Advances in Waterless Cooling for Extended Refractory Campaign Life

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ABSTRACT

Refractory campaign life in pyrometallurgical vessels is one of the critical factors in the overall profitability of operations. Failures and/or reduced throughput have direct implications on efficiencies, costs and overall business viability for the operator. Today's challenging process conditions continue to increase the wear rates and shorten campaign lives which puts additional pressure on an operation's sustainability.

For many years Hatch has assisted operators in increasing vessel life through the novel and innovative application of cooling and cooling elements, allowing organisations to increase productivity through longer campaign life, higher operating rates, or more aggressive process conditions. Water has historically been the medium of choice for the cooling of pyrometallurgical vessels but Hatch has recently designed and installed an internal, completely waterless cooling system in an existing refractory-lined smelting vessel.

Based on Hatch's air cooling technology, experience in the implementation of high-velocity air cooling of furnaces, and knowledge of corrosion protection technology, a novel solution was developed. The solution incorporates fully enclosed high velocity air channels integrated into the refractory design using corrosion - resistant metal fin plates to locally increase the heat transfer from the refractory to the air channels.

The paper describes the development and implementation of the technology at an existing site. The flexibility of the technology is illustrated by various examples of other possible applications for this novel, cost-effective and inherently safe system.

1. Introduction

Implementation of high intensity cooling technologies has been a common method to mitigate refractory wear for decades. Since first being implemented by Hatch for Falconbridge Dominicana in 1973, water-cooled copper elements have been designed for and installed in many vessels around the world [1]. In 1994, Hatch was awarded the Falconbridge Innovation Award (now Xstrata Innovation Award) for the industry acceptance of the copper cooling system [2]. Hatch also designed the first waffle cooler for areas of elevated heat loads [1]. Since then, cooling technology advancements have generally been limited to geometry and material changes.

The need for a high intensity, waterless cooling technology which generated the impetus for the development of the solution described in this paper, arose due to a confluence of two factors:

- Severe local lining wear which limited the campaign life of the process vessel
- A strict prohibition against the use of water-cooling at the particular plant site due to safety concerns

Existing waterless cooling technologies could not meet the heat removal performance required for this application, so a new concept had to be developed.

The patented Internal Air Cooling technology is a new approach for intensive heat removal from refractory by use of high velocity air [3]. Development of this design had to overcome challenges on a number of fronts. The geometry of the system had to fit within the refractory bricks while maintaining a tight cooler pitch spacing. The material selection demanded a combination of high thermal conductivity, mechanical stability, and high temperature corrosion performance. Hatch marshalled a team of experts to work together to address these issues.

Internal Air Cooling's inherent safety, economical implementation, low maintenance requirement and versatility make it an attractive alternative to water cooling. Since its successful pilot campaign in a process vessel, other potential applications have been identified and developed.

2. Cooler Use to Mitigate Refractory Wear

Refractory wear occurs due to a combination of partial melting, mechanical erosion, and high temperature corrosion. The "refractoriness" of a brick (an indicator of ability to resist wear) is largely influenced by temperature. Reducing the temperature of the refractory within the lining allows the bricks to resist wear more effectively [4]. Build-up can also be frozen onto the hot face to mitigate refractory wear. This allows for increased campaign life of process vessels which improves the commercial performance of the overall plant. There are a number of widely accepted cooling technologies described in detail in [5], [6] and summarized below.

2.1 Water-Cooled Copper Coolers

Hatch employs various cooling technologies to achieve a stable thermal equilibrium condition, leading to the formation of a freeze-lining. Water-cooled plate coolers are designed as both deep-cooled with a cast in pipe, or shallow-cooled with the water passage drilled into the portion of copper plate extending out of the sidewall.

Hatch waffle coolers are taller components, usually thinner in profile with multiple cast-in pipes located with a tight pitch spacing. This high concentration of cooling coils increases the heat removal capacity of the waffle cooler beyond that of a plate cooler [5].

A thermal model of a typical furnace wall section is shown in Figure 78 below, comprising shallow plate coolers and a waffle cooler. Both nominal and peak heat loads are applied to the hotface as indicated, and yield the thermal equilibrium wall profiles shown in Figure 78. The equilibrium point identifies the wall wear profile at which a freeze lining begins to form.

