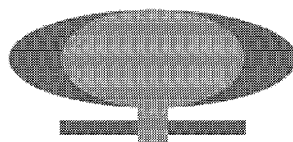


Volume III
The Carlos Díaz Symposium
on Pyrometallurgy

(Book 2)



PROCEEDINGS OF THE SIXTH INTERNATIONAL
COPPER-COBRE CONFERENCE
AUGUST 25-30, 2007, TORONTO, ONTARIO, CANADA

Volume III

The Carlos Díaz Symposium on Pyrometallurgy

(Book 2)

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*Symposium Organized by the Non-ferrous Pyrometallurgy Section of MetSoc of CIM,
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Preface

Cu2007 is the sixth in the series of international conferences devoted to the economics, the mineral processing, extractive metallurgy, environmental compatibility, and the applications of copper. The Copper-Cobre Conferences, held every four years since 1987, have become the foremost forum for the discussion of the on-going development of the world's copper industry. The 2007 meeting introduces a series of developments, building on the success of the preceding conferences at a time that copper is enjoying unprecedented activity. Most important is the globalization of the conference organization with the inclusion of European and Asian co-organizers, reflecting the globalization of the copper industry. The other major development is the much expanded focus on sustainable development, carbon-constraint concerns and the impact of community issues on the copper material production cycle.

The plenary lectures provide overviews of these subjects, in addition to the more traditional topics of copper applications, the impact of new technology on the industry as well as the critical shortage of trained professionals and skilled labour facing our industry globally. The over 330 papers included in the program originate from all the world's important copper producing nations. They provide an excellent "snapshot" of the current status of the industry and offer a range of perspectives on future directions. A substantial number of research-oriented papers are included in the proceedings, and these encompass most of the emerging topics related to copper processing.

The Sixth Copper – Cobre Conference, Cu2007, is being held in Toronto, Canada where many of the key copper mining companies have had their headquarters and is a centre for mining and metals finance. The conference is hosted by The Metallurgical Society of the Canadian Institute of Mining, Metallurgy and Petroleum (METSOC). Co-organizing institutions are the Chilean Institute of Mining Engineers, The Minerals, Metals & Materials Society (TMS), The Society of Mining, Metallurgy and Exploration (SME), The Mining and Materials Processing Institute of Japan (MMIJ) and The Society for Mining, Metallurgy, Resource and Environmental Technology of Germany (GDMB). Following the previous conferences in Viña del Mar (Chile) in 1987, Ottawa (Canada) in 1991, Santiago de Chile in 1995, Phoenix (USA) in 1999 and Santiago de Chile in 2003, the Toronto Conference will have the largest technical program to date.

We look forward to Cu2010 in Hamburg (Germany) hosted by GDMB, the first conference in the new reduced three-year cycle.

The last 4 years have been unprecedented in our industry, starting slowly but then seeing dramatic growth in copper demand driven by economic growth in China in particular. As their economy continues to grow at an average 10% per year, year after year, the demand for copper as a key input to their construction continues to rise. This in turn has led to a dramatic rise in the construction of new production facilities and expansion of existing ones. It seems clear we will be working in this very positive environment for several more years until the inevitable cyclic downturn occurs. However, community acceptance and the license to operate have become major issues. The other two emerging concerns are:

- The impact of regulations concerning carbon constraint and
- The increasing substitution of other materials if prices stay high over sustained periods.
- Key technical and operational trends that continue to evolve are:
- The impact of globalization and consolidation of the industry,
- In the realm of economics, the impact of the evolving economies in China and India on supply, demand, and the business and financial structure of the copper market and industry,
- The critical shortage of skilled professionals,
- For Mineral Processing, the application of process optimization strategies, introduction of finer grinding and flotation, larger process equipment and the linking of geology to metallurgy,
- In Pyrometallurgy, the expansion of copper smelting capacity worldwide, utilizing higher intensity smelting and converting technologies while meeting environmental pressures to reduce dust and gas emissions,
- In Hydrometallurgy, the search for cost-effective pressure leaching processes for copper concentrates and the optimization of heap/bacterial leaching by means of mathematical models,
- The search for increased economies of scale in refinery operations for very high tonnage outputs in a single facility, using process intensification through automation, enhanced process controls, higher current density and efficiency,
- A major focus on process optimization to drive sustainable profitability, productivity and EHS gains from existing operations,
- For Fabrication and Downstream Applications, the focus is on impurity management, applications and new practices in melting, casting, mechanical forming and treatment, as well as properties and characterization of refined copper products and alloys,
- For Sustainable Development as well as Health, Safety and the Environment, a range of public issues impact on the copper industry and on contributions to the sustainable production and use of copper products.

Within the above framework, the seven volumes of Cu2007 will serve as valuable reference books for the copper industry, especially the contained world surveys on copper solvent extraction, electrorefining and electrowinning.

The Organizing Committee offers its sincere thanks to all the authors, session chairpersons, members of co-sponsoring organizations and the producers of copper for their contributions to the success of Cu2007. Thanks are also due to the plenary session speakers for their thoughtful discussions on the rapidly changing state of the copper industry. Ronona Saunders and her colleagues at the Canadian Institute of Mining, Metallurgy and Petroleum deserve special recognition for their production of the proceedings volumes within a tight time schedule; Brigitte Farah of the METSOC of CIM also deserves special recognition for her work in coordinating all the diverse activities of Cu2007.

