MARTINA B. HANEL[1], ANDREAS FILZWIESER[1], IRIS FILZWIESER[1], STEFAN WALLNER[1]

BYPASSING PROBLEMS RELATED TO WATER COOLING – A CASE STUDY FOR APPLYING ILTEC IN A 100t EAF

Abstract

With the innovative ILTEC Technology, Mettop´s patented water-free cooling solution, it is possible to overcome the disadvantages of water as a cooling medium by using the perfect alternative, the ionic liquid IL-B2001. The main characteristics, that make IL-B2001 so favourable, are the negligible vapour pressure, the wide temperature operation range from 50-250 °C and the not-flammable, non-explosive and non-toxic behaviour.

Based on the example of a 100t EAF, the various different application fields of ILTEC are clearly pointed out, from the bottom vessel and upper shell to the off-gas part of the furnace. In this context, different possibilities of installing ILTEC facilities will be explained. In order to highlight possible saving potentials, the economic advantages of increased furnace availability via improved cooling solutions will be mentioned. By showing different damage scenarios, the benefits of increased safety will be emphasised and the positive impact of a change to ILTEC discussed.

It is the well-engineered technology and the sophisticated process control that prevents damage and enables immediate leak detection in the first place, combined with the outstanding properties of IL-B2001 in case of failure or leakage, that make ILTEC create new pathways towards safe and effective cooling.

Keywords

Water-free cooling, improved safety, increased furnace availability, novel cooling options, ILTEC

1. Introduction

All different metallurgical furnaces and aggregates that deal with high temperatures have in common, that they need a powerful cooling system, since temperatures from 800 up to 2000 °C are required for the production of metals. Worldwide, industrial scale cooling systems predominantly operate with water. This is mainly due to the high thermal conductivity and the convenient availability of water, making it broadly used and favourable. However, water also has several disadvantageous characteristics [1-3]. Due to its restriction to a maximum operation temperature of 60 °C and the risk of explosion - both due to volume expansion and possible hydrogen explosion - the cooling medium water can even cause severe dangers.

On taking a closer look at the safety issues it has to be noted, that due to water damages - especially in the field of highly stressed areas – several fatal accidents occur every year worldwide [4,5]. This was the main motivation to rethink the existing cooling systems in metallurgy and to finally develop the innovative “cooling with ionic liquids” concept. This

Mettop GmbH, Peter-Tunner-Str. 4, 8700 Leoben, Austria

water free cooling concept has now been approved in industry for several years and hence the possible application and resulting advantages with an EAF are discussed here.

Since it is well known that there are multiple reasons for damage caused by leaking of water within the different parts of the EAF, it is of superior interest to eliminate water as the cooling medium: within the upper shell, hydration of the refractory material, caused by small leakages in the side wall cooling panels that lead to molten steel perforation, can occur. In off-gas parts, cooler perforation due to corrosive off-gases can take place. Hot spots within the sidewall of the refractory lining in the bottom vessel, leading to additional down-time causing production losses, are a problem that can be solved. Not to forget the priceless benefit of a safe workplace.

2. Water-free cooling – Characteristics of the ILTEC Technology

With the novel ionic liquid cooling technology virtually all negative effects of a water cooled system are eliminated and even additional benefits can be provided. 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 melt or slag. Furthermore, the temperature range for cooling a system is much wider than water. An additional benefit resulting from this relatively high cooling medium temperature is the fact that hydration and corrosion problems are avoided.

The ILTEC Technology is characterised by the following:

- Instead of water the ionic liquid IL-B2001 is being used as cooling medium
- IL-B2001 is liquid at room temperature and can be used at a maximum operating temperature of up to 250 °C (on a short term basis, 200 °C on long term)
- In case of a leak in the cooling system, the IL-B2001 will disintegrate into its components without a sudden increase in volume and without the formation of hydrogen. There will be no explosion when getting in contact with liquid metal, and so work safety can be guaranteed
- No cooler corrosion problems will occur, as the IL-B2001 can be used at higher temperatures (above the dew point of the exhaust gases)
- Due to the higher temperature (up to 250 °C), the dissipated heat can be recovered. This advantage will play a particularly important role in the future, not only in case of local legal requirements
- Novel approaches to cooling beneath bath levels or at highly stressed areas because of the lack of explosive reactions and damage in case of leakage