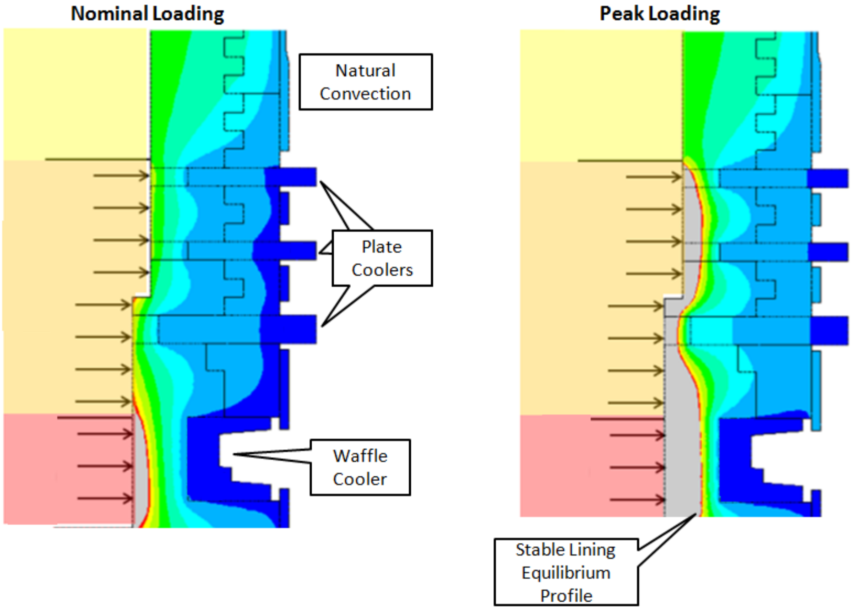


Figure 78: Thermal profile of a typical wall construction at nominal and peak thermal loads

2.2 External Finned Air Cooling

Hatch commonly employs external forced-air cooling in the matte/metal zone of a furnace. There have been many different cooling methods custom-designed for this zone to maintain the shell within acceptable limits for structural integrity and provide moderate cooling for the sidewall refractory. The standard Hatch practice includes convoluted copper fins that are bolted to the outside of the steel shell where they are enclosed by steel plates to form a duct. The system is cooled by a fan-driven draft air system. [7]

3. Internal Air Cooling

Although water-cooled copper coolers are quite common, there are some situations where they are not applicable. Some of these situations include:

- Limited water circuit availability
- No water cooling system implemented at the plant
- Water cooling prohibited due to site-specific safety concerns

Internal Air Cooling can meet the cooling requirements in these situations due to its versatility and ease of implementation. As shown in Figure 79 below, the heat removal capacity of Internal Air Cooling bridges the performance gap between external cooling methods and internal water-cooled copper coolers.

