INNOVATIVE TECHNOLOGIES FOR COPPER SMELTING AND ELECTRIC SLAG CLEANING AND MATTE SETTLING FURNACES

A. Esterhuizen, *H. Joubert, S. Essack, and N. Fowler
TENOVA PYROMET
Midrand, South Africa
*(*Corresponding author: hugo.joubert@tenova.com)*

ABSTRACT

Tenova Pyromet has developed innovative technologies for copper smelting and electric slag cleaning furnaces. Based on client feedback and requirements, innovative designs have been developed to address key design areas and improve furnace reliability, operability and hygiene. These developments include the NovaLance™ lance system to prevent lance bending on top submerged lance furnaces, the SlagFlo™ slag tapping flow control device to better control bath levels and tapping rate for granulation, and an electrode seal for improved sealing directly onto the electrode casing to allow water-cooled electrode components to be located above the furnace roof. The potential application and benefits of these innovative designs are discussed.

KEYWORDS

Electric slag cleaning furnace, Electrode seal, NovaLance™, SlagFlo™, Top submerged lance furnace

INTRODUCTION

Tenova Pyromet has a long history in the engineering and supply of innovative electric furnace and related equipment for the base metals and platinum industries. Recently Tenova Pyromet has used its furnace equipment design experience to engineer innovative solutions for top submerged lance (TSL) furnaces, and potentially other furnace technologies. These equipment design solutions are developed to address specific operating challenges and operator requirements. Three of these innovative equipment developments are discussed in this paper.

First the NovaLance™ lance technology to prevent lance bending during operation in TSL furnaces, such as used for primary copper smelting, is described. Lance bending has been identified as a significant problem for TSL furnace operators as it causes down time and affects furnace availability.

The SlagFlo™ device to control the slag flow rate during tapping has been developed based on specific requirements in the mineral wool industry. The SlagFlo™ device can be used to control slag bath levels in primary smelting, converting and slag cleaning furnaces for base metals including copper. In addition, it can be remotely activated for the safe closing of slag tapholes located upstream from a water granulation system.

Finally, Tenova Pyromet developed an electrode seal that seals directly onto an electrode surface. This is a special requirement related to base metals and platinum electric smelting and slag cleaning furnaces where furnace operators prefer to keep the water-cooled electrode equipment above the furnace roof. The seal can be used to seal directly onto the potentially hot and uneven surface of Söderberg, pre-baked and graphite electrodes.

NOVALANCE™

The lance is the heart of the TSL furnace. It transports both fuel and air for combustion to the furnace bath. The air is usually oxygen enriched. As shown in**Error! Reference source not found.** Figure 1, the lance enters through the furnace roof and extends all the way down to the furnace bath. A typical lance can be up to 20 m in length, depending on the furnace size and height. Lance diameters typically vary from 150 mm to 450 mm for most applications. The lance is usually manufactured from a combination of carbon and stainless steel, with speciality stainless steels such as 253 MA used for the lance tip in some cases (Zambrano, 2010).

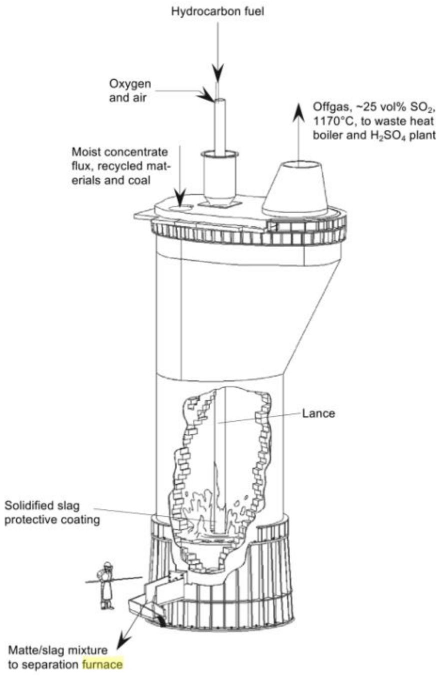

Figure 1. Typical TSL furnace arrangement (Davenport, King, Schlesinger, & Biswas, 2002)

