ILTEC - METTOP´S REVOLUTIONARY AND SAFE COOLING SOLUTION

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ABSTRACT

It is the increasing demand for an economic and cost saving operation mode that requires effective cooling in order to achieve low refractory wear and good furnace lifetime, which is making cooling technology an important aspect of furnace operation. In addition, safety awareness is becoming more and more a focal point of the operating philosophy. 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 hydration problems, corrosion, and explosion. Not to forget the severe personal as well as economical damage in case of a malfunctioning water cooling system.

With the new patented cooling technology ILTEC it is possible to overcome the disadvantages of water by using an alternative cooling medium, namely the ionic liquid IL-B2001. The main characteristics, which makes IL-B2001 so favourable, are a neglectable vapour pressure, the absence of explosion, the wide liquidus range and the operation temperature from 50-200 °C and the not flammable, non-corrosive and atoxic behaviour.

All those properties lead to many areas of applications, which can contribute to accomplishing a water-free production route for the entire metal processing industry.

INTRODUCTION

The productivity of furnace operations has been dramatically increased over the last decades by using effective cooling solutions. For a given system in terms of heat input, material composition, oxygen enrichment amongst other aspects, the performance of a furnace is depending on the availability of the entire reactor. The limiting factors of furnace availability might be manifold. In particular, 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 [1-3].

Water as the conventional cooling medium is very risky in certain areas since 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. As a worst-case scenario, personal injury and fatal accidents have a high probability. Known accidents from all over the world in every area where water is used as a cooling medium are evidence of this fact. The only effective alternative of eliminating this risk and stop using water is the approach employing the ionic liquid cooling technology (ILTEC) [4,5].

With the novel ionic liquid cooling technology virtually all negative effects of a water cooled system are eliminated and 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 the liquid melt 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 the recovery of energy. Additional benefits resulting from this relatively high cooling medium temperature are that hydration and corrosion problems are avoided.

Overall it is utmost important for industrial applications that the requirements regarding critical heat flux, thermal limits and impacts of health, safety and environment have to be fulfilled. Major data of the ionic liquid IL-B2001 for cooling are provided and discussed. This, and its commercial operation demonstrate 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) [5].

Until today industrial realized projects comprise of the cooling of a tap-hole at a blast furnace (ArcelorMittal Bremen GmbH, Germany), the cooling of the side walls of zinc oxide furnace (Nyrstar, Norway) and the cooling of flanges of a RH-facility (voestalpine Stahl Donawitz GmbH, Austria). They are described and new applications are presented.

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 [6-8]. 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 designing 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 for meeting the typical requirements for this application.

The properties are summarized given in Table 1

Table 1 – Charactersitic 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

PROPERTIES, OPPORTUNITIES AND DIFFERENCES FROM THE STATE OF THE ART

Beyond the above given data and numbers, the ionic liquid IL-B2001 has attributes different to many of the state of the art 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 melt, tests have been performed at 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 bath level with a lance. In both instances it could be seen that there is 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 most of common sealing materials. A variety of materials (steel grades, copper, aluminium and nickel-base alloy) have been investigated at room temperature but also at higher temperatures comparable to the maximum operation temperature. Different construction and piping materials were brought in contact with the ionic liquid for 30 days and at temperatures of 200 °C and 250 °C. All results showed only a negligible weight loss indicating high corrosion resistance. These results are meanwhile proven at an industrial scale installation were the ionic liquid is used since more than 17 months at operation temperature between 150 °C and 180 °C. Ever since the start-up there is no corrosion at the furnace shaft wall at all.

Non-flammable

When comparing the ionic liquid with thermal oils, as an example of an alternative cooling medium, in particular the different characteristic at high temperatures has to be emphasized. Some thermal oils are defined as non-flammable. However, once the oil temperature reaches and exceeds its ignition temperature it starts to burn and burning cannot be stopped even when the heat source is removed. This is in stark contrast to the behaviour of IL-B2001. Once the heat source is removed the decomposition stops immediately.

Non-toxic, not harmful

Since the ionic liquid is used at industrial scale in plants, an uncomplicated handling and simultaneously guaranteeing health and safety of the operators is strongly desired. In this context, all the information is collected and described in the manual as well as the technical and safety data sheets and can be summarized 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 open atmosphere. It shall not be classified as acutely toxic, the hazard class and cathegory is 2, meaning skin irritating. IL-B2001 shall not be classified as hazardous to the aquatic environment but it is not biodegradable.

