Teck's KIVCET™ lead tapping experience

D.J. Rioux, T.A. Moore, G.J. McTeer, and D.L. Verhelst
Teck Metals Ltd

Teck Metals Ltd operates an integrated zinc-lead complex at Trail, British Columbia, Canada. Since 1997, KIVCET™ flash smelting technology has been utilized for the treatment of zinc plant residues and lead concentrates. Trail Operations' furnace uses four water-cooled jackets for bullion tapping. This paper provides an overview of KIVCET bullion tapping for the past 16 years, and discusses successes and challenges encountered with respect to operations, training, and monitoring.

Introduction

Teck Metals Ltd has operated an integrated zinc-lead complex at Trail, British Columbia since the early 1900s. Close integration between the zinc and lead operations is key to maximizing metal recovery and ensuring the financial success of Trail Operations. A major advantage of this site is the ability of the lead smelting operations to treat all zinc plant iron residues currently produced, as well as stockpiled iron residues that were produced prior to the smelter modernization in 1997 (Ashman *et al*., 2000; Goosen and Martin, 2000).

The smelter modernization consisted of a new KIVCET™ furnace along with a new state-of-the-art slag fuming furnace and a new drossing plant.

The heart of the lead smelting process is the KIVCET furnace shown in Figure 1 (Rioux *et al*., 2008) The KIVCET furnace treats a dried mixture of lead concentrates, coal fuel, silica and limestone fluxes, plant recycles, and Zn plant residues mixed with a small amount of coke, and recycle dust coming from the waste heat boiler and electrostatic precipitator. The feed mixture ignites in the reaction shaft to reach a temperature of about 1425°C, desulphurizing the smelt through sulphide combustion and sulphate decomposition. The coke is sized to minimize oxidation so that it accumulates on the molten bath to form a 'coke checker' where lead oxide formed in the reaction shaft is reduced to lead bullion and some ferric iron is reduced to ferrous. Lead bullion and molten slag exit the coke checker and travel under a water-cooled partition wall to enter the electric furnace.

