Furnace Integrity – A Holistic Approach to face todays Challenges

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Introduction

Non-Ferrous Metallurgical companies, especially toll smelters are nowadays under extreme economical pressure caused by reduced metal prices and competitive treatment and refining charges. This situation is additionally worsened by degrading concentrate conditions with increased amount of impurities that have to be treated with the same smelter setup.

Therefore, an increase in the annual production and an extension of the maintenance intervals is of vital economic importance for all smelters especially in the Western hemisphere.

Process parameters as there are for example feeding rate, amount of recycling material, process temperature, blowing time, fuel consumption are changed in order to increase the throughput in the smelter. At the same time, environmental regulations and health/safety standards are tightened which further increases the responsibility and the legal pressure on the operating staff and the management.

This very complex system with a lot of parameters that influence each other requires professional expert know how and a dynamic risk management in place in order to be properly, responsibly handled.

In case of process changes all available tools as there are CFD, FEM modelling, online parameter measuring (temperature and other important process data), complete 3D design including furnace shell, refractory and cooling have to be applied together with a risk analysis based on HAZOP and FMEA to improve the visibility into the continuous metallurgical processes.

Since unknowingness is never an excuse it is of importance to be informed about latest technologies not only for process improvements but also concerning tools that have strong impact on the plant safety. The new Quality management norm 9001-2015 requires the implementation of an active risk management system which can now be made use of also as a competitive edge because of the potential in case of implementation of running a process in a more stable way on its limits.

Risk based maintenance – Productivity versus life time

The overall objective of the maintenance process is to increase the profitability of the operation and optimize the total life cycle cost without compromising safety or environmental issues. Risk assessment integrates reliability with safety and environmental issues and therefore can be used as a decision tool for preventive maintenance planning [1]. In case of several changes in a known system it is of importance to thorough analyze its influences on all involved process parameters. Further all possible and unlikely failures have to be discussed in an expert team and must be evaluated for its probability and consequences.

The resulting risk matrix system should not show results in the upper, right red corner since these are intolerable combinations that require clear actions or methods based on technical or organizational actions.

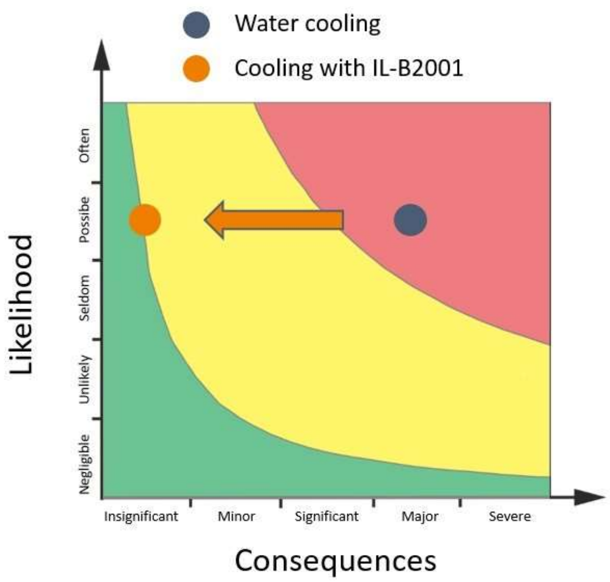

Figure 1: Comparison of 2 different cooling technologies for under bath cooling in a furnace

An additional tool coming from the oil and gas sector is Risk Based Inspection (RBI). RBI combines knowledge of damage mechanisms and damage progression rates, inspection effectiveness with load and resistance models to determine the probability of failure causing leaks. It also combines the probability of failure with the consequence of failure to obtain the risk [2]. A quantified ranking of process equipment and piping in terms of personnel and environmental risk, loss of production and damage cost allows a focuse of the inspection towards high risk components and potential damage mechanisms for an optimal utilization of inspection resources on key assets.

This approach is also very valuable in the metallurgical industry since maintenance shut downs have to be planned way in advance and only a Risk Based Inspection can help to minimize the risks of unplanned emergency shutdowns caused by limited knowledge of the furnace integrity. This is often further complicated since the necessary repair materials and service teams are then not on site.

Furnace Optimisation – CFD and Thermal Modelling

An important auxiliary tool for production improvements and better predictions for wear parameters and shut down planning is process modelling work. The origin is always the definition of boundary conditions that requires an intensive analysis of the own metallurgical process in order to avoid wrong starting conditions for the model.

