Improvement of steel cleanliness with electromagnetic stirring in tundish

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Abstract: A novel electromagnetic stirring technology is introduced into a four-strand billet caster tundish. The purpose is to increase mixing zone volume and average flow speed, and eliminate dead zones, the melt surface speed is kept low to avoid slag entrapment. From a metallurgical perspective, strand temperature is homogenized, inclusion aggregation and removal are improved, and the number of sequence casting heats increased.

Water modeling was carried out to investigate the flow characteristics, as well as numerical simulation on both fluid flow and inclusion behavior. The results show that this technology is particularly useful for improving steel cleanliness in multi-strand billet caster tundish.

Key words: Tundish, Electromagnetic stirring, Steel Cleanliness, Inclusion

Introduction

The classic theory on flow control in the tundish can be summarized as

- To check flow characteristics by studying the RTD (Residence Time Distribution) curves and maintain homogeneity among the outlets by keeping RTD curves similar at different outlets.

- To improve floatation of inclusions by increasing the ratio of plug flow volume and decreasing dead zone volume, and sometimes by guiding plug flow towards the slag layer.

- To improve inclusion removal by increasing the average residence time.

With the higher requirement for steel cleanliness, it was found that inclusions smaller than 50μm or inclusion clusters are still difficult to remove from the tundish. Recent research has been carried out in the following area:

- To improve inclusion collision, coalescence and growth by increasing turbulence energy (represented by the dissipation rate of the turbulent kinetic energy, $\varepsilon, m^2/s^3$), and consequently increase inclusion removal from the tundish.[1]

- To study inclusion reactions at melt-slag interface; it was found that collision time and chemical composition both affect absorption of inclusions at the melt-slag interface.

There are mainly two types of tundish based on continuous caster type; namely slab caster tundish and billet caster tundish. The average residence time for slab caster tundish is about 5-10 mins while for billet caster tundish it is about 20-30 mins due to its smaller throughput. For biller caster, it is quite normal to have just one tundish equipped for more than 3 casting strands and in some cases for more than 10. The

requirements for temperature homogeneity among the multi-strands of billet caster tundish are much higher than those for the slab caster tundish. The longer residence time in billet caster tundish also makes it possible to remove inclusions there.

In this paper, we follow the guidelines shown below for flow control in billet caster tundish:

- To create a gentle flow in the whole volume of the outlet zone of the tundish by applying one electromagnetic stirrer outside the tundish.

- To increase mixing volume and reduce the dead zone in the tundish in order to

    o   homogenize flow and temperature distribution, and

    o   accelerate collision and coalescence of inclusions and floatation of larger sized inclusions.

- To control the speed at the slag layer avoiding entrapment of slag inclusions

- To make full use of the long residence time in the tundish to clean the steel

The following work has been done and is presented in this paper:

- One tundish in Zenith steel Co. Ltd. is selected as a pilot installation tundish

- Water modelling with and without stirring, and investigation of simplified refractory furniture

- Numerical simulation and investigation of flow characteristics such as stirring speed, and specific stirring energy

- Simulation of inclusion collision, coalescence, and removal are also carried out to investigate the efficiency of electromagnetic stirring on inclusion removal

Water modeling

Zenith Steel Co., Ltd., located in Changzhou City, Jiangsu Province, China, was established in September 2001, and currently has an annual steel output of over 11 million tons. No.3 caster in steel plant No.3 was selected for the pilot installation of tundish electromagnetic stirring.
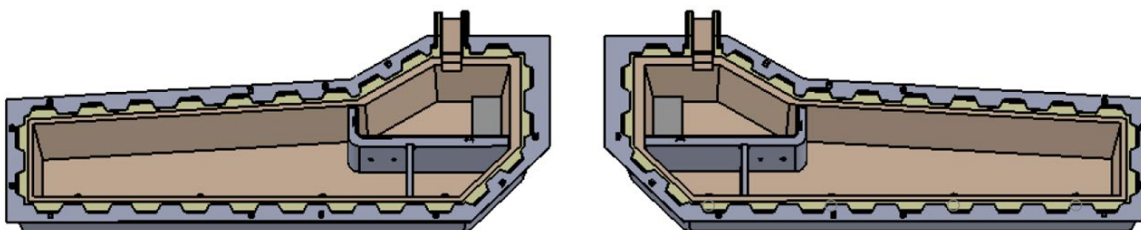

