“Innovative Shroud” – A New Possibility for Production of Clean Steel in Tundish

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Abstract. Last decade steel productions around the world have increased significantly. But there is a high demand of clean steel in domestic as well as international market. For that reason currently many research is going on in this direction. In present investigation, few innovative shrouds were developed conceptually which can be useful in terms future perspective for production of clean and green steel within the last metallurgical reactor tundish. Vacuum shroud and Novel Centrifugal Shroud with argon purging can eliminate formations of tundish open eye (TOE) during ladle transfer operation. 3D Numerical simulation by using ANSYS FLUENT software shows that these flow control products will able to reduce re- oxidation of liquid steel by suppressing slag eye formation or protecting the reaction of liquid steel from ambient air by covering inert argon gas within the tundish vessel.

Key words: *centrifugal shroud, tundish, slag eye, re-oxidation, vacuum shroud.*

1. Introduction

Slag eye, re-oxidation and contamination of the steel melt are common problems of many steel industries around the world. Although it is known to all that tundish act as refining vessel. But sometimes it behaves as a contaminator rather than metallurgical refinery due to adverse fluid flow within the tundish reactor. It is mentioned in Fig. 1 that, approximately 40% re-oxidation of steel melt took place during transfer of liquid steel from ladle to tundish and totally 55% melt contamination occur if slag entrainment and slag thinning is considered along with re-oxidation. This re-oxidation, slag entrainment, slag metal emulsifications from melt flow generates macro inclusions which sometimes clog the tundish submerged entry nozzle and indirectly hindered casting as well as is the source of major defects in final products [1].

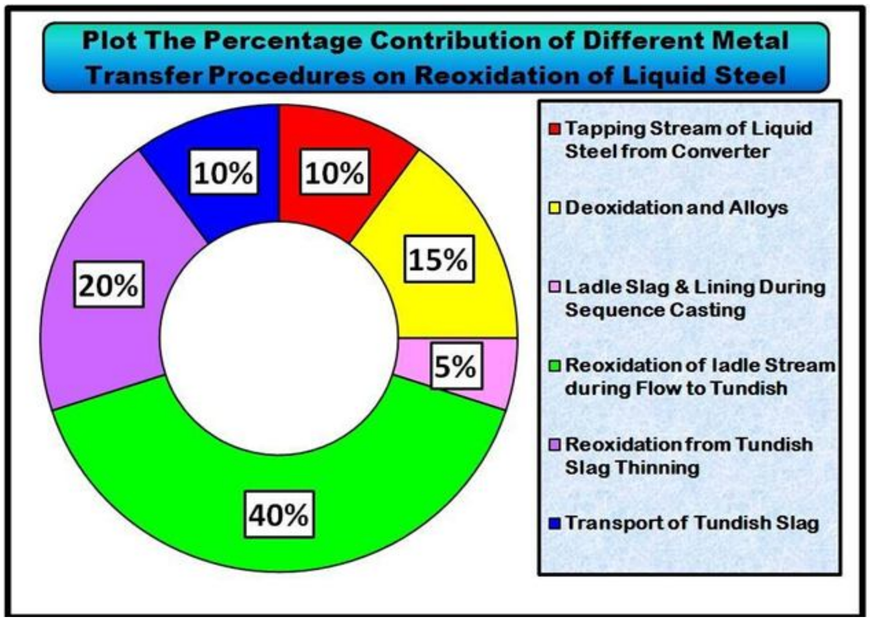


Fig. 1 Percentages of causes behind generations of inclusions in tundish (Reprinted from [1])

