

ISASMELT™ TSL – MAKING A SPLASH FOR NICKEL

*M.L. Bakker¹, G.R.F. Alvear¹, M.Kreuh²

Keywords: top submerged lance, nickel sulfides, smelting, converting

¹ Xstrata Technology, Level 4, 307 Queen Street, Brisbane, 4000, Australia
(*Corresponding author: mbakker@xstratatech.com.au)

² Xstrata Nickel Canada, Longyear Road, Falconbridge, POM 1S0, Canada

ABSTRACT

The ISASMELT™ process is top submerged lance (TSL) bath smelting technology. The technology has been developed over the last 25 years and currently treats more than 6,000,000 tonnes per year of feed materials in copper and lead smelters around the world. What is less well known is that the technology is equally effective for smelting nickel sulfide concentrates, and converting nickel mattes. This paper demonstrates how the features that make ISASMELT™ attractive for copper and lead smelting can be equally applied to nickel smelting and converting operations. Conceptual flowsheets are presented supported by results from recent pilot plant campaigns.

INTRODUCTION

The introduction of lance technology has enabled the use of stationary furnaces with simple design and very high reaction rates. The prior art involved the injection of gases into liquid slags or mattes predominantly through tuyeres, with inherent design complications and refractory problems. The top submerged lance (TSL) bath smelting technology was developed to commercial success at the Mount Isa smelting complex in Australia in the early 1990's, and subsequently called "ISASMELT™". Development of the process has focussed on smelting of lead and copper concentrates or secondaries over the last 30 years and currently commercial ISASMELT™ furnaces operated by Xstrata and external licensees have a combined annual smelting capacity exceeding 6,000,000 tonnes of feed.

THE ISASMELT™ PROCESS

ISASMELT™ technology is based on the use of a simple furnace design which is readily enclosed to eliminate emissions to the surrounding environment. It uses submerged lance injection technology to provide highly efficient mixing and reaction of feed materials in a molten slag bath. The use of advanced process control systems results in the furnace operation being largely automated. Being a vertical furnace, a very small footprint of floor space is required to accommodate the plant and so it can generally be easily retro-fitted into existing smelters to either augment or replace existing technology. The process concept is shown in Figure 1.

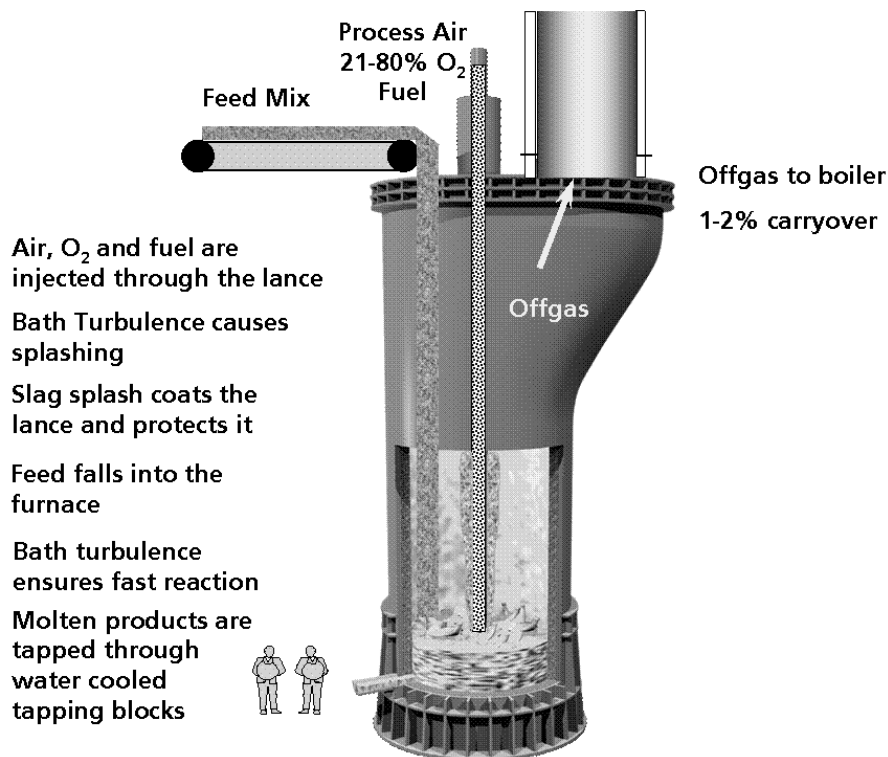


Figure 1 - ISASMELT™ Process Concept

During 30 years developing and operating submerged lance technology on large scale plants, significant technical improvements have occurred in areas such as furnace design, feed preparation systems, offgas handling, operating and process control strategies, refractory management and operator training. The combined experience led to what is well recognised by the marketplace today as the “ISASMELT™ technology package”, a technology package licensed to external clients [1]. Many of the improvements implemented by plant operators have been passed on to, and adopted by, other licensees. Exchange of ideas and technical improvements occurs through ad hoc visits to fellow licensee sites and through regular licensee workshops arranged by Xstrata Technology (XT). Figure 2 shows the location of the commercial plants that have been licensed to date.