Figure 1 Configuration of twin-tundish at Zenith steel Co., ltd

The caster has 8 billet strands and is equipped with two tundishes. The max throughput of each tundish is 1.9 ton/min, normal working capacity is 40 ton, bath depth is 850 mm, ladle size is 110 ton, and main

steel grades are gear bearing steel, spring steel, etc. One original baffle wall with three holes (as shown in Figure 2a) is mounted in the tundish in order to reach temperature homogenization among the strands.
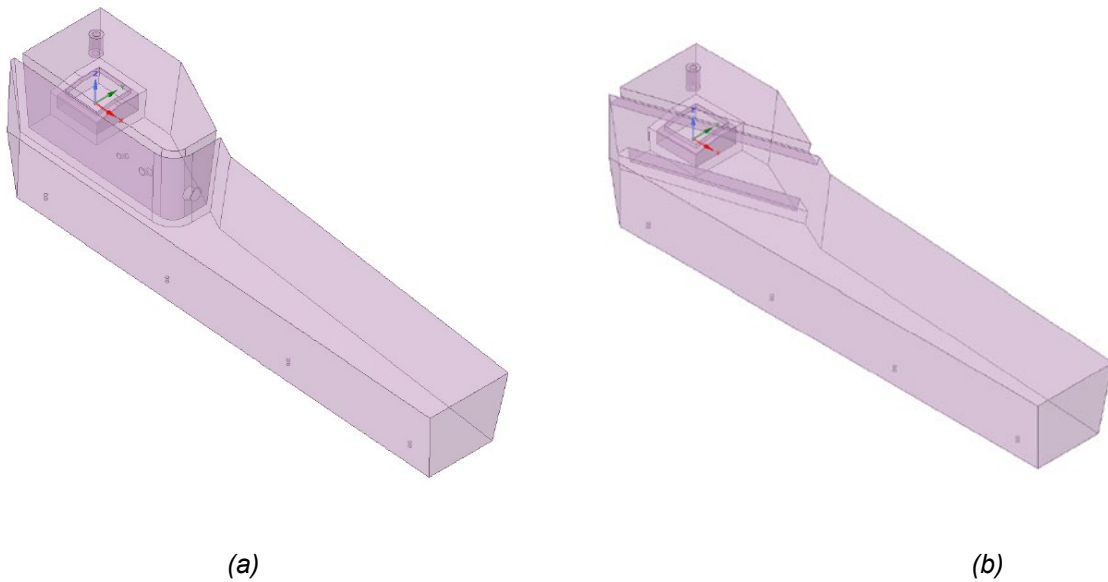

(a)   (b)

