Completing the Copper Smelter Flowsheet - ISASMELT™ and ISACONVERT™

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Abstract:

ISASMELT™ technology is based on the use of an elegant furnace system design which uses submerged lance technology to provide highly efficient mixing and reaction of feed materials in a molten slag bath. Within Peru the ISASMELT™ technology has been applied to the Southern Copper Ilo Smelter, part of Grupo Mexico. Southern Copper selected the ideal technology to meet their sulphur capture and particulate emissions requirements whilst minimising capital and operating costs. The commissioning of the ISASMELT™ in 2007 marked the modernisation of the primary smelting section of their smelter, with traditional batch converters still used for the secondary smelting stage of the copper production flowsheet. At the time the ISACONVERT™ process had yet to be demonstrated on the industrial scale.

However, with the recent success of the ISACONVERT™ Furnace at the Kansanshi Copper Smelter, both stages of the continuous copper smelting flowsheet have now been proven on an industrial scale. The ISACONVERT™ Furnace allows substantial improvements to environmental performance and CAPEX employed, compared to the incumbent copper converting technology. The small footprint of the ISACONVERT™ Furnace permits brownfield smelter upgrades, even at sites with tight space allocations, like what was completed at Southern Copper for the original ISASMELT™ installation in 2007. This paper reviews how the completion of the copper smelting flowsheet, utilising both the ISASMELT™ and ISACONVERT™ technology, allows for significant advantages for new and existing real-world operations.

1 Introduction

The ISASMELT™ top submerged lance (TSL) technology was developed at Mount Isa Mines (now part of Glencore) during the early 1980s. It was identified that the smelter was running an old technology, a reverberatory furnace, and required significant quantities of fuel to smelt the copper concentrate mined in the area. The concepts for the technology were jointly developed with the Commonwealth Scientific Industrial Research Organisation (CSIRO) in Australia and then pilot tested on a 250 kg/h test rig in Mount Isa during the 1980s.

At Mount Isa Mines (MIM), the ISASMELT™ was successfully progressed from the pilot plant scale to industrial implementation and commercial scaling of the furnace technology. The goals of the project were quickly achieved, with a 93% reduction in the energy consumed per tonne of copper concentrate (Arthur, P. et al. 2003). This resulted in MIM being the lowest cost smelter in country, and one of the lowest cost operations globally (Arthur, P. et al. 2003).

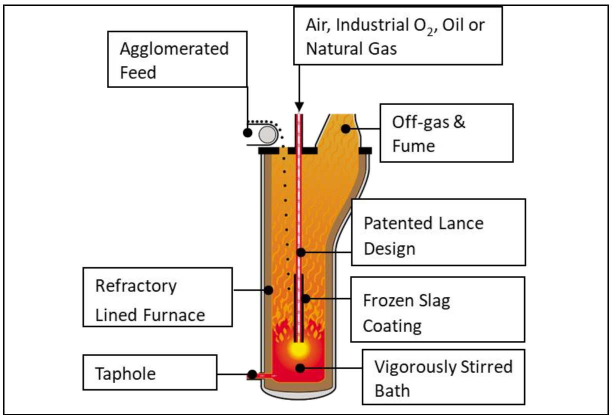
Due to the success of the ISASMELT™ at MIM, the technology has been installed at more than 20 sites around the world. It has been proven to smelt over 200 t/h of dry concentrate feed (Vries, D. et al., 2016) and treat a variety of feed materials including nickel, lead, and copper concentrates and secondary materials (Nicol, S. et al 2022). It is currently one of the leading copper smelting technologies.

Due to several unique design features, the ISASMELT™ furnace can easily be installed in brownfield smelters and is able to handle concentrates with high levels of impurities with very low $SO_{2(g)}$ fugitive emissions to the environment. Developments in the ISASMELT™ technology have led to the ISACONVERT™ technology, used for the continuous converting of copper matte to produce blister copper (Edwards, J. and Alvear, G. 2007). Both the ISASMELT™ and ISACONVERT™ technology are considered the best available technology in a range of jurisdictions around the world.

