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ANALYSIS OF RESIDENCE TIME DISTRIBUTION (RTD) CURVES FOR T-TYPE TUNDISH EQUIPPED IN FLOW CONTROL DEVICES: PHYSICAL MODELLING

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The article presents results of physical modelling of the steel continuous casting process in the tundish. Technological parameters of casting and constructive parameters of tundish were under study. Three different kinds of flow control devices were considered as well as their influence on the kinetics of steel flow and mixing in tundish. Created physical model enabled to conduct simultaneously visualization research and determine the RTD curves. According to the theory of flow in reactors the proper characteristics for estimating the flow are RTD curves E- and F-type, and they were obtained and discussed.

Key words: steel flow, tundish, physical modelling, RTD curve

INTRODUCTION

Technological parameters of casting and constructive parameters of tundish belong to basic properties that enforce the character of liquid steel flow through CC tundish [1-4].

Possibilities of forming the character of steel flow through tundish basing on technological parameters of casting, are rather limited. This is caused by the fact that these parameters are determined at the level of planning the casting technology of specific grades of steel, cross-sections of obtained cast strands, applied types of mould, parameters of secondary cooling etc. Thus, they consider mainly problems connected with solidification rate of cast strand, and as a result the productivity of the process [5]. Problems concerning the character of steel mixing in the tundish are derivative of those factors and commonly require to undertake additional research connected with optimization of steel mixing in a tundish.

Constructive parameters (geometry) of the tundish also do not give possibilities to influence the flow character. This is why, all the changes in tundish shape are connected with the necessity to work out practically new casting technologies which, taking into consideration the economy of steel production, is unjustified.

Thus there is a necessity to regulate and/or form the character of steel flow in the tundish by other methods. The solution of such problem is applying additional equipment in the working zone of the tundish, which is commonly called flow control devices [6-11]. The choice of construction of flow control devices is individual for a specific tundish. Flow control devices can be divided (taking into account the construction, shape and the main aim) into: baffles with notches, dams, weirs and turbulence inhibitors [6-11]. Such solutions are commonly used in industry and thanks to them good results of steel flow and mixing optimization in the tundish can be reached.

T. Merder, J. Pieprzyca, M. Saternus: Silesian University of Technology, Department of Metallurgy, Katowice, Poland

To ensure the optimal working of control flow devices it is necessary to determine precisely their impact on hydrodynamic conditions of steel circulation in the tundish. That is why physical and mathematical modelling is applied to determine constructive parameters of flow control devices [6-11].

Modelling research (physical and numerical) is commonly used for analyzing (getting to know better) the phenomena occurring in reactors applied in metallurgy of steel and nonferrous metals [11-16].

TESTING METHODOLOGY

Two-strand industrial T-type tundish with capacity of 7,5 Mg was examined. Figure 1 presents the scheme of the tundish, whereas Table 1 shows dimensions of the tundish model at 1:2 scale.

Due to some problems occurring in a real tundish three variants of equipping its working zone were proposed. They do not exist; they are only the suggestion for the modification of the studied object interior. Figure 2 presents the considered variants of tundish modification.

The research was carried out using physical model of continuous casting machine. It is a water segmental model built according to the theory of similarity. Figure 2 shows the test stand. Tundish model and elements of equipping were made from plexiglass. Presented model was described in details in work [12].

