

Water-cooled tap-hole blocks

I. Mc Dougall
Tenova Minerals (Pty) Ltd

Water-cooled copper tap-hole blocks provide an effective means of extending the life of tap-hole refractories, as the lower temperature of the refractory material inhibits wear and other damage and promotes the formation of a protective frozen slag layer. This is particularly beneficial during prolonged tapping cycles. The copper block forms an integral part of the lining, and provides mechanical support to the refractory, facilitating rapid replacement of tapping channel bricks without disturbing the surrounding lining. Safety considerations are an important design factor, and the positioning of the water channels is optimized to prevent leaks although the copper is not in direct contact with the molten fluids during normal operation. Water-cooled copper blocks designed by Tenova Pyromet have successfully been utilized on metal, matte, and slag tap-holes for a number of processes, including nickel, platinum group metals, and mineral wool.

Keywords: Water-cooled copper, metal tap-hole, slag tap-hole, refractory, tapping channel.

Introduction

The tap-hole region of a furnace is critical to the successful operation of the furnace, as it provides the means by which to remove product from the furnace in a manner that does not compromise the integrity of the furnace or the quality of the product. However, the tap-holes are the most vulnerable area of the furnace, as they are subject to severe operating conditions, which include thermal cycling, erosion by molten metal or slag, chemical attack by slag or molten metal, and wear caused by tap-hole opening and plugging operations. The internal temperature of the tap-hole is very important for its successful operation. The refractory must conduct heat from the molten fluid sufficiently rapidly that the tapping channel material is not damaged or degraded, but not so rapidly that the fluid freezes inside the channel to the extent that the channel closes prematurely. Consequently, there is no one-size-fits-all solution to tap-hole design.

This paper presents an overview of the factors influencing tap-hole design and compares a number of different tap-hole solutions.

Factors influencing tap-hole design

The factors considered in the design of a furnace crucible include the process chemistry and its effect on the refractory lining, the operating temperature and degree of superheat of the molten fluids, and the degree of cooling required. The selection of a refractory material that is resistant to corrosion by the slag and metal or matte at the operating temperature is the first important consideration. The second factor is the thermal behaviour of the tap-hole refractory, the balance between retaining sufficient heat inside the crucible to promote energy-effective process conditions and removing sufficient heat to keep the lining and shell at a safe operating temperature.

Tap-holes are subject to higher wear rates than other parts of the lining due to the more onerous operating conditions. At the start of the tapping cycle, the tap-hole is subject to thermal shock as the molten fluid begins to flow through the channel. The refractory rapidly heats up. At the end of the tapping cycle, once the tap-hole is closed, the refractory cools down. This may result in thermal spalling of the refractory. Thermal spalling is indicated by cracking of the refractory parallel to the hot face and occurs when the component is heated or cooled too rapidly. The maximum rate at which a material can safely be heated is a function of its thermal conductivity. For insulating materials such as aluminosilicate bricks, the maximum rate of temperature change to prevent spalling is of the order of 5°C/min, while silicon carbide can withstand 50°C/min and graphite 500°C/min (Tijhuis and Blijendaal, 1995).

The flow of molten metal or slag in the tap-hole results in erosion of both the channel and the hot face refractory surrounding the tap-hole, which gives rise to the characteristic funnel shape. In addition, oxidation of the refractory as a result of the use of oxygen lances causes wear of the tapping channel.

Chemical wear occurs when the slag or metal dissolves the refractory. The rate at which chemical wear (corrosion or dissolution) of the refractory occurs is dependent on the temperature of the refractory and the molten fluid, and increases rapidly as the temperature increases. This has been described by Eksteen in the context of the sulphide matte

used in platinum group metal (PGM) smelting (Eksteen, 2011). Conversely, if the refractory temperature can be maintained below a certain value, chemical wear is unlikely to occur at all. Slag generally has a low thermal conductivity and freezes relatively easily when cooled. The ‘freeze lining’ concept used in lining design utilizes these properties of the slag to protect the lining (Hearn, Djermejko, and Lamont, 1998). This technique may also be used to protect the tap-holes.

All these wear mechanisms are functions of temperature, either the actual temperature or the rate of change of temperature. Consequently, maintaining an optimal temperature within the tap-hole is very important for its successful operation. The refractory must conduct heat from the molten fluid sufficiently rapidly that the tapping channel material is not damaged or degraded, but not so rapidly that the fluid freezes inside the channel to the extent that the channel closes prematurely.