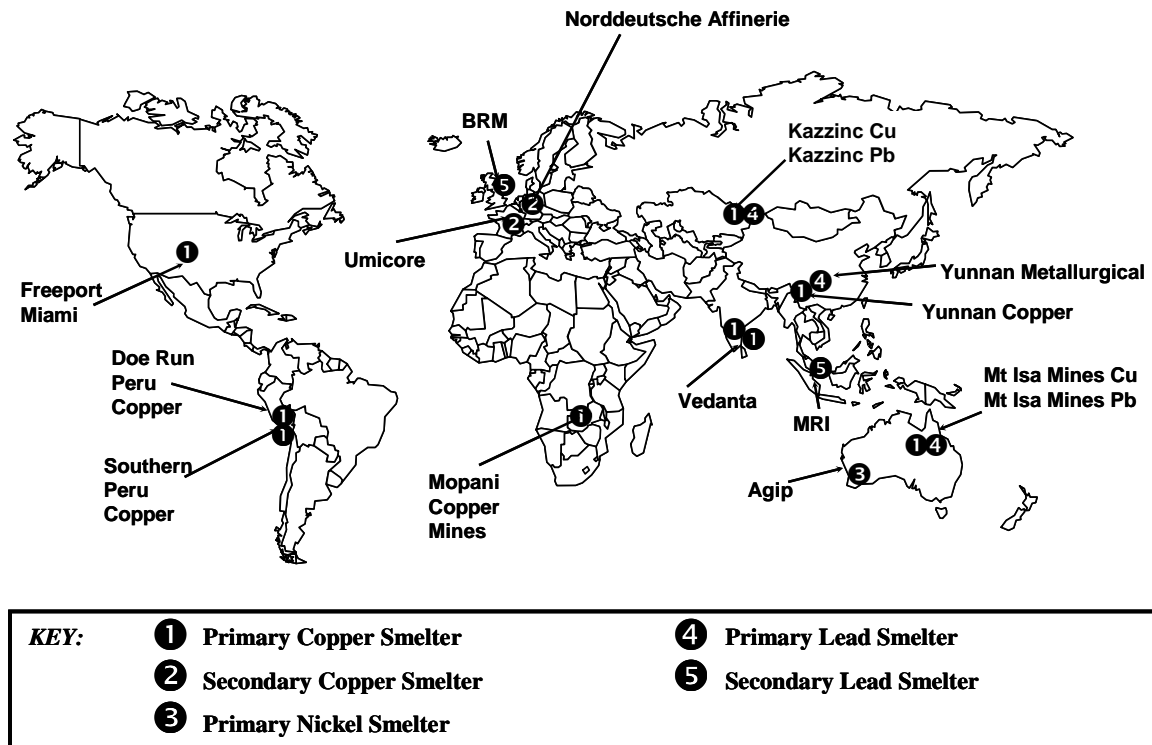


Figure 2 - ISASMELT™ Plant Locations

AGIP NICKEL ISASMELT™ PLANT

It is not widely known that the ISASMELT™ process was also adapted for the treatment of nickel bearing feeds at a very early stage of its development. A large amount of pilot-scale testwork was completed during the 1980's on nickel deposits owned by Mount Isa Mines Ltd. Testwork was also performed for AGIP Australia Pty Ltd, who owned the Radio Hill deposit in Western Australia. In 1991, AGIP decided to construct a semi-commercial ISASMELT™ plant to produce nickel-copper matte from concentrate feed; the first ISASMELT™ plant built and commissioned for an external client. Earlier in 1991, the first commercial scale ISASMELT™ plant had been commissioned to produce lead bullion from concentrates in Mount Isa. A year later, two commercial scale ISASMELT™ plants were commissioned to produce copper matte from concentrates; one in Mount Isa and the other in Miami, Arizona.

The AGIP nickel ISASMELT™ plant [2] was commissioned in September 1991 and within 3 months was running at design capacity of 7.5 t/h concentrate. It produced 45% nickel/copper matte from a

concentrate containing approximately 7% nickel and 3.5% copper. Photographs of the plant are shown in Figure 3. Unfortunately with declining nickel prices (nickel was trading at about US\$3 per pound in 1991), AGIP decided to close the mine, concentrator and smelter after less than six months of operation, despite the technical success of the project. The ISASMELT™ plant has since been demolished.