Broad operation temperature range

The operation temperature of 50-200 °C and hence the temperature difference between inlet and outlet temperature of up to 150 °C is advantageous in terms of heat recovery as well as operational practice.

Cooling within this temperature range enables an 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 a heat recovery system for direct usage or power generation under feasible conditions. This high absolute temperature and the extensive temperature range permits a heat recovery in an efficient way rather than being lost (creating steam instead of warm water). In case of continuously provided heat the possibility of heat recovery through an Organic Rankine Circle (ORC) exists, which is a technology not suitable for water as cooling medium. Under these circumstances primary energy resources can be saved.

Heat removal and specific heat capacity

Considering properties like heat capacity, heat transfer coefficients, Reynolds number and Prandtl number, it may be assumed that the amount of heat removed is less compared to 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 shows the different layers within the system melt/accretion layer/refractory/copper cooler/cooling medium and the different heat transfer coefficients (α = W/m^{2}K) and thermal conductivities (λ = W/mK). The amount of heat which 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 conductivity of the melt, the accretion layer, the refractory, the copper and again from the IL-B2001 are influencing the amount of heat removed from this system.

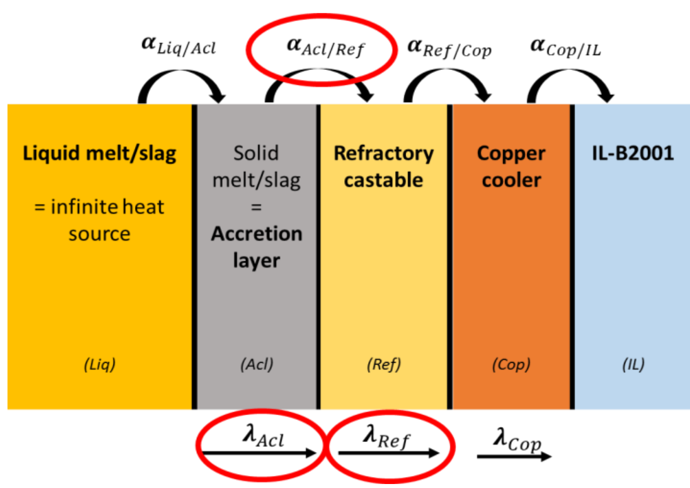

Figure 1 – Schematic picture of the different layers within the entire system in industrial scale use within a copper cooling element

It is known from calculations as well as lab scale tests, that the limiting factor for sufficient heat transfer are the thermal conductivity 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 neither the thermal conductivity of the IL-B2001. Generally speaking, a defined amount of heat will be transferred to the cooling medium and has to be removed, independently of the cooling medium itself.

Considering the basic equation for heat flux

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

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 heat transfer rate. However, this fact can be compensated by the achievable higher temperature difference (typically 15 – 20 °C in case of water but up to 150 °C for IL-B2001). Also the higher density of IL-B2001 compared to water helps balancing the equation towards the same value for Q.

On the other hand, an increase in cooling medium velocity will also lead to a heat removal at the same level.

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 special designed copper cooling element was taken into account. The geometry is given in Figure 2.

The calculation of the removed heat from this copper cooling element at a melt temperature of 1600 °C revealed that with this concept the heat removal is sufficient and the system is capable of creating a freeze lining. Compared to water, at the same boundary conditions, the difference of removed heat per square meter is lower for IL-B2001 at less than 3 %. This difference is a result of the different material properties for water and IL-B2001, namely Reynolds number, Prandtl number, dynamic viscosity and others.