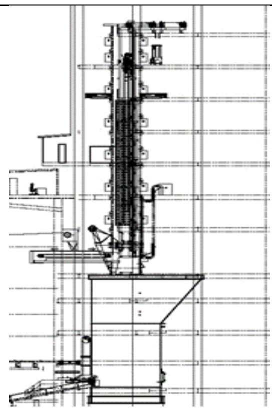
2 ISASMELT™ and ISACONVERT™ Technology

ISASMELT™ and ISACONVERT™ furnaces are modern bath-smelting processes for the smelting of non-ferrous materials to produce various matte, slag, and metal products. In a copper smelting application, the ISASMELT™ furnace is used to smelt copper concentrate to produce a copper matte and the ISACONVERT™ furnace is used to smelt this copper matte to produce blister copper.

The ISASMELT™ and ISACONVERT™ furnaces, depicted in **Figure 1**, are cylindrical vessels with a flat roof. In an ISASMELT™ furnace, the vessel is refractory lined and regularly achieves campaign lives of 4 years operation, without copper coolers (Nikolic, S., et al., 2019). Unlike flash furnaces, there is typically no need for mid-campaign shutdowns for refractory repair. An ISACONVERT™ furnace is also lined with refractory with optional high intensity copper coolers in the lower sections of the furnace. A centrally located submerged lance injects air, oxygen, and fuel into a molten slag bath. This blast of air, oxygen, and fuel down the lance oxidises and violently agitates the liquid slag to ensure a rapid reaction between the feed materials and the oxidised slag. A frozen layer of slag forms on the outside of the lance and protects it from the aggressive environment in the furnace. The ISASMELT™ furnace products, matte and slag, are tapped simultaneously through water-cooled copper tapholes. In an ISACONVERT™ furnace, the metal and slag are tapped through dedicated tapholes at two different levels within the furnace.



a) ISASMELT™ and ISACONVERT™ major features



b) ISASMELT™ and ISACONVERT™ General Arrangement

Figure 1: ISASMELT™ and ISACONVERT™ Technology

3 Impurity Control with ISASMELT™ and ISACONVERT™ Technology

Managing the recirculating load and elimination of minor elements is critical for the successful operation of a copper smelter and associated electro-refinery. Of particular importance is arsenic and bismuth, both of which are rapidly reaching levels unmanageable with smelting flowsheets based on other technologies (Avlear, G., Risopatron, C. and Pease, J., 2020). In a conventional flash smelting flowsheet, these elements are enriched in the smelting dusts and copper anodes. To remove these impurities from the flash smelter, a portion of the smelter dust is bled and either leached or dumped. In addition, the electro-refinery anode slimes and electrolyte from a flash smelting flowsheet undergo extensive purification.

The ISASMELT™ technology efficiently fumes the arsenic and bismuth in the feed materials. This reduces the arsenic and bismuth in the copper anodes to low levels, significantly simplifying the electro-refinery operation and costs. In addition, the ISASMELT™ furnace typically generates less than 1.5% dust from mechanical carry-over. This results in a low volume of dust, highly enriched in arsenic, bismuth, and other minor elements, which is more cost efficient to leach or dispose of.

The ISASMELT™ can be operated to maximise the rejection of specific minor elements. This is achieved by adjusting the lance oxygen enrichment, matte grade, furnace temperature, and slag chemistry targets. The rejection of key impurities into the dust for a typical ISASMELT™ furnace (Player, R., 1996) are:

- Lead (Pb) – 30%
- Arsenic (As) – 90%
- Bismuth (Bi) – 90%
- Cadmium (Cd) – 80%

Higher rates of rejection into the dust are possible, with the equipment and process able to be customised for specific chemistry challenges.

