Integrated Multi-physics model for determining LF processing time

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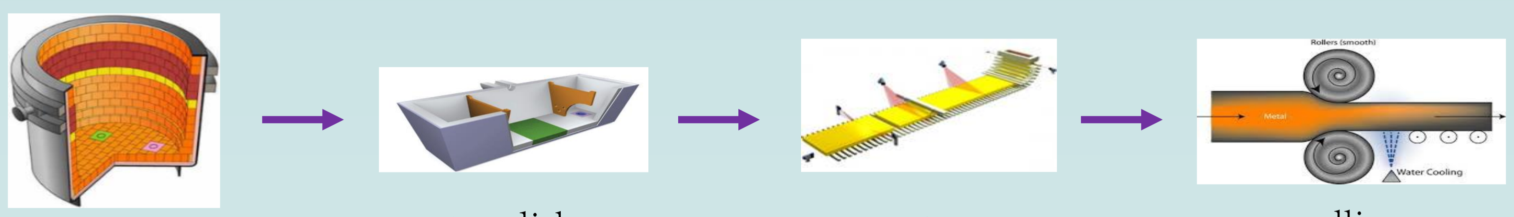
Introduction

In an integrated steel mill, the duration of BOF operations has gradually reduced on account of improved automation and control. At the same time, the productivity of continuous casting machines is improving. The present study looks at the challenges associated with the ladle furnace operation and explores ways and means of reducing the LF processing time. For the present requirement of good quality steel in competition with productivity requirements, the optimisation of ladle refining processes has to be achieved. For this objective surrogate models are beneficial in order to reduce the computation time in order to get a handle on dynamic ladle processing while the process is taking place.

Process Objective



ladle → tundish → caster → rolling

Deoxidation and reoxidation model

The deoxidation and reoxidation model is applied to incorporate the parallel inclusion removal and slag-eye oxygen pickup process. The model assumes single distribution of inclusions and stokes flow conditions.

$$\Delta t \sum_j N_s(i) = \Delta t \cdot \frac{A_{Slag} \cdot (\overline{u}_{Stoke} + \overline{u}_Z)}{V_{Fe}} \cdot \sum_j N(R_i),$$

