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ISASMELT™ – 25 YEARS OF CONTINUOUS EVOLUTION

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Authors:

P. S. Arthur, S. P. Hunt, Xstrata Technology

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For further information please contact us at isasmelt@xstratatech.com.au

www.isasmelt.com

ISASMELT™ – 25 YEARS OF CONTINUOUS EVOLUTION

P. S. Arthur, S. P. Hunt

Xstrata Technology

Level 4, 307 Queen Street

Brisbane, Qld. 4000, Australia

isasmelt@xstrata.com.au

ABSTRACT

The ISASMELT process[i] emerged into the global metals industry during the 1990's and is now processing about four million tonnes of concentrates and secondary materials each year. The submerged lance smelting technology produces either lead metal, copper matte or copper metal in plants located in Australia, the USA, Belgium, India, Germany, Malaysia and China. Further plants are under construction in Peru and Zambia.

The process is based on the air-cooled top entry submerged Sirosmelt lance, developed by Dr. John Floyd at the CSIRO Division of Mineral and Process Engineering in the 1970's. Mount Isa Mines[ii] recognised the potential in the novel top blown smelting concept and embarked on a development program that has been ongoing for more than 25 years. Pilot plants, demonstration plants and commercial scale plants have processed a wide range of materials over this time. Operation of the process on a commercial scale at the Mount Isa copper smelter has allowed ISASMELT to be developed to a stage where it is now being recognised as the most economically attractive copper smelting process available. Xstrata licenses the technology to companies around the world.

This paper traces the history of the ISASMELT process development and explores some of the reasons for it becoming a sustainable new smelting process.

INTRODUCTION

The development of the Sirosmelt lance at the CSIRO opened up new opportunities for the non-ferrous pyrometallurgy industry. Prior to its introduction the injection of gases into liquid slag or matte was achieved predominantly through tuyeres, with inherent design complications and refractory problems. Mount Isa Mines Limited were introduced to the submerged lance technology during the 1970's and recognised its potential for improving the efficiency of operations at its lead and copper smelters. The lance enabled the use of stationary furnaces with simple design but very high reaction rates. Following initial joint collaboration with CSIRO the ISASMELT process was developed to commercial success at the Mount Isa smelting complex.

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[i] ISASMELT is a registered trademark of Xstrata Technology

[ii] Mount Isa Mines is now owned by Xstrata

HISTORY OF THE ISASMELT PROCESS

First Steps

Development of the ISASMELT process began in 1977 when a Sirosmelt lance was tested for recovery of copper from anode furnace and converter slags[1]. A pilot plant with an internal diameter of 0.8 metres was used for submerged combustion treatment of copper slags produced in Mount Isa and Townsville. It was noted that the turbulence in the bath allowed rapid reduction by lump coal and rapid digestion of the flux. It was also noted that the ability to measure and control temperature was of vital importance to maximise refractory life. The authors concluded that reduction of converter slag in the Sirosmelt furnace would have advantages over the traditional practice of returning the slag to the reverberatory furnaces as these often had operating problems caused by the formation of magnetite accretions. The test results encouraged the research team to do further testwork using the novel process.

Development of Lead ISASMELT

In the late 1970's Mount Isa Mines were seeking a solution to improve and expand the operations at the Mount Isa lead smelter. Although a number of new lead smelting processes were being developed at the time, including the Kivcet, QSL and Kaldo processes,[2] it was felt that the Sirosmelt lance could be used to economically smelt Mount Isa lead concentrates. In 1978 a joint project was initiated with the CSIRO to investigate the application of the submerged combustion technology to lead smelting. The original work involving computer modelling of the process thermodynamics was followed by crucible scale testwork in 1979[3]. The crucible scale tests seemed to confirm the modelling work conclusions that fuming of lead from the bath would be limited and that reduction of lead slags occurred fairly quickly. This work was considered promising enough to justify testwork at a small pilot plant scale. It was felt that although about 40% of the lead in feed reported to fume that the fume rates would be significantly less at the larger scale.

There followed a series of process development steps including pilot plant, demonstration plant and commercial scale plant construction. Table 1 shows the lead ISASMELT plants that were constructed at Mount Isa.

Table 1 – Lead ISASMELT Plants at Mount Isa

Date	Plant Type	Plant Capacity
1980	Small Scale Pilot Plant	120-250 kg/h concentrate
1983	Lead Smelting Demonstration Plant	5-10 tph concentrate
1985	Lead Slag Reduction Demonstration Plant	5 tph lead slag
1991	Primary Lead Smelter	60,000 tpa lead in concentrate

Pilot plant tests occurred from 1980 to 1982[3]. A 120kg/h pilot plant was commissioned in September 1980. The main objectives were to prove the viability of a two stage process for lead concentrate smelting and slag reduction and to obtain reasonable estimates for fume rates, refractory wear and fuel rates. Table 2 summarises the main findings of the pilot plant work.

Table 2 – Major Findings on Pilot Plant

Lead fuming	could be controlled over a wide range of slag compositions and temperatures
Increased oxygen content of lance air	decreased the fuel requirements decreased the fume production no significant increase in lance wear
Refractory wear	less than expected higher during reduction than during oxidation
Slag reduction	demonstrated in batch operation proceeded quickly using lump coal addition
Zinc fuming	very temperature dependent

Mount Isa Mines and CSIRO were subsequently awarded a patent for the “high intensity lead smelting process”[4]. This process was named the ISASMELT process. The term "ISASMELT" was subsequently used to describe the combination of the furnace and modified lance design that incorporated the developments and know-how from the Mount Isa operations.

The results on the 120kg/h pilot plant encouraged Mount Isa management to construct a demonstration plant in order to evaluate the potential for commercial operation of the process. A throughput of approximately 5t/h was chosen because it was about one quarter to one tenth of the size of a commercial plant allowing future scale-up within acceptable risk levels. The intent was that the demonstration plant would be used to provide additional information on refractory and lance wear, fuel consumption, fume generation and hygiene. To improve the transfer of the technology to operations personnel the demonstration plant was installed within the existing lead smelter. The aim was to make the new technology part of the lead smelting operation and have ownership by the operations personnel.

It was decided to construct the plant in two stages. The first stage, commissioned in September 1983, was a single furnace rated at 5-9 t/h of feed material. It was used exclusively for oxidation smelting of the concentrate. The furnace had a 2.7 metre diameter steel shell. The furnace offtake was partly bricked and partly lined with castable refractory. It smelted approximately 15% of the concentrate treated at the Mount Isa lead smelter[5], producing a high lead slag that was granulated and subsequently added to the sinter plant feed. Sinter plant capacity was constrained by limited sulfur burning capacity at the time. By adding the ISASMELT slag to the sinter feed it was possible to increase the throughput of the sinter plant by up to 10%. The main differences observed in the demonstration plant were that the rate of fuming was less than one-half of that in the pilot plant and that the wear of the main refractory lining was less than one-tenth of that in the pilot plant.

By increasing the overall plant production, management found it easier to justify the capital cost of the demonstration plant. This strategy of seeking ways to increase the throughput of the existing plant while developing the new process was common over the ISASMELT development history.

