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ISACONVERT™ – Continuous Converting of Nickel/PGM mattes

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Abstract – The ISASMELT™ top submerged lance (TSL) bath smelting process was developed in Mount Isa, Australia by Mount Isa Mines Limited (now a subsidiary of Xstrata plc) during the 1980s. By the end of 2011, the total installed capacity of the ISASMELT™ technology will exceed 9 000 000 metric tons per year of feed materials in copper and lead smelters around the world. Commercial plants, operating in Belgium and Germany, are also batch converting copper materials in ISASMELT™ furnaces. This TSL technology is equally effective for continuous converting processes, whereupon it is called ISACONVERT™.

This paper presents the recently patented ISACONVERT™ process for the continuous converting of nickel and Platinum Group Metal (PGM) containing mattes using the calcium ferrite slag system. The paper focuses on the potential application of the ISACONVERT™ technology to existing nickel and PGM smelting complexes.

INTRODUCTION

ISASMELT™ top submerged lance (TSL) technology is well established as one of the standard technologies for primary copper smelting[1]. Over the years, ISASMELT™ has progressed from a 0.25 t/h pilot plant scale to industrial facilities that process up to 200 t/h feed. The technology can treat a variety of materials including nickel[2], lead[3], and copper[4] concentrates, and secondary materials, with the total installed capacity of ISASMELT™ plants expected to exceed 9 000 000 t/y by the end of 2011.

Batch converting in the ISASMELT™ furnace has been performed by two smelters in Europe, namely Umicore Precious Metals in Hoboken, Belgium[5], and Aurubis AG, Lünen, Germany[6], since 1997 and 2002 respectively. The process has also been adapted to continuous converting of copper matte to blister copper[7-9], and low-grade nickel matte to Bessemer matte[2,10], whereupon it is called the ISACONVERT™ process.

DEVELOPMENT OF THE NICKEL / PGM ISACONVERT™ PROCESS

The ISACONVERT™ process shares many design features with the ISASMELT™ furnace[6]. It can readily be enclosed to minimize emissions to the surrounding environment. It uses the TSL injection technology to provide highly efficient mixing and reaction of solid matte and flux, which can be charged through the roof of the furnace. The use of advanced process control systems results in the furnace operation being largely automated. Being a vertical furnace, very little floor space is required to accommodate the plant and so it can generally be easily retro-fitted into existing smelting facilities to either augment or replace existing technology. The significantly reduced off-gas volume from the ISACONVERT™ process, when compared to Peirce-Smith technology, results in lower capital and operating costs for off-gas collection and cleaning systems[6].

This technology has now been applied by Xstrata Technology (XT) for the continuous converting of low-grade nickel/PGM matte to high grade Bessemer matte – the patented Nickel ISACONVERT™ process. Analogous to the ISACONVERT™ process for copper, the Nickel ISACONVERT™ process also employs the calcium ferrite slag system.

NICKEL / PGM ISACONVERT™ PROCESS CONCEPT

The feed to a PGM smelter typically consists of nickel-copper sulfides and refractory oxide materials[11]. The product from smelting PGM smelter feeds is generally a high iron containing smelter matte which is further processed, almost exclusively using multiple units of Peirce-Smith converters, to produce finished, low iron containing matte, often referred to as 'Bessemer matte'. The exception is the Anglo Platinum Waterval smelter in South Africa, where the Anglo Platinum Converting Process (ACP) is employed[12].

Continuous PGM matte converting is not a new concept and has been investigated previously for improving productivity and emission control compared to the traditional Peirce-Smith batch converters. As noted above, the ACP plant has already commercialised this process concept.

XT has investigated nickel/PGM matte converting with the ISACONVERT™ technology[2,8,13,14] and produced mattes containing less than 4 wt% iron successfully on the pilot scale. The ISACONVERT™ process for treating PGM matte is a continuous converting process with matte and air/oxygen fed continuously to the bath. The bath consists of matte and slag at the product compositions at all times. The operating conditions effectively fix the process at what is, for Peirce-Smith converters, the end point of the converting reactions.

Figure 1 shows how the ISACONVERT™ could be integrated into the flowsheet of an existing smelting facility to treat PGM matte. Granulated smelting furnace matte feed, limestone flux, purchased feed, furnace dusts, fuel, air, and oxygen would be fed continuously to the ISACONVERT™ furnace. The product liquid, low-iron Bessemer matte would be tapped periodically from the matte tap-hole and, depending on downstream refinery requirements, the matte may be either granulated or slow-cooled.