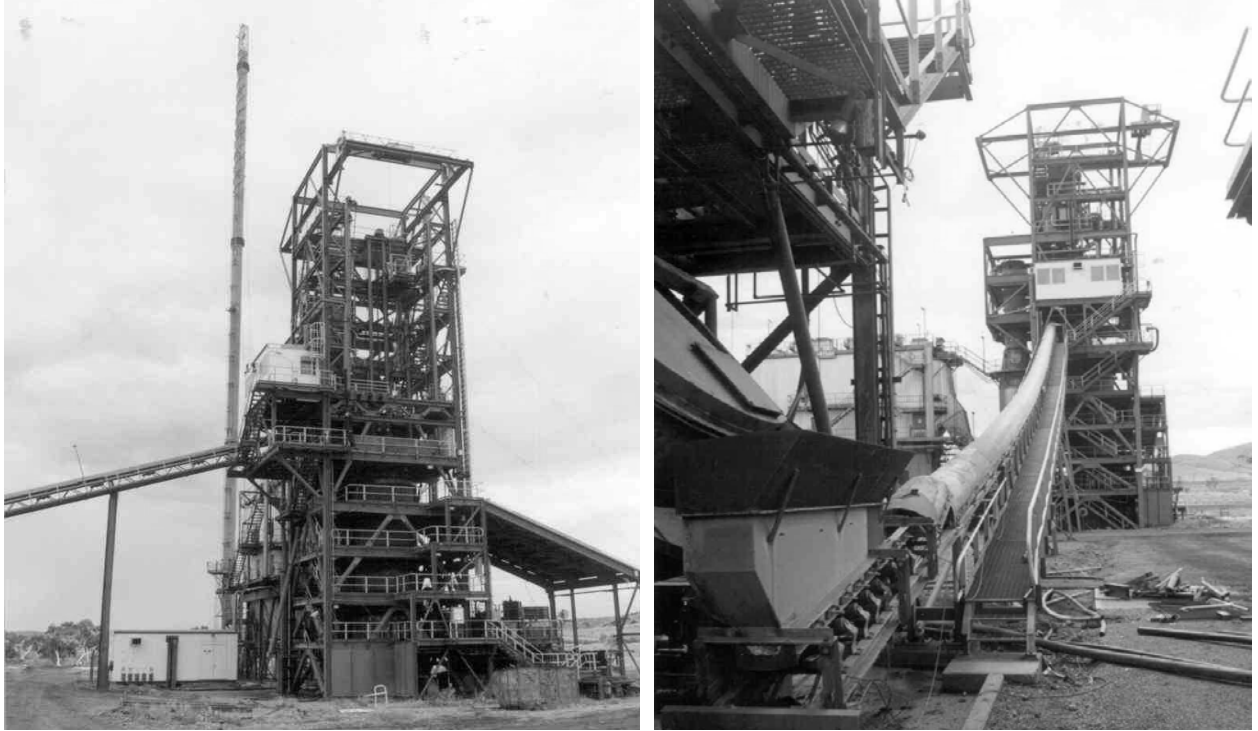


Figure 3 - Photographs of AGIP Nickel ISASMELT™ Plant

NICKEL ISASMELT™ PROCESS CONCEPT

The feed to nickel sulfide smelters normally consists of a nickel-copper concentrate, which may also contain minor amounts of cobalt and platinum group metals. The product from smelting these feeds is generally a primary smelting matte that requires further processing, typically in Peirce Smith converters, to produce finished grade matte. The finished grade matte is called “Bessemer matte”.

A recent survey of worldwide nickel sulfide smelters [3] revealed that flash smelting accounted for approximately 70% of output of the nickel sulfide smelters in 2004 with electric furnace smelting representing the balance. However, the same features that make the ISASMELT™ process an attractive alternative for copper and lead smelting can be equally applied to nickel smelting.

The basic process block diagram for a primary smelting nickel ISASMELT™ plant is shown in Figure 4. The nickel ISASMELT™ furnace continuously processes concentrate feed, fluxes, and recycled dust. The product liquid matte and slag is tapped periodically from the ISASMELT™ vessel to a separate slag cleaning furnace via a single taphole. Off-gases from the ISASMELT™ furnace are directed to a waste heat boiler (WHB) for heat recovery and de-dusted using an electro-static precipitator (ESP) before being sent to a sulfuric acid plant for sulfur capture. The primary smelting matte is transferred by ladles from the settling furnace to the Peirce Smith converters for production of Bessemer matte. Discard slag is

also intermittently tapped from the settling furnace for disposal. All dusts collected from the gas handling processes are recycled to the ISASMELT™ furnace.