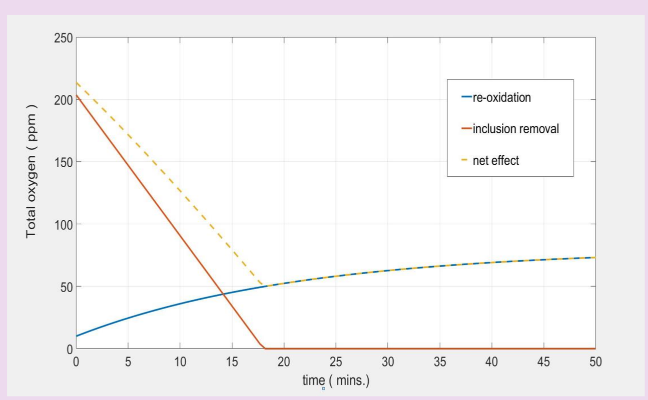
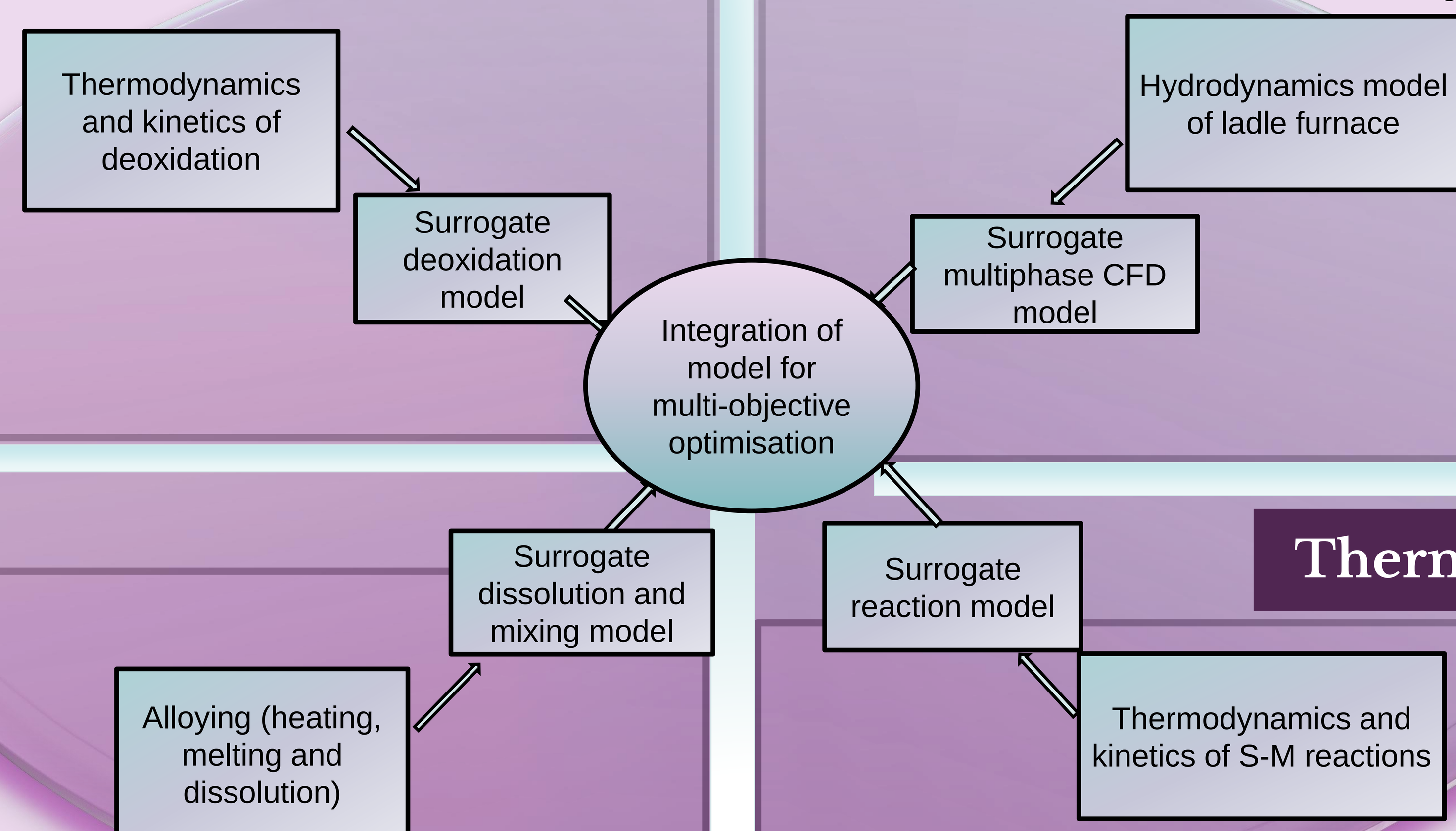


Fig 4: Plot of total oxygen content with time

$$\frac{d[\%\, O]_{tot}}{dt} = \frac{1}{W_{steel}}([\%\, O]_{int} - [\%\, O]_{eq}) \sum_{i=1}^{n} k_{O,i}\, A(i),$$

Fig 3: Average value of velocity over each cell [2]



Process overview

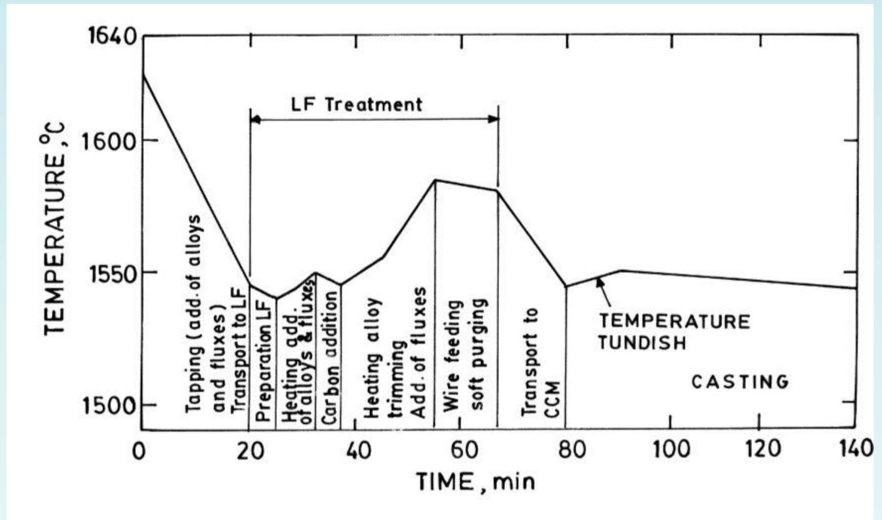


Fig 1: Temperature variation with process steps shown in series [1]