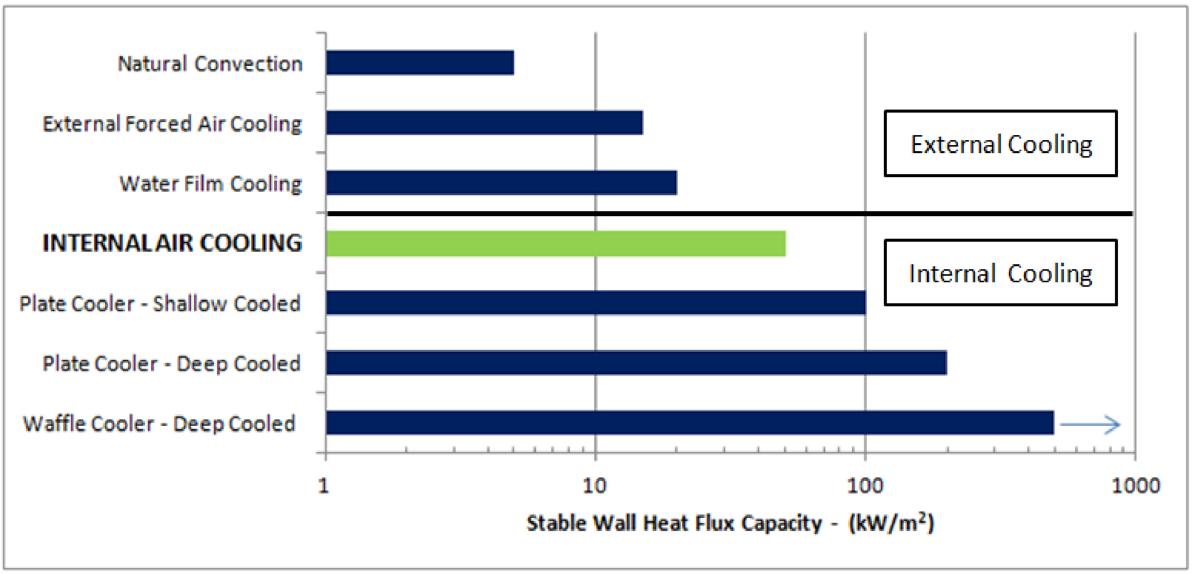


Figure 79: Relative performance of different cooling technologies [5]

3.1 Development Approach

The design challenge for Internal Air Cooling was confronted by a multidisciplinary team of engineers from within Hatch's Technologies Group. A concept was developed and thermal modelling was performed to predict the equilibrium lining thickness and heat flux removal rates. This was done with various geometry cases and cooler pitch spacings to optimize the design for cost-effective implementation.

The material selection challenges were extremely demanding. The materials chosen for the coolers had to not only provide the required thermal conductivity, but also had to mechanically and chemically withstand extreme temperatures in an aggressive environment. Our Corrosion Specialists worked closely with external laboratories to design an accelerated testing program to assist in optimal material selection and evaluation of coating protection options for the coolers.

3.2 How It Works

The technology is based on the principle that cooling is more effective with higher temperature differentials between the refractory and the cooling medium. By placing the air channels within the lining, the cooling air is less thermally insulated from the working surface of the lining, allowing for more effective heat transfer. Unlike in conventional external air-cooling systems, less lining wear is needed for thermal equilibrium to be established when the cooling system is closer to the working surface.

As shown in the partial assembly given in Figure 80, the system comprises a fabricated channel assembled within the refractory lining, connected to an external source of cooling air. Optionally, high-conductivity fin plates fabricated from a specialized material can be attached to this channel and protrude inward toward the lining hotface. These plates further increase the impact of the cooling application by locally increasing the effective thermal conductivity of the lining as shown in Section 0. Due to high operating temperatures, copper, the material traditionally used for cooling elements, may be insufficient for use in some applications.

By using closed cooling air channels, higher air flow rates can be achieved without risking leakage of air into the furnace, which may cause local process disruptions or refractory rat-holing. These channels are placed within a profiled brick course, shown below in blue. Ambient air is drawn or pushed through the air channels at a high velocity, while the hot outlet air is simply exhausted externally or sent to heat recovery.

