Iron Making and Steel Making
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Module – 09
Lecture – 45
IM: Tundish metallurgy and design

In this lecture, we will discuss about the Tundish Metallurgy and Design.

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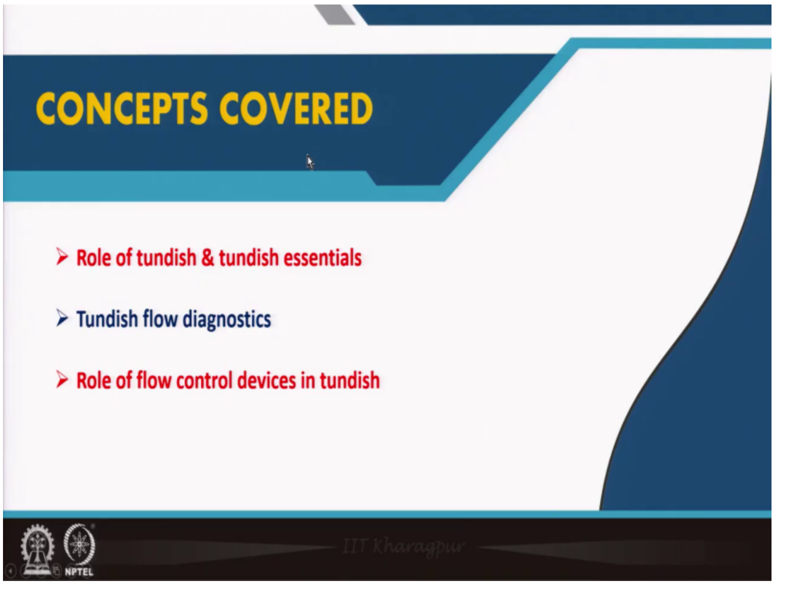

Topics covered will include role of tundish and tundish essentials, tundish flow diagnostics and the role of flow control device in the tundish.

Today tundish is not only used as an inactive reactor to feed liquid steel to the concast mould at constant flow rate, but also it acts as an active reactor to remove inclusion from steel.

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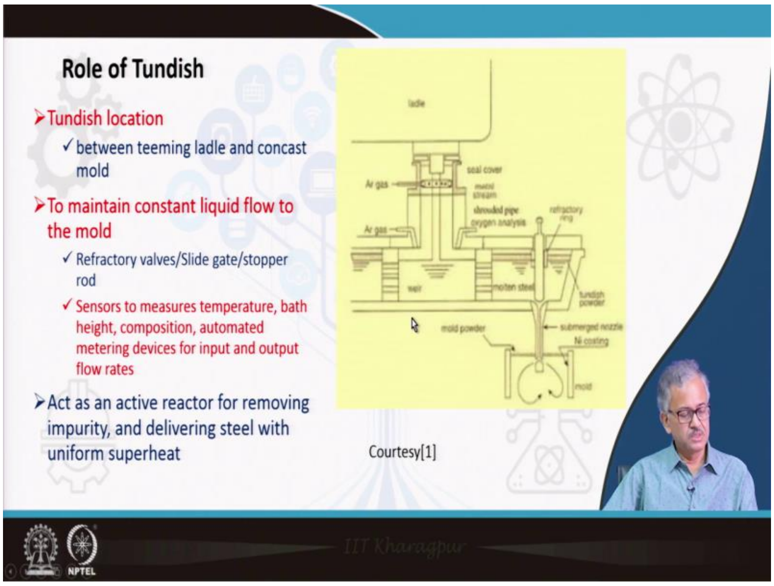

Tundish is located between the teeming ladle and the continuous casting (concast) mould. Initially tundish was introduced to feed liquid steel to multiple strand concast moulds at constant velocity to maintain a constant casting rate. In tundish the liquid level is kept constant by continuously feeding liquid steel to tundish from teeming level at appropriate flow rate.

But, today tundish function is not limited to supply of liquid steel to a multiple strand concast moulds at a constant flow rate, but also to remove the inclusions as much as possible in the tundish itself. Because, tnndish is the last resort to remove the inclusion from the steel.

From teeming ladle the liquid steel flows under an inert gas cover called the argon shrouding. The liquid steel is covered by a cylindrical shell (shroud pipe) through which argon gas is purged both from the top and bottom of the shroud pipe. Teeming stream is protected from atmospheric interaction to avoid further introduction of oxygen and nitrogen from atmosphere to contaminate the steel at the last stage of liquid pouring to concast mould. Similarly liquid steel from tundish to concast mould is poured through submerged entry nozzle, called SEN.

