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Impact Zone Solutions for an Improved Flow Performance in the Tundish

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INTRODUCTION

The tundish is an intermediate vessel in the continuous steel casting process, linking the ladle with the mold. Today the tundish not only functions as a buffer, but it also acts as a refining vessel with the aim of removing nonmetallic particles and guaranteeing thermal equilibrium between the strands, which is strongly linked to the fluid flow. Therefore, flow control in the tundish is of great interest for many steelmakers with a high focus on product quality. In many cases an impact pot is installed, which functions to eliminate initial splashing, dissipate the kinetic energy from the incoming jet, reduce turbulence in the entire vessel, and optimize the flow for enhanced particle removal and temperature distribution in the strand(s). The impact pot design is known to have a strong influence on these performance indicators. Additionally, tundishes vary in capacity, shape, and number of strands, as indicated in Figure 1. Hence different design approaches have to be considered to obtain favorable flow conditions. There is no "one size/design fits all" solution available, and therefore significant effort is invested in the development, optimization, and customization of this refractory product, to meet the requirements of each individual machine type.

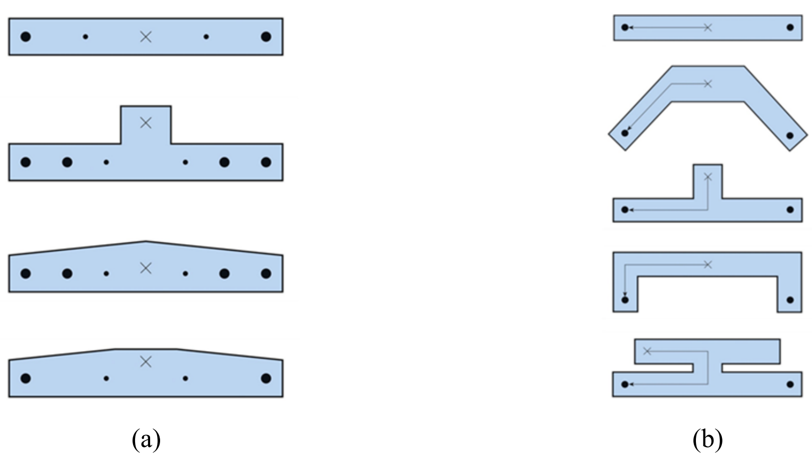

Figure 1: Schematic of typical tundish shapes for (a) billet/bloom and (b) two-strand slab casters [1,2].

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FLUID FLOW IN THE TUNDISH

Fluid flow in the tundish is closely linked to the metallurgical performance and as a consequence, to the quality of the product. Detailed understanding of flow phenomena is therefore crucial for optimizing the process. With respect to the operating conditions one can distinguish between two types of events: steady state casting vs. transient periods. For the performance under steady state casting conditions, the approach of measuring the residence time distribution (RTD) has been commonly applied by many researchers. The residence time of a fluid in a reactor, such as the tundish, is defined as the time a single fluid element will remain in the reactor. Usually, flow in any tundish is accompanied by different residence times for different fluid elements, which will end up in a distribution function of residence times. From the curve, important parameters for the characterization of the performance can be derived, such as the minimum residence time Θ_{min}, the mean residence time Θ_{mean}, the plug flow volume V_P, the well-mixed volume V_M, and the dead volume V_D. In order to maximize the flotation behavior and avoid re-oxidation in a given tundish under steady state casting conditions it is necessary to ensure the following points: Minimum spread of residence time, minimum dead volume, large ratio of plug to dead volume and plug to mixed volume, surface directed flow, quiescent slag layer and contained regions of mixing [3,4]. Transient casting conditions such as start of casting, or the event of a ladle or a grade change are known as the enemy of quality. These events, very often result in the formation of additional inclusions by re-oxidation. Splashing at the beginning of the cast, slag emulsification during a ladle change or vortex formation at the end of a sequence, which can all be the source of additional contamination, need to be avoided as much as possible.