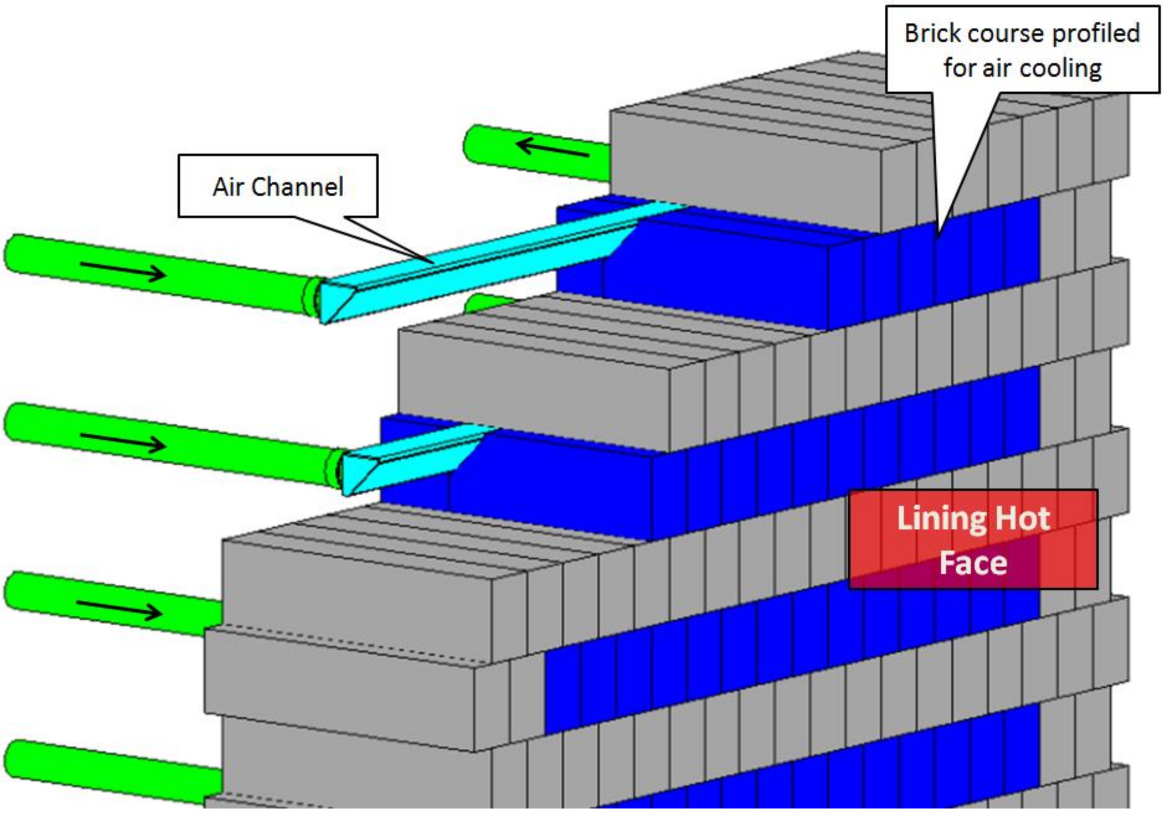


Figure 80: Partial assembly of Internal Air Cooling channels within refractory wall

3.3 Comparison to Water-Cooled Copper

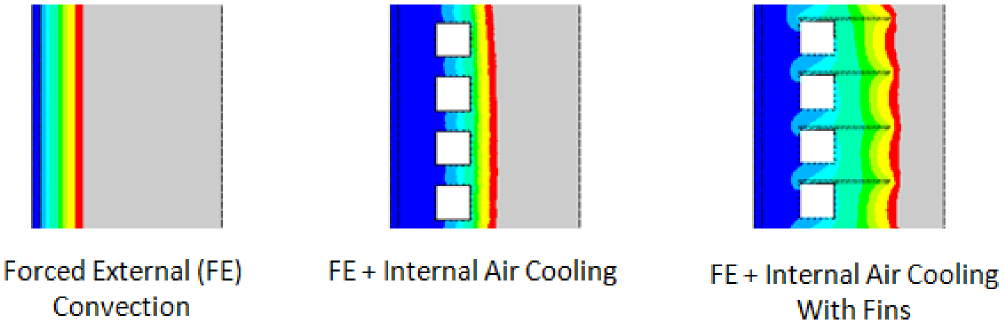
System parameters are compared in Table 20 for both Internal Air Cooling and water-cooled copper coolers.

Table 20: Performance parameter comparison between Internal Air Cooling and Water-Cooled Copper

	Internal Air Cooling	**Water-Cooled Copper**
Peak Stable Wall Heat Flux Capacity	50 kW/m^2	100-1000 kW/m^2
Maximum Cooling Media Outlet Temperature	300 °C Limited by downstream instrumentation	~90°C Nucleate and dead leg boiling
Maximum Cooler Material Temperature	900°C (Material dependent)	450°C
Cooling Media Velocity	15 - 20 m/s	1.5 – 3 m/s
Risk Due to Cooling Media Leak	Possible refractory rat-holing	Possible refractory hydration or explosion
Stable Cooler Material Life at Low/No Flow	Weeks (Pilot campaign experience)	Minutes to hours
Auxiliary Equipment Required	Fan and ductwork	Water pump, manifold, cooling tower / heat exchanger
Operating Costs	Fan power	Pump power, cooling power, water treatment, corrosion management

3.4 Options for Increased Effectiveness

The theoretical performance, as measured by lining equilibrium thickness, of air cooling with and without fins is compared to forced external air cooling using finite element thermal analysis in Figure 81. It can be seen that the implementation of internal air cooling establishes thermal equilibrium at a greater thickness, closer to the lining hotface; a very favourable benefit. Additional benefit can be obtained by the installation of conductive plates within the lining, which extend the influence of the cooling channels further towards the lining hotface.