Operation of the demonstration plant led to improvements in plant design. One improvement was the redesign of lances to allow operation at lower air pressures. The original Sirosmelt lances had been designed for operation at approximately 250 kPag and the cost of the compressed air was a significant fraction of the overall operating cost of the plant. Several lance designs were tested until one was designed that could operate at less than 100 kPag while still exhibiting low wear rates. Various fuels were used in the plant and it was demonstrated that lump coal or coke breeze, mixed with the concentrate, could be used for the major part of the fuel, with a small amount of oil injected through the lance being used for fine temperature control. This experience demonstrated that it was not necessary to use pneumatic injection systems for solid fuel injection, reducing the overall capital and operating costs of the plants.

Smelter operating personnel were involved in operation and maintenance of the plant on a daily basis and provided reality checks for the designers. Their insistence on keeping the process operation and equipment design as simple as possible is believed to be one of the factors that contributed to the overall success of the process development.

Once the first stage had demonstrated the operation of the smelting step over a period of more than a year, the second stage of the plant was constructed and was commissioned in August 1985. The second furnace was constructed adjacent to the first, to allow for transfer of molten oxidised slag between them.

Initially more than 150 batch reduction trials were carried out. Discard slag with lead levels of 4% were achieved. Lead fuming rates of about 7-8% were demonstrated for both smelting and reduction. Subsequently, during 1987, both demonstration furnaces were operated simultaneously, with continuous:

- Smelting of the lead concentrate in the smelting furnace
- Tapping and transfer of molten high lead slag to the reduction furnace
- Reduction of the slag with lump coal at 1170–1200ºC and
- Tapping of crude lead and discard slag together through a single taphole.

During these continuous reduction trials lead concentrate was treated at an average rate of 5 t/h under stable operating conditions. Discard slags containing 2 to 5% lead were achieved from the 50% lead concentrate. Lance lives of 100 to 200 hours were achieved[5].

The demonstration plant had treated more than 125,000 tonnes of lead concentrate by April 1989. On completion of these trials, a decision was made to proceed with construction of a full-scale two-stage lead ISASMELT plant at Mount Isa.

Other Developments at Mount Isa

The development of the lead smelting process from crucible to demonstration scale had taken about ten years. During this decade Mount Isa Mines had learned a great deal about the ISASMELT technology in general - ideas that could be utilised when smelting materials other than lead concentrate. In parallel to the lead demonstration plant operation, the pilot plant had been used for further development work, including investigations on nickel smelting, battery paste treatment, the treatment of copper drosses from the lead smelter and copper smelting. The results of the copper smelting work showed particular potential to solve operational problems at Mount Isa.

During the 1980's copper concentrate from the mines at Mount Isa was roasted in a fluid bed roaster and the calcine subsequently smelted in two reverberatory furnaces. There was a need to replace these units with more efficient technology and alternatives including flash smelting, the Noranda reactor and Mitsubishi continuous smelting and converting were considered. Each of these processes had disadvantages or required excessive capital expenditure and so investigations began into the use of ISASMELT for copper smelting. Pilot plant work was carried out on the lead pilot plant and at the CSIRO. Success of the pilot plant work led to approval for construction of a demonstration copper furnace. In April 1987 the new copper ISASMELT furnace, with an internal diameter of 2.3 metres, was commissioned[6].

The copper demonstration plant originally used readily available plant compressed air (supplied at 700 kPag) for the lance but after the introduction of a new lance design a blower with discharge pressure of less than 150 kPag was used. Although initially designed to operate only with air through the ISASMELT lance, the advantages of operating with oxygen enrichment soon became apparent with installation of a 70 tonne/day (tpd) oxygen plant, allowing the plant to run with 25 vol% oxygen in the process air (hereinafter referred to as '25% oxygen enrichment'). Although originally designed for 15 t/h of concentrate, the plant was able to reach 25 t/h with the addition of the oxygen to the lance air. A further short trial using liquid oxygen allowed the plant to run at 35% oxygen enrichment and feed rates of 50 t/h. There were some initial concerns that the lance life would be shortened by operating at lower pressure and increased oxygen enrichment but these problems were overcome with improved lance designs. Eventually the demonstration furnace smelted 20% of the copper smelter throughput, supplementing the production from the two reverberatory furnaces. It produced a copper matte and slag that were both tapped into one of the reverberatory furnaces for separation.

In its first two years of operation the demonstration plant treated 146,000 tonnes of copper concentrates and demonstrated that it could produce a variety of matte grades ranging from 36 wt% to 65 wt% of copper. By May 1992 it had treated 512,000 tonnes of concentrate. It demonstrated that it could treat a wide range of feed materials including recycled converter slag concentrate with a high magnetite content that had been unsuitable for treating in the reverberatory furnaces.

Minor element distributions were studied during the demonstration plant operation[7]. The operation demonstrated that the copper ISASMELT furnace consistently removed over 90% of the arsenic in the feed from the matte. In addition 80-90% of the bismuth and 60-80% of the antimony was eliminated from the matte.

During the demonstration plant operation, particular emphasis was placed on extending the refractory life of the furnace. Water-cooled copper blocks were inserted between the refractory lining and the steel shell to reduce the rate of refractory wear. Initially campaign lives of only a few months were achieved as various refractory types and installation techniques were tested. The campaign duration grew as experience was gathered, with the longest campaign lasting 90 weeks. This experience demonstrated the difficulty of achieving consistent long refractory life. Only through extended operation of the process has it been possible over the intervening years to develop a reliable refractory system. Mount Isa Mines began to amass this experience during the operation of the demonstration copper ISASMELT and continued the learning process in the first commercial plant.

Commercial Implementation

Secondary Lead ISASMELT

Following successful operation of the 5 t/h lead demonstration plant, trials were conducted on battery paste and lead fume in the 120 kg/h pilot plant. As a result of this testwork, a secondary lead ISASMELT furnace was constructed at the Britannia Refined Metals plant in England. This plant had a 2.5 metre diameter furnace shell and was commissioned in 1991[8,9]. It successfully treated battery scrap over a twelve-year life. It was shut down at the end of 2003 when Xstrata Zinc, on assuming management of the refinery, decided to discontinue secondary lead smelting operations.

Two-stage Lead ISASMELT

Following the success of the demonstration lead smelter, Mount Isa Mines management approved construction of a two stage lead ISASMELT plant. This plant began operation in February 1991. The smelting furnace had an internal diameter of 2.5 metres and the reduction furnace had an internal diameter of 3.5 metres. Some differences between the design of the demonstration plant and commercial plant were the use of a lead weir to allow continuous tapping of the lead bullion product, installation of waste heat boilers, and the injection of coal through the lance in the reduction furnace, rather than addition of lump coal. The aim of injecting the coal was primarily to increase the slag reduction rates. Based on the results of the demonstration plant, it was felt that the reduction stage of the process required further optimisation. Studies had been undertaken in the late 1980’s at CSIRO on reduction of lead slags on a crucible scale, in an attempt to understand the rate controlling mechanisms in the lead reduction process[10]. These studies demonstrated that the reduction kinetics were relatively fast in lead slags down to about 6 wt% lead, but the reduction rate dropped off significantly at lower lead concentrations. The target lead concentration for the lead ISASMELT was 3-5% so it was felt necessary to use pneumatic injection as a means to achieve the target.

The plant quickly demonstrated the ability to smelt the Mount Isa concentrate at rates of 20 t/h, producing a high lead slag[8]. The smelting operation was stable; long lance life and refractory life were achieved. The presence of zinc ferrite crystals in the molten lead slag product resulted in protective layers of zinc ferrite forming on the lance and on the refractory walls, thus protecting them from slag attack. Lances typically lasted more than one month and there was little wear of furnace walls. The oxidising conditions and the highly agitated bath in the smelting furnace managed to suppress the fuming of lead sulfide.

