ISACONVERT™—Continuous Converting of Nickel/PGM Matte with Calcium Ferrite Slag

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The ISASMELT™ process is a top submerged lance (TSL) bath smelting technology which has been developed and optimized 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. 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™. Xstrata Technology (XT) has recently patented a new ISACONVERT process for the continuous converting of nickel/platinum group metal (PGM) mattes using the calcium ferrite slag system. This paper outlines the development of this new process and presents a conceptual flowsheet for how it can be integrated into an existing nickel/PGM smelter.

INTRODUCTION

ISASMELT™ top submerged lance (TSL) technology is well established as one of the standard technologies for primary copper smelting.[1] More than 20 ISASMELT plants have been built since the first plant was commercialized at Mount Isa, Australia in 1991. The process has been readily adopted for primary copper and primary and secondary lead smelting with the total installed capacity of the ISASMELT technology exceeding 9,000,000 tonnes per year by the end of 2011. A full history of the development of the technology has been well documented elsewhere.[2–4] TSL technology is equally effective for smelting nickel sulfide concentrates[5,6] with the first nickel-copper ISASMELT furnace constructed in 1991, for Agip Australia.[5]

The ISASMELT process is also well suited to both batch and continuous converting of copper matte to blister copper[7,8] and low grade nickel matte to Bessemer matte[9]—the ISACONVERT™ process. Batch converting in the ISASMELT furnace has been performed by two smelters in Europe, namely Umicore Precious Metals in Hoboken, Belgium,[10] and Aurubis AG, Lünen, Germany[11] since 1997 and 2002, respectively.

How would you…

…describe the overall significance of this paper?

Xstrata Technology (XT) has recently patented a new ISACONVERT™ process for the continuous converting of nickel/platinum group metal (PGM) mattes using the calcium ferrite slag system. This paper outlines the development of this new process and how this process can be integrated into an existing nickel/PGM smelter.

…describe this work to a materials science and engineering professional with no experience in your technical specialty?

This paper covers the development of the nickel/PGM ISACONVERT™ calcium ferrite process involving the review of the fundamental research within this area, subsequent confirmation by process modeling, and finally by pilot-scale testwork. This process is shown to be more stable and robust and produces higher matte grades, with lower distributions of nickel, copper, and cobalt to slag.

…describe this work to a layperson?

This paper explains the development of a new high-temperature converting process for the improved production of nickel, copper, cobalt, and PGM metals. The development process is explained from the review of existing research, modeling, and the application of this process in a small scale test-rig. The results of this work have shown that the nickel/PGM ISACONVERT™ process produces superior results when compared to other high-temperature processes.

THE NICKEL/PGM ISACONVERT PROCESS

The ISACONVERT technology shares many design features with the ISASMELT furnace.[8] It can be readily 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.[8]

The union between recent applied research and pioneering pilot plant work has made possible the potential for industrial-scale implementation of the ISACONVERT process for continuous copper converting.[8] A cutaway image of an ISACONVERT plant is shown in Figure 1. This technology has now been further developed 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 ISACON-

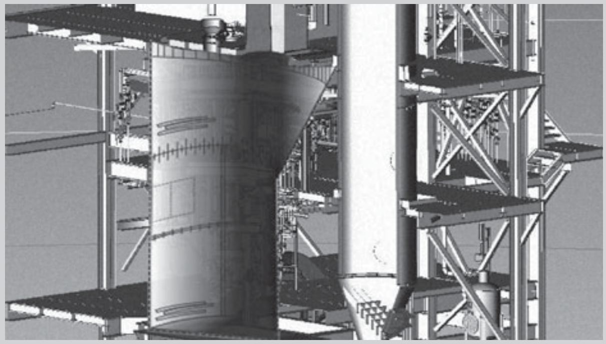

Figure 1. Cutaway of a design for the ISACONVERT™ furnace.

VERT process for copper, the nickel/PGM process also employs the calcium ferrite slag system.