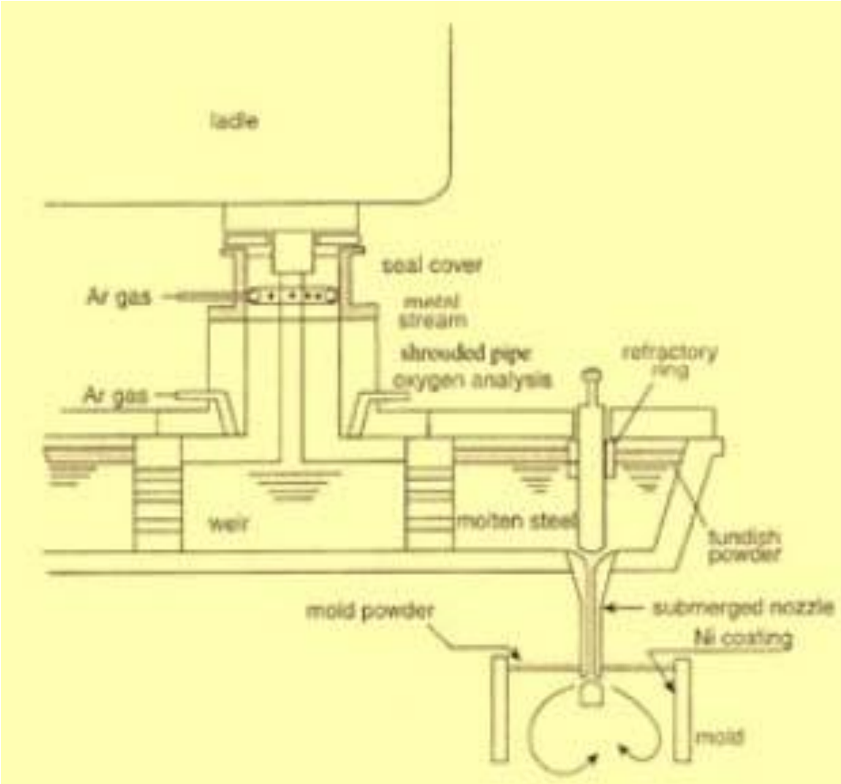

Figure 45.1: Schematics of liquid flow from teeming ladle to tundish to concast mould[1].

There is a stopper rod or, refectory valves slide gate at tundish exit to control the flow rate. Temperature sensors are also attached at the exit to monitor the liquid temperature such that liquid with constant superheat emerges from the exit end.

Tundish no longer just act as a receptor and supplying the metal at a constant flow rate, but also today it acts as an active reactor for removing the inclusions and maintaining constant superheat at the tundish exit.

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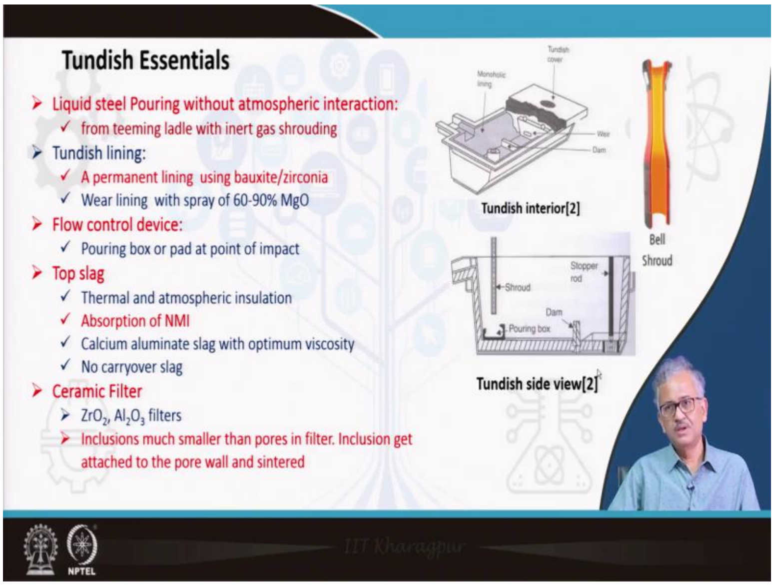
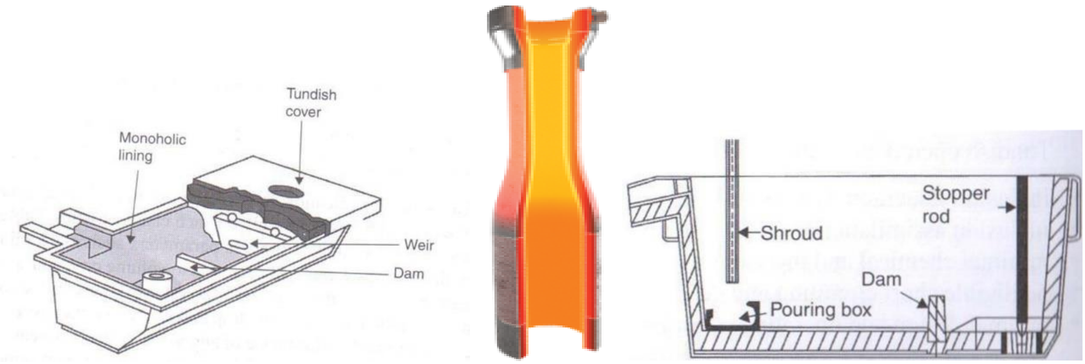


Let us discuss some tundish essentials:

First is the inert gas shrouding of liquid stream from teeming ladle to tundish. Figure 45.2(b) shows a bell shroud.