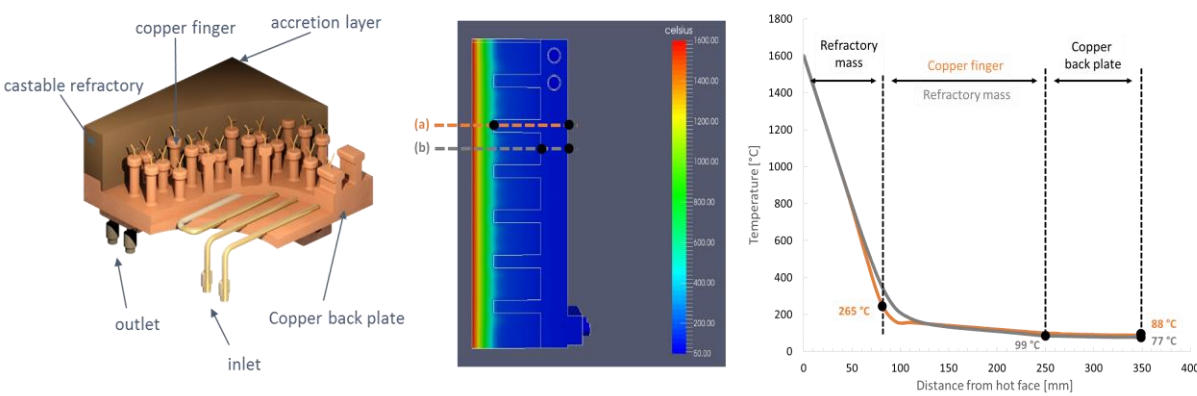

Figure 2 – Special design of a composite furnace module cooling (CFM) element for creating a freeze lining (left) and CFD modelling of the temperature distribution at a furnace temperature of 1600 °C (middle) and resulting steep temperature gradient within the refractory mass (right)

High electrical conductivity

Since the ionic liquid is per definition a salt and hence consisting of cations and anions the electrical conductivity is several orders of magnitude higher compared to water. This restricts the application of substituting water within induction furnaces or wherever a minimum electrical conductivity is required. To overcome this issue within induction furnaces a special design of the cooling circuit has to be considered.

No altering, 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 get in contact with water or open atmosphere. 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 not a consumable, as mentioned before. Experiences over the last years has proven that IL-B2001 does not change its originally properties provided. 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.

An exemplary design of an ILTEC facility is given in Figure 3 and the main components thereof can be summarized:

- 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 removing the heat to the secondary cooling circuit, again 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 additional cooling circuits can be implemented

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

It is a sad reality that from time to time accidents do happen in the metallurgy industry as well as in any other industries facing hot temperatures and water as a cooling medium. When exchanging water by IL-B2001, it is its superior properties resulting in an explosion free environment that allows cooling in a safe and sound manner.

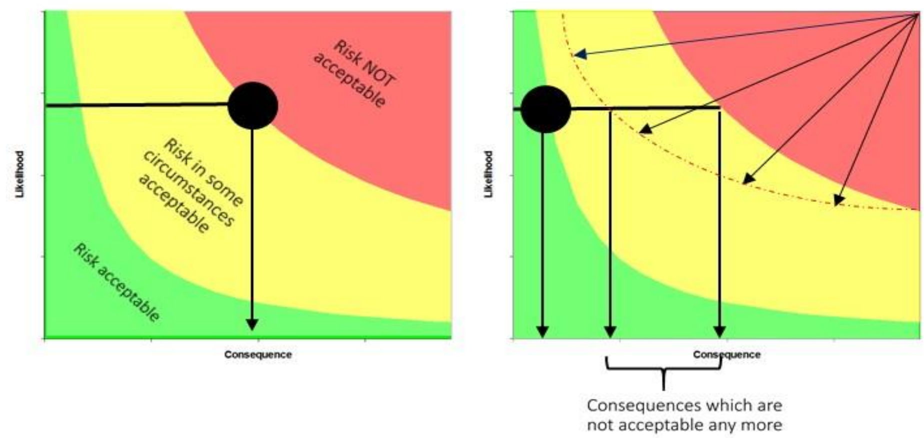

Figure 4 – 2-dimensional risk analysis of a state of the art water cooled area (left) and using the ionic liquid as cooling medium (right) [5]

The two diagrams in Figure 4 show the path of becoming best available technology [5]. The fact that accidents and incidents happen cannot be changed by substituting water as the cooling medium, the likelihood of remains at the same level. But in the case of accidents in metallurgical plants the consequences are of severe nature. Whereas the environmental impact might be limited to the operating area, the economic damage will be more massive because of the production loss. However, there is a high chance of fatalities that makes the risk of such kind of accident (marked as black dot) very close to the boarder of "not acceptable risk".

When substituting water by the ionic liquid the damage 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 (right side of the figure) will move towards lowering the acceptability of consequences.

Due to the fact that there is a much safer alternative available to water cooling the acceptance of water cooling – and the risk of injuring employees – will decrease and finally water cooling will not be tolerated any more (in dangerous areas like tapholes etc.).

OUT OF THE BOX – EXAMPLES FOR APPLICATION

With all the described facts, properties and advantageous of the ionic liquid IL-B2001 and the ILTEC technology an immense field of possible applications opens up. Below only a few of these possibilities are briefly discussed providing an inspiration.

Tap Hole Cooling – New Safety Standards at ArcelorMittal, Bremen, Germany

Every tapping area is a highly stressed furnace section mainly due to the intense heat given off by the hot liquid phase as well as of 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 a high wear of the tap-hole refractory and for increasing the 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 is running since autumn 2015 at a blast furnace in Bremen. Figure 5 shows the geometry and the calculated temperature distribution during tapping.

