FURNACE INTEGRITY – METTOP´S HOLISTIC APPROACH TO FACE TODAYS CHALLENGES

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ABSTRACT

It is the rising demand for economic and cost saving operation mode within all metallurgical plants that makes every aggregate unique and makes tailor made solutions absolutely essential for an optimized process. Especially regarding refractory lifetime and furnace availability subsequently, manifold aspects contribute to a commercial success of a process concept.

Mettop´s approach for improving and optimizing metallurgical processes is seeing the entire process as a whole. A combined consideration of furnace geometry and steel construction, of refractory material and arrangement and of metallurgical reactions and processes can lead to an increase of the life cycle time.

In order to meet costumers needs Mettop makes use of the most modern construction methods and elements for optimization and simplification the difficult topic of refractory engineering and lining sequence. The applied 3D construction method, CFD modelling as well as process modelling enables a prefect synergy of refractory design, positioning of purging plugs and arrangement of cooling solutions.

INTRODUCTION

The phrase furnace integrity is associated with considering the entire process for creating the optimum solution and the best possible performance. It is intended to always meet customer's needs, therefore the first step is an analysis of the actual state of the art situation together with the customer. Each plant has individual process routes, aggregates and facilities, meaning each solution is an individual and tailor-made approach to a problem.

The following pages will give an overview about the tools that are used by Mettop for creating the best possible result, starting from modelling the process route as a whole. Available and approved aggregates are combined and arranged leading to the best possible utilization of the prevailing situation. The entire process chain is considered, starting from considerations regarding raw materials (quality, availability,…) to the final product. Also the boundary conditions, for example availability of reducing agent, electricity, space, law situation etc., must be taken into account.

Once the process route is fixed and the aggregates are defined, the optimization goes more into detail. Modelling of single process steps can possibly achieve better material output, less refractory consumption, better material quality, less waste material and many more. Flow and temperature modelling help getting an idea about the situation inside the furnace and the interaction of the steel shell, the refractory material and the metal to be processed. Intense considerations regarding the refractory lining, starting from 3D engineering and considerations regarding purging systems results in the selection of the best suitable qualities and the best possible installation situation. 3D engineering of the entire refractory lining leads to a supplier independent material list and furthermore, with the knowledge about the refractory concept a broad range of different cooling solutions can be considered. Finally, with the new water free cooling solution ILTEC totally new pathways can be forged at simultaneous increase of safety.

All these tools for optimization are provided by Mettop and whenever thinking about process optimization this never is a strict one step after another procedure but an iterative process. With the description of the all the possibilities that are available it is intended to make it easier to understand that furnace integrity comprises of all, from simple geometrical modifications of a single small part to a totally new designed process routes. For creating a better understanding about the process and generating process knowhow of the operators, Mettop additionally offers a variety of training and teaching courses.

OPTIMIZED PROCESS – THERMODYNAMIC APPROACH

Process modelling is possible for a single step up to a complex and whole facility with numerous sub-processes. There is no restriction in achieving a sufficiently accurate model, assumed that the boundary conditions are known, enough data is available and the processing power for multitudinous calculations is sufficiently available. By means of thermodynamic modelling, which is mainly based on a combination of the software HSC Chemistry and FactSage together with empirical data, the optimum process can be identified. Every single process step is taken into account for giving a holistic picture of the route. The major benefit of an adequate process model is the possibility to run through a variety of situations in respect of:

- Raw material mixture, as well as point and time of addition
- Addition of slag forming agents and slag composition, respectively
- Atmosphere and air/natural gas consumption, respectively
- Temperatures/heat load
- Composition of intermediate and final (main) products
- Intern circulation streams
- Change of the overall operation mode

Modelling entire process routes – optimized process

The exemplary presented model given in Figure 1 includes all vessels and process steps for a secondary copper facility for low grade raw material. In the final setup, the model includes more than 150 elements and compounds and allows automatically material and energy balances.

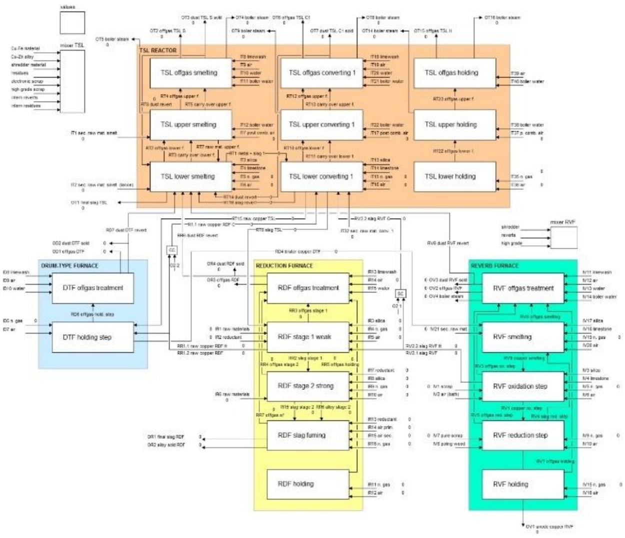

Figure 1 – Modelling of the entire secondary copper production route with a smelting reactor, a converting step, and a refining step including a drum type furnace as a mixing and holding aggregate [1]

