Tenova Pyromet - Cooled Copper Furnace Elements

Conference Paper · November 2016

4 authors:

Hugo Joubert
Tenova Pyromet

Stanko Nikolic
Glencore Australia Holdings

Martin Lluis Bakker
Tenova Australia

Isobel Mc Dougall
Tenova Pyromet

TENOVA PYROMET - COOLED COPPER FURNACE ELEMENTS

H. Joubert, S. Nikolic and M.L. Bakker
Tenova Pyromet
L10, 410 Ann St.
Brisbane, QLD 4000
Australia
hugo.joubert@tenova.com

I. McDougall
Tenova Pyromet
Midrand Business Park, Building No. 4
563 Old Pretoria Main Road
Halfway House, Midrand 1685
South Africa

ABSTRACT

The use of refractory linings not only limits the campaign life of copper production furnaces but, more importantly, can also constrain the processes themselves. Minimisation of refractory wear necessitates stringent process control philosophies and constraints. Recent developments in lining/cooling system design permit the time between overhaul for furnaces to be increased and enable the key process performance measures, such as throughput and metal recovery, to be optimised. Tenova Pyromet's first sidewall copper coolers were installed at Fortaleza De Minas in Brazil in 1996. Since that time Tenova Pyromet has supplied copper elements for many furnaces processing materials such as platinum group metals, base metals, ferroalloys and ilmenite. Within the broader base metals industry, Tenova Pyromet has supplied primary smelting furnaces, slag cleaning electric furnaces, launders, tapholes, plate coolers and cooled sidewall copper elements to a number of clients. This paper describes how Tenova Pyromet launders, plate cooler and sidewall cooled copper element designs have been applied in the base metal industry and how these concepts can enable process improvement and optimisation.

INTRODUCTION

Traditionally the majority of copper production furnaces have utilized refractory linings. A review of the evolution of refractories in the copper industry completed in the 1930s[1] highlighted the main challenges present, which are still relevant today:

The problem of refractories arises from the necessity for constructing containers in which to bring natural ores into thermal solution in order to effect… separation of the valuable metal… while producing a waste slag. The very forces known to produce thermal solution of sufficient liquidity are necessarily destructive of exposed refractory.

Since that time many advancements have been made both in copper smelting technology as well as in the area of containment. From the late 1940s onwards smelting processes such as flash smelting, Mitsubishi Process, bath tuyere smelting (side and bottom) and top submerged lance (TSL) smelting were developed. Refractory options also evolved during these advances in the processing route. Another review of the refractory industry, completed in the early 1990s[2], showed how refractories had developed from what was in the 1940s conventional burned refractory, moving through to pre-reacted, direct bonded and finally fused grain refractories. Refractory development has continued[3-5] and many investigations and studies are still being conducted in the pursuit of longer furnace campaign lives.

The pace of refractory development has, however, not been able to match that of furnace requirements. Cooled copper elements have typically been installed where refractories have been unable to withstand furnace conditions. Extensive water cooling is common place in Outotec's Flash furnaces with the Harjavalta smelter using water cooled rings at the base of the reaction shaft in the 1950s[6]. Many flash furnace operations have increased the intensity or location of their cooling in an effort to improve their campaign lives[7, 8]. The first commercial flash furnace built by the International Nickel Co. of Canada (INCO) implemented water cooled copper jackets in the high wear areas of their uptake also in the 1950s[9]. The Mitsubishi Process development at Naoshima in the 1970s recognised the importance of intensive water cooled copper cooling of bricks to improve their furnace campaign life from a few months to over two years at the time[10].

Most of these new copper smelting technologies started with refractory containment alone, but due to the high rates of erosion they needed to implement some form of copper cooling either of bricks, interweaving with bricks, or direct freeze lining of the slag bath. However, the bath smelting technologies (side/bottom)[11-13] and some TSL smelters[14, 15] adopted a separate path of employing strict process control to obtain refractory longevity. The TSL technology is unique in its development in that various lining/cooling arrangements were employed from the start. These include designs using pure refractory systems[16], refractory backed by stave coolers[17], interleaved refractory-plate cooler linings[18] and cooled copper to the hot face designs[19]. Although lining design can be dictated by the aggressiveness of the slag/process system, the reasons for the decisions for a particular lining design are not always obvious.

