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NUMERICAL SIMULATION STUDY ON THE IMPACT AREA OF SIX-HOLE OXYGEN LANCE IN A 260 t CONVERTER

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In the process of converter smelting, the impact area formed when the jet sprayed by the oxygen lance hits the molten pool to a large extent determines the steel quality. In this study, six sets of oxygen lance models with different inclination angles were established based on the a 260 t converter, and the influence of the jet angle and position of the oxygen lance nozzle on the jet impact area was studied by numerical simulation, and the law of the change of the impact area with the lance position under different impact velocity was explained through theoretical analysis. It was found that the effective impact area of the jet with an inclination angle of 15° was the largest, and the stirring of the molten pool was more uniform.

Key words: converter oxygen lance, physical model, numerical simulation, theoretical analysis, effective impact area

INTRODUCTION

The impact area is a crucial parameter to judge the quality of the jet and the uniformity of the molten pool stirring. The size of the effective impact area determines the quality of the steel to a certain extent. In terms of impact area, it has always been considered that the larger the angle of the aerobic lance nozzle, the larger the impact area [1-3]. However, some researchers have found that the effective impact area can better reflect the blowing effect of the oxygen lance than the impact area [4-5]. In this research, a mathematical model of turbulent flow is established for the jet characteristics of the traditional six-hole oxygen lance used in the 260t converter, and the numerical simulation results are verified according to the isoentropy theory. The impact area with the inclination angle and lance position of the oxygen lance at different impact velocity is analyzed. The effective impact area is taken as the index, and the optimal inclination angle is finally obtained.

MATHEMATICAL MODEL

Six schemes are designed for the six hole oxygen lance nozzle used in 260 t converter, the inclination angle of the oxygen lance is 12 °, 13 °, 14 °, 15 °, 16 °, 17 °. The control variable method is mainly used to analyze the influence of angle and lance position on the impact area of the jet. According to the actual production situation, the design flow rate is 57 000 m³/h, the outlet Mach number is 2,06, the center distance is 110 mm, and the specific parameters are shown in Table 1 and Table 2.

Table 1 **Structural parameters**

Inlet diameter / m	Outlet diameter / m	Throat diameter / m	Throat length / m	Center pitch / m
0,067	0,059	0,044	0,03	0,11

Table 2 **Process parameters**

Q m³/ h	Ma	T_0 / K	P_0 / MPa	P_b / MPa
57,000	2,06	298	0,9	0,104

Considering the symmetry of the oxygen lance structure, the arrangement of the six oxygen lance nozzles is exactly the same, so only 1 / 6 of the oxygen lance as a whole can be constructed, which can not only reduce the workload, but also greatly reduce the number of grids and thus improve the convergence speed. Taking the oxygen lance with an inclination angle of 15° as an example, the main structure of the model is a Laval nozzle and a 1 / 6 cylinder with a radius length of 2 m and a height of 3,5 m as an infinite space. The model is imported into ANSYS ICEM CFD 15,0 for meshing, and the number of meshes is around 1,5 million, and the mesh quality reaches 0,75 or more, as shown in Figure 1.

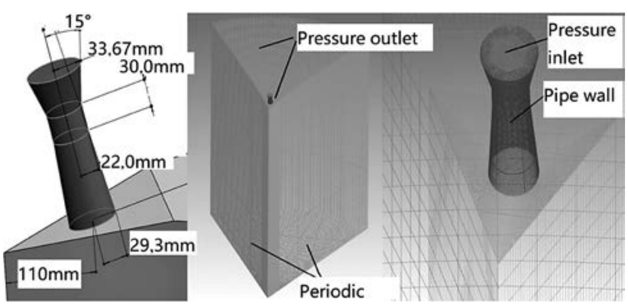

Figure 1 Physical model and grid of oxygen lance

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The basic control equations of this model include: continuity equation, momentum conservation equation and energy conservation equation, see Formula (1-4) for expressions [6].