In an ISASMELT™ operation with high levels of impurities, the entire dust stream is processed with the Albion Process™ to extract and stabilise the impurities enriched in the dust stream (Tan, P. et al, 2011). The copper in the dust is recovered and recycled back into the smelter, resulting in a high overall copper recovery. The impurities, once stabilised in a low volume residue, can be disposed of in an environmentally safe manner. A 3D layout of an ISASMELT™ and ISACONVERT™ Dust Albion Process™ is shown in Figure 2.

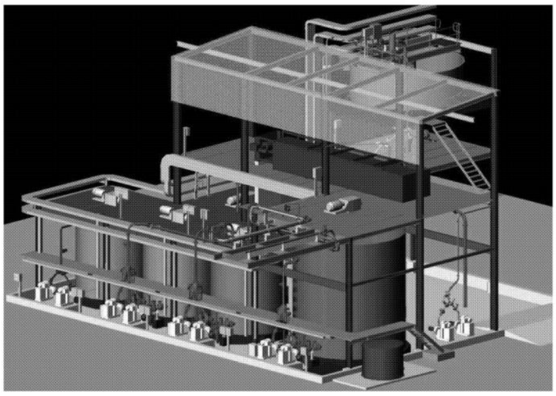


Figure 2: ISASMELT™ and ISACONVERT™ Dust Albion Process™ (Tan, P. et al, 2011)

4 ISACONVERT™ – Industrial Scale Continuous Converting

The ISACONVERT™ furnace has been successfully installed and proven on an industrial scale at the Kansanshi Copper Smelter. The hot commissioning and first operating campaign were performed in mid-2019. Between 2019 and 2021, the ISACONVERT™ furnace was operated in four short campaigns, with the campaigns required due to site requirements such as acid plant availability, concentrate stocks, and COVID-19 lockdowns. During this period the matte treatment rate steadily increased from an average of 35 tonnes per day to an average of 245 tonnes per day. No refractory relining or modifications were made to the furnace or the coolers during this period, with some minor changes made to the tapping systems (Mwanza, T et al, 2022). The furnace was ramped-up to name-plate capacity in less than 6 months, unparalleled in the smelting industry where other furnace technologies require 18 months to achieve name-plate capacity (Newman, C., et al. 1998).

The following sections will describe the successful application of fundamental research, pilot plant work, and operational experience to the industrial-scale implementation of the ISACONVERT™ technology. Specifically, the chemistry of the slag and copper products will be outlined and the emissions reductions, compared with the incumbent batch converting technology, will be explored. A summary of the operating conditions possible with the ISASMELT™ and ISACONVERT™ technologies is given in Table 1.

Table 1: ISACONVERT™ and ISASMELT™ Operating Conditions

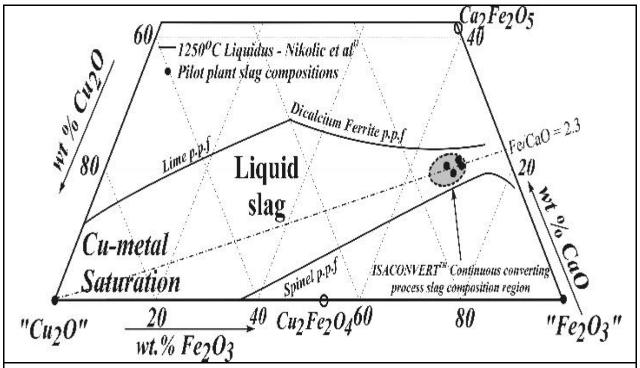
Parameter	Value
Lance Total Flowrate	200 - 71,000 Nm^3/h proven
Furnace Fuel/Reductant	Coal, Plastic, Coke, Secondary Scrap, Hydrogen
Furnace Trim Fuel Supply	Natural Gas, Diesel, Pulverised Coal, Waste Oil, Hydrogen
Lance Oxygen Enrichment	21 (air) to 95 vol% O_2 proven
Availability	92% (ISASMELT™)
Taphole Types	Combined (ISASMELT™) Separate (ISACONVERT™)
Furnace Campaign	4+ years (ISASMELT™)
Ramp-Up to Design Capacity	3 months (ISASMELT™) 6 months (ISACONVERT™)
Furnace Operation	Continuous
Feed Size	Up to 100 mm proven
Feed Moisture	0-10 wt%
Feed Delivery System to Furnace	Vibrating or Belt-Style for Coarse Feed Pneumatic Injection for Fine, Volatile, or Low-Density Feed