Overall it is of utmost importance for industrial applications, that the requirements regarding critical heat flux, thermal limits and impacts of health, safety and environment are being fulfilled. Research activities, and even more commercial operations, have proven that the ionic liquid IL-B2001 and the ILTEC Technology can lead to an industrial change regarding safety standards by becoming the new best available technology (BAT) [2,6,7]: When substituting water by the ionic liquid damages will decrease dramatically. Due to the lack of explosions the economic damage, the environmental damage and finally the personal damage will be substantially decreased and the area of acceptable risk (compare the two graphs in **Figure 1**) will move towards lowering the acceptability of consequences.

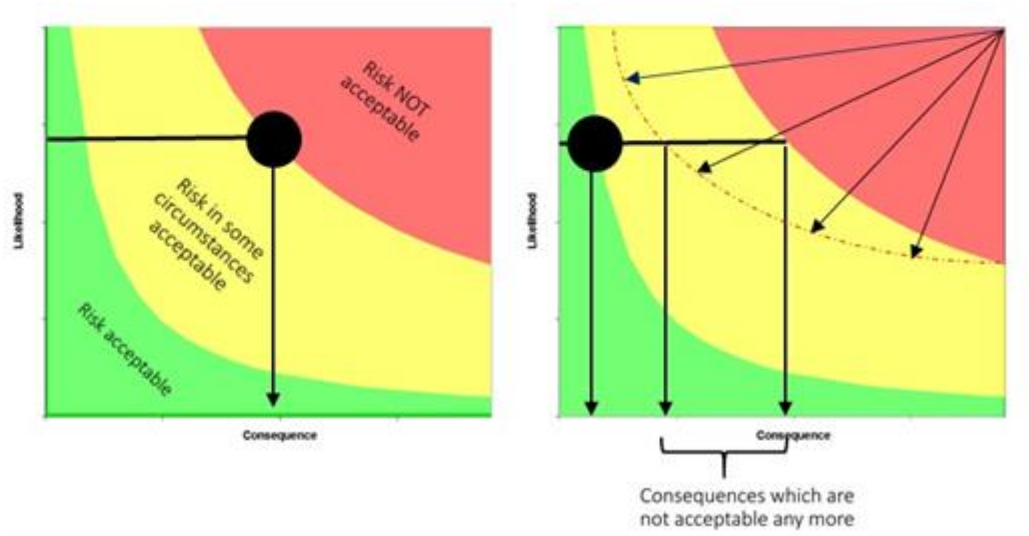

Figure 1 – 2-dimensional risk analysis of a state of the art water cooled area (left) and using the ionic liquid as cooling medium (right) [8]

3. IL-B2001 – The ionic liquid at a glance

Basically, ionic liquids are salts, meaning that they consist solely of anions and cations. Caused by their poorly coordinated ions, many of them are liquid even at room temperature [9-11]. After years of intensive research, the most optimised ionic liquid for the use as a coolant was developed.. The main properties of this special and unique ionic liquid, with the trade name IL-B2001, is given in the table below.

Table 1 - 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/dm^3]	50 – 200 °C
Heat capacity	c_p	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

The positive properties, that make IL-B2001 perfectly suitable as a cooling agent, can be emphasised as follows:

- Broad operation temperature range
- Non-explosive, non-flammable
- High electrical conductivity
- Relatively low viscosity
- Non-corrosive due to chlorine free production procedure
- Non-toxic, not harmful
- Sufficient heat removal
- No altering, non-consumable

4. 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 not consumable good. Experiences over the last years have proven, that IL-B2001 does not change its original properties. The basic design and the required equipment of the ILTEC cooling technology remain more or less the same for all application. Specific details however, especially the supply capacity of the cooling medium and the dimensioning of the component parts, are tailor-made to meet individual customer-specific demands.