In addition to the thermal considerations, it is important to consider how the tap-hole interfaces with the surrounding lining in order to prevent furnace leaks. It is also important to design tap-holes that are easy to maintain.

Uncooled or indirectly cooled tap-holes

In furnaces for ferroalloys such as ferrochromium, ferromanganese, and silicomanganese, both slag and molten product are tapped through a single tap-hole. Neither the product nor the slag is particularly aggressive to the lining, although operating temperatures are relatively high in the case of ferrochromium. The furnace crucibles do not require intensive cooling, as the water film cooling of the shell provides adequate cooling, and the tap-holes are of a relatively simple construction. The older insulating linings employ a large carbon block or carbon ramming with a hole drilled through it. The block is surrounded by thermally and electrically insulating aluminosilicate bricks and the sidewall lining is thickened locally around the tap-hole in order to accommodate the accelerated refractory wear in this area. A schematic view of a tap-hole of this type is shown in Figure 1.

The more modern carbon block-based thermally conductive ‘freeze lining’ constructions employ carbon blocks for working lining and the tap-holes, parts of which may be made of graphite to increase the thermal conductivity of the tap-holes (Hearn *et al.*, 1998; Coetzee *et al.*, 2010). Figure 2 shows a schematic of a section through the sidewall and tap-hole of a furnace with a conductive lining. A 100 mm thick layer of slag is also shown on the hot face of the refractory. Silicon metal furnaces employ a similar design, although the tap-hole block is usually made of silicon carbide.

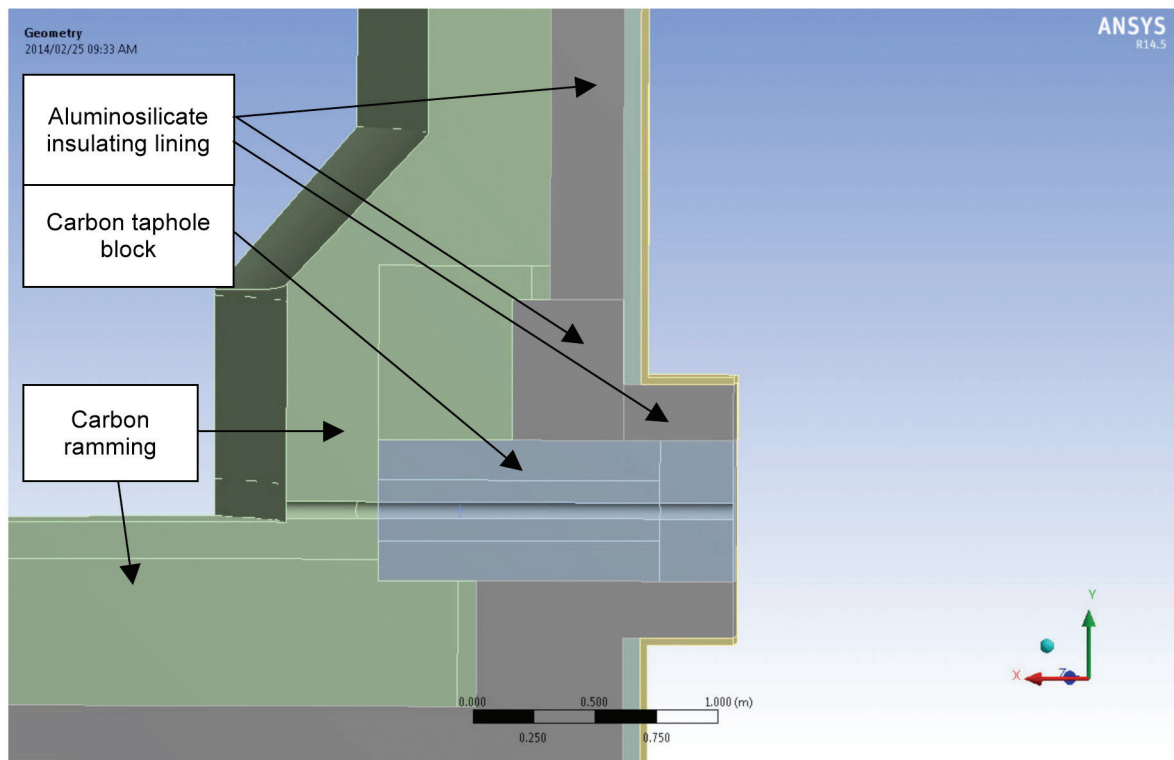


Figure 1. Schematic view of a tap-hole in a silicomanganese furnace with an insulating lining

