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NUMERICAL SIMULATION OF MOLTEN STEEL FLOW IN SECONDARY REFINING FURNACE[1]

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Abstract

The CAE simulation model of molten steel flow in secondary refining furnace was established in this paper. The phenomenon of bubbles' breakup and collision was considered in this model, so was the effect of temperature and vacuum in furnace on volume of the bubbles. The model was applied to 230t VD furnace in some melt shop to simulate the gas-fluid flow in the ladle. The simulation results matched the production status well, which validated our simulation model. Applying this model to the R&D of VD furnace, a new method of bottom argon blowing-pulse has been developed. The simulation showed that while the power of stirring was constant, pulse argon blowing method provided good performance in restraining steel splashing, reducing erosion of ladle lining and saving argon consumption. This method is not only significant for stirring of VD furnace with bottom blowing, but also provides an effective way to restrain molten steel splashing under strong bottom blowing condition for secondary refining furnace.

Keywords: Secondary refining; Argon stirring; Molten steel flow; CAE simulation.

SIMULAÇÃO NUMÉRICA DE FLUXO DE AÇO LÍQUIDO EM FORNO DE REFINO SECUNDÁRIO

Resumo

O modelo de simulação CAE de fluxo de aço líquido em forno de refino secundário foi estabelecido neste ensaio. O fenômeno da separação e colisão de bolhas foi considerado neste modelo, assim como o efeito da temperatura e vácuo no forno sobre o volume das bolhas. O modelo foi aplicado em forno VD de 230t em uma aciaria para simular o fluxo de gás-líquido na panela. Os resultados da simulação corresponderam ao status de produção também, que validaram nosso modelo de simulação. A aplicação deste modelo tem sido usada para pesquisa e desenvolvimento de forno VD e em um novo método de insuflação de argônio pelo fundo. A simulação mostrou que enquanto o poder de agitação foi constante, o método de insuflação de argônio de pulso fornece um bom desempenho no combate contra a respingos de aço líquido, reduzindo a erosão do revestimentos de panelas e consumo de argônio. Este método é importante não apenas para o processo de insuflação pelo fundo do forno VD, mas também para proporcionar uma forma eficaz de conter respingos de aço líquido sob forte condição de insuflação pelo fundo para o forno de refino secundário.

Palavras-chave: Refino secundário; Argônio; Fluxo de aço líquido; Simulação CAE

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1 INTRODUCTION

Modern steelmaking process is divided into two steps: primary melting and secondary refining. There are different types of secondary refining equipment, VD furnace is one of them. The VD furnace is devised principally to degas, fine tune the alloy ingredients and stir the molten steel by means of argon blowing. Argon blowing can homogenize the temperature and ingredients of the molten steel, accelerate the metal-slag interface reaction and so on. Thereby, the research of molten steel flow in ladle by bottom argon blowing is of very significance. It helps us to improve the design and optimize the parameters of the VD furnace.
Along with the development of computational fluid dynamics and computer science, Computer Aided Engineering (CAE) technology has been wildly applied to research & development of metallurgical equipment and optimization of metallurgical process. The molten steel flow in the VD furnace with bottom argon blowing is simulated with Fluent in order to provide a theoretic reference to optimization of the parameters of the VD furnace.

2 CAE Simulation Model

2.1 Geometric Model

Based on the mechanism analysis of bottom argon blowing in ladle during VD refining process, a CAE model of molten steel flow is established. This CAE model is applied to a 230t VD furnace. A three dimensional model and its grids are showed in Figure 1.