An exemplary design of an ILTEC facility is given in **Figure 2** and the main components can be summarised:

- Storage tank to hold the entire amount of IL-B2001, the freeboard volume above the liquid level is purged with nitrogen in order to prevent absorption of water through moisture in the air
- Two identical pumps (one for redundancy) guarantee the flow of the IL through the entire pipe system
- Two heat exchangers to remove the heat 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 operation modes
- Depending on the application, a distribution unit close to the cooling application might be part of the system

Figure 2 - Basic design of an ILTEC system (left) and photo of the optical appearance of the ionic liquid IL-B2001

By using this basic hardware, water free cooling of all different areas within the electric arc furnace can be realised. However, the following numbers for the different layouts and dimensioning of the ILTEC facilities are only estimates based on different customers´ data. For each specific application, a detailed feasibility study will be conducted to determine the most optimised solution.

5. Application within an 100t EAF – Upper shell cooling to increase safety

When thinking of cooling the shell of an EAF, the main design the side walls are welded steel pipes, only few furnaces have casted copper cooled parts. However, in both cases the cooling medium water can be substituted by the ionic liquid IL-B2001 and the multiple benefits can be highlighted:

- Increased safety because of a water-free furnace area
- Decreased damage in case of leakage due to the lack of volume expansion and explosion
- Fast leak detection in case of individual supply and supervision of each panel
- Avoidance of hydration of refractory of the bottom vessel in case of leakage
- Easy, fast and safe repair work in case of breakage

Considering a 100t EAF, there are different approaches to realise ILTEC cooling for the entire upper shell. In **Figure 3** the flow sheets of two different possible solutions are given and discussed. One option is (left flow sheet) a simple substitution of the cooling medium within the existing piping system can be conducted, in this case one single supply line pumps the IL-B2001 from the storage tank to the ring distribution unit at the furnace. In this way the supply of the individual cooling panels is realised. Having passed the panels, the cooling medium is recollected and transported to the heat exchanger unit in one single line.

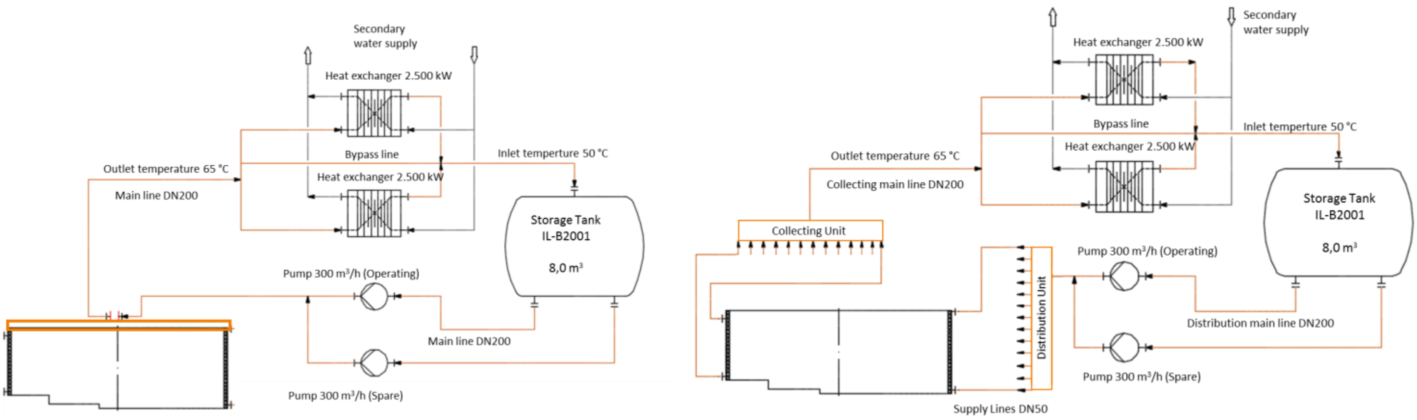

Figure 3 - Different approaches for ILTEC Technology in the upper shell of an EAF: cooling of all panels with one main supply line and a ring distributor (Option 1 - left side) and individual supply of each single cooling panel (Option 2 - right)

The other option, a technically more sophisticated approach of supplying each cooling panel (or unit which might be a serial alignment of panels) with an individual line, is shown in the right flow sheet. The transportation of the cooling medium near the furnace is again implemented by a large supply line, but in this case the distribution unit divides the total flow in individual supply lines with smaller diameter. Each single supply line is equipped with flow, temperature and pressure measuring devices to supervise the operating condition.