4.1 Slag Chemistry

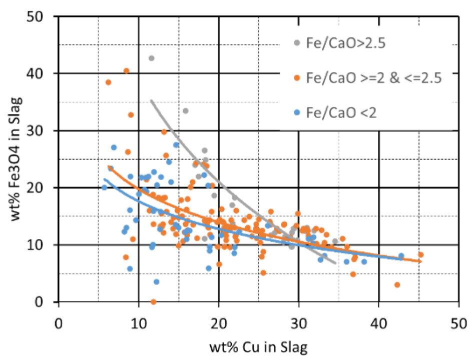
During the development of the ISACONVERT™ process, it was noted that both iron-silicate (fayalite) based slags and calcium ferrite-based slags can be used for continuous converting. For an operable furnace, a fully molten slag is required, necessitating control of both the silica or lime-based flux and the copper in the slag It was determined that the calcium ferrite slags are preferable to the iron silicate slags as they result in lower flux additions and lower copper loss to the slag (Yazawa, A. et al. 1981). This reduces both the materials being recycled in the smelter and the overall smelting cost.

Yazawa (Yazawa, A. and Takeda, Y., 1982) first undertook fundamental research into calcium ferrite slags for copper smelting processes. Takeda (Takeda, Y., et al. 1980) and Nikolic (Nikolic, S. et al 2009) performed fundamental research into the complex quaternary slag system at metallic copper saturation at conditions representative of the ISACONVERT™ process. The research involved experimental phase equilibria at temperatures (1250°C) and oxygen partial pressures relevant to continuous copper converting with slags in the Fe-Ca-Cu-O and Fe-Si-Cu-O systems at copper saturation (Nikolic, S. et al 2008a, 2008 b, 2009b). Based on the slag fundamentals that were established by this research, a comprehensive series of continuous converting pilot plant tests were performed. From the fundamental and pilot tests, it was determined that the ISACONVERT™ process can be implemented on an industrial scale with a slag that has chemistry targets for the Fe/CaO ratio of approximately 2.4 wt/wt and about 15 wt% Cu in slag. The operable slag is shown in the grey shaded area of Figure 2 (Nikolic, S., et al., 2009a). This slag composition is fully molten at temperature, superheated above the liquidus temperature. This slag sits between the spinel and dicalcium ferrite liquidus isotherms.

The industrial ISACONVERT™ furnace operated at Kansanshi was operated with a range of different slag chemistry targets to further assess the furnace performance. It was demonstrated that the furnace was able to be operated outside of the region previously established. However, the optimal furnace performance is obtained when operating within the window previously established. The slags that were able to be operated in the Kansanshi ISACONVERT™ furnace are also shown in Figure 3.



Liquidus Isotherm in the "Cu_2O" -CaO- "Fe_2O_3" system at copper saturation at 1250 °C [5] with ISACONVERT™ slag compositional region shown in grey



Magnetite (Fe_3O_4) vs Cu in Slag for industrial ISACONVERT™ Slags

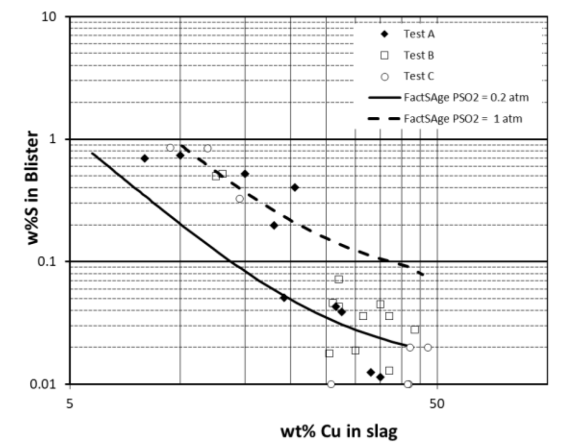
Figure 3 Continuous Converting Slag Phase Diagram and Pilot Plant Testing versus Commercial Application at Kansanshi