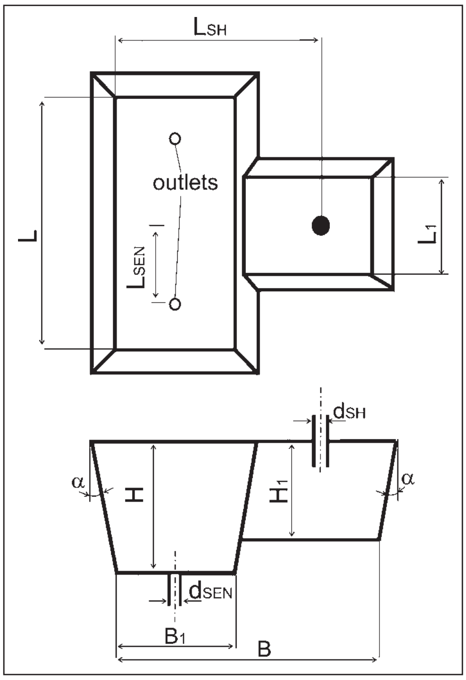

Figure 1 Scheme of the studied tundish

The construction of the model enables to conduct simultaneously visualization research and determine the RTD curves (Residence Time Distribution) describing the way that liquid steel flows through the tundish.

Every variant of experiment was carried out in the same working conditions of the tundish.Water flow rate in a model was 24 dm^3/min, which corresponds to casting rate equal 1 m/min, for cast strand with ϕ 200.

Modelling agent (water) was introduced to two tanks (Figure 3), which played the role of a ladle. Then, through the reverse valve liquid is directed into tundish trough submerged pouring nozzle. Tundish model was filled to the required level of water . In the research it was 0,3 m. It corresponds to the level of steel in a real tundish after applying linear scale. During the research the constant level of water was kept in order to control

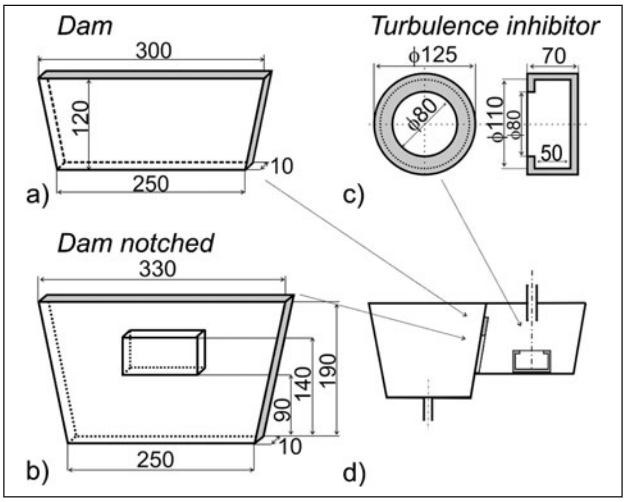

Figure 2 Geometric dimensions of proposed variants of tundish modiĀcation: a) case A, b) case B, c) case C, d) places of their installing

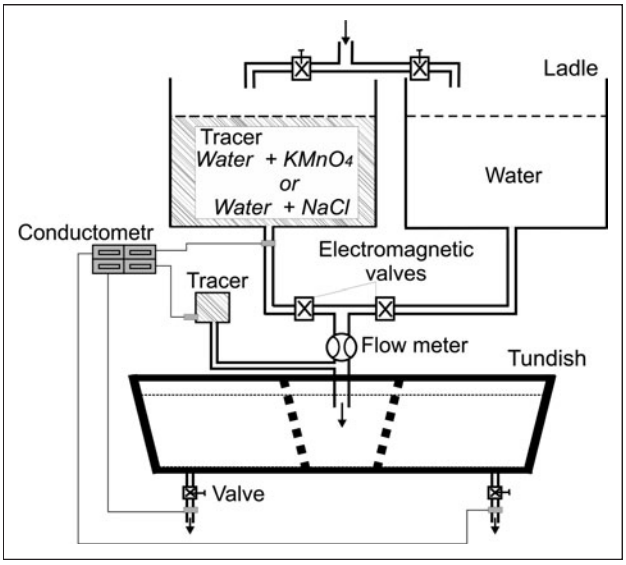

Figure 3 Scheme of test stand used in research

Table 1 **Dimensions of the tundish model at 1:2 scale**

Parameter	Symbol	Value
Volume of tundish at Ālling level H / m^3	V	0,125
Tundish length / m	L	1,150
	L_1	0,345
Tundish width / m	B	0,570
	B_1	0,300
Filling level (steady-state casting) / m	H	0,300
	H_1	0,220
Inclination of the side walls / °	α	8
Shroud diameter /m	d_{SH}	0,025
Shroud position / m	L_{SH}	0,466
SEN diameter / m	d_{SEN}	0,01
SEN position / m	L_{SEN}	0,350

the amount of water that was introduced to the model and drained from it.