For both examples, the cooling performance of the entire facility (for average values) will be calculated based on the precondition as given by the customer. For one specific case the dimensions and the capacity of these two different options can be summarised as given in **Table 2.**

Table 2 – Basic numbers of different layouts for cooling the upper shell of the EAF

	Option 1	**Option 2**	Unit
Supply lines cooling panels	1	18	---
Total flow rate IL-B2001	300	300	m^3/h
Temp. difference average (peak)	15 (30)	15 (30)	°C
Cooling load average (peak)	2500 (5000)	2500 (5000)	kW
Inlet temperature IL-B2001	50	50	°C
Outlet temperature IL-B2001 (peak)	65 (80)	65 (80)	°C
Amount of IL-B2001	6500	8700	kg

The mayor difference of these possible options is the more sophisticated supervision possibilities of individual supply lines vs. complexity of the system and amount of IL-B2001. Therefore, an optimised mixture (for example 5 supply lines for a quarterly merging of the furnace circumference) can be regarded, always depending on the customer's needs.

6. Application within an 100t EAF – Bottom vessel cooling for an increased lifetime

With the possibility to provide a cooling solution with more than sufficient heat removal AND a perfectly safe operation mode, a totally new approach of cooling the bottom vessel can be realised. Since there is no danger in case of leakage, cooling the refractory beneath bath level can contribute to a tremendous increase in lifetime and lead to decreased production costs and increase of furnace availability. The benefits of cooling beneath bath level can be summarised:

- Intensified cooling – steep temperature gradient, less infiltration zone
- Less wear – increased lifetime of refractory
- Decreased down time – more productivity
- Decreased repair work/gunning – lower production costs
- Increased safety for employees and systems
- Increased inner furnace diameter by decreasing refractory thickness

The installation of cooling beneath the bath level can technically be realised in different ways. There is a simple implementation of a cooled copper plate (comparable to staves) within the brick lining, for example by the substitution of the insulation layer or a decrease in thickness of the brick lining, as given on the left side of **Figure 4.**

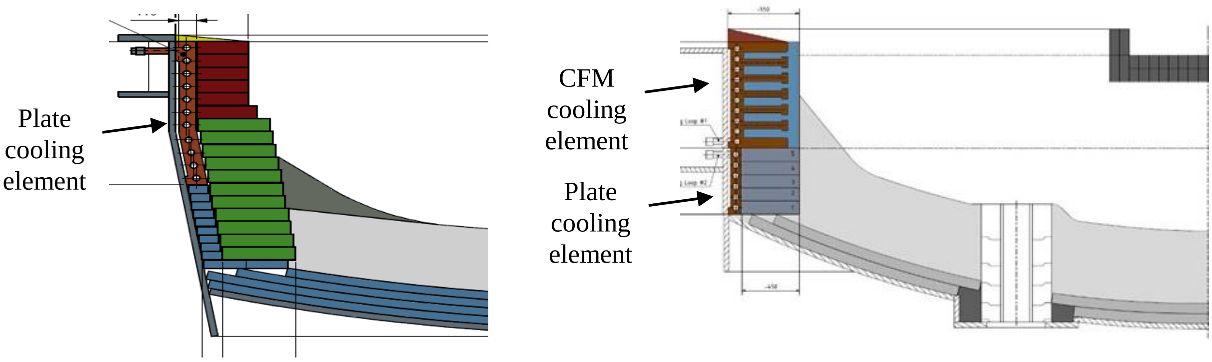

Figure 4 – Different possibilities for installation within the lower part of the EAF, left: installation of a plate cooling element between steel shell and brick lining, right: example of a high intensity cooler (CFM) combined with a copper plate cooler at the lower part

As a result, for the best possible cooling performance, the coolers themselves should in any case be part of the concept. Beside a conventional copper cooling plate in-between the steel shell and the brick lining, a solution with high intensity coolers can further improve the refractory resistance and increase the lifetime of the vessel. In **Figure 4** two different installation scenarios are given. The so-called CFM cooling elements (Composite Furnace Modules, which consist of a combination of a casted copper cooler and the refractory mass casted upon it) are installed to more or less replace the brick lining. Due to the intensified cooling performance, the formed accretion layer produced by the intense heat removal, leads to a non-wear steady-state condition [12-14].