I would also like to personally thank, on behalf of the copper community, all members of the Cu2007 Organizing Committee, the International Technical Committee, the Symposia Committees and in particular, the proceedings editors for their dedication and for their enthusiasm that has made Cu2007 such a success and these volumes such valuable references.

Chris Twigge-Molecey
Chair
Cu2007 Organizing Committee

Foreword

World mined copper in 2006 reached a record level of some 15 million tonnes; with the annual growth rate over the last decade of 3.6%. Smelting tonnages were also at an all time record, and smelting accounted for about 12.3 million tonnes of copper or 82 % of world copper, the balance was produced by Leach-SX-EW operations. Flash and bath smelting represent the major smelting technologies, with about 35% of plants world wide employing flash smelting, 35% using bath smelting, while other technologies cover the balance of 30%. In 2006, copper smelters were bigger, more energy efficient and achieved better environmental performance than ever before; but some smelters remain poor performers, particularly with respect to environmental performance.

The editors are pleased to present this collection of papers as Volume III (Book 1 and 2) of 'The Carlos Díaz Symposium on Pyrometallurgy' to honour the contribution of Carlos Díaz to the disciplines of pyrometallurgy and copper smelting technology.

Carlos Díaz received a BSc from the University of Chile, an MSc from Columbia University, and a PhD from the Imperial College of the University of London. He taught chemical thermodynamics and extractive metallurgy at the University of Chile. In 1975, he joined Inco Limited, where he was responsible for research leading to new copper and nickel smelting and converting processes. He retired in 1995. He is currently an adjunct professor in the Department of Materials Science and Engineering of the University of Toronto. He was one of the founders of Copper 87, the first of this series of international conferences on copper, and Carlos has played a key role in each of the succeeding copper conferences. A prolific author of numerous technical papers and patents; Dr. Díaz is the recipient of Canadian, Chilean and American awards for his metallurgical and educational achievements. He is a past-president of the Metallurgical Society of the CIM.

The objective of the symposium is to bring together world experts to address the latest innovations in copper pyrometallurgy and their impact on the copper industry.

The 94 papers in the two volumes cover all important aspects of modern smelting, converting and fire refining technology. The papers in this volume represent contributions from authors in 18 countries. There are 21 smelters represented, including some of the world's largest and most modern plants. All major smelting and converting technologies are covered in this volume, including Outokumpu flash smelting and Kennecott-Outokumpu Flash Converting, along with Noranda, El Teniente, Isasmelt™, Ausmelt™ and Vaniukov representing bath smelting and bath converting. The converting process developed by Messrs Peirce and Smith remains well represented after over 100 years.

As experienced at the last three Copper-Cobre Conferences about 60% of the papers are from Canada, Chile and the United States with Chile submitting 27 of the 94 papers submitted for this symposium.

The 41 papers in Book 1 have been grouped into the following sections:

- Keynote and general (3 papers)
- Fundamental metallurgy (4 papers)
- Plant upgrading (11 papers)
- Impurities (5 papers)
- Copper smelting technologies (5 papers)
- Peirce Smith Converting (13 papers)

The 53 papers in Book 2 have been grouped into the following sections:

- Continuous Converting (7 papers)
- Alternative/ Other Technologies (11 papers)
- Feed Preparation, Materials Handling, Fuels and Gases (5 papers)
- Slag Cleaning (8 papers)
- Vessel Integrity (6 papers)
- Off Gas Handling (9 papers)
- Fire Refining (7 papers)

Research and development across many copper producing countries continues to make important contributions in the advancement of smelting technology.

The editors are confident that this volume will prove a useful addition to the bookshelves of practicing and academic metallurgists alike around the world.

Toronto, Ontario, Canada
August 2007

A.E.M. Warner
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A. Vahed
D.B. George
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Editors

Editors' Biographies

Tony Warner was born and educated in England, joined Inco in 1970 at the Port Colborne Research Stations after obtaining his Ph.D. in Extractive Metallurgical Engineering at the Royal School of Mines, Imperial College, London. He transferred to Thompson in 1971 as Supervisor Smelter Process Technology and then to PT Inco in 1975 as Supt. Process Technology and in 1979 as Supt. Smelting and Converting. He returned to Canada in 1981 to the CC Smelter as Supt. Smelter Projects and in 1989 transferred to Port Colborne as Supt. Research and Process Technology. He transferred to Sheridan Park in 1994 as Section Head Advanced Materials and then as Section Head Pyrometallurgy, Inco Technical Services Ltd in August 1997 until he retired from Inco in 2005. He is currently working as a Senior Consultant to WorleyParsons HGE in Toronto. He has published numerous papers relating to non ferrous pyrometallurgy and is the co inventor of a number of patents held by Inco Ltd. He is an avid sailor who also enjoys a game of golf.

