Infacon XV: International Ferro-Alloys Congress, Edited by R.T. Jones, P. den Hoed, & M.W. Erwee,
Southern African Institute of Mining and Metallurgy, Cape Town, 25–28 February 2018

ILTEC – A revolutionary and safe cooling solution for ferro-alloy furnaces

R. Degel[1], R. Nörthemann[1], T. Lux[1], M. Hanel[3], A. Filzwieser[2,3], and A. van Niekerk[4]
[1]SMS group GmbH, Düsseldorf, Germany
[2]PolyMet Solutions GmbH, Leoben, Austria
[3]Mettop GmbH, Leoben, Austria
[4]Metix, Johannesburg, South Africa

Abstract – Effective furnace cooling is required in order to achieve low refractory wear and a good furnace lifetime. The increasing demand for an economic and cost-saving operational mode makes cooling technology a sustainable aspect of furnace operation. In addition, safety awareness is increasingly becoming a focal point of the operating philosophy of furnaces.

However, the use of water – today's standard cooling medium – has major drawbacks, as it can cause problems during furnace start-up and operation, namely refractory hydration problems, corrosion, and explosions. Not to forget the severe personal, as well as economic damage, in case of a malfunctioning water-cooling system.

ILTEC is a new patented cooling technology, developed by Mettop GmbH in Austria, to overcome the disadvantages of water by using an alternative cooling medium, namely the ionic liquid IL-B2001. IL-B2001 is non-flammable, non-corrosive, non-toxic, and minimizes explosions, due to its low vapour pressure. It also has a wide liquid range and operating temperatures between 50 and 200°C. These properties all contribute to the safe use of IL-B2001 in various cooling applications in the metal processing industry, where there is a risk of cooling-water explosions.

SMS group and Mettop have signed an exclusive cooperation agreement for the utilization of this revolutionary cooling system.

This paper emphasises potential applications for the ferro-alloy industry. It highlights safety-related items, the use of the ILTEC technology for energy recovery, and new process routes that are made possible.

Keywords: ionic liquid, cooling, cooling elements, safety, cooling medium, ferro-alloy, electric furnace, submerged arc furnace, PolyMet Solutions, Mettop, SMS group, Metix

INTRODUCTION

The productivity of furnace operations has been dramatically increased over the past few decades by using effective cooling solutions. For a given system, in terms of energy input, material composition, oxygen enrichment, amongst other aspects, the performance of a furnace depends on the availability of the entire vessel. The limiting factors of furnace availability are manifold. They can, however, be related to high-refractory-wear areas in the slag zone or tapping areas. Other areas experiencing severe corrosive attack can also cause a decrease in performance (Filzwieser *et al.*, 2014; Wallner *et al.*, 2003; Voermann *et al.*, 1999).

Water, as the conventional cooling medium, can be very risky in certain areas, as a leakage would result in an immediate explosion, causing severe damage within the furnace structure. A best-case scenario would be a production loss as a consequence of major repair work. Unfortunately, in a worst-case scenario, personal injury and fatal accidents have a higher probability. Known accidents, from all over the world, in areas where water is used as a cooling medium with direct contact potential to liquid metal or slag, serve as evidence of this fact. There are alternatives, such as inert gases, air, or organic coolants, but these are very expensive, not as effective, or critical regarding health and environment. One effective alternative to eliminate this risk of using water is the ionic liquid cooling technology (ILTEC) (Oterdoom, 2014; Filzwieser *et al.*, 2014).

This novel ionic-liquid cooling technology eliminates virtually all negative effects of a water-cooled system, and adds certain benefits. By definition, ionic liquids (IL) are salts with a liquidus temperature below 100°C. They have no noticeable vapour pressure below their thermal decomposition point, and, depending on the actual composition, there is just a minor or absolutely no reaction with liquid metal or slag. Furthermore, the temperature range for cooling a system is much wider than water. The special ionic liquid IL-B2001 can be operated from 50°C up to 200°C. This allows for a higher recovery of energy, compared with water cooling. Additional benefits resulting from this relatively high cooling-medium temperature are that refractory hydration and shell/cooler corrosion problems are avoided.

Overall, it is of utmost importance for industrial applications that the requirements regarding critical energy flux, thermal limits, and impacts on health, safety, and environment be fulfilled. The ILTEC technology can lead to an industrial change regarding safety standards by becoming the new Best Available Technology (BAT) (Filzwieser *et al.*, 2014).

Until today, industrially realized projects include: the cooling of a tap-hole at a blast furnace (ArcelorMittal Bremen GmbH, Germany), the cooling of the side walls for a zinc oxide furnace (Nyrstar, Norway), and the cooling of flanges of a RH-facility (Voestalpine Stahl Donawitz GmbH, Austria).