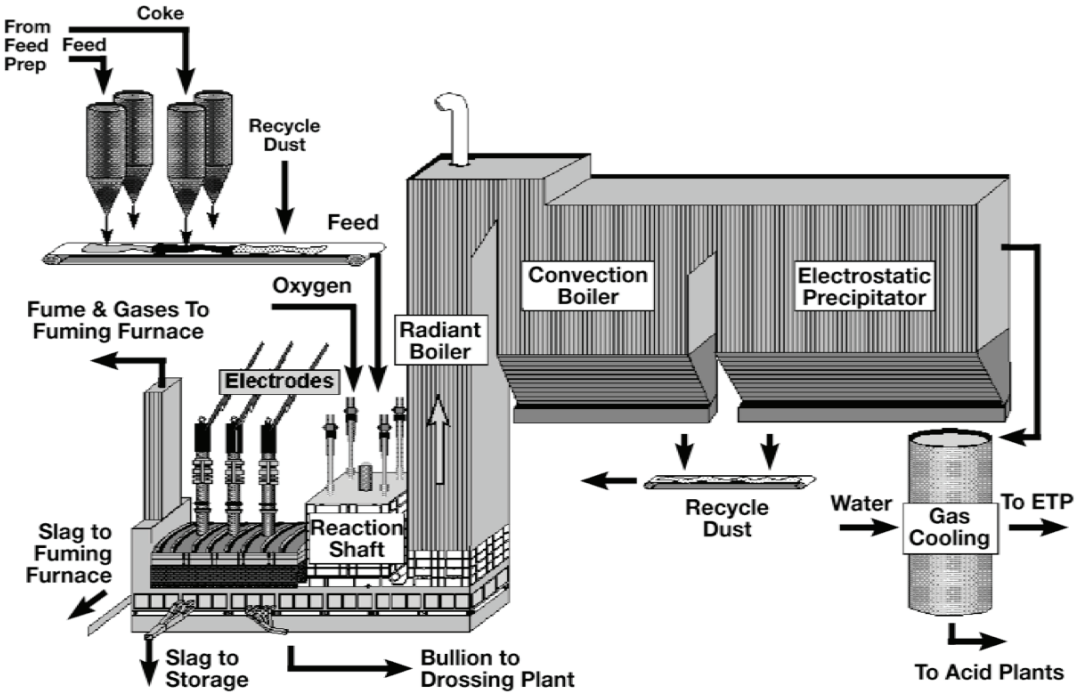

Figure 1. Schematic Diagram of the KIVCET furnace and ancillary equipment

The two primary functions of the electric furnace are phase disengagement and settling of the molten slag/bullion mixture, and heat transfer under the partition wall to complete the heat balance for the endothermic reduction reactions in the coke checker.

The engineering solutions used for the KIVCET furnace were developed and selected to provide excellent furnace integrity given the process requirements of containing molten lead bullion and an aggressive slag.

The furnace consists of large water-cooled copper elements bolted together to form the furnace sidewalls that contain the slag and the upper levels of the lead bullion. Some of the copper elements incorporate tap-holes for the slag and lead bullion. The walls of the reaction shaft, and some of the uptake shaft before the transition to the waste heat boiler, are also constructed of large water-cooled copper elements. A forced-convection air-cooled refractory hearth contains the lead bullion. The hearth construction consists of two layers separate by a thin stainless steel sheet. The purpose of the steel sheet is to prevent lead penetration below the working lining and also to allow for slippage between the two layers. The working lining is a chrome-magnesite brick to provide chemical resistance and the bottom layer is a highly conductive carbon brick to enhance the cooling of the working lining. The upper sidewalls above the copper castings of the electric furnace portion, as well as the arch in this section, are constructed of chrome-magnesite refractories. The arch design is a combination of a sprung construction with a secondary brick suspension system to ensure a gas-tight design.

Lead is removed from the furnace at intervals of approximately 2.5 hours via one of four tap-holes located on the side of the furnace, while slag is removed via one of two tap-holes located at the end of the furnace, as shown in Figure 1. The bullion and the slag operating temperature contain significant levels of superheat – up to 800°C and 150°C, respectively. For the Trail furnace, the design of the lead bullion tap-hole in particular is unique because of the need to remove bullion from the side of the furnace, compared to the siphon design, which is located at the end of the furnace in other similar furnaces. Effective training and operational and monitoring practices are needed to allow for reliable tapping of the lead bullion.

Design

The lead tap-hole is made up of two cast copper parts: the tapping jacket and the tapping insert. The jacket is part of the furnace wall construction and can be replaced during major furnace shutdowns when the furnace has been drained. The insert is a small casting which can be changed without draining the furnace. Figure 2 is a schematic representation of the jacket and insert configuration. Both castings are made with water cooling channels and equipped with temperature sensors.