Chris Newman graduated from the University of Manchester with a BSc in metallurgy and chemistry. After graduation he joined what is now Xstrata, working in the Horne smelter primarily on the Noranda Continuous Smelting Process. Prior to leaving the Horne smelter he was in charge of the operation of the Noranda reactor. In 1977 he joined what is now Xstrata at their Kidd Creek metallurgical site. Here he was smelter superintendent during the startup and subsequent operation and expansion of the new smelter, which uses the Mitsubishi Continuous Smelting and Converting Process. From 1986 to 1993 he was the copper smelter and refinery manager, responsible for all of the smelter and refinery operations. In 1993 he joined Kennecott as Technical Manager during the final stages of design, construction and subsequent startup of a new smelter using Flash Smelting and Flash Converting technology. This smelter started up in 1995. During his time at Kennecott, Chris was extensively involved in the design development of the Flash Converting Furnace, significantly enhancing the furnace integrity using the best combination of technology available. Chris left Kennecott in 2004 and is now a consultant working primarily on smelters and refineries. Chris is a Fellow of CIM and a member of TMS. He has been chairman of the non-ferrous pyrometallurgy committee of the Metallurgical Society of CIM and chairman of the pyrometallurgy committee of TMS. He is the author or coauthor of more than 30 technical papers and patents and co-editor of numerous international conference proceedings. He has participated in all of the Copper-Cobre Conferences since 1987.

Ahmed Vahed obtained his M.Eng. in Metallurgical Engineering from McMaster University in Hamilton, Ontario, in 1972. After graduation, he continued postgraduate research for two years on application of rare earth metals to refining of steel. He started his career in the non-ferrous industry by joining Falconbridge's laterite smelting operations in 1974 at Falcondo in the Dominican Republic. In 1978 he joined the Noranda Smelter at Gaspé Copper in Murdochville, Quebec and after about two years moved to Inco Limited, first in the Copper Cliff Smelter in 1980 and later to Inco's research laboratory in 1988 in Mississauga, Ontario, where he has been working ever since. He has been an active member of the Canadian Metallurgical Society of CIM since 1978, serving on the Board of Directors and numerous Conference Organizing

Committees in various capacities. Ahmed is currently the Section Head of Pyrometallurgy at CVRD Inco Limited

David George received a B.S. in Metallurgical Engineering from the University of Utah in 1969. He has 40 years of experience in the mining industry in a wide variety of roles including Technical and Operations Management, Process Innovation and Development, Environmental Permitting, Incident Investigation, Insurance, Intellectual Property and Licensing, Strategic Planning, Study and Project Management and Mergers and Acquisitions. He holds over 30 patents worldwide, has published widely and is recognized as an important innovator in the metallurgical industry. He is currently Principal Advisor at Rio Tinto Technology and Innovation and previously worked for Kennecott Corporation. He is a keen skier and mountaineer and continues to travel to remote mountains around the world in search of new challenges.

Phil Mackey is Principal Engineer at Xstrata Process Support in Sudbury, Ontario, Canada, where he plays a major role in the development of new technologies for processing nickel laterites and nickel sulphides and in copper smelting. He has over thirty-five years of broad, in-depth experience and understanding of the non-ferrous metals business and technology, in particular for nickel, copper and precious metals. He has authored or co-authored over 90 publications covering many aspects of non-ferrous metallurgy. At Noranda Mines in the 1970s and 1980s he played a leading role in the development of the Noranda Process, the world's first commercial continuous copper smelting and converting process and one of the important copper technologies developed in the twentieth century. He subsequently played a leading role during the 1980s and 1990s in the introduction of this technology in Australia, Chile and China. He has been active in the Copper Development Association and introduced the North American Initiative for Copper in Architecture to the copper industry in the 1990s. Dr. Mackey served as President of The Metallurgical Society of CIM from 1983 to 1985, and was elected as Fellow of the CIM in 1996. He was a co-founder of the Copper-Cobre conference series, was Co-Chairman of the first Copper-Cobre International Conference held in Chile in 1987 and has been active in all subsequent Copper-Cobre conferences. He was the 1998 recipient of the Noranda Award for Individual Achievement in Technology and in particular for the development of the Noranda Continuous Converter for copper converting. He received his B.Sc. degree in 1965 and his Ph. D from the same university in 1969.

Andrzej Warczok graduated in Poland with a Engineer and MSc in metallurgy from the University of Mining and Metallurgy, Cracow. He worked two years in the industrial Institute of Non-Ferrous Metals and joined the University of Mining and Metallurgy as Assistant Professor. He received from the same University a PhD in metallurgy. For almost two decades he was employed as a consultant in the GLOGOW Smelter. One year he worked as Post-Doc fellow at University of Leeds. Andrzej received the title of Doctor Habilitus (D.Sc.) in technology from the University of Mining and Metallurgy and has been promoted to Associate Professor. He taught extractive metallurgy, process modeling, thermodynamics and kinetics of metallurgical reactions, supervising numerous Master thesis and co-supervising two PhD thesis. He held the position of Head of Department of Metallurgy of Copper and Rare Metals. He then moved to Canada and joined the University of Toronto as a senior research associate, conducting fundamental and applied research on aluminum, nickel and copper

metallurgy, supervising undergraduate and graduate students. Currently, he works as Professor of Pyrometallurgy at University of Chile, teaching pyrometallurgy, heat and mass transfer, and process modeling, conducting various research projects, and consulting Chilean smelters. Simultaneously, we works part time as a senior research associate at University of Toronto. He is the author and co-author of a book on electrokinetic phenomena in metallurgical slags, over 70 papers and 9 patents. Member of CIM, TMS, SIPTH.