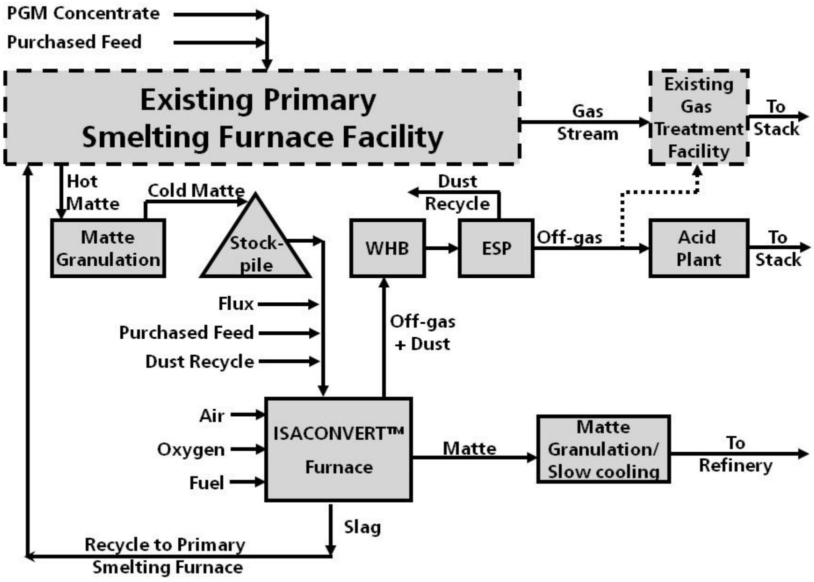

Figure 1: Process Block Diagram for the Nickel/PGM ISACONVERT™ Process

Slag would be tapped through a separate tap-hole and returned to the primary smelting plant for recovery of the metal values. Off-gases from the ISACONVERT™ furnace would be directed to a waste-heat boiler for energy recovery, and de-dusted using an electro-static precipitator before being sent to either an existing gas treatment facility or to a dedicated sulfuric acid plant for sulfur capture. All dusts collected from the gas handling systems would be recycled to the ISACONVERT™ furnace.

The ISACONVERT™ process presented in Figure 1 offers two principal advantages compared with the traditional batch Peirce-Smith converting:

Firstly, the ISACONVERT™ process generates a constant volumetric flowrate of off-gas, containing a high level of SO_2 that can readily be treated in a conventional sulfuric acid plant. This is an important benefit, considering the stringent environmental regulations affecting both current and future plant emissions and in-plant hygiene. While fitting tight converter hoods remains a potential option to capture Peirce-Smith converter off-gas, this approach, coupled with the additional need for secondary hooding to control fugitive emissions, is typically a high-cost option. The ISACONVERT™ offers a one-step, one-furnace converting process that can utilize high levels of oxygen enrichment coupled with minimal air dilution.

Secondly, the ISACONVERT™ process offers the use of solid matte as the feed material, thus eliminating molten matte ladle transfers, and further reducing the potential for fugitive emissions, with a resulting improvement in plant hygiene. The use of solid feed also allows decoupling of the smelting and converting steps, giving added flexibility and simplifying the maintenance and operational aspects of the smelter.

CONTINUOUS CONVERTING PROCESS SLAG CHEMISTRY

Current PGM matte converting slag chemistry

Both the batch Peirce-Smith converter and the continuous ACP nickel matte converting processes use an iron-silicate (fayalite) based slag system. Peirce-Smith converting furnaces typically convert molten primary smelting furnace matte to a final matte product containing 1–3 wt% iron. Rapid precipitation of magnetite (predominately nickel-ferrite) in slag restricts Peirce-Smith converters to an endpoint of approximately 2 wt% iron in matte. Some operators solidify the remaining slag within the Peirce-Smith converter vessel before continuing the blowing cycle, to lower iron in matte levels[15]. The practice of solidification during final blowing generates a mush of silica and magnetite-saturated slag that holds within it final product matte that can only be recovered through the start of a new converting cycle[15], generating process inefficiencies. Operation that is continued below 2 wt% iron in matte, without solidification of the slag, results in either excessive magnetite/slag entrainment within the product matte or increased furnace build-up[15].

