EFFICIENT HOT METAL DESULPHURIZATION LADLE

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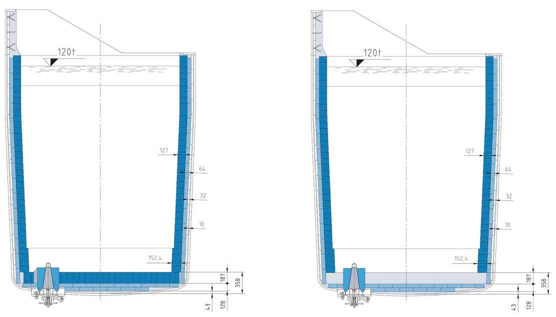
ABSTRACT

This paper provides an overview about refractories for a highly efficient hot metal (HM) ladle. Based on economic aspects for the lining concept, low thermal conductivity, and advanced purging during deslagging are the key issues in this paper. The optimal location and number of plugs were determined with CFD analysis leading to an efficient removal of the sulfur rich contaminated slag reducing iron losses and minimizing the amount of the remaining slag. Safety issues are rounding off the topic.

Key words:
Hot metal ladle, lining configuration, steel shell temperature, CFD simulation, deslagging, purging equipment, purge plugs, safety.

LINING CONFIGURATION

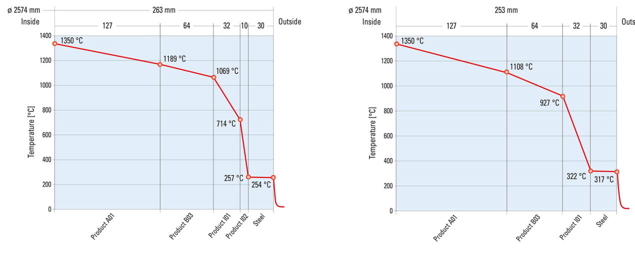
Several different lining concepts can be found for hot metal ladles. Depending on the operating, economic, environmental, and plant conditions, just to name the major influences, the best suitable lining concept has to be developed individually for each customer demand. Figure 1 describes two principle lining configurations. Usually, the working lining for hot metal ladles is lined either with fired high alumina bricks (based on bauxite or andalusite) or resin bonded high alumina bricks with additional SiC and carbon (ASC bricks) where the desulphurization takes place (Fig 1a)[1]. As an alternative, partial and full monolithic linings are also available (Fig 1b)[2]. However, monolithic ladle linings may require additional investments (e.g., template for side wall lining, mixing equipment, programmable pre-heater, etc.). The refractory consumption in the hot metal ladle is rather low, these investments for monolithic lining usually only makes economical sense, if a monolithic lining is also used in the steel teeming ladle where the machinery equipment can be used too.



(a) (b)

Fig. 1: Lining configurations for a 120 t hot metal ladle.
(a) Bottom and wall bricks; spout monolothics
(b) Bottom and spout monolothics; wall bricks

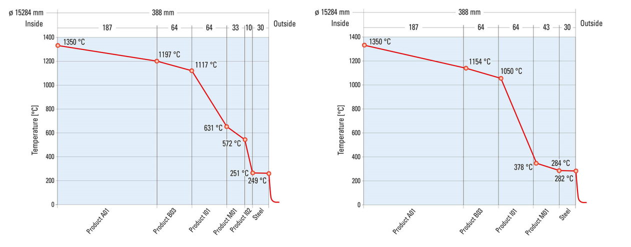
From an economic point of view the thermal conductivity has an important influence on costs due to thermal losses and should be limited. However, if the insulation is too high the refractory wear of the working lining would also be higher. A compromise has to be found to limit the temperature losses and prevent overheating of the insulating materials and ensure that the maximum allowed steel shell temperature is not exceeded. The temperature profiles are calculated as steady-state thermal conductivity and can be used for comparison of the lining concepts. Two examples with different temperature profiles for the wall are given below. Fig 2a has an additional insulating layer of 10 mm compared to a lining without this additional layer (Fig 2b). The difference in the steel shell temperature is 63 °C.



