Feasibility to Profitability with Copper ISASMELT™

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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. It is now successfully commercialised and has become the technology of choice for many new smelters and smelter modernisation projects, being extremely cost effective for smelting both copper concentrates and secondary materials. Ten copper smelters are now operating the process around the world. Two new furnaces were commissioned in 2009, while three more furnaces are under construction and are scheduled to be commissioned during 2010 and 2011.

Production capacities of more than 330,000 tonnes per year of copper are being achieved through a single ISASMELT™ furnace with instantaneous feed rates reaching up to 200 t/h.

Process development continues on the commercial scale plants at Mount Isa and elsewhere around the world. By employing the design and operational experience gained by Xstrata over more than 25 years of process development ISASMELT™ plants can be constructed in remote locations in a relatively short time and achieve rapid ramp up to design capacity with limited technical resource. As the family of ISASMELT™ licensees grows the members are able to share and capitalise on the knowledge and experience with their peers around the world.

This paper reports on copper ISASMELT™ projects completed in recent years and how licensees have progressed from feasibility studies to profitable operations using Xstrata Technology's technology transfer process.

1. Introduction

It was in 1975 when Mount Isa Mines Limited (MIM) set its sights on a new development occurring at CSIRO in Australia: the Top Submerged Lance (TSL) technology, a new concept for smelting using the Sirosmelt lance. MIM joined forces with CSIRO and participated in lab scale trials of the technology.

At that time, MIM was looking for new technologies that could be applied to its lead and copper smelter operations to reduce operating costs while improving the environmental performance. MIM's Mount Isa lead Smelter used a sinter plant and blast furnace for lead bullion production, while the copper smelter used a fluid-bed roaster and two reverberatory furnaces to produce copper matte. The matte was then converted to blister copper using Peirce-Smith converters [1].

MIM was seeking alternative smelting processes that would produce off-gases with higher SO_2 content so that the smelter gases could be treated and sulphur captured in an acid plant. MIM also needed to find a process with lower operating costs to remain cost effective with the steady decline in real metal prices.

While keeping an eye on the developments of other technologies MIM, jointly with CSIRO, developed the concepts of the Lead ISASMELT™ and Copper ISASMELT™ processes. These were pilot tested on a 250 kg/h test rig in Mount Isa in the early 1980s.

From the completion of the pilot scale tests a long history unfolded involving a multidisciplinary team of visionaries, who saw the technical and business potential that ISASMELT™ technology could offer. Over the years ISASMELT™ has progressed from a 250 kg/h pilot plant scale to industrial facilities that can run up to 200 t/h and treat a variety of materials including nickel [2], lead [3] and copper [4] concentrates and secondary materials.

Since the first plant was built at Mount Isa, twenty ISASMELT™ plants have either been constructed or are under construction. Figure 1 shows the location of the commercial plants that have been licensed to date

An important milestone in the market consolidation of the technology was when MIM became part of Xstrata plc in 2003. At that time MIM Process Technologies, the division that was responsible for the commercialization of the technology, became Xstrata Technology (XT). XT's mission was to market the core technologies developed in Xstrata's operating sites: IsaMill™ and Jameson Cell technologies in mineral processing, ISAPROCESS™ for the electrorefining and electrowinning of copper, the Albion atmospheric leaching process and the ISASMELT™ and ISACONVERT™ technologies for the smelting and converting of non-ferrous materials.

