Mixing in a Tundish

Abstract

Tundish is a large reservoir, placed just below the ladle, into which the liquid steel flows from the ladle through a shroud. The in-coming stream of liquid hits the bottom of the tundish and spreads in all direction. Thus the liquid jet creates some amount of mixing in the tundish before it goes out through the outlet. The objective of using a tundish in the steel plant is many folds. Firstly, it acts as a big buffer so that the flow from the outlet is maintained almost uniform and secondly it acts as a mixing device where the last stage chemistry for steel can be controlled. But mixing in the tundish is mainly controlled by many geometrical parameters used to make the tundish. So CFD analysis is normally required to predict the mixing behavior of a tundish. In this study we have found out the effect of locations of the outlet, height of the advanced pouring box (APB) and depth of the shroud on mixing in a tundish. However, to arrive at a more meaningful conclusion (not being biased by the models being used) it was felt that many different turbulence models must be used to find out the effect of geometrical parameters on mixing rather than just using the standard k-ε model which is normally used by researchers in the steel industry as well as in academics. So effort has been made to use many turbulence models and predictions of mixing phenomena have been made from all such models. We will proceed in a methodical manner to present the work very briefly in the following manner.

In the first chapter, mixing phenomena in a six strand billet caster tundish has been studied by numerically solving the Navier Stokes equations along with the species concentration equation in a boundary fitted coordinate system comprising the geometry of the tundish. The solution of the species concentration equation has been utilized to compute the mix, dead and plug volume of the tundish under different flow conditions. The numerical procedure and solution algorithm has been first verified by comparing the numerically obtained residence time distribution curve, which agrees well with that of the experiments done for a single strand bare tundish by Singh & Koria [42)]. It has been observed that the ratio of the mix to dead volume for the six strand tundish has a maximum value for a particular position of the outlets. At that particular position of the outlets (where mixing is best), an APB is placed on the bottom of the tundish surrounding the incoming inlet jet and the height of the APB has been varied to see the effect on mixing in the tundish. It has been observed that the ratio of mix to dead volume further increases with the use of APB and attains a peak value after which it decreases with the increase of the height of the APB signifying the existence of an optimum APB height. At this optimum height of the APB, the shroud immersion depth was made to change from 0

to 400 mm. It was also observed that there exists an optimum immersion depth of the shroud where the ratio of mix to dead volume still attains another peak signifying still better mixing. However, increasing the immersion depth to higher values spoils mixing significantly.

In chapter-1, it has been discussed that there exists optimums in all the three geometrical parameters i.e. the position of the outlets, height of APB (at optimum location of outlets) and shroud immersion depth (at optimum height of APB). Naturally one becomes more curious to know whether the optimums obtained in the study were unique or just a local optimum? If only local optimum values had been obtained then there may exist global optimum values for the above parameters at which the ratio of mixed to dead volume and the mean residence time may be the highest for a given tundish. Hence, in the second chapter, effort has been made to compute the ratio of mixed to dead volume and the mean residence time for all possible combinations of outlet positions, height of APB and shroud immersion depth to explore the global optimums for these parameters such that one can obtain highest possible mixing in a given tundish or at least can use the present methodology to design a tundish or modify an existing tundish for best possible mixing.

In chapter-1 and 2, the tracer concentration equation has been solved after obtaining a local flow field in the tundish through the use of a standard high Re number k-ε model. But many a time it is questioned whether the use of such a turbulence model is right or not. Naturally questions come to mind whether the optimum locations of the outlet, height of APB and shroud immersion depth those have been predicted from the k-ε model will be retained or not if we use some other model. So in the third chapter, the numerical prediction of the tracer concentration has been made with nine different turbulence models and has been compared with the experimental observation for a single exit tundish (because experimental observation for a multi strand tundish for the present purpose does not exist). It has been found that the prediction from the standard k-ε model, the k-ε Chen-Kim and the standard k-ε with Yap correction, matches well with that of the experiment compared to the other turbulence models as far as gross quantities like the mean residence time and the ratio of mixed to dead volume are concerned. It has been found that the initial transient development of the tracer concentration is best predicted by the Low Reynolds number Lam-Bremhorst model and then by the k-ε RNG model, while these two models under predict the mean residence time as well as the ratio of mixed to dead volume. The Chen-Kim low Re number model (with and without Yap correction) as well as the Constant Effective Viscosity model over predict the mixing parameters i.e. the mean residence time and the ratio of mixed to dead volume. Taking the solution of the k-ε model as a starting guess for the Large Eddy Simulation (LES), a solution for the LES could be arrived at after adopting a local refinement of the cells twice so that the near wall y^+ could be set lower than 1. Such a refined grid gave a time independent solution for the LES, which was used to solve the species continuity equation. The LES solution slightly over predicted the mean residence time but could predict fairly well the mixed volume. However, the LES could not predict both the peaks in the tracer concentration like the k-ε, RNG and the Lam-Bremhorst model. An analysis of the tracer concentration on the bottom plane of the tundish could help to understand the presence of plug and mixed flow in the tundish.

In chapter-4, the numerical prediction of the tracer concentration has been made with six different turbulence models; (the standard k-ε, the k-ε RNG, the Low Re number Lam-Bremhorst model, the Chen-Kim high Re number model (CK), the Chen-Kim low Re number model (CKL) and the most simplest constant effective viscosity model (CEV)) for the six strand tundish to find out the optimum locations of the outlet, height of the APB and shroud immersion depth for best possible mixing and see the effect of various turbulence models on it. With the help of the above six turbulence models, mixing parameters such as the ratio of mix to dead volume and the mean residence time are computed for the six strand tundish for different outlet positions, height of APB and shroud immersion depth. It was found that three turbulence models show a peak value in the ratio of mix to dead volume when the outlets were placed at 200mm away from the wall. An Advanced Pouring Box (APB) was put on the bottom of the tundish surrounding the inlet jet when the outlets were kept at 200mm away from the wall. It was also found that there exists an optimum height of the APB where, the ratio of mix to dead volume, attain further peak values signifying better mixing in the tundish (three of the models show this). At this optimum height of the APB, the shroud immersion depth was made to change from 0 to 400 mm. It was again observed that there exists an optimum immersion depth of the shroud where the ratio of mix to dead volume still attains another peak signifying still better mixing (three models show this). However, all the turbulence models do not predict the same optimum height of the APB and the same shroud immersion depth as the optimum depth. The optimum height of the APB and the shroud immersion depth were decided when three or more turbulence models predict the same values.