Thermo-Mechanical Modelling & Simulation for effective Refractory Design in Iron & Steel Industries

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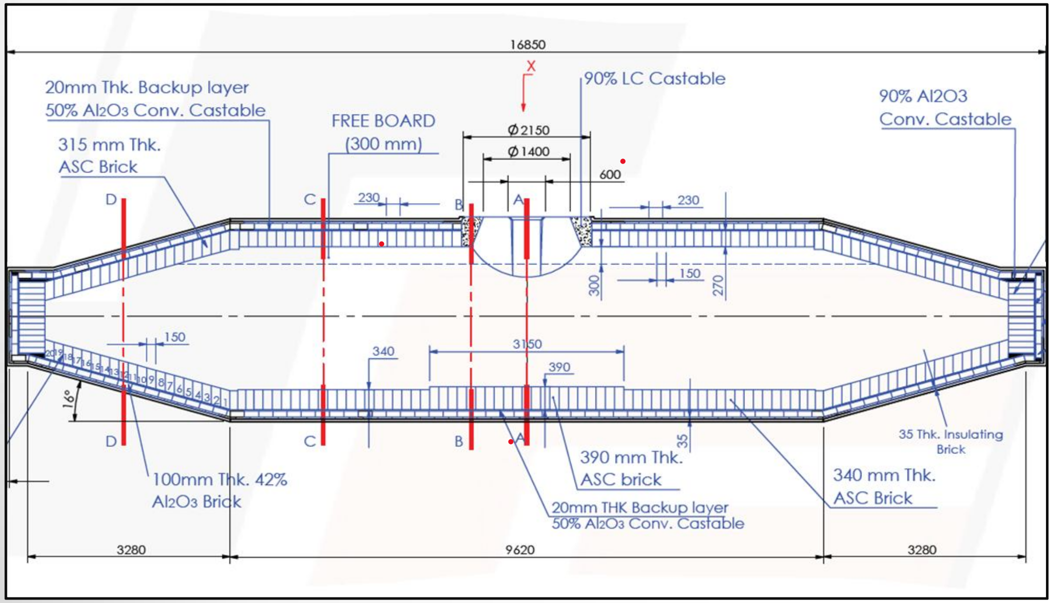
Objectives

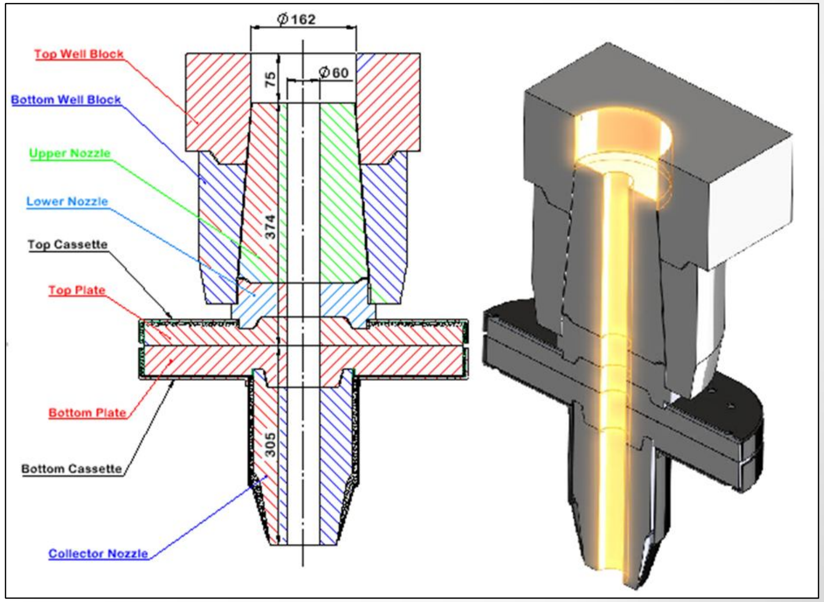
- *To study the effect of using insulation board in the refractory lining of torpedo ladle.*

- *To evaluate the impact of throttling in ladle slide gate refractory elements.*

Using Modelling & Simulation Tools



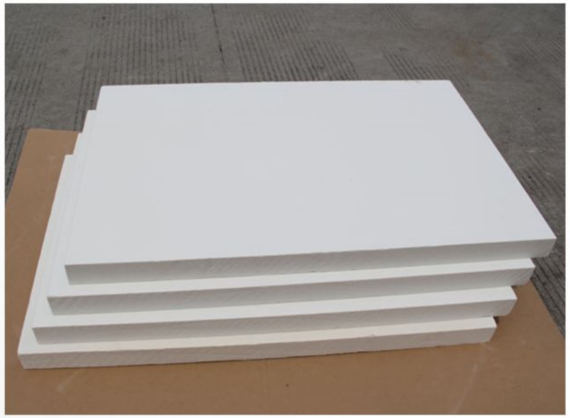
Refractory Lining design of 340T Torpedo Ladle



Ladle slide gate flow channel

(Objective-I)