(a) **(b)** **(c)**

Figure 45.2: Schematics of (a) furnished tundish (b)a bell shroud (c) longitudinal cross section of tundish [2]

Tundish lining consists of a monolith lining, followed by a permanent lining using bauxite and zirconia and finally an outer steel shell. The monolith wear lining is made of ramming mass of calcined dolomite with 60 to 90% MgO. A pouring box and a pad (Figure 45.2(c)) is used at the point of impact of the liquid stream to avoid direct interaction of the refractory and the liquid stream causing erosion of refractory and inclusions in steel. The pad-box system also damps the turbulence caused by falling stream. Tundish is also furnished with dams and weir to evolve desired flow field for inclusion removal(45.2(a) & (c)).

A synthetic slag cover is used over the liquid metal to avoid atmospheric interaction. Overlaying slag also acts as an absorbent for the inclusion in steel. It also acts as an insulator to restrict heat loss from the top liquid surface.

The overlaying slag should have optimum viscosity and favourable surface tension that helps in engulfing the inclusion particles when those rise up to the slag layer. Calcium aluminate slag is used which creates a basic and reducing atmosphere in slag. At this point BOF carryover slag is not permissible and its reducible oxides are likely to contaminate the liquid metal.

Ceramic filters are used at the tundish exit to arrest inclusions to some extent. Filters are usually zirconia-alumina filters, which provides favourable surface tension to the inclusion particles to attach those to the pore walls of the filter, which subsequently get sintered to the wall at high temperature. It may be noted they does not work like ordinary filters where pore sizes are much smaller than the particles being arrested. Here pores are much bigger than the tiny inclusions.

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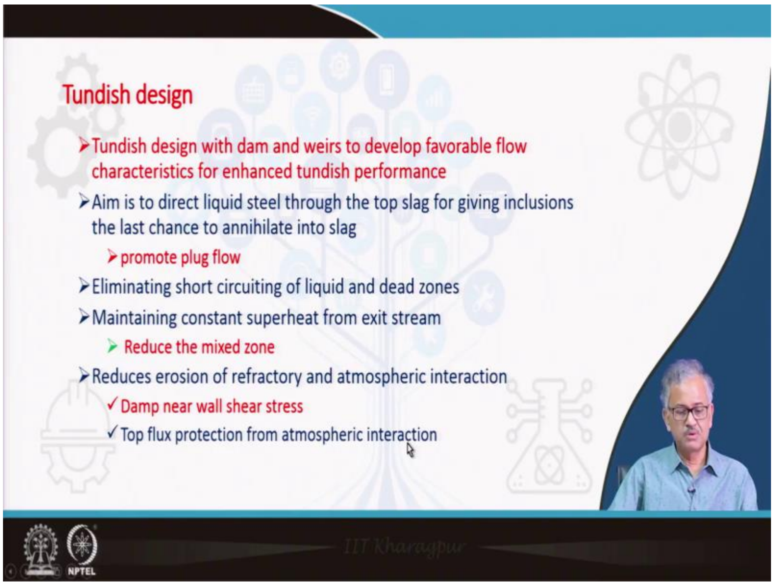

Now we will discuss the tundish design to generate favourable liquid flow pattern in the tundish that ensures inclusion float-up, constant liquid superheat at the exit stream.

Tundish is designed with dam and weirs to develop favorable flow characteristics that directs the liquid stream through the top slag for giving inclusions the last chance to annihilate into the slag. Such directed flow is called the plug flow, where fluid elements follow the similar path at constant velocity. Such flow path will bring the inclusions at the top slag layer for their engulfment into the liquid slag.

In absence of dam and weirs liquid stream may directly reach the exit point, called the short circuiting which suddenly increases the superheat of the exit stream; besides it does not allow the inclusions in liquid to reach the top slag.

In unfurnished tundish, some fluid elements may also be arrested in circulatory mixed flow regime with a wide residence time distribution of the fluid elements. In such case fluctuation of superheat in exit liquid stream is most likely to be observed. Also fluid element might not get a chance to reach top slag layer; even if they reach, strong recirculation might not allow inclusions to detach at slag layer.

Use of dampers are also used to dampen the turbulence and shear stress over the refractory to reduce erosion and incorporation of inclusions in liquid steel.