For the subsequent estimation with regards to the capacity and dimensions of the ILTEC Technology for cooling the bottom vessel, two different cases are shown, Option 1 for copper plates and Option 2 for CFM cooling elements. On considering copper plate coolers, the heat removal might be lower, caused by the isolating brick lining in front of the cooler. As peak values always the double portion of the average value is considered. However, the CFM cooling elements are capable of up to 400 kW/m^2 cooling performance as peak level, because of the design and improved contact between copper cooling fingers and the refractory [12,15,16]. Therefore the facility´s layout is designed for 200 kW/m^2 heat removal in average.

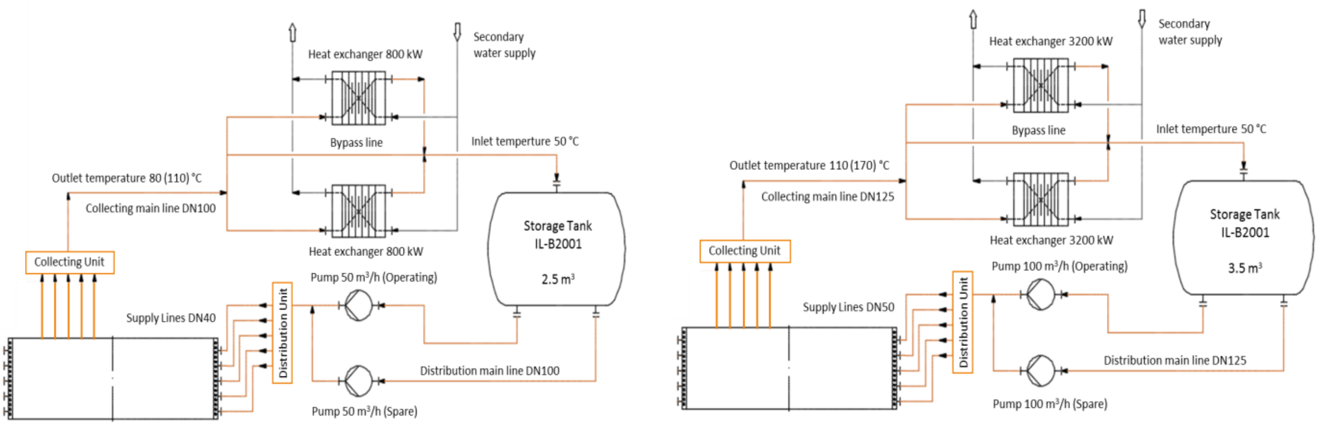

Figure 5 – ILTEC Technology for cooling the bottom vessel with 5 independent supply lines, Option 1 (left) with copper cooling plates and Option 2 (right) with high intensity CFM coolers

Compared to the case of the upper shell, always two panels are connected (serial array). Based on the assumption of average heat removal values, the capacity of the facility is given as summarised in **Table 3.** There are differences in capacity for the entire pumping and piping system (50 and 100 m^3/h IL-B2001) but also regarding the maximum cooling performance of the entire lower furnace part at full load (at simultaneous use of both heat exchangers) of 1600 and 6400 kW.

Due to the higher capacity, the piping dimensions for the high intensity CFM coolers have to be larger, also due to the larger amount of IL-B2001 needed. Still this is only a theoretical approach for this comparison and has to be adapted for each specific case after a detailed study and analysis of the actual state-of-the-art situation on site.