The reduction stage however, proved more problematic, with short lance lives and blockage and wear of the pneumatic coal injection system leading to erratic lead contents in the final slag. These problems were overcome by redesign of the coal injection equipment and modifying the lance tip design. The best performance occurred during 1993 when additional oxygen became available and up to 36 t/h of concentrates were smelted using lance air with 33-35% oxygen enrichment. During this period of high rate smelting and reduction, residual lead in final slags from the reduction furnace ranging from 2-5% were achieved.

When operating with the design offgas flows, the waste heat boilers could not reduce the offgas temperature to the level required for entry into the bag filters. It was thus necessary to add a quench air system to achieve the required temperatures. The boiler restriction was the result of a cohesive layer of dust that formed on the convection tube bundles, significantly reducing the heat transfer rate.

The refractory wear was acceptable in the reduction furnace, with brick replacement required after two years.

A decrease in the lead concentrate supply from the Mount Isa mine in late 1994 made the continued operation of the lead ISASMELT in parallel to the sinter plant and blast furnace uneconomic. As a result it was decided to shut down the lead ISASMELT plant in early 1995. It has been out of operation since that date, but is regularly reassessed for recommissioning, depending on the state of the lead market and the availability of suitable concentrate.

Copper/Nickel Smelting

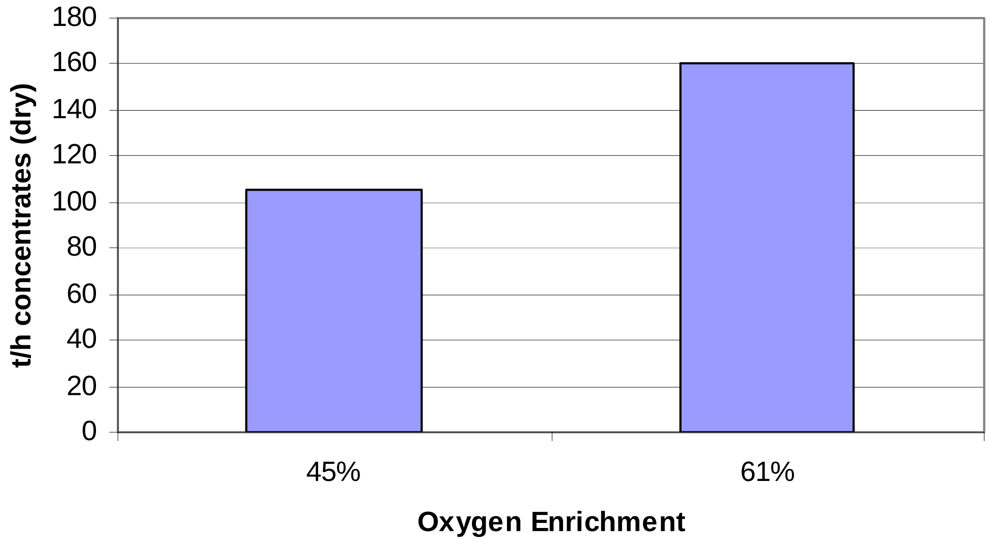
The success of the demonstration copper ISASMELT and pilot plant test work carried out on smelting of copper nickel concentrate led to the decision by Agip Australia to install a new ISASMELT furnace for production of a nickel/copper matte at their Radio Hill site in Western Australia[11]. The plant was commissioned in September 1991 and within 3 months was running at design capacity of 7.5 t/h of concentrate. It produced a 45% nickel/copper matte from a concentrate containing approximately 7% nickel and 3.5% copper. Unfortunately the nickel price, which had been above US$6 per pound in 1989 fell to about US$3 per pound by 1991. Therefore, despite the technical success of the project, Agip closed the mine, concentrator and smelter after less than six months of operation. Subsequent owners of the mine have focussed on mining and mineral processing only, and the ISASMELT plant has since been dismantled.

Copper ISASMELT

Following the success of the demonstration copper ISASMELT, Mount Isa Mines proceeded with construction of a copper ISASMELT plant rated at 180,000 tpa of copper in concentrate. The furnace, with an internal diameter of 3.75 metres, was commissioned in August 1992[12]. The new plant started operation with about 45% oxygen enrichment and produced a matte containing 55-60 wt% copper. Lump coal added to the feed mix was used as the main fuel, with diesel injected down the lance used for fine tuning the bath temperature and heating the bath after shutdowns.

Over the years the production of the furnace steadily increased, and in 1998 a new oxygen plant was installed, allowing the oxygen enrichment level of the air through the lance to be increased to more than 60%. As a result the feed rate was increased from about 105 t/h of concentrates to more than 160 t/h of concentrates (dry basis) as shown in Figure 1.

Figure 1 – Effect of Oxygen Enrichment



This increase coincided with the development of new mines at Mount Isa and Ernest Henry, and an upgrade to the copper refinery in Townsville. To reduce the technical risk associated with the increase in oxygen enrichment two high rate trials were undertaken in 1997. These trials demonstrated that the copper ISASMELT furnace could treat concentrates at a rate equivalent to 250,000 tpa contained copper[13]. The copper ISASMELT furnace is now treating approximately one million tonnes of concentrate per year. Figure 2 shows the annual tonnes of feed to the copper ISASMELT since it was commissioned. Table 3 shows typical inputs to the copper ISASMELT furnace.

Figure 2 – Annual Concentrate Feed to Copper ISASMELT

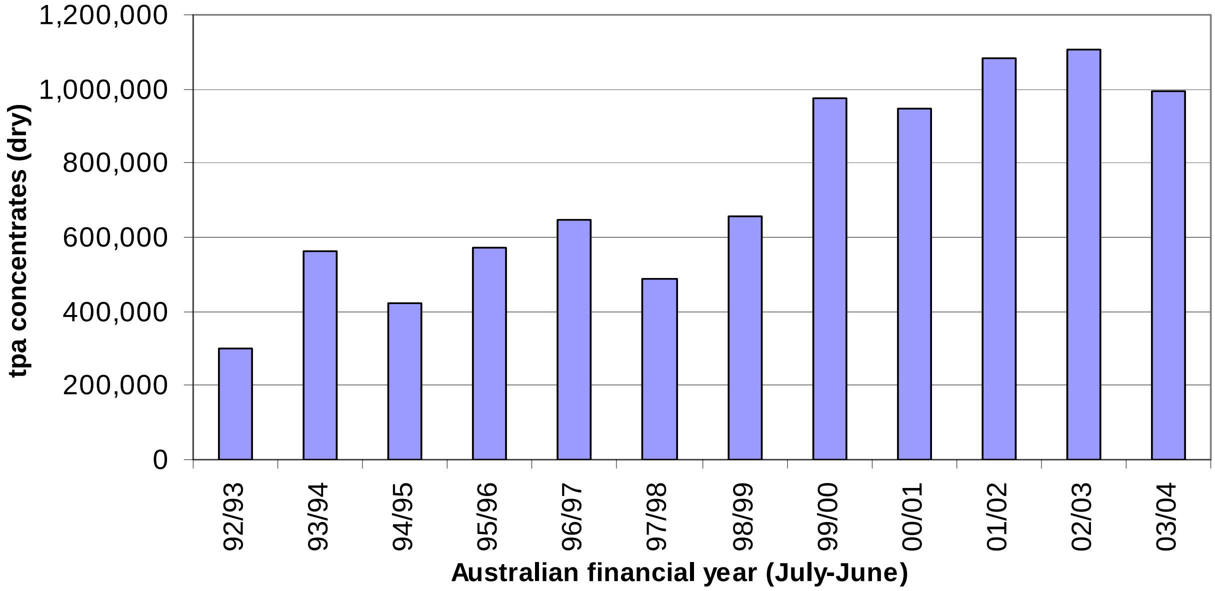


Table 3 – Typical Operating Parameters - Copper ISASMELT

Parameter	Rate	Units
Concentrate Rate	160	tph
Dry Concentrate Assay	23.8	%Cu
Silica Flux	3.4	tph
Reverts	1.6	tph
Coke Breeze	0.7	tph
Natural Gas	706	Nm3/h
Lance Air	20,210	Nm3/h
Lance Oxygen (95%)	23,580	Nm3/h
Lance Oxygen Enrichment	60.8	%
Bath Temperature	1172	degC
Matte Grade	57.0	%