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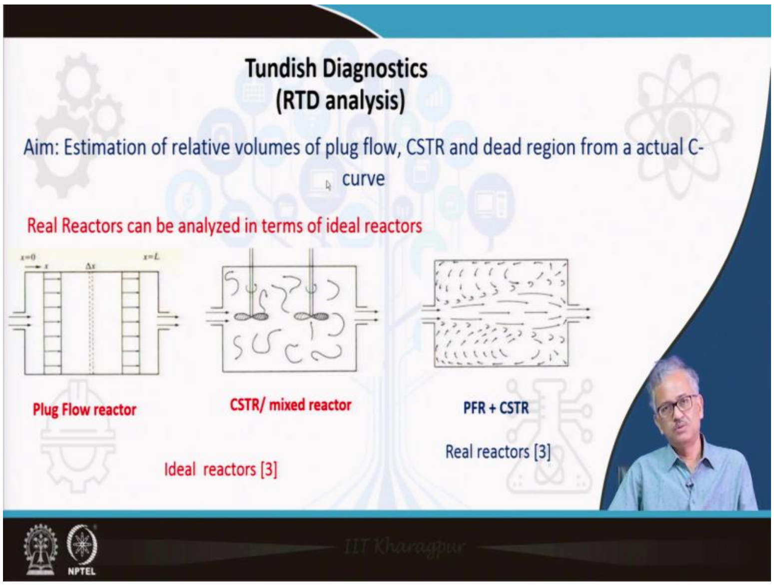

Let us discuss the tool for tundish diagnostics. Any real reactors can be analyzed in terms of ideal reactors, called the plug flow reactor and continuously stirred reactor(CSTR) or circulatory reactor, or mixed reactor (Figure 45.3).

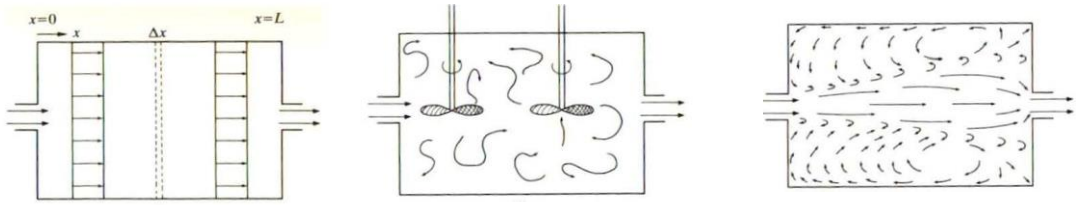

Figure 45.3: Schematics of (a) plug flow reactor, (b) CSTR, (c) Real reactor[3]

A plug flow reactor is defined as a tubular reactor where fluid elements move in a particular direction at constant velocity with same residence time. There does not exists any cross mixing. In contrast, CSTR (continuously stirred reactor) is a reactor that is completely mixed with all types of cross mixing. In CSTR fluid elements have wide distribution of residence time. There exists another reactor called the dead zone where the average velocity is several fold lower than main stream velocity and momentum, heat and mass transfer in this zone is assumed to be negligible.

A real reactor represents a combination of all these three reactors in certain proportions. In tundish diagnostics we would like to find out the proportions of these ideal reactor zones in tundish. Obviously, tundish with higher proportion of plug flow zone is preferred as it allows liquid to move through the slag layer to facilitate inclusion removal and it also allows all fluid elements to have similar residence time that ensures to maintain fixed superheat at the tundish exit. Such tundish diagnostics is done through tracer experiments. In cold model simulation it is done using some conducting material (KCL) as tracer and monitoring its concentration at the exit stream using some probe. The concentration profile (C-curve) could be analyzed to calculate proportions of plug/CSTR/dead zone. A C-curve represents the evolution of dimensionless concentration of tracer at the exit stream with dimensionless time for a pulse tracer addition. Pulse addition means tracer is added just at the onset of experiment. In case of continuous addition through-out the experiment, the corresponding curve is called F-curve.

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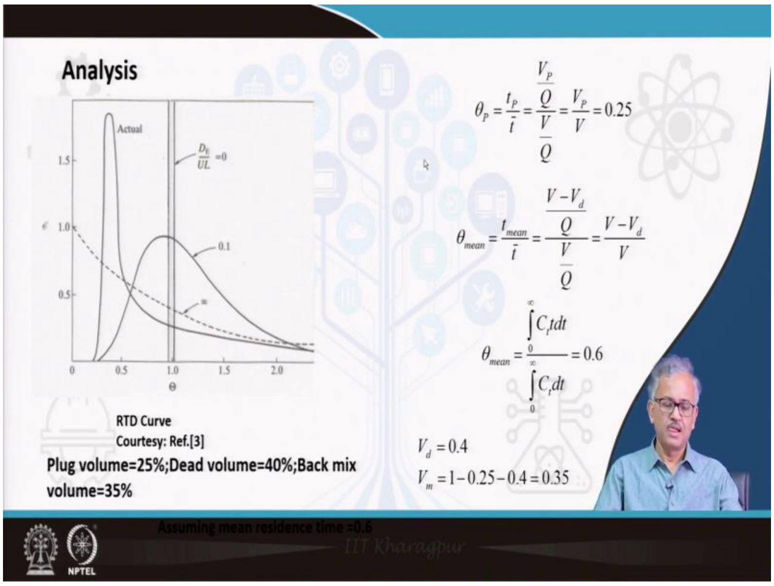