Effect of using insulation board in the refractory lining of torpedo ladle

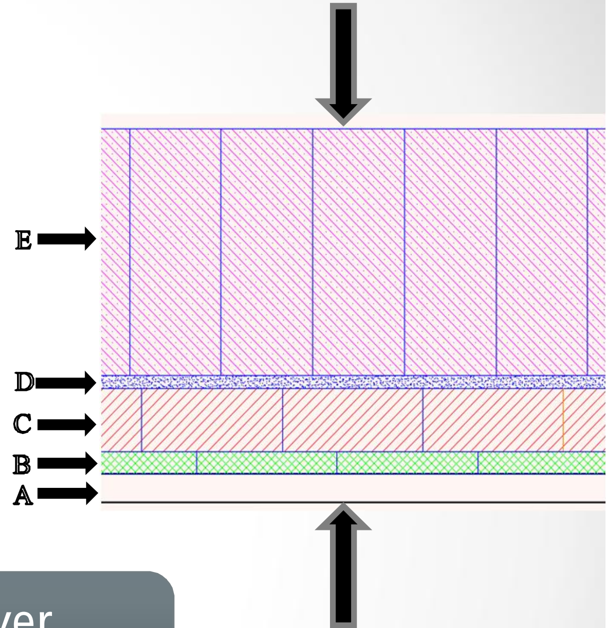


Refractory Lining of Torpedo Ladle

Layer	Layer Material	Thickness	BD (kg/m^3)	TC* (W/mK)
A	Steel Shell	45 mm	7850	48.8
B	Insulation Bricks	35 mm	1000	0.41
C	42% HA Bricks	100 mm	1200	1.6
D	50% Conv. Castable	20 mm	1300	0.43
E	ASC Bricks	390 mm	2980	3.72

* Reference values

Hot face- ASC Bricks



Steel Shell

A *SIMU-THERM* based model prepared using above layer properties and the below thermal conditions.

thermal condition inside

Type of Heat Transfer Coeff. | liquid metal

1500 °C | Ti | 10000 W/m²K | input manually

thermal condition outside

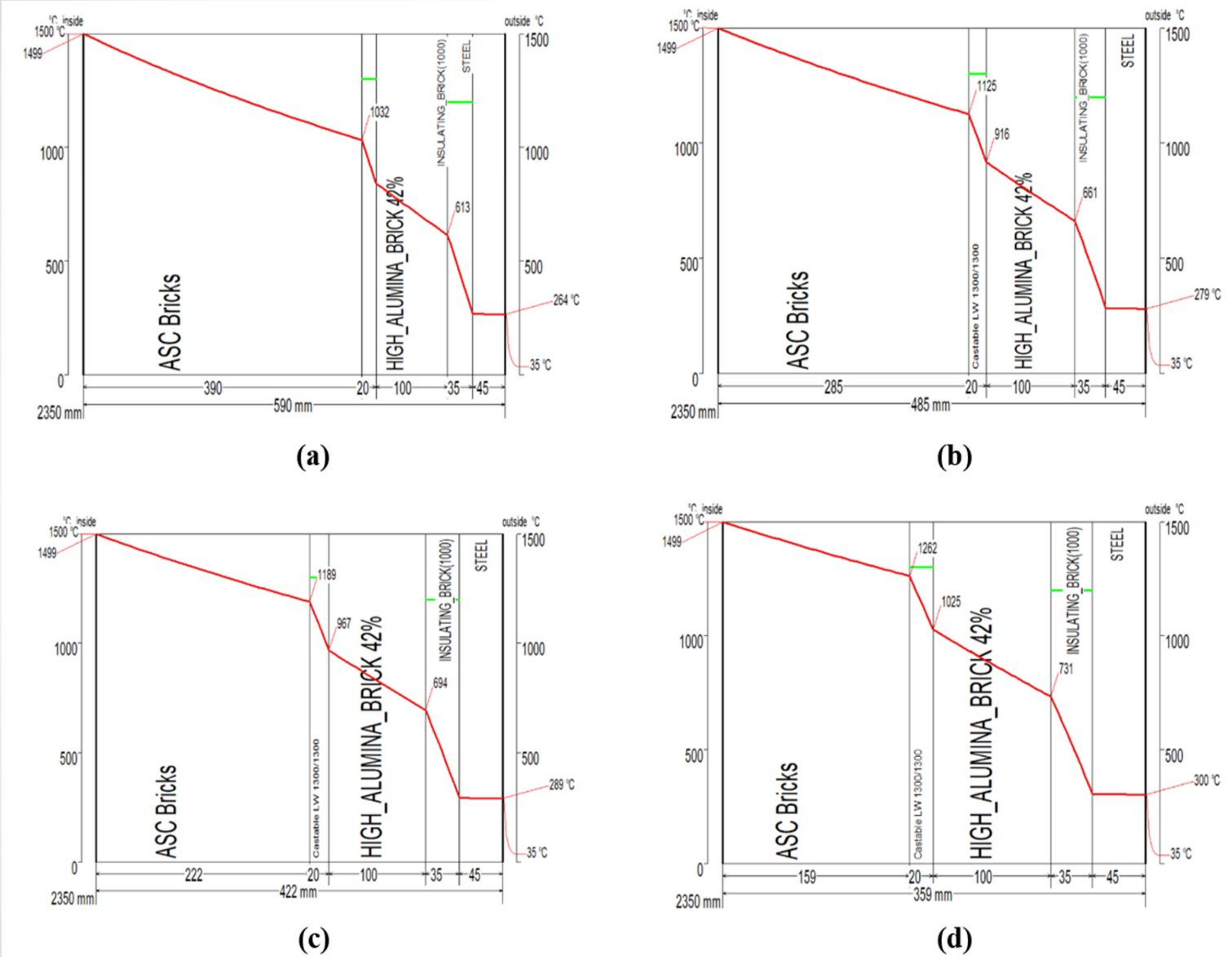
Type of Heat Transfer Coeff. | ambient air

35 °C | Ta | 15.77 W/m²K | ASTM_04

Thermal condition at Hot face and ambient condition at steel shell

Temperature Profile of Refractory Lining

(Without Insulation board)



Temperature profiles of refractory lining without insulation board (a) at beginning of campaign, (b) at life of 500, (c) at life of 800 , (d) at life of 1100