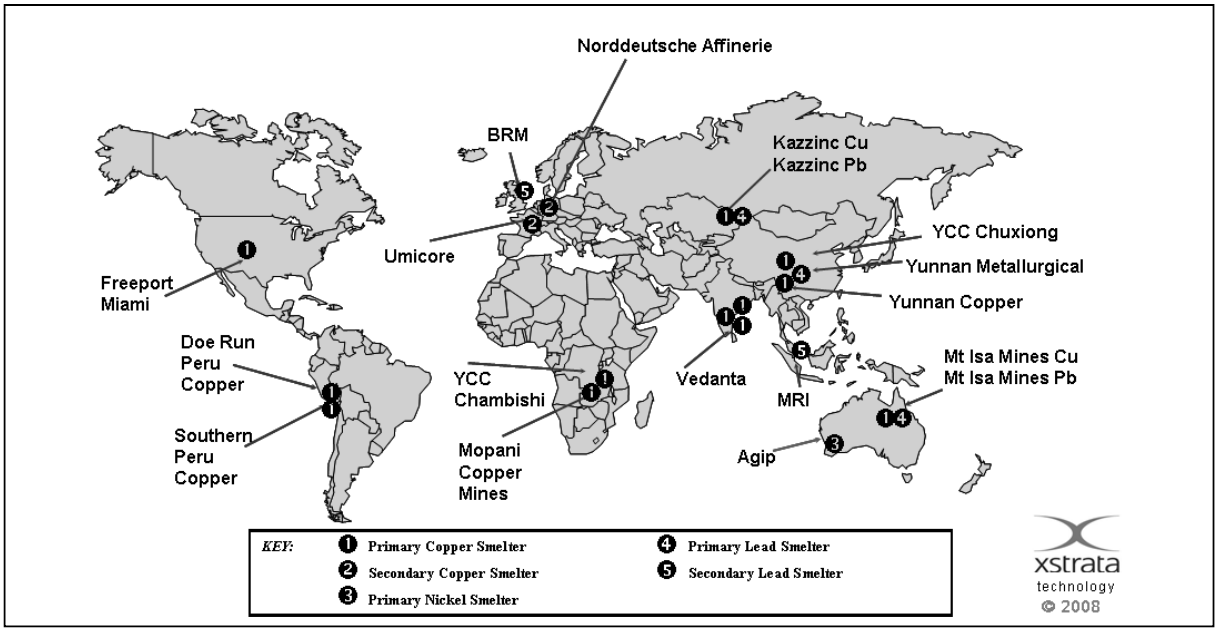

Figure 1: Location of ISASMELT™ Plants Licensed to Date

During 30 years developing and operating ISASMELT™ 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, operator training and commissioning systems. The combination of experience led to the development of the "ISASMELT™ technology package" that is licensed to external clients today [5]. 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 visits to fellow licensee sites and through regular licensee workshops arranged by XT at locations close to the ISASMELT™ installations, the most recent being at Arequipa, Peru in 2008 (Figure 2). It included a visit to the Southern Peru Copper Corporation (SPCC) ISASMELT™ plant.

Figure 2: Licensee Workshop in Arequipa, Peru, October 2008

2. The ISASMELT™ Principle

ISASMELT™ Concept

ISASMELT™ technology is based on the use of an elegant 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 an advanced process control system results in the furnace operation being largely automated. Being a vertical furnace with a small footprint it can be easily retro-fitted into existing smelters to either augment or replace existing technology. The furnace concept is shown in Figure 3.

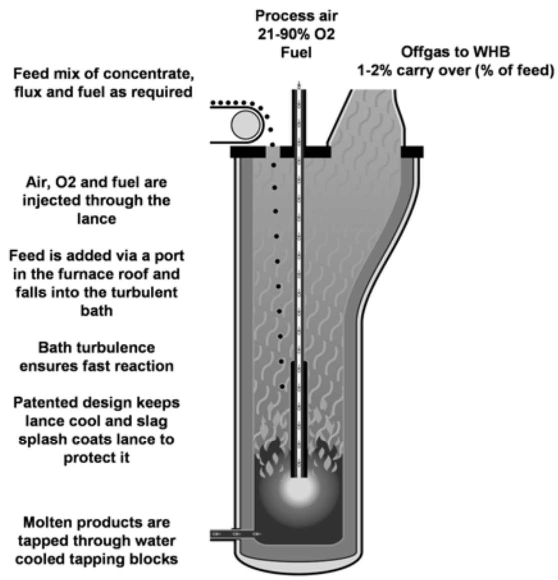

Figure 3: ISASMELT™ Process Concept

Copper ISASMELT™ Reaction Mechanism

The Copper ISASMELT™ process is a slag reaction process, where fresh feed is digested into the molten slag phase. It is in this phase where the main chemical reactions occur and oxidation of the feed takes place.