This model is also capable of doing calculations if it is planned to change the operation mode from batchwise to continuous operation, hence having a deep impact to the entire operation mode. This shows that an adequate model helps to design the facility in a way to provide major changes with foresight.

Modelling and validation of single process steps – process optimization

Each single step has to be modelled individual for achieving best possible results, but the intension is not only rely on modelling results but also do validation with tests and investigations at lab scale as well as industrial scale conditions.

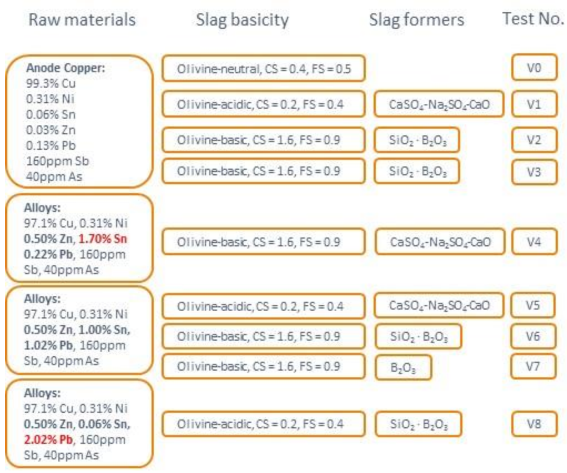

Figure 2 –HSC-Modelling of optimized slag compositions for optimum refining results, different scenarios which were finally tested at lab scale conditions for defining the ideal slag composition [2]

For giving an example, the investigation of new slag compositions for copper secondary metallurgy is shown in Figure 2. In the frame of a doctoral thesis [2] seven different slag systems were examined and compared with regard to their refining properties of nickel, lead, tin, arsenic and antimony for developing a new process route. In accordance to the prior conducted HSC modelling it could be verified that with a combination of two different basic slag systems a better overall refining result can be achieved.

METALLURGICAL OPTIMIZATION VIA GAS PURGING

Gas purging improves metallurgical work and can result in a significant reduction of process time. While it is already used in anode furnaces, there are only a few converters, which are equipped with a purging system. One reason might be the fact that for the installation of porous plugs, it is necessary to cut openings in the steel shell of the furnace. Well thought-out purging systems are designed to prevent a metal leakage or run through by various construction details, but this hazard cannot be eliminated completely; defect sources are an insufficient walling around the purging plugs or problems with the refractory quality for example.

However, the advantages of gas purging systems can be summarized [3,4]:

Thermal and analytical homogenization of the molten bath

- Reduction of fuel and auxiliary material consumption
- Decreased slag overheating and refractory wear
- Uniform chemical purity

Increased surface layer between slag and metal bath

- Decreased boundary layer
- Increased diffusion controlled reaction
- Increased metal recovery
- Decreased highly oxidized slag

Inert gas bubbles in the molten bath

- Decreased partial pressure for SO_2, H_2O and CO
- System reaches equilibrium more quickly

Also the number and the position of the gas purging plugs influences the metallurgical performance of a reactor.

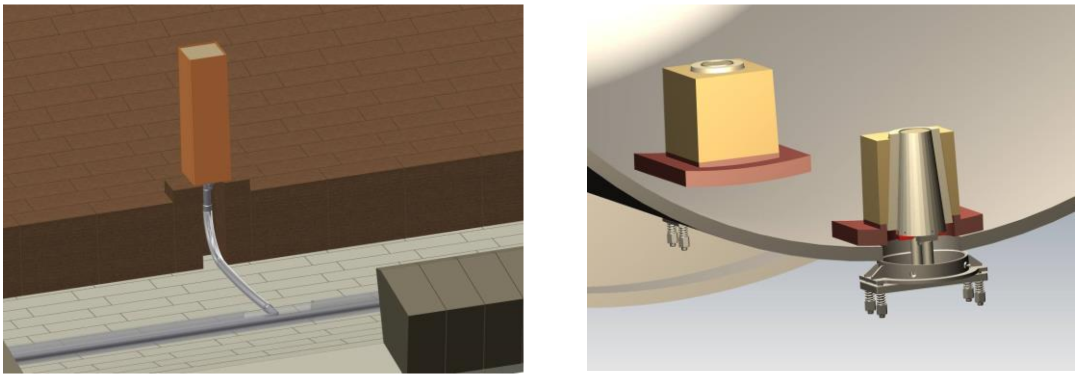

Figure 3 – Different systems of purging plugs available, non-changeable system with internal piping (left) and changeable system with external piping (right) [3]