Table 3 - Basic numbers for cooling the bottom vessel of the EAF

	Option 1 (plate cooler)	**Option 2 (CFM cooler)**	Unit
Supply lines cooling panels	5	5	---
Average (peak) heat removal	**50 (100)**	**200 (400)**	**kW/m^2**
Total flow rate IL-B2001	50	100	m^3/h
Temp. difference average (peak)	30 (60)	60 (120)	°C
Cooling load average (peak)	800 (1600)	3200 (6400)	kW
Inlet temperature IL-B2001	50	50	°C
Outlet temperature IL-B2001 (peak)	80 (110)	120 (170)	°C
Amount of IL-B2001	2800	4000	kg

With the novel approach of cooling beneath bath level, a notable increase in lifetime of the furnace is achieved, that leads to a reduction of production costs at different stages: less down time for repair and exchange of refractory and decreased costs for refractory material due to less gunning and less refractory wear. Intensified cooling at highly stressed areas (for example near the burner/injector or near an eccentric tap hole) can lead to a debottlenecking of those areas. Furthermore, with a better cooling performance a decrease of the overall refractory thickness can be realised leading to an increase in hearth diameter for even more production.

7. Application within an 100t EAF – Off-gas duct for heat recovery

One immense benefit of using a cooling medium at a temperature of up to 200 °C, is the possibility to increase the operation temperature within the refractory lining to some extent. This can eliminate problems arising from hydration or corrosion due to surface temperatures below the dew point (e.g. sulfuric acid formation at presence of sulphur-containing gases). Even more, when considering the huge amount of energy and heat that is lost within the off-gas, the higher temperatures of 200 °C can be directly used for heat recovery.
Benefits of exchanging water in the off-gas duct:

- Heat recovery due to outlet temperature of up to 200 °C
- Bypassing corrosion problems in cold spots
- Increased safety for employees and systems (no water in the furnace in case of leakage)

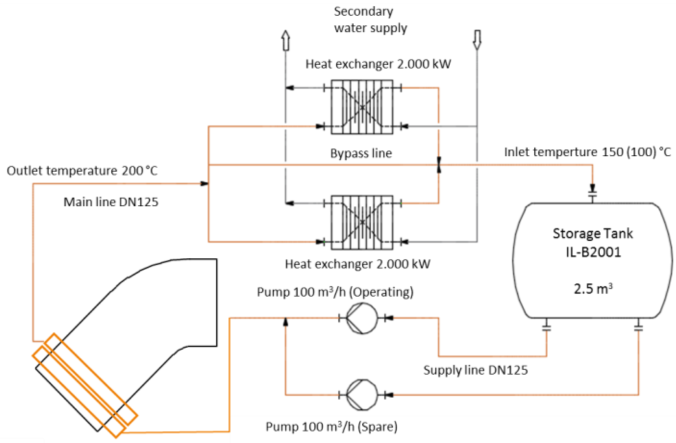

Figure 6 - Dimensions of the ILTEC facility for cooling the off-gas duct

In **Figure 6** the flow sheet and in **Table 4** the dimensions of the facility are given, based on a heat load peak value of 200 kW/m^2. For this system, as shown in the figure, a simple replacement of water as the cooling agent has been taken into account. It can be calculated that at 100 kW/m^2 the overall heat load is 2000 kW. To optimise the heat recovery a frequency controlled pump can be used and the flow rate and therefore the cooling effect can be controlled by the outlet temperature of the ionic liquid. This value can be set at 200 °C to guarantee the most efficient heat recovery.

Table 4 - Basic numbers for cooling the off-gas duct the EAF

		Unit
Supply line	1	---
Total flow rate IL-B2001	variable	m^3/h
Temp. difference (peak)	50 (100)	°C
Cooling load average (peak)	2000 (4000)	kW
Inlet temperature IL-B2001 (peak)	150 (100)	°C
Outlet temperature IL-B2001	200	°C
Amount of IL-B2001	2800	kg

In addition, a combined cooling of off-gas duct and roof part can be taken into account.

8. Summary and Outlook

The current paper describes the opportunity to increase furnace safety and operation efficiency by implementing an industrially-proven alternative cooling method. In addition, it demonstrates the substantial economic improvement by highlighting the increased lifetime of refractory lining and the potential of heat recovery.