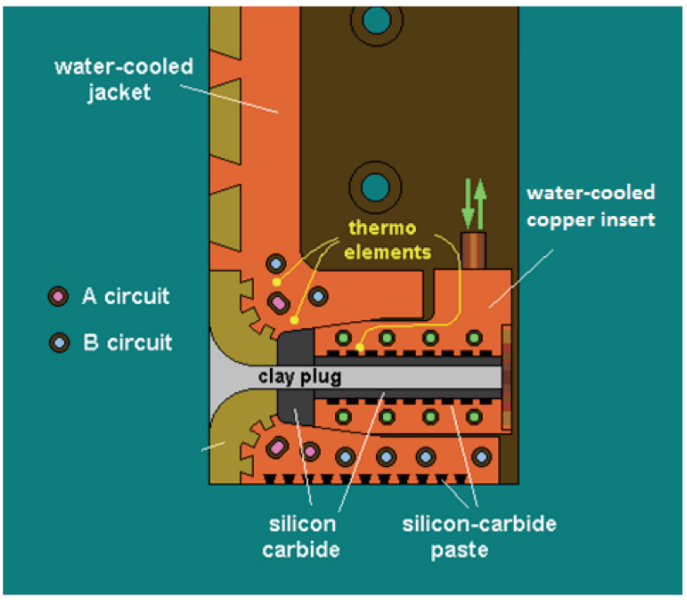

Figure 2. Cross-sectional representation of the lead tapping channel

The upper section of the water-cooled copper tapping jacket is partially lined with a chrome-magnesite refractory and a castable refractory is installed on the lower section around the tapping channel. Two water circuits ensure adequate cooling of the element during tapping operations.

The tapping channel is made up of two parts. The first part is a silicon carbide refractory cone brick at the front of the tapping channel with the cooled copper insert behind it. A silicon carbide sleeve is installed in the copper insert to protect the copper during tapping.

A manually operated hydraulic mudgun is used to close the tap-hole. The tapping operator uses a drill attached to the mudgun to open the hole. At times it may be necessary for the operator to use an oxygen lance to open the hole if drilling is unsuccessful. The oxygen lance is also used to clear out any buildup material in the tapping channel to ensure the drill is properly directed down the channel. Misdirection of the drill bit will cause mechanical damage to the silicon carbide components.

Monitoring

It is very important that the furnace operator closely assesses the condition of the tapping channel components. In addition to visual inspections of wear, the operating conditions of the castings are monitored to assess the state of the system at any given time. The instrumentation monitors copper temperatures, water temperatures, and water flow rates.

Each set of tapping jackets is equipped with 13 thermowells for monitoring of temperatures at different copper locations. The majority of the thermowell locations are around the throat of the jacket where the Pb bullion flows, as seen in Figure 3.

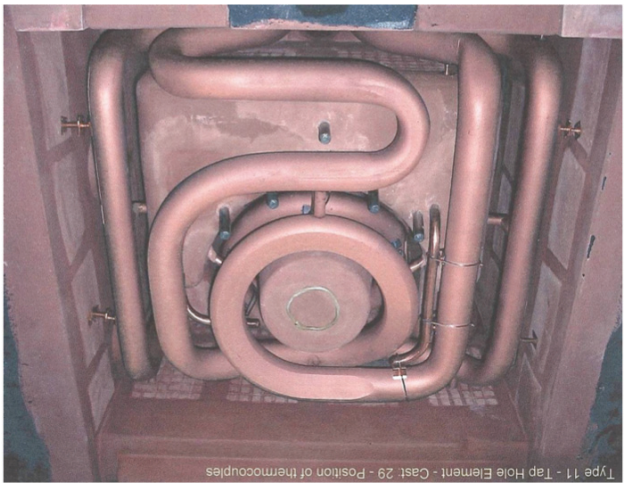

Figure 3. Thermowell locations on KIVCET lead tapping jackets

A closed-circuit water system is used to cool the copper castings, and the temperature of the water entering the casting is maintained at 40°C. Water flows and outlet water temperature are recorded by resistance temperature detectors (RTDs) for all three circuits (primary, secondary, and insert). All instrument data is fed to a central control room which is staffed 24/7 so that any alarms can be reacted to immediately. The cooling circuit for cast copper inserts is designed to maintain the insert below 50°C during lead tapping. The operating temperature of the insert, as well as the temperature rise of the cooling water as it passes through the insert, are closely monitored. The furnace operator will take corrective measures should the temperature of the insert exceed 70°C or the cooling water temperature differential increase more than 10°C. Either change could be a result of a decrease in the cooling capacity of the insert or a deterioration of the protective silicon carbide sleeve installed in the insert. Following an alarm, a review of the tap-hole performance by plant technical personnel, including an insert silicon carbide sleeve inspection, is completed before the tap-hole is put back into operation.