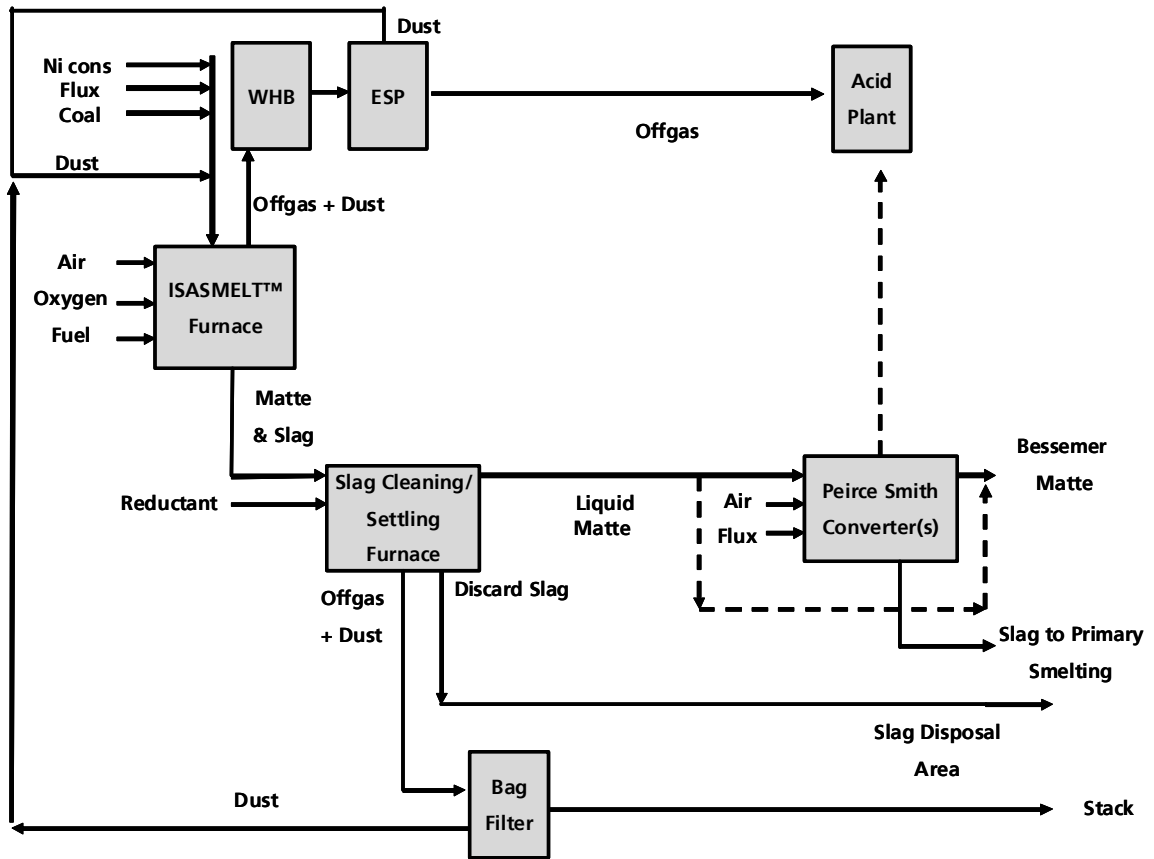


Figure 4 - Process Block Diagram for a Nickel ISASMELT™ Plant

Figure 4 also shows the possibility of using the nickel ISASMELT™ process to produce Bessemer matte with low iron content directly from concentrate feed. This would obviate the need for Peirce Smith converting altogether. The direct nickel ISASMELT™ process is similar to the Direct Outokumpu Nickel (DON) process where the metal values in the smelting slag are recovered in the slag cleaning furnace. The DON process was first applied to the Harjavalta plant on Finland in 1995 and then at a much smaller scale at the Fortaleza plant in Brazil in 1998 [4]. The nickel ISASMELT™ thus has the flexibility to produce either primary smelting matte (Fe in matte greater than 15wt%) or Bessemer matte (Fe in matte less than 5wt%) depending on the customer's requirements.

NICKEL ISA CONVERT™ PROCESS CONCEPT

Matte generated from primary smelters of nickel concentrates is almost exclusively processed to Bessemer matte using multiple units of Peirce Smith converters. The exceptions are the Anglo Platinum Watervale smelter in South Africa, where the AngloPlatinum Converting Process (ACP) is employed and Stillwater Mining Company smelter, where top blown rotary converters are used. In both cases these converting processes treat granulated primary smelting matte, however, only the ACP is fed continuously.

Continuous nickel converting is not a new concept and has been previously investigated for improved productivity and emission control compared to the traditional Peirce-Smith batch converters. As stated above the ACP plant has already commercialised the process concept, In addition, INCO completed a substantial research program into continuous nickel converting about 10-20 years ago [5,6]. INCO investigated three processes for continuous converting; their own flash converting, oxygen top blowing-nitrogen bottom stirring technology, and El Teniente converter technology. INCO reported difficulties in producing Bessemer grade matte to their required specifications, but identified a two-stage process which would potentially solve the technical challenges but was estimated to be an uneconomic solution. It should be noted that INCO's goal was to develop a continuous nickel converting technology able to produce a Bessemer matte with 0.5% iron content required for their Sudbury Refinery Operation. This iron content in the produced matte is not typical for most nickel smelters and therefore, continuous nickel converting technologies like ISACONVERT™ are suitable to meet others refinery requirements.

The basic process block diagram for a nickel ISACONVERT™ plant is shown in Figure 5. It should be noted that the nickel ISACONVERT™ process is a truly continuous converting process with matte and air/oxygen continuously fed to the bath. The bath consists of the converting products at all times.