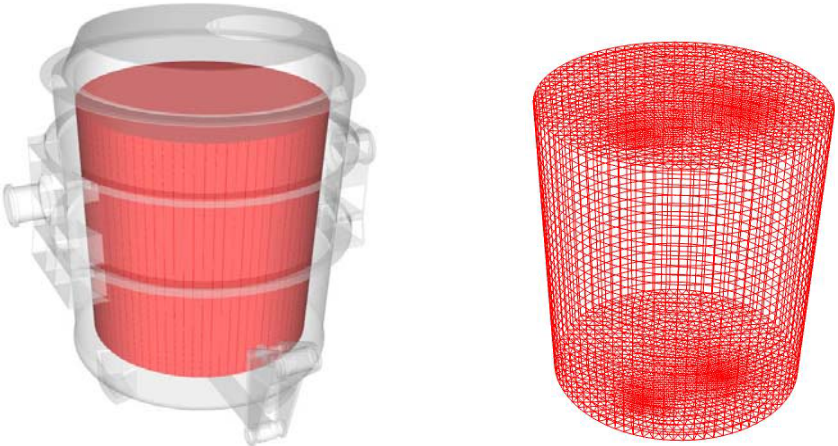


Figure 1. Model and grid of VD furnace.

2.2 Basic Assumption

As the flow of bottom argon blowing in the VD furnace is a multiphase flow, the actual phenomenon is very complex. To simplify the model, we referred to some relative research, took specific condition into account, and finally made the following assumption.[1-3]
(1) The influence of slag layer on the flow in the ladle is neglected.

(2) The shear stress between gas and liquid phases, which means the surface undulation of the molten steel, is neglected.
(3) The temperature of the molten steel is constant.
(4) The temperature of argon can be as high as that of the molten steel once it gets into the molten steel.

2.3 Mathematical Model

Eulerian model is adopted to simulate the multiphase flow. With this model, different phases are treated mathematically as interpenetrating continues. The influence between gas and liquid phases is considered through drag force. The k-ε turbulence model is adopted. And the diameter of bubbles can be computed by the following formula.[4]

$$d_{\max} = 0.35(Q^2/g)^{0.2} \tag{1}$$

$$d_b = 0.25 d_{\max} \tag{2}$$

The diameter computation results show that the biggest diameter is 95 mm and the equivalent diameter is 24 mm.
To consider the bubbles' collision and breakup process, the collision source term resulted from random impact, and the breakup source term resulted from turbulence are introduced as the following expressions.[5,6]

$$\begin{aligned} S_{RC} &= -\frac{1}{3\phi}\left(\frac{\alpha_g}{\chi_p}\right)^2 f_c n_b \lambda_c \\ &= -\left(\frac{\alpha_g}{\chi_p}\right)^2 \frac{\Gamma_c \alpha_g{}^2 \epsilon^{1/3}}{d_b{}^{11/3}(\alpha_{g\max}-\alpha_g)} \exp\left(-K_c \frac{d_b{}^{5/6} \rho_f{}^{1/2} \epsilon^{1/3}}{\sigma^{1/2}}\right) \\ &= -\frac{\Gamma_c}{\psi^{11/3}} \frac{\epsilon^{1/3}}{(\alpha_{g\max}-\alpha_g)} \alpha_g{}^{1/3} \chi_p{}^{5/3} \exp\left[-K_c \psi^{5/6} \frac{\rho_f{}^{1/2} \epsilon^{1/3}}{\sigma^{1/2}} \left(\frac{\alpha_g}{\chi_p}\right)^{5/6}\right] \end{aligned} \tag{3}$$

$$\begin{aligned} S_{TI} &= \frac{1}{3\phi}\left(\frac{\alpha_g}{\chi_p}\right)^2 f_B n_e \lambda_B \\ &= \left(\frac{\alpha_g}{\chi_p}\right)^2 \frac{\Gamma_B \alpha_g (1-\alpha_g) \varepsilon^{1/3}}{d_b{}^{11/3}(\alpha_{g\max}-\alpha_g)} \exp\left(-K_B \frac{\sigma}{\rho_f d_b{}^{5/3} \varepsilon^{2/3}}\right) \\ &= \frac{\Gamma_B}{\psi^{11/3}} \frac{(1-\alpha_g)\varepsilon^{1/3} \chi_p{}^{5/3}}{\alpha_g{}^{2/3}(\alpha_{g\max}-\alpha_g)} \exp\left[-\frac{K_B}{\psi^{5/3}} \frac{\sigma}{\rho_f \varepsilon^{2/3}} \left(\frac{\chi_p}{\alpha_g}\right)^{5/3}\right] \end{aligned} \tag{4}$$