Figure 2 The original baffle wall and the new baffle wall in the tundish

During the pilot project, the original baffle wall (Figure 2a) was replaced with a new baffle wall (Figure 2b) to be installed together with EMS.
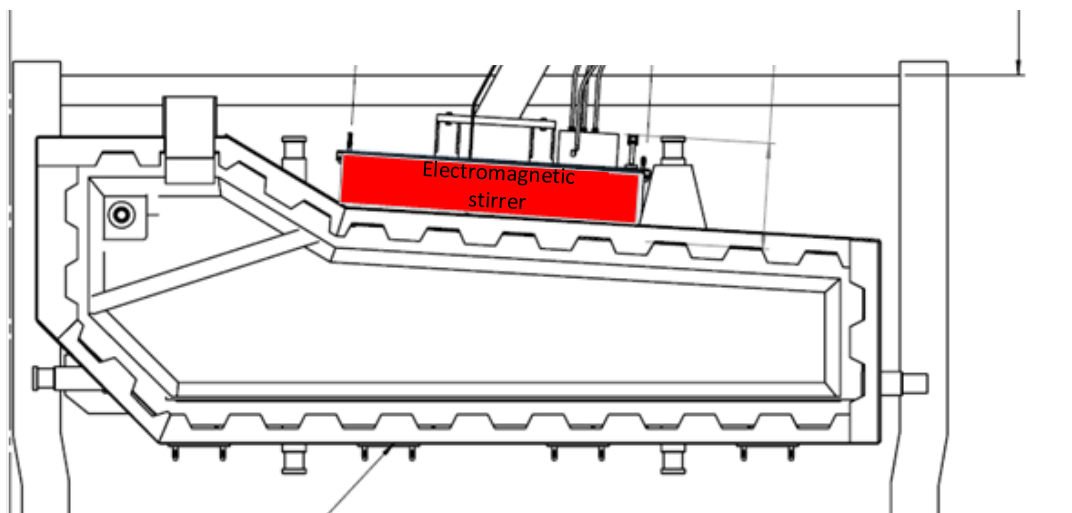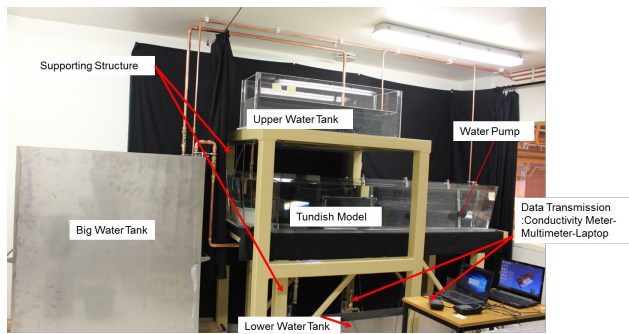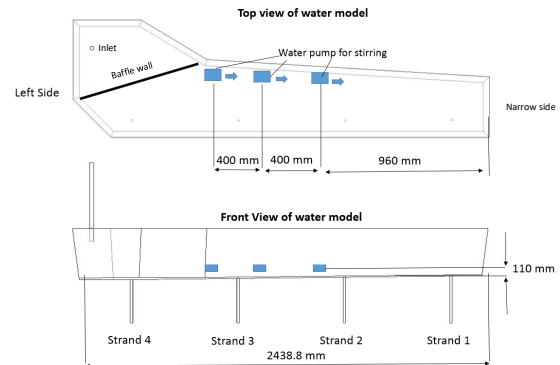

Figure 3 Position of tundish EMS

The electromagnetic stirrer (type ORG 2550) is installed on one tundish and is mounted on the side close to the turret. The electromagnetic stirrer creates a horizontal stirring in the whole volume of the tundish.

