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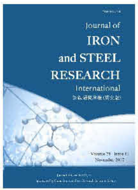

Effect of methane-hydrogen mixtures on flow and combustion of coherent jets

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ABSTRACT

Coherent jets are widely used in electric arc furnace (EAF) steelmaking to increase the oxygen utilization and chemical reaction rates. However, the influence of fuel gas combustion on jet behavior is not fully understood yet. The flow and combustion characteristics of a coherent jet were thus investigated at steelmaking temperature using Fluent software, and a detailed chemical kinetic reaction mechanism was used in the combustion reaction model. The axial velocity and total temperature of the supersonic jet were measured via hot state experiments. The simulation results were compared with the experimental data and the empirical jet model proposed by Ito and Muchi and good consistency was obtained. The research results indicated that the potential core length of the coherent jet can be prolonged by optimizing the combustion effect of the fuel gas. Besides, the behavior of the supersonic jet in the subsonic section was also investigated, as it is an important factor for controlling the position of the oxygen lance. The investigation indicated that the attenuation of the coherent jet is more notable than that of the conventional jet in the subsonic section.

1. Introduction

Supersonic jets have been widely applied in basic oxygen furnace (BOF) and electric arc furnace (EAF) steelmaking processes and play an important role in decarburization, slag foaming and component transport. Several researchers have focused on the optimization of oxygen jet technology before. For example, Mahoney[1] investigated the effect of shrouding gas and oxygen flow rate on supersonic jets via experimental measurements. Alam et al.[2] presented the results of a numerical simulation of a coherent jet, and these results were consistent with the experimental data. Odenthal et al.[3] developed a new injection system that used a high-temperature shrouding gas supplied by coaxial nozzles to increase the jet length.

One-step combustion reaction between methane and oxygen was also considered[4-6]. In a one-step reaction, all of the energy released by combustion is converted into heat energy, which causes the temperature of the flame to be excessively high and thus affects the potential core length of the supersonic jet. However, these studies only considered methane as the fuel gas of the coherent jet, and methane was proved to have a poor lean burn ability, high ignition energy and slow burning velocity[7-9]. Researchers also reported that hydrogen reduces the ignition temperature of methane and significantly increases the combustion efficiency of fuel gas[10,11], but the influence of fuel gas combustion on supersonic jets was not involved.

In this study, the eddy dissipation concept (EDC) model[12] was chosen for the combustion model with the detailed chemical kinetic reaction mechanism GRI3.0[13]. GRI3.0 consists of 53 species, in addition to argon and nitrogen, for a total of 325 step basic element reactions. Methane, hydrogen and a mixture of the two gases were chosen as the fuel gas. A computational fluid dynamics (CFD) model of a supersonic jet at steelmaking temperature was developed. The behavior of the coherent jet with dif-

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ferent fuel gases was investigated to understand the influence of fuel gas combustion on the smelting function and combustion function of the coherent oxygen lance.

2. Experimental

2.1. *Experimental equipment*

The combustion furnace shown in Fig. 1 was used to generate a high-temperature environment. The furnace temperature was controlled by a burner on the furnace wall and was monitored by 10 thermocouples. The measurement devices were fixed at the designated measuring points before performing the experiment. The experimental oxygen lance was equipped with a water-cooled copper sleeve, which was inserted at a horizontal position. The ambient temperature of the furnace was chosen as the average monitoring temperature of 10 thermocouples. When the furnace was heated to the required temperature, the flame burner was replaced with a coherent oxygen lance. The structure of the oxygen lance is shown in Fig. 2. The external and internal ring holes were used for shrouding oxygen. The middles of the ring holes were used to convey fuel gas. The Laval nozzle was used to provide the main oxygen source. The flow rate of the shrouding oxygen was twice that of the fuel gas. The structural parameters of the coherent oxygen lance for the experimental conditions are shown in Table 1.

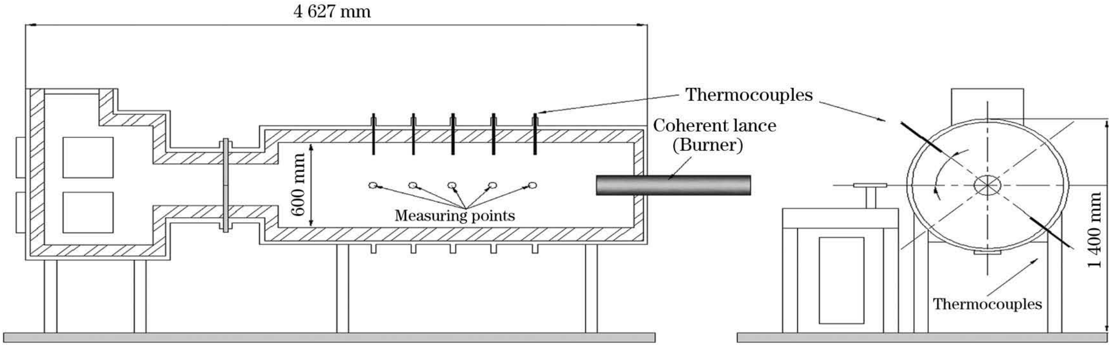
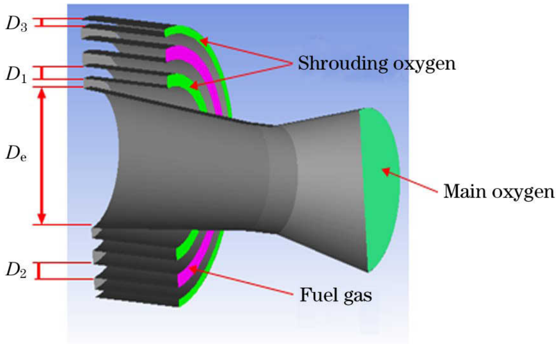


Fig. 1. Schematic view of experimental equipment.



D_e—Nozzle outlet diameter; D_1, D_3—Shrouding oxygen outlet diameter; D_2—Fuel gas outlet diameter.

Fig. 2. Nozzle structure of coherent oxygen lance.

Table 1

Structural parameters of coherent oxygen lance (mm)

Parameter	Value
D_e	34.2
D_1	3.0
D_2	4.3
D_3	4.0
Diameter of Laval nozzle throat	26.3

2.2. *Measurement method*

The experiment was carried out at an environmental temperature of 1700 K. The traditional pitot tube was equipped with a water cooling device. The pitot tube can be used in the range of 1600−1800 K. In this experiment, the total pressure and static pressure at the measuring points were measured through a pitot tube; the temperature of the measuring points was also measured. Using the measured data, the velocity at the measuring points can be obtained using Eq. (1). The oxygen jet has no effect on the mixing of molten steel at the velocities less than 0.3 *Ma* (Mach number). Hence, velocities less than 0.3 *Ma* were not measured in this study.

$$v=\sqrt{\frac{2\gamma RT}{\gamma-1}\left[\left(\frac{p_0}{p}\right)^{(\gamma-1)/\gamma}-1\right]}\qquad Ma>0.3 \tag{1}$$

where, v represents the velocity at measuring point; p_0 represents the total pressure of measuring point; p represents the static pressure of measuring point; R represents the ideal gas constant; T is the actual temperature of measuring point; and γ is the ratio of heat capacity.

3. Simulation

3.1. *Governing equations*

Continuity equation

$$\frac{\partial\rho}{\partial t}+\nabla(\rho\boldsymbol{u})=0 \tag{2}$$

Momentum conservation equation