severe dead volume formation which, in turn, lead to chromite settling and consolidation into a so-called “mushy layer”, a 3-phase suspension of slag, chromite and significant quantities of matte. The hold-up of matte in high reaches of the slag volume can lead to catastrophic attack of freeze linings and copper cooling elements leading to failure of the furnace and significant downtimes as well as major safety risks. It has been shown that an immersion-hearth power density operating regime at which Lonmin operated for a couple of months significantly contributed to a major matte runout event experienced 2009. The CFD modelling results has subsequently aided in selecting appropriate immersion-hearth power density combinations to prevent mushy layer formation.

This paper continues earlier CFD modelling done by JJ Bezuidenhout and JJ Eksteen in 2008, of which the results have been published in a number of accredited journals.

12.00 **Nickeliferous pyrrhotite – “waste or resource?”**

E. Peek, A. Barnes (Xstrata Process Support, Canada) and A. Tuzun (Xstrata Nickel, Canada)

Currently nickel producers are keeping a close eye on both economic and production developments at the Talvivaara open pit mines and their bio-heap-leach operations located in Finland. The concept of open pit mining combined with heap leaching is a popular concept in the copper industry and practiced on oxidized copper ore bodies with less than 1% Cu. In general, this process consumes large quantities of sulphuric acid when based on oxide mineralogy. Talvivaara is processing very low-grade, but complex Ni, Zn, Cu sulphide ore (0.27% Ni, 0.57% Zn and 0.14%Cu). Its full contained metal value at 70% base metal recovery is estimated at 40-50 USD/MT ore using “long-term” metal prices (all elements). Low-grade complex disseminated nickel sulphide ore bodies are fairly abundant, but in general not yet economically treatable through the conventional mine-mill-smelter route

In the Sudbury basin of Ontario there is a vast resource of ~0.8% Ni bearing pyrrhotite tailings, which has been disposed off in shallow lakes. The estimated full contained metal value at 70% nickel recovery from pyrrhotite is estimated at 90-100 USD/MT using the same long-term metal prices as for Talvivaara. Supply of sulphuric acid is abundant from smelter operations in the basin. There are, in addition, many other low-grade ore bodies where nickel-bearing pyrrhotite, with or without pentlandite exsolution flames, is readily available. This commercial context raises the question whether Ni-bearing pyrrhotite is a sustainable resource.

In this paper the historical context behind pyrrhotite processing in the Sudbury area is provided. Flow sheet design considerations based on both technical and economic factors are reviewed with the objective of providing the nickel industry with the tools for informed decision-making on the possibilities for exploitation of this low-grade nickel sulphide resource.

12.30 Lunch

14.00 *Technical Session 4*
Chairman: N.O. Lotter (Xstrata Process Support, Canada)

14.00 **Process diagnosis using quantitative mineralogy**
L. Kormos, J. Oliveira, N.O. Lotter, D. Fragomeni and E. Whiteman (Xstrata Process Support, Canada)

Process diagnosis, flowsheet design and optimisation are most effectively and efficiently achieved through the use of metallurgical testwork combined with more modern quantitative mineralogical techniques. Integration of the mineralogical data in testwork programs provides a resolution that cannot be obtained from assays alone and can direct the flow of work to result in optimized conditions more accurately than would otherwise be possible. At Xstrata Process Support (XPS), QEMSCAN (Quantitative Evaluation of Materials by Scanning Electron Microscope) and EPMA (Electron Probe Micro Analyser) information can be employed to diagnose specific issues in a plant or laboratory scale test and are routinely combined with other metallurgical data sets to benchmark performance, design and optimise flowsheets. Representative sampling protocols for orebodies, plant or test products, the use of geometallurgical unit classification, high confidence metallurgical test programs and concentrator sampling audits (*Benchmark Surveys*) are key components of the strategy. Two case studies from Xstrata Nickel's Raglan Concentrator in Quebec and Nickel Rim South Mine in Sudbury are described to show how the use of quantitative mineralogy was used to benchmark plant performance, and how mineralogical data can be integrated into metallurgical programs to assist mineral processing engineers to design and optimise flowsheets.

14.30 **Magnetic conditioning of pentlandite flotation**
D. Zoetbrood (Xstrata Nickel, Australia), P Vass and B. Lumsden (Ausmetec, Australia)

Magnetic conditioning of flotation feed has been shown to increase the flotation recovery of fine paramagnetic minerals. Previous published work has been undertaken on the well-known paramagnetic minerals of copper (chalcopyrite and bornite) and zinc (iron containing sphalerite). The paramagnetism of pentlandite is not widely published, but the testwork presented here shows that magnetic conditioning of pentlandite flotation feed gave a statistically significant increase in nickel recovery. One interesting aspect of the work was that this increase in fine nickel recovery was selective for nickel, despite the ore containing significant quantities of other paramagnetic minerals, primarily pyrrhotite. The increase in nickel recovery in the rougher circuit was similar in a massive sulfide ore and in a disseminated ore. Another interesting aspect of some of the testwork was that only the tail could be sampled automatically and so an ON-OFF test was undertaken where the effectiveness of the process was determined by analysing the proportion of <20μm nickel in the tail.

15.00 **Treatment of nickel-containing wastewater by sulfate-reducing bacteria with rice chaff as immobilized carrier**
H.R. Li et al (State Key Laboratory of Biochemical Engineering, Institute of Process Engineering, China)

A sulfate-reducing bacteria was screened from the activated sludge. Complete rice chaff、3mm-6mm size of the gravel and 4mm diameter of the alginate - calcium chloride were used to make immobilized carrier respectively. Comparative study for treating nickel-containing waste water was carried out using an immobilized column which was filled with immobilized bacteria. According to the experiments, the immobilized column using rice chaff as carrier had a short start-up time and a better treatment effect for removal of nickel ions in the waste water. So the rice chaff was used as carrier for further experiment. Experimental results showed that the nickel removal rate of the immobilized column can reach 95% within 70 days with the concentration of Ni^{2+} is 100mg/L under the conditions as follows: 31□、pH=7.The immobilized column was penetrated until the concentration and volume of the liquid feed were increased to 400mg/L and 20mL/d, the nickel removal rate was lower than 40%.This study showed that the use of sulfate-reducing bacteria with rice chaff as the immobilized carrier in treating with heavy metal-containing wastewater have many advantages: low cost、high efficiency、good application prospects.

15.30 Closing Remarks
N.O. Lotter (Xstrata Process Support, Canada) and A.J. Wills (MEI, UK)