MODELING APPROACHES

Due to the harsh conditions of the production process, only limited measurements are available. A direct measurement of the entire flow pattern is not possible. Therefore, modeling approaches via water modeling and computational fluid dynamics (CFD) represent valuable tools to investigate fluid flow in the tundish. They can be used in an efficient way and despite certain limitations, they provide useful information to further the process understanding and derive measures for improvement, such as design aspects.

Water modeling

Physical modeling, through water modeling is an efficient way to understand steel flow inside tundishes. Fundamental considerations of water modeling require the model system to approximate, as closely as possible, the conditions in the actual system. To warrant this, certain similarities between the real application and the model must be fulfilled, which includes geometric, dynamic, kinematic, and thermal similarity [5, 3]. In general, not all of these criteria can be fulfilled simultaneously, however models either full or down-scaled are able to provide useful information about the tundish flow characteristics and can help to optimize the tundish performance. Several studies have been performed in the past, which compared the results of full and down scaled models. From the observation it can be concluded, that a model tundish, scaled down on the basis of geometric similarity and fulfilling the Froude similarity criteria is likely to simulate flow phenomena of the corresponding full-scale system fairly accurately [5]. The Froude number, which is the ratio between inertial and gravitational forces, is defined as:

$$Fr = \frac{u^2}{g.l}$$

Where u is the flow velocity [m/s], g the gravitational acceleration [m/s²] and l a characteristic length of the system[m].

Computational fluid dynamics (CFD)

Computational fluid dynamics provides a framework for simulating complex three-dimensional fluid flow as well as related phenomena in the tundish. It consists of three major steps: Pre-processing (creation of a geometric model and meshing), solving, and post-processing (data analysis, visualization, and validation of results). In contrast to water models, it can provide a much more detailed image of velocity, turbulence, or temperature distribution, based on real operating conditions and melt properties. In order to simulate turbulent, transient, nonisothermal fluid flow, a set of conservation equations, such as continuity, momentum, and energy need to be solved. The effect of turbulence is typically modelled using an eddy viscosity approach, such as the k-ε model. A detailed model description can be found elsewhere [6]. Subsequently, the flow model can be extended to investigate the flotation behavior of nonmetallic inclusions, for example as a dispersed phase in the melt, in relation to specific furniture configurations.

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EXAMPLES

Over the last years, several impact pot solutions have been developed by RHI Magnesita with the focus on providing superior functionality over existing concepts [7,8]. The impact pot product family consist of the following types: TUNFLOW [9], TUNFLOW Chevron [9], TUNFLOW Chevron Push [9], TUNFLOW Meander [9] and RisaImpact [9]. A schematic of each type is shown in Figure 2.

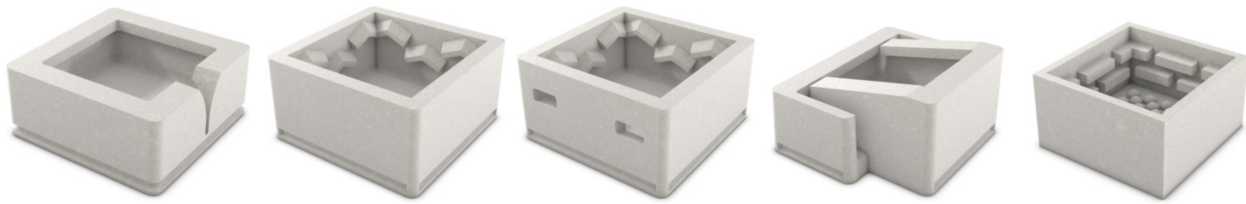


Figure 2: (a) TUNFLOW, (b) TUNFLOW Chevron, (c) TUNFLOW Chevron Push, (d) TUNFLOW Meander and (e) RisaImpact.

Each of the product types is characterized by specific geometrical features, with the target to fulfill the individual needs with respect to an optimized flow performance.