4.2 Sulphur Content of Blister Copper

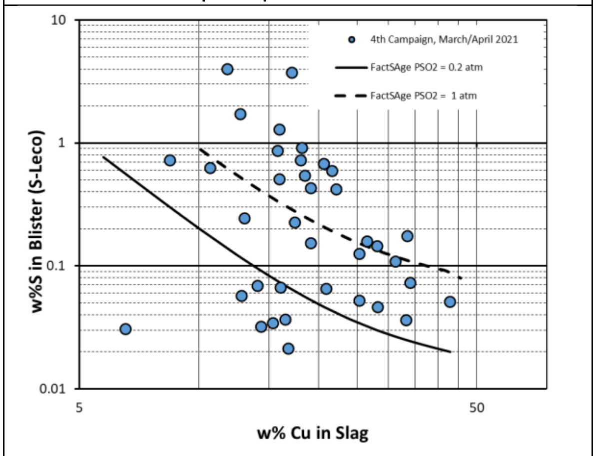
While several technical solutions have been extensively proven in industry, the blister copper produced by continuous converting processes typically have higher sulphur concentrations than blister produced by batch converting processes. This is a direct result of balancing the sulphur concentration in blister with copper losses to the converting slag.

The ISACONVERT™ furnace has lower sulphur concentrations than other continuous converting operations, a direct result of the highly agitated bath improving reaction kinetics. Both fundamental and pilot test work was initially performed to determine the likely concentrations in an industrial application of the technology. A plot of the relationship between the copper dissolved in the slag and the sulphur in the blister, as measured during ISACONVERT™ pilot plant trials is shown in Figure 4. In addition, the relationship is also shown for the full scale Kansanshi ISACONVERT™ in this figure.

The relationship observed in both pilot and industrial applications of the ISACONVERT™ technology closely aligns with the equilibrium FactSage (Bale C., Pelton A. and Thompson W.T., 2022) predictions for a calcium ferrite slag at blister copper saturation at 1230°C. FactSage predictions at sulphur dioxide partial pressures of 0.2 atm and 1 atm are shown with the pilot plant and commercial scale data in Figure 3. As expected with a highly agitated bath, the industrial furnace conditions are near equilibrium conditions. Comparing the pilot and industrial ISACONVERT™ results, some differences are observed. This is potentially a result of the variability in the plant conditions during full-scale operation, and material sampling / assaying errors.



Sulphur (wt%) in blister and copper in slag measurements from several ISACONVERT™ pilot plant trials.



Sulphur (wt%) in blister and copper in slag from plant assays at KCS ISACONVERT™ during March-April 2021

Figure 4: ISACONVERT™ Sulphur in Blister and Copper in Slag Measurements from Pilot and Commercial Scale Applications

Once operations have gained an adequate understanding of the process it is expected that the sulphur concentration in the blister copper for an industrial ISACONVERT™ furnace would be between 0.1 and 0.3 wt% S. Although levels of sulphur in blister much higher than this are processed in several anode furnaces around the world, it is higher than that observed at a typical copper smelter.