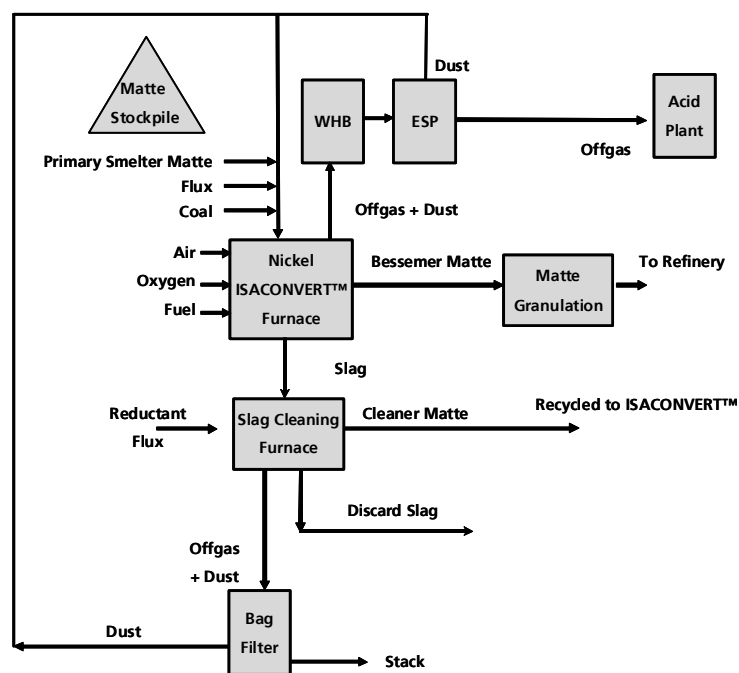


Figure 5 - Process Block Diagram for a Nickel ISACONVERT™ Plant

The nickel ISACONVERT™ furnace continuously processes primary smelting matte feed, fluxes, and recycled slag cleaner matte and dusts. The product liquid Bessemer matte is tapped periodically to; (1) a granulation system or (2) slow cooling system (depending on refinery). Slag is tapped from a separate taphole from the ISACONVERT™ vessel to a separate slag cleaning furnace where metal values are recovered by adding reductant (coke and/or concentrate) to produce a separate matte and slag phase. The slag cleaner matte is granulated and recycled to the ISACONVERT™ furnace, whereas the slag is discarded. Off-gases from the ISACONVERT™ furnace are directed to a waste heat boiler (WHB) for heat recovery and de-dusted using an electro-static precipitator (ESP) before being sent to a sulfuric acid plant for sulfur capture. All dusts collected from the gas handling processes are recycled to the ISACONVERT™ furnace.

The presented nickel ISACONVERT™ process offers two important advantages compared with the traditional batch Peirce-Smith Converting.

The first advantage of the ISACONVERT™ process is the generation of a constant volume of high strength SO₂ containing gases that can be treated in a conventional sulfuric acid plant. This is an important benefit considering future stringent environmental regulations. Current and near future environmental regulations are requiring more SO₂ capture and improvements for plant hygiene. The low SO₂ strength off-gas from the Peirce Smith's primary hood will need to be captured and may not be amenable for treatment in a conventional sulfuric acid plant. In addition, Peirce Smith converters may soon be required to install secondary hooding in order to meet new in-plant hygiene standards. These necessary modifications will result in the Peirce Smith converter becoming an expensive converting technology option. The ISACONVERT™ offers a one step converting process that uses high oxygen enrichment with minimal air dilution thus producing an off-gas readily amenable to treatment in a sulfuric acid plant.

A second advantage is the fact of using solid matte as feed material for the converting process. Feeding of solid material eliminates the use of ladles for material transfer thus significantly reducing fugitive emissions and improving plant hygiene.

Finally, the use of solid/granulated feed allows decoupling the smelting and converting processes, giving more flexibility to the maintenance and operation of the smelter.

RECENT NICKEL ISASMELT™ PILOT PLANT TRIALS

Several campaigns of trials using an ISASMELT™ pilot plant have been conducted during 2007-2008 to provide further data regarding the operability of both:

- (i) a nickel ISASMELT™ process involving the smelting of nickel/copper concentrates to either primary smelting matte or Bessemer matte, and
- (ii) a nickel ISACONVERT™ process involving the converting of primary smelting nickel/copper matte to Bessemer matte.

The main objectives of these tests were to determine the product nickel matte and slag compositions, elemental partition ratios between matte and slag (particularly nickel and cobalt), and generate slags for subsequent slag cleaning testwork.

The ISASMELT™ Pilot Plant

The pilot ISASMELT™ facilities consist of a stationary cylindrical furnace with an internal diameter of approximately 400mm and a height of approximately 2,000mm. The furnace contains a molten bath with a maximum depth of about 600mm. The vessel is lined with chrome-magnesite refractory bricks, and high alumina insulation bricks. Controlled amounts of air and oxygen are injected into the bath via either a 1.25 inch or 1.5 inch stainless steel lance. The feed is added in known amounts to a calibrated variable speed conveyor belt which drops the feed through a chute at the top of the furnace at a rate between 100 kg/h to 250kg/h. Fuel oil is injected down the lance to control bath temperature. Removal of molten products can be achieved by opening one of two tapholes and collecting the materials in cast iron ladles. The process off-gases are cooled and de-dusted before being directed to a caustic soda scrubber for removal of any sulfur containing gases prior to venting to stack.

