metals

Editorial

Advances in Molten Metal Refining Process

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1. Introduction and Scope

Molten metal is the intermediate product in metallurgical processes. As human civilization expands, the demand for product quality is increasing, which poses challenges to the development of technology. continuous improvements in refining processes are necessary for meeting customer requirements while lowering production costs, to remain competitive.

Molten metal refining technology is governed by certain laws, the optimization of which is a basic prerequisite for increasing refining efficiency. In this context, even in the classical metallurgy of iron and steel refining, constant innovative tendencies can be observed, by improving existing process to produce higher-quality metals [1–3]. The traditional models describing the refinement of metallurgical processes range from turbulent flow to multiphase flow models, including multipe processes such as heat transfer [4]. However, at the heart of these processes, very complex multiphase and multiphysics processes [5], including complex chemistry, occur and often span multiple time and length scales. In addition, numerous studies have been developed around both experimental and analytical/computer modeling aimed at disclosing the fundamental aspects of refining metallurgical processes within molten metal [6–9]. Therefore, this Special Issue is intended to collect and present the latest developments in advanced refining technologies for metallurgical processes, as well as identifying existing research gaps.

2. Contributions

This Special Issue includes ten articles in the field of molten metal refining processes.

Zhao et al. (contribution 1) have mainly studied the evolution of vortex structures inside the submerged entry nozzle and the turbulence near the mold wall during this process, using a lattice Boltzmann method (LBM) coupled with large eddy simulation (LES) to simulate the transient flow in the mold. The results are compared with the published experimental values to verify the accuracy of the LBM-LES model. The formation, development, dissipation, and impact on turbulence of vortex structures have been investigated. These new studies help us to elucidate the mechanism of vortex structure distribution in the representative flow zone of a continuous casting mold.

A reduction in the thickness of the concentration boundary layer is a necessary condition for the strengthening of chemical reactions. Although the superposition of the current and gradient magnetic field can enhance the macro-scale flow in the entire container and stimulate the micro-scale flow near the solid–liquid interface, thereby suppressing the concentration boundary layer, the mechanism of micro-scale flow excitation is not yet clear. To clarify this, Xu et al. (contribution 2) superimposed a uniform magnetic field with a direct current or a modulated current. Through this method, only the micro-scale flow was excited near the anode surface. The results indicate that an uneven distribution of electromagnetic force is the main cause of micro-scale flow excitation.

As described in the third chapter, in order to capture the complex processes that occur inside a fused magnesia furnace, Jiang et al. (contribution 3) established a 3D transient multi-physical field model and conducted a parallel numerical simulation. This model integrates multiple physical fields, such as the electromagnetic and thermal fields. In the experiment, a three-phase submerged magnesia furnace was used and, in order to optimize

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the operation design more comprehensively, the influence of different electrode insertion depths on the temperature and reaction is also discussed in the study. Through simulation, the conclusion is drawn that there is an optimal click insertion depth.

Chen et al. (contribution 4,5) conducted a quasi-three-dimensional hydraulic model experiment at a scale of 0.25 to study the transient fluid-flow phenomenon during the continuous casting of steel. In the first part of the article, the changes in hydraulic jump behavior during the filling process are studied; they were controlled via different arrangements of springs and iron filings on the virtual rod. A filling coefficient is proposed to determine the optimal filling conditions and is applied to the entire filling process. In the second part of the article, the effect of the solidification phenomenon on hydraulic jump behavior during the actual continuous casting process is simulated via the addition of a saturated sodium acetate solution at the bottom. The conclusion drawn is that solidification is very important in the early stage of the filling process and cannot be ignored. As the liquid level increases, its impact gradually decreases, until it basically disappears. There are similar laws in both cases, with and without solidification.

Qi et al. (contribution 6) have established a three-dimensional mathematical model of two-fluid multiphase flow using the CFD-PBM coupling method and have studied the bubble size distribution in a single-snorkel furnace (SSF). Via analysis, it can be concluded that the results with the addition of the population balance model (PBM) are closer to the experimental values than those without the PBM model. The flow field using the PBM model is more uniform, and the distribution of upward and downward flow within the same cross-section is more reasonable. The diameter of bubbles in the furnace increases with an increase in the liquid level height.

Li et al. (contribution 7) have established a mathematical model in their study to investigate the refining process of slot-porous matched dual tuyeres and have verified it using water model results. This mathematical model is used to describe the aggregation and rupture of two different discrete phases, taking into account density changes and bubble expansion. The new type of tuyere matching utilizes porous and slot tuyeres, improving the mixing performance and impurity removal. These results will certainly be significant in guiding future refinement.

Due to the increasing requirements for steel desulfurization efficiency and stability, Wang et al. (contribution 8) have established a three-dimensional transient coupling mathematical model, using the volume of fluid model (VOF) and discrete phase model (DPM) to simulate the Kanbara reactor (KR) desulfurization process, and have designed two new blade structures to improve the desulfurization efficiency. The results indicate that the staggered blade structure can improve the desulfurization efficiency in the KR process, and the established model has also proven effective in experiments.

The ninth article focuses on the refining process of aluminum. Due to the high efficiency of the aluminum refinement process, which is determined by the wear and geometric shape of the rotor and the fact that testing of rotor wear has not been widely conducted, PrášIL et al. (contribution 9) carried out wear experiments on graphite rotors of different shapes and compared the operation of the two types of rotors under industrial conditions. They found that rotor I (a pump-type rotor) was more durable than rotor II (a propeller-type rotor) in their tests and, at the same time, provided a good level of hydrogen removal throughout the operation period.

Bending control is one of the main methods of controlling the shape of hot-rolled plates. However, the existing bending force setting models based on traditional mathematical methods are complex and have a low control accuracy, resulting in the strip steel outlet having a poor shape. In the final article, Shi et al. (contribution 10) propose a prediction model based on a twin support vector machine to address the complex setting of bending forces in traditional algorithms. They use an improved whale swarm optimization algorithm for data analysis. Through on-site experimental data analysis, they have identified the main factors affecting the magnitude of the bending force.

3. Conclusions and Outlook

The aim of this Special Issue on "Advances in Molten Metal Refining Process" is to present the current knowledge and trends in the field of molten metal refining processes, especially regarding iron, steel, and aluminum, magnesium and titanium; and the possibility of the secondary processing of these metals in a liquid state via blowing inert gases, vacuuming, synthetic slag, etc., including the physical and numerical modeling of these processes.

As Guest Editor, I would firstly like to thank the authors of these papers for providing excellent articles for this Special Issue. Secondly, I would like to thank all the editors and reviewers of Metals for their trust and assistance, as well as the efforts of other staff that have made the publication of this Special Issue possible.

Conflicts of Interest: The author declares no conflict of interest.

List of Contributions:

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