NICKEL/PGM ISACONVERT PROCESS CONCEPT

The feed to a nickel sulfide smelter typically consists of a nickel-copper concentrate, which may also contain minor amounts of cobalt and platinum group metals.[12] Process flow sheets for the nickel ISASMELT furnace have been developed and presented in previous publications.[9] The feed to a PGM smelter is typically lower in nickel-copper sulfides and higher in refractory oxide materials, when compared to traditional nickel smelters.[12] The product from smelting either nickel-copper concentrate or PGM 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 exceptions are the Anglo Platinum Waterval smelter in South Africa, where the Anglo Platinum Converting Process (ACP) is employed[13] and Stillwater Mining Company (SMC) smelter in Montana, where top blown rotary Converters (TBRCs) are used.[14] Both the ACP and SMC processes convert granulated high iron matte to Bessemer matte, however, of the two, only the ACP is fed continuously.

Continuous nickel/PGM 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 commercialized the basic process concept. Furthermore, Vale Inco invested in a substantial research and development program, conducted over a 10 year period, in an attempt to commercialize a continuous nickel converting process.[15]

XT has investigated nickel/PGM converting with the ISACONVERT technology[5,9,16] and produced Bessemer mattes containing less than 4 wt.% iron successfully on the pilot scale. It should be noted that the nickel/PGM ISACONVERT process 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 process operates effectively at similar conditions to those present at the end point of the converting process currently applied in the batch PSC nickel/PGM matte converting process.

Figure 2 shows how the ISACONVERT could be integrated into the flowsheet of an existing primary smelting facility (EPSF). Granulated EPSF matte, limestone flux, purchased feed, furnace dusts, fuel, air and oxygen would be fed continuously to the nickel/PGM ISACONVERT furnace. The product liquid Bessemer matte would be tapped periodically from the matte taphole and depending on downstream nickel/PGM refinery requirements, the matte could be either granulated for hydrometallurgical processing[17] or slow cooled for separation of the nickel-sulfide, copper-sulfide and alloy phases by flotation before refining.[18]

Slag would be tapped through a separate taphole and returned to the EPSF for recovery of the metal values. Off-gases from the ISACONVERT furnace would be directed to a waste heat boiler (WHB) for heat recovery and dedusted using an electro-static precipitator (ESP) before being sent to a sulfuric acid plant for sulfur capture. All dusts collected from the gas handling systems are recycled to the ISACONVERT furnace.

If the nickel/PGM ISACONVERT is replacing existing Peirce–Smith converters, the acid plant of the EPSF may need to be modified. This would allow for the high strength sulfur dioxide (SO_2) stream produced from the ISACONVERT furnace to be captured. The ISACONVERT flowsheet can be easily modified so that slag cleaning is performed in a vessel separate from the EPSF; this and other options can be tailored to optimize recovery and minimize unit operations and molten material transfer.

The nickel/PGM ISACONVERT process presented in Figure 2 offers two principal advantages compared with the traditional batch Peirce–Smith Converting: Firstly, the ISACONVERT process generates a low and constant volumetric flowrate of off-gas containing a high level of SO_2 that can be readily treated in a conventional sulfuric acid plant. This is an important benefit

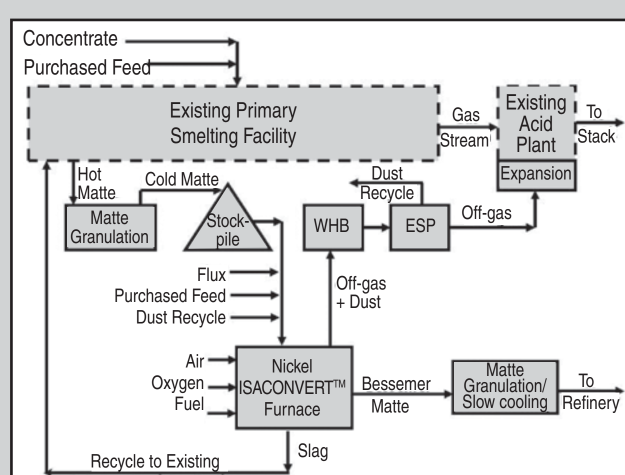

Figure 2. Process block diagram for the Nickel/PGM ISACONVERT™ process.