Nickel ISASMELT™ Trials

Nickel concentrates were successfully smelted to produce mattes over a wide range of iron contents; from 1.6wt% Fe to 20.0wt% Fe. The purpose of the testwork was to demonstrate the process capability of producing whatever matte grade was required by the customer, ranging in composition from

primary smelting matte (Fe in matte greater than 15wt%) to Bessemer matte (Fe in matte less than 5wt%) from feed concentrates. The typical nickel/copper concentrate feed composition is shown in Table 1.

Table 1 – Nickel/Copper concentrate feed composition

Element	Average Content (wt%)
Ni	17.1
Cu	4.3
Co	0.4
Fe	31.0
S	27.0
SiO ₂	9.8
MgO	6.5
Al ₂ O ₃	1.0
CaO	0.7

The concentrate was pelletised with silica flux and charged to the furnace at a rate equivalent to 150 kg/h of wet concentrate. Granular coal was added to the feedbelt at a rate equivalent to 5% of the concentrate feedrate. Smelting air and oxygen were metered through separate rotameters at a ratio to yield 40-45 v/v% total oxygen. Fuel oil was injected down the lance to maintain the bath temperatures between 1,310 °C and 1,450 °C depending on the test conditions.

Fluid slags were produced under all test conditions. The iron-silica ratio in ISASMELT™ slag generated during the tests ranged from 0.9-1.4. Composition ranges for the ISASMELT™ slag for the tests are shown in Table 2.

Table 2 – Range of ISASMELT™ slag compositions

Element	Range (wt%)
Ni	0.8-7.0
Cu	0.3-1.5
Co	0.2-0.3
Fe	32.0-37.6
SiO ₂	25.6-34.9
MgO	6.7-10.3
Al ₂ O ₃	3.8-5.1
CaO	1.4-2.5

On completion of the ISASMELT™ pilot plant test work, additional slag cleaning test work was carried out with Xstrata Process Support. The Bessemer matte produced is typically high in nickel (40-70 wt.%). A small amount of matte entrainment can significantly skew the nickel content measured in slag. To remove the possible effect of matte entrainment, slag samples were analysed using an electron probe micro-analyser (EPMA). The glassy phases of the samples were analysed and the wt.% nickel in glassy slag as a function of iron content in bulk matte is shown in Figure 6, both for the ISASMELT™ and ISACONVERT™ tests (discussed later in the ISACONVERT™ trials section). The slag samples were either granulated from the pilot plant, or remelted and quenched at the desired temperature.

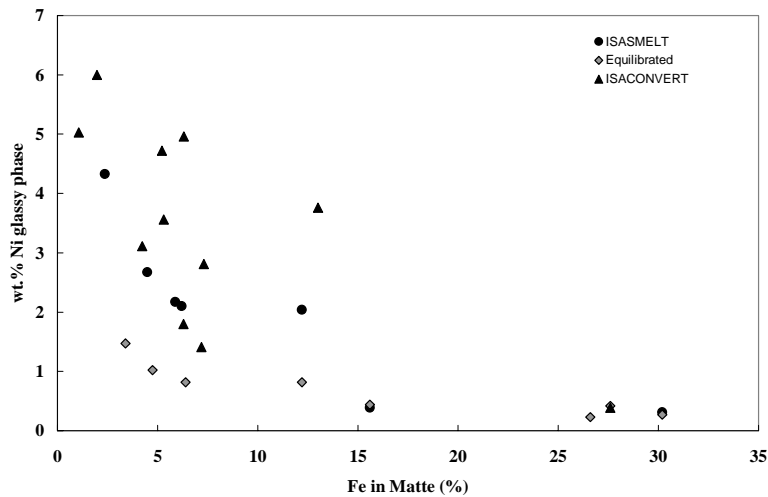


Figure 6 – Nickel in slag as a function of iron in ISASMELT™ matte.

The soluble nickel in slag was higher than expected for mattes containing low amounts of iron, compared to an equilibrated system. To confirm this, slag and matte from the ISASMELT™ and ISACONVERT™ pilot was equilibrated by remelting them together. The new wt.% nickel in the glassy phase is also shown in Figure 6 as “Equilibrated” data.

The distribution of coefficients of cobalt (wt.% Co matte/wt.% Co slag) as a function of iron content in bulk matte are shown in Figure 7. Assays are from the bulk slag and bulk matte taken as spoon samples.

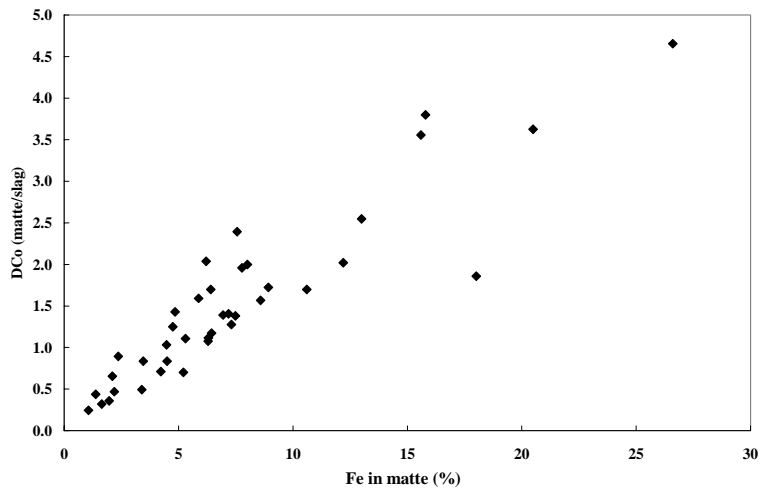


Figure 7 – Co distribution as a function of iron in ISASMELT™ matte.