Lance bending is a major issue for TSL furnaces. A severely bent lance makes it difficult to re-insert the lance into the furnace and can result in increased lining wear on one side of the furnace due to skew lancing (Seetharaman, 2014). Severely bent lances have to be removed from the furnace for straightening in the workshop using a special jig and press (Figure 2). The straightening process can cause weakening or rupture of the lance body, resulting in the premature replacement of large sections or the complete lance. Straightening of a bent lance is less feasible for some TSL furnace lance designs. This is due to the use of more than one conically arranged pipe to form the lance body, separately transporting either air, oxygen or mixtures thereof prior to final mixing occurs close to the lance tip (Mounsey, 1999).

Figure 2. Severely bent TSL furnace lance being transported to the workshop for repair (Zambrano, 2010)

Lance bending occurs due to differential heating and thermal cycling of the lance resulting in permanent plastic deformation (Gwynn-Jones, 2014). During operation the length of the lance is exposed to high freeboard temperatures. The temperatures in the freeboard can vary from one side of the furnace to the other, resulting in differential heat loads around the lance circumference and along the length of the lance. In addition, molten slag splashing from the furnace bath freezes onto the lance body due to the cooling effect of the combustion air flowing through the lance. The frozen slag forms a protective layer, limiting the lance body operating temperature. However, the slag layer location and thickness can vary significantly around the circumference and along the length of the lance. This further exacerbates the temperature gradients present in the lance body.

Tenova Pyromet has developed the NovaLance™, patent pending, to overcome lance bending during TSL furnace operation. The NovaLance™ consists of a rotating lance body and tip relative to a stationary lance head. The lance head is installed in the lance carriage or cradle as is normal practise. By rotating the lance, the unsymmetrical heating of the lance body is prevented. As a result, the lance bending due to differential heating and thermal cycling is prevented or significantly reduced.

In Figure 3 the maximum differential external lance body temperature is plotted against time. Initially the freeboard gas and surface temperatures that are responsible for convective and radiative heat transfer to the lance body are assumed to be stable at 800°C. The freeboard temperature on one side of the lance is then increased to 1300°C whilst being maintained at 800°C on the other side. This represents a typical worst-case scenario due to either a loss of a frozen slag layer from one side of the lance, an increase in combustion activity on one side of the lance, or a combination of such events. For a typical TSL furnace lance the external body temperature on the hot side will increase relative to that on the cold side. As shown in Figure 3, within 5 minutes the temperature difference from one side of the lance to the other could be as high as 350°C. For the NovaLance™ under similar conditions, the temperature difference will remain below 10°C. Whilst lance bending, and permanent plastic deformation of the lance body is likely for the typical TSL lance under these conditions, it is unlikely for the NovaLance™.