The furnace refractory wear rates have decreased gradually over the 12 years of operation. It was decided during the construction phase that water-cooling would not be used on the furnace despite positive experience in the demonstration plant. This decision was based on concerns related to the use of water cooling in the bath zone on a commercial furnace. Also it was felt that it should be possible - with careful refractory selection, installation techniques and control methodology - to achieve a refractory life of two years without water-cooling. Initial campaigns were of 12-15 months duration as various refractory types and installation methodologies were tested. By 1998, however, based on the operating experience gained, and coupled with advances in the process control systems, significantly improved refractory performance was achieved. The refractory wear is now monitored on-line, allowing real time feedback to the operators of the conditions within the furnace. As a result, since 1998 each campaign has been at least 2 years in duration.

Figure 3 shows the copper ISASMELT furnace refractory campaign lives to date while Figure 4 shows the wear rate of the refractory in the furnace barrel for each of the campaigns since 1998.

Figure 3 – Copper ISASMELT Campaign Life History

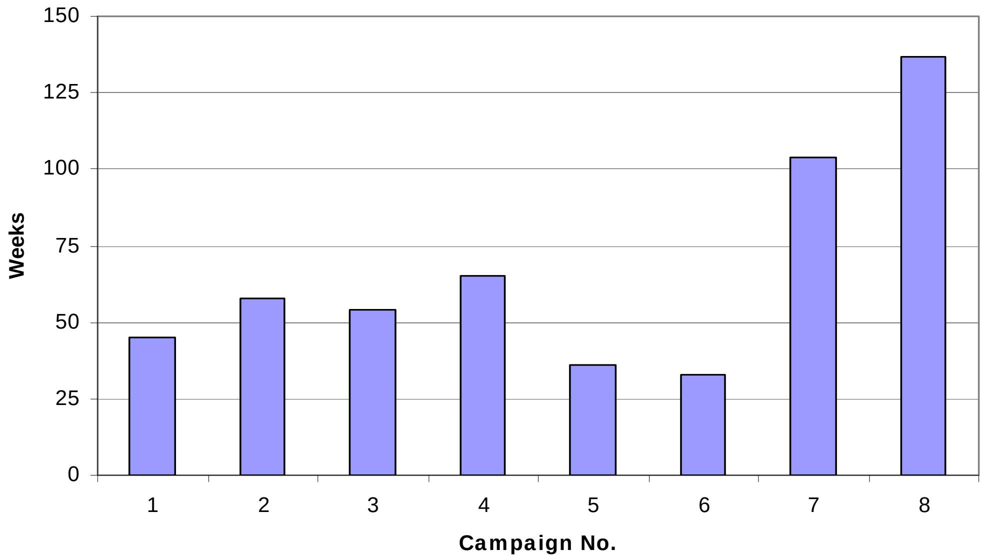
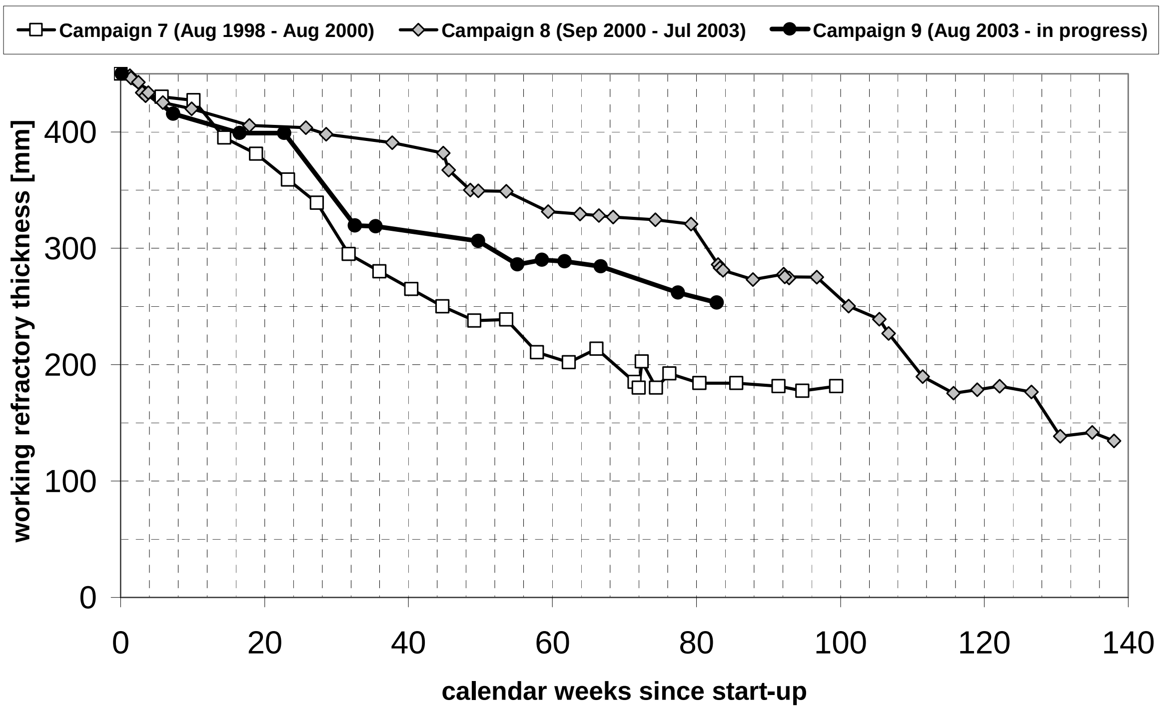


Figure 4 – Copper ISASMELT Refractory Wear



Client Copper Smelters

The operational advantages of the copper ISASMELT plant over alternatives led to interest from external companies in the process. As a result, Mount Isa Mines decided to license the technology to external clients at the end of the 1980's and continues to do so. Table 4 summarises the licensee smelters that are either operating or under construction.