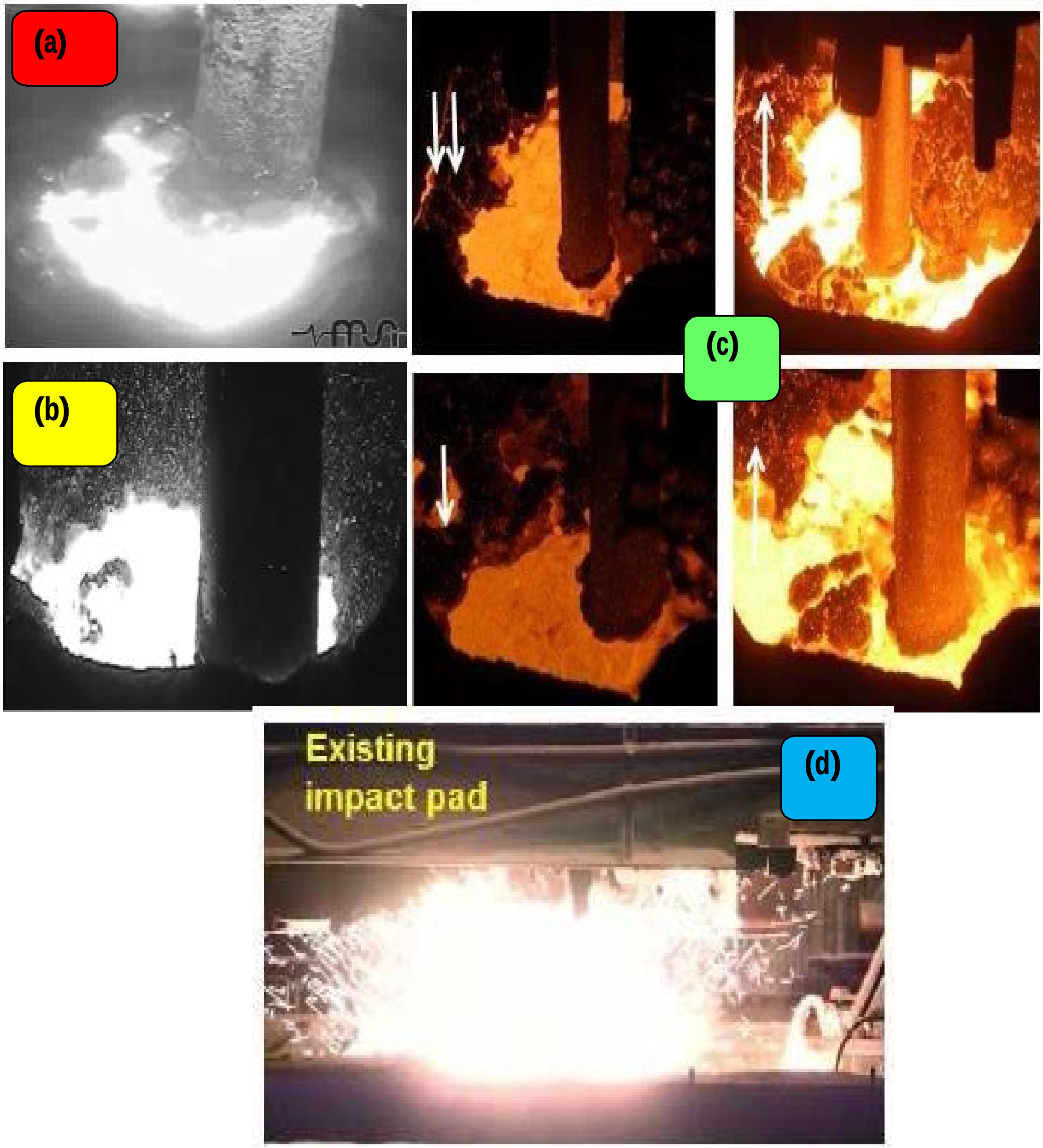


Fig. 2 Industrial observations of slag eye (a), (b) Normal condition(c) Shroud argon purging period and (d) 'Blow Back' effect (Reprinted from [2-3])

Fig. 2 (a) and (b) explore the real conditions of slag eye at billet and slab caster during pouring of liquid steel from ladle to tundish at normal condition. Generally 30-40 minutes is the processing time of transfer of liquid metal from ladle to tundish during each heat casting. During this period the casting powder near the ladle shroud pushed aside for a period of 20-30 minutes if unnoticed which cause pick up of oxygen around 30-40 ppm as found from many industrial data [2]. Argon injection enhance strong surface flow which aggravate formation of 'Tundish Open Eye' as depicted in the Fig. 2 (c) and Fig. 2 (d) is showing the splashing behavior of impact pad during initial poring period [3].

To overcome those abnormalities mentioned earlier researchers have tried to develop different shroud and pour box as well as turbo-stop configurations which will help to make clean steel in tundish. Those developments are schematically shown in the Fig. 3 (a) to (f) respectively. Besides conventional shroud with turbo-stop, many advanced flow control refractory products were developed over the decades like innovative turbo-stop, trumpet-shaped shroud, dissipative shroud, swirling shroud, velocity break shroud, bending nozzle, advanced pouring box etc. [5-12]. Those shrouds and advanced pouring boxes are capable to remove of slag eye formation, reducing of liquid contamination from re-oxidation at open eye, eliminating emulsification during ladle changing period as well as improving the indigenous and exogenous floatation of inclusions at some extent. But clean steel production is not possible to achieve by incorporating above mentioned technology or steel flow control refractory's still today. Especially in mini mill, it is very difficult task to achieve quality steel as well as high production simultaneously due to small size of the tundish. Hence some new innovative shrouds are required to develop to reach both targets.