2.4 Boundary Condition

The argon blowing orifice at the bottom of the model is set as velocity inlet, and the free surface of molten steel is set as symmetric boundary condition. The free surface is the degassing surface to gas which would escape from the surface, and slip boundary condition to molten steel. This kind of boundary condition setup is realized by Fluent UDF. Besides, the volume change due to temperature and vacuum in the VD furnace is considered in this simulation.[4,7]

3 SIMULATION RESULTS VALIDATION

3.1 Comparison between Simulation Results and Water Model Experiment

With the CAE model, the blending time of one water model experiment for the VD furnace is obtained.[4] The comparison of experimental and simulation results are showed in Figures 2 and 3.

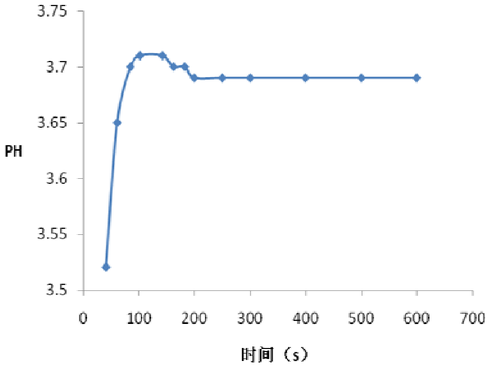


Figure 2.- Liquor PH value curve along with time in water model experiment result.[4]

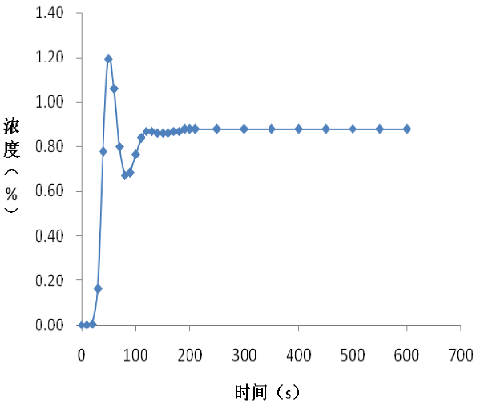


Figure 3. Tracer concentration curve along with time in simulation result.

As it can be seen from Figures 2 and 3, the blending time of the VD furnace in the water model experiment is about 200s, and the corresponding value of the simulation result is about 180s. Therefore, the simulation result matched the experiment result well, which validates the CAE model.

3.2 Comparison between Simulation Results and Local Condition

With the CAE model, the flow of the 230t VD furnace is simulated. The distribution of argon bubbles in the molten steel derived from our simulation result is shown in Figure 4.

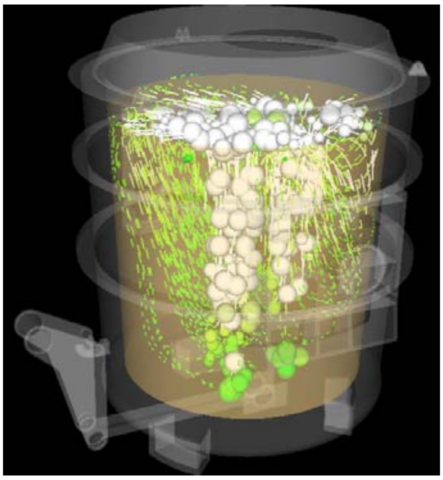


Figure 4- Argon bubbles distribution in molten steel.