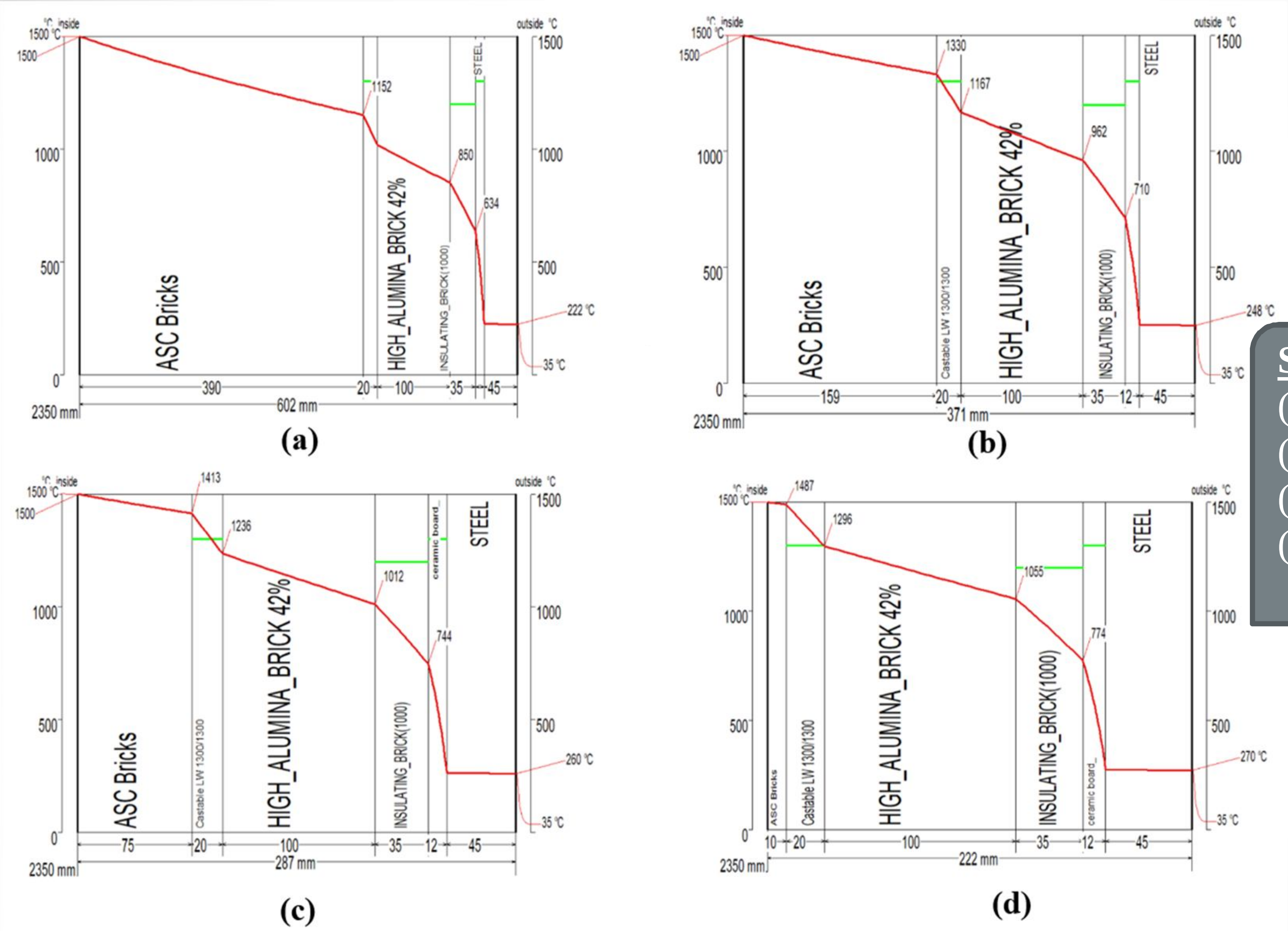
Shell Temperature:

(a) At beginning- 254°C
(b) At 500 heats- 279°C
(c) At 800 heats- 289°C
(d) At 1100 heats- 300°C

- * Wear rate of working lining is assumed to be 0.21 mm/heat based on LOT data collected from different campaigns of Torpedo Ladle

Temperature Profile of Refractory Lining

(With Insulation board)



Shell Temperature:

(a) At beginning- 222°C

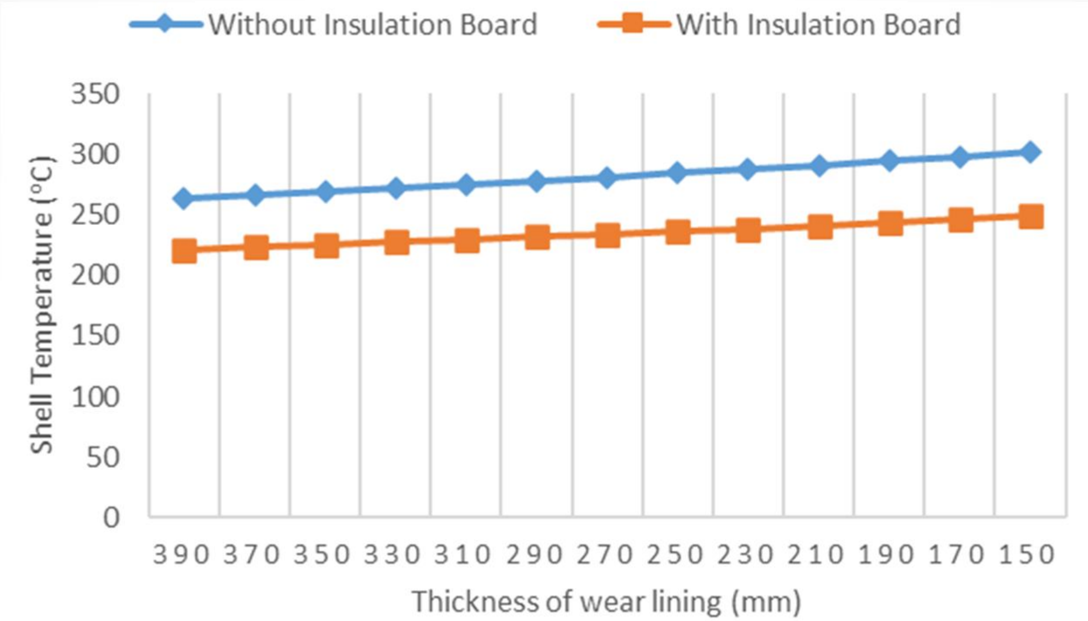
(b) At 1100 heats- 248°C

(c) At 1500 heats- 260°C

(d) Near to worn-out stage- 270°C

Temperature profiles of refractory lining with insulation board (a) at beginning of campaign, (b) at life of 1100, (c) at life of 1500, (d) near to worn-out stage of ASC bricks