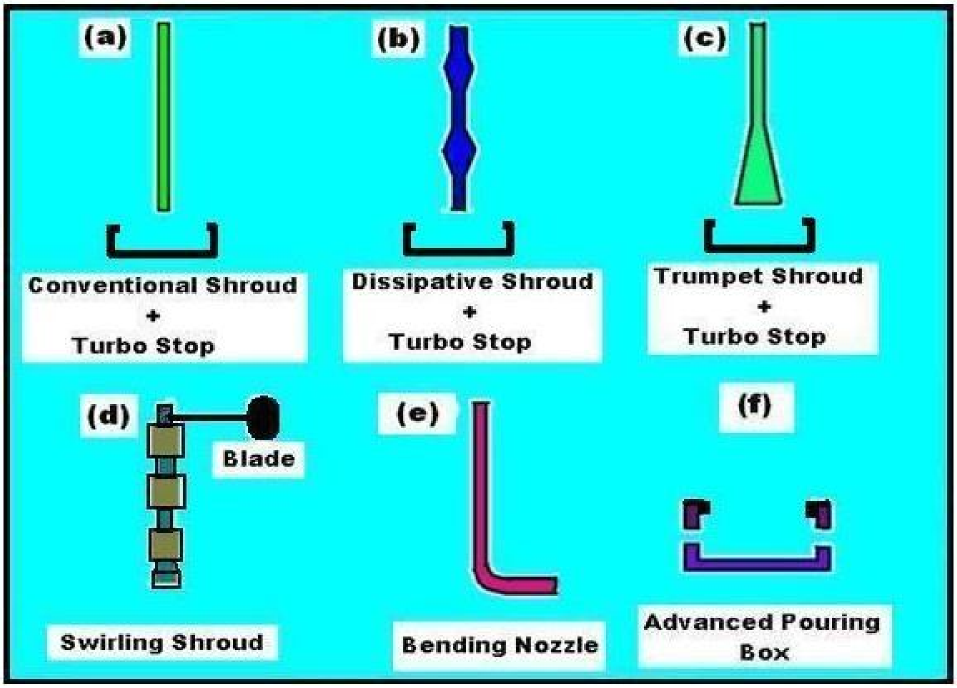


Fig 3 Typical Innovative Shroud and Pouring Box development over last three decades (Reprinted from [4])

Several efforts were made by academics and industry collaboration over the last 2 decades to enhance the performance of tundish reactor [13, 14]. It was found from numerous physical and mathematical modeling as well as plant trials that, flow modifiers like baffle, dam, impact pad, slotted baffle, weir, electromagnetic stirring, argon shrouding, centrifugal flow tundish, swirling ladle shroud and extended shroud have a great impact on RTD (Residence Time Distribution), inclusion separation, grade mixing, emulsification (especially during ladle change over period), open eye formation of tundish vessel [13-21]. So fluid flow in metallurgical reactor act as integral part of producing high quality steel and cast microstructures as well as help to develop new process for improving the plant performance and productivity [22]. Especially for small tundish it is very difficult task to remove inclusions due to low residence time. In those cases innovative shroud concept can take a leading role towards production of clean and green steel.

From 1975 to 2010, significant United States patents have been contributed by several researchers to control turbulence, open eye formation, emulsification and enhancing inclusion floatation within the tundish reactor [23-29].

2. Method

In the present investigation along with conventional shroud with turbo-stop, innovative vacuum shroud with argon purging and new concept Novel Centrifugal Shroud with argon purging were used to control slag eye formation and inclusion removal in tundish as depicted in the Fig. 4 (a), (b), (c) and Fig. 5 (a), (b), (c) respectively. Numerical investigations were performed by ANSYS FLUENT simulation software.

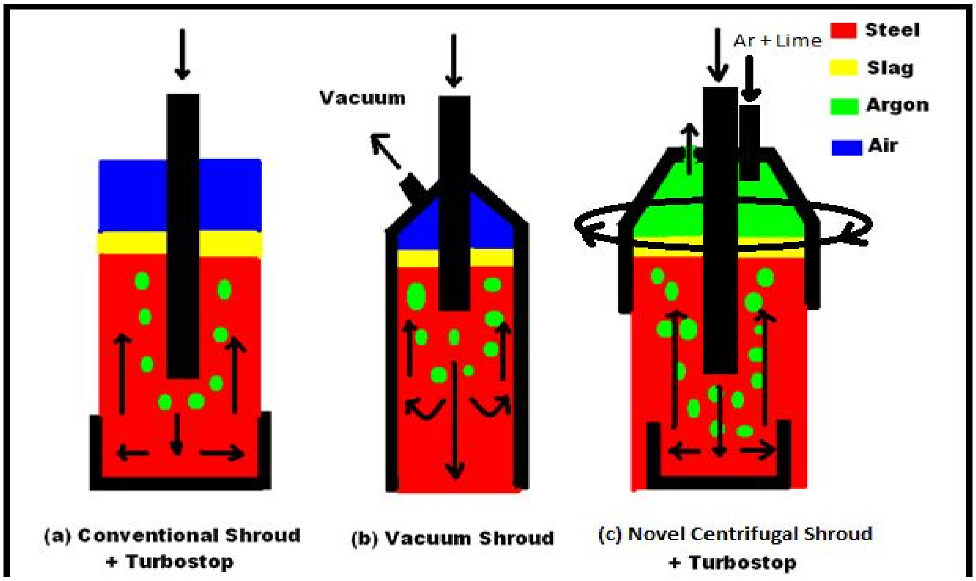


Fig. 4 Schematic of (a) Conventional Shroud and turbo-stop, (b) Vacuum Shroud with Argon Purging (Invented by Dr. Debasish Chatterjee) and (c) Novel Centrifugal Shroud (Invented Dr. Debasish Chatterjee)-Turbo-stop with Argon Purging