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

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

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

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

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 terms of porous oxygen lance jets, according to the previous research on turbulent flow, the simulation results of the standard *k*-ε model are in good agreement with the actual situation. Therefore, the model used in this article is a standard k-ε model.

The outer boundary in the model of this research should be set with boundary conditions, the solver is Pressure-Based, the time is set to steady state, where the oxygen lance nozzle inlet is set as the pressure inlet, the oxygen lance nozzle tube wall is set as a non-slip wall, the internal infinite space interface adopts periodic boundary conditions, the other surfaces are set as pressure outlets, when the energy equation convergence residual is 10^{-6}, the other is 10^{-3}, and the convergence condition is considered to be reached. See Table 3 for details.

Table 3 **Boundary condition**

Boundary conditions	Numeric value / Mpa	Temperature / K
Pressure-inlet	0,9	298
Pressure-outlet	0,104	-

MODEL VALIDATION

The verification of mathematical models in numerical simulations is indispensable, and this research compares the isentropy theory calculation of Laval nozzle with the numerical simulation results, and finds that whether it is the throat or the outlet, their numerical simulation results are almost no different from the isoentropy theory calculation results [7], and the mass flow error is only 2,4 %.

Table 4 **Comparison between numerical simulation and isentropic calculation**

Category	P/P_0	T/T_0	ρ/ρ_0	*Ma*
Numerical simulation of *Dt*	0,525	0,840	0,638	1,004
Numerical simulation of *De*	0,112	0,543	0,210	2,072
Theoretical calculation of *Dt*	0,528	0,833	0,634	1,000
Theoretical calculation of *De*	0,116	0,541	0,215	2,060

RESULTS AND DISCUSSION

This section collates the impact area simulation data of the six sets of schemes, and studies the influence of the angle of the oxygen lance and the lance position on the impact area. According to the principle of single variable, the impact area under different impact velocities is analyzed. The effective impact area of these six schemes is compared, and the best angle is obtained. All the impact area simulation data in this research are derived from the Tecplot software, measured by Image-J software, and the corresponding impact area at a certain impact velocity X is specified by S - X, for example, the impact area at an impact velocity of 75 m / s is S - 75.

Impact area

It can be seen from Figure 2 that although the impact velocity is different, the impact area of the six schemes at different impact velocity varies with the lance position and nozzle inclination. After 25*D*e, at the same angle, the impact area increases with the increase of the lance position; Under the same lance position, the impact area increases with the increase of the angle, which shows that the angle is also the main factor affecting the S-10, S-30, and S-50.

Effective impact area

The effective impact area generally refers to the impact area where the jet impact force completely disperses the surface slag of the molten pool and chemically reacts with the metal inside the molten pool [8-9]. The main function is to stir the molten pool, so that the heating of the molten pool is more uniform, and it has the effect of strengthening heat transfer. The larger the effective impact area, the more uniformly the jet stirs the molten pool, and the better the heat transfer effect, so the size of the effective impact area is the most important indicator of all impact areas. According to the literature, when the impact velocity reaches 75 m / s (the dynamic pressure is 4 000 Pa), the corresponding impact area is the effective impact area.

It can be found from Figure 3 that the effective impact area for the six sets schemes is increased with the increase of the lance position, showing a trend of first increasing and then decreasing. The design of the oxygen lance with an inclination of 15 degrees can obtain the maximum effective impact area. When the lance position is 40-45 *De*, the optimal slag melting lance position can be obtained.