The original flowsheet for the ACP involved two-stage batch production of Bessemer matte: a first stage to lower the iron in matte content to ~13 wt%, and the second stage to lower it to ~3 wt% iron in matte[12]. Due to difficulties associated with determining starting points for the second stage of converting, slag eruptions occurred due to over-oxidation of the bath[12]. The batch nature of the process resulted in poor or incomplete mixing, which led to non-equilibrium stratification of the melts within the furnace. Subsequent rapid mixing of the melt layers due to bath perturbations resulted in explosive foaming of the bath contents at low iron in matte levels[12]. For these reasons, and to maintain a constant high-strength SO_2 gas stream to their off-gas processing facility, the ACP was modified to a continuous process; with granulated matte continuously fed to the furnace and converting at an end-point of 3 wt% iron in matte[12].

Preliminary pilot-plant test-work campaigns for the ISACONVERT™ process used iron-silicate based slags for treating two different matte feeds, as shown in Table I. Final mattes produced contained between 0.7–13 wt% iron from Matte 1 feed[14] and 2.2–10 wt% iron from Matte 2 feed[2,8]. The results of the iron-silicate slag converting test-work campaigns highlighted that production of mattes containing less than 2 wt% iron, required the temperature of the process to be increased substantially to maintain fluidity of the iron-silicate slag. XT therefore investigated the applicability of a calcium-flux based slag system, as used successfully in the copper ISACONVERT™ process.

Table I: Primary Smelting Nickel/PGM Matte Composition used in ISACONVERT™ Trials

Element	Matte 1 Average (wt%)	Matte 2 Average (wt%)
Ni	16.2	44.5
Cu	10.6	9.7
Co	0.53	2.9
Fe	40.1	25.3
S	26.9	17.2

ISACONVERT™ Nickel/PGM Converting Slag Chemistry

The calcium ferrite slag system has been successfully applied to continuous copper converting technologies since the mid 1970s[16]. The beneficial properties of calcium ferrite slags, for copper converting, were established and outlined in the 1980s by the research of Yazawa[17-18] and Takeda[19]. These include the ability of the liquid phase to contain higher ferric iron concentrations at high oxygen potentials, lower slag volume, lower valuable metal losses, and greater fluidity.

These beneficial properties were investigated and confirmed by the lab-scale research work of Font[20] and Henao[21], indicating higher valuable metal recovery (Ni, Cu, and Co – which carry PGM components) whilst also increasing the distribution of impurity elements (As and Sb) to the slag. XT used the thermodynamic modelling package FactSage[22] to confirm that the beneficial properties of the calcium ferrite system, in terms of fluidity and ferric iron capacity, also applied to the process of converting nickel/PGM mattes.

Nickel matte converting using calcium ferrite slag at the commercial scale has been successfully applied by Stillwater Mining Company (SMC) in batch Top Blown Rotary Converters (TBRC), producing a Bessemer matte containing about 2 wt% iron[11] since 1991. The TBRC process at SMC originally used an iron-silicate based slag for converting, but experienced sudden slag foaming at low iron in matte levels, from over-oxidation, causing loss of charges and potential threats to the safety of the equipment and the operators[23]. SMC consequently altered their process slag chemistry by adding lime-based flux instead of silica, thereby avoiding the formation of unstable bath conditions.

Considering the successful application of calcium ferrite slags to batch nickel matte converting at SMC, and the proven ability of the ISACONVERT™ and other processes to use calcium ferrite slags for copper production[5-7,16], the application of this slag system to a continuous TSL process for nickel/PGM matte production was investigated by XT through pilot-scale test-work.

The objective of the pilot-scale converting test-work was to confirm and demonstrate the nickel/PGM matte ISACONVERT™ process chemistry for converting high-iron primary smelting matte feed to low-iron Bessemer matte, utilising a calcium ferrite based slag. The tests involved converting solid matte (refer to Matte 2 composition in Table I), with the addition of limestone flux to the pilot furnace at a rate of 100–150 kg/h of 'as received' solid matte. The details of the ISACONVERT™ pilot-plant facility have been published elsewhere[8]. The pilot-plant tests revealed that fluid slags were produced under all test conditions.

ISACONVERT™ TEST-WORK RESULTS

The target grade for nickel/PGM Bessemer matte is typically matched to the requirements of the downstream refinery that specifies the permissible level of iron and sulfur within the matte. A comparison of the matte grade with respect to the concentration of iron within the matte, between the ISACONVERT™ calcium ferrite process test work and Peirce-Smith converters and a TSL using iron-silicate slag, is shown in Figure 2. Sources for the Peirce-Smith converting and TSL iron-silicate slag data included:

- Results from TSL iron-silicate slag matte converting pilot-plant tests conducted by XT[2,8];
- Results from a sampling campaign of a Peirce-Smith converter blow at:
    - The Xstrata Nickel Falconbridge smelter[24]; and
    - The Vale Inco Thompson smelter[25].