To determine RTD curve (F-type) in the moment of reaching the required level of water and stabilizing the flow, the tank with clear water was closed and then a tank with the tracer (water solution of $KMnO_4$ and NaCl) was opened. In the same time measuring series started. Tracer was introduced during the whole measuring time and registered by means of conductimeters continuously on the model tundish outlets. Simultaneously the process was recorded by camera.

To determine RTD curve (E-type) in the moment of reaching the required level of water and stabilizing the flow, small amount of 2 % NaCl was introduced to the tank. The amount of tracer was 0,002 dm^3 and the change of its concentration was registered continuously on the model tundish outlets.

RESULTS AND DISCUSSION

Presented results are part of the wide research program concerning the change of fl ow control system in the examined tundish. Results were partly presented in works [12, 17].

Flow of the fluid

Registered film enables to analyze the change of flow and mixing kinetics in studied cases. Figures 4 to 7 show the chosen results of tracer propagation during the experiment for examined cases. Analysis of obtained results shows that the amount of well mixing area in bare tundish (Figure 34) is not sufficient. This area influences the quality of obtained cast strands; steel refining, by impurities floating to slag, occurs. The further flow has circulative character. Tracer propagated in the direction of water surface and on the head wall falls down creating right circulation (movement is in accordance with clockwise). Dangerously low kinetics of mixing is also seen in the area of back walls of the model. Such phenomenon can cause the creation of dead zones in this area of a real tundish.

For cases A and B (Figures 5 and 6) in which dams were installed, kinetics of liquid flow is more intensive than in a bare tundish. The area of well mixing is also bigger. However kinetics of ascending the liquid to the surface is smaller. Such flow does not threaten the coherence of slag layer and in the same time makes non-metallic inclusions easily assimilated by this layer Such equipping is the reason why tundish inlet area becomes integrated with its construction by high volume turbulence inhibitor.

In case B (dam with notches) movement of modelling liquid in an inlet part of the tundish model has such a character that it spills over the upper edge of dam, whereas through the notch window, the flow practically does not exist. During dam construction it was assumed that this window would play the role of culvert increasing the kinetics of modelling agent flow to the channel part of the tundish model. Results of visualization research were negative.

For Cases C (Figure 7) beneficial character of modelling fluid flow was observed in the area of well mixed flow. Mixing was sufficient and the strong mixing of ascending jet with surface layer of the bath was not observed. Turned up upper walls of turbulence infhibitors cause an additional rotational movement of a modelling agent in the area of well mixed flow. However, similarly to other cases, the kinetics of mixing in the area of back walls of the model is not sufficient.

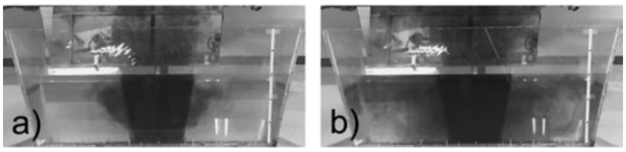

Figure 4 Tracer propagation in tundish model (bare tundish) after time: a) 30 s, b) 70 s

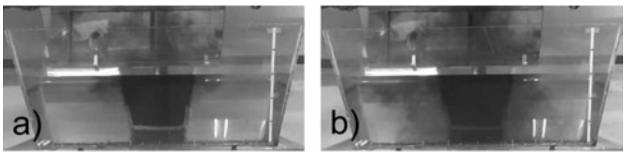

Figure 5 Tracer propagation in tundish model (case A) after time: a) 30 s, b) 70 s