Forced External (FE) Convection

FE + Internal Air Cooling

FE + Internal Air Cooling With Fins

Figure 81: Thermal comparison between various sidewall cooling methods

The above model was run to simulate a 25 kW/m^2 heat flux with a fused grain Mg-Cr refractory lining inside of a 5 cm thick steel shell. The internal air is modeled at 15 m/s with a bulk air temperature of 100°C. This model assumes full thermal contact between the bricks and the shell, which artificially boosts the performance of the forced external cooling only model (left) relative to the other cases.

Heat removal performance of the Internal Air Cooling system could be improved by a number of measures:

- Decrease the pitch spacing between cooling channels
- Increase air pressure within the channels
- Increase air velocity

3.5 Vertical Arrangement

An alternate Internal Air Cooling channel design, shown in Figure 82, was developed by placing the air channels vertically within the refractory. The straight channel is designed within the refractory so that brick bonding is maintained. In this particular arrangement, only one hole is required in the shell for air to circulate through the channel. This allows for cooling of bath zones with all shell perforations above the bath surface – with the goal of maintaining a sealed bath zone shell. If used beneath the taphole, Internal Air Cooling could substantially mitigate the potential risks posed by water leaks (hydration of magnesia brickwork and possible explosion).

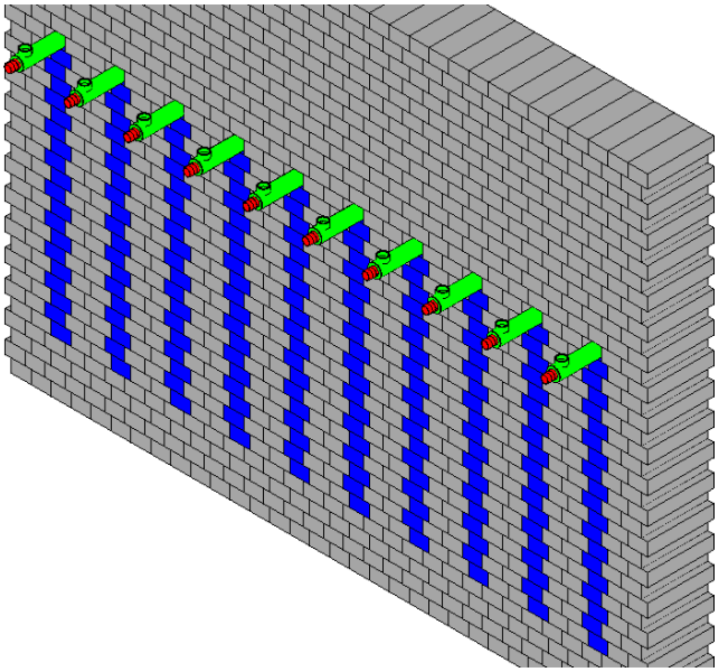


Figure 82: Vertically oriented Internal Air Cooling channels within refractory bricks

4. Successful Implementation in a Process Vessel

The Internal Air Cooling system has been implemented in a confidential smelting vessel. Localized refractory wear limited the campaign life of the vessel and water-cooled technology was prohibited by the plant due to safety concerns. Internal Air Cooling with fin plates was proposed and designed for the requirements of the vessel and refractory geometry. Both horizontal and vertical Internal Air Cooling channels have been installed. Prior to implementation, efficient methods of installing the system were developed to allow implementation without undue disruption to brick installation.

After a full campaign, retained lining thickness in the high wear zone was increased by ~300%. The cooling channels were removed with the fin and channel materials showing marginal corrosion and wear. The wall was then rebuilt with a new set of coolers installed.

