Operational Experiences of Mufulira ISASMELT™ Technology Since Inception

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Mopani Copper Mines, owned by Carlisa Investments Corporation (a joint venture company comprising Glencore International AG, First Quantum Minerals Ltd (16.9%)) and ZCCM-IH (10%) has been running the Mufulira ISASMELT™ furnace since 2006. The ISASMELT™ furnace was preferred over other furnace technologies because of its flexibility on feeding both low (26% Cu) and high (41%Cu) copper concentrate grades, ease of operation, low power usage, no necessity for a milling and drying facility for feed. The ISASMELT™ furnace at Mufulira has successfully completed five campaigns since commissioning. Various operational challenges have been progressively resolved. More recently optimization of operating temperatures through control of slag chemistry by use of the Commonwealth Scientific Industrial Research Organisation's (CSIRO) *Multi Phase Equilibrium* (MPE) package and introduction of shell air cooling have resulted in improved plant performance. Total dry feed per campaign progressively improved from 817 000 to 1 728 000 tonnes, with campaign life increasing from 22 to 36 months. The improved performance of the ISASMELT™ technology has contributed significantly to the overall performance of the company.

INTRODUCTION

The ISASMELT™ process was jointly developed by the cooperation of Mount Isa Mines, now owned by Glencore, and the Commonwealth Scientific Industrial Research Organisation (CSIRO) (Arthur and Alvear, 2011). The ISASMELT™ technology works on the principle of using a central lance to inject air and oxygen into a molten bath which vigorously agitates the liquid. This agitation ensures very rapid mixing and reaction between the concentrates and the oxygen as well as any trim fuel that is added if required. Matte and slag are tapped from the bottom of the furnace through a water-cooled tap hole. At Mufulira the molten products then flow into a matte settling electric furnace (MSEF), where the matte separates from the slag and eletro-thermal reduction takes place to minimize the copper concentrations in the final slag (Gao *et al.*, 2004; Arthur and Hunt, 2005; Ross and deVries, 2005). The ISASMELT™ technology is managed and marketed by Glencore Technology (the original equipment manufacturer, OEM).

Background

The Mufulira Smelter was initially commissioned in 1937 with two reverberatory furnaces and four Peirce–Smith converters. In 1972, a 36 MVA electric furnace and one holding furnace were commissioned. Later, the number of converters was increased to six. The electric furnace had a capacity of 420 000 tpa concentrates (Ross and deVries, 2005). At the end of 2003, a project commenced to replace the primary electric smelting furnace and upgrade the smelter with the installation of an ISASMELT™ furnace and a new MSEF. The new facility was designed with a view to toll treat concentrate in addition to those produced from Mopani mines (Ross and deVries, 2005). The ISASMELT™ furnace was designed, constructed and commissioned within 30 months, and production has been steadily increasing in the years since.

Mufulira Smelter Process Flowsheet

The current Mufulira Smelter and ISASMELT™ process flowsheets are shown in Figures 1 and 2.

