SINGLE AND MULTIPHASE MODELLING OF MELT-SLAG - ARGON FLOWS IN LADLE METALLURGY AND CASTING OPERATIONS

(Title: CAPITALISED 14 PT. SIZE; TIMES NEW ROMAN FONT and SINGLE LINE SPACING THROUGHOUT & CENTERED)

[One inch margin all around on every page]

[ONE LINE GAP]

Lipsa Das[1], Krishnaavtar[2] and Rishikesh Misra ***(12pt.size)***

Department of Materials Science and Engineering

Indian Institute of Technology, Kanpur, INDIA

(1. Graduate student: Colorado School of Mines, USA; 2 Researcher, Essar Steel, India) ***(10 pt.)***

Corresponding author's e-mail: mrishi@iiitk.ac.in ***(10 pt.)***

[Two lines gap]

Abstract: Transient, turbulent flow simulations were carried out via RANS based homogeneous as well as multiphase flow calculation procedures to investigate simultaneous flow of molten steel, slag and argon in steel processing, casting and transfer units. It is shown d that the onset of slag vortexing during tundish emptying and the effect of erroneous argon injection in a vertical shroud could be predicted realistically which have been substantiated through water modelling experiments. ……***[Abstract: 10 pt. size; Times New Roman; maximum 150 words]*** ………, simulation results for a tall runner during ingot casting has indicated high shearing forces in certain regions of the runner suggesting possible hydrodynamic erosion and consequent contamination of steel with exogenous inclusions. The present study has demonstrated….. multi-phase, turbulent flows in steel processing and transfer units.

[One line gap]

Keywords: ***(Maximum 4 and in one line).*** Steelmaking, computational fluid dynamics (CFD), physical modeling.

[text in twin column format and section headings and subheadings in 11pt. throughout and bold faced]

[One line gap]

1. Introduction ***[11pt., Times New Roman]***

(One line gap)

Rate calculation in steelmaking is rarely possible without detailed knowledge of flow. Therefore, knowledge of melt flow is a *pre- requisite* to the prediction, analysis and control of steelmaking …. ***(text in 10.5 pt. size throughout)*** ……involving melting, dissolution, dispersion, inclusion removal, solidification and so on. Laminar or viscous flow occurs at low Reynolds number. Large size of steelmaking reactors, low kinematic viscosity of steel as well as high intensity of agitation are known to precludes low Reynolds number flows. Turbulent, rather than laminar, flows are more typical of steelmaking………

[One line gap]

2. Mathematical modelling

[One line gap]

The volume of fluid (VOF) approach relies on the concept of a mixture velocity and hence solves only one set of continuity and momentum equations that in essence is similar to the quasi single phase procedure[1]. ***[Reference must be superscripted within a square bracket throughout the text and sequentially]*********

In the unsteady, VOF formulation, the time averaged equation of continuity and motion in terms of mixture velocity is represented for axi-symmetrical flow, in the cylindrical polar coordinate system as:

Equation of continuity:

$$\frac{\partial \rho_{mix}}{\partial t}+\frac{\partial}{\partial z}\left(\rho_{mix} v_{z,mix}\right)+\frac{1}{r}\frac{\partial}{\partial r}\left(\rho_{mix} r v_{r,mix}\right)=0 \quad (1)$$

(Equations must be numbered sequentially and equation number must be placed adjacent to the Equation, within a round bracket)

All simulations reported in the manuscript were carried out via Ansys Fluent™ . ***[Proprietary items must be properly acknowledged]***

3. Steelmaking process modeling

[One line gap]

Several case studies are presented in the following section illustrating application of CFD to ladle, tundish casting operations………..

(between subsequent sub-sections enforce 1 line gap always)

3.1 Shrouding of steel stream in trumpet during ingot casting operation ***[11pt., Times New Roman]*** ***(one line gap)***

A schematic of an up-hill teeming process is shown in Fig. 1. Corresponding physical dimensions and operating parameters are summarised in Table 1. ………To examine the effectiveness of argon shrouding in the trumpet for an industrial scale casting operation, a CFD study ***[All labels in the body of a figure must not be smaller than 9pt. size]*** was carried out in which, a steady turbulent flow model in conjunction with a scalar transport equation was used. Predicted result is shown in Fig.2.