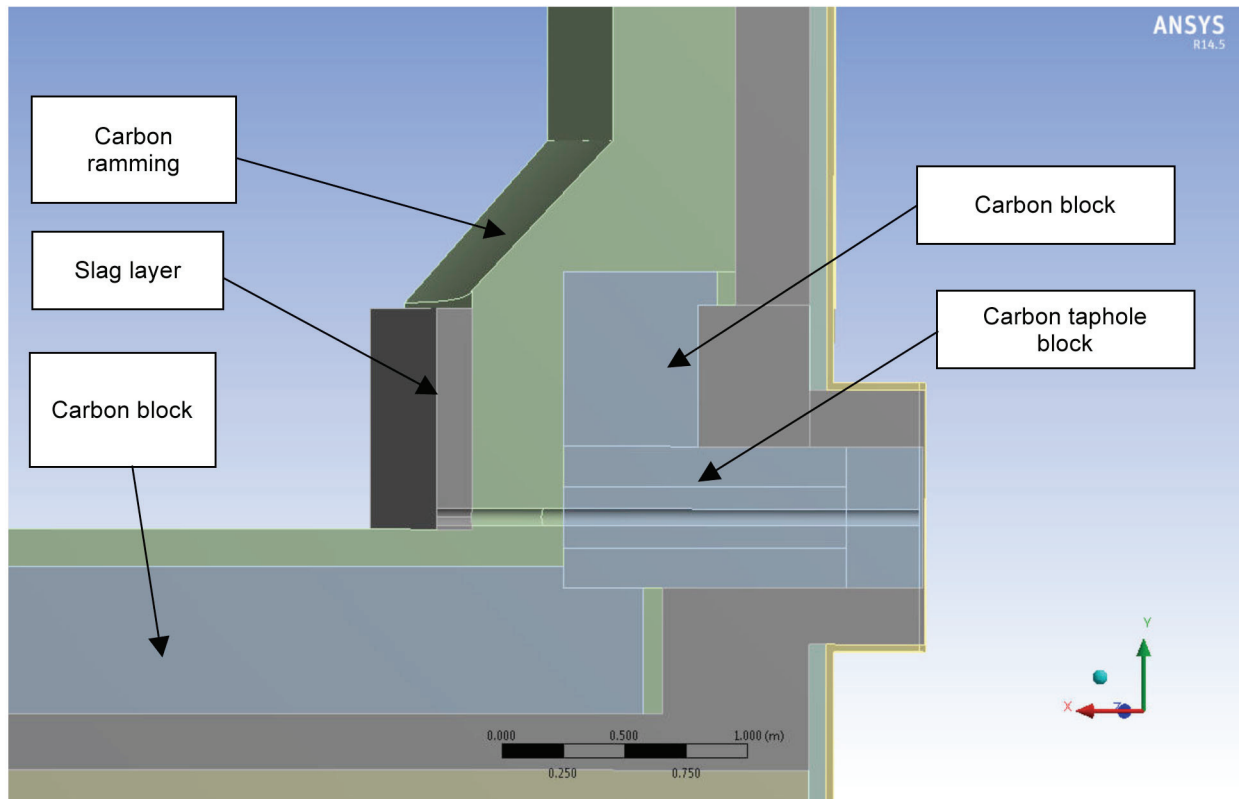


Figure 2. Schematic view of a tap-hole in a silicomanganese furnace with a conductive lining

The temperature profiles through the tap-holes for these two configurations are shown in Figure 3 (the insulating lining) and Figure 4 (the conductive lining with a slag layer on the hot face). The position of the 1200°C isotherm is a useful measure for comparison, as it represents the typical liquidus temperature of a silicomanganese slag. The conductive lining displays a substantial temperature gradient through the frozen slag layer above the tap-hole. Consequently, a greater portion of the lining is at a lower temperature, which extends the life of the lining and prevents infiltration of slag or metal into the lining. This effect is smaller at the tap-hole itself, and the slag layer is above its liquidus temperature at the tap-hole height, indicating that the freeze lining does not extend to the hot face of the refractory at the tap-hole. The temperature profile in the tap-hole and tapblock is similar for the two cases, although the tap-hole in the conductive lining is approximately 80°C cooler.