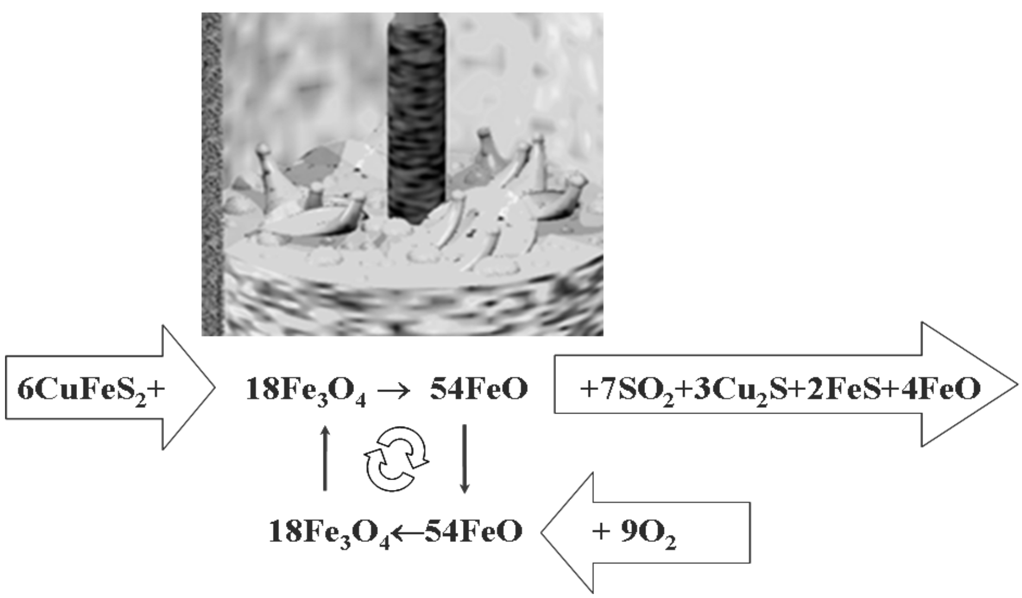

Figure 4: Cu ISASMELT™ Reaction Mechanism

The oxygen transfer process is achieved through the controlled oxidation of the slag (FeO) and subsequent formation of magnetite (Fe_3O_4) as shown schematically in Figure 4. It is the "liquid oxygen" from the magnetite ($Fe_2O_3 \cdot FeO$) that reacts with the concentrate and fluxes to form copper matte, a fayalite slag and SO_2 gas.

Slag – Matte Separation: The Role of the Rotary Holding Furnace

Copper matte and slag generated from the reactions occurring in the Copper ISASMELT™ furnace are tapped and mechanically settled in a separate furnace. The type of settling furnace will depend on the economics of each operation. XT supplies a proprietary technology known as the Rotary Holding Furnace (RHF). This process was developed at MIM and is currently used at the Mount Isa smelter, the Sterlite smelter in India, and the SPCC smelter in Peru. The RHF is a horizontal, cylindrical, refractory-lined furnace that allows mechanical settling of the matte and the slag. Typically, for ISASMELT™ furnaces with instantaneous feed rates greater than 150 t/h, the stream of slag and copper matte tapped from the ISASMELT™ furnace is fed to either of two RHF's operating in parallel.

The RHF has the following three primary functions:

- Holding function – it provides a storage location for copper matte; this provides surge capacity between the (upstream) continuous ISASMELT™ furnace and the (downstream) batch Peirce-Smith converters.
- Settling function – molten copper matte is separated via gravity separation from molten slag
- Separation function – molten slag is skimmed from the top of the RHF bath into a granulation system or ladle; molten matte can be poured from the lower portion of the RHF bath into a ladle for delivery to the converters.

The RHF has an entry port, or "feed port", to receive the mixed matte and slag stream tapped from the ISASMELT™ furnace. Matte and slag products are poured out of the RHF via a matte spout and slag spout respectively. These spouts are located at the far end of the RHF, resulting in maximum residence time for separation to occur. The RHF can be tilted away from the converter aisle to allow skimming of discard slag, or towards the aisle to allow pouring of matte. A hydraulic drive is used to rotate the furnace via a heavy duty chain and sprocket system. When pouring slag an automated system is used to provide slow and steady skimming of slag from the slag port. This system enables a slag skim that minimises the amount of matte carryover to the slag.