Table 4 – Licensee ISASMELT Plants

Startup Date	Licensee	Plant Location	Plant Capacity
1992	Phelps Dodge Miami	Arizona, USA	650,000 tpa copper concentrate
1996	Sterlite Industries (India) Ltd	Tuticorin, India	450,000 tpa copper concentrate
1997	Umicore Precious Metals	Hoboken, Belgium	200,000 tpa mixed feed
2000	Metal Reclamation Industries	Pulau Indah, Malaysia	40,000 tpa Lead metal
2002	Hüttenwerke Kayser	Lünen, Germany	150,000 tpa copper scrap
2002	Yunnan Copper Corporation	Kunming, China	600,000 tpa copper concentrate

2005 (under construction)	Sterlite Industries (India) Ltd	Tuticorin, India	1,200,000 tpa copper concentrate
2005 (under construction)	Yunnan Metallurgical Group	Qujing, China	160,000 tpa lead concentrate
2006 (under construction)	Southern Peru Copper	Ilo, Peru	1,200,000 tpa copper concentrate
2006 (under construction)	Mopani Copper Mines	Mufulira, Zambia	650,000 tpa copper concentrate

Phelps Dodge Miami Copper Smelter

Cyprus Miami Mining Corporation (now Phelps Dodge Miami) selected ISASMELT for their modernisation in 1990. The decision was based on observation of the operation of the demonstration copper ISASMELT plant at Mount Isa. The Miami plant, located in Claypool Arizona, was designed and constructed at the same time as the 180,000 tpa copper ISASMELT plant at Mount Isa. It was commissioned in June 1992, two months before the Mount Isa plant. Cyprus chose ISASMELT after comparing it with Contop, Inco, Mitsubishi, Noranda, Outokumpu and Teniente technologies[14]. An electric furnace, previously used for smelting copper concentrates, was modified to act as a settling furnace for the copper matte and slag, and for reduction of Peirce Smith converter slag.

Cyprus recognised the risk of using ISASMELT technology that was not proven on a full commercial scale at the time, so instigated a risk mitigation program. This program included a detailed training program, with 35 employees sent to Mount Isa for training on the demonstration copper ISASMELT and in the lead smelter. There were however still many design features that differed from those on the Mount Isa plant. First was the use of the electric furnace as settling furnace; second was the use of a sloping water cooled gas offtake hood followed by a radiation/convection waste heat boiler; and third was the use of natural gas injected through the lance as the main fuel for the furnace. Oxygen enrichment was up to 50% of the lance air. Of these differences, the major cause of downtime during the first few years was the offtake, which suffered from serious corrosion and accretion problems. Eventually the offtake hood was replaced with a vertical radiation channel connected to the boiler system. Problems with higher than acceptable copper losses in the electric furnace slag were a concern until the end of the 1990’s when work carried out with natural gas lancing resulted in a considerable improvement in slag cleaning performance[15].

The feed rate at Miami increased over 12 years of operation. Figure 5 shows the feed rates over that period. The refractory campaigns have also improved over time, as shown in Figure 6.

Figure 5 – Phelps Dodge Miami ISASMELT Feed Rate

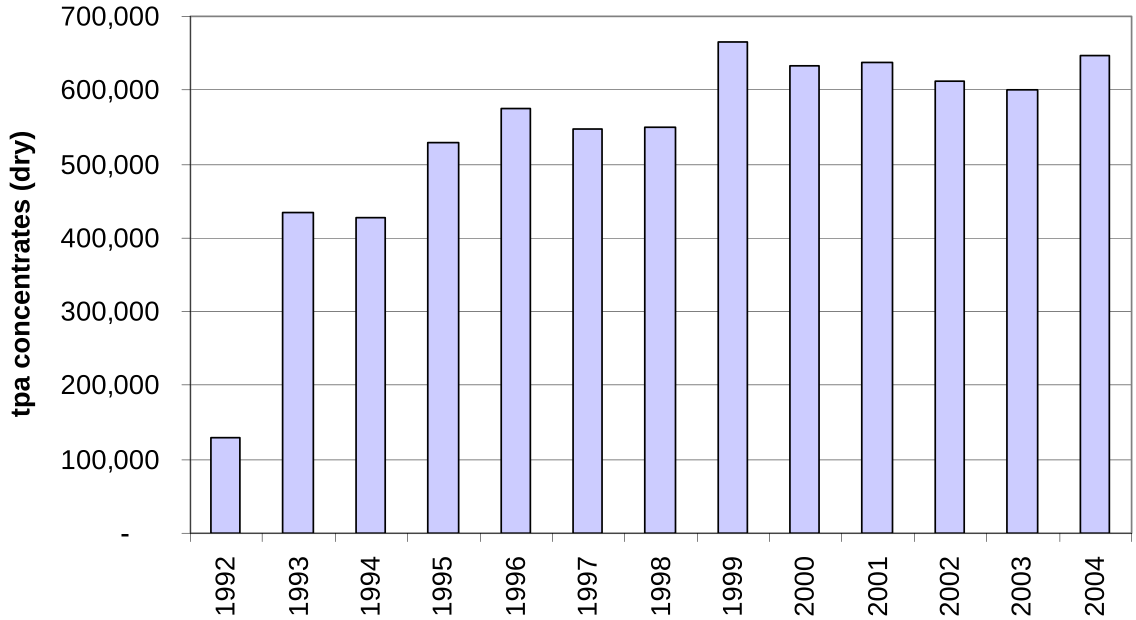
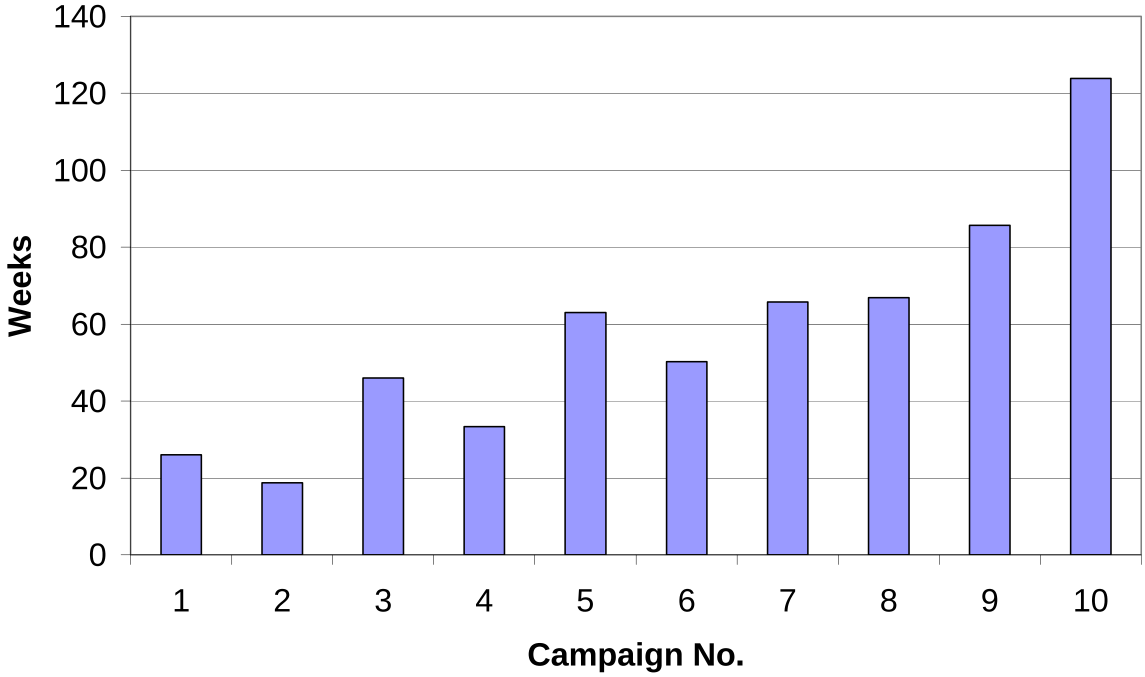


Figure 6 – Phelps Dodge Miami ISASMELT Campaign Life History



Sterlite Industries Copper Smelter

The Sterlite Industries copper ISASMELT plant is located at Tuticorin, on the southern tip of India. The smelter was commissioned in 1996 and was constructed on a greenfield site to smelt imported concentrates. The ISASMELT furnace originally had a design capacity of 60,000 tpa of copper in matte but has been expanded to 180,000 tpa of copper. The capacity increase was achieved by installating additional tonnage oxygen and expanding the associated plant and equipment. Sterlite, which did not operate a copper smelter prior to the construction of the Tuticorin plant, is now a significant copper producer.