Comparison of Shell Temperature



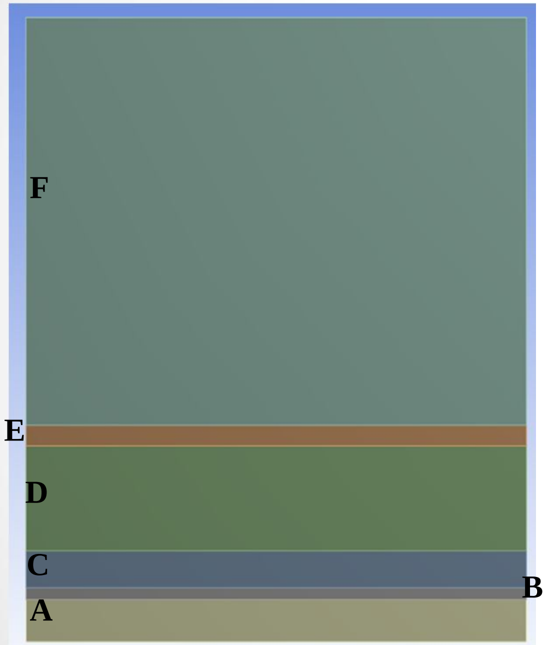
Without Insulation Board

Life/Heats taken (Nos.)	LOT (mm)	Shell Temperature (°C)
0	390	254
500	285	279
800	222	289
1100	159	300

With Insulation Board

Life/Heats taken (Nos.)	LOT (mm)	Shell Temperature (°C)
0	390	222
1100	159	248
1500	75	260