| (a) Picture of the water model setup | (b) Configurtion of water model |

Figure 4 Water model set-up

One water model at a scale of 1:2.5 is set up as shown in Figure 4. Three water pumps are installed to simulate electromagnetic stirring. The stirring direction of the water pump can be adjusted towards the tundish inlet or towards the tundish narrow side.
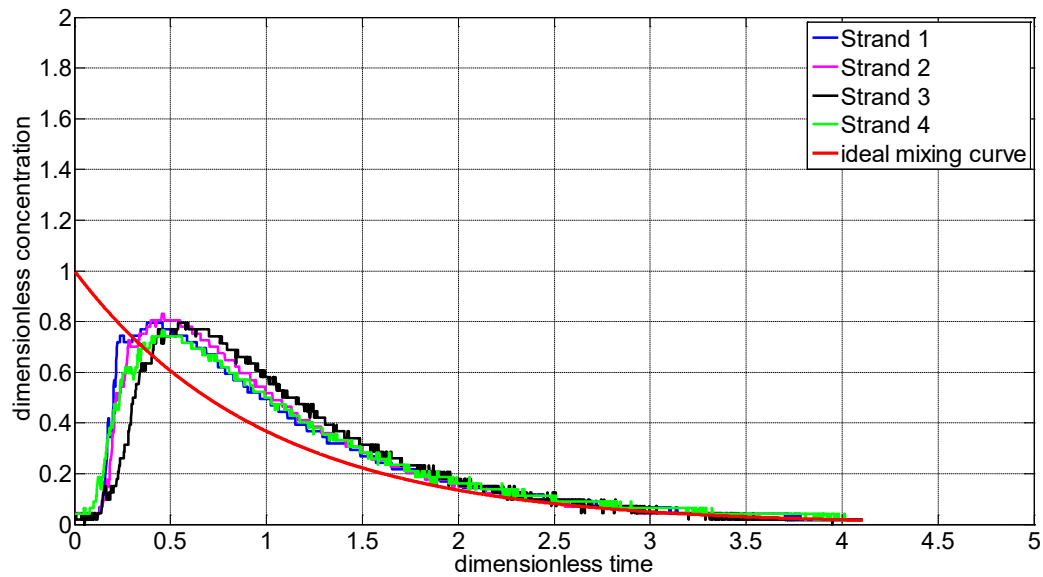

| (a) With the original baffle wall, without stirring | (b) With the new baffle wall, with stirring |

Figure 5 Snapshots of tracer color distribution in the tundish at different times

As a first step, a tracer color is added into the tundish inlet to visualize the mixing and homogenizing phenomena of different configurations, Figure 5a shows that it takes the tundish with original baffle wall and without stirring about 409 seconds to achieve complete mixing in the tundish while it takes only 236 seconds with the revised baffle wall and stirring.

(a) With the original baffle wall and without stirring
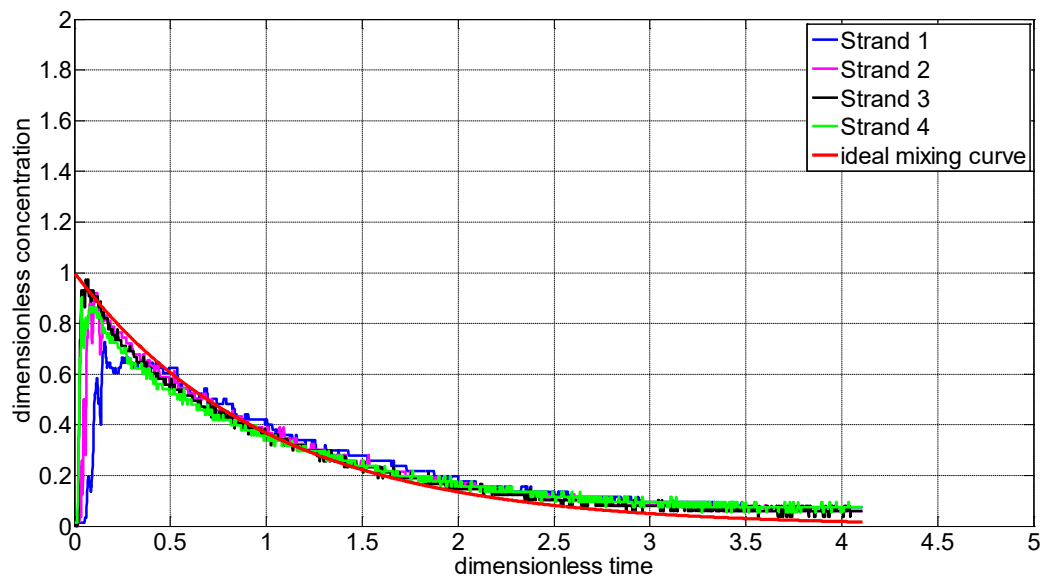
(b) With new baffle wall, and with stirring