IL-B2001 – THE IONIC LIQUID AT A GLANCE

In general, ionic liquids are salts, meaning they consist solely of anions and cations. Per definition, ionic liquids show a melting point below 100°C; many of them are liquid even at room temperature, caused by their poorly coordinated ions (Joglekar *et al.*, 2007; Wasserscheid & Welton, 2008; IoLiTec, 2013). Dislocated charging, and one ion based on an organic molecule, avoid the formation of a stable crystal lattice, so that only a minor amount of thermal energy is required to conquer the lattice energy and break the crystal lattice. Varying the cations and anions allows for the design of ILs with different properties (*e.g.*, melting point, viscosity, and solubility).

For the cooling application, the ionic liquid IL-B2001 was designed as a medium to meet the typical requirements for this application. The properties are summarised in Table I.

Table I: Characteristic properties of IL-B2001

	Symbol	Value	Unit	Range
Operating temperature		50 – 200	[°C]	ΔT = 150°C
Short-term stability		250	[°C]	
Decomposition temperature		450	[°C]	
Crystallization temperature		< 15	[°C]	
Density	ρ	1.25 – 1.14	[kg/dm3]	50 – 200°C
Heat capacity	Cp	1.38 – 1.70	[J/gK]	50 – 200°C
Electrical conductivity	κ	30 – 130	[mS/cm]	
Dynamic viscosity	η	20 – 5	[mPa·s]	50 – 100°C

PROPERTIES, OPPORTUNITIES, AND DIFFERENCES FROM OTHER COOLING MEDIA

Beyond the data and numbers given above, the ionic liquid IL-B2001 has attributes different from those of many other cooling media. The following sections provide an overview about the most essential characteristics.

Non-explosive

Whenever the decomposition temperature of 450°C is reached and exceeded, the ionic liquid will completely decompose into its gaseous components. In order to demonstrate that there is no explosive reaction occurring when IL-B2001 gets in contact with hot liquid metal, tests have been performed on industrial-scale operating furnaces. The ionic liquid was brought in contact with molten copper (at 1250°C) as well as liquid steel (at 1750°C) by pumping it beneath the bath level with a lance. In both instances, it could be seen that there was virtually no reaction. Only slight bubbling of the melt was apparent.

Non-corrosive

An essential characteristic of IL-B2001 is its chemical composition and the production procedure. A special and patented production process ensures that this ionic liquid is free of chlorine. As a direct consequence, IL-B2001 can be employed as a coolant in every conventional cooling element and with most common sealing materials. A variety of materials (steel grades, copper, and nickel-base alloy) have been investigated at both room temperature and also at higher temperatures comparable to the maximum operating temperature. Different construction and piping materials were brought into contact with the ionic liquid for 30 days, at temperatures of 200°C and 250°C. All results showed only a negligible weight loss, indicating high corrosion resistance. These results have meanwhile been proven at an industrial-scale installation where the ionic liquid was used for more than 17 months in continuous operation at temperatures between 150°C and 180°C. Since the start-up there has been no corrosion at the furnace shaft wall at all.

Non-flammable

When comparing the ionic liquid with thermal oils, as an example of a particular alternative cooling medium, the different high-temperature characteristics have to be emphasised. Some thermal oils which are defined as non-flammable will still burn once the oil temperature reaches and exceeds its ignition temperature. After ignition, burning cannot be stopped even when the energy source is removed. This is in stark contrast to the behaviour of IL-B2001. Once the energy source is removed, the decomposition stops immediately. Other oils, such as fluorinated oils, are truly non-flammable, but carry other risks such as having toxic decomposition products, as well as having a high cost.

Non-toxic, not harmful

As the ionic liquid is used at industrial scale in plants, it is highly desirable to have uncomplicated handling procedures, simultaneously guaranteeing the health and safety of the operators. In this context, all the information is collected and described in the manual as well as in the technical and safety data sheets and can be summarised as follows. The ionic liquid is REACH certified (registration number 01-2120086816-43-0000) and has a CAS number (143314-16-3). It is classified as a non-dangerous good, and can be stored and transported without any special restrictions except preventing contact with water and the open atmosphere. It shall not be classified as acutely toxic; the hazard class and category is 2, meaning skin irritating. IL-B2001 shall not be classified as hazardous to the aquatic environment; however, it is not biodegradable.

Broad operating temperature range

The operating temperature of the ionic liquid is 50–200°C, and hence the allowable temperature difference between inlet and outlet temperature of up to 150°C is advantageous in terms of energy recovery as well as operational practice. Cooling within this temperature range enables a somewhat adjustable intensity of cooling. A higher cooling element temperature can prevent the condensation of water vapour and, as a direct consequence, can minimize the risk of refractory hydration during heating up or due to leakages. Furthermore, a sufficiently high cooling element surface temperature avoids the formation of condensed corrosive compounds and dew point corrosion, respectively.