Result verification through FEA



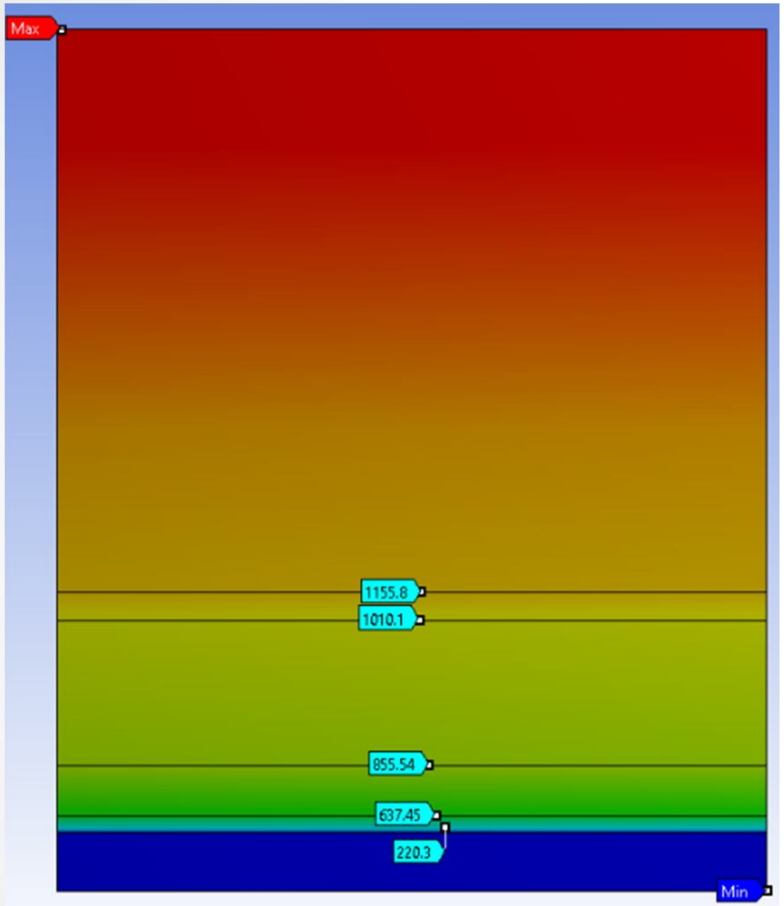
Geometry for Refractory layers

Meshing of geometry

Mesh Details

- Meshing Method: **Body Sizing**
- Elements: **223132**
- Nodes: **1015570**

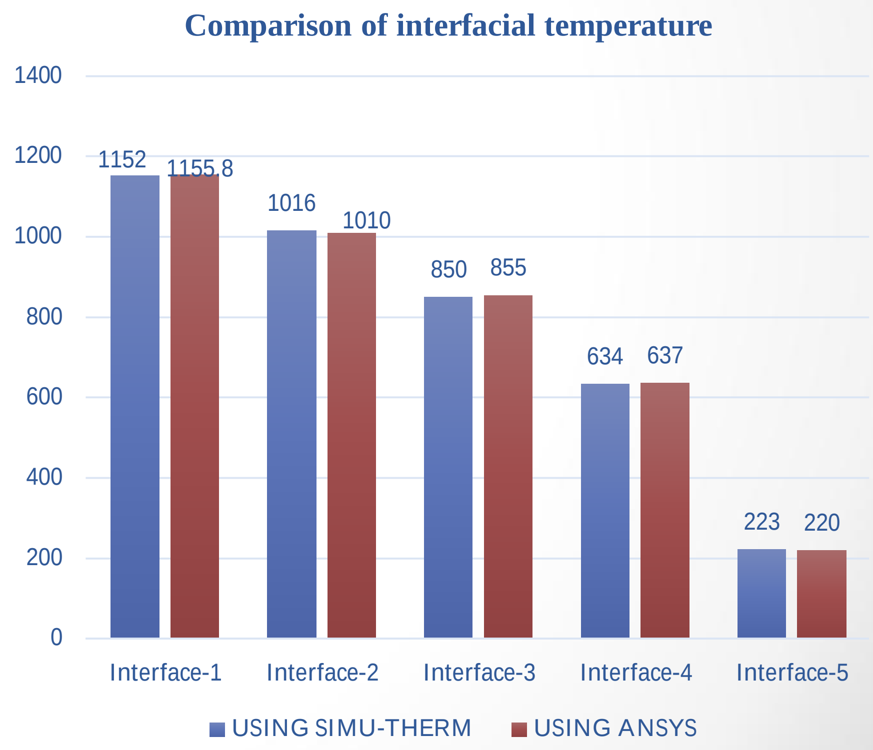
Result verification through FEA



Contours of temperature

Boundary Condition:

- Hot face : **Convective heat transfer through liquid metal**
- Steel Shell : **Ambient Condition**

