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DESIGN AND OPTIMIZATION OF OXYGEN LANCE FOR 210 T CONVERTER

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In order to satisfy the requirements of modern steelmaking for high oxygen supply intensity and high efficient smelting, the oxygen lance of 210 t converter with different structures are simulated by numerical simulation. The effects of the number of nozzles, Mach number and inclination angle on the velocity distribution, coalescence behavior and the impact area of the jet are discussed. The results demonstrate that compared with the five-hole oxygen lance, the increase of the number of nozzles accelerates the attenuation of jet and increases the coalescence of jet. At the same inclination angle, the change of Mach number has almost no influence on the jet. At the same Mach number, the increase of inclination angle causes the range of impact increases and the strength of impact decreases. Based on effective impact area, the optimal oxygen lance is scheme 9

Keywords: steel, converter, oxygen lance, numerical simulation, effective impact area

INTRODUCTION

In modern steelmaking, the behavior of oxygen jet has an important influence on the dephosphorization and decarburization effect of molten steel in converter. Previous researchers have done a lot of research on the influence of structural parameters of oxygen lance on the behavior of oxygen jet [1-4]. Odenthal [5] simulated the behavior of a single nozzle supersonic jet through computational fluid dynamics (CFD). Alam [6] studied the basic characteristics of supersonic jet at room temperature and steelmaking temperature. In recent years, with the increase of steel production and the development of large-scale converter, the current nozzle has been difficult to meet the requirements of high-intensity smelting. Therefore, the nozzle needs to be re optimized to improve the oxygen supply intensity. This study simulates and optimizes the six-hole oxygen lance of 210 t converter and analyzed the jet characteristics of oxygen lance under different structural parameters, which provide theoretical guidance for the design of the oxygen lance.

COMPUTATIONAL MODEL

This study takes the six-hole oxygen lance of 210 t converter as the research object, and designs different schemes with different numbers of nozzles, Mach numbers and inclination angles. The structural parameters of the scheme are shown in Table 1. Assuming that the jet enters a cylindrical space with r = 1,5 m and h = 2,7 m. In order to improve the calculation speed, a part of the calculation domain is created. Physical model and grid diagram is shown in Figure 1.

Table 1 **Structural parameters**

Number scheme	Number nozzles / -	Inclination angle / °	Throat diameter / mm	Mach number / -
1	5	15	51,04	2,04
2	5	15	50,66	2,05
3	5	16	50,27	2,06
4	5	16	49,88	2,07
5	6	15	46,6	2,04
6	6	15	46,24	2,05
7	6	15,5	46,24	2,05
8	6	15,5	45,89	2,06
9	6	16	45,89	2,06
10	6	16	45,54	2,07

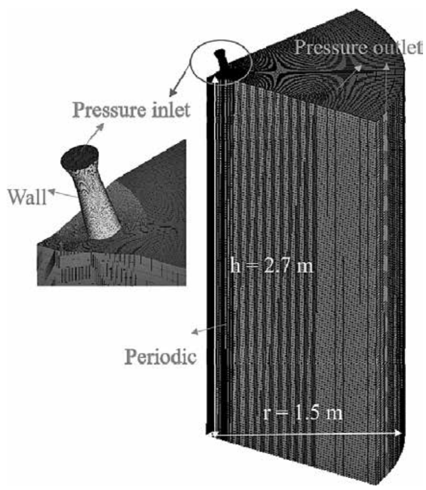

Figure 1 Physical model and grid of oxygen lance

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The inlet boundary condition is set as the pressure inlet, the outlet boundary condition is set as the pressure outlet and the inner interface is set as the periodic boundary condition. The part of the rest is set as the wall. Boundary condition parameters are shown in Table 2. The coupling between pressure and velocity is solved by SIMPLE algorithm. The continuity equation, continuity equation and energy equation are discretized by second-order upwind scheme. The solution is considered to have converged when the numerical residual is smaller than 10^{-6} for energy and less than 10^{-3} for other dependent variables.

Table 2 **Boundary condition**

Boundary conditions	Numeric value / Mpa	Temperature / K
Pressure-inlet	0,867-0,907	300
Pressure-outlet	0,104	300

MATHEMATICAL MODEL

The equations involved in this mathematical model include:

$$\frac{\partial(\rho u_i)}{\partial x_i} = 0 \tag{1}$$

$$\frac{\partial\left(\rho u_i u_j\right)}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial\left(\tau_{ij} - \rho\overline{u_i u_j}\right)}{\partial x_j} \tag{2}$$

$$\frac{\partial\left(\rho u_j C_p T\right)}{\partial x_i} = u_j\frac{\partial P}{\partial x_j} + \tau_{ij}\frac{\partial u_i}{\partial x_j} + \lambda_{eff}\frac{\partial^2 T}{\partial x_j^2} \tag{3}$$

$$\tau_{ij} = \mu_{eff}\left(\frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j}\right) - \frac{2}{3}\mu_{eff}\frac{\partial u_k}{\partial x_k}\delta_{ij} \tag{4}$$