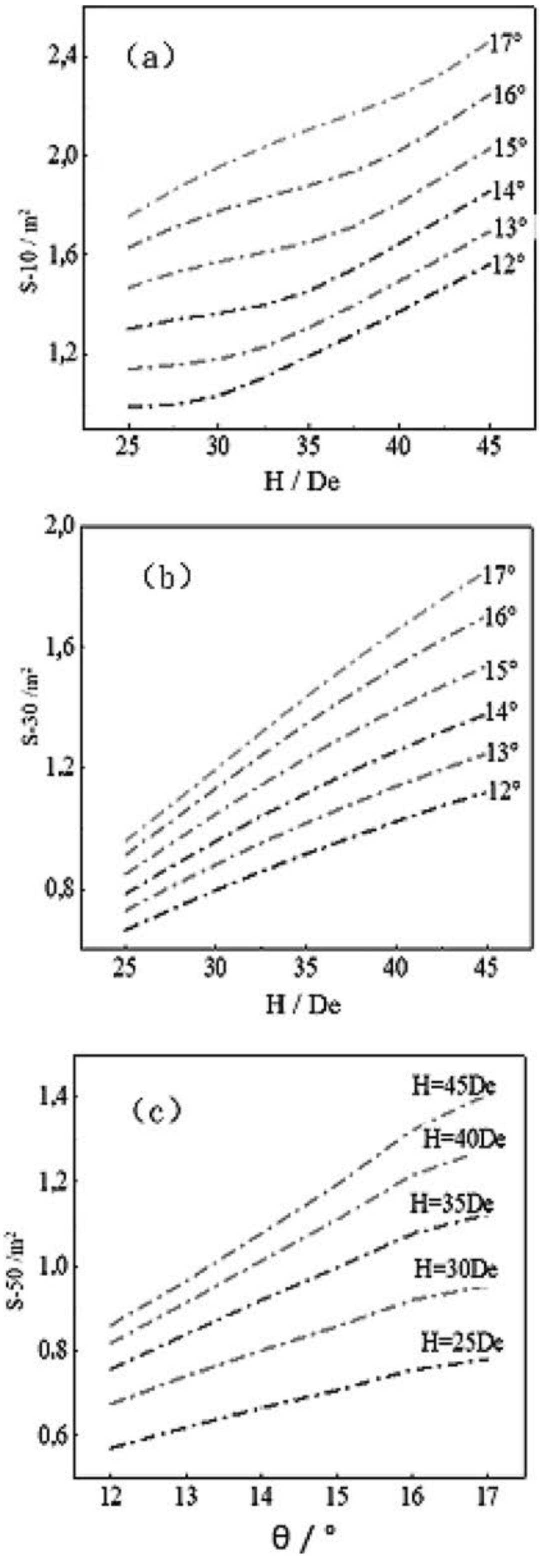

Figure 2 Impact area of six schemes under impact velocity of 10 m / s, 30 m / s and 50 m / s

At the same time, it can also be found that the larger the angle, the greater the impact area, according to Figure 4, it can also be observed that when the lance position is in the range from 25*De* to 45*De*, the effective impact area under the same lance position increases first and then decreases with the increase of the angle, and the maximum impact area under each lance position (except 25*De*) is reached at 15 °. The reason for this