EVALUATION OF LINING OPTIONS FOR COPPER FURNACES

The majority of the copper smelting furnace technologies have incorporated some form of copper cooling. TSL smelting furnaces are the only technology that has installations with vastly different types of linings and consequently this technology was examined in more detail to compare the benefits and limitations of the different options.

Refractory Lined Furnaces

Differences in furnace lining solutions that have been adopted by the TSL technology are a result of each operation addressing their refractory wear problems differently, either early on during pilot scale testing or later during full scale operation. The most ardent supporter of refractory lining systems has been the Mount Isa Mines copper smelter operation which has been able to achieve refractory campaign lives, without any copper cooling, of over four years[16]. However, during its early years, the Mount Isa copper smelter suffered from short campaign lives of less than a year. It was only at their seventh refractory campaign installation, where strict process controls were implemented, that an extended campaign life was achieved[14, 15]. The Mount Isa TSL is unique in being able to achieve a campaign life of over four years with a refractory only lining. Other TSL furnaces with this arrangement average a refractory lining life of around two years [20-22].

The strict process controls that were implemented to achieve the four year campaign life required that the heat balance of the Mount Isa furnace be carefully managed[14, 15]. The Mount Isa operation is not a custom smelter and therefore receives a consistent grade of concentrate from the local mines. This allows the operation to maintain close control of the heat balance for the TSL furnace. In addition, the furnace is operated such that trim fuel is usually required to allow the flexibility to strictly control the bath temperature[23]. In the Mount Isa case, which has standard copper concentrate feed, it is necessary to add over 20 t/h of reverts as coolant[23]. When this principle is applied to higher energy containing concentrates, such as those containing organic matter or high sulfur levels, the amount of coolant required is even greater. Some TSL operations even recycle cold slag that was produced by that same furnace to achieve the appropriate heat balance. This operating strategy increases slag make, lowers the capacity of the furnace for treatment of new feed and decreases process efficiency.

A process operated using the Mount Isa TSL furnace strategy can never truly operate auto-thermally to be able to maintain proper temperature control. If there are low temperature deviations the fuel rate must be increased rapidly and if there are high temperature deviations a bath over-temperature trip may be activated, thus lowering plant availability[14]. Overall this leads to higher fuel rates being required, with the Mount Isa operation showing an average usage of approximately 450 Nm^3/h and 1,200 Nm^3/h of natural gas during “higher” energy and “lower” energy concentrate smelting cases respectively[23]. This fuel usage, to maintain temperature for refractory life, increases the operating cost component for refractory lined furnaces.

Incorporation of Cooled Copper Linings

When confronted with the refractory wear issues present in the TSL furnace technology, other operations have opted for including cooled copper within their lining design. Examples include:

- Refractory linings backed by copper stave coolers[17],
- Interleaved refractory-copper plate cooler linings[18],
- Majority cooled copper lining to the hot face[19].

Only the refractory linings backed by copper stave coolers have been applied to primary copper TSL smelting furnaces. A review of the campaign life of the custom copper smelter at Tuticorin, part of Vedanta Resources PLC, reveals that their TSL furnace has been able to attain a campaign life of two to three years[24, 25]. Being a custom smelter, this operation does not have the luxury of controlling the feed grades and smelting requirements of the feed as in the Mount Isa case. It is claimed the application of the copper stave coolers within the lining system has been able to grant this operation added flexibility and high availability without the need to impose as restrictive process control conditions.