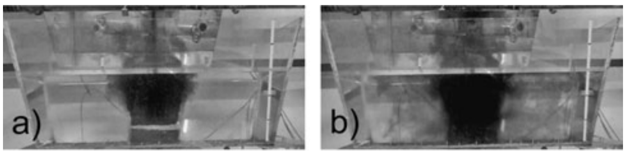

Figure 6 Tracer propagation in tundish model (case B) after time: a) 30 s, b) 70 s

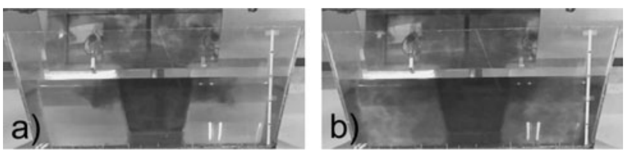

Figure 7 Tracer propagation in tundish model (case C) after time: a) 30 s, b) 70 s

RTD characteristcs

RTD characteristics contain cumulated information about hydrodynamic conditions of steel flow through tundish and enable to estimate initially the quality of the object considering the steel mixing and possibilities of refining processes intensification. According to the theory of flow in reactors [7-10], the proper characteristics for estimating the flow are RTD curve E- and F-type.

Figure 8 presents the shape and course of the RTD curves (F-type) registered for analyzed configurations of tundish equipping. Presented curves show that the kinetics of steel mixing for all studied cases is much the same. To compare the results, the tracer concentration was transformed in dimensionless form in such a way that the minimal value was 0, whereas maximal was 1. Such operation was possible applying relationships described in works [2,12].

To make more detailed comparison time interval Δt was determined (range of mixing kinetics).The lower

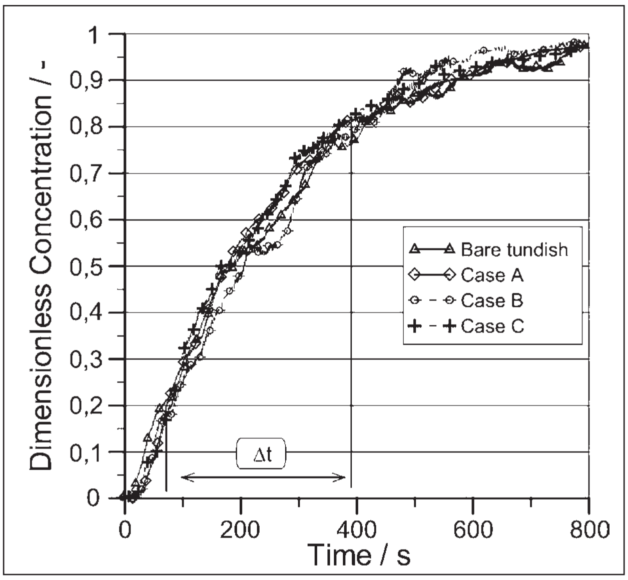

Figure 8 The F-type characteristics obtained from water model: a) bare tundish [12], b) Case A, c) Case B, d) Case C

values of Δt, the better conditions of mixing. Table 2 presents results characterizing the kinetics of mixing in examined cases.

Table 2 **Kinetics of steel mixing for studied cases**

Case	Δt / s	
	Outlet No 1	Outlet No 2
Bare tundish	348,5	349,5
Dam (Case A)	350	354
Dam notched (Case B)	315,5	322
Turbulence inhibitor (Case C)	292,5	290

Additionally Table 2 shows the data for both outlets to check the symmetry condition. Values of Δt on both outlets of the examined variants dif fer insignificantly. These differences come from abnormal levelling of the tundish model.

Basing on E-type curves, using relationships described in works [2, 12], particular volume fraction of flows for studied cases were calculated.Table 3 presents these results. The increase of mixing kinetics was observed for cases B and C, which is a positive phenomenon. Bare tundish used nowadays and proposed variant of its equipping – Case A (dam) have kinetics of steel mixing at the same level. It is not optimal equipment for casting process taking into account the transient zone during sequence casting of different grades of steel. Table 3 shows that there is an increase of well mixed flow contribution mainly at the expense of dead flow for cases A to C.