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

Both the batch Peirce–Smith converter and continuous ACP nickel/PGM matte converting processes use an iron-silicate (fayalite) based slag system. Peirce–Smith converting furnaces typically convert molten primary smelting facility matte to a final matte product containing 2–3 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 (Vale-Inco[19] and Lonmin[20]) solidify the remaining slag within the Peirce–Smith converter vessel before continuing the blowing cycle to lower iron in matte levels. The practice of solidification during final blowing generates a mush of silica and magnetite saturated slag that holds within it Bessemer matte that can only be recovered through the start of a new converting cycle,[20] generating process inefficiencies. Operation that continues below 2 wt.% iron in matte, without solidification of the slag, results in either excessive magnetite/slag entrainment within the product matte or increased build-up inside the furnace.[15,20]

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.[13] Due to difficulties associated with determining starting points for the second stage of converting, slag eruptions occurred due to over-oxidation of the bath.[13] 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.[13] 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 to an end-point of 3 wt.% iron in matte.[13]

During Vale Inco's research and development period[15] three approaches for continuous converting were investigated: their own flash converting,[21] oxygen top blowing-nitrogen bottom stirring bath converting technology, and a Noranda/El Teniente type bath converting technology.[22] It is noted that the primary goal in this work was to develop a continuous converting technology applicable for the Copper Cliff nickel facility, where downstream refining specifies a 0.5 wt.% iron in matte. While technically feasible, the testwork showed that the oxidized iron-silicate slag produced at this very low iron content was unstable and operation led to severe build-up within the reactors.[22] Instead, preference was given to a "two-stage" approach involving continuous converting to about 2–3% iron in matte product, followed by batch finishing for final matte grade adjustment.

Preliminary pilot-plant testwork for the ISACONVERT process used iron-silicate based slags for converting two different primary matte feed grades as shown in Table I. Final mattes were produced containing between 0.7–13.5 wt.% iron from Matte 1 feed[16] and 2.2–10 wt.% iron from Matte 2 feed.[9] The results of the preliminary iron-silicate slag converting test work highlighted that production of Bessemer 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. Therefore, the applicability of an alternative slag system was considered.

Table I. Primary Smelting Nickel/PGM Matte Converted during 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
SiO_2	—	0.3

Nickel matte converting using calcium ferrite slag at the commercial scale has been successfully applied by SMC in TBRC's, producing a Bessemer matte containing about 2 wt.% iron since 1991.[12] The TBRC process is a batch process, similar to Peirce-Smith converters. 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.[14] 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 process and other processes to use calcium ferrite slags for copper production,[7,8,23] the application of this slag system to a continuous TSL process for nickel/PGM matte production was investigated by XT.

The calcium ferrite slag system has been successfully applied to continuous copper converting technologies since the mid-1970s.[23] The beneficial properties of calcium ferrite slags, for copper converting, were established and outlined in the 1980s by the research of Yazawa[24,25] and Takeda.[26] 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. Font[27]

Table II. Summary of Comparison between Calcium Ferrite and Iron-silicate Slag

Conditions at Fe < 4wt.% in Matte	Calcium Ferrite Slag	Iron-silicate Slag
Valuable metal distribution to matte (Ni, Cu and Co)	Higher	Lower
Impurity distribution to slag (As and Sb)	Higher	Lower
Minimum slag liquidus temperature (FactSage)	~1,250ºC	>1,400ºC
Fluidity	Higher	Lower

Table III. Range of ISACONVERT™ Slag Compositions

Element	Range (wt.%)
Ni	4.1–12.8
Cu	0.9–2.3
Co	1.6–2.9
Fe	46.2–51.0
CaO	11.9–15.6
SiO_2	1.7–2.2

and Henao[28] researched the application of calcium ferrite slags for nickel matte converting in lab-scale test-work. These researchers equilibrated matte-slag melts at 1,500ºC or 1,600ºC for set time periods at a specific fixed oxygen (Po_2) and sulfur dioxide (Pso_2) partial pressures (set by S_2/SO_2 and CO/CO_2 ratio control). At the end of each equilibrated test, quenched samples of matte and slag were taken for assay. The results indicated that, when compared to iron-silicate slags, calcium ferrite slags achieved higher valuable metal recovery (Ni, Cu, and Co) whilst increasing the distribution of impurity elements (As and Sb) to the slag phase.[27,28]

XT has used the thermodynamic modeling package FactSage[29] to confirm that the beneficial properties of the calcium ferrite system, in terms of fluidity and ferric iron capacity, also apply to the process of converting nickel/PGM matte. These modeling results, combined with the fundamental research,[27,28] are summarized in Table II.