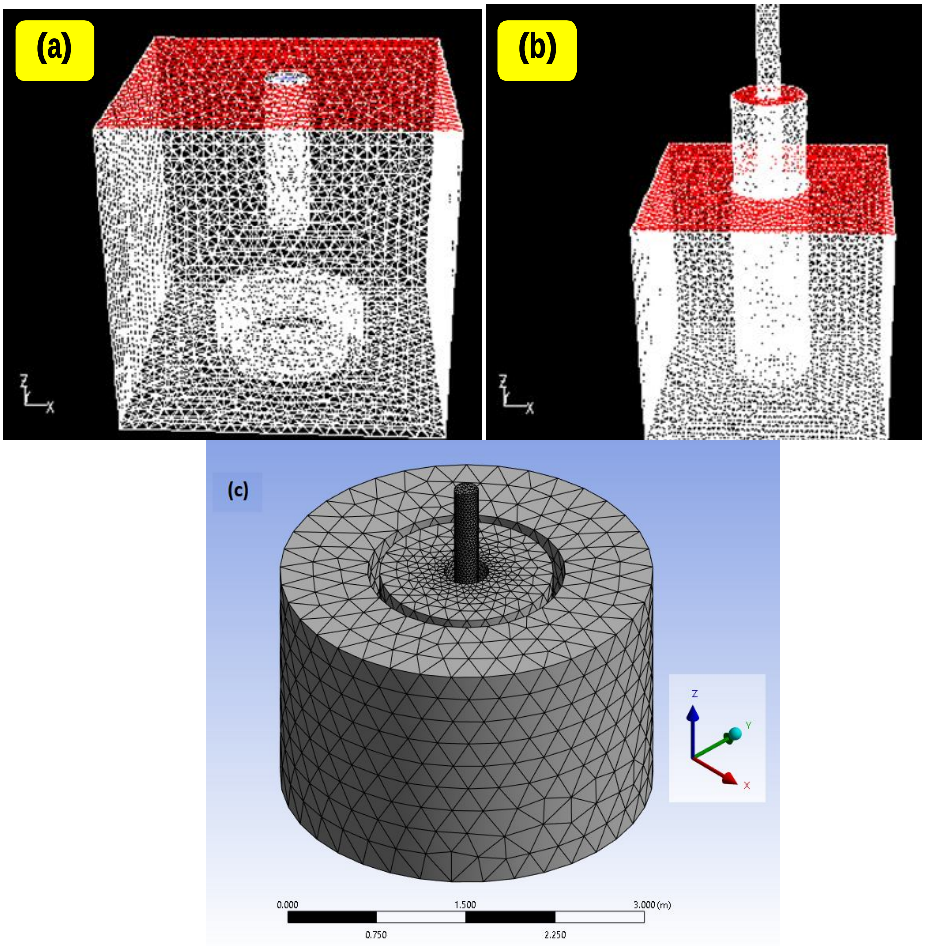


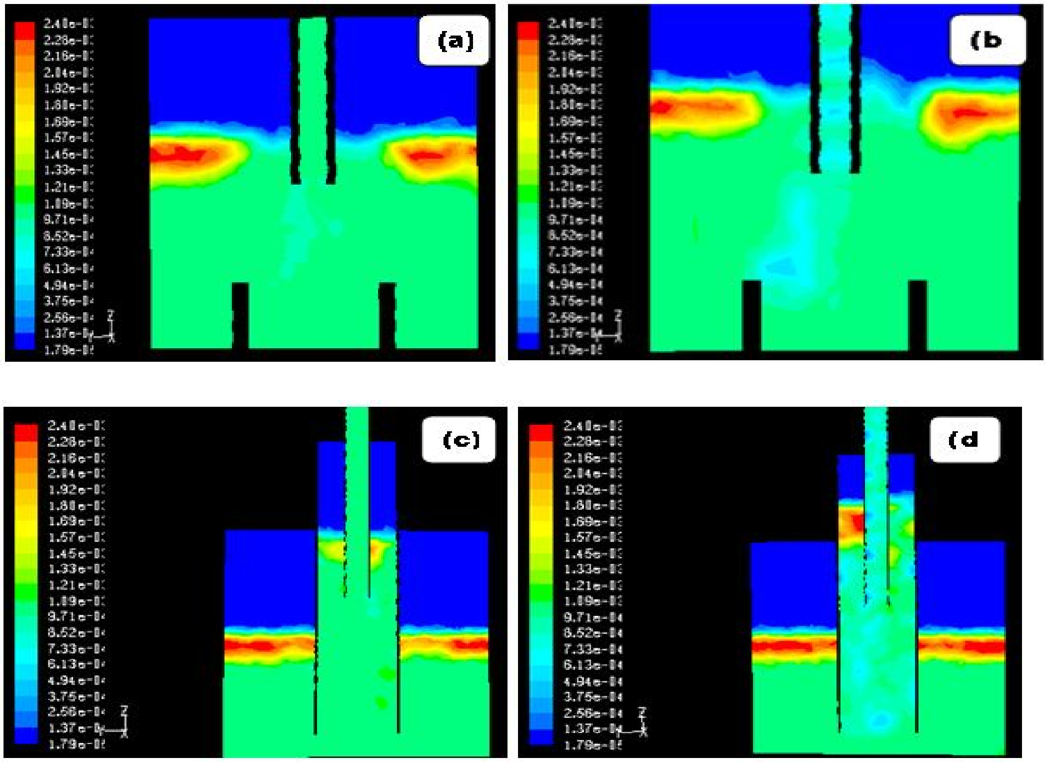
Fig. 5 Grid displays of (a) Conventional Shroud with turbo-stop (b) Vacuum Shroud
(c) Novel Centrifugal Shroud + Argon purging + Turbo-stop