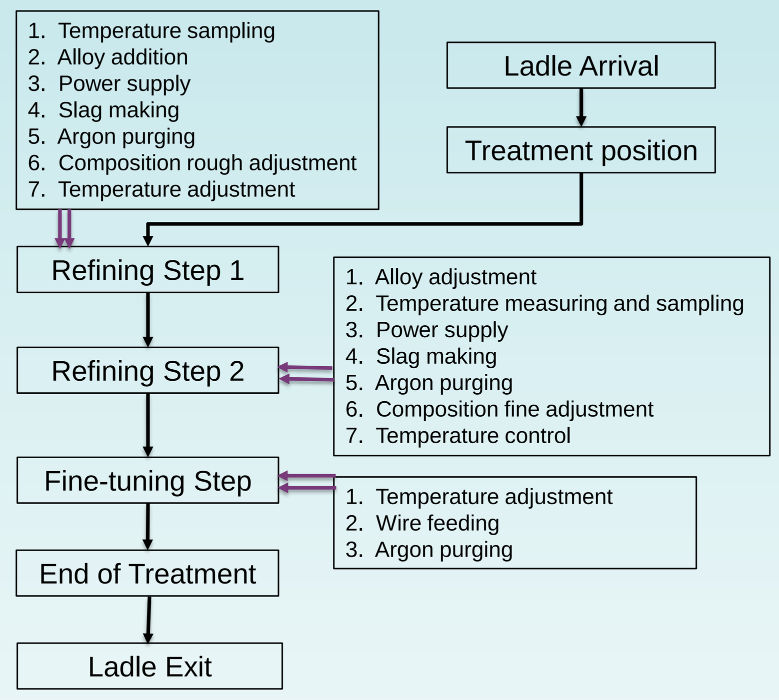


Fig 2: Steps in the LR process

Multiphase Fluid flow model

Steelmaking industry use gas-stirring, since the hostile process nature negates all forms of mechanical stirring. Broadly the system should be able to direct a kinetic energy to the quiescent medium in order to facilitate various processes like Slag-metal reaction, inclusion floatation and alloy dissolution!

The model is developed by taking the DPM-VOF coupled approach [3]