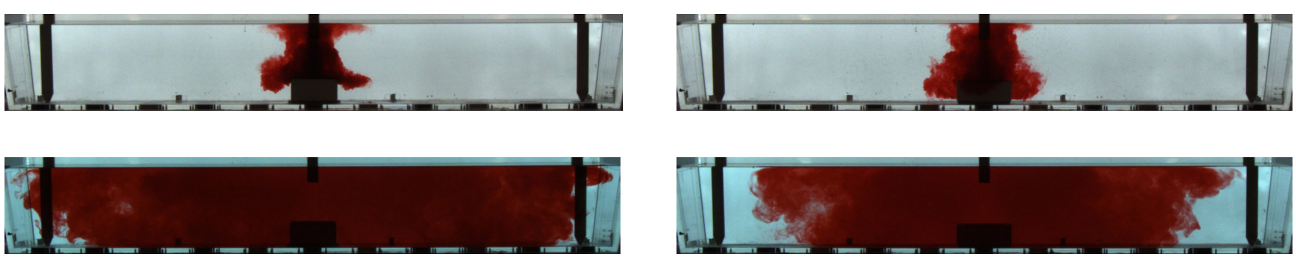
Improvement of RTD parameters for a twin strand slab caster

The objective in this study was a comparison of different impact pot solution for a twin strand slab caster. The current impact pot (design 01) was therefore compared to alternative solutions, with respect to the RTD parameters. The tundish shape was a boat type without any additional furniture. The operating conditions during steady state casting are provided in Table 1.

Table 1: Operating conditions.

Tundish capacity [t]	40
Throughput [t/min]	3.9
Bath level [mm]	900
Ladle shroud immersion depth [mm]	180

A water model study based on the previously listed operating conditions was performed. The RTD curve was simultaneously measured on both strands. Four repetitions of each set up were conducted. Furthermore, snap shots after a pulse injection of dye for the current solution and the best performer, a TUNFLOW with two progressive slots, are shown in Figure 3. The obtained RTD parameters are listed in Table 2 and the average curve is provided in Figure 4. It can be concluded, that a significant improvement of the flow performance can be obtained by the TUNFLOW.



(a) (b)

Figure 3: Image sequence of dye injection experiment for (a) current set-up and (b) TUNFLOW.

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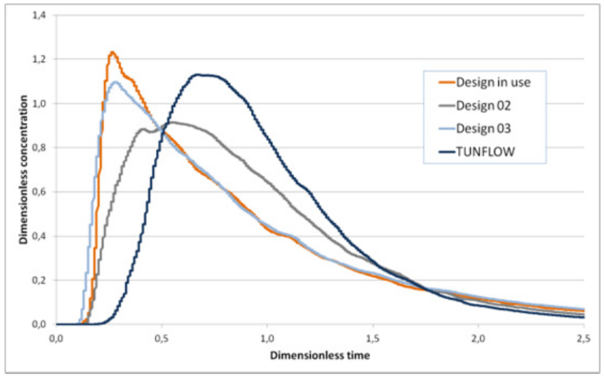

Figure 4: RTD curves of different impact pot designs.

Table 2: Corresponding RTD parameters.

	Design in use	**TUNFLOW**
θ_{MIN}	0.13	0.22
θ_{MEAN}	0.76	0.93
V_{DEAD} [%]	32.0	11.0
V_{PLUG} [%]	12.6	21.8
V_{MIX} [%]	55.4	67.2

Improvement of RTD parameters for a single strand slab caster

With the target to increase the active volume over the stagnant, especially in single strand tundishes, the MEANDER type impact pot was developed. The feature of this impact pot is a design configuration to direct the flow into regions, which are usually poorly supplied with fresh steel, namely the bottom region in the vicinity of the impact pot itself. Due to the design, part of the incoming stream is forced to make a u-turn before it leaves the product in a calm and smooth manner. As a consequence, the region beside and behind the pot is not stagnant and there is no impingement flow onto the wear lining of the side wall. Furthermore, the flow towards the strand, which is opposite the u-turn opening, can be slowed, resulting in an increase of the minimum residence time. A water model study of a single strand slab caster was conducted with the target to improve the flow performance compared to the existing set-up. Table 3 shows the considered operating conditions.

Table 3: Operating conditions.