Figure 6 RTD curve of water modeling

Figure 6 shows the measured RTD curves at the outlets (strand one is located closest to the tundish narrow face). Strong similarities are shown between the 4 strands in the tundish with the existing baffle wall though there is big portion of plug flow volume and dead zone volume, which is a real disadvantage. In the tundish with revised baffle wall and stirring, strand similarity is even better, with the whole RTD curve very close to an ideal mixing curve, and the plug flow volume and dead zone volume are almost entirely eliminated as shown in Figure 7.
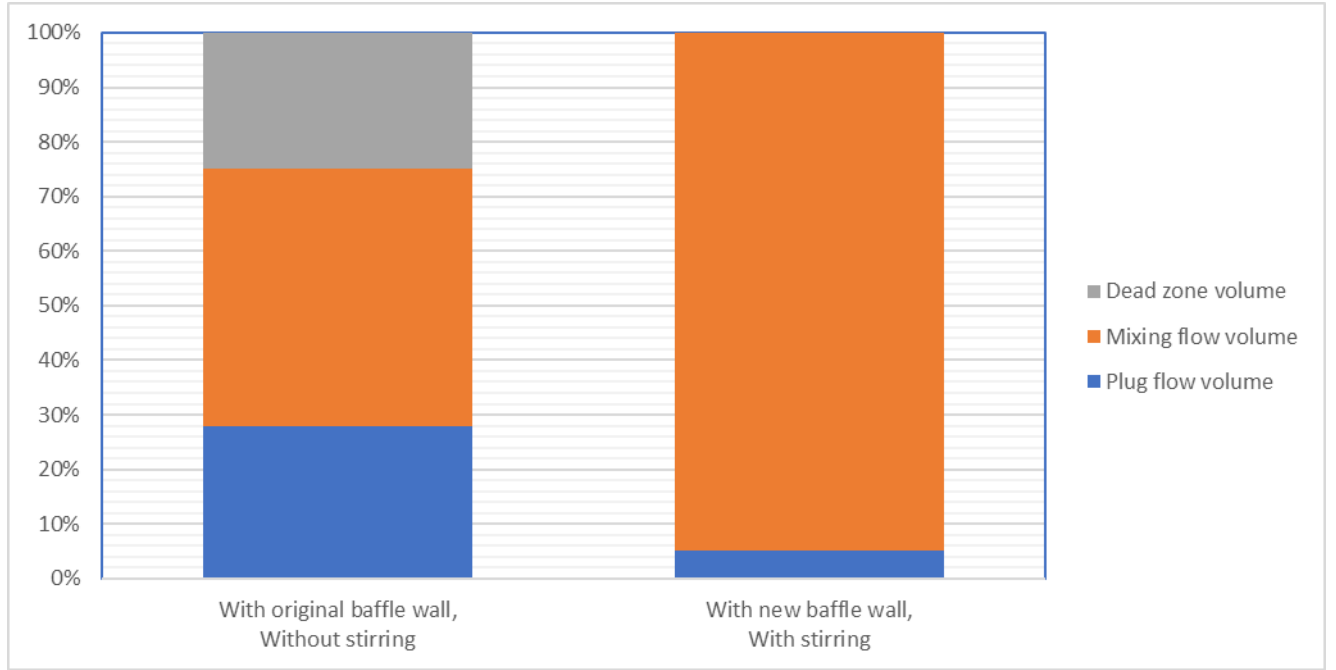
*Figure 7 Quantification of RTD curves from water model*

Flow modeling

Numerical fluid simulations have been carried out to investigate flow characteristics such as flow velocity and stirring energy.