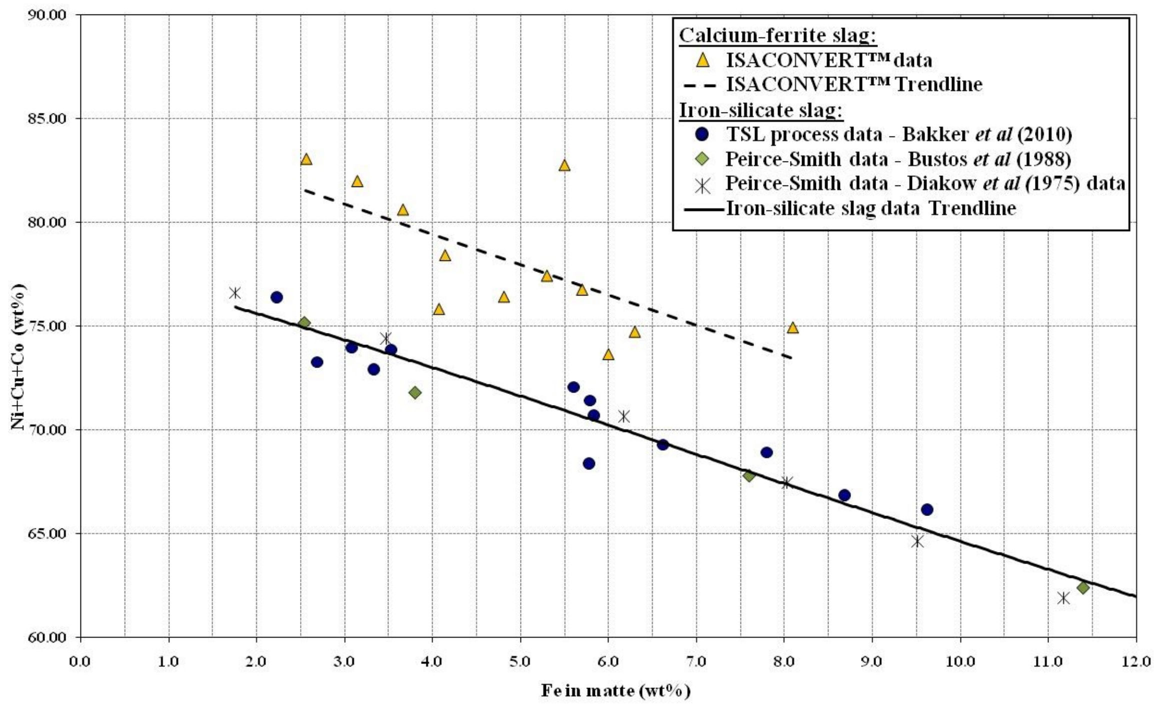

Figure 2: Matte grade (Ni+Cu+Co, wt%) as a function of iron in matte

At a fixed iron-in-matte concentration, the ISACONVERT™ calcium ferrite process produces a matte grade that is over five mass percent richer in nickel, copper, and cobalt, when compared to converting with an iron-silicate slag process. The increased Bessemer matte grade achieved using calcium ferrite slags is a consequence of lower sulfur concentrations within the matte phase, when compared to iron-silicate slags. This is displayed graphically in Figure 3, where the sulfur deficiency within the matte (defined in equation 1 of reference[26]) is compared to the iron concentration in the matte.

$$\text{Sulfur Deficiency \%} = (S_T - S_{Actual}) / S_T \qquad [1]$$

where:

- S_T = Sulfur required to form sulfide phases Ni_3S_2, Cu_2S, Co_9S_8, and FeS;
- S_{Actual} = Measured sulfur concentration within the matte phase.

Feed matte to a nickel/PGM converting process is typically sulfur deficient; refer to Table I. Figure 3 shows that iron-silicate nickel/PGM matte converting processes generate matte that is between 20–30% sulfur-deficient. Even after nitrogen-induced slow cooling, as practised by Vale Inco, sulfur deficiency is normally maximized at approximately 35%[27]. The ISACONVERT™ calcium ferrite slag process, however, allows for the production of a final product matte with an over 45% level of sulfur deficiency.