Generally, there are two possibilities for the installation of a gas purging system, namely non-changeable systems with internal piping and changeable systems with external piping. The choice of the optimum gas purging system for the individual furnace has to be made under consideration of the actual metallurgical process and the furnace type, as well as the general safety situation.

Especially in copper industry, the following advantages within different aggregates can be emphasized:

- Anode furnace: Gas purging in the anode furnace results in 30% shorter oxidation, 50% shorter deslagging, less reductant consumption, less refractory wear, time savings and finally cost savings
- Peirce Smith converter: Gas purging can also be applied in the converter to achieve lower sulphur content, lower oxygen content, decreased process time and decreased deslagging time.

OPTIMIZED REFRACTORY DESIGN – 3D REFRACTORY ENGINEERING

Although different smelters use the same furnace type, there are differences in steel structure and refractory, making every furnace a unique aggregate. In contrast to the state of the art refractory engineering in two dimensions, Mettop uses 3D refractory engineering to optimize refractory linings and furnace concepts. 3D refractory engineering requires a full design of all lining details during the construction and drawing stage. This is a big advantage compared to 2D refractory engineering, as cutting bricks on site can be avoided with the detailed 3D design. Consequently, time and also costs during installation can be saved. Furthermore, the 3D refractory engineering allows a step-by-step visualization of the installation procedure. This again facilitates the refractory installation [5].

3D engineering of the furnace allows the automatic generation of a complete parts list of all bricks and additional parts (e.g., steel plates, hanging hooks, expansion inserts), as all parts are named systematically and are saved in a comprehensive list. Each brick format and every additional part is only drawn once and then copied, so that the parts list can be generated automatically and contains all the information required for the refractory lining installation, for example required amounts of brick formats and qualities, number of expansion inserts, weight, volume and positioning of bricks in different furnace areas [6].

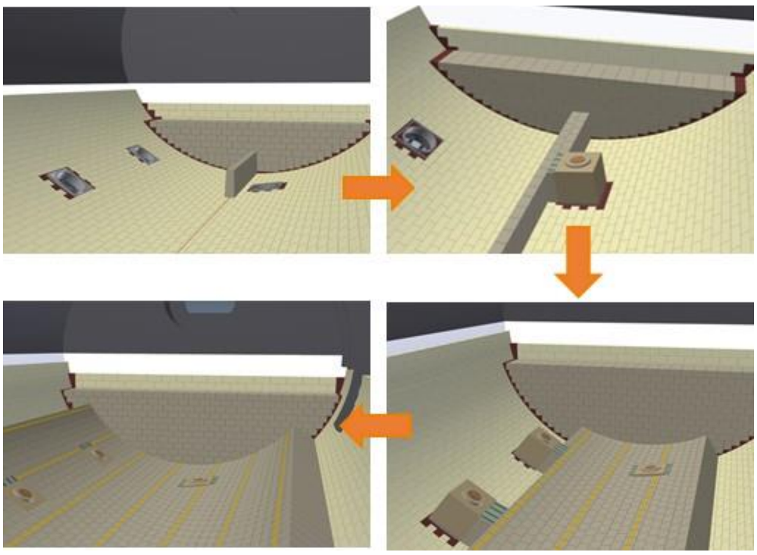

Figure 4 – Example of a 3D model of the entire refractory lining of an anode furnace: single steps for the step by step lining sequence including purging plugs

The complete 3D drawing allows having a closer look on any furnace area and providing a step-by-step installation instruction for this area for the installation team on site. To provide an example, a part of the step-by-step installation instruction for the bottom lining of an anode furnace is given in Figure 4.

SELECTING THE BEST MATERIAL – OPTIMIZED QUALITY CONCEPT

As an independent refractory supplier without any production site or contract to refractory producers, Mettop can select the best available material for providing independent and process orientated optimized concept. Since the scope of supply can only consist of refractory engineering, a material list totally neutral and without any relation to manufacturer can be offered. This allows the customer to independently order the refractory material according to the provided quality concept. In addition Mettop provides full service in terms of ordering, shipping and delivery including supervision on site.