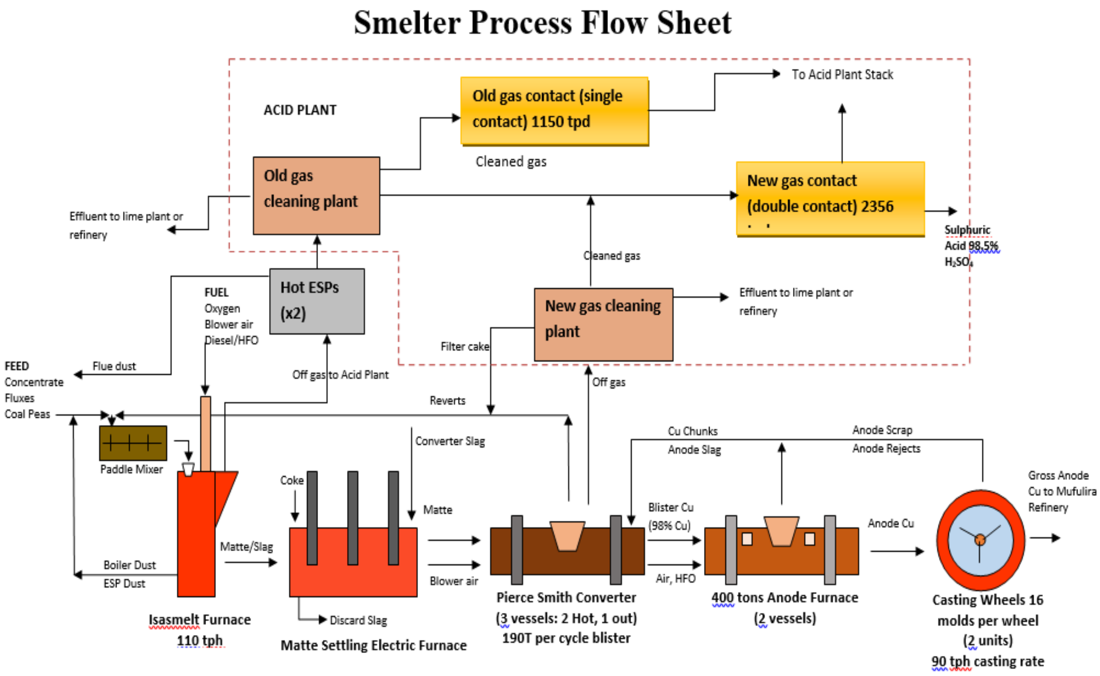

Figure 1: Current Mufulira Smelter process flowsheet.

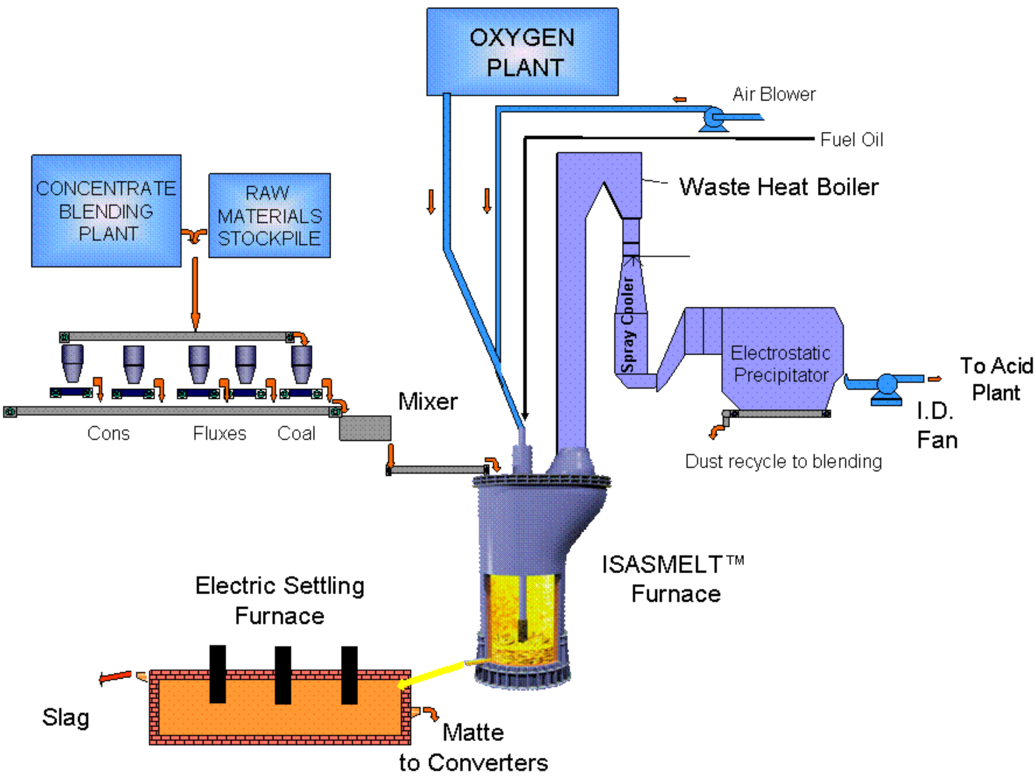

Figure 2: ISASMELT™ flowsheet used at Mufulira Smelter.

SMELTER PERFORMANCE SUMMARY (2006–2017)

From 26 September 2006, when the ISASMELT™ hot-commissioning commenced, to date the Smelter has successfully operated five campaigns. The performance of the plant is summarised in Table I.

