OPTIMIZATION OF TUNDISH EQUIPMENT

B. Buľko, J. Kijac
Department of Ferrous Metallurgy and Foundry, Faculty of Metallurgy, Technical University Košice, Slovakia

Received 08.06.2010
Accepted 26.06.2010

Corresponding author: B. Buľko, Tel: +21 55 602 3153, E-mail: branislav.bulko@tuke.sk, Department of Ferrous Metallurgy and Foundry, Faculty of Metallurgy, Technical University Košice, Slovakia

Abstract
This paper compares residence times of non equipped tundish and tundish equipped with Turbostop and weirs at three different casting speed. Set of measurements in this paper was performed in laboratory simulated flow processes (LSSP). Water model is assembled at scale 1:3 to original. Measurements were evaluated by graphical measuring of water conductivity variation at tundish inlet and outlet by adding potassium chloride into tundish inlet and visually where $KMnO_4$ was used as indicator.
Within the frame of tundish equipment optimization three different variants were compared with support of Turbostop and weirs in two different distances from impact area.

Keywords: tundish, continuous casting, water model, physical modelling

Introduction

In present 92,8% of world steel production is casted on continuous casting machine [1]. Therefore great emphasis is given to maximalize effectivity of this process. The key phase of continuous casting is tundish so that's why major attention is given to it [2]. Beside of refining effect of slag phase also steel flow in tundish is very important factor [3]. Study of liquid metal flow in tundish in continuous casting of steel is problematic in practical conditions in term of great count of empirical experiments or technological difficulty of performing these experiments, they are also expensive. In term of mentioned problems physical or mathematical modelling is used for simulation, eventually combination of these methods [4-5]. In physical modelling is molten steel substituted by water, which also allows visual flow examination in tundish [6-7]. This substitution of flow medium is made by similar viscosity parameters for water and steel **Tab.1** [8].

Table 1 Comparison of physical properties of water at 20°C and steel at 1600°C (1)

Property	Water at 20°C	Steel at 1600°C
Dynamic viscosity ($kg.m^{-1}.s^{-1}$)	0,001	0,0064
Density ($kg.m^{-3}$)	1000	7014
Kinematic viscosity ($m^2.s^{-1}$)	1.10^{-6}	$0,913.10^{-6}$
Surface tension ($N.m^{-1}$)	0,073	1,6

Flow of steel in tundish is affected by geometry of tundish, dimensions, shape and arrangement of dams and weirs, steel level in tundish, volume flowages, position of ladle shroud, there through quality of steel is expressively influenced [9-11].

Used methods

Number of various measuring methods was developed by worldwide intensive long term study of possibilities of flow in tundish. [12]. Tundish can operate in two modes. Case that steel level in tundish is constant and amount of steel incoming into tundish is equivalent to steel amount leaving tundish through shrouds we call Steady State. If tundish operates in transient casting it means that steel flow in tundish is changing with time together with steel level in tundish. These happen during changing of ladles [13-14]. Noted experiments were performed in steady state. For discovering residence times of tundish was used LSPP water model for continuous casting in 1:3 scale. In this article so called C-curves method was used which allows us to define characteristics of steel flow in tundish at constant parameters of casting [15]. After reaching required level in crystallizer and establishing of cast speed water solution of KCl is injected into ladle shroud. Conductivity probes are placed on entry into tundish and its shrouds which records changes of conductivity of water effected by added salt by which C-curve is acquired [16-17]. By this curve we can determine minimum residence time τ_{min} which is minimum time for injected fugitive dye into ladle shroud (τ_0 =0s) detected at tundish shroud. Maximum residence time have definitive influence on time which inclusions have to rise from steel into slag [18-20]. Maximum residence time τ_{max} is time between τ_0 and maximum measured concentration of fugitive dye on shroud [21-22]. Non equipped tundish was compared with tundish equipped with Turbostop [23], Turbostop and weirs in distance 480mm or 570mm from center at three various casting speed **Fig.1**. There are 12 measurements presented in the paper.
Water model consists of two ladles which are able to change during simulation of casting, ladle shroud and tundish which outlet through shrouds into crystallizers are regulated by two stopper rod. Induction flow meters are placed in every separate shroud. Every vessel has temperature and level meter. Model is controlled by electronic system Simatic, which can control every flow rate, levels, ladle shift and ladle shroud. Water can be supplied externally or can circulate in model. Model is equipped with instruments for temperature and conductivity reading from Moravian Instruments concern. Water heating system is installed for non-isothermic measurements.