Interleaved refractory-plate cooler linings are common in TSL furnaces in lead and zinc processing[18] as well as in copper flash furnaces[7, 8]. Cooled copper linings to the operating hot face have been successfully applied in a copper-nickel TSL system which upgrades matte to form a higher grade matte and a fayalite slag[19]. This would arguably represent a more arduous duty for a cooled copper lining due to the higher superheat of the copper-nickel matte and operating temperature of the slag[19]. Some cooled copper elements have been employed in specialty applications within copper TSL furnaces such as tapholes and launders. Even unlined cooled copper tapholes, which are used for combined matte-slag tapping, are commonplace in TSL furnaces[26]. Therefore no technical or functional limitations should be imposed on the application of cooled copper elements to these furnaces.

The application of cooled copper eliminates the need for restrictive process control procedures and the process limitations highlighted in the TSLs operating with refractory only linings. This can allow for the process to be optimized for throughput and metal recovery. In turn this would result in lower fuel usage and allow for the coolant rate to be matched to the reverts generation rate, rather than fixed to specific smelting rates and/or rationed for periods of higher energy concentrate treatment.

COOLED COPPER ELEMENTS FOR USE IN COPPER SMELTING

Tenova Pyromet’s first sidewall copper coolers were installed at Fortaleza De Minas in Brazil in 1996. Since that time Tenova Pyromet has supplied copper elements for many furnaces processing materials such as platinum group metals, base metals, ferroalloys and ilmenite. Within the broader base metals industry, Tenova Pyromet has supplied launders, tapholes, plate and sidewall cooled copper elements to a number of clients. This section of the paper describes how Tenova Pyromet launders, plate coolers and sidewall cooled copper element designs have been applied.

Launder Systems

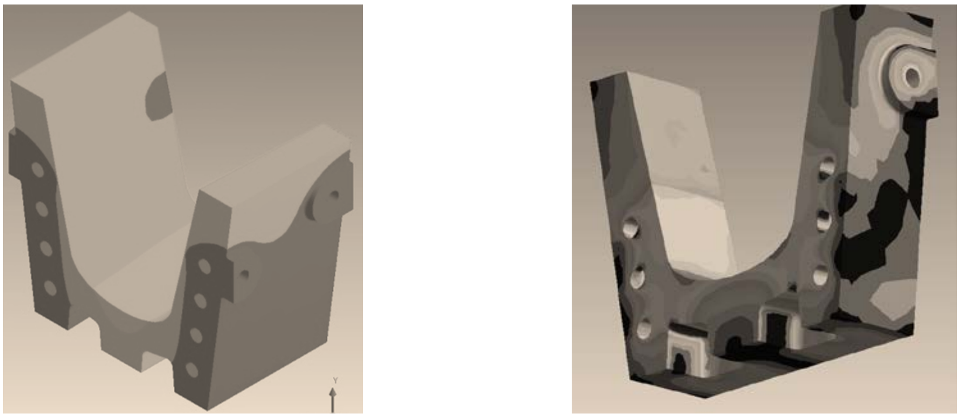
Tenova Pyromet's patented copper launders are designed for receiving the tapped products from copper smelting furnaces. By removing the heat from the passing flow at a high rate, the surface temperature of the copper can be kept below temperatures that result in launder damage and a freeze lining of process material can be created to protect the launder. What has made the Tenova Pyromet launder designs innovative and safe compared to other copper launders, is that they do not have any water channels under the molten flow, whilst still effectively removing the heat from the bottom of the launder through the sidewall cooling channels[27]. Therefore, on those occasions where burn-throughs occur, there is a greatly reduced risk of explosions. In addition, since the water channels are not damaged, the launder can be repaired and reused.

Tenova Pyromet has designed and made launders of various lengths with either drilled water passages or cast-in pipes. Launders longer than 2 metres in length are typically made in separate sections that are bolted together. This not only allows the water passages to be drilled, but also provides the client with the flexibility to change damaged sections rather than replacing an entire launder. Photos showing examples of a launder spout (less than 2m in length) and an upside-down 7 m long launder are shown in Figure 1.