Table I: Performance summary 2006–2017.

	Campaign 1 Sep 2006 – Jul 2008	Campaign 2 Sep 2008 – Apr 2010	Campaign 3 Jun 2010 – Apr 2012	Campaign 4 Jun 2012 – Apr 2014	Campaign 5 Jun 2014 – Apr 2017
Campaign life (months)	22.3	20.2	23.3	23.0	36.0
Concentrates treated (t)	745 779	859 922	1 247 912	1 295 541	1 504 184
Reverts treated (t)	71 571	158 603	216 334	196 069	219 846

A view of the ISASMELT™ plant is shown in Figure 3.

Figure 3: ISASMELT™ Plant at Mufulira Smelter.

At the time of initiating the Mufulira smelter upgrade project, Mopani's production forecasts anticipated relatively consistent production of approximately 400 000 tpa concentrate from the Nkana and Mufulira mines and concentrators (Ross and deVries, 2005), with these providing much of the feed to the ISASMELT™ furnace. Typically, Nkana produced 55–60% of Mopani's mined production, with Mufulira producing the remainder (Mining Review Africa, 2006); both of which produced bornite-rich concentrates.

During the past few years, toll-treated-based concentrates have gradually become more prevalent due to increased smelter throughput. The effect of treating more third-party concentrate has been a decline in the average copper grade of the smelter feed. Whereas Mufulira concentrate contains a significant amount of bornite and chalcocite, the toll-treated concentrates overwhelmingly contain only chalcopyrite. Although this would have been detrimental to the smelter production using the original primary smelting electric furnace flowsheet, Mopani have been able to smelt productively using the current flowsheet, which includes the ISASMELT™ furnace and MSEF (Burrows *et al*., 2011). Mufulira smelter now produces, per unit of copper production, much more sulphuric acid than would otherwise have been the case. The acid can be used for leaching operations or sold to other operations in the region.

Furnace Campaign Life

The first campaign lasted 22.3 months and the life has progressively increased to 36 months in Campaign 5, as shown in Figure 4. This increase has been as a result of an intensive monitoring programme and additional resources being allocated to review plant performance. Based on the reviews, plant operating set points were adjusted appropriately. Working together with the OEM during the most recent campaign, this has been further expanded to utilize the CSIRO *Multi-Phase Equilibria* (MPE) package for metallurgical blending. This allows for the slag chemistry of the concentrate feeds to be proportioned, blended, and through combined in-plant monitoring of the bath temperatures and slag condition, allow for the ISASMELT™ furnace performance to be actively controlled and managed.

Concentrates and Reverts Treatment

There was a progressive increase in the treatment of concentrates from Campaign 1 to 5, as seen in Figure 5. Apart from treatment of reverts in the ISASMELT™ furnace, the plant also successfully started treating reverts in the MSEF from Campaign 3. This was made possible by controlling the furnace matte sump build up using pig iron. This has significantly improved throughput.

Sulphur Capture

Mopani has been committed to continuously improving emissions capture from the Mufulira smelter. Completion of Phase 3 Smelter Upgrade Project, which included installation of a new double contact acid plant, has improved sulphur capture to well above 90% in the most recent campaign and thus nearing world's best practice.