Figure 4 shows that the argon bubbles in the molten steel are distributed like an inverted cone. This conclusion agrees with the great majority of relevant papers.

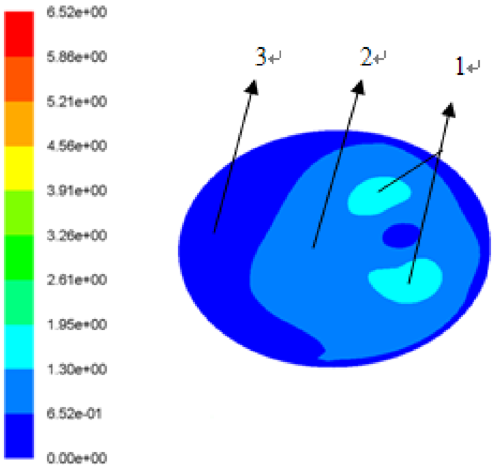


Figura 5- Velocity at molten steel surface.

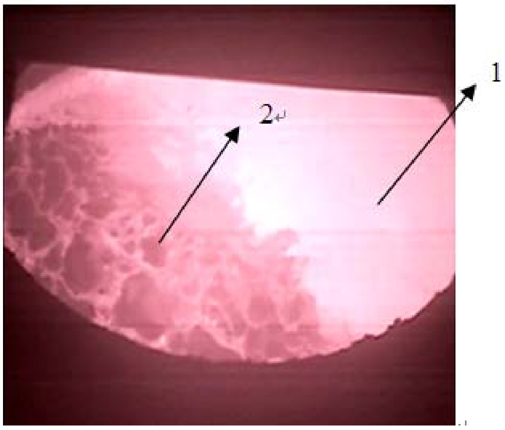


Figura 6- Acutal condition of molten steel surface.

The velocity contour at the molten steel surface from the simulation result is showed in Figure 5. And the actual condition of the molten steel surface in some melt shop is showed in Figure 6. Figure 5 shows that the high velocity part is distributed in Areas 1 and 2, and the low velocity part is distributed in Area 3. Meanwhile Figure 6 shows that the high velocity part is distributed in Area 1 while the low velocity part is distributed in Area 2. If comparing Figure 5 with Figure 6, it can be concluded that the simulation results of the flow at the molten steel surface match the actual situation very well.

4. Analysis on VD Furnace Inner Flow

4.1 Analysis on Traditional Argon Blowing Method

The simulation results of the 230t VD furnace inner flow are shown in Figure 7.

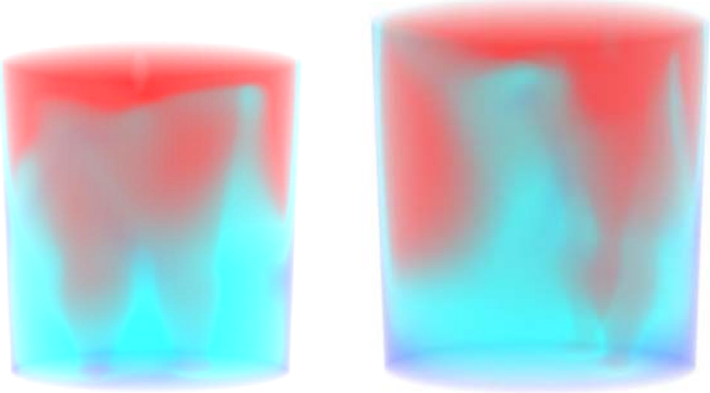


Figure 7- Molten steel velocity distribution in the ladle

In Figure 7, the molten steel velocity of the red part is over 0.36 m/s, while that of the light blue part is between 0.12-0.36 m/s and that of the blue part below 0.12 m/s. According to the statistical analysis on velocity of the molten steel in ladle, the mean velocity of the whole ladle is about 0.41m/s, while that of the upper part of the ladle is about 0.55m/s, that of the lower part about 0.27m/s, and that of the molten steel surface about 0.82 m/s. Therefore, the intense stirring area focused on the upper part of ladle and the argon column, and the stirring intensity at the lower part of ladle is little. Besides, the velocity at the molten steel surface is so high that the molten steel is prone to splash and erode the ladle linings.