Figure 45.4 represent a C-curve of a real reactor with superimposed C-curves for ideal plug flow and mixed reactor.

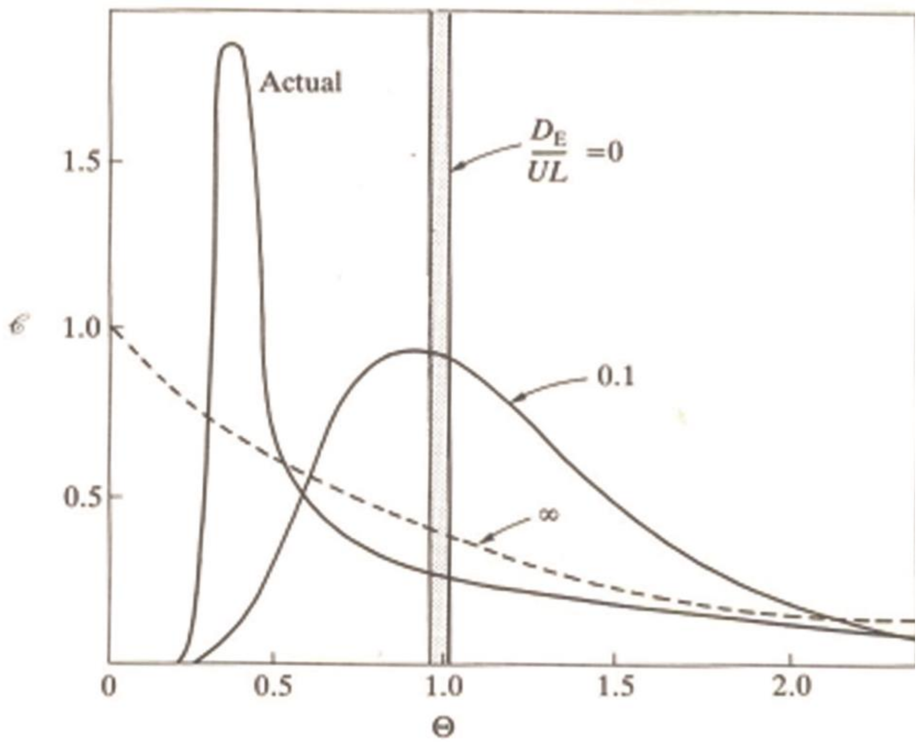

Figure 45.4: C-curve for a real reactor with superimposed C-curves for plug flow reactor and mixed reactor[3].

The C-curves of plug flow reactor (PFR) is represented by vertical line; since all fluid element has same residence time, all tracer will appear in the exit stream at a time after the nominal residence time (V/Q) of fluid elements in the reactor, where V and Q are the volume of the reactor and volumetric flowrate. Based on material balance, the C-curve for a CSTR is obtained as an exponential curve (dotted line). D_E/UL, called the axial dispersion number, measures the extent of cross mixing. D_E is the eddy diffusivity and U,L are the free stream velocity and length of the tubular reactor, respectively. Since in ideal plug flow reactor there is no cross mixing, D_E/UL is zero and it is infinity for ideal CSTR or completely mixed reactor. A hypothetical reactor with axial dispersion number of 0.1 is also shown in the figure. The other curve is the C-curve for tundish, which we need to analyze.

It is found that initial feature of this curve is similar to a PFR; where an almost vertical line rise up and subsequently come down. This part represent the PFR part of the tundish. Rest of the curve follows that of a mixed reactor. The proportion of various reactors in tundish can be estimated using the following calculation.

Calculation of fraction of PFR in Tundish:

$$\theta_P = \frac{t_P}{\bar{t}} = \frac{\frac{V_P}{Q}}{\frac{V}{Q}} = \frac{V_P}{V} = 0.25 \tag{45.1}$$

From the figure, it may be observed that first appearance of tracer in the exit stream occurs at a dimensionless time of 0.25. So plug flow volume appears to be 25% of the total volume in the tundish.

Calculation of mixed reactor portion in the tundish:

$$\theta_{mean} = \frac{t_{mean}}{\bar{t}} = \frac{\frac{V - V_d}{Q}}{\frac{V}{Q}} = \frac{V - V_d}{V} \tag{45.2}$$

Mean residence time may be calculated by considering volume excluding the dead volume.