The fact that the IL-B2001 allows an outlet temperature of up to 200°C makes the process suitable to be combined with an energy recovery system for direct usage or power generation under feasible conditions. This high absolute temperature and the extensive temperature range permits energy recovery in an efficient way (by creating steam instead of warm water) rather than being lost. In the case of continuously provided energy, the possibility of energy recovery through an Organic Rankine Cycle (ORC) exists, such as the plant installed at Anglo Platinum in South Africa. Under these circumstances, primary energy resources can be saved.

Current developments point toward a slightly modified ionic liquid with an operating temperature range of -15 – 300°C. There are several tests running by now, and we are optimistic to introduce it into the market soon.

Energy removal and specific heat capacity

Considering properties such as heat capacity, heat transfer coefficients, Reynolds number, and Prandtl number, it may be assumed that the capacity for energy removal is less than that of a water-cooled system. But, comparing an IL-B2001 cooled application with the same application cooled by water, the entire system has to be taken into account.

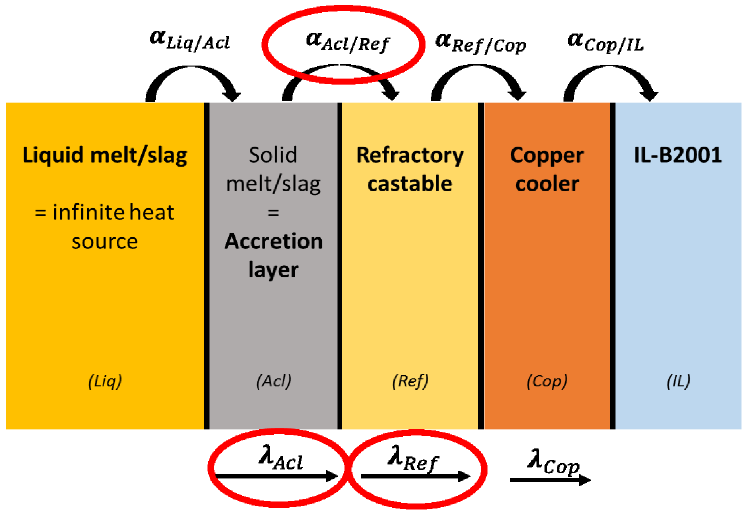

Figure 1: Schematic illustration of the different layers within the entire system in industrial-scale use within a copper cooling element

Figure 1 shows the different layers within the system melt – accretion layer – refractory – copper cooler – cooling medium, and the different heat transfer coefficients ($\alpha = W/m^2K$) and thermal conductivities ($\lambda = W/mK$). The amount of energy that will be removed from the melt depends on the heat transfer coefficients between melt and accretion layer, between accretion layer and refractory, between refractory and copper, and between copper and ionic liquid. Also, the thermal conductivities of the melt, the accretion layer, the refractory, the copper, and again from the IL-B2001, all influence the amount of energy removed from this system.

It is known from calculations, as well as laboratory-scale tests, that the limiting factors for energy transfer are the thermal conductivities of the accretion layer and the refractory, as well as the heat transfer coefficient between accretion layer and refractory (marked red in the picture). The limiting factor is neither the heat transfer coefficient between copper and IL-B2001, nor the thermal conductivity of the IL-B2001. Generally speaking, under steady-state conditions, a defined amount of energy will be transferred to the cooling medium, and has to be removed, independent of the cooling medium itself.

Considering the basic equation for energy flux

$$\dot{Q}[W] = \dot{m}\left[\frac{m}{s}\right] \cdot C_P\left[\frac{J}{gK}\right] \cdot \Delta T[K] \qquad [1]$$

it can be derived that, at the same cooling-medium velocity, the lower heat capacity value (C_P) compared to water (C_P for water is 4.17 J/gK) will result in a higher temperature or lower rate of energy transfer. However, this fact can be compensated for by the achievable higher temperature difference (typically 15–20°C in the case of water, but up to 150°C for IL-B2001). Also, the higher density of IL-B2001 compared to water helps to 'balance the equation' towards the same value for Q. On the other hand, an increase in cooling-medium velocity will also lead to the same level of energy removal.

A direct comparison between water and IL-B2001 as the cooling media within a given system was conducted with CFD (Computational Fluid Dynamics) modelling. A specially designed copper cooling element was taken into account. The geometry is shown in Figure 2.