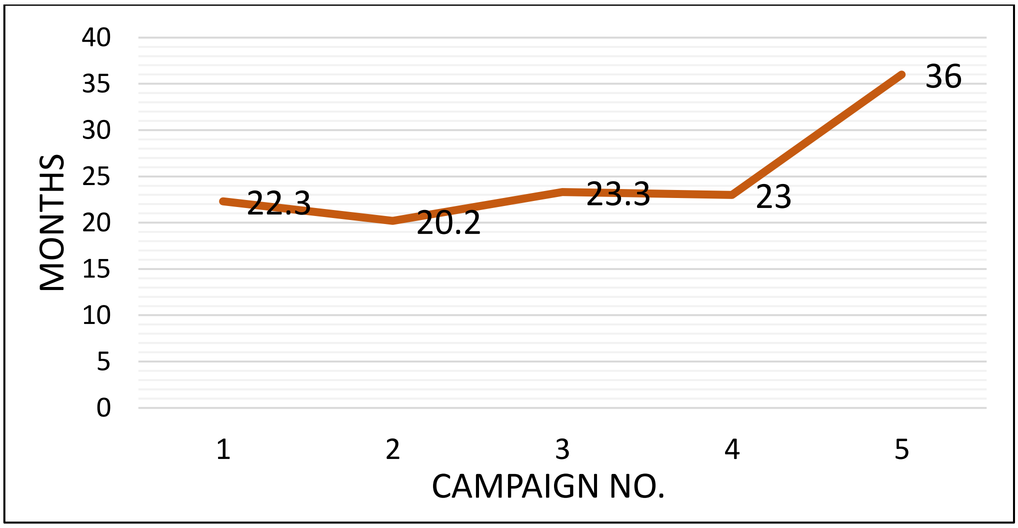

Figure 4: Smelter campaign life since commissioning in 2006.

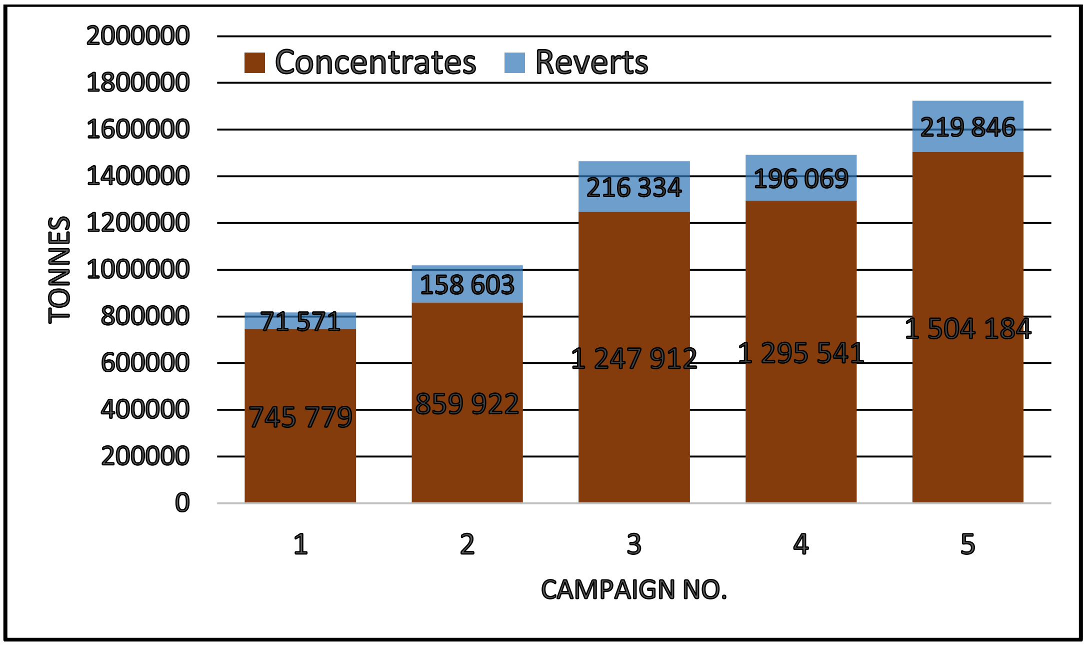

Figure 5: Concentrate and reverts processed for the different Smelter campaigns.

OPERATIONAL CHALLENGES EXPERIENCED DURING THE CAMPAIGNS

A number of operational challenges have been experienced and discussed in this paper based on each campaign.

Campaign 1

Matte settling electric furnace
Originally it was expected that the MSEF would be able to last two ISASMELT™ campaigns before requiring a full re-brick. However, after the first campaign the MSEF was shut down due to excessive wear on the side wall to replace the refractory bricks with high quality magnesia chrome bricks. To monitor and control the brick wear in the subsequent campaigns, thermocouples were installed as a part of this process.

Reduced matte sump holding capacity due to hearth buildups was subsequently resolved by regular addition of pig iron. The practice of tapping one ladle at a time was a major constraint. This was resolved by installing a matte bogie to minimize tapping delays.