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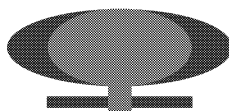
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KENNECOTT UTAH COPPER SMELTER REBUILD OVER 11 MILLION TONNES OF CONCENTRATE SMELTED

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ABSTRACT

Kennecott's Utah Smelter commenced operations in June 1995 utilizing Outokumpu Flash Smelting (FSF) and Kennecott-Outokumpu Flash Converting (FCF) technology. After some initial teething and equipment problems the smelter achieved its design capacity in mid-1997 and now processes over 1.0 million tonnes of copper concentrate per year with exceptional environmental performance. The smelting furnace has operated for 11 years and the converting furnace for 5 years without major shutdowns. The first major smelter shutdown commenced in September 2006 after extensive planning. The FSF was completely re-bricked and the latest above and below bath containment systems installed. The FCF was inspected and re-bricked with some improvements made to the above bath containment system. The FCF life is now anticipated to be the same as the FSF. Numerous improvements and modifications were made to the rest of smelter facility including extensive upgrades to the dry electrostatic precipitators. Production ramp-up was smooth with the smelter now frequently operating at acid plant capacity.



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INTRODUCTION

The Kennecott Utah Copper Corporation's (KUCC) Smelter is located approximately 35 km (20 miles) west of Salt Lake City, Utah. The Smelter is part of an integrated mining and processing operation that produces cathode copper, molybdenite concentrate, gold, silver and other metals. The Bingham Canyon mine and Copperton concentrator are located 35 km (20 miles) south of the Smelter. The KUCC Smelter site is steeped in smelting history going back over 100 years. The current Smelter was placed into operation in June 1995 to process over one million tonnes of copper concentrate per year.

The Smelter uses an Outokumpu Flash Smelting Furnace (FSF) with high levels of oxygen enrichment to produce 70% copper matte from copper concentrate supplied by slurry pipeline and filtered at the Smelter. About 2,900 tonnes (3,200 tons) of concentrate is smelted to produce 1,225 tonnes (1,350 tons) per day of matte and 1,950 tonnes (2,150 tons) per day of slag. The slag is slow cooled in 18 m³ (640 ft³) steel pots, crushed, ground and subjected to froth flotation to recover the copper. Typical slag tailings contain less than 0.4% copper.

The molten matte is granulated with water, ground and dried in a vertical roller mill and then converted in a Kennecott-Outokumpu Flash Converting Furnace (FCF). The Flash Converting Furnace processes all of the matte produced by the FSF using a lime based slag system. Typical blister copper production is 770 tonnes (850 tons) per day containing 0.2% sulfur. The FCF slag is granulated and recycled to the FSF.

The blister copper is further refined in two refining furnaces prior to casting 340 kg (750 pound) anodes on a Outokumpu-Wenmec Twin M-16 casting system.

Off-gas from both the FSF and FCF contain 35% to 45% sulfur dioxide, a result of using high levels of oxygen enrichment. Very little supplementary fuel is used in either furnace when operating. The combined furnace off-gas is treated in a Monsanto Enviro-Chem sulfuric acid plant with a capacity of 248,000 Nm³/hr (140,000 Ncfm) at 14% SO₂. The tail gas from the acid plant contains less than 100 PPMV SO₂.

Copper anodes are delivered by rail to the Refinery located approximately 3 miles east of the Smelter. The copper refinery produces high quality cathode copper from anodes with high levels of impurities that would pose a challenge to the majority of other copper refineries around the world.

The FSF has operated for 11 years without a major rebuild or design changes. Since the start of operation, the FCF has been rebuilt and portions of the furnace upgraded in 1995, 1997, 1999, 2001 and 2006. Two of these outages were due to premature failures of the FCF. During these outages upgrades were made to the settler cooling elements, the cooling element monitoring system and the furnace refractory

design [2, 4]. Details of the KUCC Smelter equipment have been reviewed in other papers, so only a brief description is provided in this paper [1-7].

2006 SHUTDOWN OVERVIEW

The 63 day rebuild that took place in the fall of 2006 included a complete re-bricking of the FSF hearth, side walls, reaction shaft and uptake shaft. Along with the re-bricking, newly designed settler sidewall cooling elements, reaction shaft transition elements, settler and uptake shaft roof cooling elements and boiler transition elements were installed. These upgrades were put in place to implement the most recent improvements in furnace cooling technology. The rebuild also included a complete re-bricking of the FCF and the installation of additional cooling capacity in the FCF reaction shaft and settler freeboard. In addition to the furnaces and work in the acid plant, General Electric (G.E formerly BHA) Dry Electrostatic Precipitators were installed to replace the original ABB Flakt units. This shutdown was the second part of the smelter rebuild scope of work with the first executed over 15 days in May 2005 and focusing on the acid plant. This paper will describe the furnace rebuilds in 2006.