To handle these higher sulphur levels, two potential options have been established:

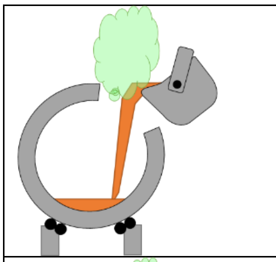
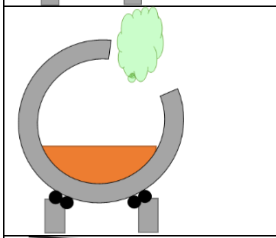
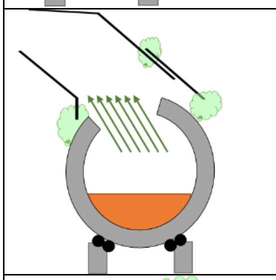
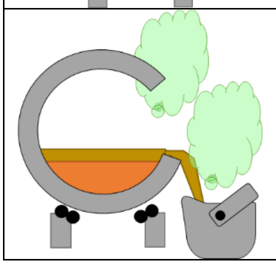
1. Installing a Rotary Oxidation Furnace (ROF) for holding blister copper:
    - Provides initial desulphurisation prior to the anode furnace.
    - Acts as surge capacity between the ISACONVERT™ and anode furnace.
    - Allows the ISACONVERT™ to target higher sulphur in blister, reducing the copper content in recycled calcium ferrite slag.
    - Provides the physical capacity for the consumption of copper scrap like anode wheel rejects or refinery spent anode.
2. Minor modification to the existing anode furnaces (Ramachandran, V. et al. 2003) to enhance the rate of desulphurisation by installing:
    - Additional tuyeres and/or
    - Porous plugs for bath stirring

Both the ROF concept, as practiced at the Horne Smelter in Canada, and the modified anode furnace, as practiced at American, African, and Australian copper smelters, are viable options for greenfield and brownfield applications (Ramachandran, V. et al. 2003) .

4.3 Environmental performance of converting furnaces

Batch converting furnaces, like the Peirce Smith (PS) converter and Hoboken converter, have long been used worldwide. Their popularity and longevity as the incumbent copper converting technology is due to their operational versatility and the significant industrial precedence of the technology. Despite these advantages, they suffer from safety concerns with foam overs and molten material handling, short campaigns with rapid refractory wear at the tuyere line, high labour requirements, direct coupling with both the smelting and fire-refining equipment, and, of increasing importance, poor fugitive emissions controls.

In terms of environmental performance, the existing batch converters require significant capital expenditure to meet emissions requirements. These expenses are typically greater than the cost to retrofit the converting aisle with low cost ISACONVERT™ technology. The cost of these upgrades is due to the fugitive emissions from molten matte transfer in ladles, charging and skimming materials, and the batch converter roll in and roll outs. The typical batch steps leading to these emissions are shown in Figure 5.

	a) Emissions during matte charging
	b) Emissions during furnace roll in/out
	c) Leakage during slag blow
	d) Emissions during slag skimming

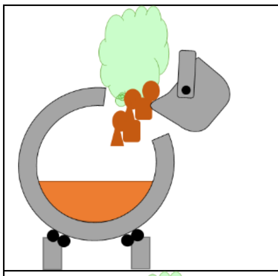
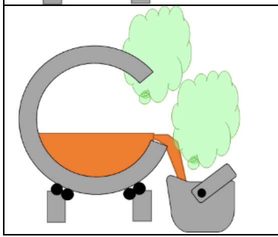
	e) Emissions during charging scrap and reverts
	f) Emissions during copper pour

Figure 5: Batch Converting Steps Leading to Emissions

The extent of hooding and equipment required to meet current environmental standards is shown in Figure 6.

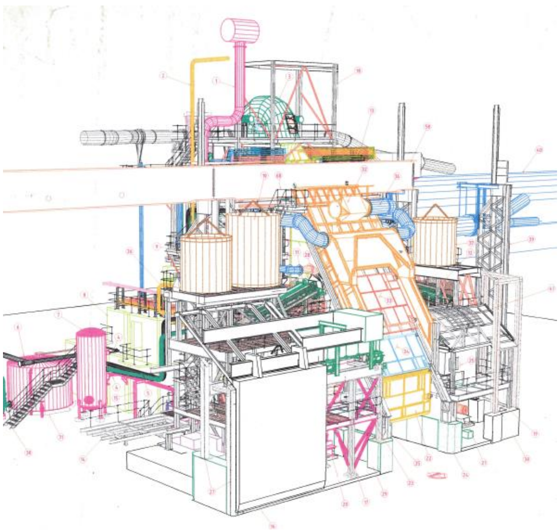


Figure 6: Hooding of a batch converter to meet stringent emissions requirements.