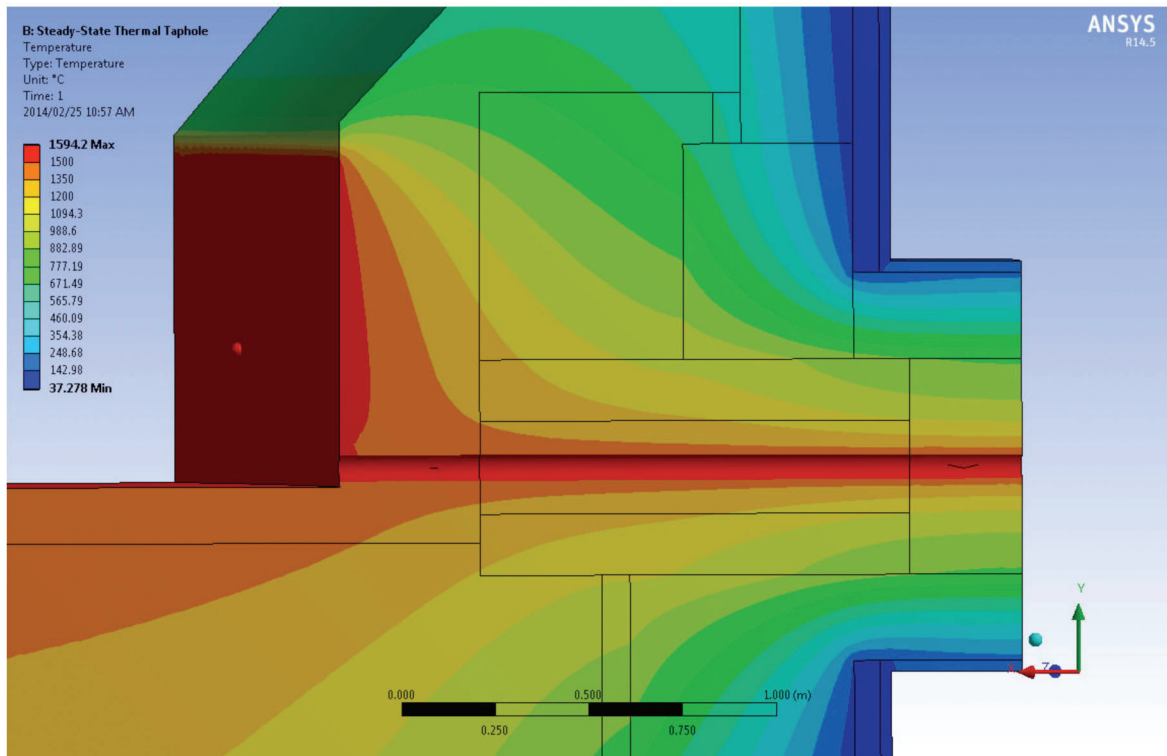


Figure 3. Temperature profile through the tap-hole block (insulating lining)