3. Results and Discussions

The 3D numerical studies were performed by using some mathematical models like continuity equation, momentum equation, turbulence and kinetic model, VOF (Volume Fraction Equation), DPM (Discrete Phase Model) etc. [4, 30-31]. Most of the dimensions and numerical data were used in earlier research papers regarding this are same for this papers also and those parameters were not mentioned earlier are explained in Table 1. The velocity used in current study was 5 m/sec which is high due judge the adverse effect of velocity on slag eye, turbulence as well as emulsification. In vacuum shroud and Novel Centrifugal Shroud argon purging were introduced from the upper side of the nozzle to avoid air aspiration at the ladle shroud joining and at the same time enhance the inclusion floatation to the top surface of the tundish.

Table 1: Dimensional and Numerical Parameters used in present investigation

Sl. No.	Dimensions & Parameters	Value	Remarks
1	Initial Velocity of pouring from velocity inlet	5 meter/sec	High Velocity
2	Bath diameter and height	L & W = 1.0 meter, H = 1.0 meter, D = 1 meter	Turbostop diameter = 0.3 meter
3	Turbulent Kinetic Energy (k)	12.5	$K=0.5v^2$[32,33]
4	Turbulent Dissipation rate (€)	2.8	$€=C_\mu*k^2/v$[32,33]
5	Argon (secondary phase)	Density – 1.629 kg/m^3	Flow rate-20% volume fraction of water from velocity inlet
6	Vacuum Used	Atmospheric pressure-760 torr, Pressure maintained Vacuum Chamber of Shroud 720-750 torr	This vacuum pressure maintained within the vacuum chamber of the shroud



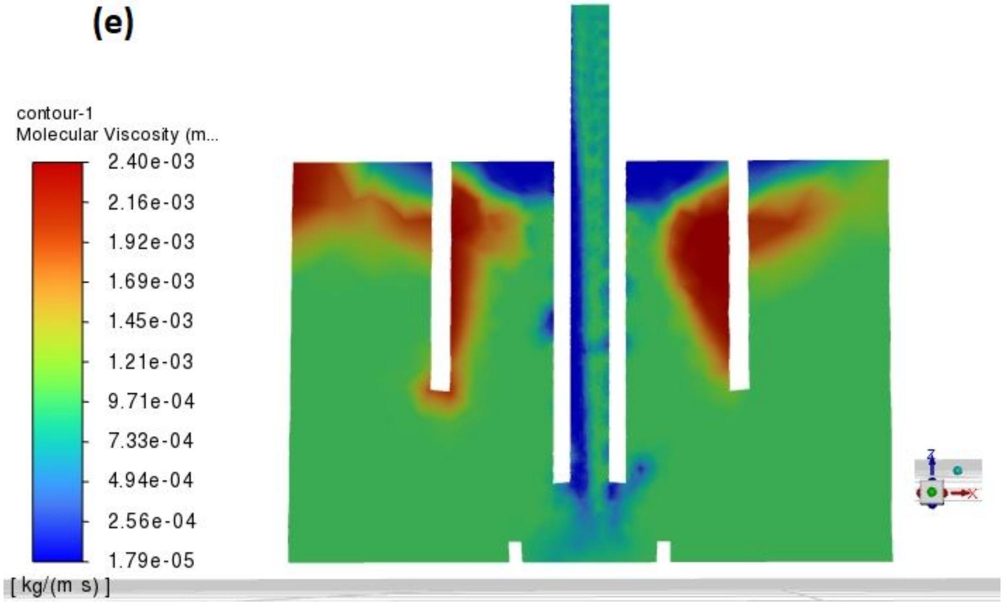


Fig. 6 Molecular properties of fluids (water + oil + air + argon) (a) Conventional shroud + Turbo-stop (b) Conventional shroud + Turbo-stop + Argon purging (c) Vacuum Shroud (d) Vacuum Shroud + Argon purging (e) Novel Centrifugal Shroud + Turbo-stop + Argon purging