Two smelters utilising batch converters have recently been upgraded, at significant expense. At the Hayden smelter, Peirce Smith Converters were used to convert molten matte from a flash furnace, with 5% of the sulphur in the feed being emitted as $SO_{2(g)}$ to the surrounds, prior to upgrading the converter emissions controls (Rusell, M. et al. 2019). At the Freeport Miami smelter, Hoboken Converters are used to convert the molten matte from the ISASMELT™ furnace. This Hoboken Converter has inherently lower sulphur emissions than a Peirce Smith Converter, with 2% of the sulphur in the feed emitted to the surrounding environment as $SO_{2(g)}$ (Jones, D., et al. 2019). Both smelters were able to achieve the required emissions limits (<0.1% of sulphur in the feed emitted as fugitives) by upgrading the converting aisles, but the costs for these upgrades was significant at $*270* million USD (Wichner, D., 2019) and $450 million USD respectively *(*Davis, T., 2014*)*.

Table 2: Emissions Capture Upgrade Costs

Site	Asarco Hayden	Freeport Miami	Freeport Miami
Furnace Type	Peirce Smith	Hoboken	ISASMELT
Emissions (%S in Feed)	5%	2%	<0.02%
Vessels (#)	4	5	1
Copper Production (kt/a)	250	190	190
Matte Grade (wt% Cu)	58	60	58
Upgrade Cost (Million USD)	270	450	0
Emissions Achieved (% S in Feed)	<0.1	<0.1	<0.02

By comparison, the ISASMELT™ and ISACONVERT™ furnaces have extremely low fugitive emissions. At the Miami smelter, the ISASMELT™ and associated electric furnace only release 0.01-0.02% of the sulphur in the feed as $SO_{2(g)}$ in fugitive emissions (Jones, D., et al. 2019). Modern ISACONVERT™ and ISASMELT™ furnaces can achieve significantly lower fugitive emissions than this via low-cost fugitive emission control techniques. These include:

1) Advanced furnace draught and pressure control systems
2) Induced Draft Ports – Glencore Technology proprietary equipment
3) Sealed Lance Ports – Glencore Technology proprietary equipment

4) Sealed Feed Ports – Glencore Technology proprietary equipment
5) Secondary hooding on furnace ports
6) Taphole and launder hooding
7) Shortened matte launders

The cost for installing these emissions control systems is typically less than 5% of the capital cost for an ISASMELT™ or ISACONVERT™ furnace. This is due to the continuous nature and steady control of the process, significantly reducing the volume of gas generated during an emission event and restricting this emission to several known locations only. In addition, the small furnace ports and openings decreasing the size of the emissions control equipment required.

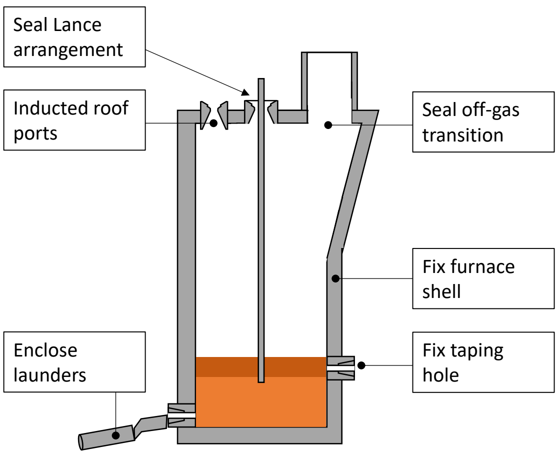


Figure 7: Advanced Emissions Controls on ISASMELT™ and ISACONVERT™ Furnaces.

5 ISASMELT™ and ISACONVERT™ Technology Installations

The ISASMELT™ and ISACONVERT™ Technology can be installed in both greenfield and brownfield applications. The following sections outline how this technology is implemented in both scenarios.