(a) (b)

Figure 1 –Pyromet's Patented Copper Launder Design with (a) Launder Spout and (b) a 7m Long Launder

The basic principle of the Tenova Pyromet launder design is remove heat from the launder centre through the cooling water channels into the sidewalls. A Finite Element Analysis (FEA) model is produced for every launder design to optimise the geometry and cooling. Inputs into the model involve the slag composition, the tapping temperature and tapping rate required by the client. These values are then applied to the launder model and a static FEA thermal analysis is performed. Figure 2 shows thermal and heat flux results for a typical launder cross section. The geometry of the model is then adjusted or the number of cooling water passages increased to ensure that the copper hot face temperature is less than 800°C to prevent erosion of the copper. The bulk temperature of the copper launder is kept below 400°C to maintain its structural integrity and strength.



(a) (b)

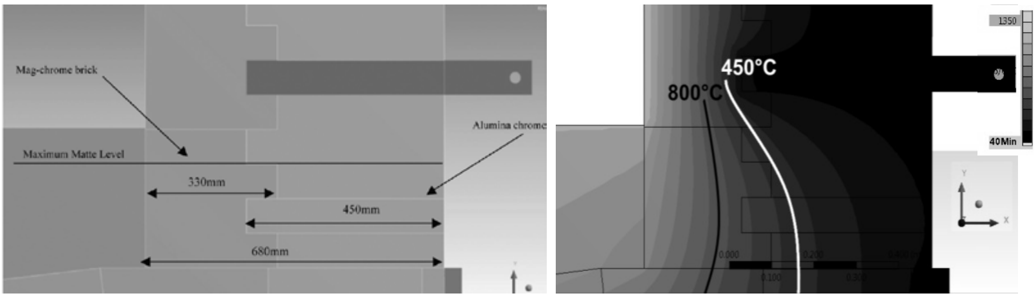
Figure 2 – Typical results from FEA model showing (a) Thermal results with a maximum Runner Temperature of Approximately 300°C and (b) Heat flux

Copper Plate Cooling System Design

Copper plate cooling of refractories is used in many of the copper smelting furnace technologies and as discussed previously is interleaved with the refractory. Tenova Pyromet has applied their plate cooling technology to a number of furnaces, with the following example taken from a copper-nickel-platinum group metal production furnace[28]. The design of this lining required there to be no cooled copper elements below the maximum matte level attainable in the furnace or in direct contact with the bath. Plate cooler technology, combined with graphite, was applied in this case to reduce the average temperature of the bricks and to allow for a significant increase in lining life.

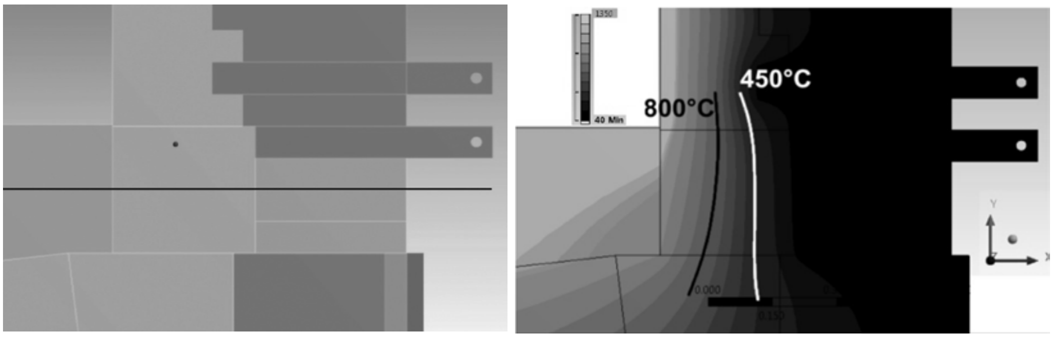
The base case for this design is shown in Figure 3(a), which has no plate coolers at or below the maximum matte level and alumina chrome brick installed behind the magnesia chrome brick working lining. The isotherms calculated with an FEA model for the base case are shown in Figure 3(b) with the 800°C isotherm representing the matte freezing temperature[29], and the 450°C isotherm representing the graphite maximum operating temperature prior to oxidation. The results for the base case calculations indicated a 700°C hot face temperature for the alumina chrome backing lining adjacent to the tidal zone and hearth.