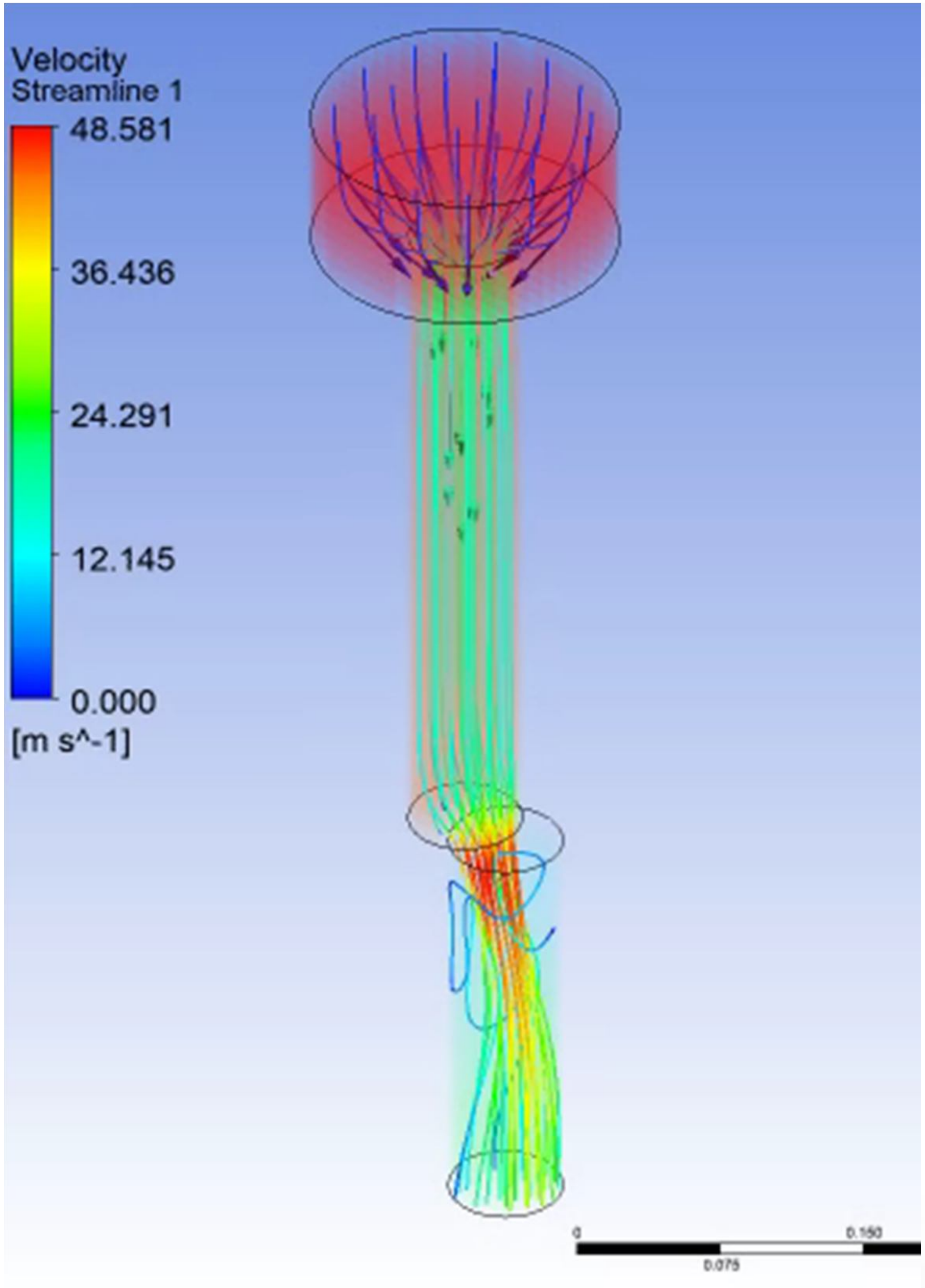


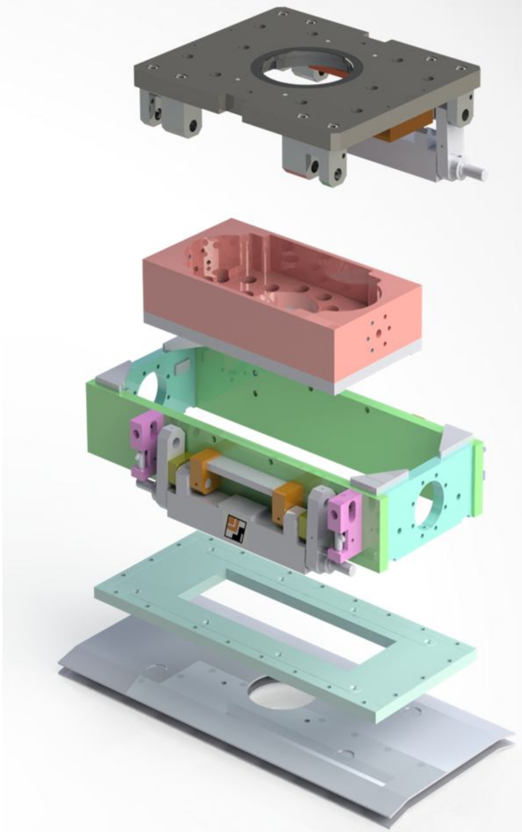
Inference

(Objective-I)

Insulation board helps:

- To maintain a comparatively lower shell temperature (approx. 50^{o}C less) at same LOT.
- To utilize the maximum optimal thickness of the working lining.
- To reach a comparatively higher campaign life depending upon other operational parameters.

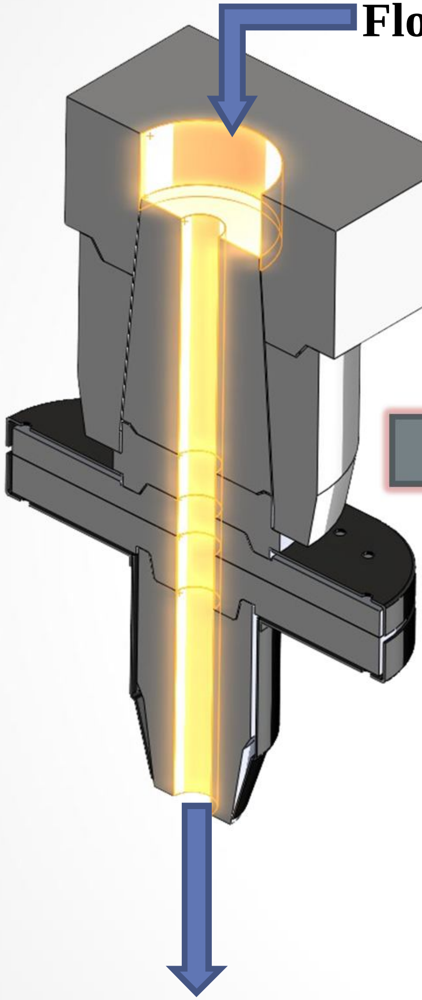




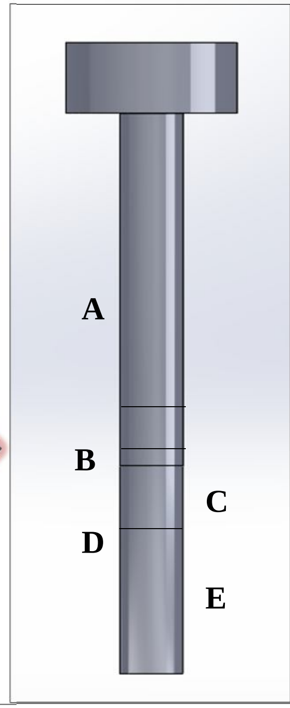
(Objective-II)

Impact of throttling in ladle slide gate refractory elements

Preparing the Geometry



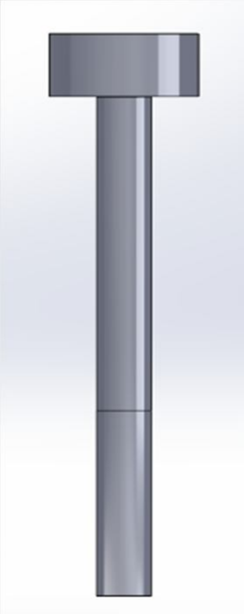
Flow domain extraction



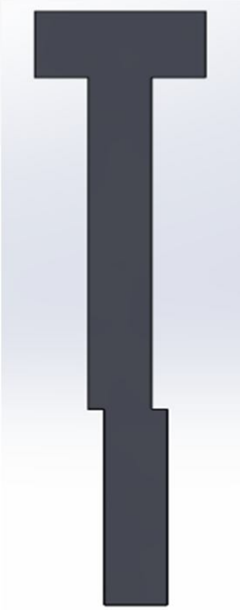
A. Upper Nozzle
B. Lower Nozzle
C. Top Plate
D. Bottom Plate
E. Collector Nozzle