The temperature of the RHF is maintained by means of burners located in the roof and the end wall of the furnace.

Advantages of the RHF technology

The use of the Rotary Holding Furnace technology to hold, settle and separate copper matte and slag generated in the ISASMELT™ furnace has a number of advantages:

- No electrical energy required: The matte and slag are physically separated in the furnace without the need of electrical energy for reduction. RHF's have been applied for copper matte grades up to about 65% Cu.
- Low copper in slag can be achieved: The slag is slow poured via an automated system to minimize matte carryover to the slag.
- Avoids back-contamination of the matte with minor elements already deported to the slag phase: By avoiding reduction of the slag, the minor element distribution between the slag, matte and gas phase remains unchanged.
- Ability to provide matte to the Peirce-Smith Converters in a very short period of time: By tilting the furnace and pouring through the matte spout a 30 tonne matte ladle can be filled in one minute.
- Provision of a surge capacity between the smelting and converting processes.

3. Recent Copper ISASMELT™ Projects

Since the last review of the technology presented in the Copper/Cobre 2007 conference, in Toronto, Canada, new projects and plants were added to the list of Copper ISASMELT™ plants around the world. The new projects and plants are identified in Table 1. The SPCC project that was commissioned in the first quarter of 2007 is also included in Table 1.

Table 1: New Copper ISASMELT™ Projects Since 2007

Project	**Country**	**Design Capacity (t/y concentrate)**	**Commissioning Year**
Southern Peru Copper Corporation	Peru	1,200,00	2007
YCC Chuxiong	China	500,000	2009
YCC Chambishi	Zambia	350,000	2009
Kazzinc	Kazakhstan	290,000	2010
Doe Run Peru	Peru	280,000	2011
Sterlite III	India	1,360,000	2011

The new projects include plants of relatively small capacity like Doe Run Peru and Kazzinc with important strategic value as both plants will treat complex sulphide concentrates containing high contents of minor elements such as As, Pb, Zn and Sb. In these two cases the ISASMELT™ furnace's ability to eliminate highly volatile minor elements to the gas phase will contribute to producing a relatively clean copper matte compared with the product that could be produced by using alternative smelting technologies [6]. The application of the ISASMELT™ technology in Yunnan Copper Corporation (YCC) plants in Chuxiong, China and Chambishi, Zambia was the natural path to follow by this company after the successful implementation of their first ISASMELT™ plant at Kunming, China in 2002. Figure 5 shows a view of the ISASMELT™ plant in Chambishi that was commissioned in early 2009.

Figure 5: View of the YCC Chambishi ISASMELT™ Plant in Zambia

Kazzinc's Ust-Kamenogorsk Metallurgical Complex in Kazakhstan is a fully integrated plant, in which most by-products from each stage of the operation are enriched to form saleable metal products. A new copper smelter and refinery is being installed as part of the Kazzinc New Metallurgy Project. Figure 6 shows a view of the Kazzinc Copper ISASMELT™ Plant. In addition, the lead smelting process flowsheet will be upgraded by replacing the traditional Sinter Plant – Blast Furnace process with more modern technology in the form of a Lead ISASMELT™ Furnace that will produce a lead rich slag to feed an existing Lead Blast Furnace.

The copper smelter will use an ISASMELT™ furnace to produce copper matte. The matte and slag will be tapped from the ISASMELT™ furnace to an electric settling furnace. The matte will then be converted and refined to produce anode in a conventional Peirce-Smith converter/anode furnace aisle. Anode will then be refined using XT's ISAPROCESS™ technology. The Copper ISASMELT™ plant is scheduled to be commissioned in 2010.