A number of other arrangements were trialed for the client[28]. The final design implemented on site included a plate cooler installed in the fourth brick course above the hearth. Although this plate cooler is adjacent to the tidal zone it is above the maximum matte level. As an added precaution, the plate cooler was shortened to be 350 mm into the bricks, as shown in Figure 4(a). To achieve the required high level of cooling in the sidewall and hearth, a low-porosity, high-strength graphite brick was installed as the backing brick for the magnesia chrome working lining. The results of the FEA temperature analysis are also shown in Figure 4(b) with the matte freezing and graphite oxidation temperature sitting well within the mag-chrome working lining.



(a) (b)

Figure 3 – Base Case for the Plate Cooler Application.



(a) (b)

Figure 4 – Final Design Involving 350 mm Plate Cooler and Graphite Backing Brick

During construction of the furnace, two thermocouples were placed in the graphite, 160 mm from the inside of the shell. The temperatures measured over a period of several months during stable operation of the furnace varied between 85°C and 105°C, which compares well with the calculated FEA value for that depth of 89°C. As the lining wears and the thickness of the hot face brick is reduced these temperatures are expected to increase. The gradual increase in temperature, combined with other lining life monitoring techniques, was used by the site to estimate the rate at which the lining had been eroded. The copper plate coolers in this region operated successful and were reinstalled after the first campaign as they were still in pristine condition.

MAXICOOL® Copper Cooling System

The MAXICOOL® copper cooling system is a high intensity sidewall cooling system of the waffle or stave type, as shown in Figure 5. It consists of cast copper of high purity and conductivity with cast-in monel piping forming the cooling water circuits. A unique star pattern is used for the hot face of the coolers to provide support initially for the castable refractory, and later on for the frozen slag layer, whilst limiting thermal stress transmitted to the base of the cooler. Two cooling water circuits are used per cooler, which run in parallel through the copper cooler, each designed to carry the maximum heat load of the individual cooler[30].

Evaluation of Sidewall Lining Design in a Furnace System at Extreme Conditions

The application of the MAXICOOL® sidewall lining design was evaluated for use in a copper-nickel-platinum industry smelting application under extreme operating conditions. An FEA model was used for this purpose and involved a symmetrical section of a MAXICOOL® copper cooler in the furnace sidewall. For the purpose of the analysis the refractory material in front of the copper was assumed to have worn back to the copper surface. It was further assumed that the stable freeze lining had dislodged from the lining hot face, leaving the copper and lining hot face surfaces directly exposed and in contact with the slag bath. The extreme bath operating temperature of 1750°C was applied to the sidewall hot face through a maximum slag to sidewall heat transfer coefficient of 350 W/(m^2K). The initial FEA model is shown in Figure 6(a).