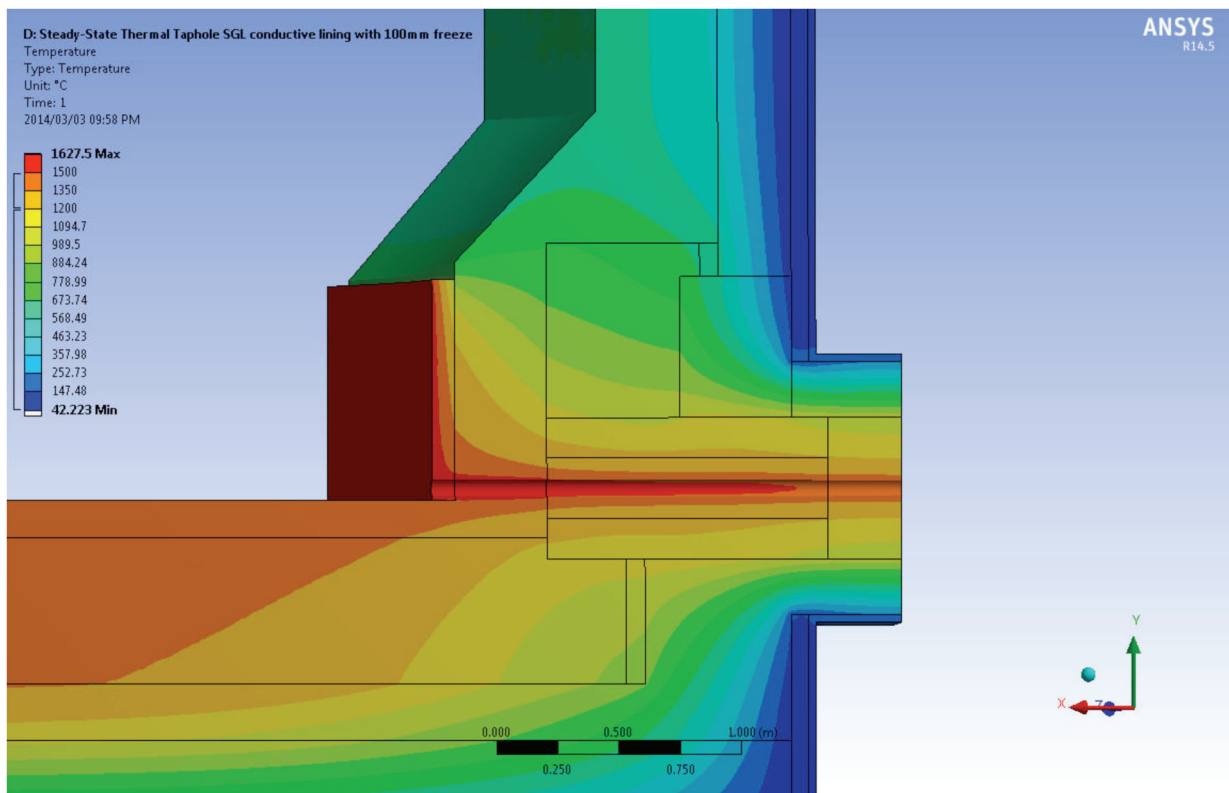


Figure 4. Temperature profile through the tap-hole block (conductive lining with slag layer on hot face)

Water-cooled tap-holes

In processes such as the production of pig iron, titanium dioxide, ferronickel, and PGMs, there are dedicated slag tap-holes and metal/matte tap-holes. In all these processes, the slag and, in some cases, the metal or matte, is aggressive to the refractories. This can cause rapid wear of the tap-holes. The construction of these tap-holes is optimized to provide sufficient cooling of the inside of the tapping channel to limit or prevent this problem.

This has led to the development of copper tap-hole blocks. The copper is usually not placed in direct contact with the molten fluids, as the melting point of copper is generally several hundred degrees below the process temperature. However, molten slag rapidly freezes when in contact with water-cooled copper. As the copper temperature in a water-cooled element does not usually exceed 200°C, a stable slag freeze lining forms on the copper surface, further protecting the copper from the process fluids. Should the frozen slag melt due to a temperature event in the area, it will rapidly refreeze. A CAD model view of a copper slag tap-hole set into a copper support cooler is shown in Figure 5. The tapping channel is initially lined with a suitable castable refractory, although this is eventually replaced by a layer of frozen slag (Joubert *et.al.*, 2005). Both the faceplate and the copper tap-hole block can be replaced without entering the furnace.

A copper slag tap-hole that does not require a support cooler is shown schematically in Figure 6. Temperature contours for this slag tap-hole, when used in a PGM smelting furnace, are shown in Figure 7. The maximum operating temperature in this case is 1650°C, with a typical slag liquidus temperature of 1350°C. When the furnace is in operation, the refractory lining wears away to the position of the slag liquidus isotherm. In contrast to the temperature fields shown in Figures 3 and 4, the temperature in the water-cooled tap-hole of Figure 7 decreases rapidly away from the tapping channel. The copper temperature does not usually exceed 200°C. Consequently, the refractory is cold a short distance from the molten slag. Although this creates a large temperature gradient in the refractory of the tapping channel, the bulk of the refractory is kept at a temperature at which wear due to the temperature is unlikely to occur.