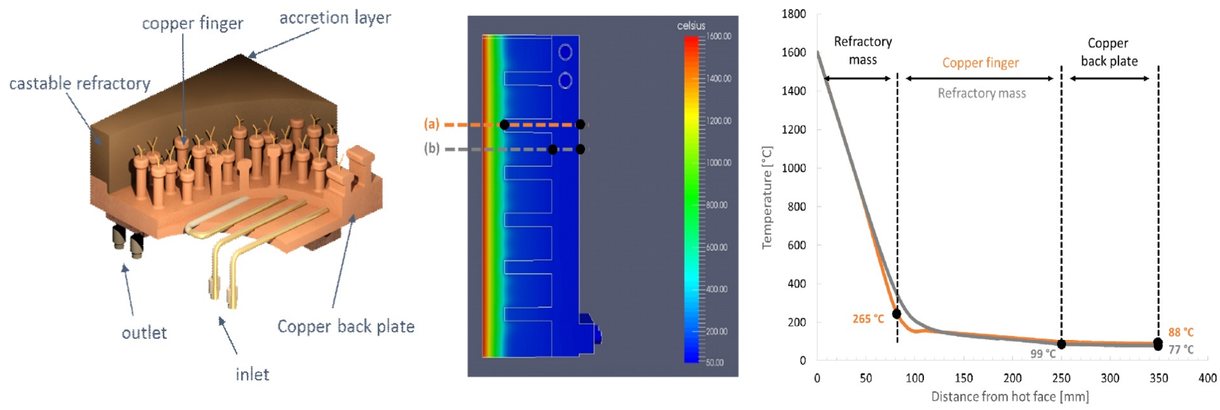

Figure 2: Special design of a composite furnace module cooling (CFM) element for creating a freeze lining (left); CFD modelling of the temperature distribution at a furnace temperature of 1600°C (middle); and the resulting steep temperature gradient within the refractory mass (right)

The calculation of the energy removed from this copper cooling element at a melt temperature of 1600°C revealed that, with this concept, the energy removal is sufficient, and the system is capable of creating a freeze lining. Compared to water, at the same steady-state boundary conditions, the energy removed per square metre is 3% lower for IL-B2001. This difference is a result of the different material properties between water and IL-B2001, namely Reynolds number, Prandtl number, dynamic viscosity, and others. Again, this decrease in energy removal might be compensated by an increase in cooling-medium velocity, if necessary.

High electrical conductivity
As the ionic liquid is by definition a salt, consisting of cations and anions, the electrical conductivity is several orders of magnitude higher than that of water.

Stable, non-consumable
In contrast to other cooling media, IL-B2001 shows no ageing phenomena whenever the cooling circuit is closed and the liquid does not come into contact with water or the open atmosphere. Even the exposure to strong magnetic fields, or high voltage or current ranges, does not affect the properties of the liquid. This makes it a non-consumable good.

ILTEC TECHNOLOGY – HARDWARE AND FEATURES

A fundamental characteristic of ILTEC is the application of a closed-circuit loop for the ionic liquid – the primary cooling circuit. The prevention of any contact between the ionic liquid and water and/or air makes IL-B2001 a non-consumable, as mentioned before. Experiences over the past years have proven that IL-B2001 does not change its original properties. The basic design and required equipment of the ILTEC cooling technology remain more or less the same for each application, whereas the details, especially the supply capacity of the cooling medium and the dimensioning of the component parts, are individually tailor-made to meet customer-specific demands.

A typical design of an ILTEC facility is shown in Figure 3, and the main components thereof can be summarised:

- Tank filled with IL-B2001; the freeboard volume above the liquid level is purged with nitrogen to prevent absorption of water through moisture in the air
- Two identical pumps (one for redundancy in case of breakage or malfunction) guarantee the flow of the IL through the entire pipe system
- Two heat exchangers for transferring the energy to the secondary cooling circuit (one in operation, one for redundancy)
- Numerous measuring devices (digital as well as analogue) throughout the entire system, to measure temperature, flow, pressure, and differential pressure
- Variety of valves, adjusting wheels, and shut-off devices for all different operational modes

Depending on the application, additional cooling circuits can be implemented.

Figure 3: Basic design of an ILTEC system, as installed at ArcelorMittal Bremen GmbH in Germany (left); and photograph showing the optical appearance of the ionic liquid IL-B2001

New safety standards – becoming Best Available Technology (BAT)
It is a sad reality that, from time to time, accidents do happen in the metallurgy industry, as well as in other industries facing hot temperatures and using water as a cooling medium. When exchanging water with IL-B2001, its superior properties can result in an explosion-free environment that allows cooling in a safe and sound manner.

The two diagrams in Figure 4 show the path of becoming best available technology (Filzwieser *et al.*, 2014). The fact that accidents and incidents happen cannot be changed by substituting water as the cooling medium; the likelihood remains at the same level. But, in the case of accidents in metallurgical plants, the consequences are of a very severe nature. Whereas the environmental impact might be limited to the operating area, the economic damage can be massive because of the production loss. However, there is a high chance of fatalities that makes the risk of such a kind of accident (marked as a black dot) very close to the border of 'non-acceptable risk'.