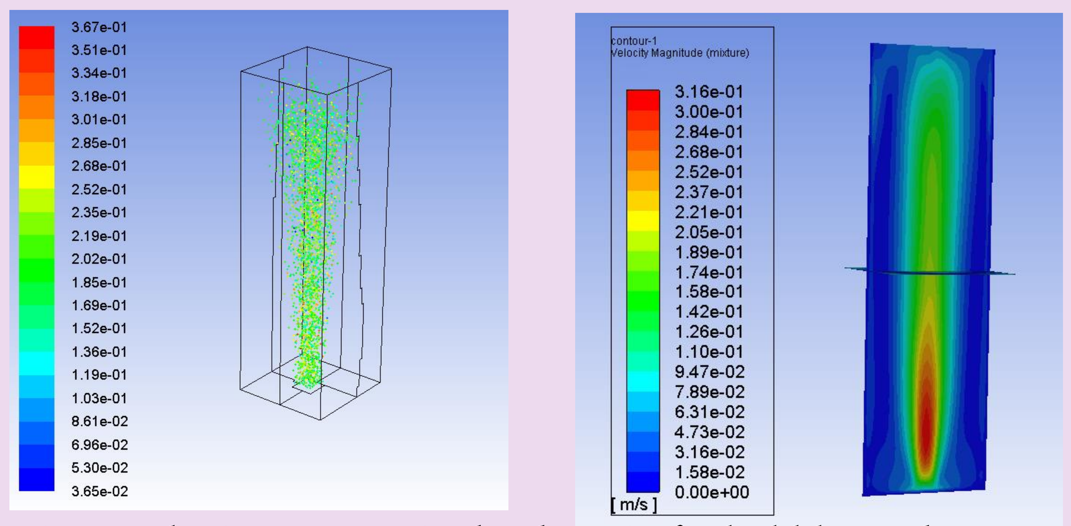


Fig 5: Velocity contour in the domain for bubbles and water

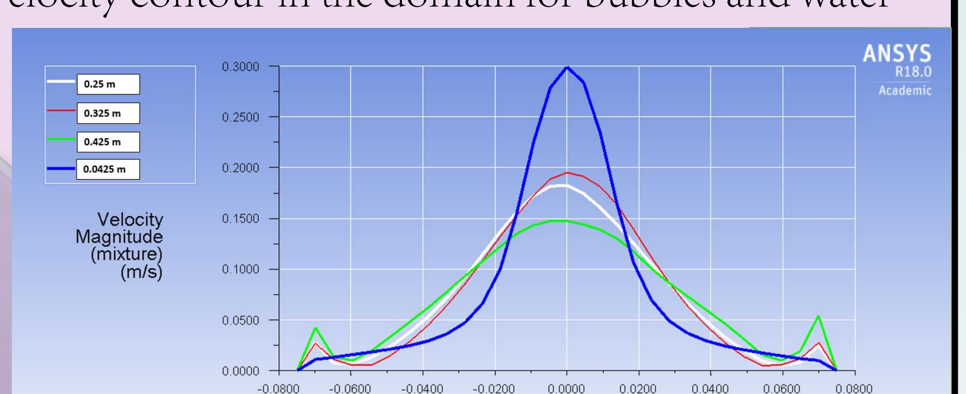


Fig 6: Plot of fluid velocity at various heights

Alloy Dissolution model

The alloy dissolution is a series process during ladle refining! The net time for dissolution is governed by Temperature and concentration profile of the ladle along with the fluid flow conditions!.

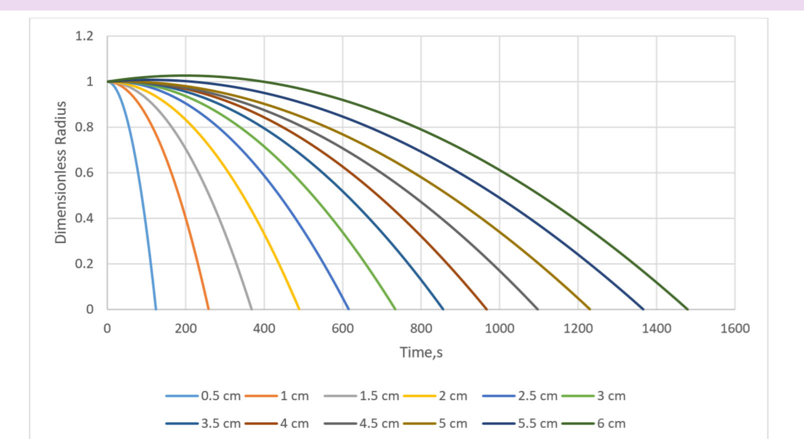


Fig 7: Effect of size on dissolution time of FeNb particles in liquid steel at 1873 K [4]

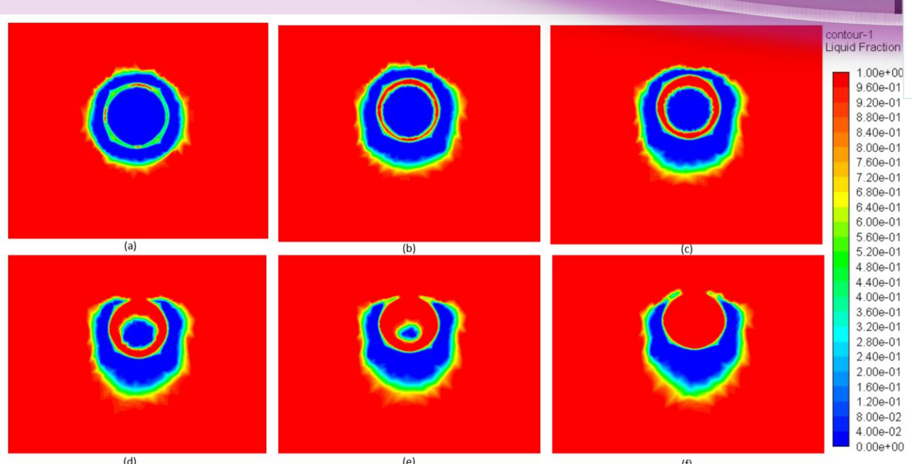


Fig 8: Liquid fraction profile at (a) 5s (b) 10s (c) 15s (d) 20s (e) 25s (f) 30s for Mn in Fe. [4]

Thermodynamic & Kinetic 'Reaction model'

The ladle processing itself requires various interphase reactions, where a non desired entity (species) from the melt is exchanged for a desired entity (species) from the slag phase through and ion exchange reaction between liquid metal and molten slag!