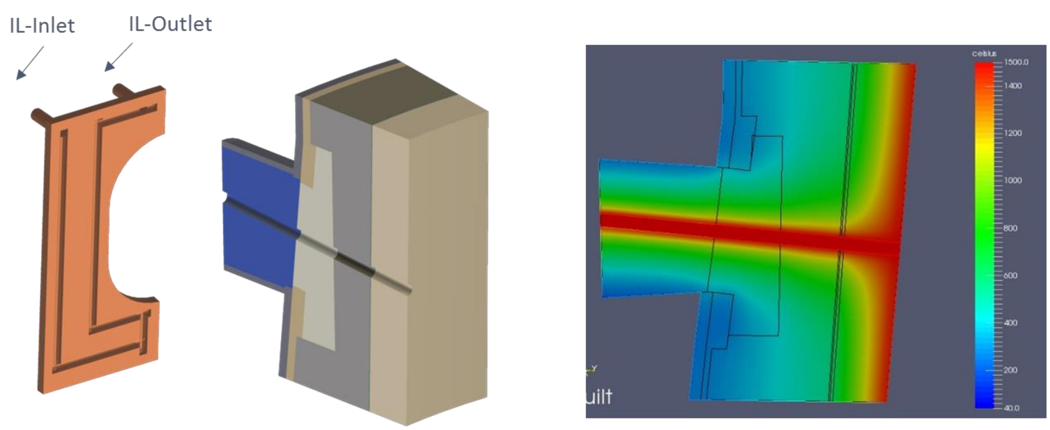

Figure 5 – Special design of the cooled tap hole with the copper cooled back plate mounted upon the steel shell (left and middle) and CFD modelling of the temperature distribution during the taping of hot metal

In most cases, the cooled area is limited to the area near the steel shell instead of reaching close to the hot phase of the refractory due to safety aspects concerning water. With the new ILTEC cooling technology this existing state of the art design can be reconsidered.

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. This freeze lining concept is attributed to the fact that the removed amount of heat is high enough for creating a frozen slag/metal layer upon the castable refractory. The slag/metal bath is locally (at the contact face melt and c astable 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.

Once this slag/metal layer is created there is no further wear and consumption of the refractory material since an equilibrium between melting of the frozen layer and freezing of a new layer is formed

The special cooler design as shown in Figure 2 and the different possibilities of applying this high intensity cooler with the side wall of an EAF are given in Figure 6. 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 a heat transfer of more than 300 kW/m^2 can be realized.

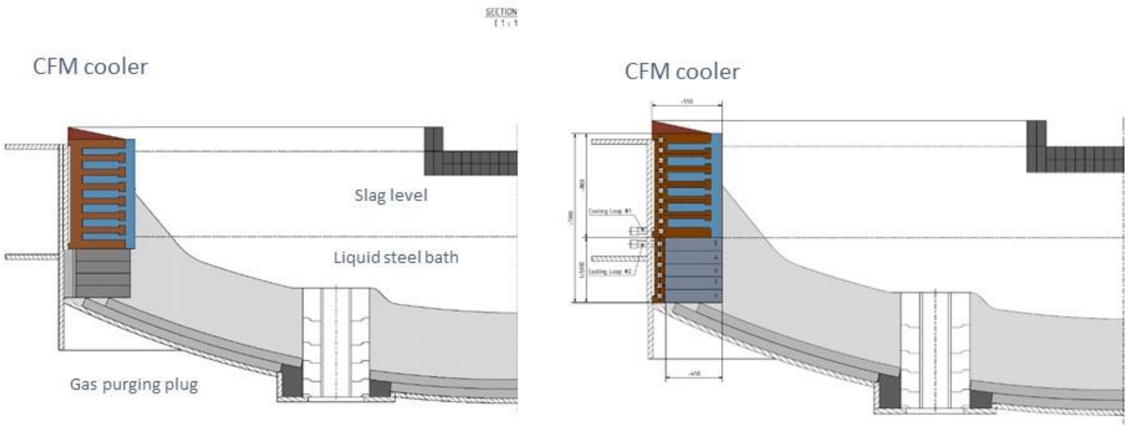

Figure 6 – Different opportunities for installation of a high intensity cooler within the side wall of an EAF, left: installation of the cooler only at the slag line; right: slag line cooling with CFM elements and cooled copper plate behind the brick lining at the lower part

