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Research article

An experimental study on the spectroscopic characteristics in coal-water slurry diffusion flames based on hot-oxygen burner technology

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ABSTRACT

The characteristics of spectral emissions in coal-water slurry (CWS) diffusion flames are investigated in this paper. Using Praxair's improved hot-oxygen burner (HOB) technology, CWS can be ignited directly in the ambient atmosphere. Moreover, the spectral emissions in methane and CWS diffusion flames are obtained by a fiber-optic spectrometer and a high-spatial-resolution ultraviolet imaging system, respectively. The results indicate that the spectral emission lines of the excited radicals in CWS flames can be used to evaluate whether the coal has been ignited. Besides, the peak intensity evolutions of several main radicals under different conditions were analyzed. Based on the two-dimensional OH* distributions, the axial and radial OH* intensity distribution in CH_4 and CWS flames were discussed. Moreover, the areas of the flames and reaction regions show the proportions of the reaction region in the flame. Additionally, for the CWS diffusion flames, the OH* radicals can be considered as a good indicator of heat release rate. The OH*/CH* and OH*/C_2* intensity ratios can be used to estimate the *O*/*C* or CWS flow rate.

1. Introduction

The flame spectroscopic diagnostic technique can provide much information such as flame structure, equivalence ratio, temperature, heat release rate, flame strain rate and type of fuel. At present, the spectroscopic analysis of gas flames (e.g., methane, propane, butane, syngas flames, etc.) has been extensively reported [1], whereas the research on heterogeneous flames (e.g., biomass, pulverized coal, CWS, etc.) is still insufficient. Especially the study on the spectroscopic characteristics in CWS flames has been almost nonexistent. Moreover, the flames play an important role in the steady operation of the CWS gasifier, which is the key piece of equipment in coal gasification technology. Therefore, in order to diagnose the properties of CWS flames and monitor the operation of the entrained-flow CWS gasifier, the characteristics of spectral emissions in CWS diffusion flames have been investigated in this article based on hot-oxygen burner technology developed by Praxair.

Most published works are focused on the chemiluminescence in homogeneous flames. Higgins et al. [2–3] reported OH∗ and CH∗ chemiluminescence in methane flames under different strain rates and pressures. Orain and Hardalupas [4–5] evaluated the feasibility of the measurement of equivalence ratio and heat release rate using OH*, CH* and C_2* chemiluminescence with different fuel types. OH*, CH*, and C_2* also can be used to analyze the flame structure in Jeongseog and Dongsoon's reports [6]. Zhang et al. [7] studied the influence of velocity and equivalence ratio on the generation of impinging reaction regions with two-dimensional OH* emission intensity in methane diffusion flames.

Compared with the studies on gas flames, less work has been conducted on heterogeneous flames because the chemical reaction mechanisms and the experimental systems are relatively complex. Pourhoseini and Moghiman [8] discovered the qualitative distribution of soot particles in pulverized coal flames. The corrected chemiluminescence intensity ratios were investigated to diagnose air-fuel equivalence ratio of oil flames in the work of Viktor Józsa and Attila Kun-Balog [9]. In research conducted by Sung and Moon et al. [10–11], the CH* chemiluminescence images and intensity were used to observe the heat release region in pulverized coal flames and the combustion reaction regions in coal-biomass blend flames.

Hot-oxygen burner (HOB) technology was first put forward by Anderson [12] in the 1990s. The oxygen can be heated to 1600 °C without any other heating equipment. Subsequently, Riley [13] invented a commercial-scale hot-oxygen coal ignition system using hot-oxygen nozzle technology. It has been proved that the system can achieve the direct ignition of pulverized coal. Guo et al. [14] applied HOB technology in a bench-scale entrained-flow opposed multi-burner (OMB) gasifier to ignite diesel oil and CWS, which reduced the preheating time and operation costs effectively.

In this paper, improved HOB technology is employed to ignite CWS directly in the ambient atmosphere. The spectral emission lines, two-dimensional OH* distributions and heat flux of methane and CWS

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Nomenclature

CWS	coal-water slurry
HOB	hot-oxygen burner
d_e	the momentum equivalent diameter of burner, mm
O/C	the molar ratio of oxygen atom and carbon atom
I	the emission intensity, $\mu W \cdot cm^{-2} \cdot nm^{-1}$
X	the axial distance, mm
Y	the radial distance, mm
S_f	the CWS flame areas, cm^2
S_r	the reaction region areas, cm^2
H_{local}	the local heat release rate, $J/m^3 \cdot s$
Q_m	the CWS mass flow rate, $kg \cdot h^{-1}$