PILOT-PLANT CONTINUOUS CONVERTING USING CALCIUM FERRITE SLAGS

The objective of the pilot-scale converting test-work was to confirm and demonstrate the nickel/PGM ISACONVERT process chemistry for converting high iron primary smelting matte feed to low iron Bessemer mattes utilizing a calcium ferrite based slag. The details of the ISACONVERT pilot-plant facility have been published elsewhere.[9] The typical primary smelting matte composition used for all ISACONVERT test work with calcium ferrite slags were similar to the "Matte 2" composition shown in Table I. The primary smelting matte was successfully converted to mattes with iron contents ranging from 2.6 wt.% to 8.0 wt.% Fe.

The tests involved charging solid matte and limestone flux to the pilot furnace at a rate of 100–150 kg/h of "as received" solid matte. Converting air and oxygen were metered through separate rotameters at a ratio to yield 25–35 v/vol.% total oxygen enrichment. Natural gas was injected down the lance as trim fuel to maintain bath temperatures between 1,300–1,380ºC.

The pilot-plant tests revealed that fluid slags were produced under all test conditions. Compositional ranges for the ISACONVERT slag produced in the test-work are shown in Table III.

The distribution coefficients for nickel, copper and cobalt, as defined by Equation 1, are shown as a function of matte grade (summation of mass percent of nickel, copper and cobalt) in Figure 3 to Figure 5, respectively. These figures compare the distribution coefficients from the ISACONVERT calcium ferrite process test-work with Peirce–Smith converters and TSL test-work using an iron-silicate based slag. 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;[9] and results from a sampling campaign of a Peirce-Smith converter blow at the Xstrata Nickel (XNi) Falconbridge smelter[30] and the Vale Inco Thompson smelter.[31]

$$L_X^{s/m} = (\text{wt.\% X in slag})/(\text{wt.\% X in matte}) \quad (1)$$

where L – distribution coefficient, s – slag, X – element which is the focus of the distribution, m – matte.

A comparison of the both the pilot-plant and smelter survey data shows that the nickel (Figure 3) and cobalt (Figure 5) distributions to slag are lower for the nickel/PGM ISACONVERT calcium ferrite slag process, when compared to iron-silicate slag processes. Figure 5 shows that the nickel/PGM ISACONVERT process using calcium-ferrite slag is vastly superior with respect to cobalt distribution with a greater than 40% reduction in the cobalt distribution to slag, at matte grades above 76 wt.%. The distribution of copper (Figure 4) to slag was lower for the ISACONVERT calcium ferrite process but only at high matte grades corresponding to Bessemer matte production. There was insufficient information for the calculation of the copper distribution coefficient in the XNi Smelter data.[30] The target grade for nickel/PGM Bessemer matte is typically matched to the requirements of the downstream refinery which 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 nickel/PGM ISACONVERT calcium ferrite process test work and all other iron-silicate slag results[9,30,31] is shown in Figure 6. At a fixed iron in matte concentration the nickel/PGM 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 result of lower sulfur concentrations within the matte phase, when compared to iron-silicate slags processes, refer to Figure 7. Feed matte to the nickel/PGM converting process is typically sulfur deficient, refer to Table I, with calcium ferrite slag converting allowing for further metallization of the matte to less than 15 wt.% sulfur. Iron-silicate nickel matte converting processes generate matte that is less sulfur-deficient, at a minimum of 20 wt.% sulfur, which consequently results in a lower matte grade than that achieved with the nickel/PGM ISACONVERT process. Mineralogical analysis of Peirce-Smith converter matte has revealed that metalized phases with the Bessemer matte are nickel-dominant and act as collec-