Based on the metallurgical and process knowhow the decision about the best available refractory material has to be considered individually for every customer and application. Although normally magnesia-chrome is the choice quality within the non-ferrous industry, Mettop is considering other qualities whenever necessary and useful. For example in anode furnaces during certain process steps there are some areas where the oxygen content may be increased up to 8,000 to 10,000ppm or even higher. This high oxygen content may lead to the formation of CuO which can deeply infiltrate the MgCr bricks. For preventing this infiltration, the usage of alternative qualities like aluminium-chrome bricks with a Cr_2O_3 content of more than 28% can be used. The Cr_2O_3 results in the formation of a CuCr type spinel during operation making this type of refractory tight and only little infiltration will occur.

This means also that for one single furnace different brick qualities and subsequently different suppliers are used.

FURNACE OPTIMIZATION – CFD AND THERMAL MODELLING

Once the type of 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 understanding the temperature distribution and can avoid a decreased lifetime because of refractory wear.

The knowledge about the furnace geometry (steel construction, refractory thickness of each layer,…) combined with material data (refractory material, input material, temperatures of metal/slag,…) 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 heating up phase
- 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 5. In this case only a small adaption of the offgas 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.

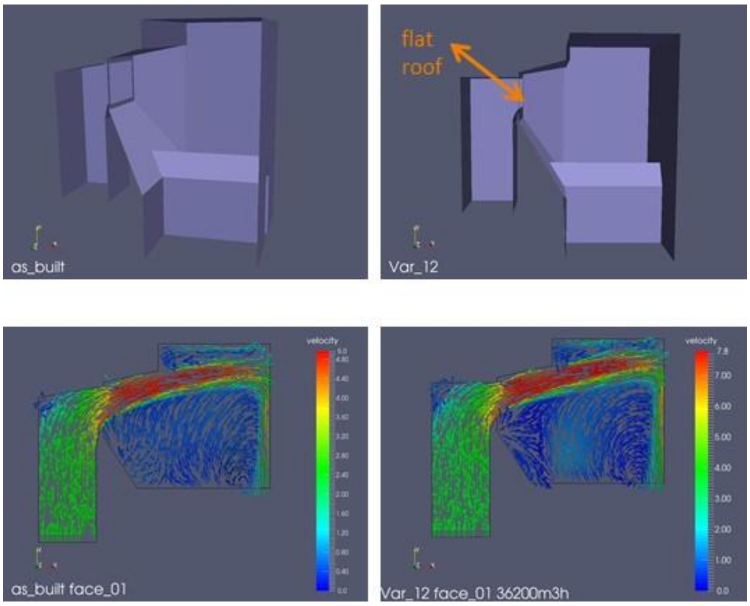

Figure 5 – Vanyukov-furnace post-combustion chamber; Flow model for optimized geometry of the post-combustion chamber for preventing any built-ups as a result of preferably high offgas velocity

INCREASING FURNACE LIFETIME – APPLYING COOLING SOLUTIONS

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. At some areas it is of need to apply cooling as an additional measure for increase furnace lifetime and optimize the furnace performance. Therefore as a result of the CFD models (Computational Fluid Dynamics) and from the knowhow of the customer, a variety of different cooling solutions can be thought of.

Cooling of refractory is generally associated with the following advantages:

- Cooling of refractory is inevitable for smelting operations to intensify the performance
- Better cooling of the refractory leads to a steeper temperature gradient within the brick lining
- Steeper temperature gradient means less area for possible infiltration by liquid slag or metal
- Less infiltration leads to better wear performance of the refractory material
- Better performance of refractory lead to increase in lifetime, increase in campaign lifetime and to a more cost saving and economical production

In Figure 6 an example of different options for cooling a side wall of a plasma furnace is shown. The temperature distribution within the furnace wall for different water cooled copper cooling elements indicate that the difference between the installation location of plate coolers is hardly influencing the cooling effect inside the refractory lining. However, a high intensity cooler with copper fingers and a castable refractory 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.