Dimensionless mean residence time may also be calculated from the time, exit concentration product integral as follows:

$$\theta_{mean} = \frac{\int_0^\infty C_t t dt}{\int_0^\infty C_t dt} = 0.6$$

(45.3)

From equations (45.2) & (45.3), the dead volume is calculated as 40% of the total volume.

So mixed volume is (100-25-40)=35%. Definitely evolved flow pattern in the tundish is not desirable and need to be modified by using dam and weirs.

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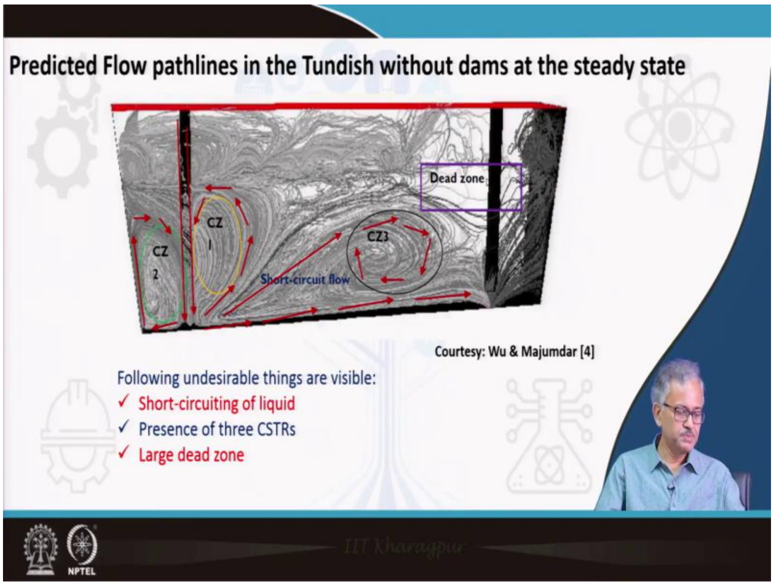

Now, let us see some predicted flow paths of fluid elements in tundish. Figure 45.5 shows the flow characteristics in an unfurnished tundish.

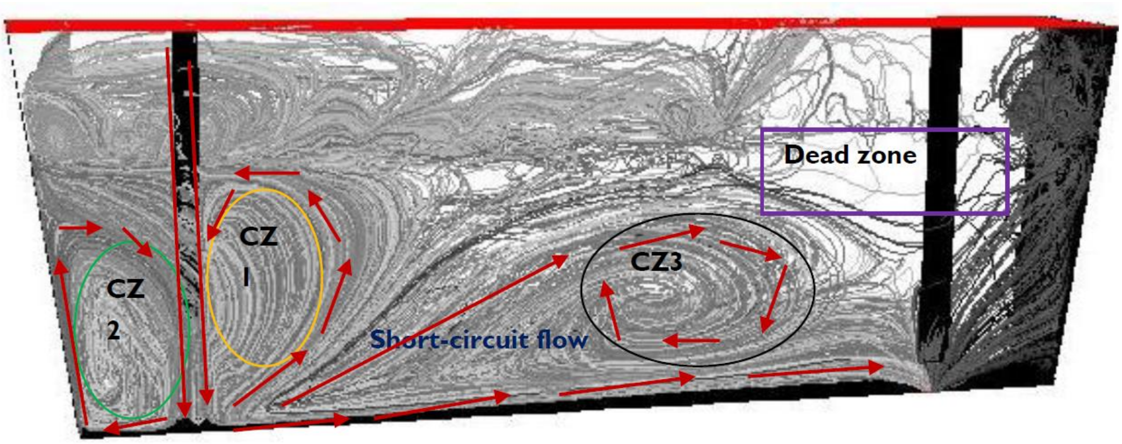

Figure 45.5 Streamlines showing the flow characteristics in an unfurnished tundish [4]

It is seen three circulatory mixed reactor exists CZ1, CZ2, CZ3. Short circuiting of inlet liquid directly to exit stream is also noticed. There also exists large dead zone (white region devoid of streamlines). No well defined PFR is noticed. Definitely it is not the desirable flow pattern in the tundish.