Tundish capacity [t]	28
Throughput [t/min]	2.6
Bath level [mm]	800
Ladle shroud immersion depth [mm]	250

An image sequence showing different moments of time taken during the dye injection test for the standard product and TUNFLOW Meander is shown in Figure 5. In the TUNFLOW set-up, the tracer fluid is obviously moving more slowly towards the outlet of the tundish, resulting in a significantly longer minimum residence time. The corresponding RTD curves and the calculated RTD parameters are provided in Figure 6 and Table 4. Again, a significant improvement of the flow performance was observed.

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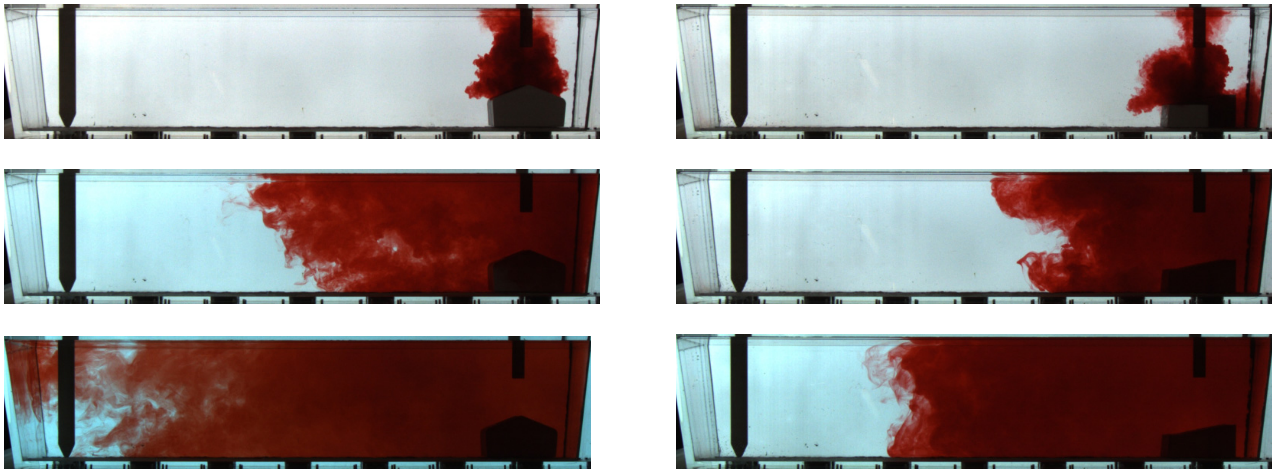

(a) (b)

Figure 5: Image sequence of dye injection experiment for (a) current set-up and (b) TUNFLOW.

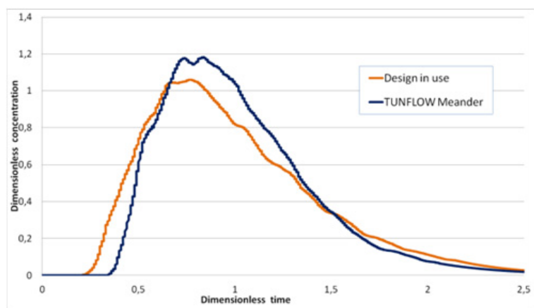

Figure 6: RTD curves of different impact pot designs.

Table 4: Corresponding RTD parameters.

	Design in use	TUNFLOW Meander
θ_{MIN}	0.28	0.38
θ_{MEAN}	0.94	0.98
V_{DEAD} [%]	8.7	5.1
V_{PLUG} [%]	28.3	38.2
V_{MIX} [%]	63.0	56.7

Reduction of surface turbulence and risk for “open eye” formation

One of the key functions of an impact pot is the dissipation of kinetic energy, which is linked to splashing prevention at start of casting and a reduction of surface turbulence, to minimize the risk for open eye formation. One very effective way is provided by TUNFLOW Chevron, characterized by special shaped protrusions on the side wall.