Flow and temperature modelling help getting a better understanding about the situation inside the furnace and the interaction of the steel shell, the refractory material and the metal to be processed.

The knowledge about the furnace geometry (steel construction, refractory lining setup) combined with material data (input material, temperatures of metal/slag, off gas composition, surrounding refractory material) enables a thermal modelling resulting in better understanding of:

- Heat and energy losses
- Temperature distribution within all layers
- Areas of increased temperature (hot spots)
- Expansion for the correct refractory heating up
- Cold spots for preventing hydration and corrosion

Furthermore, CFD modelling can be used for flow optimization of gaseous and liquid media. One example of a minor geometrical change with a high impact as a result of a CFD model is shown in Figure 2. In this case, only a small adaption of the off-gas post combustion chamber (a flattening of the roof element) led to a distinct increase of the gas velocity leading further to prevention of built-ups.

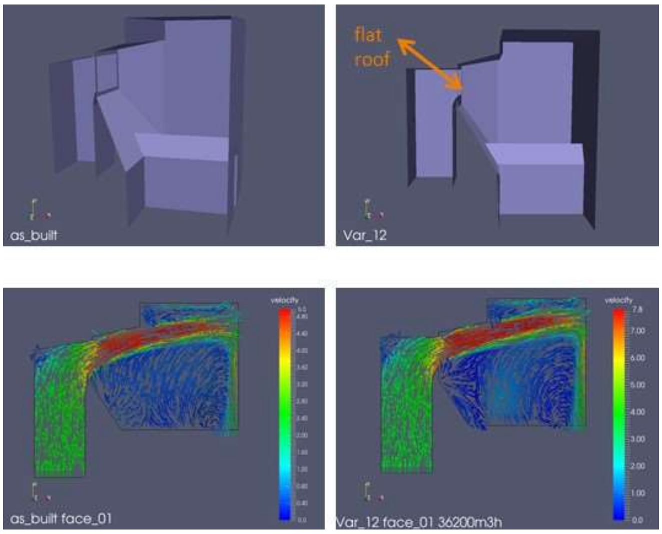

Figure 2: Vanyukov-furnace post-combustion chamber; Flow model for optimized geometry of the post-combustion chamber for preventing any built-ups as a result of preferably high off-gas velocity

Once the design of a reactor vessel is fixed, the geometries are known and the refractory material is defined, investigations in terms of the heat load and temperature distribution can be conducted. Being aware of the geometry, the temperature and composition of the metal and slag, the power and amount of heat sources; a CFD (computational fluid dynamics) model can help to better understand the temperature distribution and thereby avoid a decreased furnace lifetime because of excessive undetected (because not anticipated) refractory wear.

Metallurgical Optimisation – Online process control

Of outmost importance in case of severe process changes is an existing online monitoring system of the important process parameter. One of the key elements is the temperature that is measured in the off-gas, the melt and the refractory lining. Also of importance is the temperature reading in water cooled tuyere or taphole blocks because of the risk of explosions.

The existing thermo-couples are nowadays supplemented by fibre optic systems that can give additionally not only a point measurement but also a reading of a whole area of the furnace sidewall.

Also, it is of advantage to have a redundant system especially in case of a furnace lifetime of several years. If a single reading is lost it means that for the rest of the lifetime there is no further information available.

The monitoring system works on the basis of temperature measurements and delivers reliable information on the refractory lining condition, under consideration of the respective type of lining and the material charge. The HMI screen displays isothermal processes in high definition. It is possible, for instance, to determine fine structures such as the current thickness of the frozen slag layer of the freeze lining design [3]. These evaluations can help to plan the right moment for a shut down and allow to keep track on this timing based on the evaluation of the continuous online readings.

Since a lot of metallurgical processes are optimized because of experienced operators and stable process conditions it is very difficult to change this setup. A successful example of the implementation of an online process control system in the last 20 years was the OPC system of SEMTECH. By the follow up of the light emission readings of PbS, PbO and CuOH in the flame of the Peirce Smith converter off-gas (Figure 6) it is possible to optimize the charging and fluxing procedure and to find consistently the best time for the endpoint of the slag and copper blow.

Figure 3: Online process parameter reading during a Peirce Smith converter cycle; OPC system SEMTECH, Wilhelm Wendt

This is independent of the person of operator and more importantly it also works under changing matte grades and revert amounts. A clear view for the metallurgical process is then also positively effecting the converter maintenance since the produced slag is less aggressive and there is less need for punching in the tuyere zone.