(a) (b)

Fig. 2: Temperature profile with (a) and without (b) additional insulating materials for the ladle wall.

Fig 3 demonstrates two bottom lining configurations. Fig 3a with a 10 mm insulation layer compared to a lining without this layer (Fig 3b). The steel shell temperature is 33 °C lower with the additional 10 mm layer.



(a) (b)

Fig. 3: Temperature profile with (a) and without (b) additional insulating materials for the ladle bottom.

Tab. 1: ASC bricks- chemistry and material properties.

ASC bricks											
Grade	Al_2O_3	SiO_2	SiC	Fe_2O_3	C	BD	AP	CCS	AOX	Bonding	Raw material
	%	%	%	%	%	g/cm³	vol. %	N/mm²			
All areas											
Product A01	85.0	6.0	5.0	1.0	7.0	3.00	5	100	■	Resin	Bauxite
Product A02	79.0	4.0	5.0	1.0	7.5	2.97	7	100	■	Resin	Bauxite
Product A03	85.0	5.5	6.5	0.6	8.0	3.06	7	85	■	Resin	Fused alumina
Product A04	81.0	3.5	6.3	0.5	6.0	3.05	7	80	■	Resin	Fused alumina

Tab. 2: Burned bricks- chemistry and material properties.

Burned bricks								
Grade	Al_2O_3	SiO_2	Fe_2O_3	BD	AP	CCS	Bonding	Raw material
	%	%	%	g/cm³	vol. %	N/mm²		
All areas								
Product B01	60.0	37.5	0.9	2.60	14	70	Ceramic	Andalusite
Product B02	66.0	32.0	0.7	2.70	13	80	Ceramic	Andalusite
Product B03	80.0	13.0	2.5	2.75	19	80	Ceramic	Bauxite
Permanent lining								
Product B04	43.0	52.0	1.5	2.28	15	50	Ceramic	Fireclay
Insulation								
Product I01	36.0	57.0	1.3	1.06		9	Ceramic	Lightweight fireclay

Tab. 3: Mixes- chemistry and material properties.

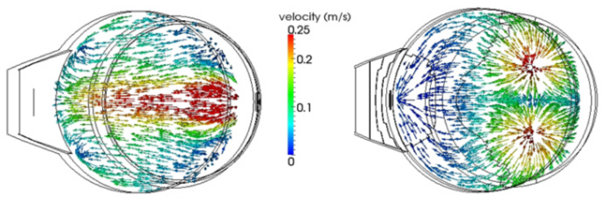
Mixes										
Grade	Al_2O_3	SiO_2	CaO	Fe_2O_3	GS	TL	BD	Bonding	Application	Raw material
	%	%	%	%	mm	°C	g/cm³			
Spout casting										
Product M01	82.5	12.0	1.1	1.2	6	1700	2.85	Hydraulic	Casting	Bauxite
Product M02	90.0	6.0	1.5	0.9	6	1700	2.89	Hydraulic	Free-flowing	Bauxite
Product M03	87.5	8.1	0.8	1.2	6	1700	2.85	Sol-bonded	Casting	Bauxite
Spout gunning										
Product M04	63.0	30.5	3.0	0.8	6	1650	2.31	Hydraulic	Gunning	Mullite

DESLAGGING PROCESS – CFD MODELING AND PRACTICAL RESULTS

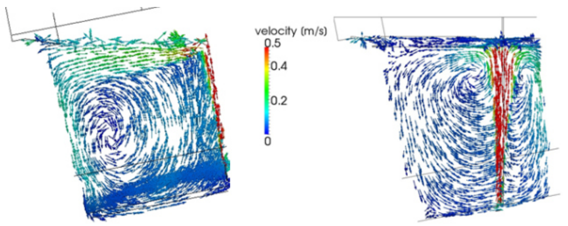
Hot metal desulphurization is nowadays state-of-the-art and mostly done in the hot metal charging ladle[3]. Desulphurization and deslagging are the main time consuming steps for the HM treatment. This paper describes measures to shorten the deslagging duration through efficient bottom stirring. The method of computational fluid dynamics (CFD) was employed to determine the optimal plug location. Gas stirring was simulated by the use of the discrete phase model[4]. The CFD calculation was carried out for a 290 t hot metal ladle with one purging plug which was located in the side wall and two purging plugs which were located in the bottom (Fig. 4). The purging rate for the two configurations was 38 Nm³/h per plug.