Extracted flow region geometry

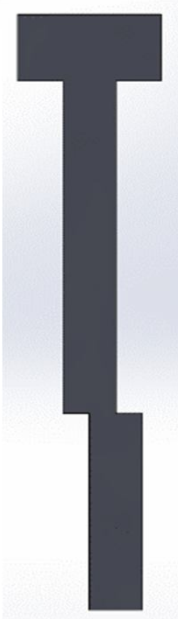
Preparing the Model



At full open condition



At 75% open condition



At 50% open condition

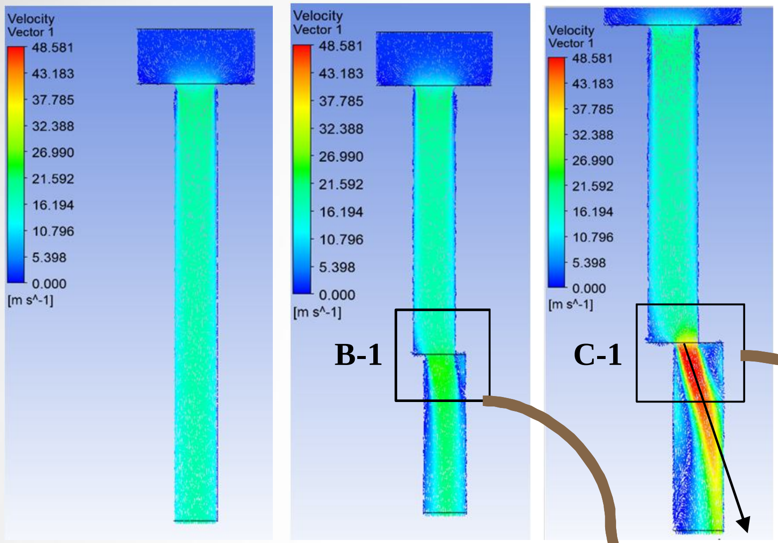
Meshing:
- Tetrahedral elements with suitable body sizing.
- Average skewness value : 0.15 (≈ 0)

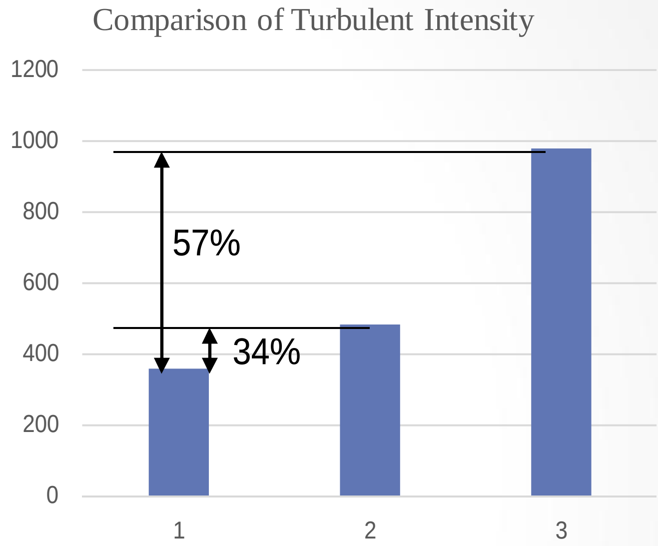
Solver Setting:
- Pressure based Steady state solver with k-epsilon model engaged.

Boundary Conditions:
- Inlet: mass flow type
- Outlet: pressure outlet

Assumptions:
- All three cases are simulated with the same casting speed and without clogging and erosion.

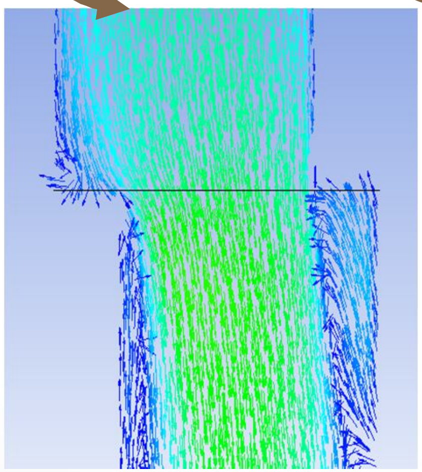
Comparison of Flow & Turbulence



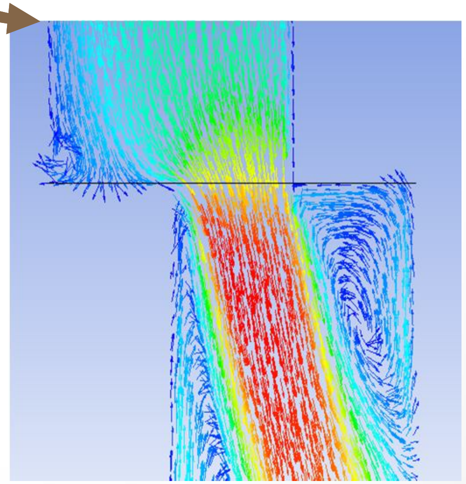


Observations at Throttled case:

- Flow Asymmetry
- Higher Turbulence
- Higher erosion rate of Collector nozzle than normal