FLASH SMELTING FURNACE REBUILD

Since the facility is a captive Smelter with limited blending capability, process control is more complicated than at custom smelters where feed quality is planned well in advance of treatment. Control is further compounded by a lack of blending capability up stream. As the Bingham Canyon Mine matures, fewer ore faces are exposed for mining and efficient large shovels limit the ore blending that at one time occurred from numerous small shovels operating at multiple ore faces. Consequently, a high variation in ore types (approximately 28 in total) is presented to the concentrator resulting in a large variation in concentrate quality presented to the Smelter. This issue impacted smelting performance and was one of the drivers behind upgrading parts of the FSF. Concentrate grades vary from a low of 22% copper to over 30% copper with similar variations in iron, sulfur and silica bearing gangue. Magnesia is an occasional problem when high talc ores are encountered.

Furnace Upgrades

The FSF operated for over 11 years and processed over 11 million tonnes of concentrate without a major rebuild. During this time, several weaknesses in the furnace design were identified. These include:

- **Settler Containment.** Growing gaps between the settler sidewall cooling elements that increased the likelihood of a leak due to process upsets. As the settler expanded over the campaign, some of these gaps increased to over 75mm (3 inches).

- Corrosion of cooling elements. The settler sidewall cooling elements were a drilled and plugged design and the plugs were beginning to develop leaks due to external corrosion. This contributed to localized sidewall hydration.
- Inadequate reaction shaft cooling. Feed rate limitations and frequent repair associated with poor cooling density in and around the reaction shaft transition and particularly the settler roof.
- Up to 200 mm (8 inches) of hearth lateral movement was observed due to high arsenic matte infiltration into the hearth working lining.

These weaknesses were compounded by the issues with inconsistent feed quality highlighted above. As a result, specific operating practices were instituted to minimize risk associated with the furnace operation. In spite of these precautions several leaks did occur but with minor effect. At times, these practices limited production.

The new furnace design incorporates the following main features to further enhance integrity:

- Outokumpu design to upgrade side wall cooling elements
 - Concentric pipe cooling channels to eliminate below melt/enclosed plug requirement.
 - Element overlap allowing for movement without exposing an area that is not cooled.
 - One piece element to eliminate the gap between the skew back and side wall elements.
 - Taller settler cooling elements to allow increased bath levels.
- Outokumpu design to upgrade cooling capacity in the lower third of the reaction shaft.
 - Reduced spacing between horizontal cooling elements.
 - Outokumpu designed transition elements on the reaction shaft to increase cooling in this area (see Figure 1).
- Outokumpu design BIC (Brick Implanted Copper) cooling elements added in the settler roof around the reaction shaft (see Figure 2).
- Outokumpu BIC cooling elements added to the uptake shaft roof.

Sidewall sections (Figures 3, 4, and 5) demonstrate the change in design of the settler side walls. Between 1998 and 2000 shelf “nose” cooling elements were added to the original sidewall between the skew and vertical cooling elements. This was done to reduce the frequency of breaches in this area. The new design creates a more robust containment and will improve element life.