4.2 Analysis on Pulse Bottom Argon Blowing Method

The previous section indicates that during the refining process, the velocity of the molten steel surface in the VD furnace is quite high, which can lead to steel splashing and fast erosion of the ladle linings. To overcome this disadvantage, a method to ameliorate the argon blowing in the VD furnace is developed in this research. Two orifices are provided to blow argon alternately with 1Hz pulse frequency, and the argon blowing quantity is unchanged. The simulation result is shown as follows.

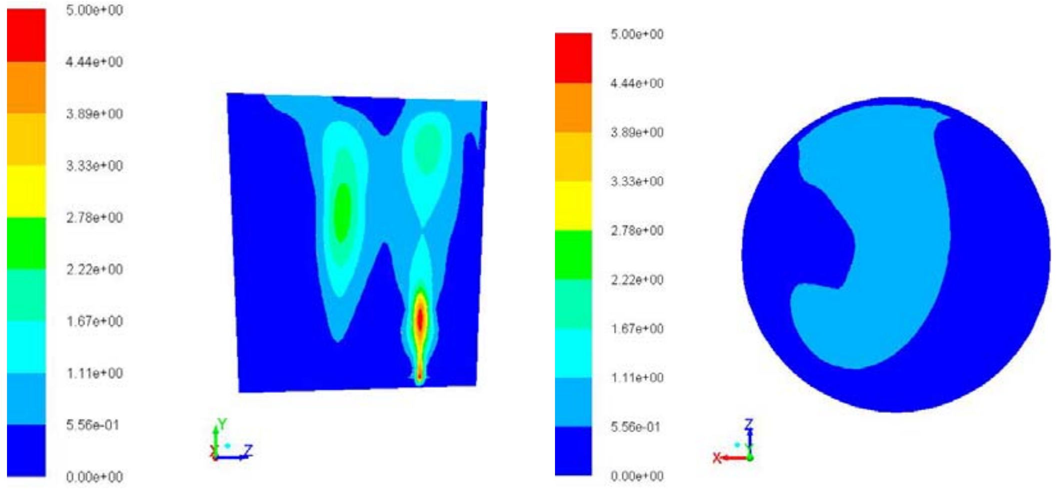
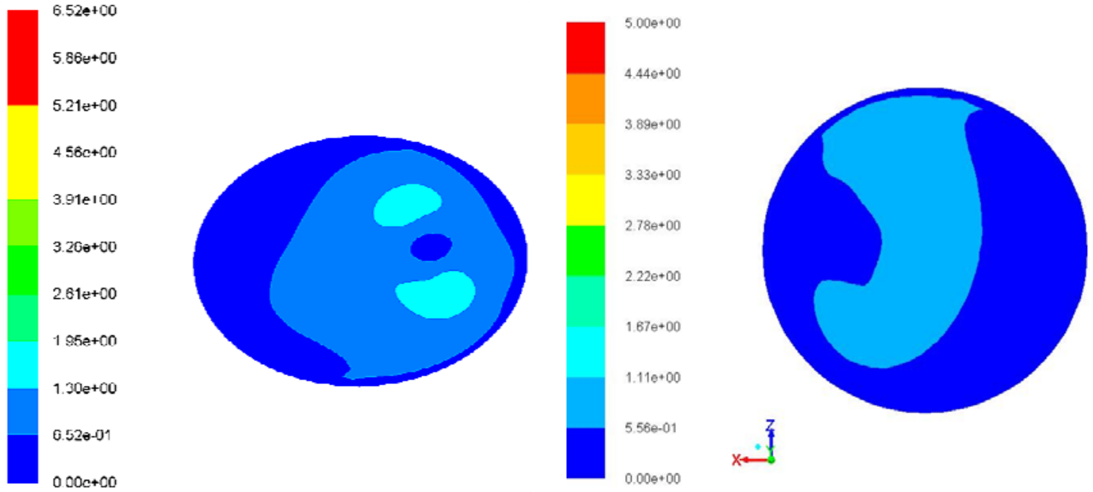