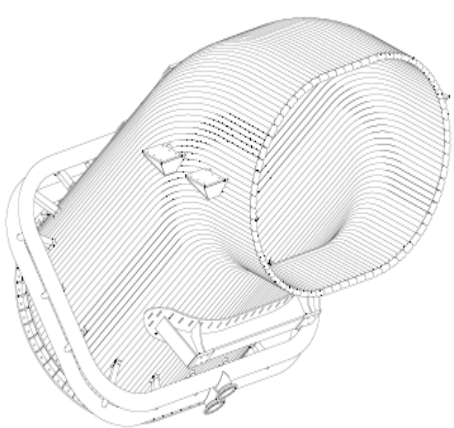

Figure 7 – Water cooled part of the offgas duct of an EAF

Cooling of Offgas Systems – Adjustable Cooling and Heat 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 cooling medium is cooling the duct to a high extent and off gas temperature might fall below the dew point of different corrosive media within the offgas (sulphur containing components,…). Condensation of parts of the off gas will lead to corrosion and less availability of the off gas duct. For preventing this phenomenon the operation of a higher inlet and outlet temperature at or above 180 °C of the cooling medium 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, this energy can perfectly be used for heat recovery.

Shaft furnace wall 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 operation temperature with the refractory lining. This helps wherever problems arise with hydration or corrosion due to surface temperatures below the dew point.

One well known problem in non-ferrous metallurgy is the formation of sulfidic acid in the off-gas of sulphur containing raw material processing aggregates. In conjunction with the almost always existing moisture of the raw materials and concentrates, there is a chance of forming gaseous sulfidic acid (H_2SO_4) as a result of the reactants 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 formed acid is ascending within the furnace uptake. During the ascend, the sulfuric acid containing gas comes in 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 condensate as sulfuric acid on the refractory material or steel shell. Which then causes a very accelerated material destruction through corrosion.

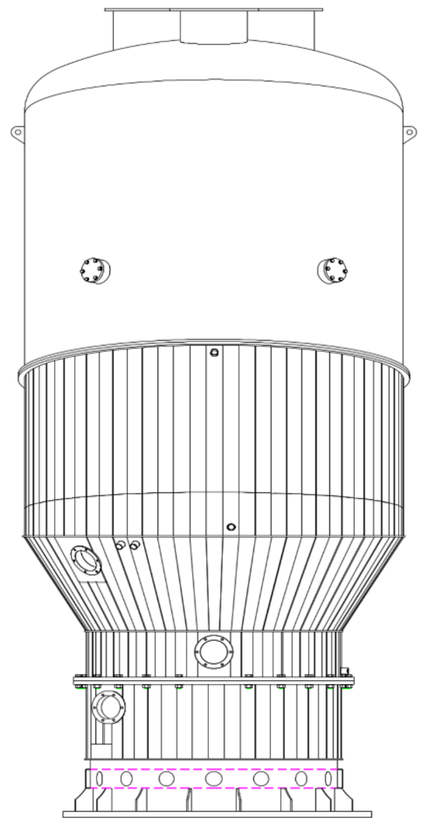

Figure 8 – Construction drawing of the shaft furnace where cooling of the lower part of the shaft is realized with ILTEC Technology

The installation of cooling the furnace walls of a plasma furnace was completed at the beginning of 2015 and is in operation at Nyrstar in Hoyanger, Norway. Due to a changed of the input material mix, water as cooling medium resulted in equipment corrosion due to temperatures below the dew point of sulfidic acid. This circumstance could be eliminated by replacing water with IL-B2001.

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

CHANGE OF AN INDUSTRY – SUMMARY AND OUTLOOK

The current paper describes the opportunity to increase furnace safety and operation efficiency by a commercially proven alternative cooling method. In addition, it substantially improves the operation economically by increasing life time of refractory lining and the potential of heat recovery.

The described examples demonstrate that it is possible to employ the new cooling technology as an alternative replacing water in existing cooling circuit for different reasons. The replacement of the water in a tap hole is more or less driven 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 only limited to these mentioned applications but could be used in multiple other application were cooling with water is not possible mainly due to safety reasons and become best available technology (BAT) in the future.

One important future trend in terms of a cost efficient and environmentally friendly operation mode is inevitably leading towards better methods of using waste heat. The higher outlet temperature and higher temperature difference between inlet and outlet make IL-B2001 the perfect available cooling medium for effective heat recovery. The cooling medium temperature of up to 200 °C can either be used for conversion into electricity or as direct heating.

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