Sterlite Industries (India) Limited recently decided to expand their copper smelting and refining complex at Tuticorin in southern India. They will build their third ISASMELT™ plant to continue their expansion in the copper business. The new smelter will be located adjacent to the current facility and will have a design throughput capacity of 400,000 tonnes per year of copper (equivalent to

1,360,000 tonnes of copper concentrate) through a single ISASMELT™ furnace. The matte and the slag from the ISASMELT™ furnace will be separated in two RHF's and the matte will be converted in Peirce-Smith converters. Anode copper will be refined using XT's ISAPROCESS™ technology.

Figure 6: View of the Kazzinc ISASMELT™ Plant in Kazakhstan

As a result of these new plant installations the Copper ISASMELT™ family has continued to grow, resulting in a transformation of the copper smelting industry. Figure 7 shows the increase in global capacity of Copper ISASMELT™ plants since the first commercial plants were commissioned in 1992. The total capacity of the installed Copper ISASMELT™ plants in 2011 will be over 9 million tonnes of copper bearing materials.

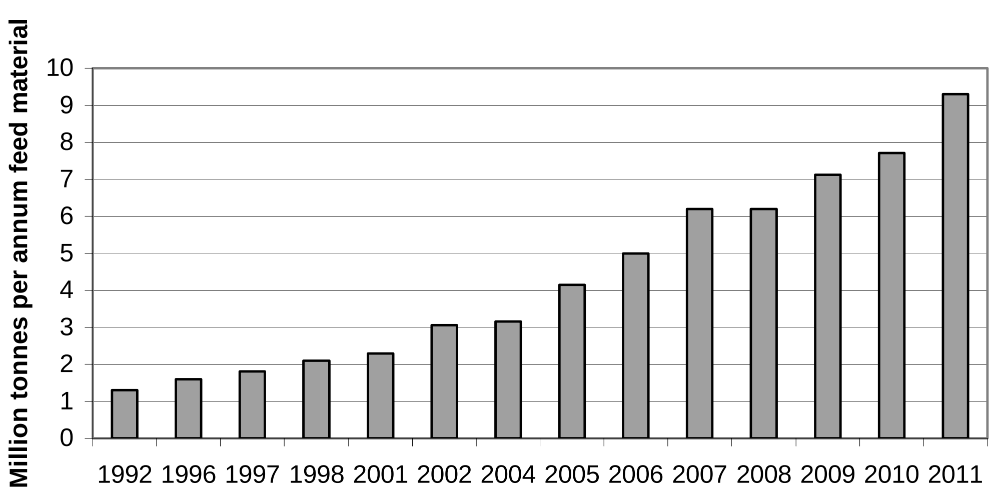

Figure 7: Copper ISASMELT™ Capacity

4. The ISASMELT technology Package

Behind this transformation of the copper smelting industry is the concept of delivering a technology package where all the components need to work in concert - the furnace, the lance system, the refractories, feed preparation and product tapping systems, control system, offgas cooling and cleaning systems, together with training and procedures for operations and maintenance personnel.

The ISASMELT™ technology package is an integrated assortment of technological research and development, specialist process and mechanical design, proprietary equipment, know-how, training programs, commissioning assistance and on-going technical support and collaboration that combine to ensure successful smelter projects for XT's licensees. The technology transfer includes a unique arrangement for training operators from new licensees - they learn by operating the full scale production smelter at Mt Isa. Clients from the USA, Belgium, Germany, China, Peru, India, Zambia and Kazakhstan have been trained at the MIM smelter in Mt Isa over the years. During the training period, client operators and maintenance personnel are given the opportunity to operate and maintain the Mount Isa plant. This "real life" training is a great advantage for the trainees when it comes to operating their own plants. By applying accumulated operating and maintenance know-how along with the full technology package, new users can very quickly achieve high production levels and long furnace campaigns, avoiding the pitfalls that often plague new smelter projects and reduce their profitability.

A further important part of the technology package is the interaction achieved through both informal contact between technical personnel at the many operations and regular licensee workshops, where ISASMELT™ users share innovations for mutual benefit. The companies can harness the ideas of operators from all over the globe.

In addition, XT's engineers and metallurgists are involved from conceptual design through the detailed design process, manufacturing of specialist equipment, commissioning, and then a long-term ongoing relationship with licensees. So they are currently not only busy designing four major smelters on three continents but are also actively "closing the loop" after witnessing the results of the design process in operation.

