Improving Steel Quality with CFD

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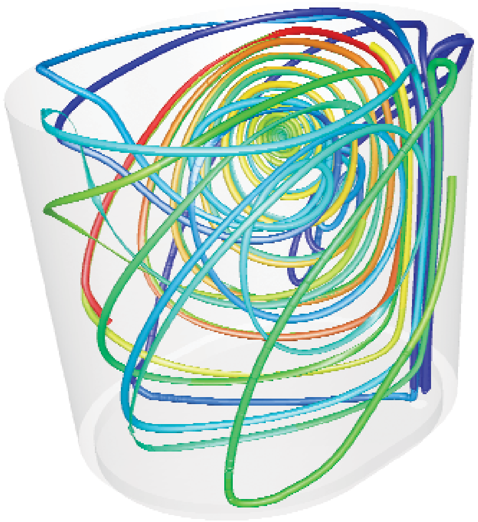
The manufacture of high quality steel is a multi-step process. After an initial period of heating, mixing and chemical reaction in a basic oxygen furnace (BOF), the molten mixture is transferred to a ladle. Alloy components are added at this point and gaseous and solid pollutants are removed by a purging procedure. Argon gas is often bubbled through the ladle during alloying and purging to keep the mixture stirred. The gas is introduced at the bottom of the ladle and the rising bubble plume causes circulation currents that play a crucial role in determining the quality of the final steel product.

Because of the high temperatures of molten metal and the opacity of the ladle and its contents, CFD is a useful tool for understanding and visualizing the flow characteristics in this environment. In a recent project, the mixing and purging processes in a metallurgic ladle were studied using CFD at Dunaferr Company (Hungary). To simulate the argon gas plume, a simple



Flow field inside the ladle represented by pathlines colored by residence time; blue regions are early in the argon plume trajectory into the ladle and red regions are after several circulation loops have occurred; a “dead” region where the flow is weak was identified near the floor of the ladle, opposite the plume

Velocity vector field on the argon plume (left) and center (right) planes of the ladle show that circulation is ongoing, even at a distance from the jet entrance

momentum source model was developed and applied in the region of the plume. The behavior of bubble groups in liquids was analyzed and an approximate equation for the buoyant force was derived. This force depends on the relative volume of the argon bubbles in the steel, i.e. the mass flow rate of the argon gas, the local pressure, the vertical velocity of the steel and the relative velocity of the bubbles. The model also incorporated the heating of the gas and expansion of the bubbles as they rise. The model was validated using measurements of the rising time of the argon plume in both static and stirred steel.

While in the ladle, most of the surface of the molten steel is covered by a slag layer. This layer plays several important roles. It prevents steel from oxidizing and cooling too quickly and it traps solid pollutants, such as aluminum-oxide particulates. Because its viscosity is much larger than that of steel, the slag layer can be modeled with sufficient accuracy as a solid wall.

However, the rising mixture of argon gas and steel in the region of the plume breaks through the slag layer, leading to an open area on the steel surface. Through this opening in the slag surface, argon gas exits into the nearby atmosphere and the liquid mixture is exposed. The diameter of this opening depends on the argon flow rate and can be computed by using a transient, two-dimensional CFD model that predicts the free surface shape.

The hole open area (or free surface) diameters were predicted for a range of argon gas flows and they were found to be in very good agreement with measurements. Using the size and location of the open area for each gas flow rate, more rigorous three-dimensional models were set up to study the flow characteristics of the molten steel in the presence of the plume, the mixing of the alloys, and the collection of unwanted particulates.

The initial CFD results included flow pathlines that pointed to a “dead” region, where very low velocities were detected opposite the argon inlet and close to the bottom of the ladle. Dead regions are areas where adequate circulation of the molten metal is not taking place, and they were found even when the flow rate of the argon gas was increased.

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In addition to an examination of pathlines, surfaces were constructed that marked a range of turbulence levels in the ladle. Turbulence contributes to mixing, so this type of result helps to assess the extent to which a single plume leads to intensive stirring. The CFD results were also used to deduce the time needed to reach a uniform distribution of the alloys added to the molten metal from different locations. This type of result allows engineers to compare the efficiency of one feed location relative to another.

The other phenomenon investigated was the capture of the aluminum-oxide particles during the stirring period to illustrate the effectiveness of the purging process. Tiny particles, 5 and 10 microns in diameter, were assumed to be uniformly distributed in the steel at the beginning of a transient calculation. These particles were tracked as they responded to buoyancy, the circulating flow generated by the argon plume, as well as turbulence. When the particles reached the lower surface of the slag layer, they were trapped and removed from the molten metal. Based on a number of calculations, a relationship for the capture rate as a function of purging time, gas flow rate, and particle diameter was developed. This relationship is now being used to define the parameters of importance in the design of ladle metallurgy. ■

Surfaces inside the ladle illustrate widespread turbulent kinetic energy in the ladle, even though it decreases in strength (green to light blue) as the distance from the plume increases; turbulence contributes to mixing, so it is an important ingredient in the ladle fluid dynamics