In addition, the instrument readings are fed into a bullion tapping guidance system (BTGS) that was developed by Hatch in 2004 (Plikas *et al.*, 2005). It consists of a computational fluid dynamics (CFD) model that relates thermocouple readings, bullion temperatures, and increases in water temperatures to jacket conditions and coil bonding. It then uses multivariate statistical analysis (principal component analysis) to monitor each tap in real time to identify unusual conditions. When a tapping anomaly is identified, an e-mail is sent out to Teck's furnace specialists for review. The original intent of the system was to have the results sent directly to the operators – but this was not implemented, due mainly to many false positives. The overall results have been used to give a qualitative representation of refractory wear in the front of the tapping jackets, along with an indication of when this wear occurs, as seen in Figure 4.

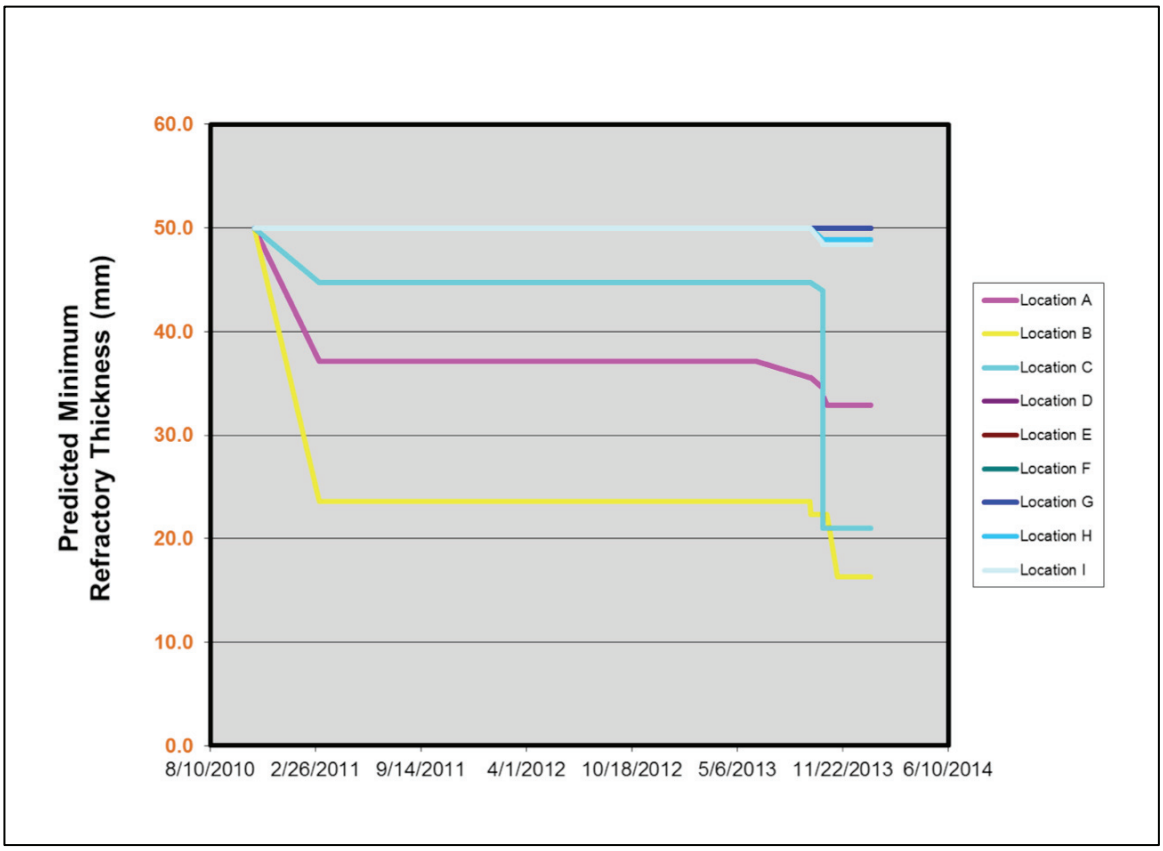

Figure 4. BTGS-predicted minimum thickness for a bullion tapping jacket (2010–2013)

Operational and maintenance history

When the KIVCET furnace began operation in March 1997 there were three lead tapping jackets with copper inserts. One additional tapping jacket that did not contain an insert was used for draining the furnace for major shutdowns. Tapping inserts can be changed while a molten bath is maintained in the furnace, but the tapping jackets can be changed only when the furnace is empty.