5. SPCC's Project: The Technology Package at Work

XT provided a number of studies for SPCC during the 1990's when they were considering how best to upgrade their smelter at Ilo, Peru. It was in early 2003, when SPCC was in the process of selecting a new technology that would meet their requirements while keeping capital and operating costs low, when XT offered ISASMELT™ as an option for the modernisation of the smelter. At that time, SPCC was facing the challenge of modernising its installations in order to comply with new environmental regulations defined by the Peruvian government in terms of sulphur capture and particulate material emissions during a period of historically low copper prices.

XT in partnership with Fluor Chile S.A. (Fluor) presented an offer to evaluate, at conceptual level, the use of the ISASMELT™ and RHF's as the core technology for processing 1,200,000 t/y of copper concentrate.

After technical and economic evaluation of the conceptual study completed by XT and Fluor, SPCC decided to select the ISASMELT™ and RHF technology package for the modernisation of the Ilo smelter in the middle of 2003. SPCC have stated that key criteria for selecting ISASMELT™ were the fact that the ISASMELT™ technology was proven for the planned capacity (1,200,000 tonnes per year through a single furnace) and the lower capital and operating cost of the ISASMELT™ technology compared with the other competing technologies [7]. Figure 8 shows a view of the SPCC ISASMELT plant™.

Figure 8: SPCC Ilo Smelter Copper ISASMELT™ plant view

The Development of the SPCC Project

The scope of work for XT was divided into the following stages:

- Phase 1 – Preliminary Engineering: Preliminary engineering for the ISASMELT™ and RHF furnaces was carried out at the XT office in Australia with active participation of Fluor and SPCC. Several technical review meetings were scheduled to review the progress of the project in Brisbane and Santiago. A project team from SPCC was established and located in Fluor's Santiago office. XT provided highly qualified technical support to the project team with design engineers allocated to the project team in the Santiago office for an extended period. This model allowed working 24 hours a day by having people based in Santiago, Ilo and

Brisbane. Regular use of advanced project management tools allowed the three parties to share and review documents on line on both sides of the Pacific Ocean. During this stage, the ISASMELT™ licensees network played an important role, with XT arranging industrial scale tests of SPCC's Cuajone and Toquepala concentrates at the YCC ISASMELT™ plant in China, in order to confirm relevant process information required for the design.

- Phase 2 – Detailed Engineering: Following evaluation of the estimated costs on completion of Phase 1, SPCC decided to continue with the project. In February 2004 SPCC signed a Professional Services Agreement with XT and an engineering, procurement and construction management (EPCM) contract with Fluor. That month the Phase 2 kick off meeting was held to start the detailed design of the plant. During Phase 2 XT delivered the technical information required by Fluor to continue with the detailed design process of the smelter. In addition, XT reviewed the mechanical and structural engineering completed by Fluor during this stage.
- XT Equipment Supply: As part of the services agreement with SPCC, XT was awarded with the supply of core equipment for the ISASMELT™ plant. Lance hoisting, lances, specialist instrumentation and control equipment and the hydraulic RHF drive system were part of the XT package.
- Process Control System Design and Supply: An important part of the success of the ISASMELT™ technology is its process control system. XT in conjunction with its partner MIPAC delivered a complete process control package for the ISASMELT™ plant.
- Training Programme: Thorough training is essential to enable successful transfer of technology. The process training for SPCC took place in four phases:
    1. An initial familiarisation training at the Freeport Copper Smelter in Arizona
    2. Full scale three month plant training at the MIM smelter in Australia
    3. A detailed training workshop at the Ilo smelter prior to plant startup, and
    4. On-site training during commissioning of the plant where cold and hot commissioning of the furnaces, cold test runs, start-up, shut-downs, and maintenance and trouble-shooting cases were explained.
- Technical Assistance: An important part of the project was the technical assistance provided by XT to SPCC during the engineering, pre and post commissioning stages of the project. The technical services included secondment of XT and MIM smelter personnel to Fluor's Santiago office and the Ilo smelter to carry out the following duties:
    1. To assist Fluor with the detailed design of the plant
    2. To assist Fluor with installation of key equipment items
    3. To assist with training of SPCC personnel on the new ISASMELT™ plant.
    4. To assist with the supervision of distributed control system installation.