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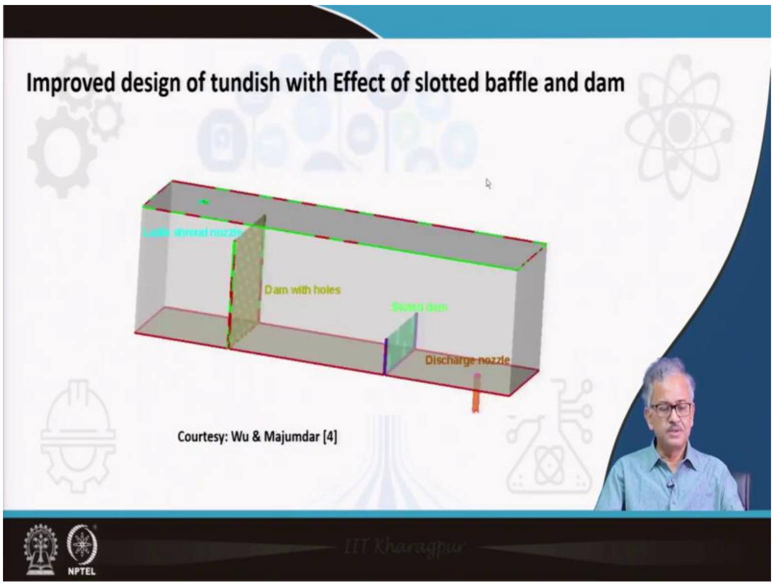

So, simulation is again carried out with furnished tundish with slotted baffle and dam as shown in the Figure 45.6.

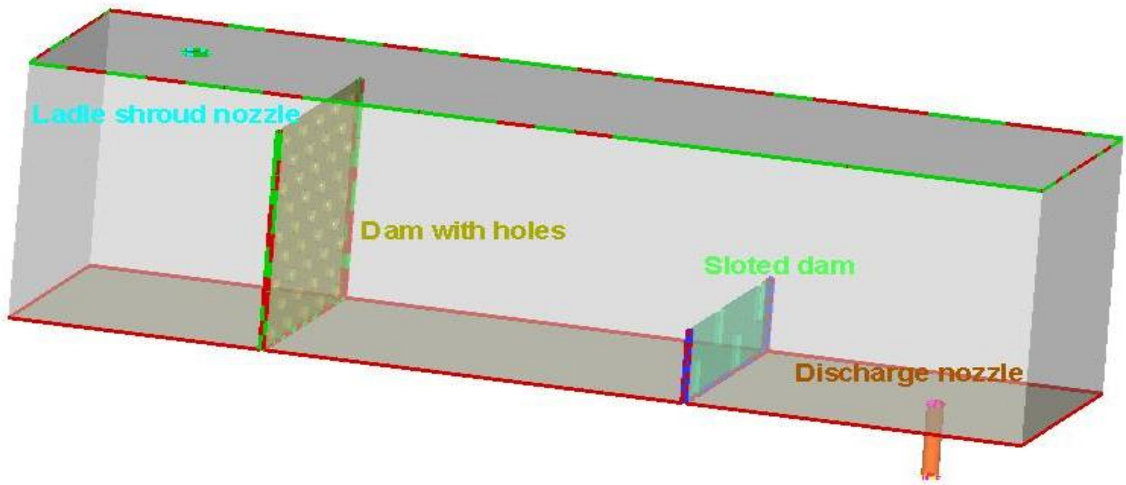

Figure 45.6: Furnished tundish with slotted dams[4]

Two dam are placed in the tundish. One big dam with holes near the liquid inlet and a slotted dam near the nozzle exit of the tundish. Figure 45.7 shows the resulting streamlines.

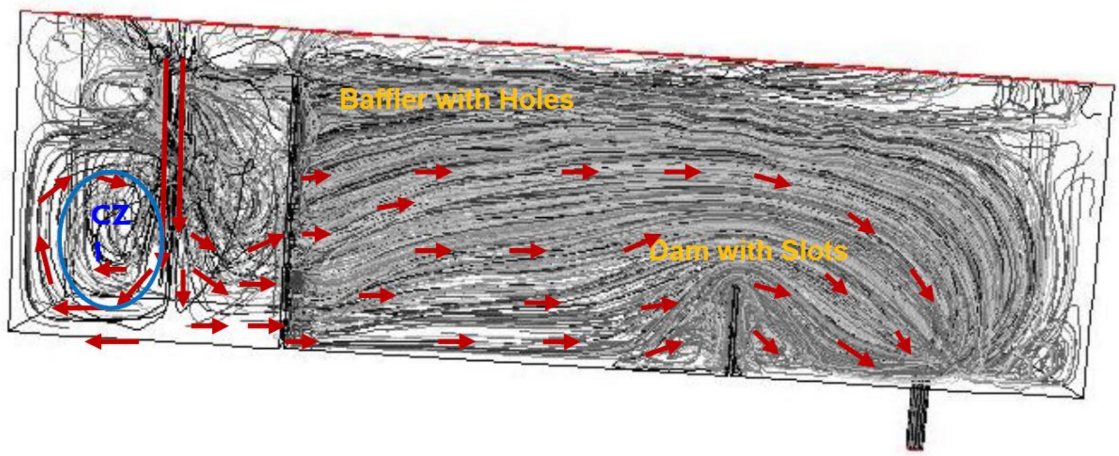

Figure 45.7: Streamlines with furnished tundish [4]

From Figure 45.7 it is seen that only one circulation zone exists on the left hand side of liquid inlet. On the right both the circulation zones are vanished due to the presence of perforated dam and the flow has been converted to plug flow where liquid flows across the slag before reporting to the exit stream. Dead zone also has been reduced significantly. Obviously, dams has generated desired flow field with predominant plug flow portion.