A tapping jacket will be taken out of service and replaced if the operating temperatures indicate that the jacket condition has deteriorated. During the shutdown in 2000, the three lead regular tapping jackets were changed, and in 2001 two of the jackets were changed. In 2003 all three jackets were again replaced. In 2005, it was decided to replace the fourth tapping jacket with a regular jacket containing an insert and four new tapping jackets were installed. All four jackets were again replaced in 2007 when all of bath zone jackets of the furnace were replaced. The four tapping jackets were replaced in 2010, and will again be replaced during the shutdown in the fall of 2014.

Replacement of the tapping jackets has been primarily as a preventive measure. In general, the condition of the jackets has been found to be very good, with limited loss of the refractory material around the tap hole. Replacing the refractory *in-situ* posed more risk than changing the jacket with newly installed refractory. Since the start-up of the furnace, there has only been once instance where a jacket has been taken out of service before a major shutdown. Since 2003, the number of taps performed on a single jacket has increased from approximately 1100 to 2200 over the life of a tapping jacket.

Unlike the tapping jackets, the copper inserts can be changed while the furnace still holds a molten bath. The furnace operation is suspended while the insert is changed to minimize the risk of a break-out of molten metal during the procedure. Replacement of the insert is typically motivated by damage to the silicon carbide sleeve. The inserts are also replaced whenever a tapping jacket is replaced during a major shutdown. Between the 2005 and 2007 shutdowns, there were 18 inserts changes amongst the four tapping jackets, with an average of 260 taps on each insert. Between the 2007 and 2010 shutdowns there were 14 inserts changes with an average of nearly 500 taps per insert.

Quality assurance of copper castings

Quality inspections of copper castings are performed by the manufacturer prior to delivery to Teck, as well as on site after the castings have been received. Typical inspections performed by the manufacturer include:

- Chemical analysis of the copper
- Electrical conductivity of the casting
- Dimensional tolerances of the casting
- Ultrasonic measurements to verify the position of the cooling coil in the casting
- Pressure checks of the cooling coil before and after casting
- Water flow volume checks of the cooling coil before and after casting
- Ball test of the cooling coil after casting to ensure no penetration of the coil during casting
- Optional X-ray inspection of the as-cast product to ensure proper casting techniques have been followed to minimize porosity, cracking, and nonmetallic inclusions.

Additional checks of the castings are performed after the castings have been received by Teck, such as an internal visual inspection of the cooling coil using an optical boroscope and a detailed surface conductivity survey to locate any welding repairs to the casting.

Because of the critical nature of the copper inserts and the ability of the inserts to extract heat, the insert is thermally tested to semi-quantitatively determine the degree of bonding between the cooling coil and the surrounding copper. The thermal test involves heating the coil to 110°C and then passing cooling water through the coil. The insert and water temperatures are monitored. As the test progresses, the temperature change of the cooling water decreases and the test is considered to be completed when the temperature differential is less than 0.1°C. The change in the water temperature is trended and the degree of bonding is assessed by comparing the trend to a linear trend for a theoretically perfectly bonded coil. Figure 5 shows the results of two tests, and illustrates the difference between a well-bonded and a poorly-bonded casting. For a poorly-bonded coil there is a rapid initial decrease in the water temperature change, followed by a long period with a temperature differential above 0.1°C. The same test is performed on an insert after it has been removed from service to determine if the degree of bonding deteriorated through the operational life of the insert.