5. To assist with supervision of plant commissioning and startup.
6. Supervision of the startup and hot commissioning of the integrated plant.
7. Regular support on site after finishing commissioning with XT process experts
8. Joint task force work with SPCC to optimise furnace operation during the first two years of plant operation

The plant was commissioned in February 2007, 36 months after signing of the Professional Services Agreement.

Commissioning of the Plant and Post Commissioning Assistance

In addition to the assistance from XT in equipment installation and cold commissioning activities MIM smelter operators and XT metallurgists and engineers, with many years of operating experience in ISASMELT™ plants, worked on site with SPCC's project team and operations personnel to carry out the hot commissioning of the plant. Hot commissioning commenced with heat up of the ISASMELT™ furnace and RHF's, to bath make in the ISASMELT™ furnace, first feed on, first tap of matte and slag to the Rotary Holding Furnaces and then over a number of weeks to stable smelting operations.

After stable operations were achieved XT and SPCC formed a taskforce to optimise the process. One example of the task force's activities was the optimisation of the slag chemistry. Relatively high alumina contents in the SPCC concentrates result in higher alumina contents in the slag (4 to 7%) than at ISASMELT™ operations elsewhere. Relatively high alumina contents in the slag can cause not only a decrease in the liquidus temperature of the slag but also an increase in the viscosity for a given temperature. New targets for the slag chemistry and operating temperature were defined following joint efforts between SPCC and XT that included fundamental work on slag modelling in conjunction with the University of Queensland and Xstrata Process Support in Sudbury, Canada, plant observations and trials. As a result of the change in slag chemistry the operation was improved. The benefit of modifying the ISASMELT™ slag chemistry was that a less viscous slag was produced leading to improved tapping operations and a decrease in the copper content of the RHF discard slag.

Current Operation at SPCC

Table 2 shows key process parameters for the SPCC plant for June 2009. At time of writing this paper the plant was running at high availability with a feed rate of up to 183 t/h (nominal feed rate: 165.2 t/h of copper concentrate, dry basis).

Table 2: Typical Process Parameters for SPCC ISASMELT™ Plant for June 2009

Parameter	Value	Unit
Maximum concentrate feed rate	183	dry t/h
Average concentrate feed rate	165.2	dry t/h
Average Cu content in concentrate	27.3	%
Average Moisture of the feed	9.2	%
Average silica flux feed rate	22.1	dry t/h
Average coal feed rate	1.1	dry t/h
Average reverts feed rate	6.3	dry t/h
Total average feed to the furnace	211.6	wet t/h
Average copper matte grade	62.5	%
Average SiO_2/Fe in slag	0.7	--
Average ISASMELT™ lance air flow rate	15.4	Nm^3/s
Average oxygen enrichment in ISASMELT™ lance air	66.7	%
Bath Temperature Range	1175 - 1185	°C

6. Conclusions

The application of the Copper ISASMELT™ technology to process primary and secondary materials has steadily grown over the past 10 years, transforming the copper smelting industry. Copper ISASMELT™ capacity is expected to exceed 9 million tonnes per year by 2011.

The basis for the success of the technology is a combination of the elegance of the process concept with the diverse plant experience gained over more than 20 years operation of ISASMELT™ plants at Mount Isa and a technology package that allows XT to provide its clients with process and engineering designs, equipment supply and strong technical assistance through all the stages of the project from initial conceptual studies at feasibility level through construction and the hot commissioning of the plant and into the initial years of plant operation until the process is optimised for the specific feed materials being treated. This process does not end there but continues through the life of the plant with a continuous collaboration with the ISASMELT™ licensees through regular contact and Licensees Workshops held on a regular basis and regular XT support to the clients when required.

The Ilo smelter modernisation project constitutes an example of how XT assists a licensee from feasibility to profitability. A collaborative effort with a strong technical team comprising specialists from both companies are continuing to work together to bring the Ilo ISASMELT™ plant to new horizons.

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