Fig 4a depicts the formation of an open eye having an elongated elliptical shape in horizontal orientation (red and yellow arcs). The slag will be mainly directed vertically to the wall 90 and 180 ° (light blue arcs). This means that the slag front is not parallel to the spout and the deslagging with a hook is more time consuming to remove the slag. Fig. 4b demonstrates the two wide open eyes which creates a slag front parallel to the slag spout. This slag front enhances the deslagging process.

Fig 4c demonstrates that the up-streaming vertical component collides with the refractory wall. This leads to a pre- wear of refractory especially in this specific wall area. Fig. 4d simulates the cross section through one plug which is located near the centreline of the bottom. The vertical streaming vectors are not interacting with the wall and the gas will be released with minimal contact on the surface compared with the example Fig. 4c.



(a) (b)

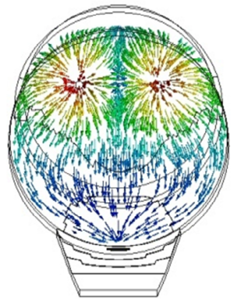


(c) (d)

Fig. 4: CFD simulations at a purging flow rate of 38 Nm³/h. (a) top view one plug, (b) top view two plugs, (c) cross section one plug, (d) cross section two plugs.

After the desulphurization the ladle is tilted into the deslagging position and the gas purging is initialized. Usually nitrogen gas is used and the flow rate can reach up to 40 Nm³/h per plug. The flow rate is mainly influenced by the slag viscosity, HM heat size, and ladle geometry. The released gas drives the open-eye formation via the purging effect (Fig. 5a). The slag will be moved from the open eye as a front towards the spout. A movable arm with a skimmer plate is used to release the slag out of the spout into a slag pit[5]. The amount of slag which has to be removed can reach up to 20 kg/t of hot metal. The deslagging process takes approximately 4 to 8 minutes while purging is affected by the operator skills, the size of the skimmer plate, as well as the amount and constitution of the slag.

(a)



(b)

Fig. 5: (a) Photo from the deslagging process, (b) CFD model top view.

The solution with two plugs placed in the bottom shows significant benefits:

- A better momentum at the hot metal-slag interface.
- No gas flow along the wall. This results in less erosion of the refractory wall lining

The benefits in general for bottom gas purging during HM deslagging are:

- Higher productivity due to reduced deslagging duration.
- Efficient deslagging results in less residual sulphur-rich slag.
- Less iron losses during deslagging.

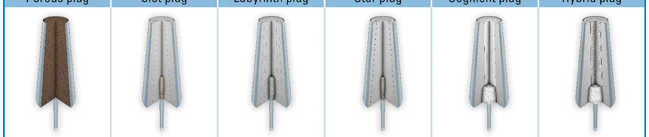
Finally, this CFD study accurately reflects field observations. The open eye formation and the subsequent movement of the slag towards the spout support the deslagging process and enhance the deslagging efficiency with the skimmer plate (Fig. 5a).

PURGE PLUG

Different purging plugs are used. The portfolio is listed below (Tab. 4)[6].

Tab. 4: Different purging plug configurations.

Purging plug types					
	Single component plugs			Multi component plugs	
Porous plug	Slot plug	Labyrinth plug	Star plug	Segment plug	Hybrid plug
Random pore structure	Direct pore structure			Random and direct pore structure	
High porosity	Separate slots	Cross linked slots	Continuous slots	High porosity and planar parallel slots	High porosity and surrounding slots
Pressed	Cast			Pressed and cast	



Not only is the best suitable purging plug essential, the gas flow regulation equipment has a tremendous influence on the purging availability. The gas connection is usually made with an auto coupling system which is activated when the ladle is placed in the desulphurization stand and released when the ladle leaves the stand. Purging starts when the ladle is turned into the deslagging position and stops when deslagging is finished.