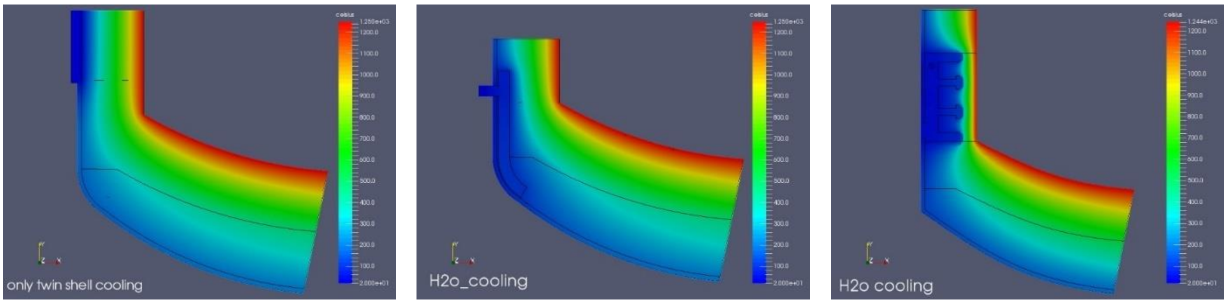

Figure 6 – CFD Model of the temperature distribution depending on different cooling solutions for the cooling of a furnace side wall, cooled plate at the outside of the steel shell (left), inside the steel shell (middle) and high intensity cooler (right)

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. Figure 7 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.

Figure 7 – CFM (composite furnace module) cooling element for charging mouth of an anode furnace

INCREASING SAFETY AND FORGING NEW PATHS – ILTEC COOLING TECHNOLOGY

Since water, as the most commonly used cooling medium, is always associated with safety issues [7,8], the approach of Mettop is replacing water as the cooling medium by an ionic liquid. The 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 8 – 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

This new cooling technology can easily replace water whenever there is closed cooling loop and a secondary heat removal available and can make the operation more safe for people and environment.

What makes this new cooling technology even more interesting and revolutionary is the fact, that with the new safe possibility of cooling, areas might be cooled that are not cooled so far because of safety concerns. As an example the tuyere zone of a Peirce Smith converter is mentioned. For increasing the lifetime of the furnace it is of severe interest to increase the lifetime of the refractory at the tuyere level, which is an areas subjected to severe stresses and strains. One the one hand the erosive attack form the introduced air stream, one the other hand the permanent change of the thermal heat load lead to severe wear and therefore the tuyeres need to be replaced at regular intervals.

Also punching, as another mechanism causing severe wear of tuyere and bricks surrounding it, has to be mentioned. Caused by the high oxygen and iron content and the lower temperature caused by the air stream, some magnetite built ups (Fe_3O_4) will form. Getting rid of these built ups is done by a punishing machine leading to mechanical damage and breakouts.

With the new ILTEC Technology combined with an optimized geometry of the cooler (shown in Figure 9) Mettop is capable of significantly increase the tuyere lifetime. The figure shows the two-part copper cooler for cooling tuyere level of a Peirce Smith converter consisting of casted copper construction including a back plate which is flown through by the cooling medium and copper fingers for a better heat removal. A castable refractory mass is applied upon the copper. Again with this kind of high intensity cooler a freeze lining is intended to form because of the increased heat removal.

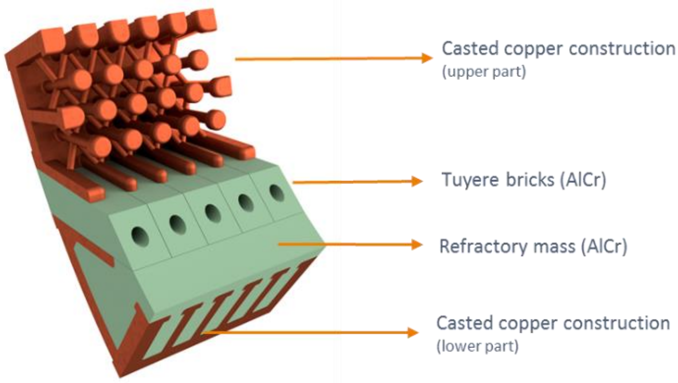

Figure 9 – Advanced CFM (composite furnace module) cooler for cooling tuyeres of a Peirce Smith converter

BENEFITS AND ECONOMICAL IMPACT – SUMMARY AND CONCLUSION

All the described possibilities and tools for improving and optimizing metallurgical processes is seeing the entire process as a whole. Starting from sharing know how to the operators with trainings courses, which is leading to a better understanding of single aggregates as well as the up and downstream within the process chain. Via an optimized refractory concept and the combination with new cooling elements and geometries the process performance is tried to be maximized. With the support of different modelling tools, the optimized operation mode can be achieved, finally leading to an optimized extent of automatization and process control.

At first sight and on considering all the time that has to be invested applying the tools furnace integrity is comprising of, this approach might looks complex and expensive. But on summarizing all the benefits that can be achieved, things turn out differently:

- Energy savings because of optimized process
- Increased product quality because of purging systems
- Less time for installation because of lining sequence and 3D refractory engineering
- Increased lifetime of wear parts and refractory
- Less down time for repair work, failures or breakages
- Increased safety because of water free cooling
- Decreased OPEX

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