Sterlite are now completing construction of a new ISASMELT furnace. This new furnace will be commissioned during 2005 and will treat concentrates containing 300,000 tpa of copper.

Umicore Precious Metals Smelter

The Umicore Precious Metals smelter at Hoboken, Belgium, uses the ISASMELT process to treat a variety of primary and secondary feed materials. The Hoboken site underwent a dramatic modernisation in the late 1990's in order to remain competitive while operating under strict environmental regulations. A key feature of the modernisation was installation of the ISASMELT furnace. The furnace replaced a large number of unit processes, allowing the company to reduce operating costs significantly while reducing emissions to the environment. The new smelter has been operating since the end of 1997 and plays an important role in Umicore's recycling business.

Huettenwerke Kayser Copper Smelter

Huettenwerke Kayser, a subsidiary of Norddeutsche Affinerie, operate an ISASMELT plant for secondary copper smelting within their smelting and refining operation near Dortmund in Germany. The ISASMELT furnace replaced two blast furnaces and three Peirce Smith converters used for smelting scrap copper. The ISASMELT furnace installation has allowed the company to significantly reduce operating costs and improve the environmental performance of the smelter.

Yunnan Copper Corporation Copper Smelter

Yunnan Copper Corporation (YCC) commissioned their copper ISASMELT plant in May 2002 as part of a copper smelter modernisation project[16,17]. The ISASMELT furnace treats more than 600,000 tpa of copper concentrate. The furnace replaced a sinter plant and two electric furnaces and produces a copper matte with a copper content of 55%. Process air is enriched to 50% oxygen content. The ISASMELT furnace installation has significantly improved the environmental performance of the smelter and reduced the operating costs, with sulfur capture increasing from 79% to 96% and energy consumption decreasing by 32%.

Table 5 – Change in YCC Smelter Energy Consumption

Year	Energy Consumption (concentrate to blister) tonnes of standard coal / tonne copper
2001	0.729

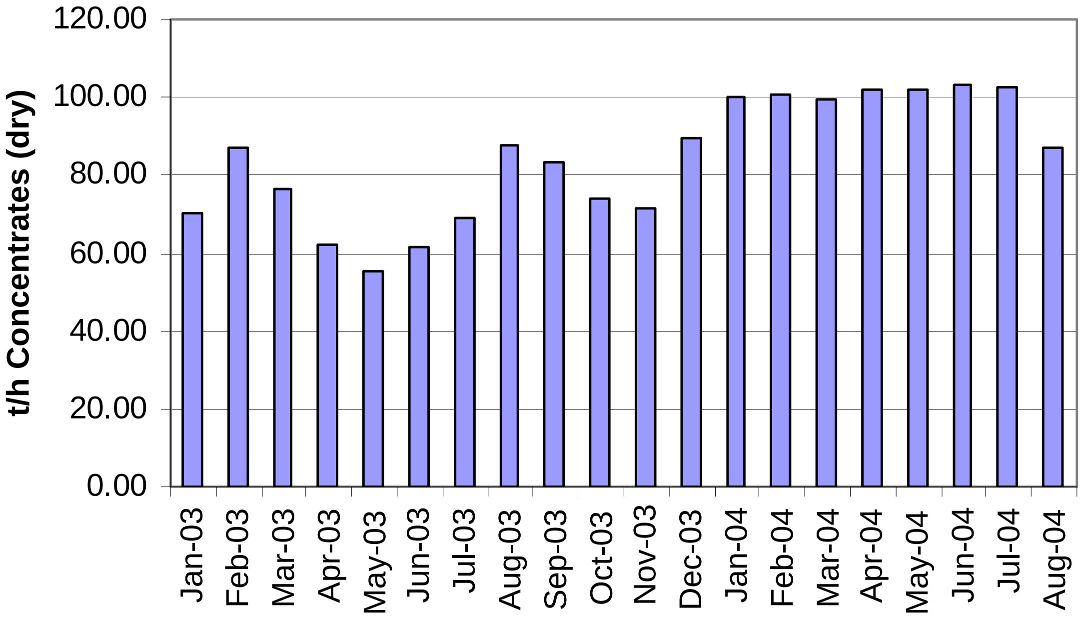
2003	0.523
2004	0.493

The YCC plant incorporated latest design improvements developed at Mount Isa. YCC personnel were trained at Mount Isa over a period of 7 months. The result was that the plant reached design capacity (averaged over a 7-day period) within two months of the first concentrate being fed to the furnace.

Following the successful commissioning the major impediment to reaching design capacity on a consistent basis was the concentrate supply.

Figure 7 shows the average monthly feed rate from January 2003 to the end of the first operating campaign. During most of 2002 and into 2003 YCC could not obtain sufficient feed because of the tight concentrate market at the time. Once sufficient concentrate became available the YCC plant was able to consistently exceed design capacity. The first campaign lasted for two years and 4 months, from May 2002 to September 2004, demonstrating similar refractory performance to that achieved at Mount Isa.

Figure 7 – YCC ISASMELT Feed Rate



Southern Peru Copper Corporation Copper Smelter

Southern Peru Copper Corporation (SPCC) have commenced construction of a new ISASMELT furnace at their copper smelter located in Ilo, Peru. SPCC investigated a wide range of alternative technologies including flash smelting, Teniente Converter, Noranda and Mitsubishi, before deciding to construct the ISASMELT furnace. The ISASMELT furnace will treat 1,200,000 tpa of concentrate and will replace two reverberatory furnaces and a Teniente converter. Two rotary settling furnaces will be used for separating the matte and slag products of the ISASMELT furnace. A waste heat boiler and electrostatic precipitator will be used to cool and clean the gas before passing it to a new sulfuric acid plant. Peirce Smith converters will be used for converting matte to blister copper. The plant is due to start operation in 2006.

Mopani Copper Mines Copper Smelter

Mopani Copper Mines Plc (MCM) has commenced construction of a new ISASMELT plant at the Mufulira copper smelter in Zambia. MCM decided to install an ISASMELT furnace after comparing it with alternative technologies including flash smelting, Mitsubishi process, and Teniente converters. They concluded that the advantages of the ISASMELT process[18] include:

- Its compact size and small footprint, which could be easily accommodated in the Mufulira smelter.
- The relatively low capital cost.
- The low operating costs.
- The high strength offgas well suited for sulfuric acid production.
- The relative ease of operation.
- The feed rate flexibility, suitable for operation at an initial production rate in 2006 of 650,000 tpa of concentrate while still having capacity for future upgrades greater than 850,000 tpa.

The ISASMELT furnace will replace an existing electric furnace. The plant will include a new feed preparation system, waste heat boiler, electric settling furnace, oxygen plant and acid plant, as well as improvements to the converter aisle and anode plants. It is due to start operation in 2006.