Fig 6 demonstrates that each purge plug has its own flow control unit and the purging effectiveness will be controlled via cameras from the control room.

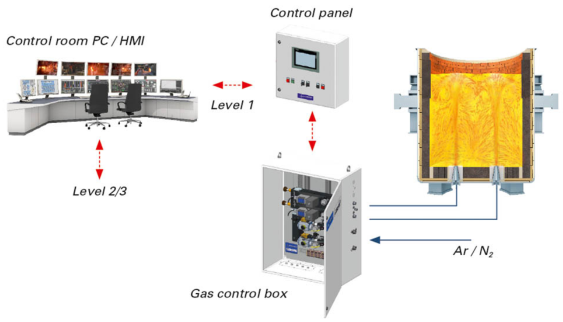
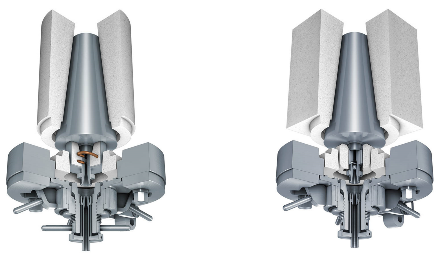


Fig. 6: Layout and instrumentation of a purging system[7].

SAFETY

Prevention of Break outs Through the Purge Plug

Hot metal has a very low viscosity which is critical for operational safety. The plugs can achieve a lifetime of several hundred heats without being checked on a regular basis. To reduce safety risks (e.g., HM breakout in the purging area) a closing system with best available technology (BAT) is required. The safety operating closing system with hinged door (SOC-H) provides a high level of operational safety and simple handling for the operator. It is able to stop a breakout in the event of penetration with hot metal if liquid material passes through the plug. The HM will be guided into the copper spiral or into the non return valve (NRV) (Fig 7). Both configurations display a high thermal conductivity, which leads to solidification of the HM.



(a) (b)

Fig. 7: SOC- H with (a) exchangeable safety pad with Cu spiral, (b) non return valve [8].

Hot spot Detection System

It is very difficult to determine the residual thickness of the wear lining. The main reasons are the high life time which is in some plants > 1500 heats and partly huge skull formation especially in the slag line area. The temperature distribution on the wall and bottom is monitored during the whole process time when the ladle is placed in the HM desulphurization stand. Several fixed installed infrared cameras monitor the steel shell temperature. The system displays the temperature distribution over the steel shell from each view angle as well as trend curves for selected areas, providing operators with information on an eventual problem area indicated by higher shell temperature. Potential hot spots are automatically detected and an alarm is displayed to the operators. An example is shown below (Fig 8). The results of each measurement are displayed directly in the control room. Each measurement sequence is recorded on the server for data trend analysis. This hot spot detection system is a part of condition monitoring for HM ladle and has been introduced in some integrated steel plants.

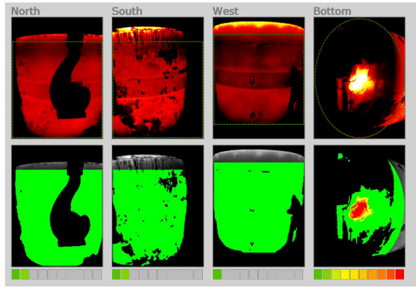


Fig. 8: Hot spot detection system for ladles[9].

CONCLUSION

Over the past decades the function of the hot metal ladle has transformed from a simple transport vessel to a treatment unit mainly for desulphurization in many of the steel mills due to economic reasons. Refractory concepts have to be chosen individually for each customer's processes and operating conditions. The lifetime of hot metal wear lining can vary up to > 2000 heats. Desulphurization and deslagging has to be done as rapidly as possible. CFD simulation is a useful tool to determine the best position for the purging plug. The specific chosen plugs and the gas stirring facility are key factors. Operational safety is an important point for the purge plugs; the SOC-H is an appropriate system to guarantee a high level of safety. The steel shell temperature will be continuously monitored if the ladle is in the desulphurization stand by means of infrared cameras and displayed at the control room.

All mentioned aspects are parts of an efficient cost effective and safe desulphurization process.

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