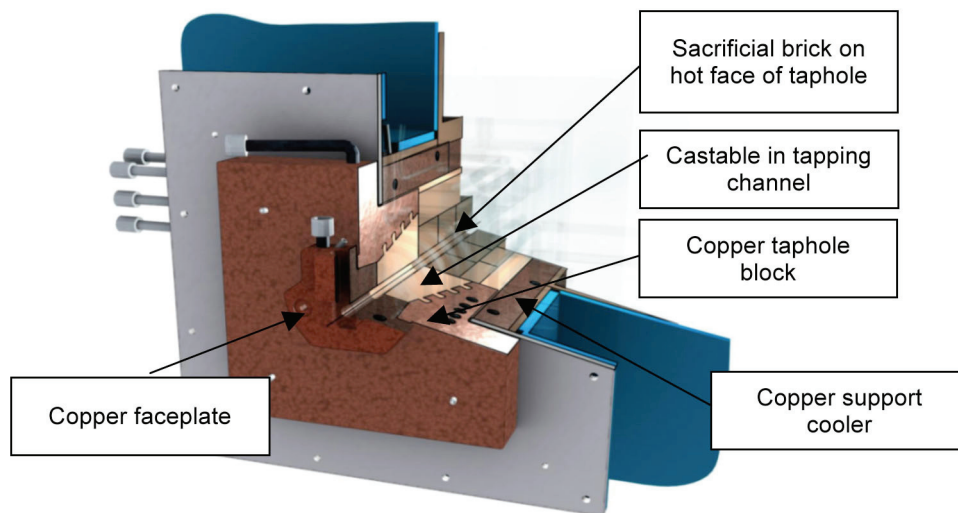


Figure 5. Copper slag tap-hole block set into a support cooler

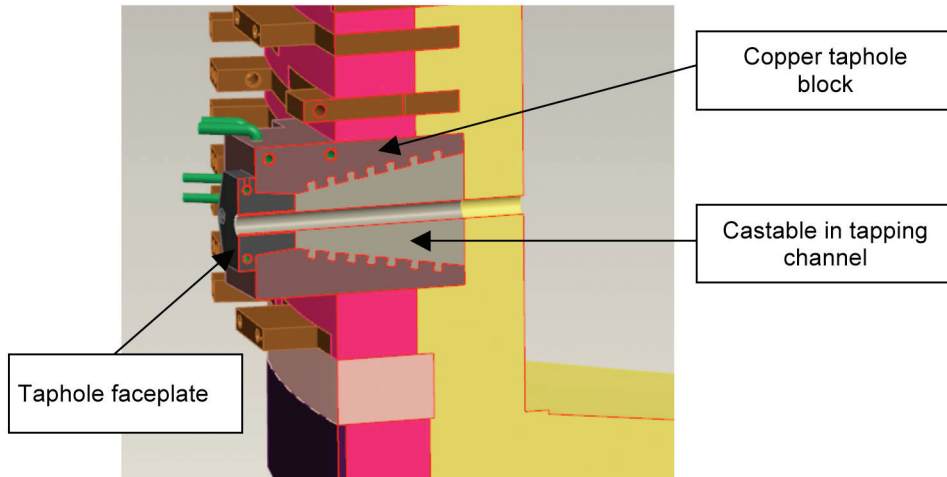


Figure 6. Copper slag tap-hole without a support cooler used in a PGM furnace

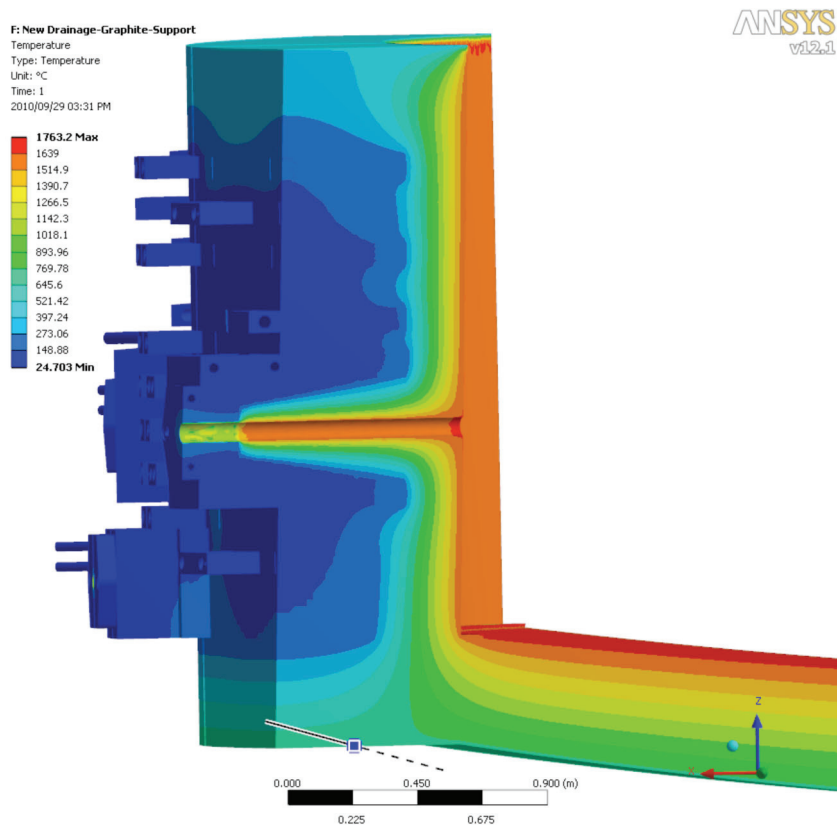


Figure 7. Temperature contours in the water-cooled slag tap-hole of Figure 6.

A third example of a water-cooled copper tap-hole arrangement is shown in Figure 8. This tap-hole is a matte tap-hole for a PGM furnace. Molten metals or metal sulphide mattes exhibit a high thermal conductivity and are generally considerably more fluid than the corresponding slags. Consequently, they do not freeze as easily on cooling. The high thermal conductivity means that any molten metal in contact with a water-cooled copper tap-hole is likely to heat the tap-hole to a considerable degree before the metal cools down sufficiently to solidify. The operating temperatures of molten pig iron, ferronickel, copper matte, or copper-nickel matte may be several hundred degrees higher than the melting point of copper. Consequently, the risk of damage to the copper caused by exposure to molten metal is significant. For tapping molten metal, the tap-hole is drilled into a refractory channel, which is surrounded by a cast

copper block fitted with water passages. The water passages are positioned such that the danger of contact between water and molten metal is minimized in the event of a water leak.

In the tap-hole configuration shown in Figure 8, the copper block is split into two, to allow for ease of replacement of tapping channel bricks. All the bricks inside the copper tapping channel can be replaced without entering the furnace. It is also possible to replace the inner refractory tapping channel from outside the furnace, with some effort. The copper channel is lined with two concentric layers of bricks. For normal maintenance, only the inner tapping channel bricks are replaced. The outer surround bricks protect the copper against damage during maintenance activities. From the temperature contour plot of Figure 9 it may be noted that there is a large temperature gradient through the inner tapping channel bricks, but that the surround bricks are relatively cold. The surround bricks therefore wear at a considerably lower rate than the tapping channel bricks, and consequently do not need to be replaced as frequently.