A CFD simulation was carried out to determine the influence of different impact zone solutions on the surface velocity/turbulence dependent on the casting rate. Four different set-ups, namely the bare tundish (impact plate), a simple pot solution (Design 1), a impact pot with overhang (Design 2) and a TUNFLOW Chevron were investigated. A model tundish with a bath level of 900 mm and a ladle shroud immersion depth of 250 mm was considered. The casting rate was varied between 2 and 5 t/min, which represents a typical operational window for slab casters. In Figure 7, a velocity contour plot focusing on the surface in the impact zone for each different case assuming a casting rate of 4 t/min is illustrated.

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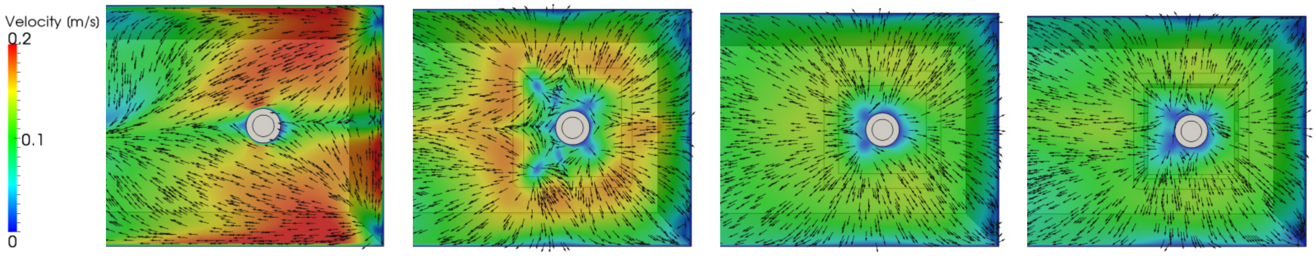
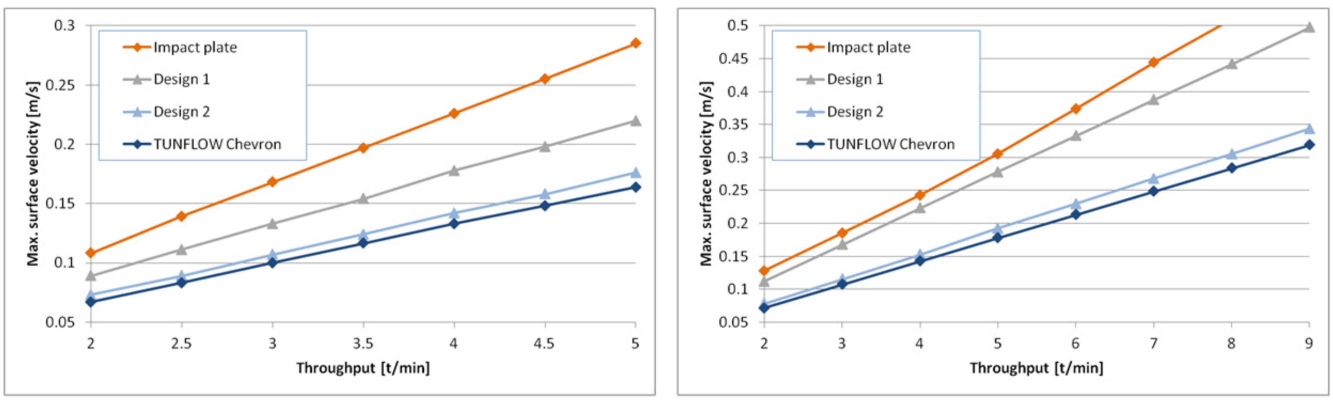


(a) (b) (c) (d)

Figure 7: Calculated surface velocity plot for (a) impact plate, (b) Design 1, (c) Design 2 and (d) TUNFLOW Chevron.

Figure 8(a) indicates the maximum occurring surface velocity dependent on the casting rate for the different set-ups. A linear relationship was found for all tested configurations. It is evident, the pure impact plate set-up suffers from the highest velocities and also the highest gradient was obtained. Ideally, the target was to keep the velocity as low as possible, TUNFLOW Chevron shows the best performance over the entire simulation range. During a ladle change, when the bath level is usually reduced and the throughput is above nominal casting rate, the differences can become even greater. In the second example the bath level was reduced to 700 mm and the throughput range was increased to 9 t/min. The results for these conditions are shown in Figure 8(b), TUNFLOW Chevron again shows the best performance among the tested configurations.