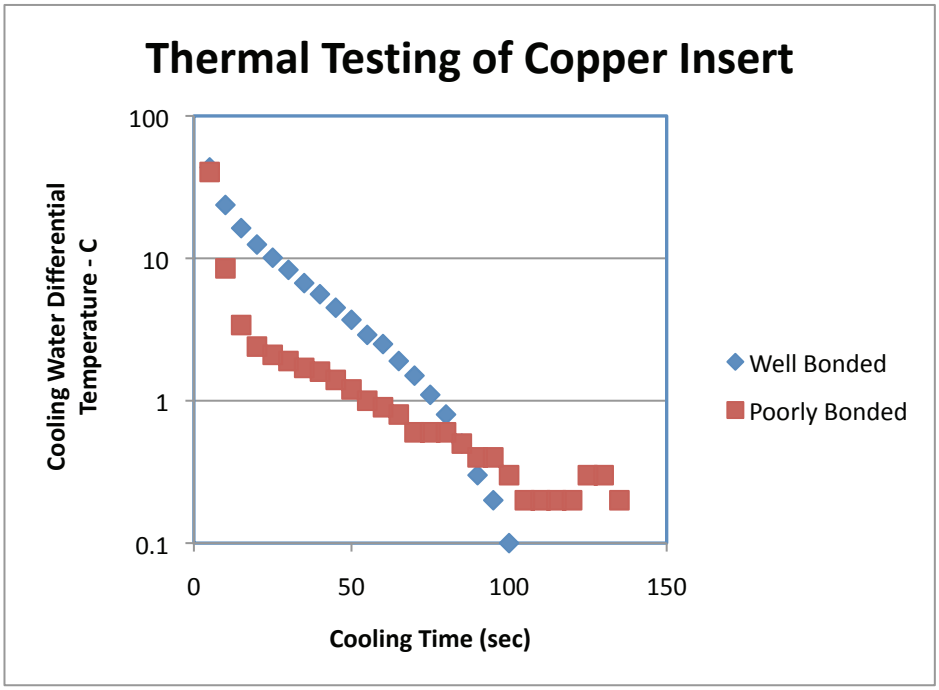

Figure 5. Thermal testing of bullion tapping insert

Training

Lead bullion has been tapped at Trail Operations for over a century, and until 1997 was done on the lead blast furnace. From 1970 to the present, the experience level of the operators tapping lead bullion from the blast furnaces and the KIVCET furnace has varied dramatically, as seen in Figure 6. This was due to a variety of factors, including personnel movement.

In addition, the change in technology from blast furnaces to the KIVCET furnace, coupled with the uniqueness of the new lead tap-hole design, posed significant challenges and required changes in operational and training practices.