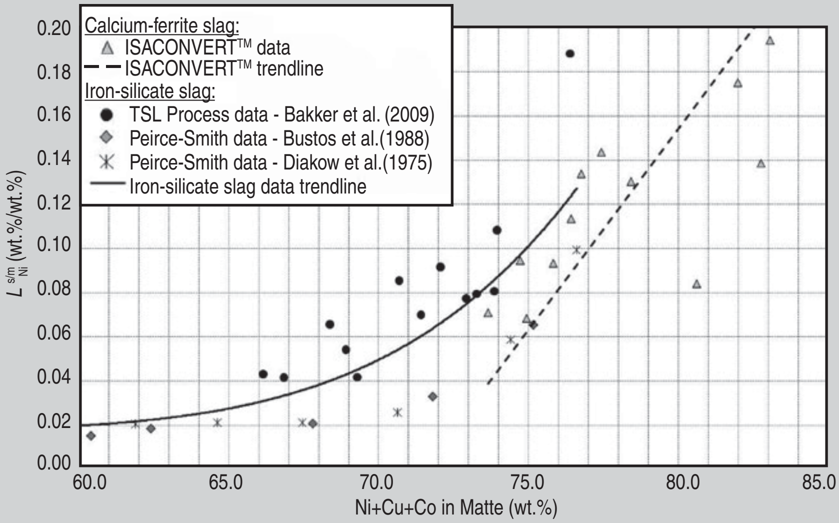

Figure 3. Distribution coefficient of nickel, between slag and matte, as a function of Bessemer matte grade (Ni+Cu+Co wt.% in matte).

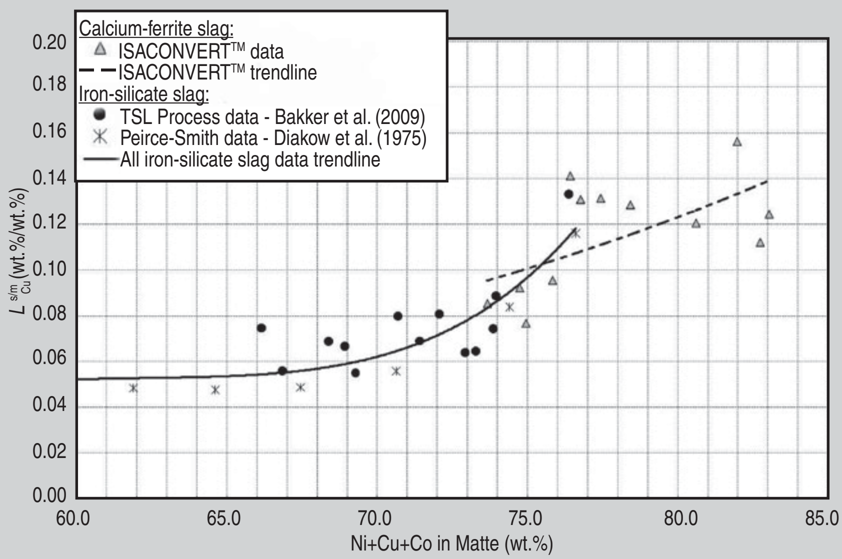

Figure 4. Distribution coefficient of copper, between slag and matte, as a function of Bessemer matte grade (Ni+Cu+Co wt.% in matte).

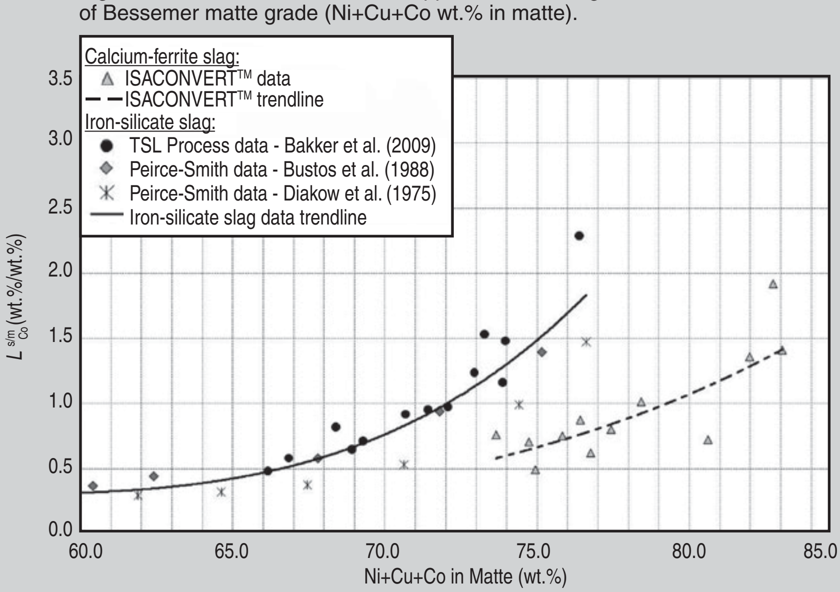

Figure 5. Distribution coefficient of cobalt, between slag and matte, as a function of Bessemer matte grade (Ni+Cu+Co wt.% in matte).

tors for PGMs.[32] The increased metallization of the ISACONVERT process (refer to Figure 7) should therefore 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.