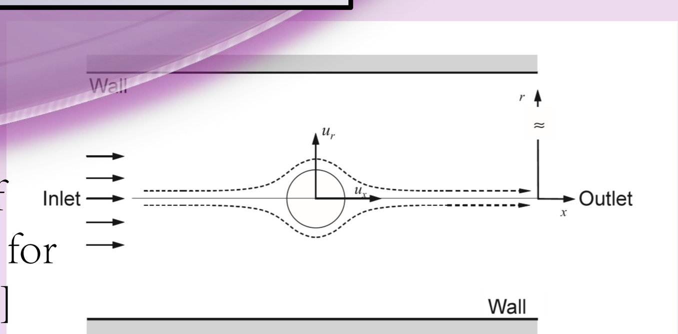


Fig 9: Schematic of numerical domain for a single droplet. [5]

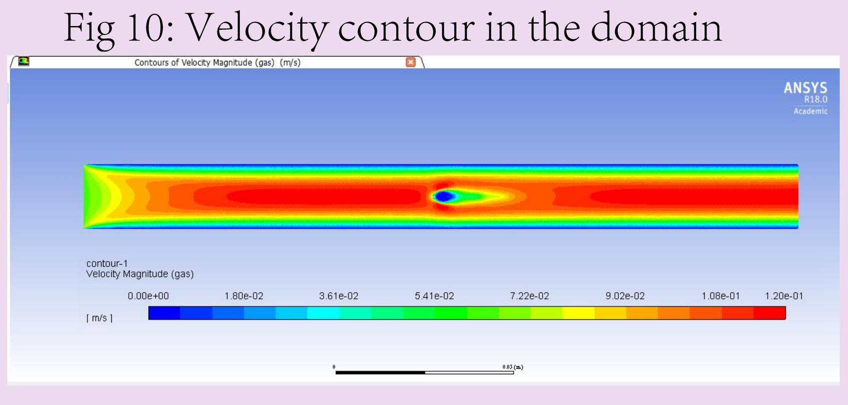


Fig 10: Velocity contour in the domain

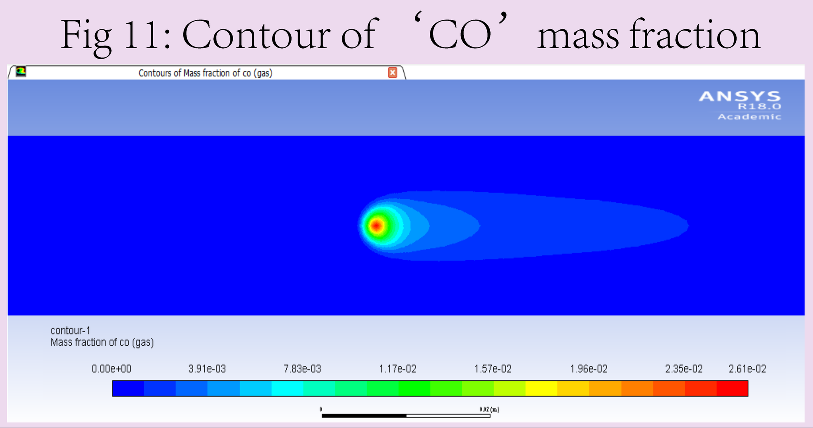
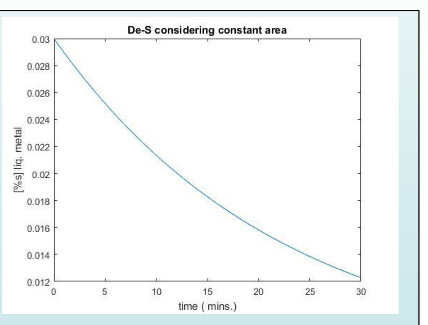
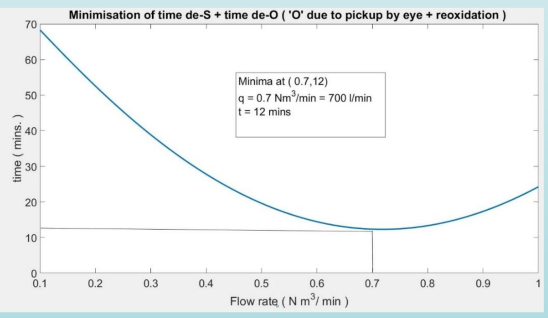


Fig 11: Contour of 'CO' mass fraction

Conclusion

- The multi-physics model discussed above has many interdependent factors among them, hence making the whole process difficult to model in an exhaustive way.
- Hence forth, the authors have attempted to first develop miniature model of each of the separate processes.
- The integration of model is currently in progress.





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[1] Ghosh A., (2000), Secondary steelmaking: principles and applications. CRC Press.
[2] Hallberg, M., et al. "Process model of inclusion separation in a stirred steel ladle. "
[3] Roghair, I., et al. "On the drag force of bubbles in bubble swarms (2011)
[4] Abhishek Arya, M.Tech thesis. IIT Kanpur.
[5] Cho, Hyun-Jin, et al. "Decarburization of Molten Fe − C Droplet: Numerical Simulation and Experimental Validation."

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