Waste heat boiler
A number of issues within the first campaign, mainly to do with the gas cooler spray and localized gas flow, resulted in higher corrosion of the boiler tubes than anticipated. Physical damage from surrounding equipment also resulted in boiler tube maintenance works, which were addressed with proper welding procedures. The design holding and condensing capacity of the waste heat boiler (WHB) was increased to 50 tph during the first campaign to allow for an additional 10 MW of capacity. This allowed further flexibility to treat the variety of feeds on the copper belt.

Lance life
By the original plant design, the lance was supplied with oxygen, from the site industrial oxygen plants, and air, from a dedicated process air blower. During this period, the lance life was as high as twenty-one days. In an attempt to lower the operating and maintenance costs of the smelter, the ISASMELT™ lance air was switched over to utilize a common header arrangement and share the air supplied to the site Peirce–Smith Converters. When the dedicated blower was decommissioned the

control of lance height became more challenging due to the pressure fluctuations in the main supply line from the common header during the roll-in and roll-out of the converter operations. As a result, lance life dropped to a maximum of seven days. This is currently being addressed with the assistance of the OEM to ensure that the converter operations do not affect the air supply to the ISASMELT™ lance.

Campaign 2

ISASMELT™ Lining
About 0.5 m² area of bricks spalled off in the middle of the campaign as shown in Figure 6. The cause of the spalling was considered to be a combination of operating methodology, stagnant airflow around the furnace shell, flame condition and flame impingement.

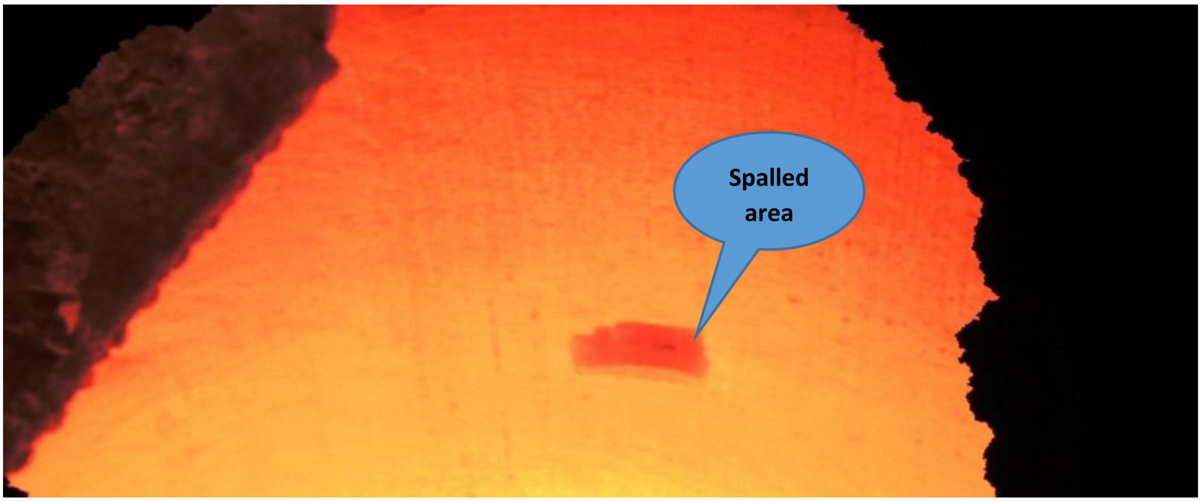

Figure 6: Area where the refractory bricks came off.

To resolve these problems the following interventions were taken:

- the ISASMELT™ lance was used as a central burner for extended shut-downs;
- the maximum lance height was readjusted to limit molten slag contact with the spalled area;
- additional cooling fans were introduced around the failed area to externally cool the shell, prevent overheating and attain a frozen protective slag layer;
- shell temperature monitoring was introduced to locate and manage any hot spots before they developed.

Introduction of the above measures in August 2009 tremendously reduced the brick wear rate, as can be seen in Figure 7. Level three north a (L3Na) shows the wear rate before the measures were introduced, and Level three north b (L3Nb) refers to the wear rate after.