Client Lead Smelters

Metal Reclamation Industries Lead Smelter

Metal Reclamation Industries commissioned a secondary lead smelter at Pulau Indah, Malaysia in 2000. The plant produces up to 40,000 tpa of refined lead primarily from recycled lead acid batteries. The plant was based on the design of the Britannia Refined Metals plant in England and operates a batch process.

YMG Lead Smelter

Xstrata Technology designed an ISASMELT furnace for Yunnan Metallurgical Group's (YMG) new lead smelter at Qujing, China. The ISASMELT furnace will smelt 160,000 tpa of lead concentrate to produce lead bullion and a high lead slag. The high lead slag will be solidified and fed to a YMG-designed blast furnace for reduction. This process, a joint development of Xstrata and YMG, will combine the benefits of the ISASMELT furnace for smelting with the benefits of the blast furnace for reduction. The ISASMELT furnace will effectively replace the sinter plant of a traditional lead smelter. The ISASMELT furnace has an advantage over the sinter plant in that it can convert a fraction of the lead in feed directly to lead metal, thus decreasing the slag reduction duty of the blast furnace. In the YMG plant over 40% of the lead in feed will report directly to lead metal in the smelting furnace. The ISASMELT furnace also has the advantage that it is much smaller and simpler than a sinter plant and can be readily enclosed to eliminate emissions. The offgas from the ISASMELT furnace has a relatively high sulfur dioxide content, suitable for conversion to acid in a conventional sulfuric acid plant. The slag product is low in sulfur compared with sinter and thus the blast furnace offgas contains a much lower concentration of sulfur dioxide than in the case of a blast furnace being fed with sinter.

TWENTY FIVE YEARS TO A SUSTAINABLE TECHNOLOGY

The startup of the YCC ISASMELT plant coincided with the 25th anniversary of the first Sirosmelt testwork undertaken by Mount Isa Mines and CSIRO. Twenty five years of hard work and tenacity by a wide range of individuals had led to the successful commercialisation of a truly sustainable new metals processing technology. The YCC plant incorporated design features that had been developed and optimised on preceding ISASMELT plants. After 25 years of ISASMELT development, the YCC plant demonstrated how successfully the copper ISASMELT process can be incorporated into copper smelters anywhere in the world. By drawing on the decades of experience gained at Mount Isa and elsewhere, Xstrata now designs plants that can ramp up to design capacity quickly. With a combination of proven design, comprehensive training programs in the Mount Isa smelter operations and commissioning assistance from plant operators with many years of plant experience, clients have minimal exposure to risk in incorporating the technology into their plants. The ISASMELT process is helping to improve the environmental performance of smelters around the world. Introduction of the copper ISASMELT at Mount Isa helped to decrease the fuel consumption in the copper smelter by more than 90% between 1991 and 2002[19].

A large number of design features were optimised over the first 25 years of development and improvements will continue further. Some of the critical features are listed below.

Refractories

Long refractory life is crucial for the success of any pyrometallurgical process. Development of durable refractory systems takes many years because of the time involved in testing whether certain refractory types, installation methods, cooling systems and monitoring devices result in reduced wear. Mount Isa Mines focussed on improved refractory systems from the start of the development program. In conjunction with CSIRO, universities, AMIRA, refractory suppliers and other industry partners a series of research programs investigated how to optimise refractory performance. The fundamentals of refractory wear were studied and the practical implications of the discoveries put into practice in the operating plants.

As mentioned previously, there have been various attempts to cool the furnace walls, in order to reduce the refractory wear, in particular around the slag line in the copper furnaces. Some of the plants have copper blocks installed between the refractory lining and the steel shell, while some have had external shower cooling installed. In Mount Isa, the copper ISASMELT furnace does not have any water-cooling applied to the walls and campaigns of over two and a half years are achieved. This performance is possible through the use of high quality refractories, careful installation procedures, on-line condition monitoring and very tight control of bath temperature using the control systems that have been developed over more than a decade in the operating plant. Recently the goal of achieving a five year campaign has been raised, and studies are currently underway to determine how best to achieve this.

Control Systems

Control of the ISASMELT process for the operator is now relatively straightforward thanks to the automation of key process parameters. Development of this automation has taken many years on the industrial scale. Given that the furnace was fed continuously - but batch tapped - it became necessary to develop a method to automatically control the movement of the ISASMELT lance within the furnace. The movement is required so that the lance tip is always properly positioned in the bath, thereby achieving the required mixing and reaction rates while minimising lance tip wear. Systems developed in the pilot and demonstration plants were improved in the full-scale furnace and now allow the immersion of the lance tip to be automatically controlled to within an extremely tight tolerance. During normal operation, the lance position is completely controlled by the plant control system and human intervention is not required.

The ISASMELT furnace is essentially a classic continuous stirred tank reactor. As such the composition of the bath and the temperature is very uniform throughout the vessel. This allows the temperature to be controlled very precisely when a reliable temperature measurement and feedback system is used. Such systems were developed throughout the 1990's and now allow the bath temperature to be controlled within a range of approximately ±10 degrees Celsius.

Offgas Systems

The offgas system should be viewed as an integral part of the furnace. The problems associated with cooling of sticky metallurgical dusts makes the design of furnace offgas systems especially difficult. As a result it has taken many years and experience with a variety of plant situations until a completely satisfactory solution was found. Pilot plants and demonstration plants typically used evaporative coolers and refractory-lined ducts. For full-scale plants, however, it was mostly considered preferable to install waste heat boilers to improve the thermal efficiency of the process. Various configurations of boilers have been tried over the years with differing degrees of success. The Mount Isa copper ISASMELT has a circulating fluidised bed boiler which has the advantage of quenching the gases quickly but the disadvantage of a relatively high pressure drop. The Phelps Dodge plant originally had a water-cooled offtake that suffered major problems with accretion formation and corrosion from acid condensation[20]. The Mount Isa lead ISASMELT had a conventional radiation and convection boiler on both the oxidation furnace and the reduction furnace, but suffered from inadequate capacity because of low heat transfer, caused by the nature of the lead fume and dust.

Over the years, in co-operation with major vendors, solutions to these problems have been found. As a result Xstrata can now ensure that ISASMELT furnace offgas systems can be designed successfully, as evidenced by trouble-free performance of the YCC boiler since startup.

Furnace Design

The original Sirosmelt patent primarily covered the concept of the air-cooled lance. The original furnace design seemed appropriate at the time for a top submerged lance process. Experience over the intervening years has shown that the original design had shortcomings when used in a commercial operation. As the furnace size has increased, so has the recognition that there are extremely high forces produced by the slopping of the molten bath. The injected gases produce a complex wave motion, which imparts cyclic horizontal and vertical forces onto the furnace walls and base[21]. As a result of these high forces the foundations and furnace support system need to be designed carefully. The method of connecting the furnace to the support system also had to be improved to ensure furnace stability while allowing for expansion of the refractory and the steel shell.

The original sloped furnace roof was initially designed to enhance gas flow dynamics, but in practice it was found that a horizontal roof was easier to construct and maintain, while suffering no significant disadvantages compared with the original. The first design used refractory-lined or water-cooled steel sections. Subsequently water-cooled copper blocks were used as they were easier to maintain. More recently however, it has been found that for copper smelting a flat roof constructed of boiler tube and operating at temperatures significantly above the dew point of the offgas is a better solution. There are still some disadvantages with a pressurised system, however, so alternative solutions are still under development.