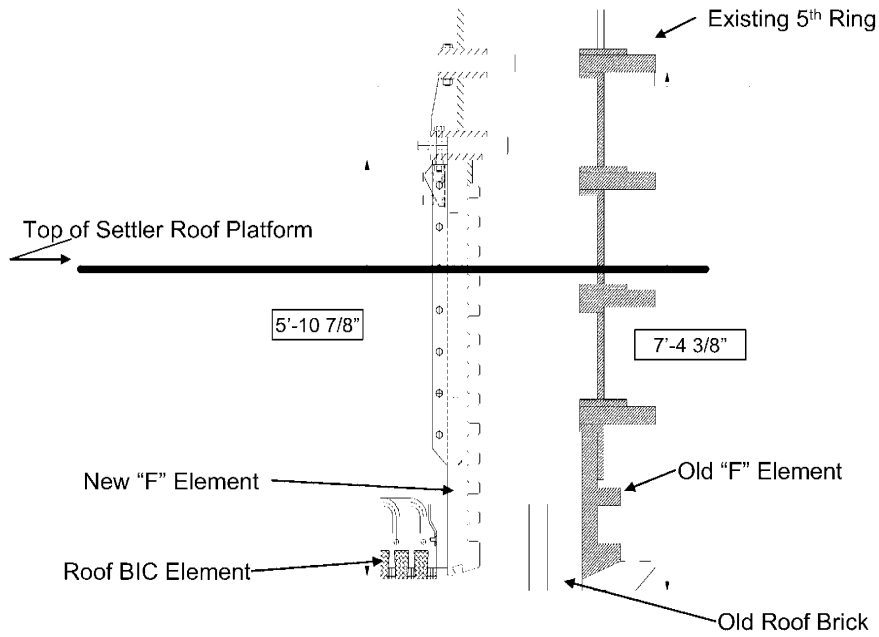


Figure 1 – The New FSF Reaction Shaft Transition is compared to Old

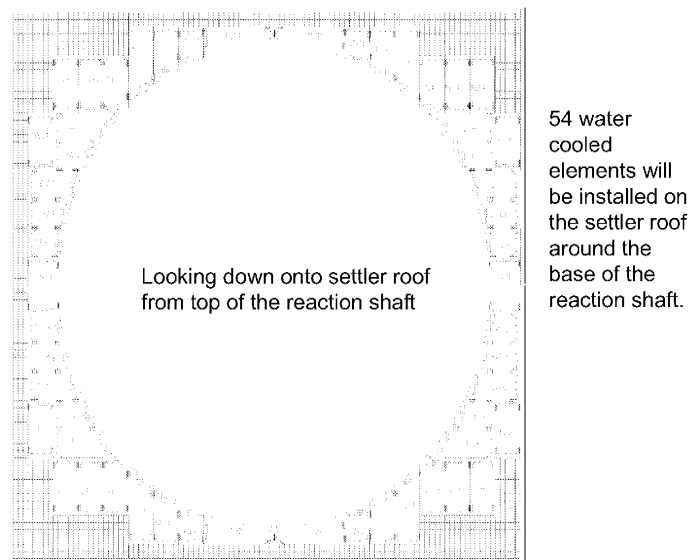


Figure 2 – The Settler Roof Cooling Arrangement Around Reaction Shaft

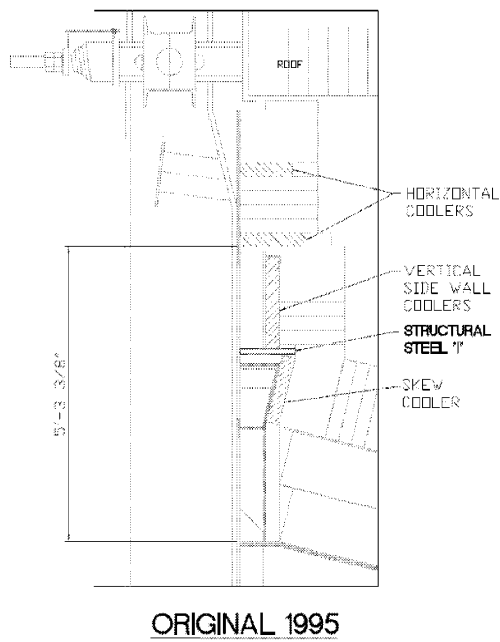


Figure 3 – Old Side Wall Section

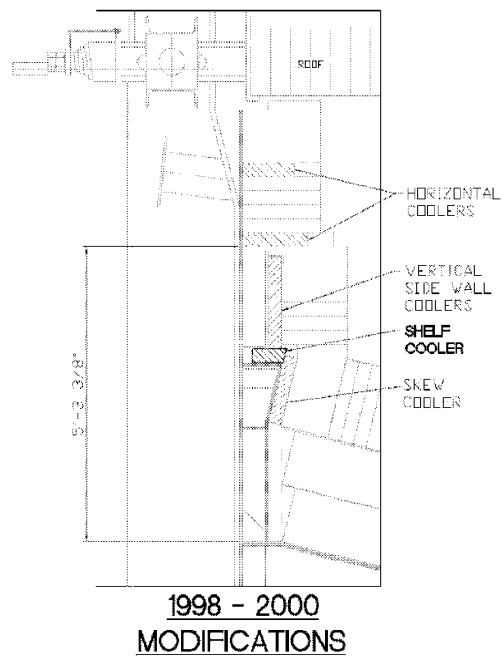


Figure 4 – Modified Side Wall Section

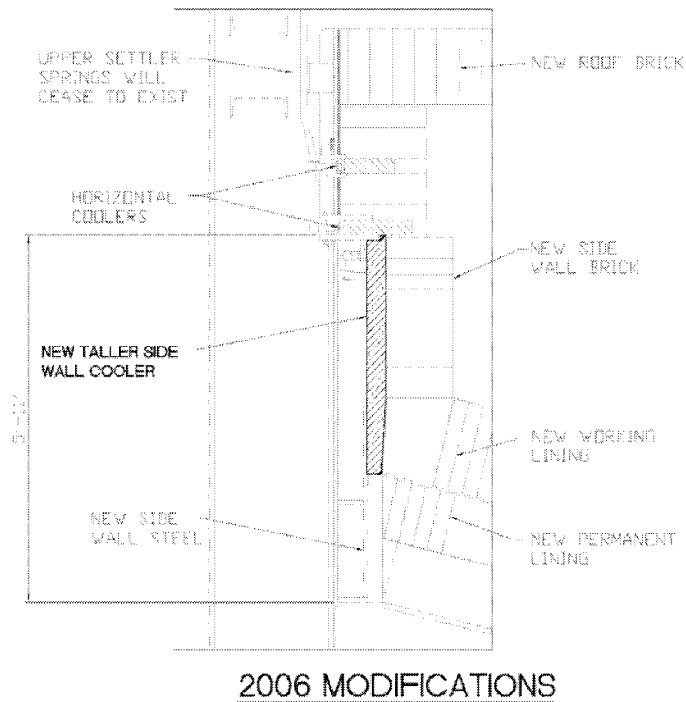


Figure 5 – New Side Wall Section

Engineering

A proposal for the design of the upgraded FSF was solicited and received in late April 2004 from Outokumpu Technology. Basic engineering was completed in June 2004, and the final cooling element drawings and the final sidewall steel structure drawings were received June 2005. A mechanical scope and refractory scope were developed and sent out for bids in September 2005. Bids were awarded in early 2006.