Fig. 6 (a), (b), (c), (d) and (e) are embodying the Molecular viscosity properties of various fluids after pouring of water inside the bath for conventional shroud + turbo-stop, conventional shroud + turbo-stop + argon purging, vacuum shroud without argon purging and with argon purging, Novel Centrifugal Shroud + turbo-stop + argon purging respectively. The water, oil, air and argon phases are representing by the green, red, blue and light blue colors. It is observed from the figures that for conventional shroud without or with argon purging the oil phase is removed more towards bath wall rather than vacuum shroud with or without argon purging and Novel Centrifugal Shroud with argon purging. The oil layer is dispersed and emulsified more for conventional shroud system as found from the simulated results. It signifies that in case of traditional system, generally use in steel industry, the contamination of liquid steel will be more due to formation of large exposed eye as well as from emulsification of slag and metal.

Fig. 7 (a) and (b) are showing the slag eye or open eye formation for conventional shroud with and without argon purging. The exposed eye is large and approximately 0.5 meter diameter. For conventional shroud with argon purging system some dispersed slag eye are also found along with large exposed eye due to inert gas shrouding. Fig. 7 (c), (d) and (e) are top view images of slag phase for vacuum shroud without vacuum condition as well as vacuum without argon purging and with argon purging situation respectively. When vacuum is not applied to vacuum shroud, air infiltration to flowing fluid took place due to large outer diameter of shroud. These infiltrated air exposed to bath surface and remove the top slag layer which creates dispersed slag eye as seen from image. When vacuum is applied air infiltration or aspiration is inhibited caused removal of formation of open eye. After argon shrouding from side wall of vacuum shroud, more effect of reduction of turbulence is observed as found from images at Fig. 6 (d) and Fig. 7 (e) respectively. Novel Centrifugal Shroud with argon purging indicates no slag eye formation at Fig. 7 (f). There is also no dispersed slag eye was found. But from mixing of liquid steel, drained argon from cap and slag layer the top surface is not showing 100% slag layer as depicted in the Fig. 6 (e) and 7 (f). This will indirectly help to remove inclusions from melt by better slag metal interactions due to centrifugal motion.

The velocity vector and corresponding velocity vector plots for conventional shroud, vacuum shroud with argon purging and Novel Centrifugal Shroud with argon purging have been shown in the Fig. 8 (a) to (e) respectively. It is found from Fig. 8 (a) that, after impinging on the turbo-stop the fluid is moving upwards at a high speed and the velocity ranges are between 1.0 meter/sec to 3.0 meter/sec. For vacuum shroud with argon purging the velocity of fluid outside nozzle/shroud is extremely low less than 0.5 meter/sec as depicted in the Fig. 8 (b). Within the nozzle or shroud the velocity drops drastically from <0.5 meter/sec to 2.5 meter/sec. For Novel centrifugal shroud with argon purging the overall velocity is low within the range from 0.5 meter/sec to 1.5 meter/sec as depicted in Fig. 8 (c), (d) and (e). For this type shroud argon shrouding is essential. Because within the cap the slag eye or open eye will be generated and this will be protected from re-oxidation due to presence or filling of cap from the shrouded argon. Not only re-oxidation will be hindered, simultaneously inclusions will be entrapped within the cap by slag and baffle refractory. So it will indirectly help to produce clean steel especially mini steel plant where small tundish is used during continuous casting. Those tundish have high prone to choking due to low residence time of fluid within the reactor. Fig. 9 (a) and (b) are showing that the many slag eye exposed for centrifugal shroud without cap rotation and no slag eye exposed after centrifugal rotation of cap.