Poor tapping
Higher insolubles in the Nkana concentrate, which had gone up to 18–20% against the target of 11%, were prevalent in this campaign. The high insolubles were as a result of the treatment of oxide ore from the open pit due to a lower availability of sulphide ores from mining. Without the inclusion of appropriate thermo-chemistry evaluation of the effect of the insolubles, this resulted in poorer tapping conditions.

Feed system
The feed system drives were upgraded to improve their availability and maintainability.

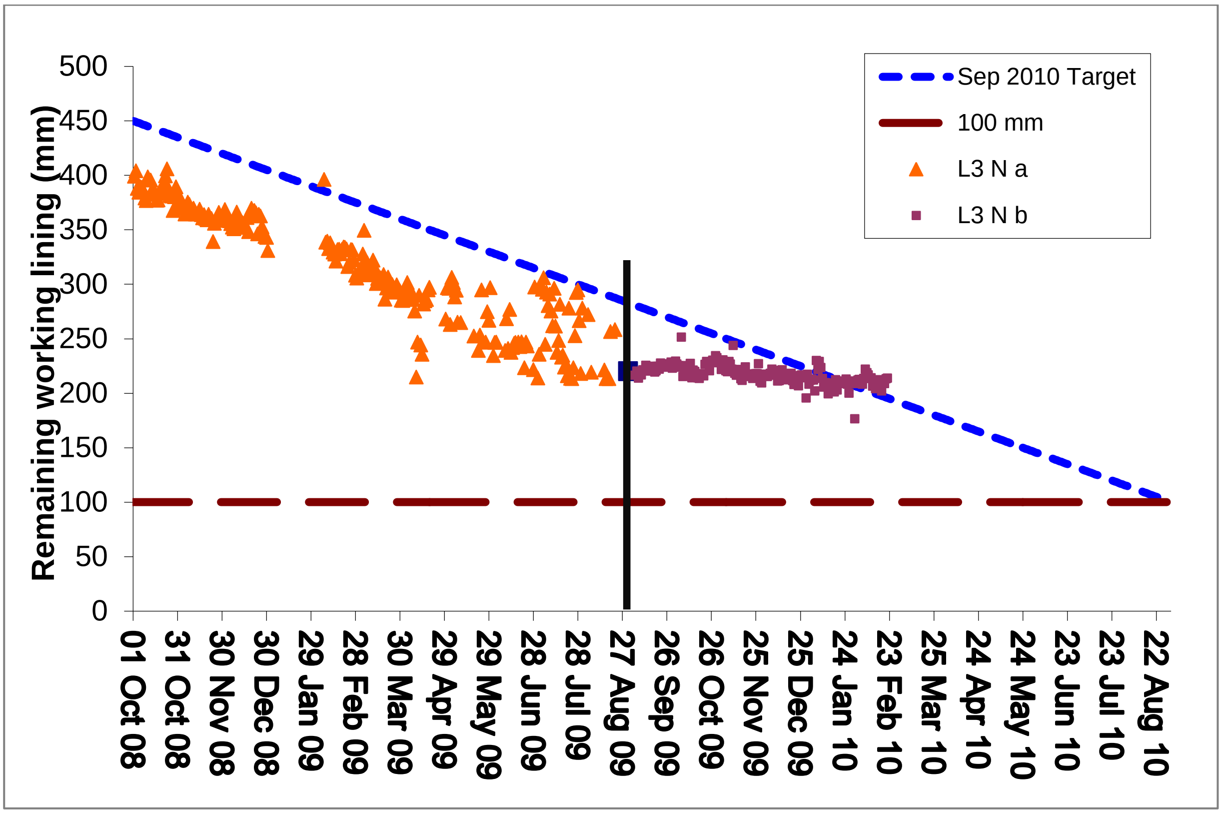

Figure 7: Refractory wear rate before and after wear reducing interventions.

Converter capacity
There was insufficient converter space due to small capacity converters in use (six-off x 90 tonnes of blister each). This restricted the throughput of the ISASMELT™ furnace and the MSEF. Three x 190 tonnes blister converters were later installed subsequent to this, as a part of the Phase 3 Smelter Upgrade Project, to increase capacity.

Campaign 3

ISASMELT™ furnace
High insolubles in the Nkana concentrate continued in this campaign. This was compounded by the difficulty in controlling slag quality and in a bid to resolve the problem various slag chemistry control systems were considered.