The Importance of Refractories – From Design to Start up

Although different smelters use the same furnace type, there are differences in steel structure and internal refractory lining, making every furnace a unique aggregate. In contrast to the state of the art refractory engineering in two dimensions, the 3D refractory engineering helps to optimize refractory lining designs and to integrate the refractory concept into the whole steel construction.

The complete 3D drawing allows having a closer look on any furnace area from different angles and thereby showing already on the screen difficult installation designs. An example, a part of the step-by-step installation instruction for the bottom lining of an anode furnace is given in Figure 4.

Furthermore, the 3D refractory engineering can be used as a training video because of its step-by-step visualization of the installation procedure for speeding up the refractory installation [4].

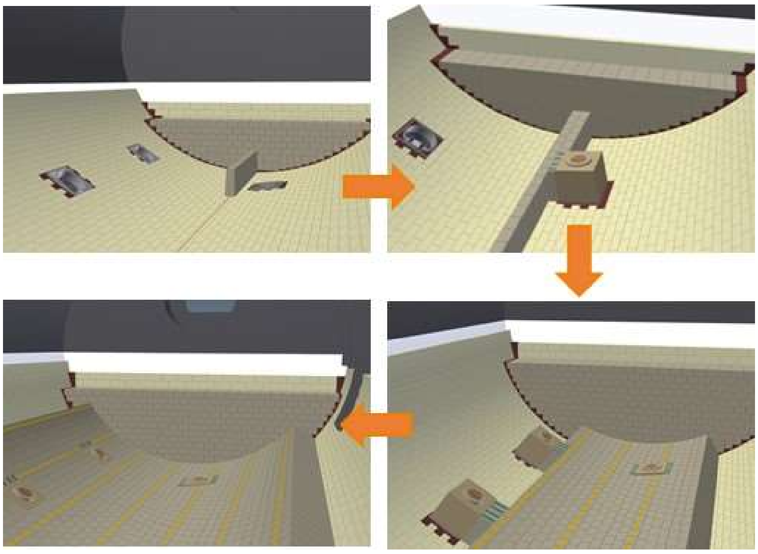

Figure 4: Example of a 3D model of the entire refractory lining of an anode furnace: single steps for the step by step lining sequence including purging plugs

Since in a 3D model each brick with its shape is drawn separately it is easy afterwards to make design changes because of inputs from a CFD model or to transfer design changes from the steel shell to the refractory lining [6]. Also, the wear profiles gained after each breakout can be stored in the corresponding 3D drawings and thereby extending the historical databank an important source for the risk analysis.

Increasing Furnace Lifetime – Applying Cooling Solutions

It is the increasing demand for productivity and cost saving operation mode that requires intensive cooling technology in order to reduce refractory wear and increase furnace lifetime. Higher process temperatures and slag corrosivety are additionally accelerating the refractory wear. CFD models (Computational Fluid Dynamics) for uncooled linings in comparison with different cooling technologies show already in theory the benefits in the dramatically changed temperature gradients. The experiences of different customer applications have already proven the advantages in the last 20 years.

The intensive cooling of refractory linings is generally associated with the following advantages:

- Better cooling of the refractory leads to a steeper temperature gradient within the brick lining
- Steeper temperature gradient means less infiltration area by liquid slag or metal
- Less infiltration leads to reduced chemical wear at the contact area with refractory material
- Intensive cooling leads to the formation of a freeze layer at the refractory surface

In Figure 5 examples of different side wall cooling setups of a plasma furnace are shown. The temperature distribution within the furnace wall for different water cooled copper elements indicate that the difference in the location of plate coolers is hardly influencing the cooling effect inside the refractory lining. However, a high intensity cooler with copper fingers within a castable increases the removed heat and the temperature gradient becomes steeper. Even more, with this kind of high intensity coolers it will be possible to create an accretion layer of solid material. This freeze lining concept can lead to an immense increase in furnace lifetime since a solid frozen metal/slag layer will protect the refractory lining and there will be no further consumption of the refractory material.