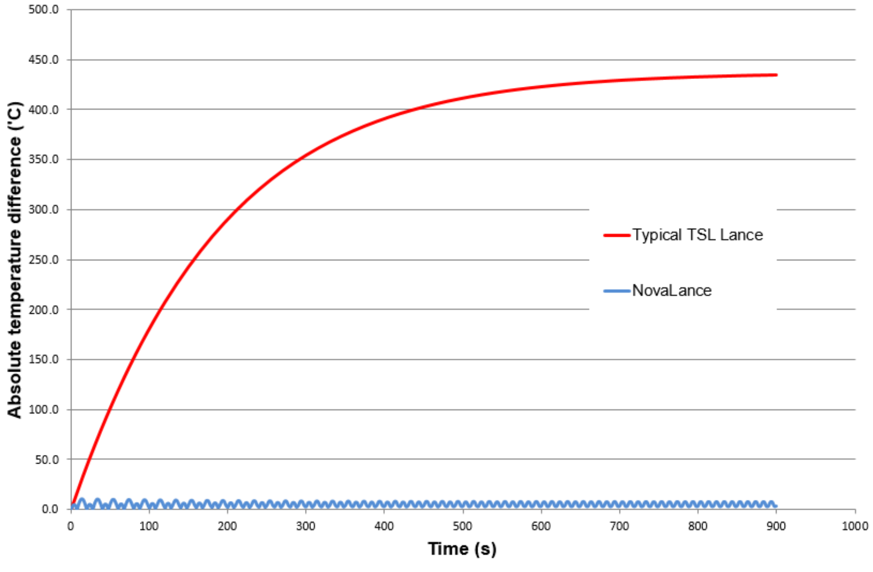

Figure 3. Maximum differential circumferential lance body temperature relative to time when furnace freeboard temperature changes from 800°C to 1300°C on one side of the lance

Alternatively, the case where a stable 30 mm slag freeze lining has formed on the lance body is considered. In Figure 4 the slag freeze lining hot face temperature is plotted against time. At time 0, with stable prior freeboard conditions assuming gas and surface temperatures of 1200°C, the freeze lining hot face temperature is well below the slag freezing temperature. As such it may even grow in thickness under these conditions. If the freeboard temperature is now increased by 100°C to 1300°C on one side of the lance, Figure 4 shows that the freeze lining hot face temperature on that side of a typical TSL lance will increase to well above the slag freezing temperature within less than 10 minutes. As a result, the freeze lining thickness will reduce, or potentially completely dislodge on this side of the lance compared to the other side. In turn, this will result in a significant change in lance body temperature on one side of the lance compared to the other, and lead to potential lance bending. For the NovaLance™ the freeze lining hot face temperature, and by implication the lance body temperature, increases equally on all sides due to the increase in freeboard temperatures. In addition, the freeze lining hot face temperature remains well below the slag freezing temperature and the freeze lining should remain intact. Lance bending is highly unlikely as a result for the NovaLance™.

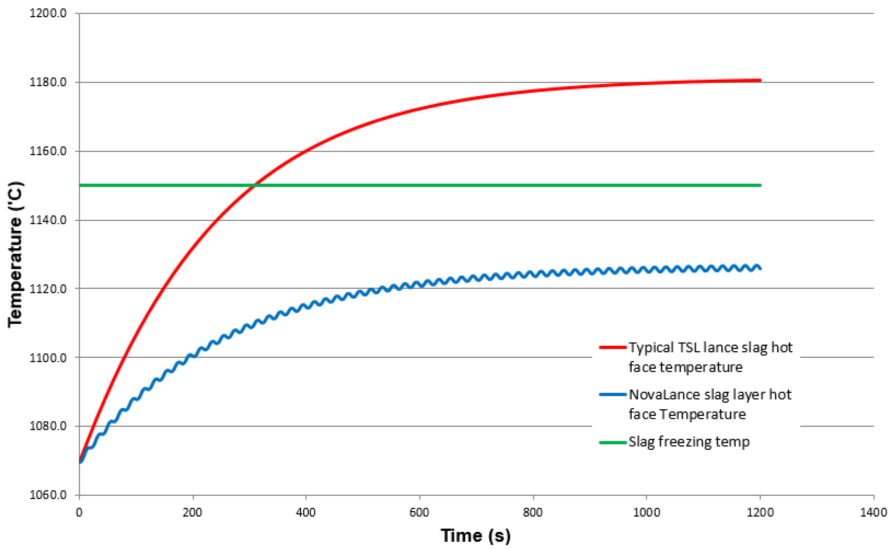

Figure 4. Maximum hot face temperature for 30 mm slag freeze lining on lance body relative to time after changing freeboard temperature from 1200°C to 1300°C on one side of the lance

Tenova Pyromet has designed and built a prototype NovaLance™ with a lance body and tip diameter of 450 mm. The lance is currently on site ready for testing on a primary copper smelting TSL furnace. Apart from oxygen enriched air, the lance delivers diesel fuel to the furnace bath and incorporates lance tip pressure measurement to assist with controlling the tip immersion depth. The head of the NovaLance™ is shown in Figure 5.