Campaign 4

ISASMELT™ furnace
Poor bath chemistry was experienced due to high insolubles in concentrates treated. To manage these insolubles, higher temperature operation was attempted but this caused a higher rate of refractory wear. Figure 8 shows the wear rate of the bricks during this campaign.

Campaign 5

ISASMELT™ furnace
Working together with the OEM, the use of the CSIRO's MPE model was introduced to effectively control the ISASMELT™ slag chemistry. The details of the MPE model are covered elsewhere (Zhang *et al.*, 2002), with an example output from the blending model calculation shown in Figure 9. The main advantage of the MPE modelling method is the integration of the package within Microsoft *Excel®* and the ability to calculate viscosity with the impact of solid components in the slag. This was

combined with in-plant monitoring of the bath temperatures and slag condition to allow for the ISASMELT™ furnace operation to be actively controlled and managed.

However, during this campaign frequent and prolonged downtime was experienced due to reduced power supply caused by the nationwide load shedding. Furthermore, there was hydration of refractory bricks due to a boiler tube leak, resulting in collapsing of the bricks from one region of the furnace.

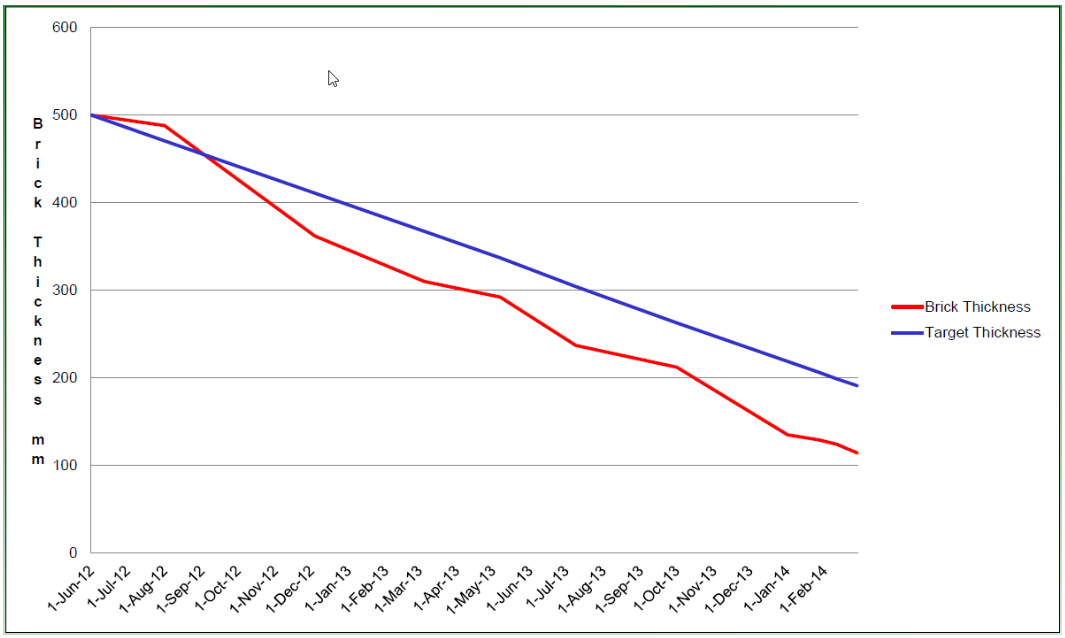

Figure 8: ISASMELT™ wear rate.