In the formula: ρ is the fluid density, kg / m³; u_i and u_j are the velocities in the direction *of i* and *j*, m / s; *P* is static pressure/ Pa; For effective dynamic viscosity/ Pa·s; C_p is the specific heat capacity, J / kg·K; *T* is the jet temperature/ K; λ_{eff} is the effective thermal conductivity, W / m·K; τ_{ij} is a viscous stress/ Pa; μ_{eff} is effective viscosity/ Pa·s.

In this study, the standard k-ε turbulence model is used for numerical simulation. The transport equation of turbulent kinetic energy k and turbulent dissipation rate ε are:

$$\frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\alpha_k}\right)\frac{\partial k}{\partial x_j}\right] + G_k + G_b - \rho\varepsilon - Y_M + S_k \tag{5}$$

$$\frac{\partial(\rho\varepsilon u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\alpha_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right] + C_{1\varepsilon}\frac{\varepsilon}{k}\left(G_k + C_{3\varepsilon}G_b\right) - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} + S_\varepsilon \tag{6}$$

The parameter μ_t is the turbulent viscosity Pa·s; The parameter G_k is the generation of turbulence kinetic energy due to mean velocity gradients, and G_b is the generation of the specific dissipation rate; Y_M are the dissipations of k; $C_{1\varepsilon}$ = 1,44; $C_{2\varepsilon}$ = 1,92

RESULTS AND DISCUSSION

Velocity distribution

In the steelmaking process, the force of the jet is the main force for stirring the molten pool and metal droplets and slag splashing. Figure 2 (a) displays the distribution of jet velocity of five-hole oxygen lance at different axial distances. It can be noted that at the same inclination angle, Mach number has little effect on jet velocity. However, at the same Mach number, the jet velocity decreases as the inclination angle increases. It can also be seen in Figure 2 (b) that the influences of the Mach number and inclination angle on the jet of six-hole oxygen lance are consistent with that of the five-hole oxygen lance. Compared with the five-hole oxygen lance, the six-hole oxygen lance has a lower jet velocity and converges more toward the center, which makes it easy for each jet to converge into a single jet.

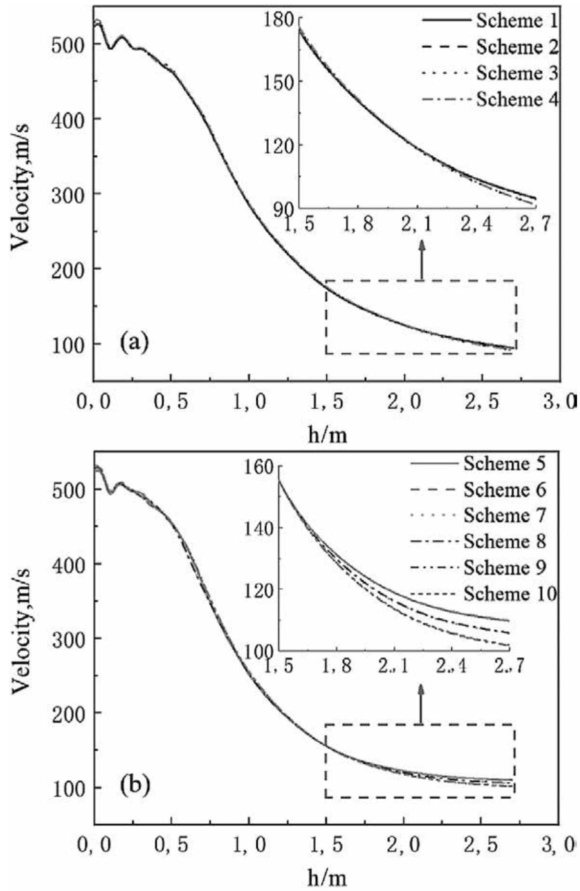

Figure 2 Jet velocity distribution of oxygen lance with different five-hole (a) and six-hole (b)

Coalescence morphology

The coalescence of multiple jets is the focus of the study on the jet characteristics of oxygen lance. The coalescence of jets affects the movement mode of jet, and then affects the interaction between the jet and the molten pool.