At 75% open condition

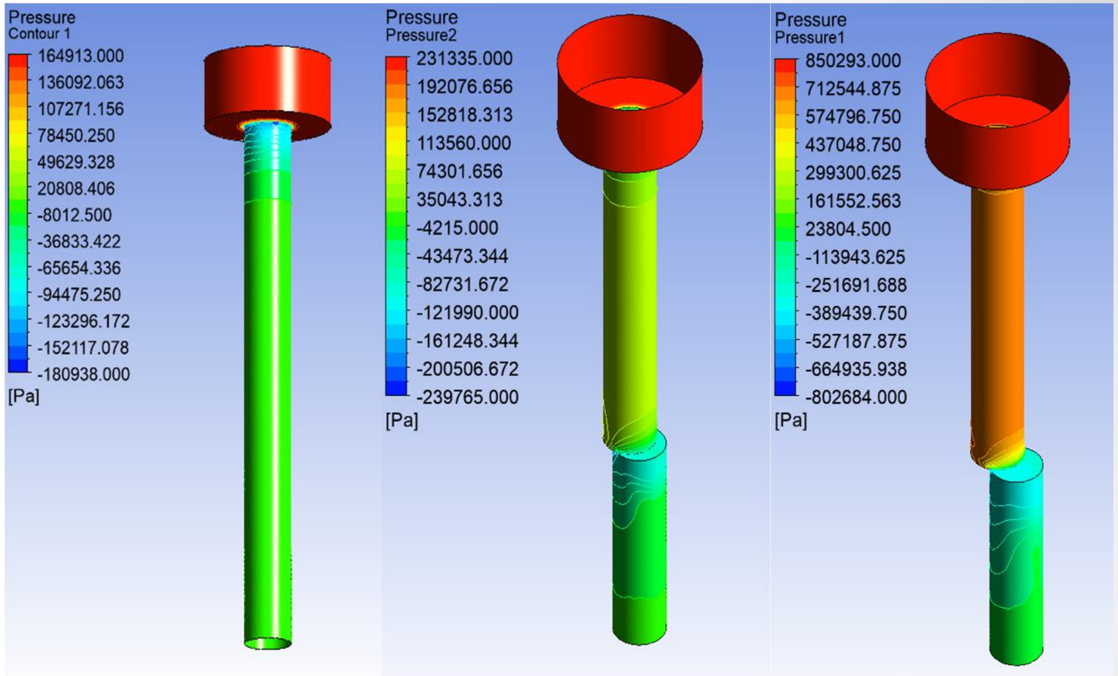


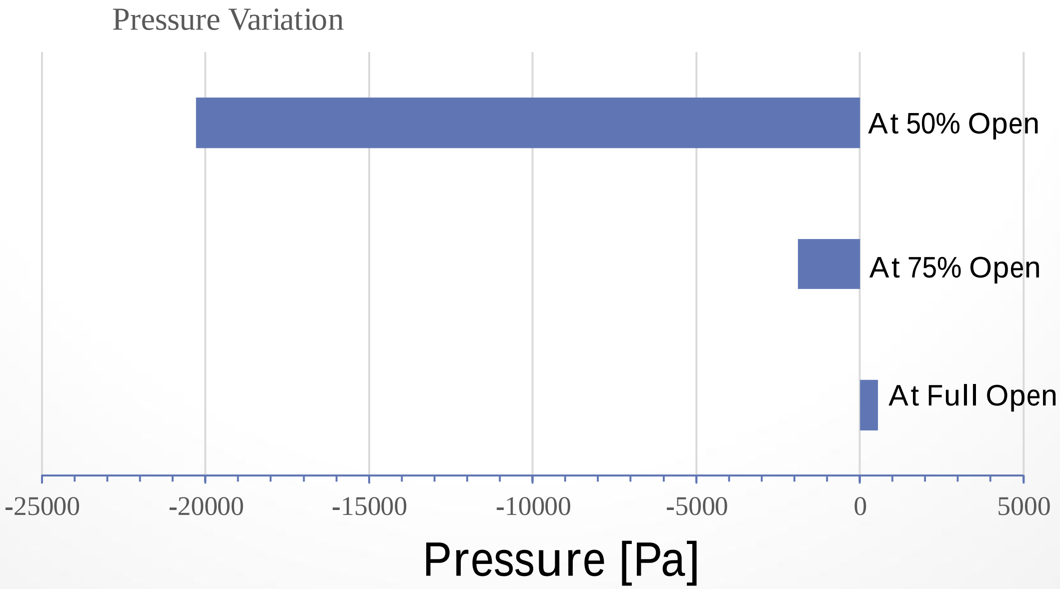
At 50% open condition

Comparison of Pressure

Observations at Throttled Condition:

- Pressure drop and flow separation
- Negative pressure zone creation
- Air aspiration inside flow channel





Inference

(Objective-II)

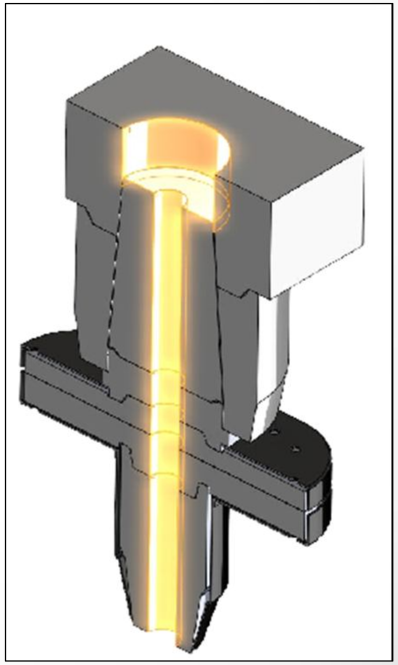
CFD Modelling and results of THREE different Opening conditions shows:

- Flow behaviour is symmetric and have uniform velocity throughout the channel.

Un-throttled or Full open case

- Asymmetric flow and gradual increase in turbulent intensity with reduction of cross-section (which may severely affect the life of refractory component below throttled region)
- Generation of negative pressure below the throttled region (may lead to air aspiration inside flow channel affecting quality of steel)

Throttled case



References:

1. S. Biswas, D. Sarkar, “**Introduction to Refractories for Iron and Steelmaking**"; Springer Nature, 2020.
2. D. R. Kreuzer, C. Wagner, G. Unterreiter and J. Schmidl, “**Refractory Design and the Role of Numerical Simulation**”; The Minerals, Metals & Materials Society; 2018.
3. Shiwei Liu, Jingkun Yu, Feixiong Mao, “**Thermal Behavior Modeling of Interior Refractory Lining of Torpedo-ladle by Finite Element Method**”, Advanced Materials Research, Trans Tech Publications, Switzerland; 2011; Vols 282-283.
4. S. W. Liu, J. K. Yu, L. Han, Z. Q. Li & Z. G. Yan, “**Thermal insulation performance analysis of nanoporous thermal insulating materials applied in torpedo ladle**”; Materials Research Innovations; 2014; VOL 18.
5. Hyunjin Yang , Hamed Olia and Brian G. Thomas, “**Modeling Air Aspiration in Steel Continuous Casting Slide-Gate Nozzles**”; Metals; 2021.
6. J. Rong, H. Jiang, L. M. Song and J. Li, “**Effect evaluation algorithm of heat preservation improvement for torpedo car in Bao steel**”, J. Mater. Metall; 2006, 2, (5); 90–95.

Thank You!

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