5. Potential Applications

As with water-cooled copper cooling elements, the Internal Air Cooling system can be adapted to wear zones in most metallurgical process vessels. A number of potential applications have been identified and analyzed. These early stage concepts require further engineering to optimize the particular system and installation requirements. A brief outline of the opportunities is provided below.

5.1 Hung Roof Cooling

Hung refractory roofs are normally cooled by natural air convection. This convection is inhibited by dust build up on the refractory cold face, which leads to higher refractory temperatures and wear rates. Implementation of water cooling would require a complete redesign of the brick roof to incorporate cooled panels, and also introduces a water leak risk in the event of cooling element failure.

By profiling the refractory to accept an Internal Air Channel, the thermal performance of the roof can be increased, as shown in Figure 83, to help mitigate wear of the lining. A secondary benefit is that the exhaust cooling air could be ducted outside of the building, thereby dramatically reducing the ambient temperatures at the roof level and improving working conditions for the plant personnel.

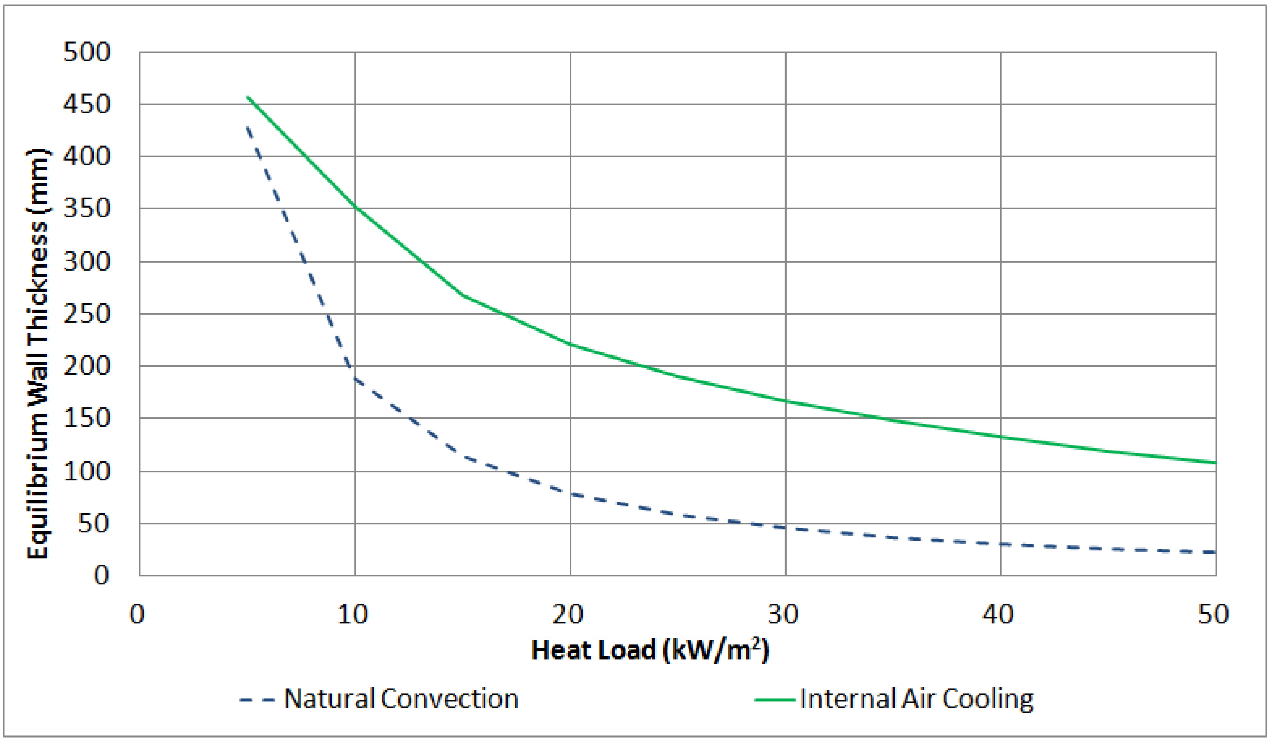


Figure 83: Predicted refractory thickness of Internal Air Cooling vs natural air convection

It can be seen from Figure 83 that a roof using Internal Air Cooling maintains an equilibrium lining thickness 2-3 times greater than a natural convection cooled roof for heat loads between 10 – 25 kW/m^2.