Figure 8- Velocity contour of molten steel

It can be seen from Figure 8 that the pulse bottom argon blowing can produce one stable and large stirring area with strong stirring intensity. The flow on the molten steel surface can be divided into two parts: strong flow part and weak flow part. And the velocity of the molten steel in the strong flow part is mostly between 0.5-1m/s.

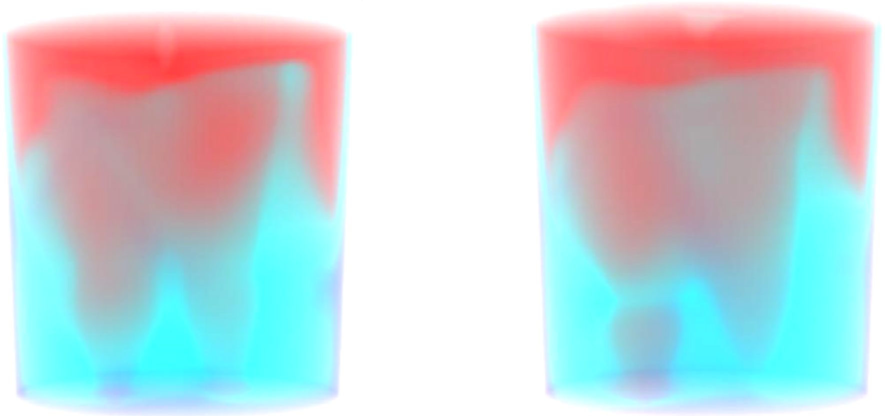
4.3 Comparison between Traditional Bottom Argon Blowing Method and Pulse Bottom Argon Blowing Method



a) Traditional bottom argon blowing method b) Pulse bottom argon blowing method

Figure 9- Molten steel velocity contour at free surface.

The comparison shown in Figure 9 indicates that with the traditional bottom argon blowing method, the highest velocity on the molten steel surface is about 2.5m/s, the velocity on most of the surface is 1-1.5m/s; and with pulse bottom argon blowing method, the velocity on most of the molten steel surface is below 1.5m/s. Therefore, the new argon blowing method can effectively reduce splashing of molten steel.



a) Traditional bottom argon blowing method b) Pulse bottom argon blowing method

Figure 10- Molten steel velocity contour in the ladle.

Figure 10 shows the molten steel velocity contour in the ladle adopting two argon blowing methods. The statistical analysis indicates that with pulse bottom argon blowing method, the mean velocity of the molten steel in the whole ladle is about 0.36m/s, that in the upper part of ladle is about 0.46m/s, that in the lower part 0.26m/s, and that on the molten steel surface 0.53m/s.

Compared with the results of traditional bottom argon blowing method described in the previous section, it is found that the pulse bottom argon blowing method provides an equal stirring ability, and the velocity on the molten steel surface with this new method is lower than that of the traditional method, reducing splashing of molten steel, erosion of ladle linings and consumption of argon.

5 CONCLUSIONS

A CAE simulation model of flow in the secondary refining furnace is established. After applying this model to the R&D of the VD furnace, pulse argon blowing method-a new method of bottom argon blowing is developed.
The simulation shows, while the power of stirring is constant, the method of pulse argon blowing provides good performance on restraining steel splashing, reducing erosion of ladle linings and saving argon consumption. This method is not only significant for stirring of the VD furnace with bottom blowing, but also provides an effective way to restrain molten steel splashing under strong bottom blowing condition for secondary refining furnace.

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