(a) (b)

Figure 8: Maximum occurring surface velocity dependent on throughput for (a) 900 mm bath level and (b) 700mm bath level.

Optimization techniques for impact pot geometries

The geometric features of an impact pot have a significant role in promoting energy dissipation and consequently on the flow obtained in the tundish. For this reason, a parametric optimization of the geometric features of a RisaImpact design was performed. The optimized parameters were the vertical distance between the bottom and the first row of wall tabs (P1), the vertical gap between the rows of tabs (P2), the tab length (P3) and the horizontal gap between the tabs (P4), illustrated in Figure 9.

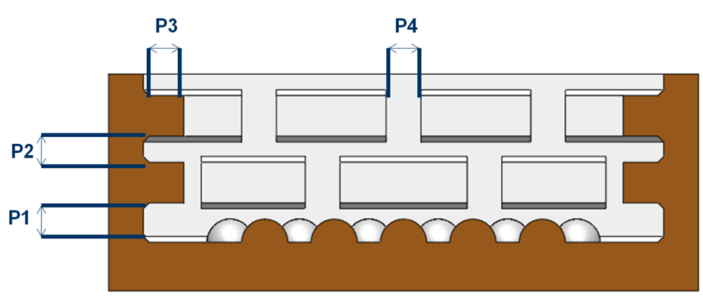


Figure 9: Cross section of a RisaImpact design, showing the parameters which were varied.

The optimization procedure was divided into three steps:

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- First, a design of experiments (DOE) matrix was generated with several different combinations of the design parameters (P1, P2, P3 and P4) in order to cover the whole range of admissible parameters with the fewest number of simulations as possible.
- Then, a response surface was adjusted in the obtained data from the CFD model and extra refinement points (represented as additional combinations of the design parameters) were computed and added to the response surface calculation in order to increase accuracy.
- Finally, a verification algorithm was run with the goal of assessing the accuracy of the response surface and searching for the global maximum and minimum of the desired outputs.

In the subsequent analysis the desired results from the optimization model were the global minimum for the turbulence kinetic energy at the slag surface, the global minimum for the wall shear stresses at the refractory lining, and the global maximum for the minimum residence time. As it consists in a multiple objective problem, the optimization model solution consisted of three alternative candidates, each with a higher score in one of these goals. The overall results are shown in Figure 10. The central black square with the thicker lines is the reference case, scoring 0% at every desired output. The results for the other cases have been calculated in relative percentage compared to the reference case. In the results where improvement has been obtained, positive percentage values have been assigned, even if the improvement means a reduction in the absolute value of the variable (e.g. if the turbulence value reduces by 30%, this result is shown as positive 30% in Figure 10 because it means a 30% improvement has been obtained with respect to this variable).

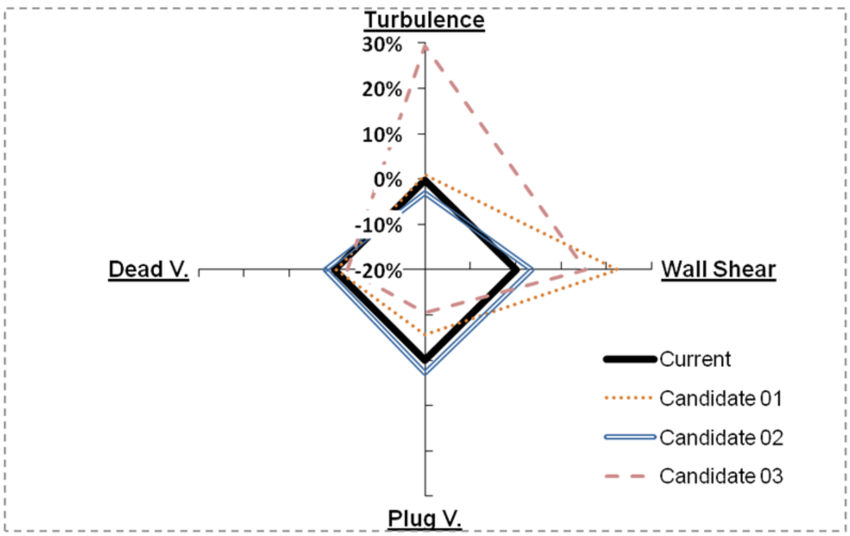

Figure 10: Results of the optimization study.