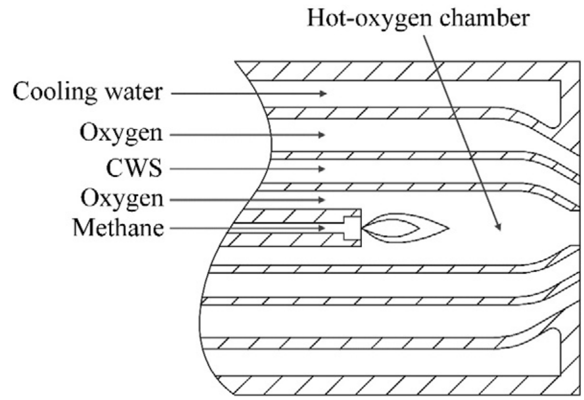

Fig. 2. Head structure sketch of HOB.

diffusion flames are measured by a fiber-optic spectrometer, a high-spatial-resolution ultraviolet imaging system and a bolometer, respectively. Furthermore, the emission intensity and two-dimensional OH* distributions under different conditions are investigated, and the ability to characterize heat release, equivalence ratio and CWS flow rate using chemiluminescence emissions is assessed.

2. Experimental work

2.1. Experimental facilities

Fig. 1 shows the experimental facilities sketch of the measurement system for the CWS diffusion flames. Experiments are carried out in the ambient atmosphere. The experimental facilities consist of a CWS combustion system, heat flux measurement system and spectrum radiation measurement system. The HOB is the key piece of equipment in the combustion system and includes the CWS channel, methane channel, two oxygen channels and cooling water jacket. CH_4 and O_2 were supplied by methane and oxygen cylinders, respectively. CWS was fed into the burners by a screw pump. Moreover, the bolometer can measure the heat flux (i.e., units of $J/m^2 \cdot s$) of the position where the sensor is placed. The optical measurement system includes a fiber-optic spectrometer and an ultraviolet imaging system, which can obtain the spectral emission properties, peak intensity of the excited radicals, two-dimensional distributions of OH radicals, etc.

The HOB was reformed based on a coaxial two-channel burner, and head structure is shown in Fig. 2. The CH_4 central tube is inside the O_2 channel (the inner one) and shrinks with increasing distance. A small chamber in which O_2 and CH_4 react is then formed. CWS can be ignited directly in the open space by excess high-temperature hot oxygen generated by the heat release from CH_4 combustion. However, compared with Guo's reports [13], the difference with respect to the HOB in this paper is that another O_2 channel (the outer one) is added between the CWS channel and the cooling water jacket. The addition of the outer O_2 channel can sufficiently atomize CWS, promoting the mixture of fuel and O_2 and the chemical reactions.

The heat flux measurement is carried out using a bolometer, which consists of a host (Type JTDL-4) and a high-temperature resisting heat sensor (Type JTC03B). Resolution is 0.1 $J/m^2 \cdot s$ and accuracy class is 4%. Moreover, the sensor was parallel to flames and fixed in a position where 3 cm from the HOB outlet in the axial direction and 5 cm from the flame front in the radial direction. The heat flux under different conditions was measured as well.

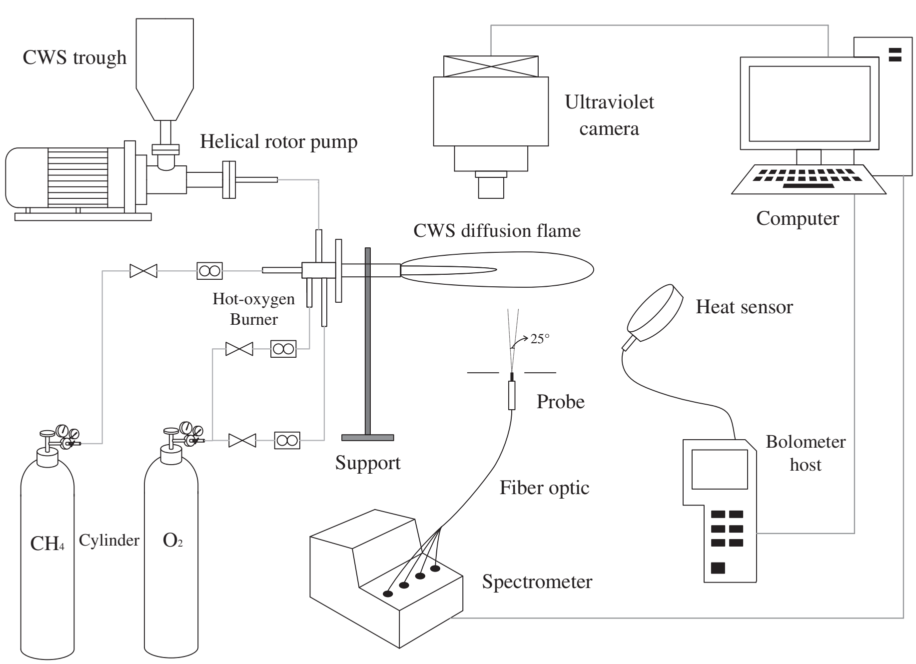

Fig. 1. Experimental facilities sketch.