Pre-Assembly

In the early spring of 2006, the FSF settler and reaction shaft transition were pre-assembled (see Figure 6). The same mechanical contractor awarded the bid to rebuild the furnace was utilized to pre-assemble the furnace. In this way, the craftsmen would become familiar with the piping arrangements and identify any difficulties associated with assembly. During this process, components or sections of the furnace were preassembled and tested for fit. Several lifting and positioning jigs were made to aid in the rigging and installation of the copper coolers. These jigs and rigging plans were practiced in the pre-assembly. The reaction shaft elements and rings were assembled as a unit and then taken apart and piece marked for installation. The cooling line jumpers were prefabricated and bent for faster installation during the rebuild. Coolers, steel and piping were all piece marked and identified for use during furnace construction.

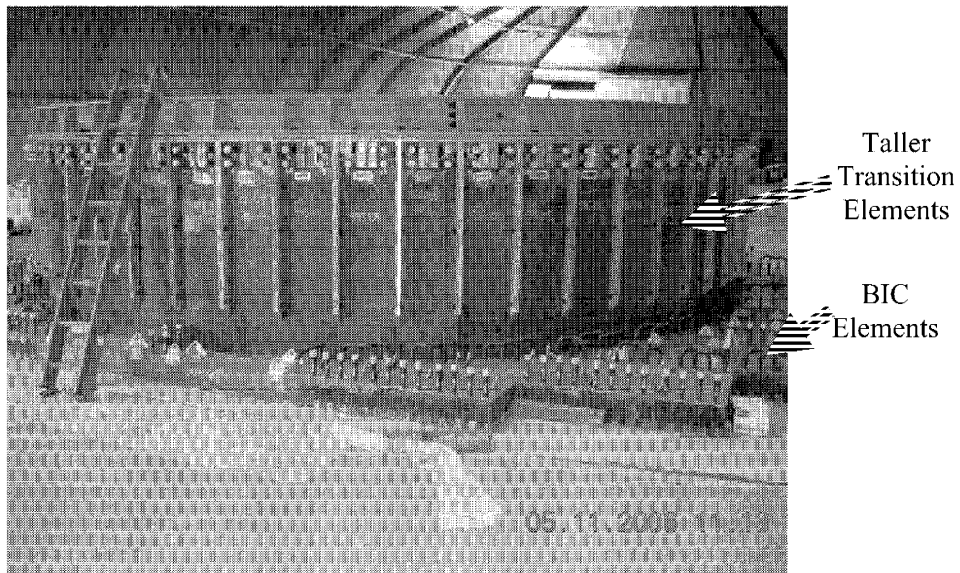


Figure 6 – Pre-assembly of FSF Reaction Shaft Transition and BIC Roof Elements

Pre Outage

All prep work that could be accomplished prior to the furnace being taken offline was accomplished. Materials were staged inside the building, reaction shaft rings and cooling elements were staged on the upper floors. Floor grating, launders and covers were all tagged to help with the reinstallation.

The KUCC maintenance group was assigned to remove and replace needed instrumentation. Instrumentation packets for each affected instrument were put together to aid in the removal, installation and operational verification of the instrument. Each packet contained a check sheet for removal and replacement, data sheets, loop and P&ID drawings and a section for comments. Affected instruments were tagged in advance with manila tags.

Tear Out

The contractor's approach to using Brokk and Bobcat machines for clean up proved to be a great time saver. The hearth material proved to be very hard, particularly in the reaction shaft end of the furnace. All the material was allowed to fall into the furnace and then removed from either the North (uptake) or South (reaction) end of the furnace with the Bobcats. Debris removal was carried out simultaneously from both ends of the furnace.

The uptake shaft cleaning was accomplished by lowering a Brokk on a platform and securing it in place with cables.

Furnace Condition

Starting in fall of 2004 and leading up to the shutdown, Hatch Associates, Ltd. was contracted to conduct five non-destructive acoustic testing (NDT) surveys to determine FSF hearth condition. This test work was utilized to establish a level of risk around the timing of the shutdown and allowed KUCC to confidently push the shutdown out from the originally planned 2005 date. The capability of the method to detect unusual melt penetration into the hearth and between the hearth refractory layers was validated during the shutdown.

The working lining of the FSF hearth was generally in good condition. The refractory was full thickness, but high arsenic matte (40 %Cu, 30 %As, 350 g/t Au) had penetrated throughout. In some areas, a layer of matte was observed between the permanent and working lining. Additionally, a layer of matte between the permanent and insulating lining was observed at the uptake shaft end. This prompted the decision to replace both the working and permanent linings.

The uptake shaft of the furnace had a significant amount of build up that was removed along with the refractory after cool down. The uptake shaft steel mantel and structure was in poor condition and the decision was made to replace the uptake steel and brick lining. The scope of this work significantly exceeded the plan.

Furnace Assembly

Prior to beginning work inside the furnace the insulating lining was covered with belting material to protect it from damage. A monorail system was installed from an opening in the East wall of the building through the North end wall of the furnace and along the length of both side walls for installing the side wall steel and elements. Uptake shaft and reaction shaft bulkheads were installed to permit concurrent work in the settler area. The masons began installation of the permanent hearth brick from the North end of the furnace. After they had progressed far enough away from the North end wall the mechanical team added the lower wall sections and coolers. After the completion of the permanent hearth and the North end lower wall steel and coolers, the masons began the installation of the working hearth lining and the bricking of the North end wall.