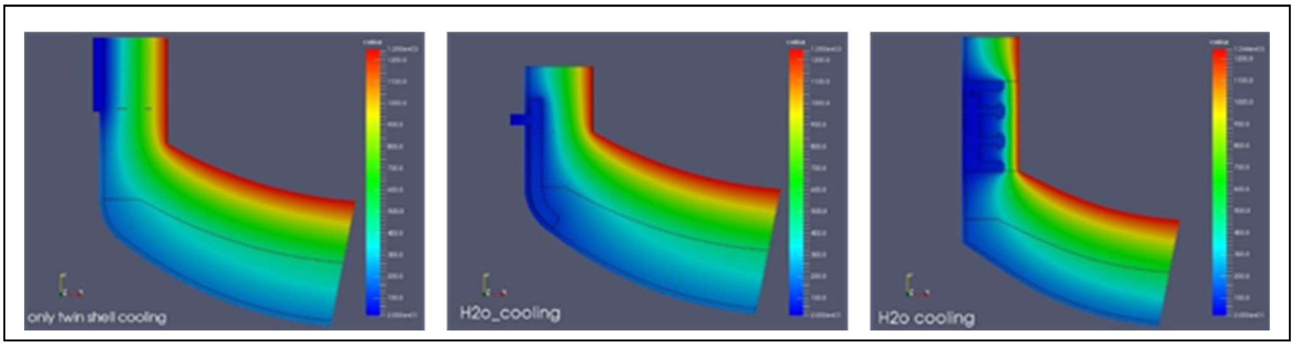

Figure 5: CFD Model of the temperature distribution depending on different cooling solutions for the cooling of a furnace side wall, cooled plate at the outside of the steel shell (left), inside the steel shell (middle) and high intensity cooler (right)

Figure 6: CFM cooling element for charging mouth of an anode furnace

As another example of the CFM (composite furnace module) high intensity cooling solution working on a freeze lining concept, the charging mouth of an anode furnace. **Fehler! Verweisquelle konnte nicht gefunden werden.** shows the different process steps, from the construction drawing (left) to the casted copper parts prior to the casting of the refractory (middle) and the final installation situation in operation.

Safety first – ILTEC Cooling Technology

Since water, as the most commonly used cooling medium, is always associated to a certain explosion risk [5,6], an important step was done with the implementation of ionic liquids as a cooling medium. The patented technology is named ILTEC (ionic liquid cooling technology) and characterized by the following:

- Instead of water the ionic liquid IL-B2001 is used as cooling medium
- IL-B2001 is a special designed ionic liquid which is liquid at room temperature and can be used within a temperature range of 50-200°C operating temperature

- If there is a leak in the cooling system, the IL-B2001 decomposes into its components (at 450°C) without sudden increase in volume and without formation of hydrogen. If it comes in contact with liquid metal there will be no explosions and work safety can be guaranteed
- Easy handling because of non-corrosive, non-toxic and non-flammable behaviour
- Due to the higher temperature (up to 200°C), the dissipated heat can also be recovered again. This advantage will play a particularly important role in the future

Figure 7: 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

With the ILTEC Technology combined with an optimized geometry of the cooler (shown in Figure 8) it is now also possible to increase significantly the tuyere lifetime of a Peirce Smith converter. The figure shows the two-part copper cooler for cooling the newly designed tuyere block consisting of casted copper fingers with a back plate that has an infused pipe with the internal IL-cooling circle for a high heat removal. The copper fingers are embedded in a AlCr-castable that is pre-dried. This high intensity cooler will form in the surface area a freeze lining because of the increased heat removal and thereby balance the refractory wear in the Peirce Smith converter.

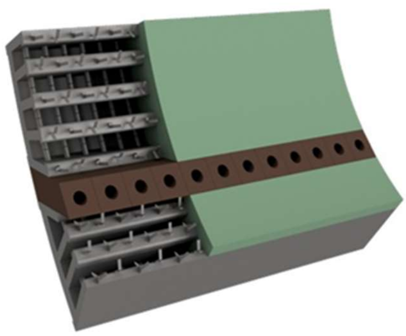

Figure 8: Advanced CFM (composite furnace module) cooler for cooling tuyeres of a Peirce Smith converter

Active risk management in a furnace – Summary and Conclusion

The need for a production increase based on existing furnaces together with an extension of the maintenance cycles requires to make use of all available technologies that help to reduce the risk of failures. A combination between modern design tools, improved online process control and the implementation of latest cooling technology will be the key for the move from standardized maintenance cycle to a Risk Based Maintenance.

This is a dynamic system that is built on latest technology and makes use of all historical process experience. It is supported by a dynamic learning risk management system that includes also unlikely failures and its consequences in its procedures and evaluates always latest technology and their possible use for the own application. A professional responsible system will always react and set actions in case of unacceptable safety risks in the production process.

The final benefit is then a sustainable production increase and the cost optimization of the maintenance process under compliance of environmental and safety regulations.

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