Figure 8 (a,b) shows the flow velocity vector plots at the horizontal midplane of tundish. In order to quantify the flow characteristics, the whole tundish volume is divided into two zones; the zone on the inlet side of the baffle wall is named as inlet zone, and the zone on the outlet side of the baffle wall is named as outlet zone. From Figure 8 it can be seen that, with EMS, a macro rotating flow is formed in the outlet zone which will homogenize the temperature among the outlets, and also transform the whole outlet zone into mixing volume. Figure 8(c,d) shows the trajectory of tracer particles in the tundish in a 3-dimensional view.
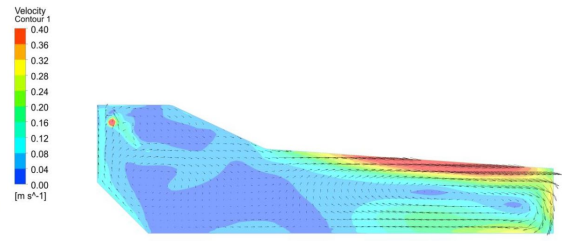
The specific stirring energy has been used in this work to quantify the flow characteristics,

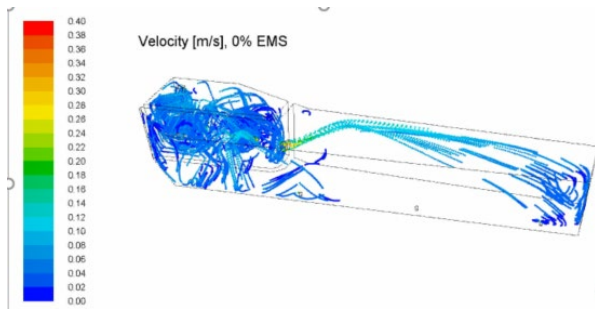$$\dot{\varepsilon} = \frac{\int_0^\Omega \varepsilon \, d\Omega}{\int_0^\Omega d\Omega} \cdot g \cdot 10^3 \, , \qquad\qquad\qquad Equation\ 1$$

Where $\dot{\varepsilon}$ is the specific stirring energy, w/ton, ε is the dissipation rate of the turbulent kinetic energy, m^2/s^3, g is the gravitational acceleration, m/s^2.
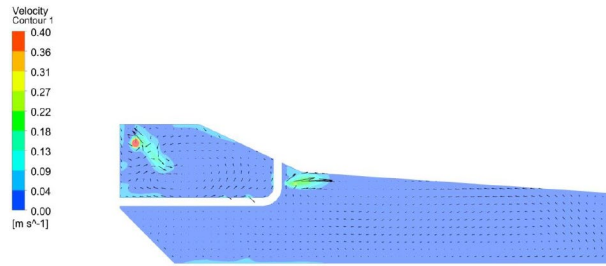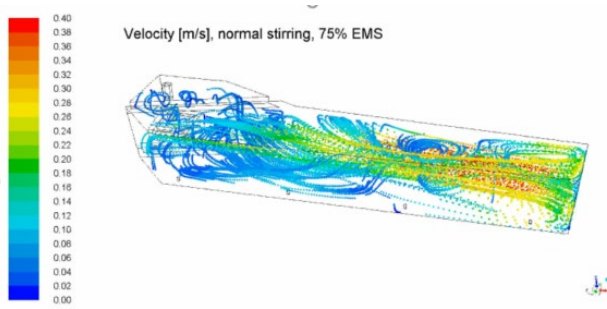
(a) Velocity vectors with orginal baffle wall, without EMS   (b) Velocity vectors with new baffle wall and EMS

(c) Trajectory with orginal baffle wall, without EMS   (d) Trajectory with new baffle wall and EMS

Figure 8 Flow velocity at the mid plane of the tundish and trajectory

Table 1 Flow speed quantification with and without EMS

Case	Volume averaged speed in the outlet zone (m/sec)	Max surface speed in the outlet zone (m/sec)	Specific stirring energy in the outlet zone (w/ton)
With original baffle wall, without EMS	0.024	0.35	0.83
With new baffle wall, with EMS	0.11	0.38	15.3

Table 1 lists the flow speed quantification with and without EMS. For the case without EMS, the volume averaged speed and specific stirring energy is very low, and not favorable for inclusion collision and coalescence. With EMS, both the stirring speed and specific stirring energy are increased, and the inclusion collision and coalescence will be accelerated (as shown in the next section). In order to avoid slag entrapment, the maximum surface speed with EMS is still almost the same as that without EMS.