FactSage[7] was used to predict the liquidus in the MgO-‘FeO’-SiO₂-Al₂O₃-CaO slag system at $pO_2 = 10^{-7.6}$ atm, Al₂O₃ = 3 wt% and CaO = 1 wt%. Compositions of the final slags are plotted in Figure 8. All slags are in the olivine primary phase field.

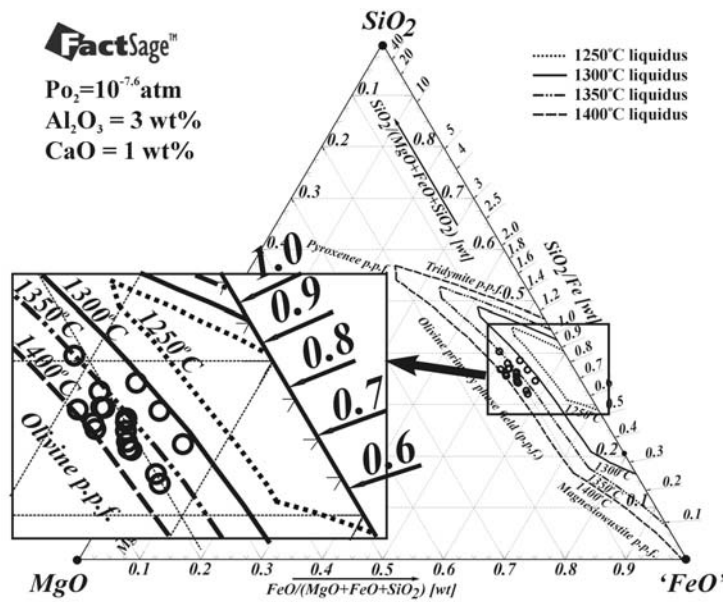


Figure 8 – Liquidus in the system MgO-‘FeO’-SiO₂-Al₂O₃-CaO at $pO_2 = 10^{-7.6}$ atm, Al₂O₃ = 3 wt% and CaO=1 wt %.

Nickel ISACONVERT™ Trials

Primary smelting mattes were successfully converted to produce finished mattes with iron contents from 2.2wt% Fe to 9.6wt% Fe. The purpose of the converting testwork was to demonstrate the ISACONVERT™ process for treating solid primary smelting matte feed to low iron containing product mattes. The typical primary smelting matte composition is shown in Table 3.

Table 3 – Primary smelting nickel matte composition

Element	Average Content (wt%)
Ni	44.5
Cu	9.7
Co	2.9
Fe	25.3
S	17.2
SiO ₂	0.3

The solid primary smelting matte was charged to the furnace at a rate equivalent to 200 kg/h of “as received” solid matte. High grade silica flux was added to achieve the target iron to silica ratio in product slag. Granular coal was added to the feedbelt at a rate equivalent to 5% of the matte feedrate. Smelting air and oxygen were metered through separate rotameters at a ratio to yield 35-40 v/v% total oxygen. Fuel oil was injected down the lance to maintain the bath temperatures between 1,310 °C and 1,380 °C depending on the test conditions.

Fluid slags were produced under all test conditions and the iron-silica ratio in ISACONVERT™ slag generated during the tests ranged from 1.1-2.3. Composition ranges for the ISACONVERT™ slag for the tests are shown in Table 4.

Table 4 – Range of ISACONVERT™ slag compositions

Element	Range (wt%)
Ni	2.2-6.4
Cu	0.6-1.2
Co	1.3-2.5
Fe	37.8-48.0
SiO ₂	25.6-34.9

The results of the ISACONVERT™ tests are also shown in Figure 6. The nickel ISACONVERT™ tests were typically targeted to achieve low iron content in matte. As can be appreciated, low iron contents in matte produce high nickel contents in slags. Although a high nickel slag has a higher liquidus, the Fe/SiO₂ is a factor that can be optimized to reduce the liquidus temperature.

FactSage[7] was used to predict liquidus in the slag system NiO-‘FeO’-SiO₂-Al₂O₃-CaO-MgO at $pO_2 = 10^{-7.6}$ atm, Al₂O₃ = 2.5 wt %, CaO=1.5 wt, and MgO = 2.5wt%. Compositions of the final slags are plotted in Figure 9. All slags are in the olivine primary phase field.