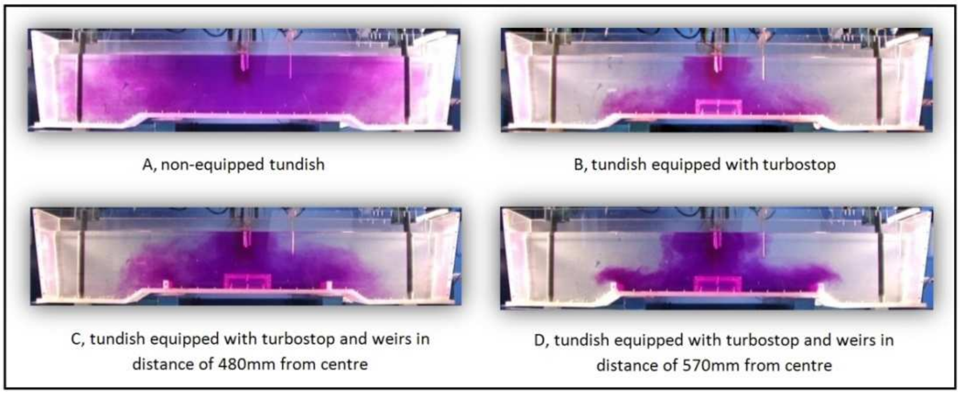

Fig.1 Used flow modificator combinations in tundish

KCl was injected to the ladle shroud together with $KMnO_4$, which acted as contrastive substance, what also enabled visual observation of flow in the tundish. Measured conductivity values were converted to dimensionless concentration owing to uniform form of obtained curves.

Conditions of similarity

In the case of utilization of longitudinal criterion of 1:1, the model would meet the Reynolds and Froud criterions of similarity. Because of reasons mentioned above the model was constructed in the scale 1:3, and so based on its dimensions gravity and inertial forces were abided. For this reason it was not simultaneously possible to abide gravity and viscosity similarity requirements. Gravity and inertial forces are characterized by Froud criterion for model as well as for original [24]:

$$Fr = Fr' \tag{1}$$

$$\frac{w^2}{g.l} = \frac{w'^2}{g'.l'} \tag{2}$$

Where: w is speed [$m.s^{-1}$]
g is acceleration of gravity [$m.s^{-2}$]
l is length [m]

Both this original and model are exposed to the same gravity acceleration and that's why this can by neglected, thus next equation is obtained:

$$\frac{w^2}{l} = \frac{w'^2}{l'} \tag{3}$$

Time is then established by the ratio:

$$\tau = \frac{l}{w}$$

Where: τ is time [s] (4)

Next relationships are acquired by gradual derivation [6]:

$$M_l = M_\tau^2 \tag{5}$$

$$M_l = M_Q^{2/5} \tag{6}$$

Where: M_1 is longitudinal scale,
M_τ is time scale
M_Q is scale of volume flow

In the case of model constructed in the scale 1:3 the M_1 is 0,33. For the original with mold dimensions of 225x1590 mm we can consider at casting velocity with minute production Q_m = 5335kg/min, if we consider steel density ς=7800kg.m^{-3}. Volume flow rate from ladle to the tundish is then Q_v=0,0475m^3.min^{-1}=47,58l.min^{-1}. If this volume flow rate is abided in the model, then Fr=Fr´ condition is satisfied. According to the equation (5), the time scale is then:

$$M_\tau = M_l^{1/2} = 0{,}33^{1/2} = 0{,}5773 \tag{7}$$

From the mentioned calculations it results that within the used water model there will be reached velocities 1,73 times lower than on the work and at satisfying equation (1) there will be similar states reached at time 1,73 times shorter that on the original [6].