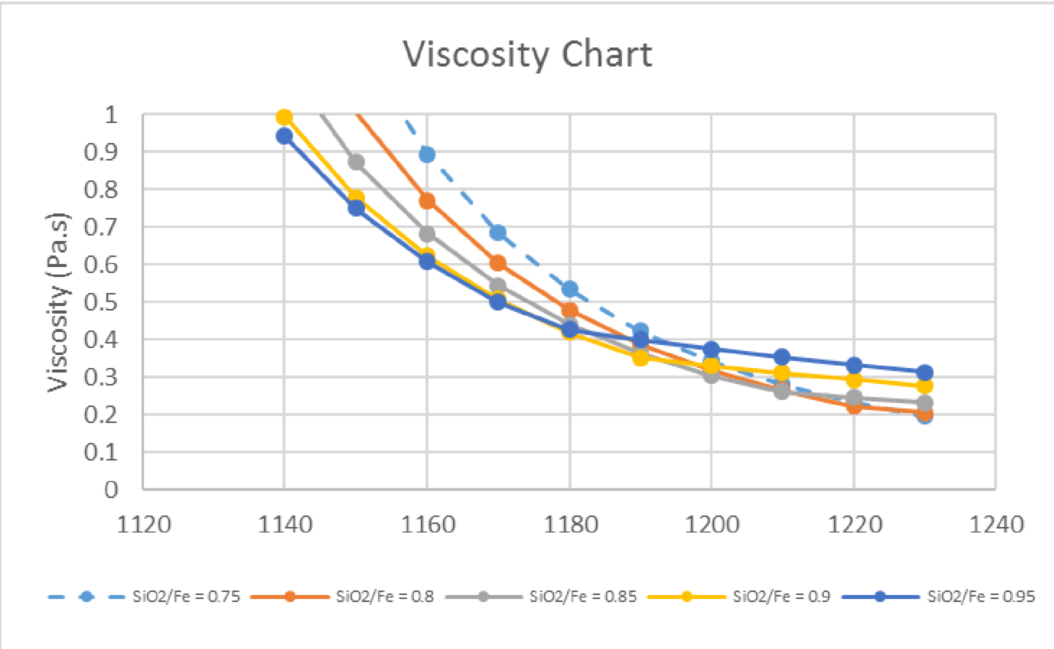

Figure 9: ISASMELT™ slag viscosity calculation performed using MPE package.

Waste heat boiler

Owing to erratic supply of local water utility company, the water source was changed to Kafue river water supplied by Mopani on 15 October 2015. The water conductivity of this source was, however, very high at 800–1000 μS/cm, compared with 200 μS/cm from the local water utility company. The prolonged use of this poor water quality adversely affected the Demineralisation plant as well as the boiler plant operation and resulted in failure of the boiler transition piece. The transition piece was replaced and use of the Kafue water was discontinued.

FUTURE OUTLOOK FOR MUFULIRA SMELTER

The key process parameters for the Mufulira smelter ISASMELT™ plant are given in Table II. At time of writing this paper, the plant is running at high availability but, due to concentrate shortages on the Copper Belt, with a feed rate of 80 t/h (of copper concentrate, excluding internal recycle streams, dry basis).

Table II: Typical process parameters for Mufulira ISASMELT™ plant.

Parameter	Value	Unit
Typical concentrate feed rate	80–110	dry t/h
Average Cu content in concentrate	24–29	%
Average Moisture of the feed	9–10	%
Average silica flux feed rate	1.5	dry t/h
Average coal feed rate	1.5	dry t/h
Average reverts feed rate	15	dry t/h
Average copper matte grade	54–58	%
Average SiO_2/Fe in slag	0.85–0.95	–
Average ISASMELT™ lance air flow rate	5.0–7.0	Nm^3/s
Average oxygen content in ISASMELT™ lance air	65–80	%
Bath temperature range	1175–1185	°C

CONCLUSION

The five campaigns have provided key lessons and vast experiences drawn in the operation of the ISASMELT™ Furnace technology at Mufulira smelter. The improved plant capacity to now 1 504 184 tonnes concentrate treatment per campaign has given rise to expansion projects in underground mining to increase overall copper production, thus contributing towards the 2023 Mopani vision (150 000 tonnes per annum of saleable copper). The improvement in the sulphur capture of up to 93% has greatly improved environmental control and the resulting sulphuric acid produced has increased revenue for the company. The use of the MPE model improved control of slag chemistry and, together with plant measurements and monitoring, played a significant part in the activities that resulted in an increase in the furnace campaign life from 22 to 36 months.

The challenges experienced provided opportunities for performance improvement in the following areas:

- there is need to review the operations of the Demineralisation plant to ensure strict control of water quality;
- investigate and apply effective models for controlling ISASMELT™ bath process chemistry;
- investigate ways of prolonging ISASMELT™ furnace lance life;
- focus on training and exposure of smelter technical staff to enhance their skills.

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