Inclusion modeling

Mathematical modeling is carried out to predict transient concentration and size distribution of inclusions, removal of inclusions at slag layer is also modeled by considering the relationship between collision time and rupture time.

The simulations of collision, coalescence and growth of inclusions are realized via Population Balance Model in Ansys Fluent. The coalescence rate is determined by the sum of Brownian, Stokes and turbulence collisions. To reduce the computation time only Al_2O_3 inclusions are considered.

The inclusions are divided into 16 classes in diameter between 1µm and 97µm, the initial volume fraction in the inlet and tundish is set as 10ppm. Concentration of particles and volume fraction of inclusions on inlet is fixed and not change in time. A detailed description of the model is referred to in the paper by Ling, et, al [1]. 300 seconds process time is simulated in this work.
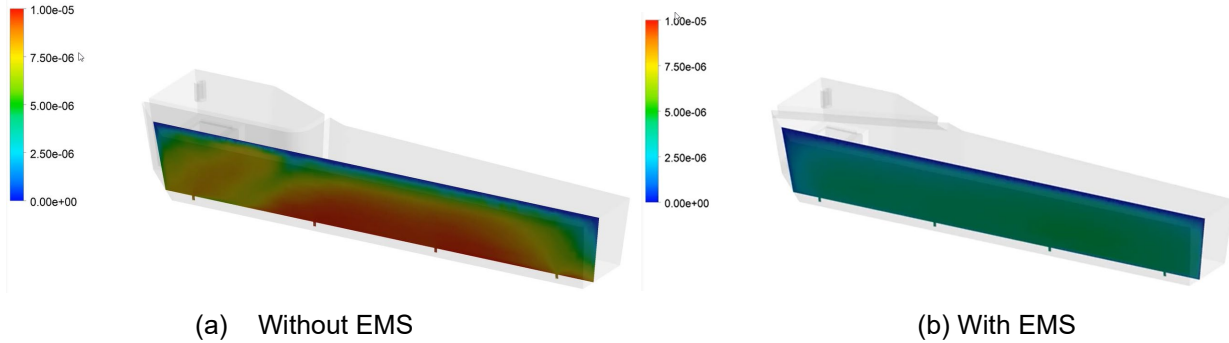

(a)   Without EMS   (b) With EMS

Figure 9 Volume fraction of inclusions in the vertical cross section

Figure 9 shows the distribution of volume fraction of inclusion at the vertical cross section across the outlets after 300 seconds simulation time. It can be seen that, with EMS, the volume fraction of inclusion is homogeneously distributed in the whole outlet zone and reduced into a lower level than that without EMS.
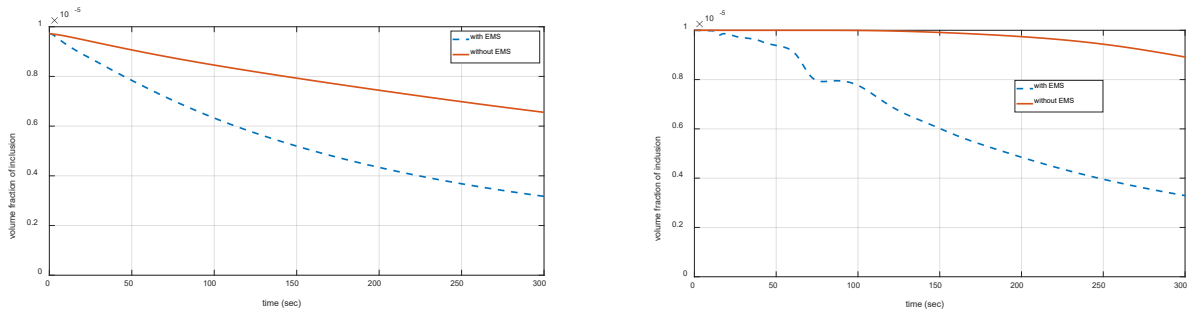
(a)   Volume fraction of inclusion inside the tundish   (b) Volume fraction of inclusion at the outlets of tundish