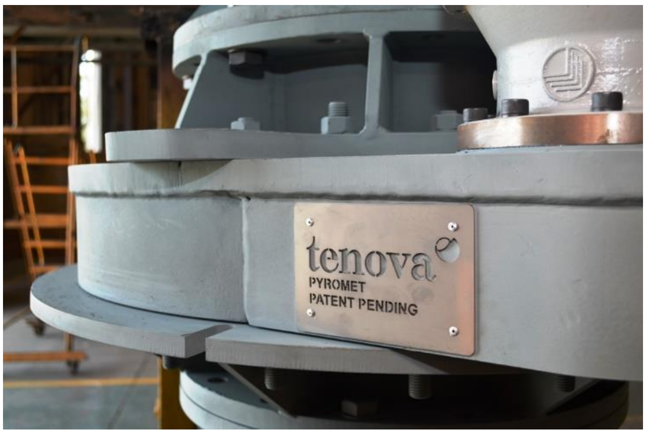

Figure 5. Tenova Pyromet's NovaLance™ for TSL furnaces to prevent lance bending

SLAGFLO™ DEVICE

Circa 2010, a need was identified by our clients to develop equipment that is able to modulate the flow of slag from a side-tapped electric furnace. In order to meet this need, Tenova Pyromet developed the SlagFlo™ device (Essack, 2014). The SlagFlo™ device is designed to control the slag tapping rate as a means of controlling downstream processes.

The design concept is based on an adjustable orifice and makes use of a water cooled copper element. The hydraulically controlled water-cooled element is raised or lowered to adjust the taphole opening size, thereby adjusting the tapping rate. The SlagFlo™ device is shown in Figures 6 and 7 during operation.

Figure 6. SlagFlo™ device in operation – tapping rate being reduced

Figure 7. Installed SlagFlo™ device in operation

The SlagFlo™ device has been installed on continuous and batch processes in several locations. Specific references are listed in Table 1 together with the maximum slag tapping rate and slag tapping temperatures. In a continuous tapping type operation, the SlagFlo™ device has been seen to smooth the tapping rate in applications such as mineral wool. In mineral wool operations, slag is turned into fibres. The fibre quality is important to the end product and largely influenced by the consistency of the slag tapping rate. In batch operations the SlagFlo™ device has been used to adjust the slag tapping rate as a means of controlling slag granulation rates and reducing the risk of steam explosions. It has also reliably been used as a means of remotely closing slag tapholes. This provides a safe means to close slag tapholes upstream from a water granulation system.

Table 1. SlagFlo™ device installation references

	Reference	Tapping Temperature °C	Tapping Rate tph
1	Armstrong World Industries (2 tapholes operating concurrently)	1430 - 1580	6
2	KCC mineral wool – furnace 1	1550 -1650	6
3	KCC mineral wool – furnace 2	1550 -1650	6

For base metal smelting and converting furnaces the SlagFlo™ device can be used in applications where control of the slag flow rate from the taphole is important. The potential benefits for installations where the slag is granulated have already been described above. Where a slag caster is in use, the slag tapping rate is of particular importance to ensure it matches the casting machine capacity, speed and required cooling rate. A more even flow rate with less variability is desirable.

For certain top submerged lance (TSL) furnace applications, such as lead smelting and copper converting, the SlagFlo™ device can be used to maintain a more stable slag bath level and depth. This is important to ensure a more stable lance immersion depth in the slag bath and prevent lance tip damage due to metal or matte attack during smelting and, in particular, the final stages of typical batch slag tapping.