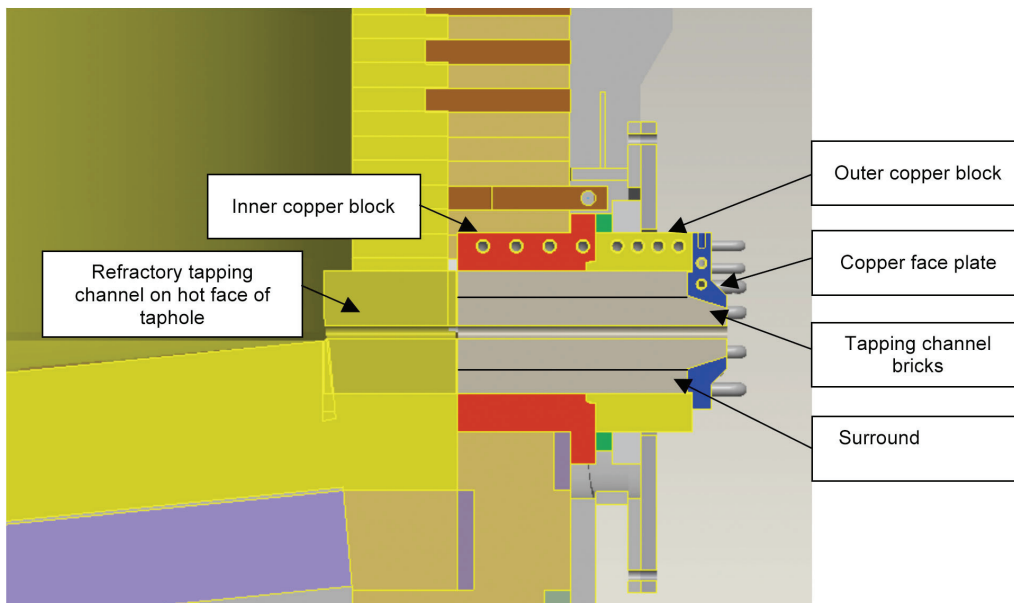


Figure 8. Water-cooled copper tap-hole arrangement for tapping PGM matte

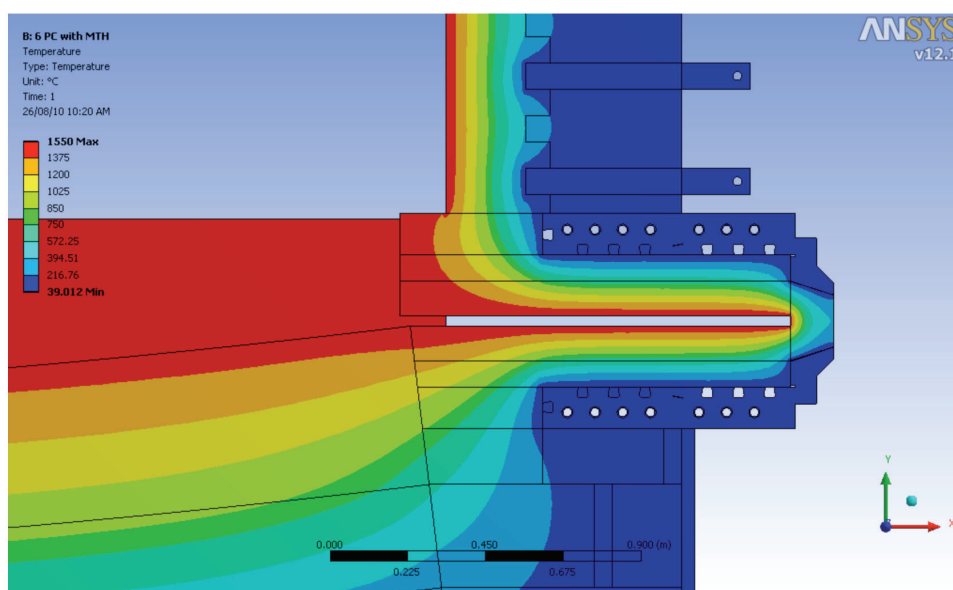


Figure 9. Temperature contours in the copper matte tap-hole during tapping

Copper tap-hole blocks are set into the lining. The mechanical strength of the copper is considerably superior to that of carbon or graphite blocks or refractories, and the copper is not as brittle. The tap-hole block is therefore ideally suited to improve the stability of the lining in this area and support the bricks above the tapping channel, which facilitates replacement of these bricks during routine maintenance outages. In Figure 8, the square copper block supports the bricks above it. The tapping channel blocks can therefore be removed safely and easily without disturbing the surrounding lining. Careful design of the lining surrounding the copper block is required in order to minimize the occurrence of leaks between bricks and copper.

Conclusion

Uncooled carbon metal and slag tap-holes have been in use for many years, and operate successfully where the metal and slag do not aggressively attack the refractory lining. Their low cost and ease of use make them suitable for many applications. However, where the metal and/or slag are aggressive to the refractory or where they operate at several hundred degrees of superheat, water-cooled copper tap-holes provide a robust solution. Water-cooled copper tap-hole blocks provide an effective means of extending the life of tap-hole refractories, as the lower temperature of the refractory material inhibits wear and other damage and promotes the formation of a protective frozen slag layer. This is particularly beneficial during prolonged tapping cycles. The copper block forms an integral part of the lining, and provides mechanical support to the refractory, facilitating rapid replacement of tapping channel bricks without disturbing the surrounding lining.

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The Author



Isobel Mc Dougall, *Consulting Engineer*, Tenova Pyromet

Isobel Mc Dougall qualified as a Mechanical Engineer in 1984, and has worked in various positions in heavy industry since then, starting as an Engineer-on-Training at Eskom. Since she joined Tenova Pyromet during 2008, she has been involved in the design of submerged arc furnaces and ancillary equipment. Her main job functions include basic furnace design, development of new equipment, FEA of heat transfer and structural problems and problem solving for internal and external clients. Her particular interest is finite element modeling of the coupled-field problems associated with smelting processes. Prior to joining Pyromet, she was employed by CSIR for 10 years, performing analysis and design work on smelting equipment and other industrial plant as well as participating in the establishment and certification of a high temperature materials testing laboratory.