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 copper converting can be applied equally to 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) It is a one-step, one-furnace converting process that can utilize high levels of oxygen enrichment coupled with minimal air dilution. (3) Solid matte can be used as the feed material, eliminating molten matte ladle transfers, further reducing fugitive emissions, and 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 copper/nickel matte converting has been successfully demonstrated on the pilot scale. Results have shown that when compared to iron-silicate slag processes the nickel/PGM ISACONVERT calcium ferrite process: (1) Produces a higher grade matte (summation of mass percent of nickel, copper, and cobalt in the matte) at Bessemer matte conditions through the production of a matte with a lower final sulfur concentration. (2) Achieves improved recovery of valuable metals to the Bessemer matte. The latter lowers distribution of nickel and copper to slag, which gives greater than 40% lower distribution of cobalt to slag.

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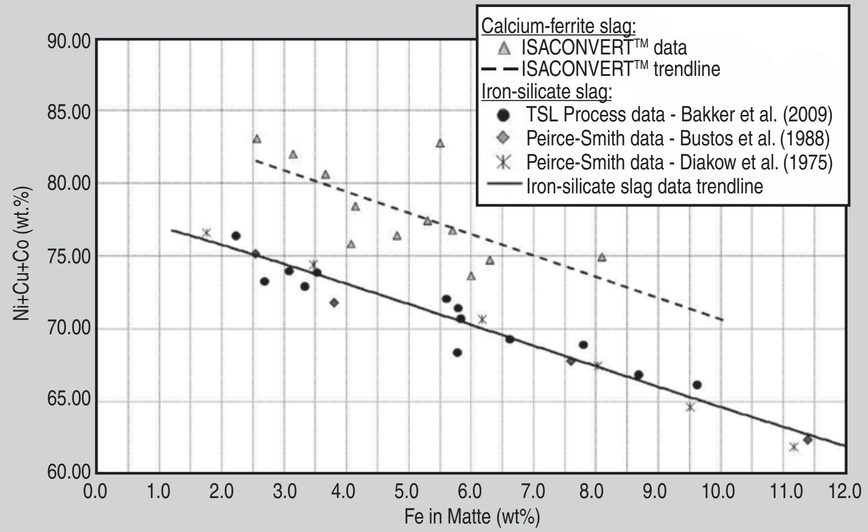

Figure 6. Matte grade (Ni+Cu+Co wt.%) as a function of iron in matte.

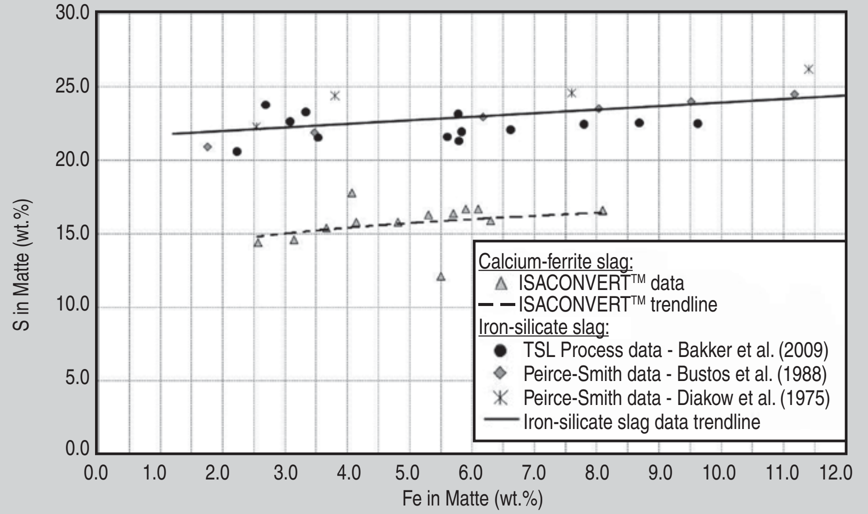

Figure 7. Sulfur concentration in the Bessemer matte as a function of iron in matte.

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