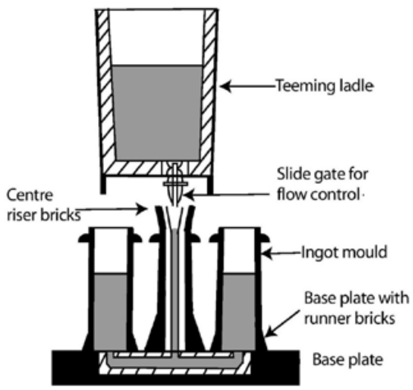

Figure 1 A schematic of an up-hill teeming processes during ingot casting operation ***[Figure caption: 9pt. size, Times New Roman and bold faced and centered; below figure]***

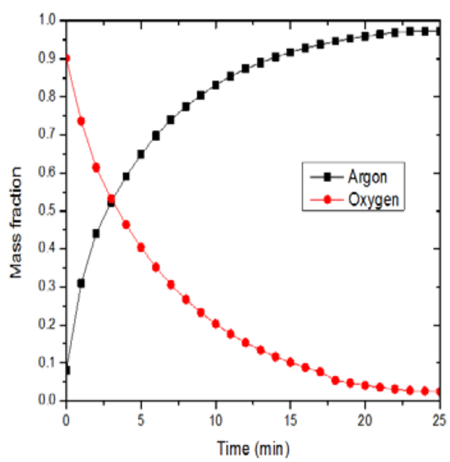

Figure 2 Predicted mass fractions of argon and oxygen inside the trumpet as a function of time ***[Figure caption: 9pt. size, Times new roman and bold faced and centered; below figure]***

4. Conclusions ***[11pt.size, Times New Roman and bold faced)***

(One line gap)

The role of CFD in steelmaking process analysis and design is highlighted…***(10.5pt.size)***... Useful inferences can be drawn through CFD leading to improved understanding of steelmaking process dynamics with attendant process performance enhancement.

(One line gap)

Table 1 Experimental conditions for results shown in Fig.1***[Table caption: 9pt. size, Times New Roman, centered and bold faced; immediately above table]***

<table>
<tr><th>Ingot size, tonne</th><th>Major physical dimensions</th><th>Teeming rate , Kg/s</th><th>Trumpet height, m</th><th>Argon flow rate, Nm^3/min</th></tr>
<tr><td colspan="5">Table contents 8pt. size, Times new Roman and contents cell centered</td></tr>
<tr><td rowspan="3">5.7</td><td>Internal diameter =0.5m</td><td rowspan="3">25</td><td rowspan="3">4.2</td><td rowspan="3">2x10^{-4}</td></tr>
<tr><td>External diameter =0.81m</td></tr>
<tr><td>Mold height =3.8m</td></tr>
</table>

(One line gap)

References ***[11pt.size, Times New Roman and bold faced)***

(One line gap)

1. M.Rudman: International Journal of Numerical Methods in Fluids, Vol.24, 1997, p.671. ***[10pt.size throughout; style for journal paper]***

2.D.Mazumdar and J.W.Evans: *Modelling of Steelmaking Processes*, 1st Edition, CRC Press, Boca Raton, USA,2010,p 210. ***[10pt.size throughout; style for text book/reference book]***

3.S.Chakraborty,S.Bhambure, S.Patil and S.Roychowdhury: Procd., *Asia Steel International Conference*, Yokohama, Japan, 2015,p.244 ***[10pt.size throughout; style for conference proceedings]***

4.Internal Report: IITK-MSSSL project report No. MET/MSSLL/20120263, Unpublished work, IIT Kanpur, 2015. ***[10pt.size; style for unpublished work,/personal communication etc.]***

[Maximum 6 pages for plenary and 4 pages for all other category of presentations. Manuscript Must accompany CTF duly filled in]