Discussion to measured values of minimal residence time

The basic parameter which is often used for tundish flow description is minimal residence time. This time is defined as shortest time when particle injected to the ladle shroud can be observed on the tundish output [25]. Very low values of τ_{min} can show short-circuiting. This means that steel incoming to the tundish flow to the tundish output shortest possible trajectory which can be observed together with dead zones in the tundish [26]. One of aims of steel flow optimization is to reach maximum value of minimal residence time.

From visual arbitration of flow in non-equipped tundish at **Fig.2** is possible to expect high tendency of strong turbulent flow even if casting speed is low. This phenomenon is more significant at higher casting speed at **Fig.6** and **Fig.10**. Effect of this turbulent flow is very low value of minimal residence time. When Turbostop is applied, minimal residence time is higher at all tested casting speed within the range from 75% to 131%, **Tab.2**. Negative effects of standalone Turbostop application are dead zones above submerged entry nozzles visible at **Fig.4**, **Fig.7** and **Fig.11**. One of possibilities to compensate this defection flow is application of weirs to direct steel flow from bottom of the tundish to reaction interface between steel and slag. For experiments were used 50 millimeters high weirs. At first alternative was weirs set 480mm from the middle of the tundish, **Fig.4**, **Fig.8** and **Fig.12**. This effect by increase of minimal residence time at 0,8 m.min^{-1} casting speed about 100%. Other series of experiments was done with weirs set 570mm from the middle of the tundish, as shown at **Fig.1**. This set achieved the highest values of minimal residence times at all tested casting speed. Minimal residence time was increased within range from 140% to 155% opposite non-equipped tundish. In all cases is visible, that the highest flow speed of water is at the bottom of tundish.

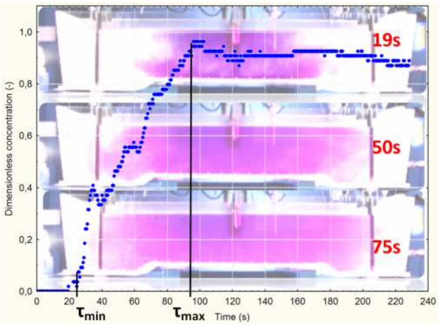

Fig.2 C-curve of non – equipped tundish at casting speed 0,5 m.min^{-1}

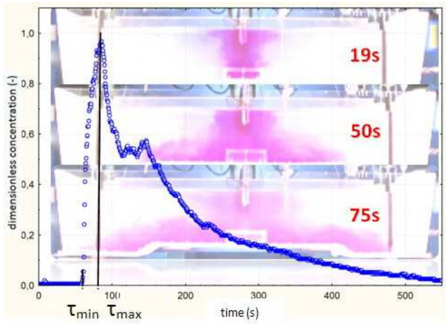

Fig.3 C-curve of tundish equipped with Turbostop at casting speed 0,5 m.min^{-1}

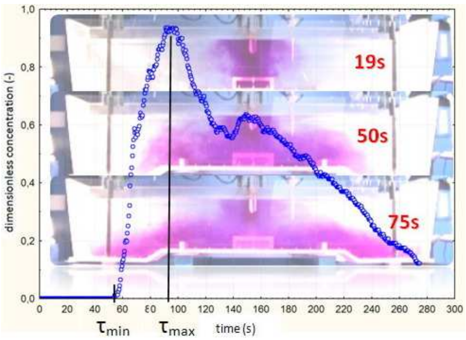

Fig.4 C-curve of tundish equipped with Turbostop and weirs (480mm from centre) at casting speed 0,5 m.min^{-1}