5.1 ISASMELT™ Technology for Brownfield Smelter Upgrades

In an ISASMELT™ Furnace upgrade of an existing smelter, the primary smelting furnace is upgraded with an ISASMELT™ Furnace. The ISASMELT™ furnace is tied into the existing off gas and feed handling systems, with some modifications to these systems. The furnace is installed near the existing converter aisle, with a slag settling furnace positioned such that matte ladles can be transported directly by the converter crane.

Due to the small footprint of the ISASMELT™ furnace and associated equipment, the furnace is installed while continuing to operate the existing smelter. This minimises production downtimes during the technology transition. In addition, due to the fast ramp-up of approximately 3 months, once the existing primary furnace is taken out of operation, there is minimal impact on the sites annual copper production.

The brownfield upgrade of a smelter with the ISASMELT™ technology was successfully performed at Southern Copper Corporation Ilo Smelter. At this site, the ISASMELT™ Furnace was installed to decrease fuel consumption onsite by more than 65%, decrease $SO_{2(g)}$ emissions from the smelter by >3% of the sulphur in the feed, and to simplify the smelting flowsheet (Walqui, H. et al. 2006, 2007).

5.2 ISACONVERT™ Technology for Brownfield Smelter Upgrades

The ISACONVERT™ technology can be installed in brownfield applications to upgrade an existing smelter. In this application, the batch converting furnaces would typically be replaced by a single ISACONVERT™ furnace. This would be associated with a significant reduction in fugitive emissions, a simplified smelter layout, and a more flexible (de-coupled) smelter. To perform this upgrade, a matte granulation or crushing system and a matte blending and stockpile area is required to prepare the feed for the ISACONVERT™. In addition, upgrades to the existing Anode

Furnaces or the installation of a Rotary Oxidation Furnace (ROF) is required. The cost for this upgrade is usually significantly less than the cost to upgrade or install a batch converter aisle that meets modern emissions limits.

5.3 Double ISA Flowsheet for Greenfield Applications

The Double ISA flowsheet for the smelting of primary copper concentrate offers the most environmentally friendly, energy efficient, flexible, automatable, easy to operate, and low-cost smelting option for smelting copper materials. In addition, the ISASMELT™ technology has demonstrated the ability to process both primary copper concentrates and a wide range of secondary materials, including e-waste, copper scrap, copper sludges, dusts, reverts, and slags simultaneously in the feed blend.

By installing the ISASMELT™ and ISACONVERT™ furnaces side-by-side in a single furnace building, a number of utilities, services, facilities, and spares can be shared between the furnaces (e.g. overhead lance crane and lance workshop). Due to the similarities of the furnace design and operation, and their proximity, the operators can work across both furnaces. By doing this there is a reduction in skilled labour requirements, a rapid smelter ramp-up, and the ability to implement continuous improvements swiftly. This results in an extremely compact and cost-effective layout, while still retaining a highly level of operational efficiency and flexibility. The Double ISA flowsheet is envisaged to be installed as a single line smelter, with existing smelter designs able to be used to install a smelter with a capacity anywhere between 1-500 kt/a of copper.

6 Conclusions

The ISASMELT™ and ISACONVERT™ furnace technologies are industrially proven and modern solutions for copper smelting. These two technologies can be installed in both greenfield and brownfield applications to upgrade smelters and to reduce environmental emissions. The furnaces can be installed in existing or new flowsheets with other technologies, or as a Double ISA flowsheet.

The two furnace technologies can process concentrates with high levels of impurities and with minimal $SO_{2(g)}$ emissions. The impurities, rapidly increasing in concentrate feeds around the world, can be concentrated in the dust stream and processed using Albion Technology™ to recover copper and produce a stable residue for disposal. Compared to expensive batch converting fugitive emissions hooding options, the ISACONVERT™ offers a low cost and flexible way to reduce $SO2_{(g)}$ emissions onsite.

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