Examples of the results for the occurring wall shear at the refractory wall for the reference case and the optimum case are shown in Figure 11.

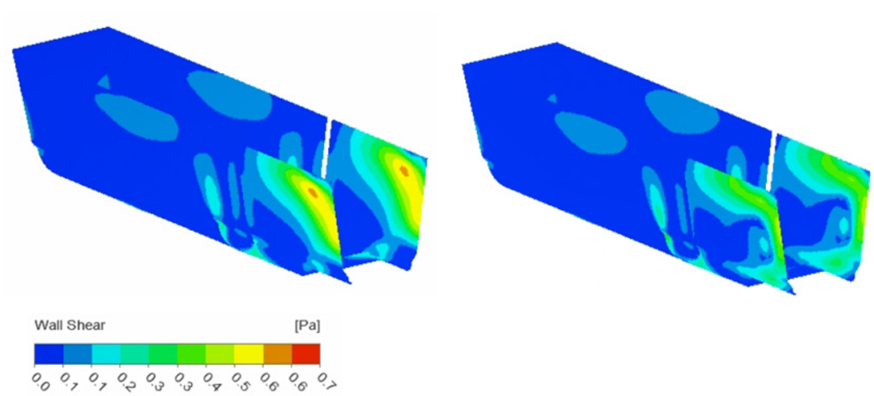

Figure 11: Comparison between wall shear stresses of the reference case (left) and the optimum case (right).

SUMMARY

In order to improve the overall flow performance in the tundish, the design of flow modifiers, like impact pots, has to be carefully evaluated. Different tundishes require different concept approaches to meet the specific targets, such as minimization of surface turbulence or the maximization of residence time. With the aid of physical and numerical methods, RHI Magnesita has developed a product family to cover the complete range of applications. Several examples, such as the potential to reduce surface velocity and turbulence to minimize the risk for open eye formation and the improvement of residence time distribution were shown in this paper. Furthermore, numerical optimization algorithms were applied to further improve the design of flow control devices, tailored to the needs of customers.

REFERENCES

1. J. Schade, ed., "Clean Steel with Improved Tundish Design and Practices," Tundish Metallurgy, Vol. 2 (Warrendale, Pa.: Iron and Steel Society, 1991), 3-71
2. M.M. Wolf, "Slab Caster Tundish Configuration and Operation – A Review," *Proc. Steelmaking Conf.*, 79, 367-381, 1996
3. Y. Sahai, T. Emi, "Melt Flow Characterization in Continuous Casting Tundishes," ISIJ International, Vol. 36, No. 6, pp. 667-672, 1996
4. R. Ahuja, Y Sahai, "Fluid Flow and Mixing of Melt in Steelmaking Tundishes," Ironmaking and Steelmaking, Vol. 13, pp. 241, 247, 1986
5. D. Mazumdar, R. I. L. Guthrie, "The Physical and Mathematical Modelling of Continuous Casting Tundish Systems," ISIJ International, Vol. 39, No. 6, pp. 524-547, 1999
6. B.A. Launder, D.B. Spalding "The numerical computation of turbulent flows," Computer Methods in Applied Mechanics and Engineering, 3, 1974.
7. G. Arth, D. Meurer, Y. Tang, G. Hackl, B. Petritz, "Tundish Technology and Processes: Ladle to Mould Systems and Solutions (Part II)," Bulletin, pp. 64-70, 2017
8. G. Arth, D. Meurer, M. Kappel, P. Loop, B. Petritz, "Tundish Technology and Processes: Ladle to Mould Systems and Solutions (Part III)," Bulletin, pp. 64-70, 2018
9. Patents and patent applications pending.

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