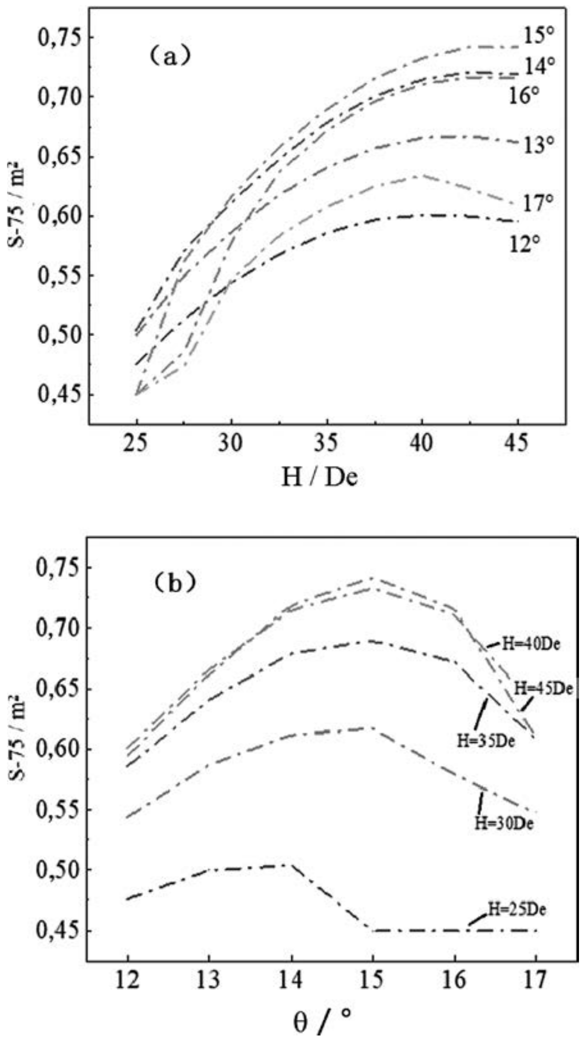

Figure 3 Variation of effective impact area with lance position and angle

gap is that the nozzle angle of these six schemes is different, the deflection of the jet centerline and the suction intensity of the jet stream strands and the fusion shape of the multi-strand jet velocity boundary are also different, which shows that the size of the impact area and the optimal lance position are affected by the angle, and the effective impact area of the oxygen lance nozzle with an angle of 15° in these six schemes is the largest. Therefore, if only the effective impact area is considered, the optimal angle is 15°.

CONCLUSIONS

At the same angle, the impact area increases with the increase of the lance position; Under the same lance position, the impact area increases with the increase of the angle, and the impact area of the oxygen lance with an inclination angle of 17° is the largest.

No matter how much the jet velocity, the impact area is always increased with the increase of the lance position and then decreased, as long as the lower limit of the lance position is low enough, the upper limit is high enough, the maximum value can be observed.

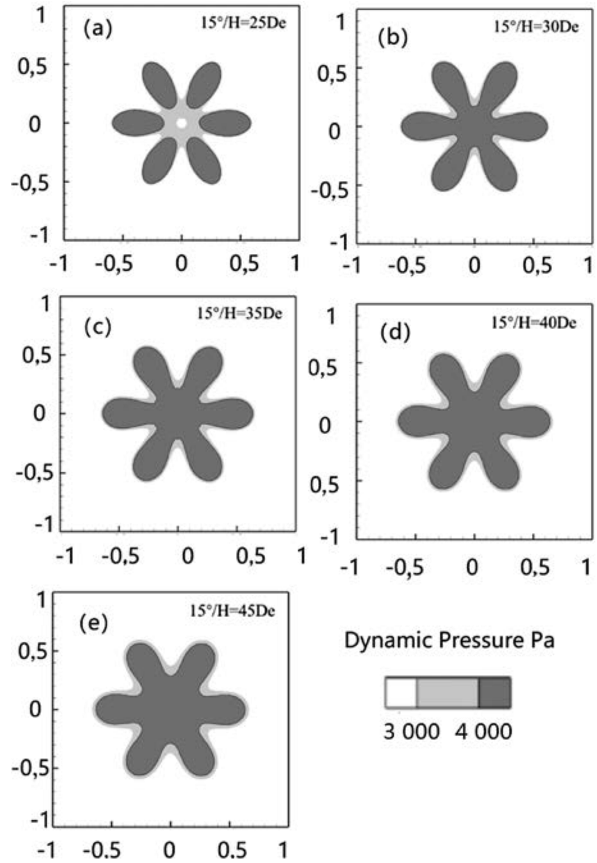

Figure 4 Effective impact area diagram of 15 ° inclined oxygen lance at different lance positions

The effective impact area increases first with the increase of the lance position and then decreases, and the effective impact area under the same lance position increases first and then decreases with the increase of the angle.

The oxygen lance with an inclination angle of 15 ° has the largest effective impact area, and the stirring of the molten pool is more uniform, so the optimal angle is 15 °.

Supporting projects: Innovation and entrepreneurship training program for College Students of university of science and technology Liaoning

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Note: Lin Zenghua is the responsible translator and the corresponding author