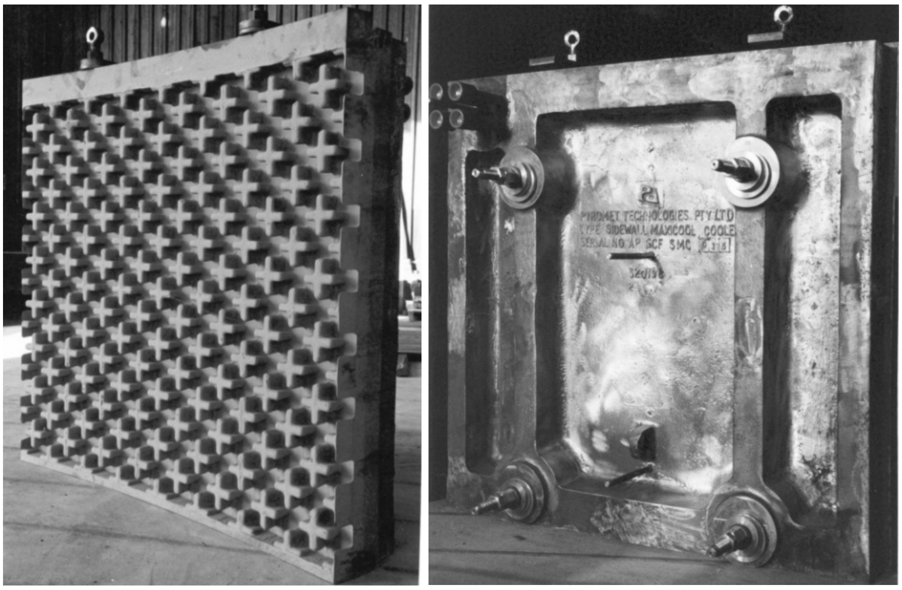


Figure 5 – Typical MAXICOOL® copper cooler.

The thermal FEA results, as shown in Figure 6(b), indicate a maximum hot face temperature on the lining/cooling system of 1160°C and a heat flux of 376 kW/m^2 when subjected to these extreme operating conditions. This is below the slag liquidus temperature of a normal copper smelting furnace and therefore a frozen slag layer would immediately start forming on the sidewall hot face, even under these extreme operating conditions. This will reduce the heat flux through the sidewall and lower the copper and refractory temperatures. Also shown in Figure 6(c) is the maximum estimated copper temperature of 408°C under these extreme operating conditions. Although the melting point of copper is 1080°C, it loses most of its strength above 400°C and becomes an unstable structural member. The MAXICOOL® coolers are therefore designed to limit extreme operating copper temperatures close to 400°C.

As previously discussed, the MAXICOOL® coolers are designed with parallel cooling water circuits. Shown in Figure 6(d) is the FEA result for copper temperature under extreme operating conditions with one circuit off line. The copper temperature is estimated to rise to 537°C, assuming that a frozen slag layer does not immediately begin to form. Although parts of the cooler hot face will lose their strength, the cooler body is well below 400°C and will maintain its structural integrity under these extreme conditions. This example illustrates the ability of the MAXICOOL® elements to resist arduous furnace conditions.