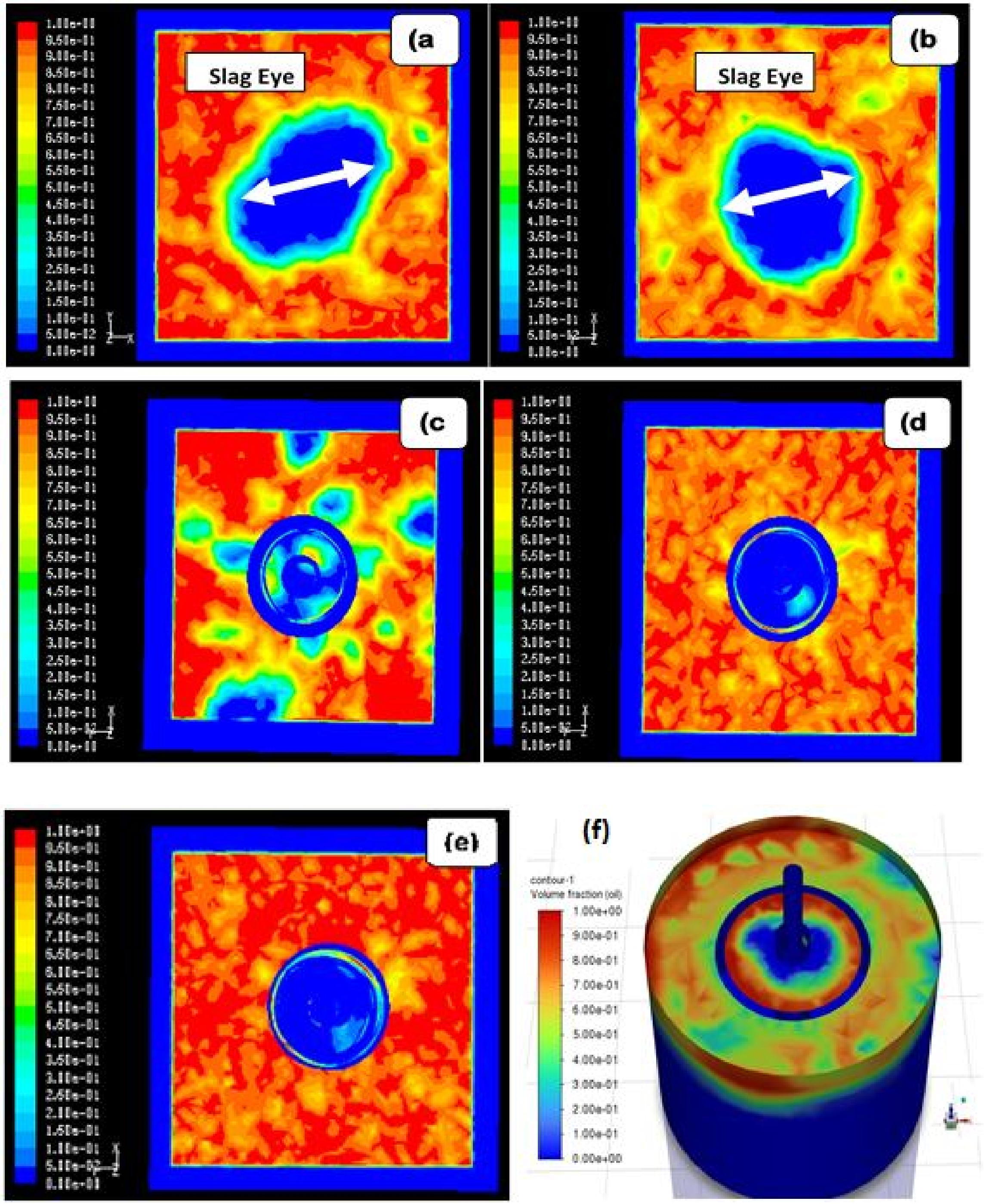


Fig. 7 Slag eye (a) Conventional Shroud without argon purging (b) argon purging (c) Dispersed Slag eye for Vacuum Shroud without vacuum (d) No slag eye for Vacuum Shroud with vacuum (e) No slag eye for Vacuum Shroud with vacuum and argon purging (f) No slag eye for Novel Centrifugal Shroud with Argon purging.