The given applications for the EAF demonstrate the many possibilities to employ the new cooling technology as an alternative to water in existing cooling circuits for different reasons. The replacement of water in the upper shell is more or less initiated by safety considerations. The approach of implementing cooling within in the side walls beneath bath level, combined with a new design of coolers, is driven by the increase in refractory lifetime and an increase in furnace availability.

However, this technology is not only limited to the given examples, but can also be used in multiple other applications where water cooling is not possible due to safety reasons, making it best available technology (BAT) in the future.

An important future trend in terms of a cost-effective and environmentally friendly operating mode inevitably leads to a better utilization of waste heat. The higher outlet temperature and the higher temperature difference between inlet and outlet make IL-B2001 the perfect cooling medium for effective heat recovery. The temperature of up to 200 °C of the cooling medium can either be used for conversion into electricity or as a direct heating agent.

9. References

[1] K. Verscheure, A.K. Kyllo, A. Filzwieser, B. Blanpain, P. Wollants, Furnace cooling Technology in Pyrometallurgical Processes, Sohn International Symposium: Advanced Processing of Metals and Materials, Proceedings Non-Ferrous Materials Extraction and Processing, Volume 4 (2006)

[2] S. Wallner, A. Filzwieser and J. Kleicker, Some aspects for the use of water cooled furnace walls -Water the best refractory? Proceedings of the International Copper Conference, (2003)

[3] N. Voermann et al., Furnace Cooling Design for Modern, High-Intensity Pyrometallurgical Processes, Proceedings of the 4th Int. Conf. Copper 99, Vol. V: Smelting Operations and Advances, (1999), p. 573
[4] H.J. Oterdoom, Furnace Explosions with a Focus on Water, COM 2014 – Conference of Metallurgists, Vancouver, Canada (2014)
[5] A. Filzwieser, S. Konetschnik, I. Filzwieser, S. Wallner and R. Preiss: Mettop´s new Cooling Technology is the safest way to cool a Furnace, Conference of Metallurgists, Vancouver, Canada (2014)
[6] A. Filzwieser, A. Siegmund, I. Filzwieser and M.B. Hanel, Using Mettop´s Ionic Liquid Cooling Technology – A Breakthrough Technology, Proceedings of the AISTech (2016) p. 2827
[7] M. B. Hanel, A. Filzwieser, I. Filzwieser, S. Wallner and S. Ruhs, ILTEC – Mettop´s Revolutionary AND Safe Cooling Solution, Proceedings of the Copper Conference (2016)
[8] R. Preiss, Methoden der Risikoanalyse in der Technik, TÜV Austria Akademie GmbH, 2009, ISBN-10 3-901942-09-2
[9] H. Joglekar, I. Rahman and B. Kulkarni, The Path ahead for ionic liquids, Chem. Eng. Technol. No. 7, (2007)
[10] P. Wasserscheid and T. Welton, Ionic liquid in synthesis, Volume 1, Wiley-VCH Verlag GmbH & Co. KGaA., Weinheim, Germany (2008)
[11] IoLiTec: Wärmeträgermedien, Thermofluide, http://www.iolitec.de/Warmespeicherung-Transport/waermetraegermedien-thermofluide.html, access on 20/03/2013
[12] Kyllo, A.K. and N.B. Gray: Composite Furnace Module Cooling Systems in the Electric Slag Cleaning Furnace, Proceedings of the EMC (2005), p.1027
[13] A. Fallah-Mehrjardi, P.C. Hayes, S. Vervynckt, E. Jak, Investigation of Freeze-Linings in a Nonferrous Industrial Slag, Metallurgical and Materials Transactions B, Volume 45B (2014), p. 850
[14] A. Fallah-Mehrjardi, P.C. Hayes, E. Jak, Understanding Slag Freeze Linings, JOM, Vol. 66, No. 9 (2014), p. 1654
[15] A.K. Kyllo, N.B. Gray, D. Papazoglou, and B.J. Elliot: Developing Composite Furnace Module Cooling Systems, JOM, (2000) p. 66
[16] L.R. Nelson et al: Application of a high-intensity cooling system to a DC-ARC Furnace production of Ferrocobalt at Chambishi, Proceedings: Tenth International Ferroalloys Congress, Cape Town, South Africa (2004) p. 508