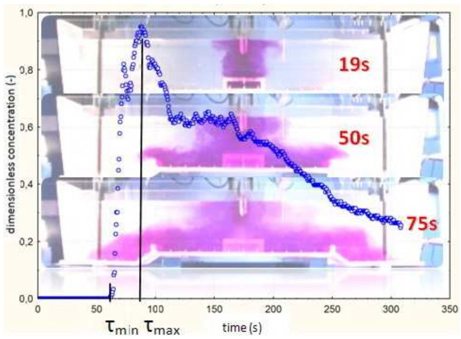

Fig.5 C-curve of tundish equipped with Turbostop and weirs (570mm from centre) at casting speed 0,5 m.min^{-1}

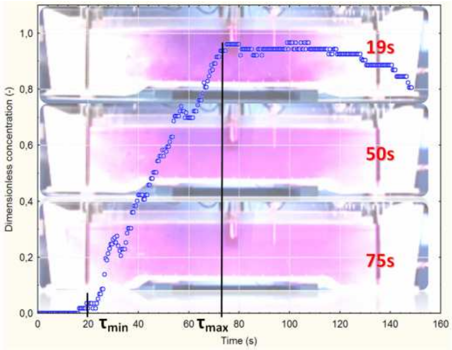

Fig.6 C-curve of non – equipped tundish at casting speed 0,8 m.min^{-1}

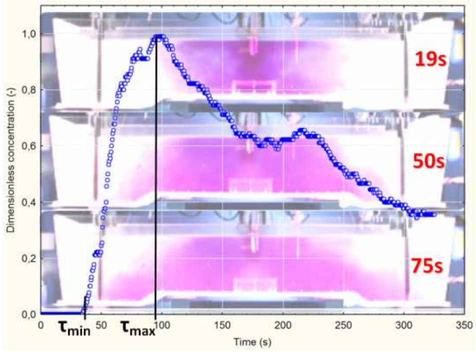

Fig.7 C-curve of tundish equipped with Turbostop at casting speed 0,8 m.min^{-1}

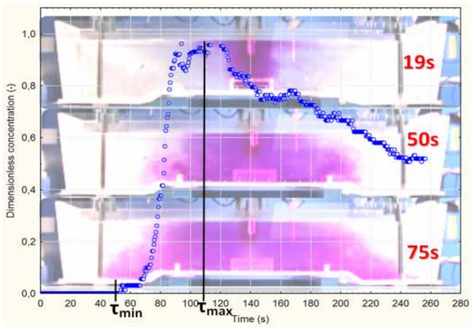

Fig.8 C-curve of tundish equipped with Turbostop and weirs (480mm from centre) at casting speed 0,8 m.min^{-1}

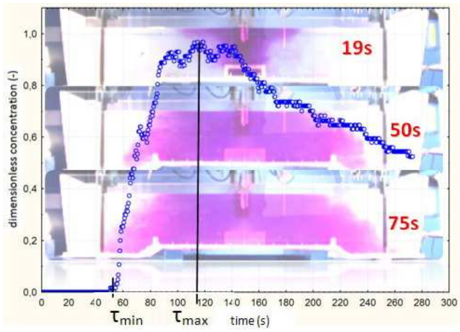

Fig.9 C-curve of tundish equipped with Turbostop and weirs (570mm from centre) at casting speed 0,8 m.min^{-1}

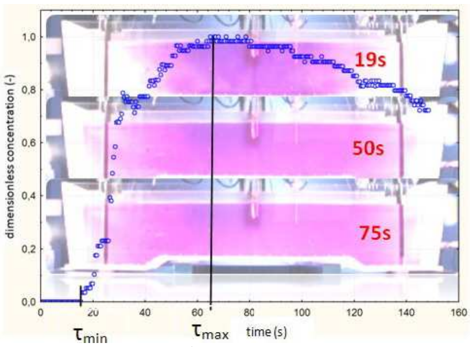

Fig.10 C- C-curve of non – equipped tundish at casting speed 1,1 m.min^{-1}

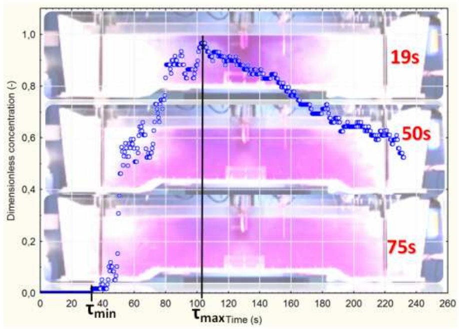

Fig.11 C- curve of tundish equipped with Turbostop at casting speed 1,1 m.min^{-1}