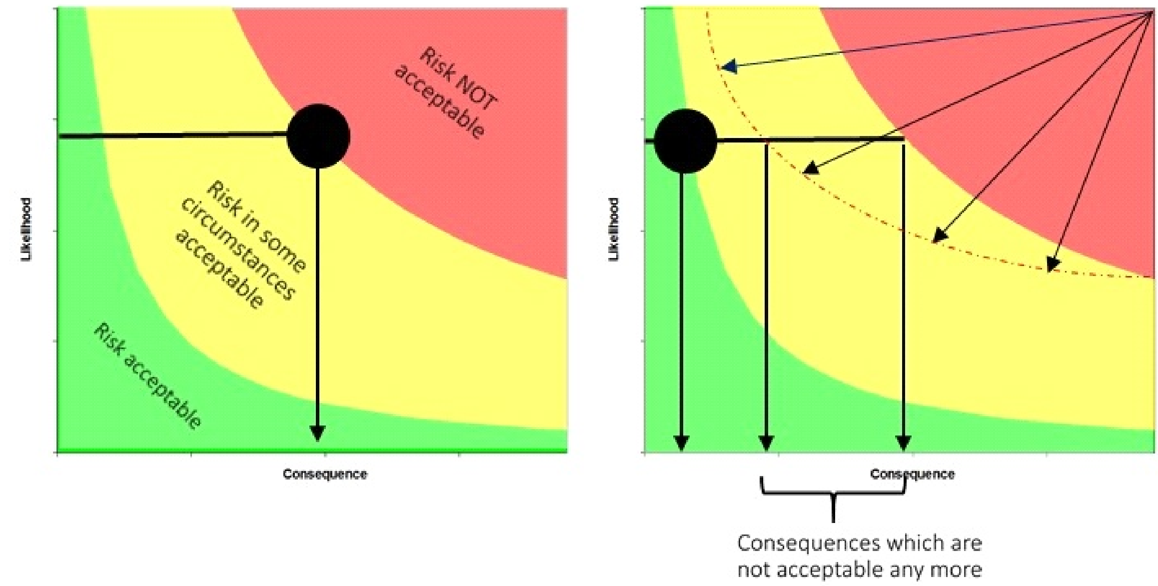

Figure 4: 2-dimensional risk analysis of a state-of-the-art water-cooled area (left); and using the ionic liquid as cooling medium (right) (Filzwieser *et al.*, 2014)

If ionic liquid is used in place of water as a cooling medium, the potential for damage decreases dramatically. Due to the absence of explosions, economic, environmental, and personal damage will be substantially decreased. As shown on the right side of Figure 4, this results in a move towards a more acceptable level of risk.

Due to the fact that there is a much safer alternative available to water cooling, the acceptance of water cooling – with its risk of injuring employees – will decrease, and finally water cooling will not be tolerated any more, particularly in high-risk areas such as tap-holes, *etc*.

OUT OF THE BOX – EXAMPLES FOR APPLICATION

With all the described facts, properties, and advantages of the ionic liquid IL-B2001 and the ILTEC Technology, an immense field of possible applications opens up. A few of these possibilities are briefly discussed below, thereby providing some inspiration.

Tap-hole cooling – New safety standards at ArcelorMittal, Bremen, Germany

Every tapping area is a highly stressed furnace section, mainly because of the intense heating coming from the hot liquid phase, as well as its erosive behaviour during material discharge. In addition, the temperature variation in between each furnace cycle is a major stress on the refractory lining. The mechanical stress and erosion results in high wear of the tap-hole refractory; to increase their lifetime, tap-holes are partially water cooled.

At ArcelorMittal Bremen GmbH in Germany a water-cooled tap-hole was converted and equipped with an ILTEC system by Mettop, in order to increase safety. This system has been running on a blast furnace since autumn 2015. Figure 5 shows the geometry and the calculated temperature distribution during tapping.

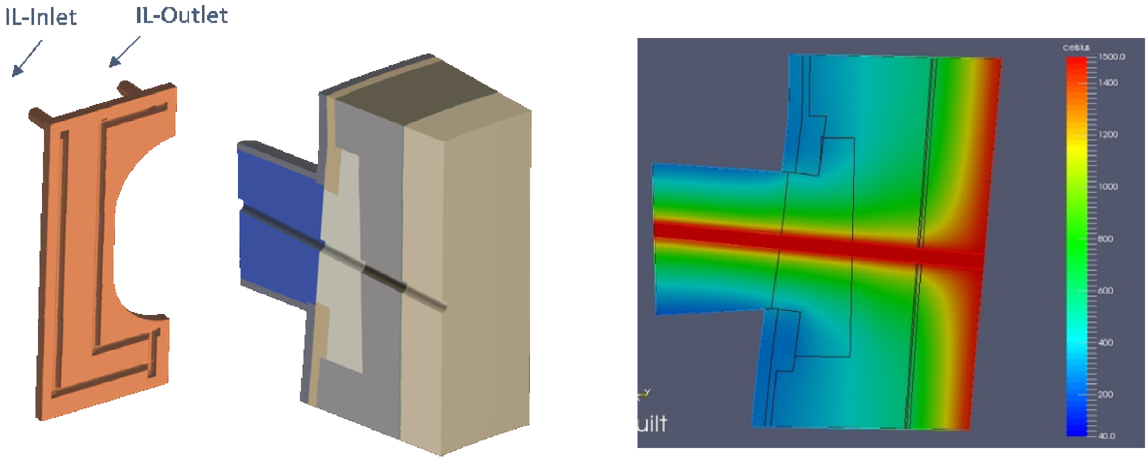

Figure 5: Special design of the cooled tap-hole with the copper-cooled back-plate mounted upon the steel shell (left and middle), and CFD modelling of the temperature distribution during the tapping of hot metal

In most cases, the cooled area is limited to the area near the steel shell, instead of reaching close to the hot face of the refractory, due to safety concerns with water. With the new ILTEC cooling technology, this existing state-of-the-art design can be reconsidered. This also applies for all electric furnaces as applied in the ferro-alloy industry.