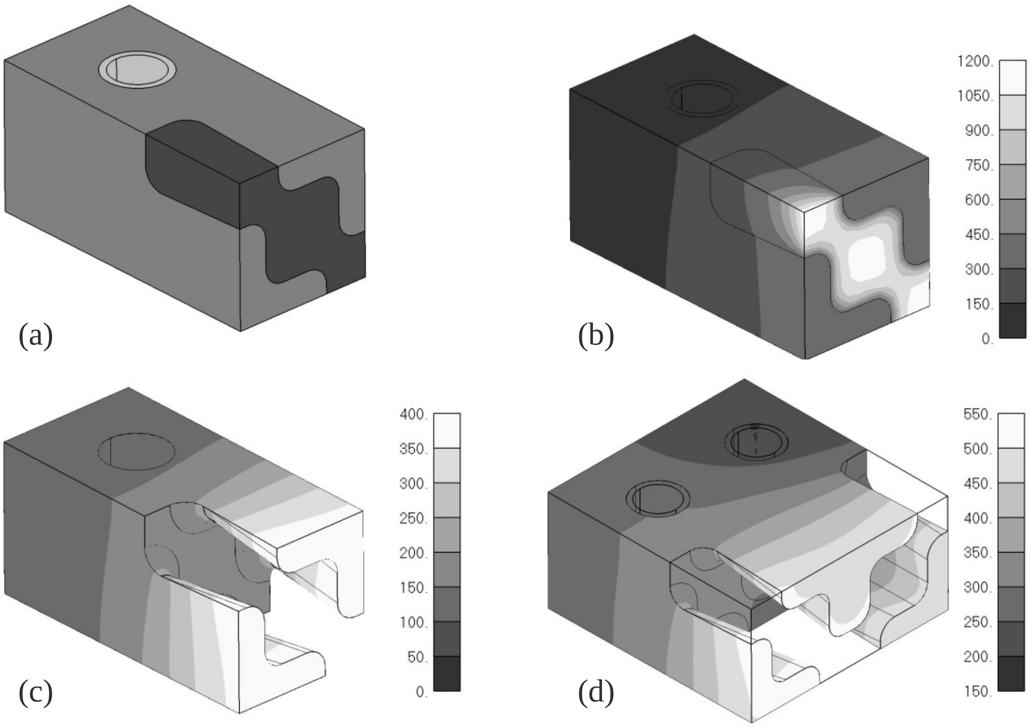


Figure 6 – FEA Results for MAXICOOL® coolers under extreme operating conditions

CONCLUSIONS

The development of copper smelting furnace linings was discussed with reference to furnace technology innovations. Although refractories have been continuously improved through the years, their ability to withstand furnace conditions is limited. Some furnace technologies have maintained refractory only linings but this has necessitated stringent process control philosophies and constraints to production and operation. The application of cooled copper allows for the process limitations to be lifted and for processes to be optimized for throughput and metal recovery. A number of examples of Tenova Pyromet cooled copper element designs were discussed with reference to how these concepts facilitated process improvement and optimization.

ACKNOWLEDGEMENTS

This paper is published by permission of Tenova Pyromet. The contributions of our colleagues and clients are gratefully acknowledged.

REFERENCES

1. Suydam, A.G., *Application of Refractories to the Copper Industry.* The American Institute of Mining, Metallurgical, and Petroleum Engineers, 1934: p. 262-277.
2. Allen, J.E. and M.A. Stett, *Trends in Refractory Technology*, in *EPD Congress*, G. Warren, Editor. 1994, The Minerals, Metals and Materials Society. p. 541-553.
3. Gregurek, D., et al., *Refractory Wear Mechanisms in the Nonferrous Metal Industry: Testing and Modeling Results.* JOM, 2013. **65**(11): p. 1622-1630.
4. Gregurek, D., et al., *Slag Characterization: A Necessary Tool for Modeling and Simulating Refractory Corrosion on a Pilot Scale.* JOM, 2014. **66**(9): p. 1677-1686.
5. Gregurek, D., et al., *Wear Phenomena of Basic Brick Lining in the Copper Industry*, in *Copper International Conference*, R. Bassa, et al., Editors. 2013, The Chilean Institute of Mining Engineers: Santiago, Chile. p. 473-483.
6. Bryk, P., et al., *Flash Smelting Copper Concentrates.* Mining Engineering, 1958: p. 683-684.
7. Yasuda, Y., T. Motomura, and T. Kawasaki, *Improvements to the Operation of the Saganoseki Flash Smelting Furnace*, in *Conference of Metallurgists*. 2014.
8. Marx, F., M. Shapiro, and B. Henning, *Application of High Intensity Refractory Cooling Systems in Pyrometallurgical Vessel Design*, in *The Twelfth International Ferroalloys Congress*. 2010: Helsinki, Finland. p. 769-778.
9. INCO, S.a.M.S.D., *Oxygen Flash Smelting Process Swings into Commercial Operation.* Mining Engineering, 1955: p. 534-541.
10. Goto, M. and K. Kanamori, *Refractory Practice for Mitsubishi Process*, in *Proceedings of the 112th AIME Annual Meeting*. 1983: Atlanta, Georgia.
11. Santander, N., P. Grau, and L. Castro, *Chilean Refractory Experience in El Teniente Copper Converters*, in *Copper-Cobre 91 International Conference*, C. Diaz, et al., Editors. 1991, Pergamon Press: Ottawa, Canada. p. 247-258.
12. Harris, C., *Bath Smelting in the Noranda Process Reactor and the El Teniente Converter Compared*, in *Copper-Cobre 99 International Conference*, D.B. George, et al., Editors. 1999, The Minerals, Metals and Materials Society. p. 305-318.
13. Prevost, Y., M. Bedard, and C. Levac, *Forty Years of Operation of the Noranda Reactor Process*, in *Proceedings of Copper 2013*. Santiago, Chile. p. 265-277.
14. MacLeod, I.M., et al. *Temperature control of a Copper Isasmelt plant*. in *Control Conference (ECC), 1997 European*. 1997.
15. Bill, J.L., et al., *ISASMELT-Mount Isa Copper Smelter Progress Update*, in *Sulfide Smelting 2002*, R.L. Stephens and H.Y. Sohn, Editors. 2002, The Minerals, Metals and Materials Society. p. 181-193.