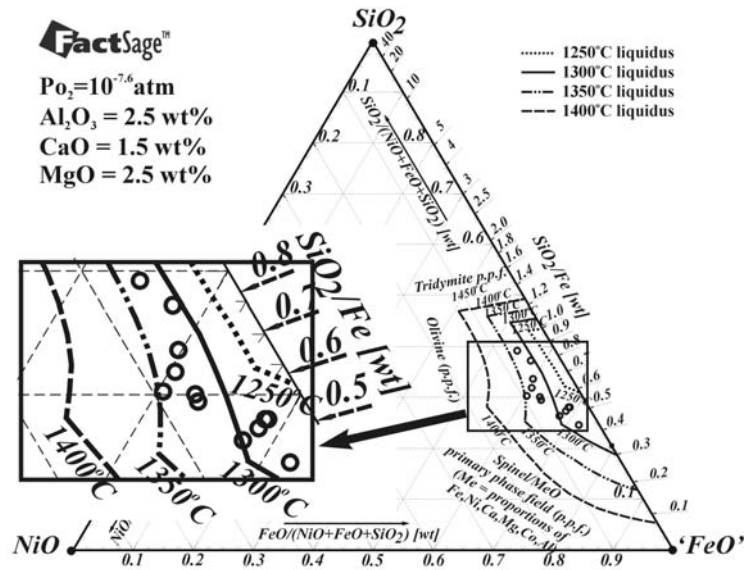


Figure 9 – Liquidus in the system MgO-‘FeO’-SiO₂-Al₂O₃-CaO at $pO_2 = 10^{-7.6}$ atm, Al₂O₃ = 2.5 wt%, CaO=1.5 wt % and MgO = 2.5 wt%.

FUTURE DEVELOPMENT

XT has demonstrated that the ISASMELT™ process is an attractive option for both primary and secondary copper and lead smelting. More than 6,000,000 tonnes per year of feed materials are processed in ISASMELT™ furnaces in copper and lead smelters around the world. The features that make ISASMELT™ attractive for copper and lead smelting can be equally applied to nickel smelting and converting operations and the use of the ISASMELT™ process for copper/nickel smelting has already been successfully demonstrated on a commercial scale.

Recent pilot plant testwork has been completed on the nickel ISASMELT™ process for producing both primary smelting matte and Bessemer matte directly from concentrates. Additionally, piloting the nickel ISACONVERT™ processes for production of Bessemer matte from low grade matte proved successful.

Future development of the nickel ISASMELT™ process may require additional improvements to be made to the existing furnace designs. These include:

- Furnace cooling – operation at temperatures above 1,300°C will require furnace cooling systems to ensure long campaign life
- Tapping blocks – tapping of nickel matte will require improved tapping block design
- Pneumatic injection – exploitation of dry concentrate injection through the ISASMELT™ lance to minimise fuel requirements.
- Optimisation of the ISASMELT™ slag cleaning process to maximise payable metal recoveries.

These development issues are currently being addressed.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. Stanko Nikolic for the FactSage contributions to this paper.

The authors would also like to thank Xstrata Technology and Xstrata Nickel for permission to publish this paper.

REFERENCES

1. B. Burford, "The ISASMELT™ Technology Package: Over 30 Years of Innovation", AusIMM Bulletin, No. 1, Feb 2009, 26-30.
2. P.S. Arthur and S.P. Hunt, "ISASMELT™ - 25 Years of Continuous Evolution", John Floyd International Symposium on Sustainable Developments of Metals Processing, M. Nilmani and W.J. Rankin, Eds., NCS Associates, Melbourne, Australia, 2005, 73-94.
3. A.E.M. Warner, C.M. Diaz, A.D. Dalvi, P.J. Mackey, A.V. Tarasov and R.T. Jones, "JOM World Nonferrous Smelter Survey Part IV: Nickel: Sulfide", JOM, April 2007, 58-72.
4. T. Mäkinen and P. Taskinen, "The State of the Art in Nickel Smelting: Direct Outokumpu Nickel Technology", Sohn International Symposium Advanced Processing of Metals and Materials, F. Kongoli and R.G. Reddy, Eds., The Minerals, Metals & Materials Society, USA, 2006, 313-325.
5. A.E.M Warner and C.M. Diaz, "An Overview of the Metallurgy of Nickel-Copper Matte Converting", Yazawa International Symposium Metallurgical and Materials Processing: Principles and Technologies, F. Kongoli, K. Itagaki, C. Yamauchi and H. Y Sohn, Eds., The Minerals, Metals & Materials Society, USA, 2003, 113-129.
6. J.R. Donald, A.E.M Warner, A.D. Dalvi, K. Scholey, A. Ross and C. Harris, "Risks and Opportunities in Continuous Converting for Nickel at Inco", Converter and Fire Refining Practices, A. Ross, T. Warner and K. Scholey, Eds., The Minerals, Metals & Materials Society, USA, 2005, 295-307.
7. Bale C.W., Pelton A. D. and Thompson W.T.. "*Facility for the analysis of Chemical Thermodynamics*" (FactSage version 5.5), Ecole Polytechnique de Montreal, (2007) (<http://www.crct.polymtl.ca>).