5.2 Clover Wear Mitigation

In circular Ferroalloy furnaces, wear is commonly experienced in areas close to the electrodes producing a “clover” shaped wall wear pattern. The sidewalls are commonly cooled by external water film cooling, which exploits the high conductivity of a graphite lining.

The effectiveness of this cooling is linked to the contact loss between the lining and the shell. This is difficult to prevent, as voids are common due to lining movement and shell distortion. By installing Internal Air Channels within the lining, as shown in Figure 84, the requirement for this shell contact is reduced as the cooling occurs inside the shell, and can be maintained by the vertical loads due to self-weight of the lining.

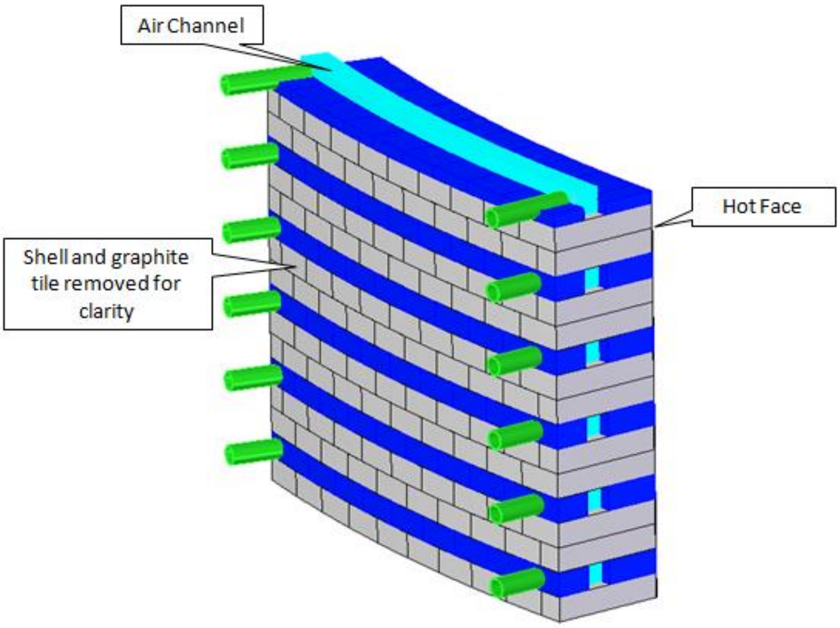


Figure 84: Horizontal Internal Air Cooling channels in a circular furnace wall

5.3 Other

Aside from those already mentioned, numerous other potential applications exist. Implementation of Internal Air Cooling is relatively simple and entails low CAPEX and OPEX, thereby making it an attractive alternative to more conventional cooling elements in many situations. Application-specific safety concerns, insufficient cooling tower or water system capacity, or other economic considerations can all potentially favour the implementation of Internal Air Cooling.

Examples of potential applications include:

- Converter tuyere lines
- Launders
- Matte/Metal zones
- Hot gas duct cooling

6. Conclusion

This paper presents a new, patented air cooling technology that can be installed within the refractory lining of any pyrometallurgical process vessel. The technology comprises vertically or horizontally oriented enclosed air channels, embedded within profiled refractory bricks, and integrated with the lining to provide high intensity cooling. Cooling effectiveness can be further enhanced by furnishing the channels with high conductivity fin plates to extend the influence of the cooling air toward the working face of the lining. This technology can be used to mitigate lining wear in a variety of applications, in any area of a process vessel.

Internal Air Cooling’s safe operation makes it an attractive candidate for high intensity cooling where water-cooled copper coolers or falling film water may not be applicable. The versatility of the design allows for Internal Air Cooling to be safely implemented in situations where constraints make the application of water cooling difficult, uneconomical, or impossible. This allows reduced lining wear, and the economic benefits of prolonged campaign life, to be realized at low cost in applications where it was not previously feasible to do so.

7. References

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