From graphical comparsion of residence times in dependency on casting speed and tundish equipment at **Fig.14** result that suitable setting of weirs can optimize residence time of tundish [27-28]. Dimensions and location of weirs in combination with optimal design of impact pad affects significantly steel flow in the tundish. All presented residence times are valid only for water model, for their comparsion with original is necessary to multiply them with coefficient 1.75 derivates from equation (5).

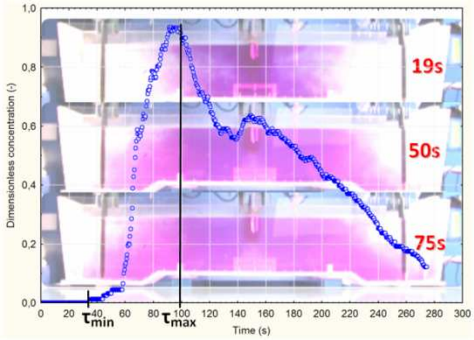

Fig.12 C-curve of tundish equipped with Turbostop and weirs (480mm from centre) at casting speed 1,1 $m.min^{-1}$

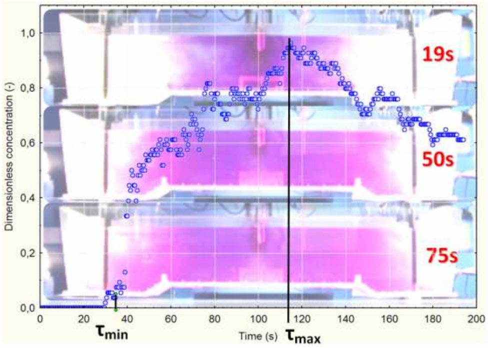

Fig.13 C-curve of tundish equipped with Turbostop and weirs (570mm from centre) at casting speed 1,1 $m.min^{-1}$

Table 2 Residence times in dependency of casting speed and tundish equipment (in parentheses are percentage differences opposite non-equipped tundish)

TUNDISH EQUIPMENT	CASTING SPEED ($m.min^{-1}$)	MINIMAL RESIDENCE TIME (s)	MAXIMAL RESIDENCE TIME (s)
Non - equipped	0,5	25,5	92
Turbostop	0,5	59 (+131%)	85,5
Turbostop and weirs 480mm	0,5	59 (+131%)	95,5
Turbostop and weirs 570mm	0,5	61,5 (+141%)	90
Non - equipped	0,8	20	72
Turbostop	0,8	35 (+75%)	95
Turbostop and weirs 480mm	0,8	46 (+130%)	105,5
Turbostop and weirs 570mm	0,8	51 (+155%)	115
Non - equipped	1,1	16	65
Turbostop	1,1	33,5 (+110%)	102,5
Turbostop and weirs 480mm	1,1	30,5 (+91%)	100
Turbostop and weirs 570mm	1,1	38,5(+140%)	115

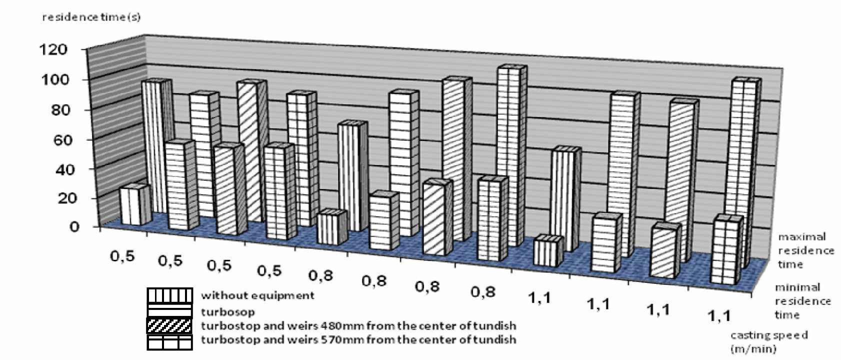

Fig.14 Graphical comparsion of residence times in dependency on casting speed and tundish equipment