Side-wall cooling – Increasing furnace availability

The basic concept of the high-intensity cooling elements in conjunction with the cooling medium IL-B2001 for cooling electric arc furnace side-walls is a freeze lining concept – also at and below the metal bath level.

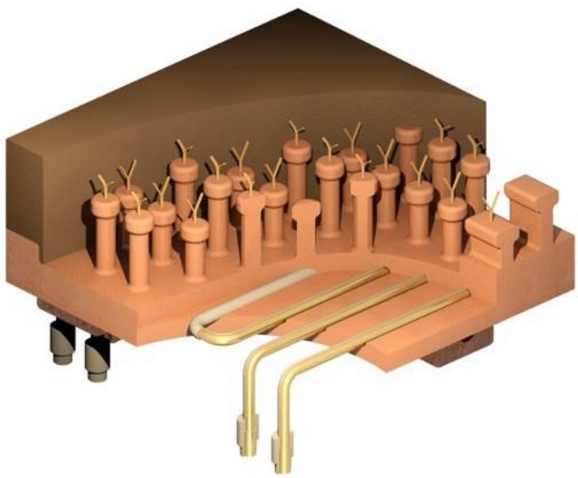

Figure 6: Illustration of a CFM cooler

This freeze-lining concept is attributed to the fact that the amount of energy removed is high enough to create a frozen slag/metal layer upon the castable refractory. The slag/metal bath is locally (at the contact face between melt and castable refractory) cooled to such an extent that the temperature of the liquid falls below the liquidus temperature. Consequently, a solid slag/metal layer is formed.

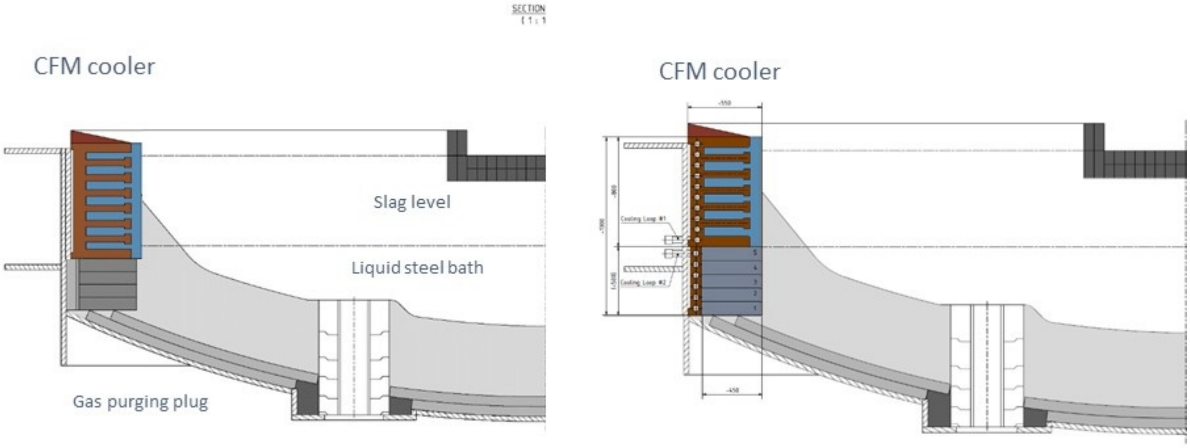

Figure 7: Different opportunities for installation of a high-intensity cooler within the side-wall of an EAF. Left: installation of the cooler only at the slag line. Right: slag-line cooling with CFM elements and cooled copper plate behind the brick lining at the lower part

Once this slag/metal layer is created, there is no further wear and consumption of the refractory material at steady state, as an equilibrium is established between melting of the frozen layer and freezing of a new layer.

The special cooler design, as shown in Figure 6, and the different possibilities of applying this high-intensity cooler with the side-wall of an EAF are presented in Figure 7. From the CFD modelling, it is known that a steep temperature gradient can be achieved within the refractory material, for creating an accretion layer on the surface. Also known from the CFD modelling is that energy transfer of more than 300 kW/m^2 can be realised.