Metal in slag is a key performance parameter for base metal slag cleaning furnace. If the slag taphole height above the metal or matte bath can be increased, the metal carryover in the slag can potentially be reduced. In addition, if the tapping rate can be reduced, slag with more entrained metal from less settled zones below and further away from the taphole is less likely to be drawn into the tapping stream. The SlagFlo™ device has the potential to enable both an increased slag taphole height and a reduced slag tapping rate. A more continuous tapping regime will negate the need to build a high slag bath above the taphole for batch tapping whilst reducing the instantaneous tapping rate. The SlagFlo™ device can be adopted for both new and existing furnace installations.

ELECTRODE SEAL

In certain electric furnace applications, most notably primary platinum smelting and base metal slag cleaning furnaces, Söderberg type electrodes are employed with the contact shoes and pressure rings above the furnace roof. This is to prevent water-cooled electrode components from operating below the furnace roof and reduce the risk of water leaks inside the furnace freeboard. As a consequence, the electrode seal has to interface directly with the Söderberg electrode casing compared to other industries, such as ferroalloys, where sealing occurs onto a water-cooled heat shield. During operation the electrode is lifted partially out of the furnace. This may cause deformed and abrasive surfaces of the worn casing being extracted through the seal contact area. Traditional seals, most commonly actuated rope seals, cannot accommodate this. A common occurrence is seal damage or in a worst-case scenario damage to the furnace roof or the electrode itself. More robust seals, such as a simple "stuffing box" arrangement, has been implemented with reasonable success. However, due to the maintenance required to keep the "stuffing box" adequately filled, many of these seals are not functioning optimally and in some cases are discarded. This results in fumes escaping from the furnace causing a hygiene and safety risk, or excessive air ingress into the furnace.

An added design constraint is the seal height. If the seal is too high, it can thermally insulate a large part of the Söderberg electrode and cause overbaking before the electrode enters the furnace freeboard. This could lead to electrode breaks with potential safety and operational risks.

The new electrode seal design is more forgiving to electrode surface irregularities whilst maintaining adequate sealing efficiency. The seal height is limited to prevent overbaking whilst effective at prohibiting air ingress into the furnace and preventing excessive off gas emissions escaping through the electrode-roof interface. In addition, the seal requires limited maintenance and is easily accessible.

Design concept

The seal design uses the elasticity, strength and temperature tolerance of 304 stainless steel rope in a brush arrangement to give the seal its robust flexibility and longevity. Ceramic fibre rope and mineral wool blanket are used to improve the sealing efficiency as well as temperature resistance. 304 stainless steel is used for the frame and cassette structures due to its high temperature and non-magnetic properties.

The seal consists of a containment ring that houses the sealing ring and can act as an electrode guide. The sealing ring consists of multiple cassettes to allow for easy maintenance where each cassette can be installed or removed by hand. Care is given to hold down and guide details to allow for easy installation and removal during installation and maintenance. The basic seal design is shown in Figure 8.

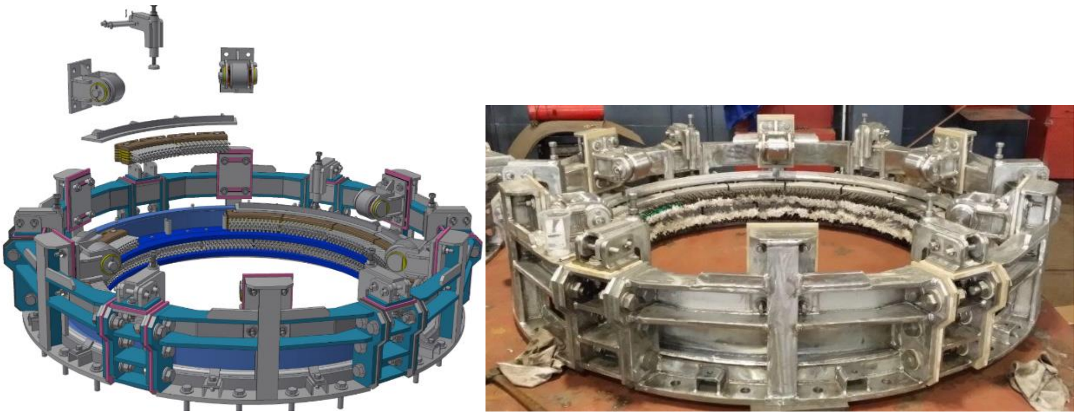

Figure 8. Assembly view exploded for maintenance and corresponding shop assembly photograph