Conclusion

This paper descript one of possible yields from the laboratory simulated flow processes (LSSP) in water model of continuous casting at Department of metallurgy and casting at Faculty of metallurgy in Košice. This paper demonstrates that minimal tundish tuning can prolong minimal residence time. Best results were obtained with combination of turbostop and weirs set570 from the middle of the tundish. Measuring of residence times in tundish in steady state is only one of methods from many techniques we can use to investigate and optimize tundish equipment. In future, other experiments will be concerning about F-curves at transient casting, non isothermal experiments and utilization of inert gas in tundish.

References

[1] Steel Statistical Yearbook 2009, World Steel Association, 03 Mar 2010, [10.5.2010], http://www.worldsteel.org/pictures/publicationfiles/Steel%20Statistical%20Yearbook%202009.pdf
[2] P. Kováč et al.: Steel Cleanliness Improvement through Tundish Configuration Optimizing, Metalurgija, 2003, No.4, p. 249 – 255
[3] J. Kijac, P. Kováč, E. Steranka, V. Masek, P. Marek: The current status of Tundish covering slags in slab caster plant, Metallurgija, Vol.43, 2004, , No.1, p.59-62
[4] J. M. Drezet, M. Rappaz: Outils numériques appliqués aux procédés de coulée continue, STI Ecole de Mécanique des Matériaux Mécamat, Aussois 2008
[5] M. B. Goldschmit, S. P. Ferro, R. J. Príncipe, A. Heriberto Coppola Owen: Numerical Modelling of Liquid Steel Flow in Continuous Casting Processes, [16.5.2010], http://www.exa.unicen.edu.ar/fluidos/dfyp/Fluidos2001/Datos/Contenido/Lectures/Goldschmit.PDF
[6] K. Michalek: Využití fyzikálního a numerického modelování pro optimalizaci metalurgických procesů, Vysoká škola báňská – technická univerzita Ostrava, 2001, ISBN 80-7078-861-5
[7] B. Li, F. Tsukihashi: Vortexing Flow Patterns in a Water Model of Slab Continuous casting Mold, ISIJ International, Vol. 45, 2005, No. 1, pp. 30-36
[8] D. J. De Kock: Optimal Tundish design methodology in a continuous casting process, Doctoral Thesis, University of Pretoria, Electronic theses and dissertations, 2002, [16.5.2010]http://upetd.up.ac.za/thesis/available/etd-10072005-095941/unrestricted/01thesis.pdf
[9] B.G. Thomas: Continuous Casting: Complex Models, The Encyclopedia of Materials: Science and Technology, K.H. J. Buschow, R. Cahn, M. Flemings, B. Ilschner, E. J. Kramer, S. Mahajan, eds., (J. Dantzig, subject ed.) Elsevier Science Ltd., Oxford, UK, Vol. 2, 2001, pp. 1599-1609, [15.5.2010], http://ccc.illinois.edu/PDF%20Files/Publications/01_Dantz_Ch_final.pdf
[10] B.G. Thomas: Continuous Casting: Modelling, The Encyclopedia of Advanced Materials, (J. Dantzig, A. Greenwell, J. Michalczyk, eds.) Pergamon Elsevier Science Ltd., Oxford, UK, Vol.2, 2001, p. 8, Revision 3, Oct. 12, 1999
[11] R. Miranda, M. Barron, A. J. Barreto., L. Hoyos, J. Gonzales: Experimental and Numerical analysis of the Free Surface in a Water Model of a Slab Continuous Casting Mold, ISIJ International, Vol. 45, 2005, No. 11, p. 1626 - 1635
[12] P. Väyrynen et al.: Tundish Flow Model Tuning and Validation: Steady State and Transient Casting Situations, Graz/Seggau, Austria, In: SteelSim 2007, September 12-14 2007