As cooling elements became available for water piping the pipe fitting crews would make the connections. No circuits were energized until they could be coordinated and checked by a water commissioning team.

FLASH CONVERTING FURNACE REBUILD

The FCF was last rebuilt in 2001 [2] with the expected campaign life of five years governed by long term uncertainty regarding sidewall blister containment. Prior to the planned outage, there were no outward signs of any integrity threats. The FCF operated reliably throughout the campaign [1] and for significant periods was limited due to lack of matte inventory.

Furnace Upgrades

The FCF operated for over five years and processed over 2 million tonnes of matte since the last rebuild. During this time, operational problems continued with reaction shaft integrity. These include:

- Inadequate reaction shaft cooling. Feed rate restrictions and occasional repair associated with poor cooling density in the lower one third of the reaction shaft.
- Reaction shaft plume impacts on stadium hearth. Uncertainty existed as to how much damage was being experienced by the stadium hearth under the reaction shaft.

These problems were compounded by the continued sensitivity of the reaction shaft plume symmetry to feed and gas radial distribution.

The new furnace design incorporates the following main features to further enhance integrity:

- Increased cooling capacity in the lower third of the reaction shaft.
 - Reduced spacing between horizontal cooling elements.
 - Outokumpu designed transition elements on the reaction shaft to increase cooling in this area.
- Hatch designed cooling elements at the reaction end settler freeboard.
- Outokumpu BIC cooling elements added to the uptake shaft roof.

Furnace Condition

Starting in winter 2005 and leading up to the shutdown, Hatch Associates, Ltd. was contracted to conduct two non-destructive acoustic testing (NDT) surveys to determine FCF hearth condition. The surveys indicated that the hearth condition was likely to be sound, which was subsequently validated during the shutdown.

Some cracking and blister penetration was noted throughout the working lining but there was no evidence of further migration to the permanent lining. There was no evidence of any plume related hearth damage.

There were a number of surprising cooling element observations. These included:

- Most of the reaction end settler freeboard cooling elements were found to be worn more than expected. Contingency plans have been developed to change these without a major outage.
- One of the blister drain hole cooling elements showed evidence of oxygen lance contact. The damaged was attributed to a single event that occurred early in the campaign. The cooling element was not replaced.
- Both of the duty slag hole cooling elements showed evidence of oxygen lance contact and one of them concurrent blister contact. The damage could not be pinpointed to any particular event or period. The cooling elements were not replaced. Tapping practice, hole insert maintenance, blister level control and condition monitoring have all been upgraded significantly. This has reduced the risk of operating with these damaged elements.

FURNACE OPERATING CAMPAIGN HISTORY

Data for the operating campaign of the FSF is shown in Table 1 and data for the last five operating campaigns of the FCF is shown in Table 2.

Table 1 - Flash Smelting Furnace Campaign History

Operating Campaign	Campaign Length – Days	Concentrate Smelted - Tonnes
1 June 1995 – 6 September 2006	4,116	11,773,304

Table 2 - Flash Converting Furnace Campaign History

Operating Campaign	Campaign Length – Days	Matte Converted - Tonnes
4 July 1995 – 16 September 1995	75	19,315
1 December 1995 – 9 April 1996	131	28,428
8 May 1996 – 13 April 1997	341	189,750
26 May 1997 – 8 January 1999	593	658,501
1 February 1999 – 8 July 2001	889	1,079,677
8 August 2001 – 5 September 2006	1,855	2,104,878

CONCLUSION

The 2006 shutdown was followed by a successful start up and corresponding ramp up to full production over a three week period. This shutdown was accomplished with extraordinary safety performance. KUCC established four main goals and prioritized them based on importance to the company. These goals are listed below in order of priority.

1. Complete the rebuild without a serious injury.
2. Quality of work will not be compromised.
3. On schedule
4. On Budget

The first two goals were tied together as the top priority so that schedule and cost would not drive decisions that negatively impact safety and quality of work. The following bullets highlight the actions taken to achieve these goals.

- Developed a written "Smelter Shutdown Safety Plan"
- Completed "Risk Assessments" for all projects.
- Prepared a detailed training "CD" which was viewed by every contract employee, and then a test was completed to show understanding.
- Split the work scope between many qualified contractors
- Conducted a "Safety Summit" (extended safety meeting) with all Contractors just prior to the outage

- Challenges associated with a strong labor market created concerns, so a comprehensive safety and retention incentive plan was established.
- Reduced fatigue by managing contractor hours in set limits.

The results of the shutdown are highlighted in the following bullets.

- Contractors did experience a large turnover; over 2,200 employees were trained to maintain a work force of 1,000 people
- 735,058 hours worked with 1 lost time injury(fractured metatarsal), 6 Recordable injuries(fingers contusions and lacerations) and 45 First Aid injuries (dust in eyes, burns and rashes)
- Work quality met or exceeded expectations. Since the ramp up, on-line times and rates have significantly exceeded budget.
- Original schedule was exceeded due to scope changes that were made during the shutdown. These changes were driven by quality expectations.
- Project costs were on budget.

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