Prototype testing

Prototype testing was performed at the University of Pretoria to ascertain the design’s ability to handle irregularities of the sealing surface combined with the cyclical nature of the operational load. The test setup is shown in Figure 9. The seal performed well under all load conditions, including the extraction of a severely damaged dummy casing through the sealing interface.

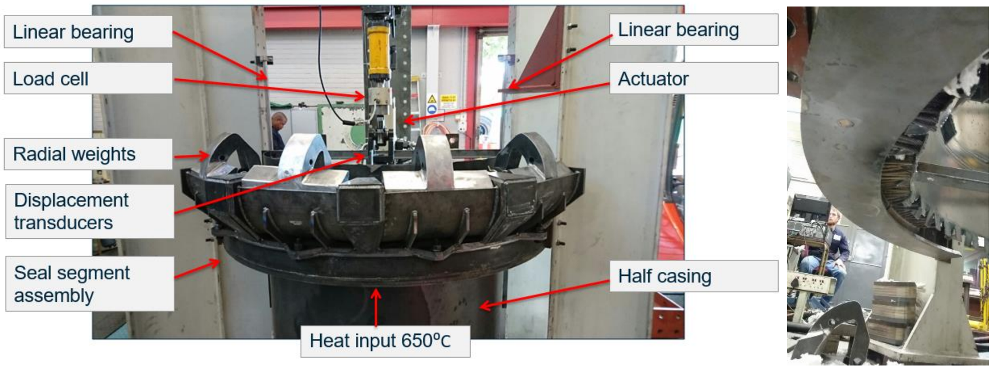

Figure 9. Laboratory test rig

Commercial installation

The seal design operates currently in a commercial primary platinum smelter at Northam Platinum's Zondereine facility in South Africa. The feedback from the client has been positive. Figure 10 below illustrates the seal following installation and after more than a year of operation.

Figure 10. Seal installed on circular AC primary platinum smelting furnace design and supplied by Tenova Pyromet (new and used)

CONCLUSIONS

Tenova Pyromet is continuously developing new designs and equipment solutions based on the needs and requirements of plant operators. In particular, new designs and solutions for application on base metals smelting and converting furnaces have been developed.

The NovaLance™ for top submerged lance furnaces has been developed to prevent lance bending during operation. As a result, lance maintenance can be reduced, lance campaign life can be increased, and overall furnace availability can potentially be improved. Currently a prototype NovaLance™ system is awaiting final testing on an operating copper smelter.

The SlagFlo™ device has been proven in the mineral wool industry to effectively control the slag tapping rate from an electric furnace slag taphole. Potential applications on base metal furnaces include slag bath level control to reduce lance tip damage in top submerged lance furnaces, slag bath level control to improve settling and recoveries for slag cleaning furnaces, slag tapping rate control upstream from granulation systems or slag casting machines, or remote activation to safely close slag tapholes upstream from a water granulation system.

A new electrode seal has been developed for sealing directly onto the electrode surface. Sealing directly onto the electrode is a requirement for base metal and platinum furnace applications where operators prefer the water-cooled electrode equipment to remain above the furnace roof for safety reasons. The seal is designed to cope with electrode surface irregularities whilst providing adequate sealing to prevent fumes escaping from or air ingress into the furnace. The seal underwent extensive testing and has been in successful operation since January 2017.

ACKNOWLEDGMENTS

The authors would like to acknowledge the information provided by Armstrong World Industries, KCC Corporation and Northam Platinum.

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