Figure 10 Change of volume fraction of inclusions with time

Figure 10 shows that the volume fraction of inclusions both inside the tundish and at the outlets decreases at a faster rate with EMS than without EMS.
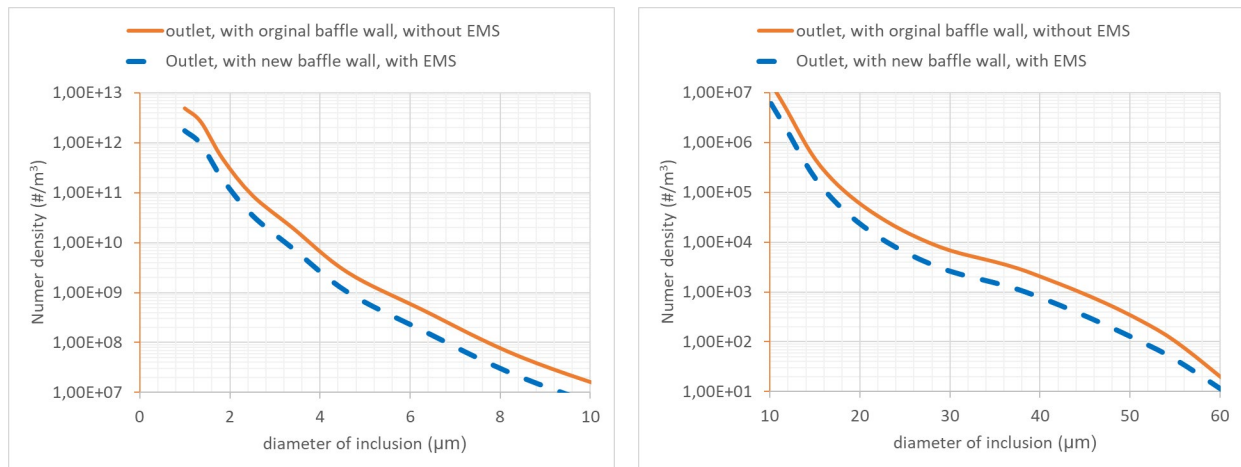
Figure 11 Influence of EMS on the number density of inclusions with different sizes

Figure 11 shows the influence of EMS on the number density of inclusions at the outlet of tundish. It can be seen that both the small inclusions (smaller than 10 µm) and middle size inclusions (between 10 µm and 60 µm) are reduced by EMS, the number density of big inclusions (bigger than 60 µm) are very small and ignorable in this study.

Conclusion

The flow velocity and stirring energy in multi-strand billet tundishes is very low due to the relatively low throughput, this makes tundish an unfavorable vessel for inclusion removal. On the other hand, the long residence time can be fully utilized by applying a gentle electromagnetic stirring in the tundish to increase mixing volume and stirring energy. Consequently, the homogeneity among the strands will be improved, the dead zone will be reduced, and inclusion removal increased.

The pilot installation at Zenith Steel Co. Ltd. will be commissioned in the summer of 2020, and we look forward to validating the cleaning and homogenizing effect of electromagnetic stirring in multi-strand billet caster tundish as part of this project.

References

1. Ling, H. Mathematical modeling on the growth and removal of non-metallic inclusions in the molten steel in a two-strand continuous casting tundish. Metallurgical and materials transactions B, 2016, 47B, p. 2991-3016.