Mineralogical analysis of Peirce-Smith converter matte has revealed that metallised phases with the Bessemer matte are nickel-dominant and act as collectors for PGMs[28]. XT therefore postulates that the increased metallisation of the ISACONVERT™ process, refer to Figure 3, would also result in increased concentration and deportment of PGMs to the final product Bessemer matte, when compared to Peirce-Smith converting or TSL iron-silicate slag processes. Further pilot-plant test-work will be required to confirm these PGM deportments.

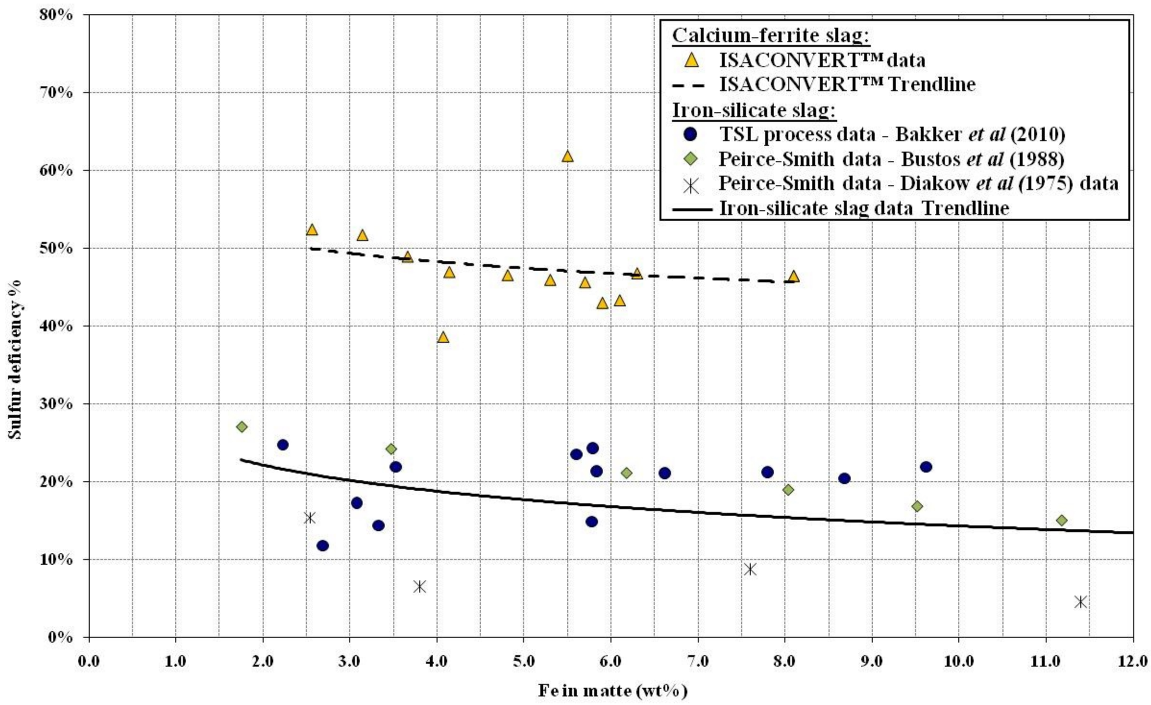

Figure 3: Sulfur deficiency in the Bessemer matte as a function of iron in matte

CONCLUSIONS

ISASMELT™ TSL technology is well established for both primary and secondary copper and lead smelting. Batch smelting and converting using ISASMELT™ technology is also well established. The technology is equally effective for continuous converting processes, whereby it is called ISACONVERT™.

The features that make ISACONVERT™ attractive for nickel/PGM converting operations are:

1. Generation of a constant volumetric flowrate of off-gas containing a high level of SO_2 that can be treated in a conventional sulfuric acid plant;

2. A one-step, one-furnace converting process that can utilize high levels of oxygen enrichment, coupled with minimal air dilution; and
3. Solid matte can be used as the feed material:
    a. Eliminating molten matte ladle transfers, further reducing the potential for fugitive emissions; and
    b. Allowing for decoupling of the smelting and converting steps, increasing flexibility, and simplifying maintenance and operational aspects of the smelter.

The use of the ISACONVERT™ process for primary smelting furnace matte converting has been successfully demonstrated on the pilot scale. Results have shown that, when compared to iron-silicate slag Peirce-Smith and TSL processes, the ISACONVERT™ calcium ferrite process:
1. Produces a higher-grade matte (nickel, copper, and cobalt) at iron in matte levels corresponding to Bessemer matte production;
2. Produces a lower sulfur, higher metallised content matte product.

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