In this study, the radial shift distance of jet is used to quantitatively analyze the degree of jet coalescence. The radial shift distance represents the horizontal distance between the center of jet and the axis of oxygen lance. It can be observed in Figure 3 that the radial shift distance of the five-hole oxygen lance is larger than that of the six-hole oxygen lance at different axial distances. With the increase of the inclination angle, the radial movement distance of the jet is larger for the five-hole

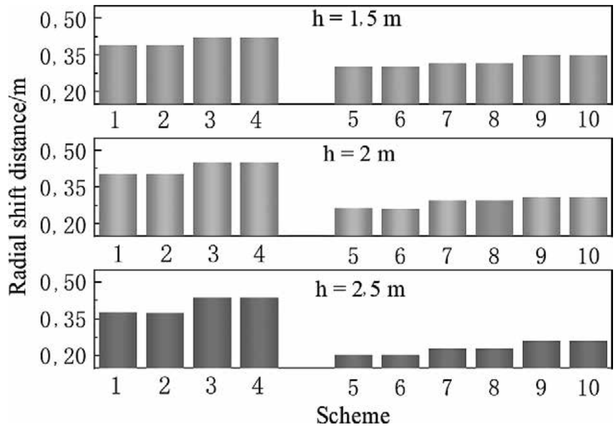

Figure 3 Radial shift distance of different oxygen lances

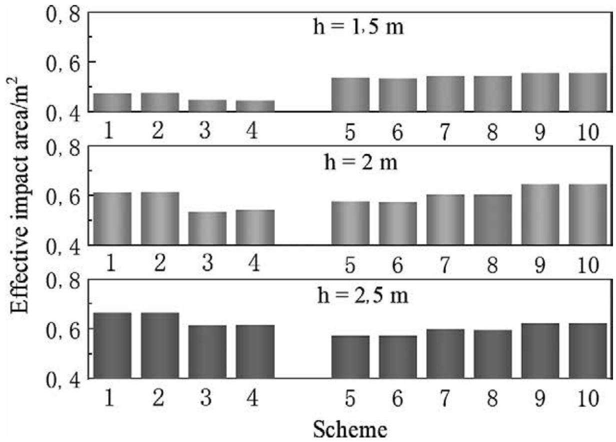

Figure 5 Effective impact area of different oxygen lance at different axial distance

or six-hole oxygen lance. Therefore, increasing the inclination angle can reduce the degree of jet coalescence.

Effective impact area

In basic oxygen furnace (BOF) practices, the impact area of the jets was applied to evaluate the cavity width, and the axial velocity magnitude determines the cavity depth [7]. When the jet velocity is 75 m/s, the oxygen jet can continuously break away the slag and have mechanical stirring and chemical action with the molten steel. Therefore, the effective impact area is defined as the area enclosed by the 75 m/s isokinetic line [8]. Figure 4 shows that the jet velocity distribution of different oxygen lances at h = 1,5 m. The red area in the figure represents the effective impact area. It can be seen from Figure 4 that the jet of five-hole oxygen lance is independently distributed, while the jet of six-hole oxygen lance is polymerized at h = 1,5 m.

In order to compare the effective impact areas of different oxygen lances more clearly, the area at different axial distance is counted, and the results are shown in Figure 5. When h = 1,5 m or 2 m, the effective impact area of scheme 9 is the largest, which means that scheme 9 can improve decarburization efficiency, shorten smelting time, and improve oxygen supply intensity.

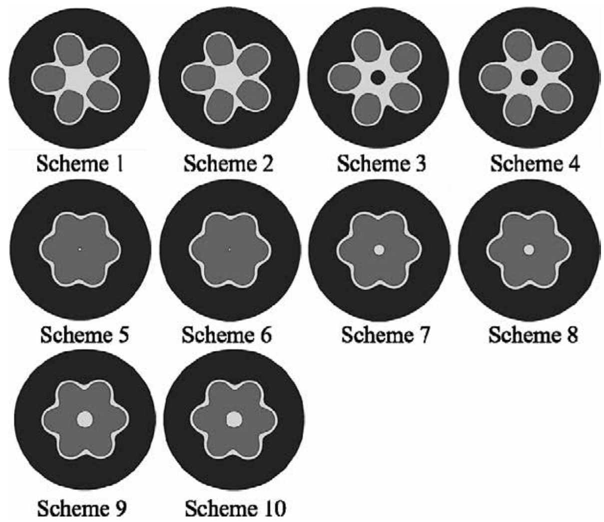

Figure 4 Jet velocity distribution of different oxygen lance at h = 1,5 m

Therefore, the best scheme for optimization design of 210 t converter oxygen lance is scheme 9.

CONCLUSIONS

Compared with the five-hole oxygen lance, the increase of the number of nozzles accelerates the attenuation of jet and increases the coalescence of jet.

At the same inclination angle, the change of Mach number has almost no influence on the jet. At the same Mach number, the increase of inclination angle causes the range of impact increases and the strength of impact decreases.

Based on effective impact area, the optimal oxygen lance is scheme 9

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Note: Peng Qichun is the responsible translator and the corresponding author