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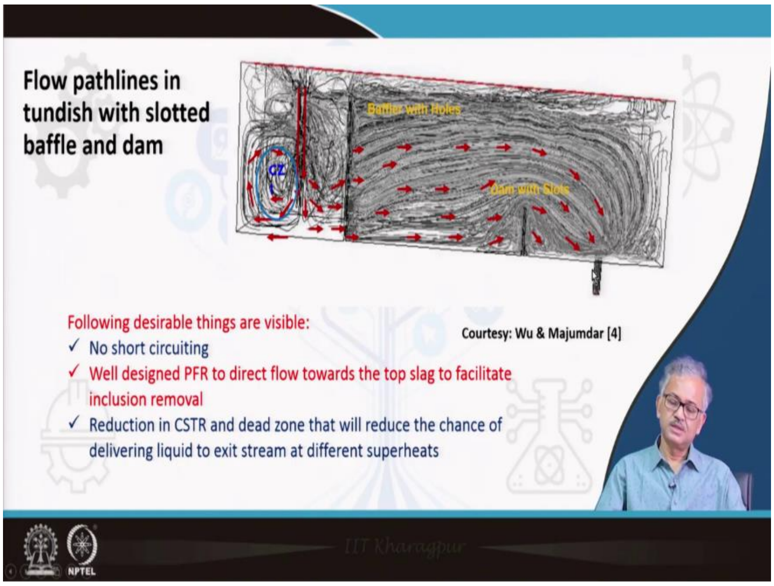

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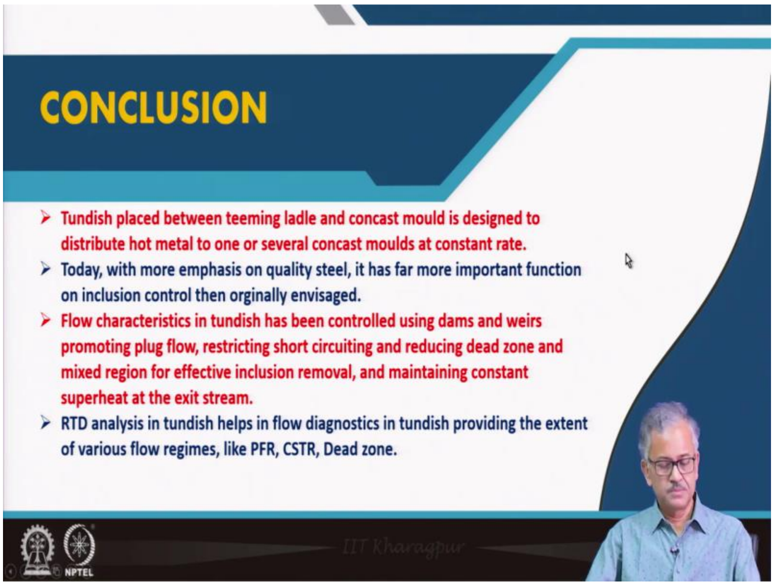
The references are:

1) https://www.ispatguru.com/refractory-lining-of-a-continuous-casting-tundish
2) Dipak Majumdar: A First Course in Iron and Steelmaking, UP, Hyderabad, 2015
3) RIL Guthrie: Engineering in process Metallurgy, Oxford Engineering Press, Oxford, UK, 1992
4) Zhonghua Wu and Arun S. Mujumdar: Modeling of Flow Behavior in Tundishes: Effect of Geometric Modifications, Book chapter-9 in ebook Mathematical Modeling of Industrial Transport Processes , TPR Group, NUS, June, 2009, Singapur



Conclusion: Tundish is placed between teeming ladle and the concast mould to distribute the hot metal in several concast moulds at a constant rate. The role of tnndish today goes far beyond originally envisaged. It acts as an active reactor to remove inclusions.

Tundish is designed with flow modifiers like dams and weirs that develops the desired flow pattern for inclusion removal. Aim is to develop dominant plug flow in the reactor that facilitates inclusion removal, and maintaining constant superheat at the exit stream. Besides, tundish nozzle is equipped with sensors, automatic slide gates, ceramic filters.

Tundish flow can be diagnosed in terms of proportion of plug flow, mixed flow and dead zone by monitoring tracer flow at the exit stream and analyzing the C-curve. Mathematical simulations have also been developed to generate streamlines to visualize the flow pattern with and without flow modifiers.