Cooling of off-gas systems – Adjustable cooling and energy recovery

For preventing corrosion problems, a variety of different off-gas duct designs can be cooled with IL-B2001 instead of water. With the implementation of ILTEC, two advantages can be combined:

On one hand, there are often corrosion problems within the off-gas ducts, caused by the temperature decrease during downtime. Water, as a cooling medium, cools the duct to a great extent, and the off-gas temperature might fall below the dew point of different corrosive media within the off-gas (sulphur-containing components, halogens, *etc.*). Condensation of parts of the off-gas lead to corrosion and decreased availability of the off-gas duct. This phenomenon can be prevented by the operation of a higher inlet and outlet temperature, at or above 180°C for the cooling medium, which will prevent condensation of water vapour or acidic components.

On the other hand, with an increase of the cooling-medium outlet temperature to about 200°C, much of this energy can be recovered efficiently.

Shaft furnace wall and heat exchanger cooling – Eliminating corrosion problems

One immense benefit of using a cooling medium at a temperature of up to 200°C, is the possibility of adjusting the operating temperature with the refractory lining. This helps wherever problems arise with hydration or corrosion, due to surface temperatures below the dew point.

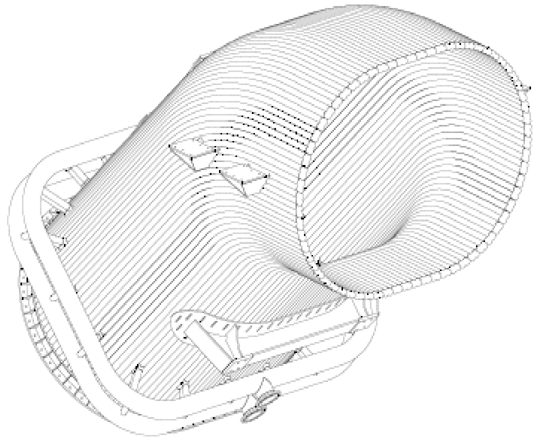

Figure 8: Water-cooled part of the off-gas duct of an EAF

One well-known problem in non-ferrous metallurgy is the formation of sulfuric acid in the off-gas of processes treating sulfur-containing raw materials. In conjunction with the almost-always existing moisture of the raw materials and concentrates, there is a chance of forming gaseous sulfuric acid (H_2SO_4) as a result of the reaction between H_2O and SO_3. Depending on the composition, prevailing water vapour and sulphur content, as well as the temperature and pressure profile, a certain amount of acid gas ascends within the furnace uptake. During the ascent, the sulfuric acid-containing gas comes into contact with the cooled side-wall. With the surface temperature of these cooled walls potentially being below the dew point, the acidic vapours start to condense as sulfuric acid on the refractory material or steel shell. This then causes an accelerated material destruction through corrosion.

An installation to cool the furnace walls of a plasma furnace was completed at the beginning of 2015, and is in operation at Nyrstar in Høyanger, Norway. Due to a change in the input material mix, water as the cooling medium resulted in equipment corrosion due to temperatures below the dew point of sulfuric acid. These circumstances could be eliminated by replacing water with IL-B2001, and operating at elevated temperature.

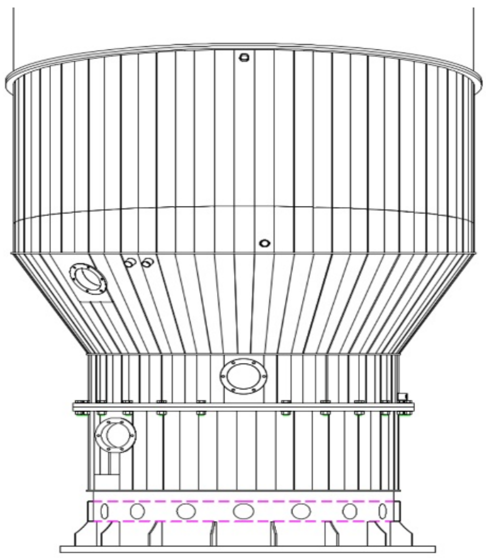

Figure 9: Construction drawing of the shaft furnace where cooling of the lower part of the shaft is realised with ILTEC technology

An increase of the inlet temperature from 3°C (water) to 150°C (IL-B2001), and an increase in outlet temperature from 13°C (water) to 180°C (IL-B2001) totally eliminated this phenomenon. Ever since the commissioning in January 2015, the furnace has been in operation without the necessity for a furnace wall replacement.

Additional application areas for ILTEC

This revolutionary new approach allows cooling of areas where safe water-cooling was difficult to imagine, creating new solution paths. See an overview of possible application areas in Table II.