[13] H.-J. Odenthal, R. Bolling, H. Pfeifer: Numerical and Physical Simulation of Tundish Fluid Flow Phenomena, In: Steel Research 74, 2003, No.1

[14] M. J. Cho., I. J. Kim: Simple Tundish Mixing Model of Continuous Casting during a Grade Transition, ISIJ International, Vol. 46, 2006, No. 10, p. 1416–1420

[15] M. Clark, T. Wagner, A. Trousset: Modelling for Tundish Applications, In: Refractories Engineer, January 2003

[16] Y. Sahai, T. Emi: Melt Flow Characterization in Continuous Casting Tundishes, ISIJ International, Vol.36, 1996, No.6

[17] Y. Sahai, T. Emi: Criteria for Water Modelling of Melt flow and Inclusion Removal in Continuous Casting tundishes, ISIJ International, Vol.36, 1996, No.9

[18] H. Yamaura et al.: Development of Technology for blowing Fine Bubbles into Tundish through Porous Plug Using Molten Steel Flow, ISSTech 2003 Conference Proceedings

[19] J. Falkus, J. Lamut: Model Testing of the Bath Flow Through the Tundish of the Continuous Casting Machine, In: Archives Of Metallurgy and Materials, 2005, Issue 3

[20] M. Iguchi, K. Takahashi, O. J. Ilegbusi, M. Sano, H. Kiuchi: Effects of the Physical properties of Top Oil Layer on Bubble and Liquid Flow Characteristics in a bottom Blown Water Bath, ISIJ International, Vol.38, 1988, No. 9

[21] A. Aguilar - Corona, R. D. Morales, M. Díaz – Cruz, J. Palafox – Ramos, L. García Demedices: Thermal stratification of steel flow in tundishes with off-centred ladle shrouds using different flow control designs, Canadian metallurgical Quartely, Vol 42, No. 4

[22] P. J. Väyrynen, S. K. Vapalahti, S. J. Louhenkilpi: On Validation of Mathematical Fluid Flow Models for Simulation of Tundish Water Models and Industrial Examples, [16.5.2010] http://www.flow3d.com/pdfs/tp/cast_tp/FloSci-Bib03-08.pdf

[23] K. G. Venkatesan, S. K. Bera, S. Khurana: Water Modelling – A tool for Effective Designing of Turbulence-suppressing Tundish Impact Pad, TURBOSTOP, [13.5.2010], http://www.foseco-steel.com/steel/downloads/technical_papers/01.pdf

[24] F. Kemeny, D. J. Harris, A. McLean, T. R. Meadowcroft, J. D. Young: Fluid flow studies in the tundish of slab caster, Continuous Casting of Steel, 2nd Process Technology Conference, Vol.2, 1981

[25] B. G. Thomas, L. Zhang: Mathematical Modelling of Fluid Flow in Continuous Casting, ISIJ International, Vol. 41, 2001, No. 10, p. 1181–1193

[26] T. Debroy, J. A. Sychterz: Numerical Calculation of Fluid Flow in a Continuous Casting Tundish, Metallurgical transactions B, Vol. 16B, 1985

[27] C. M. Fan, R. J. Shie, W. S. Hwang: Studies by mathematical and physical modelling of fluid flow and inclusion removal phenomena in slab tundish for casting stainless steel using various flow control device designs, Iron and Steelmaking, Vol. 30,2003, No.5

[28] B. G. Thomas, A. Dennisov, H. Bai: Behavior of Argon Bubbles during Continuous Casting of Steel, In: ISS 80th Steelmaking Conference, Chicago, IL, ISS, 1997, p. 375-384