16. Edwards, J.S., P. Telford, and L. Yunus, *Coming of Age - 21 Years Commercial Operation of Copper ISASMELT™ at Mount Isa*, in *Copper International Conference*, R. Bassa, et al., Editors. 2013, The Chilean Institute of Mining Engineers: Santiago, Chile. p. 367-373.
17. Bhappu, R.R., K.H. Larson, and R.D. Tunis, *Cyprus Miami Mining Corporation Smelter Modernization Project Summary and Status*, in *EPD Congress 1994*, G. Warren, Editor. 1994. p. 555-570.
18. Kim, M.B., W.S. Lee, and Y.H. Lee, *The QSL Lead Slag Fuming Process using an Ausmelt Furnace*, in *Lead-Zinc 2000*, J.E. Dutrizac, et al., Editors. 2000, The Minerals, Metals and Materials Society. p. 331-343.
19. Viviers, P. and K. Hines, *The New Anglo Platinum Converting Project*, in *First Extractive Metallurgy Operators' Conference*. 2005, AusIMM: Brisbane. p. 101-108.
20. PLC, G.I., *Annual Report*. 2012. p. 53.
21. Arthur, P.S. and S.P. Hunt, *Isasmelt - 25 Years of Continuous Evolution*, in *John Floyd International Symposium on Sustainable Developments in Metals Processing*, M. Nilmani and W.J. Rankin, Editors. 2005: Melbourne, Australia. p. 73-94.
22. Staff, G. *Dundee Precious Metals Announces Maintenance of the Tsumeb Smelter*. 2015 [cited 2015 16/09/2015].
23. Tan, P. and P. Vix, *Modelling and Control of Copper IsaSmelt Furnace*, in *EPD Congress 2006*, S.M. Howard, et al., Editors. 2006, The Minerals, Metals and Materials Society. p. 1111-1121.
24. PLC, V.R., *Production Release for the Fourth Quarter and Year Ended 31 May 2011*. 2011. p. 2.
25. PLC, V.R., *Production Release for the Fourth Quarter and Year Ended 31 May 2015*. 2015. p. 31.
26. Nelson, L.R. and R.J. Hundermark, *"The Tap-Hole" - Key to Furnace Performance*, in *Furnace Tapping Conference 2014*. 2014, The Southern African Institute of Mining and Metallurgy: Muldersdrift, South Africa. p. 1-32.
27. Leong, B. and H. Joubert, *Innovative and Safe Copper Launder Design*, in *Southern African Pyrometallurgy*, R.T. Jones, Editor. 2006, South African Institute of Mining and Metallurgy. p. 385-394.
28. McDougall, I., *Sidewall Design for Improved Lining Life in a PGM Smelting Furnace*. The Journal of the Southern African Institute of Mining and Metallurgy, 2013. **113**: p. 631-636.
29. Thyse, E., G. Akdogan, and J.J. Eksteen, *The Effect of Changes in Iron-Endpoint During Peirce-Smith Converting on PGE-Containing Nickel Converter Matte Mineralization*, in *Processing of Nickel Ores and Concentrates '10*, B. Wills, Editor. 2010, MEI: Falmouth, Britain.
30. Joubert, H., et al., *Copper Cooling Design, Installation and Operational Results for the Slag Cleaning Furnace at Waterval Smelter, Rustenburg Platinum, South Africa*, in *Nickel and Cobalt 2005 - Challenges in Extraction and Production*, J. Donald and R. Schonewille, Editors. 2005: Calgary, Canada. p. 19-35.