Table 3 **RTD parameters and volume fraction of flow**

Case	Volume fraction / %		
	Dispersed plug volume (V_{dp})	Well mixed volume (V_m)	Dead volume (V_d)
Bare tundish	18,8	45,6	35,6
A	17,4	53	29,6
B	15,2	52,1	32,7
C	17,9	52,4	29,7

The next analysis was done taking into account the dependence between ratio of well mixed fl ow to dead volume V_m/V_d and ratio of dispersed plug fl ow to dead volume V_{dp}/V_d (Table 4). The last one (ratio V_{dp}/V_d) indicated the quiescent region of tundish which promotes the inclusion floatation behaviour inside the tundish, whereas ratio (V_m/V_d) indicats the well mixed region which in turn is supposed to provide better homogeneity inside the tundish [2]. The best results were obtained for case C.

Table 4 **Comparison of different tundish volumes ratio**

Case	Overall (V_m/V_d)	Overall (V_{dp}/V_d)
Bare tundish	1,28	0,53
A	1,79	0,59
B	1,56	0,46
C	1,76	0,60

CONCLUSION

Basing on the carried out experiments it was stated that applying fl ow control devices in working area of the tundish causes:

- favourable change of flow kinetics,
- increasing the volume of dead areas, however they cannot be totally eliminated; places especially susceptible to this disturbance of flow are areaa near the back wall of the tundish model (close by liquid surface),
- lengthening the time which tracer spent in the tundish; this influences the process of transient zone, forming at the same time favourable conditions to sequence casting,
- the dead area is smaller, as a consequence the area with well mixed flow increases,
- improving mixed to dead volume of about 13,2 % and plug to dead volume of about 37,5 %.

Modelling research negatively verifi ed assumption for Case B (dam equipped with notch window which should play the role of culvert increasing the kinetics of liquid flow).

REFERENCES

[1] S. Lopez – Ramirez, J. Barreto, R. D. Morales: Steel Research Int. 69 (1998), 423–428.

[2] R. D. Morales, J. J. Barreto, S. Lopez-Ramirez, J. Palafox-Ramos and D. Zacharias: Metall. Mater . Trans. B, 31B (2000), 1505–1515.

[3] S. Singh, K. M. Godiwalla, D. K. Shaw: Scan. Journal of Metall., 30 (2001), 103–107.

[4] T. Merder , J. Jowsa, A. Bogusławski: Metalur gija, 46 (2007) 4, 245–249.

[5] J. Pieprzyca: Metalurgija, 52 (2013) 2, 157-160.

[6] K. Janiszewski, Z. Kudliński: Steel Research Int., 3 (2006), 169-176.

[7] R. Schwarze, F . Obermeier , J. Hantusch, A. Franke, D. Janke: Steel Research Int., 72 (2001), 215–220.

[8] A. Cwudziński: Steel Research Int., 81 (2010), 123–131.

[9] A. Sengupta P. Mishra, V. Singh, S. Mishra, P. J. Jha, S.K. Ajmani, S. C. Sharma: Ironmaking and Steelmaking, 40 (2013) 3, 159–166.

[10] K. Gryc, K. Michalek, Z. Hudzieczek, M. Tkadlečkova: Metal 2010, Conference proceedings. 2010, 42–46.

[11] M. Warzecha: Metalurgija, 50 (2011) 3, 147-150.

[12] T. Merder , J. Pieprzyca: Steel Research Int., 1 1 (2012), 1029–1037.

[13] T. Merder , J. Pieprzyca: Metalur gija, 50 (201 1) 4, 223–226.

[14] B. Panic: Metalurgija, 52 (2013) 2, 177–180.

[15] K. Michalek, J. Morávka, K. Gryc: Metalurgija, 48 (2009) 4, 219–222.

[16] R. Przylucki, S. Golak: Int. Journal of Thermophysics, 34 (2013) 4, 642–654.

[17] M. Warzecha, T. Merder: Metalur gija, 52 (2013) 2, 153–156.

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