FACTORS CONTRIBUTING TO SUCCESSFUL INNOVATION

The history of technological innovation has provided many examples of extraordinary concepts and ideas that did not survive the transition from conceptualisation to implementation on an industrial scale. It is therefore important to review the main reasons that have contributed to the successful implementation and internationalisation of ISASMELT technology.

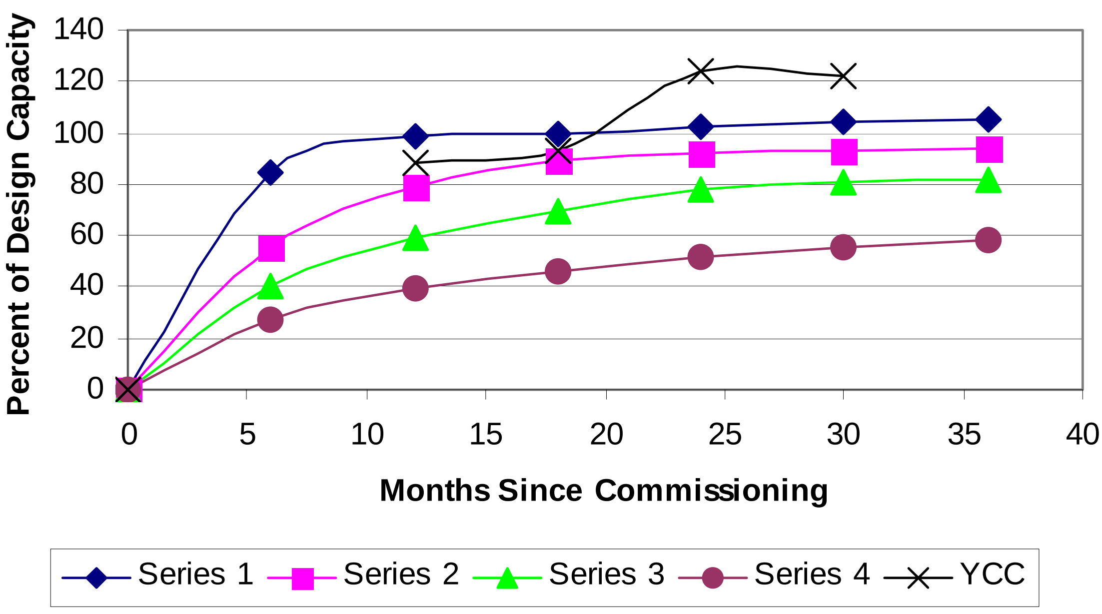
Many factors have contributed to the success. The CSIRO lance development was the initial breakthrough. A key element in the success, however, was the fact that the process was developed to commercial viability in operating smelter environments combining the talents of skilled engineers, metallurgists and technicians. Other factors were the entrepreneurial drive of the Mount Isa staff including a number of technology ‘champions’ and the support of the Australian government in the early years, through the Australian Industrial Research Development Incentives Board (AIRDIB). It was also critical that the process was proven through a disciplined series of development steps, including laboratory work, pilot plant testing, operation of demonstration plants over extended periods, and full scale commercial plants that were subsequently expanded after dedicated test campaigns.

Finally, it is believed that the close attachment by operations personnel to the new process played a major role in its success. A process is much more likely to be successful if it is driven by operations personnel who recognise a benefit in using it and see it as a means to improve their future quality of life. At Mount Isa operators were brought ‘on board’ early in the life of the development program and encouraged to contribute to the program. They reacted enthusiastically and proved to be extremely useful sounding boards and sources of pragmatic advice at critical phases in the development. Through a consistent emphasis on simplifying features of the process, operations personnel helped ensure that a robust and industrially reliable and sustainable process resulted.

The startup of the YCC ISASMELT plant, as a result, was impressive when compared with the first commercial ISASMELT plants and general historical precedents. A number of studies have been undertaken over the past few decades looking at the startup performance of process plants and these have highlighted factors that play an important role in determining how quickly a new plant ramps up to full capacity. In one study by Charles River and Associates (CRA)[22], it was noted that about 50% of smelters showed an average annual production of less than 70% of the design capacity in the first through third year of production. They concluded that a major cause of startup problems was the improper scale-up of the commercial plant from the laboratory and pilot plant stages. The extent of laboratory and pilot plant work carried out at Mount Isa contributed to the fact that scale up was not a major problem for the ISASMELT process. The CRA study concluded that major causes of delays in pyrometallurgical operations were refractory failures and difficulties in handling hot gases. These problems were certainly encountered during the development of ISASMELT. The offgas system caused major problems at Phelps Dodge Miami for about the first 5 years, resulting in major redesign and modifications. It also was a major cause of downtime at Mount Isa for the first 5-6 years of operation of the commercial plant. About 5-6 years of development were also required on the commercial scale at Mount Isa until satisfactory refractory performance was achieved. Now that these problems have been overcome, however, it is possible to design the complete furnace and offgas system in such a way that ramp up of new ISASMELT plants occurs very quickly.

A paper by Terry McNulty[23] analysed case histories for 41 various process plants, including six copper and nickel smelters. He divided the projects into four series based on the percentage of design capacity they had achieved six, 12, 24 and 36 months after startup, as shown in Figure 8.

Figure 8 – Rate of Achievement of Annualized Design (after McNulty)



The most successful plants, those in series 1, achieved 100% of design capacity within 12 months of startup. Series 4 plants achieved on average less than 40% of design capacity after 36 months. According to McNulty's system, the Mount Isa and Phelps Dodge Miami copper smelters could be classed as series 2 plants. Series 2 plants have at least one and sometimes two or three of the following characteristics:

- If the process was licensed technology, it was one of the first licenses (this was the case)
- Equipment specified for a unit operation was a prototype in terms of size or application (both furnaces were the first of their size)
- Pilot scale testwork was incomplete (this was not the case)
- Process conditions in the key unit operation were severe eg high temperature (this was the case)
- The innovative sections of the plant may have worked well but other operations had not been properly engineered (offgas systems were the main problem, but it could be argued that these were also innovative)

On the McNulty scale, and given the fact that the YCC plant's feed rate was mainly constrained by insufficient concentrate supply, the YCC ISASMELT could be classed as a series 1 plant. These plants are generally characterised by:

- reliance on a mature technology (this was the case)
- equipment similar in size and duty to that used in earlier successful projects (this was the case)
- if the technology was licensed there were many prior licensees (this was the case)

CONCLUSIONS

Innovations are generally either revolutionary or evolutionary. The invention of the Sirosmelt lance by Dr. John Floyd almost 30 year ago was most definitely revolutionary. The development of that idea to a sustainable smelting process has been the combination of many evolutionary innovations. The combination of revolutionary and evolutionary innovations has led to the ISASMELT copper smelting process that is now being used for copper production throughout the world. The lead ISASMELT process is also growing in popularity. Secondary and scrap ISASMELT furnaces are used in smelters in Europe and Asia. Further applications for the process are still to be developed.

Many factors have contributed to the success, including the contributions of many individuals, not only at CSIRO and Mount Isa but also in the licensee companies around the world. It is believed that the close attachment by operations personnel to the new process played a major role in its success.

Over the last ten years, ISASMELT has had the highest adoption rate of any base metals smelting process, with six copper ISASMELT plants and two lead ISASMELT plants designed and constructed. The technical and economic success of these plants should ensure continuing adoption of the process by smelters around the world.

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