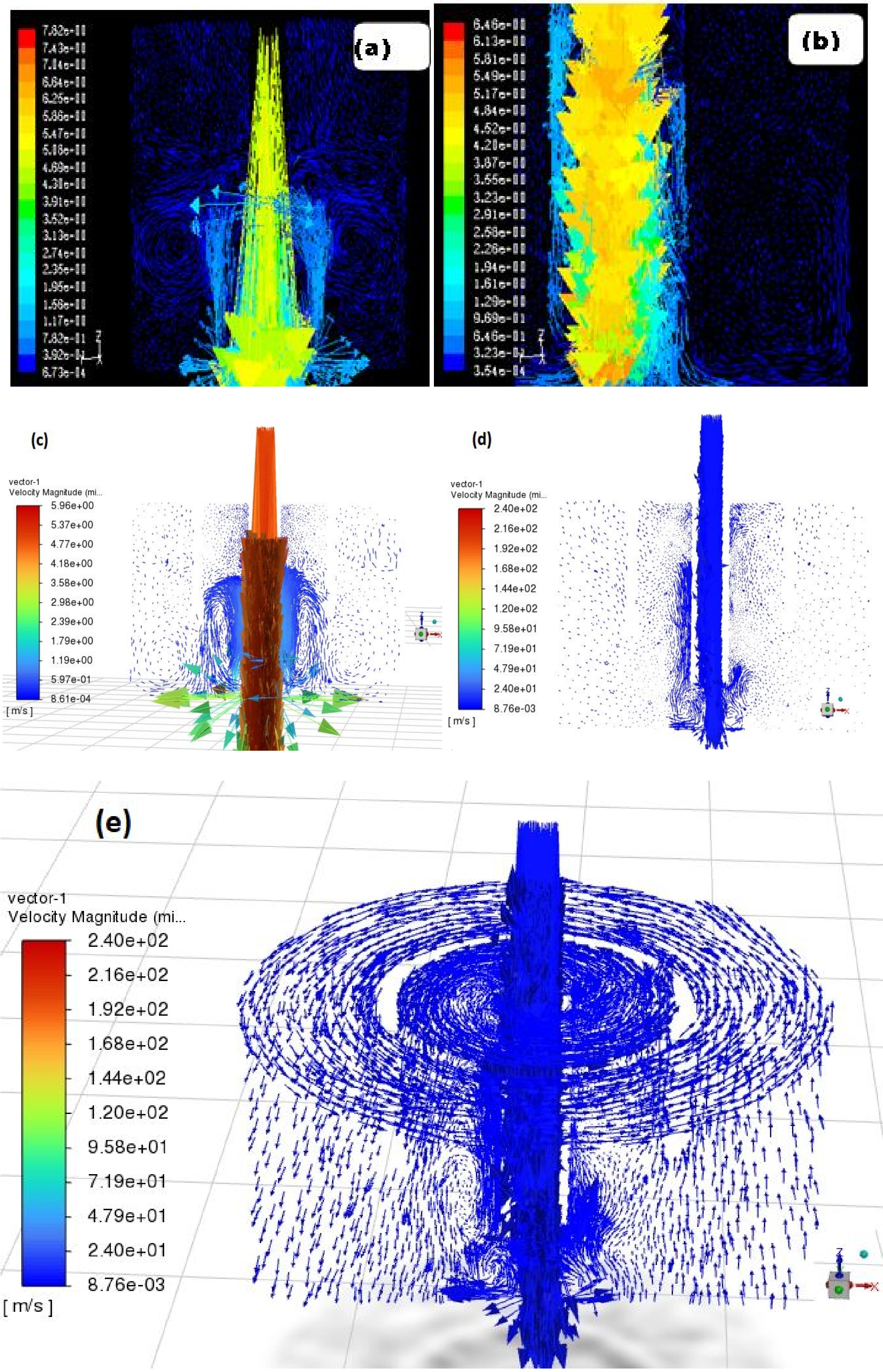


Fig. 8 Velocity vector plots of (a) Conventional Shroud (b) Vacuum Shroud with argon purging (c) (d) (e) Novel Centrifugal Shroud with argon purging

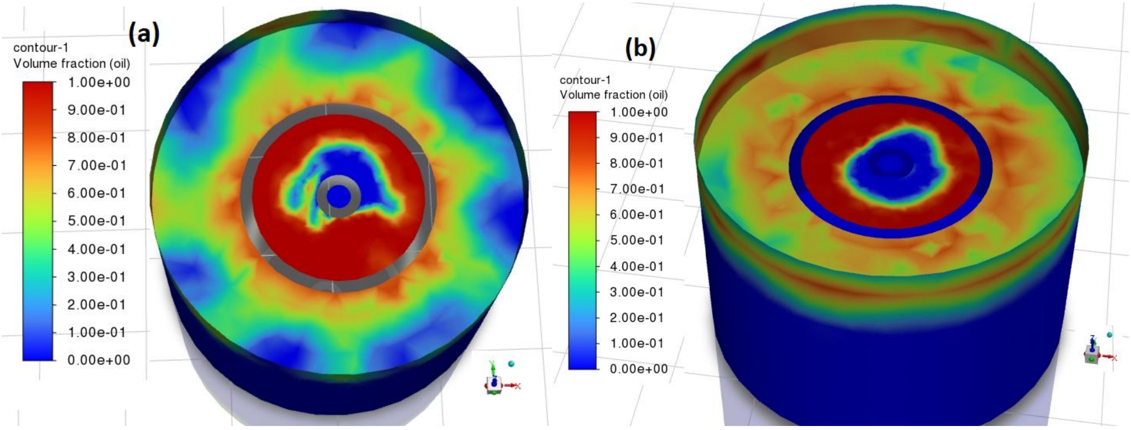


Fig. 9 Top view of Centrifugal flow Shroud (a) Before Centrifugal Rotation Showing many Slag eye and (b) After Centrifugal Rotation of Cap Showing No Slag Eye

4. Conclusions

The following conclusions can be drawn from the above numerical study of different shroud configurations.

- Vacuum shroud and Novel Centrifugal Shroud are two innovative flow control devices which can avoid re-oxidation of steel melt during pouring from ladle to tundish by reducing/suppressing tundish open eye (TOE) formation.
- Not only slag eye, liquid turbulence within the reactor will be dropped for those above mentioned shrouds due to suction effect of vacuum as well as centrifugal motion generated by cap wall of the Novel Centrifugal Shroud.
- Due to presence of argon inert gas within the cap of Novel Centrifugal Shroud re-oxidations from ambient air can be avoided.

- 7 numbers small slag eye observed before rotation of cap which has been totally eliminated after centrifugal rotation of cap in centrifugal flow shroud.

5. Future Study

As a future scope of study the author wants to do water modeling investigations of those new conceptual flow control device. For Novel Centrifugal Shroud along with argon shrouding at upper side wall of the shroud nozzle, basic flux injection will be incorporated from the top of the cap to enhance inclusion removal from the upward driven liquid steel. Both novel shrouds like vacuum shroud and Novel Centrifugal Shroud are required to implement in steel plants and finally patent file will be tried for future perspective of these steel flow control refractory products.

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