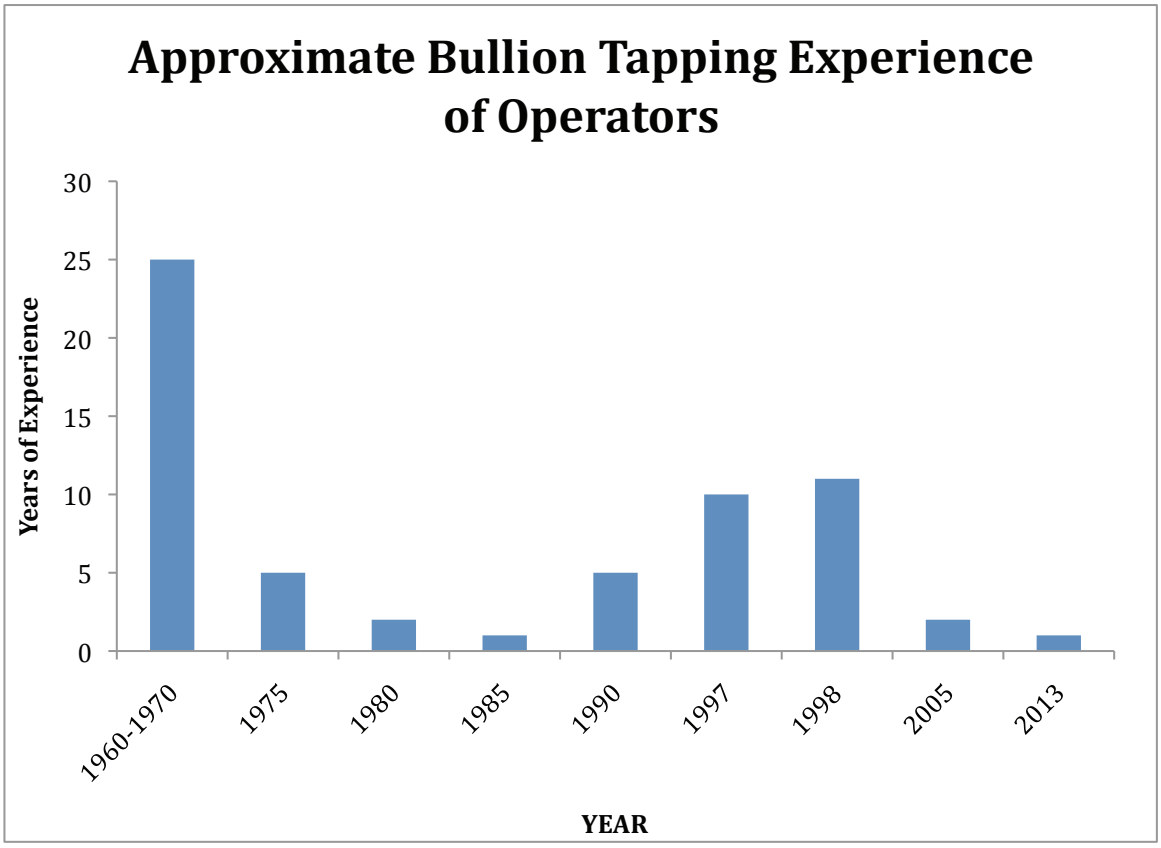

Figure 6. Bullion tapping experience of operators

The training programme for lead bullion tapping operators had to evolve from learning on the job with more experienced operators to a detailed training programme that consists of:

- Formal classroom training
- Field training on the drill and mudgun
- Field training on the use of oxygen lances
- Evaluation of skills via verifiable learning objectives (VLO) after each stage
- Final evaluation for signoff.

The lead bullion tapping training programme covers a large amount of information, which includes:

- Furnace structure and furnace equipment
- Lead bullion tapping system and related equipmen,t including oxygen handling equipment
- Specific safety training on the hazards associated with tapping lead bullion
- Lead bullion tapping procedures, including emergency response procedures
- Safe use of oxygen lances
- Monitoring practices of the tapping system
- Details on maintenance of the tapping system.

Any changes to the lead tapping practices and to the training programme are first assessed using a hazard risk assessment process to ensure unintentional risks are not introduced into the work practices. Although the experience of the bullion tappers has decreased over the years, the lead tapping programme developed has enabled Trail Operations to successfully improve the reliability of the lead bullion tapping system through a change in lead smelting technology.

Conclusions

Lead bullion tapping at Trail Operations has gone through significant changes in the past few decades. the technology change with the adoption of the KIVCET furnace, along with a changing labour demographic, has posed significant challenges. Improvements in operational, monitoring, and training practices, together with a solid tap-hole design, have resulted in a reliable tapping system at Trail Operations.

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The Author

Timothy A. Moore, *Technical Superintendent, Lead South*, Teck Metals Ltd.

Following graduation from the University of British Columbia in Engineering Physics, I began a career in metallurgical research and development at Cominco. I worked as a team member designing and commissioning both pilot and demonstration plants for the CESL process, a proprietary hydrometallurgical process for refining copper, nickel and precious metals. Continuing an emphasis on research and development, I moved into the field of naval architecture, conducting model scale experimental evaluation of ships and other floating structures for an independent research firm in St. John's, Newfoundland. I returned to the metallurgical field in 2009 with Teck Trail Operations, initially as a Maintenance Engineer, and currently as Technical Superintendent in the lead smelter.