Table II: Application areas for ILTEC in the metals industry

Application ILTEC in the metallurgical industry		
Iron making	Blast Furnace	Tap blocks/runners, tuyers, cooling elements, bottom cooling, instruments, energy recovery
	Coke ovens	Heat exchangers
	Rotary hearth furnace	Discharge screw cooling, energy recovery
Steel making	EAF	Bottom, side wall, roof, off-gas ducts, burners and injectors, energy recovery
	BOF	Cooled lances, instuments, off-gas, energy recovery
	AOD, RH degassing, VOD/VD	Sidewall tuyers, nozzele and flange cooling, various parts
	Casting, hot and cold rolling	Inductive heating, hydraulic units, shear, tunnel furnace, annealing, heat treatment, hearth and pusher furnaces, zinc pot
	Induction furnace and equipment	Coil cooling
Ferro alloys	Electric furnace	Sidewall, roff, bottom, tap blocks, runners, high current lines, instruments
Non-ferrous metals and e-waste recycling	Primary smelter, TSL, Flash furnaces, PS converter, electric furnaces	Sidewall, lance, instruments, tap holes, under bath tuyers

BUSINESS CONCEPTS AND COMMERCIAL ASPECTS

ILTEC technology improves safety in certain areas. This will have a positive influence on insurance policies. Furthermore, SMS is prepared to offer complete service packages, and can also offer financing models for the proposed systems.

CHANGE OF AN INDUSTRY – SUMMARY AND OUTLOOK

This paper describes the opportunity to increase furnace safety and operational efficiency by a commercially proven alternative cooling method. In addition, the use of an ionic liquid coolant substantially improves the operation economically, by increasing the lifetime of the refractory lining, and preventing corrosion, while offering the potential for high-quality energy recovery.

The described examples demonstrate that it is possible to employ the new cooling technology as an alternative, replacing water in existing cooling circuits for different reasons. The replacement of the water in a tap-hole is driven more-or-less exclusively by safety considerations. The approach of replacing the water in the side-wall cooling, combined with a new design of the cooler of an electric arc furnace (for example), is driven by the increase in lifetime of the refractory, and an increase in furnace availability.

This technology is, however, not limited only to these specific applications, but could be used in multiple other applications where cooling with water is not possible mainly due to safety reasons. ILTEC could become the Best Available Technology (BAT) for cooling in the future. One important future trend, in terms of a cost-efficient and environmentally friendly operation mode, is the inevitable improvement in the use of waste energy. The higher outlet temperature and higher temperature difference between inlet and outlet make IL-B2001 a very desirable cooling medium for high-quality energy recovery. The cooling-medium at a temperature of up to 200°C can be used either for conversion into electricity or as direct heating.

REFERENCES

Filzwieser A., Konetschnik S., Filzwieser I., Wallner S., and Preiss R. 2014. Mettop's new cooling technology is the safest way to cool a furnace, *COM 2014: 53rd Annual Conference of Metallurgists*, Vancouver, Canada, 28 September – 1 October 2014, Paper No. 8622.

IoLiTec: Wärmeträgermedien, Thermofluide. http://www.iolitec.de/Warmespeicherung-Transport/waermetraegermedien-thermofluide.html (accessed on 20 March 2013).

Joglekar H., Rahman I., and Kulkarni B. 2007. The path ahead for ionic liquids, *Chemical Engineering Technology*, No.7.

Oterdoom H.J. 2014. Furnace Explosions with a Focus on Water, *COM 2014: 53rd Annual Conference of Metallurgists*, Vancouver, Canada, 28 September – 1 October 2014, Paper No. 8647.

Verscheure K., Kyllo A.K., Filzwieser A., Blanpain B., Wollants P. 2006. Furnace cooling technology in pyrometallurgical processes, *Sohn International Symposium: Advanced Processing of Metals and Materials, Proceedings Non-Ferrous Materials Extraction and Processing, Volume 4*.

Voermann N., Ham F., Merry J., Veenstra R., and Hutchinson K. 1999. Furnace cooling design for modern, high-intensity pyrometallurgical processes, *Copper 99 – Cobre 99: Proceedings of the Fourth International Conference, Vol. V, Smelting Operations and Advances*, Phoenix, Arizona, USA, October 1999, Edited by D.B. George, W.J. Chen, P.J. Mackey, and A.J. Weddick, TMS, Warrendale, PA, pp.573-582.

Wallner S., Filzwieser A., and Kleicker J. 2003. Some aspects for the use of water cooled furnace walls – Water the best refractory?, *Proceedings of the International Copper Conference*.

Wasserscheid P. and Welton T. 2008. *Ionic liquid in synthesis*, Volume 1, Wiley-VCH Verlag GmbH & Co. KGaA., Weinheim, Germany.

Rolf Degel

Vice President Non Ferrous Metals, SMS group GmbH

Rolf holds a PhD in Ironmaking from the RWTH Aachen, Germany, where he worked until 1996. He was Project Manager and Head of R+D for NSM in Thailand until 1998; Senior Sales Manager Iron Making and Ferro Alloy Technologies for SMS group in Pittsburgh until 2001; and Head of Submerged Arc Furnace department for SMS group in Düsseldorf until 2015. He is currently Head of the Non Ferrous Metals Department of SMS group in Düsseldorf, Germany, and a Board Member of PolyMet Solutions in Leoben, Austria.