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Alkalis atomic emission spectroscopy and flame temperature measurement of diesel impinging flames in an opposed multi-burner gasifier

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ABSTRACT

Atomic emission spectroscopy can well characterize atom release properties and flame temperature. This work aims to investigate the spectroscopic characteristics of alkalis atoms and measurement method of flame temperature in diesel impinging flames, based on a bench-scale opposed multi-burner (OMB) gasifier. A fiber-optic spectrometer and a CCD camera coupled with multiple bandpass filters are used to obtain the spectral emission lines and two-dimensional emission distributions of Na∗ and K∗, respectively. The results indicate that alkalis atoms can be released and excited in impinging region and four jet regions. The emission intensities of Na∗ and K∗ under different *O/C* are the strongest in the impinging region, suggesting that the atom release concentration and flame temperature are the highest. Moreover, the thermal excitation degree is related to the type of atom, and Na atom is much easier to be excited than K atom. It is confirmed that alkalis atom content and flame temperature were the two main influence factors on the emission intensity, and emission intensity can be used to qualitatively characterize flame temperature under the same *O/C*. In addition, atomic emission spectroscopy (AES) was given to quantitatively calculate the flame temperature. It is verified that the AES method is and feasible to derive diesel flame temperature and monitor the temperature changes of OMB gasifiers in real time.

1. Introduction

Coal gasification technology is significant for the efficient and clean utilization of coal. Entrained-flow gasification technologies, especially the opposed multi-burner (OMB) coal-water slurry (CWS) gasification technology, can efficiently achieve the clean production of syngas. Over 140 OMB gasifiers were licensed by more than 50 companies [1]. Moreover, the impinging flame was used to strengthen heat and mass transfer, improve residence time and reaction efficiency [2]. The flame in the gasifier is the symbol of CWS gasification and plays the key role in the operation of gasifier. And the spectroscopic information in flames has close relationship with flame characteristics and operation parameters [3,4]. Hence the spectroscopy of impinging flames in OMB gasifier were investigated in this paper.

The release of alkalis atoms during coal combustion or gasification is a significant but poorly understood factor of fouling and corrosion in the industrial equipment [5]. Although some authors have reported the behavior of sodium and potassium in coal [6–8], the analysis was mainly focused on the deposits formed during coal combustion. Specially, the final forms of sodium in have been well studied and can be well modelled by use of established reaction mechanisms [9,10]. Atomic emission spectrometry has been widely used in the determination of alkalis metals (Li, Na, and K) in oil samples [11,12]. This method has many advantages such as specificity, low detection limits, minimal sample preparation and availability of automation [13]. Wei et al. [14] applied ultraviolet spectra to investigate the decomposition kinetics of sodium aluminate. However, the spectroscopy of alkalis atoms which can indicate the release characteristics in flames was still rarely studied.

It is reported that there are two main existence forms of the alkalis elements in coal. One is water-bound form (they are dissolved in the moisture in coal). The other one is solid form (they combine with other kinds of mineral substance in coal) [15,16]. Under the high-temperature flames, the alkalis compounds can liquefy and evaporate because the flame temperature is much higher than the boiling point of alkalis compounds [17]. Then the splitting decomposition and atomization will occur, which is the release process of alkalis atoms [18]. Thermal excitation causes the energy level transition of spontaneous emission, then the spectral emission lines are generated [19,20]. At present, less work was conducted to investigate the emission characteristics of alkalis atoms in flames, hence they were systematically analyzed in this work on the basis of a bench-scale OMB gasifier.

Flame temperature is a significant parameter for combustion or

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gasification state. The non-invasive measurement methods, which have no damage to the flame structure, mainly include laser absorption spectroscopy, laser-induced fluorescence, spontaneous Raman scattering, coherent anti-stokes Raman spectroscopy, CCD image pyrometry, etc. [21–23]. The common disadvantages are that measuring systems are complex and the costs are high, which makes them difficult to be applied in the actual industry. However, the spectral emission of alkalis atoms has relation to flame temperature [24]. Hence this paper also verified the measurement method of flame temperature through atomic emission spectroscopy.

In this article, the spectroscopic characteristics and flame temperature measurement in diesel impinging flames were studied based on an entrained-flow OMB gasifier. The two-dimensional distributions of Na^* and K^* emissions were firstly derived using a CCD camera coupled with several filters and image processing method. The effects of two-burner and four-burner impinging, *O/C* and temperature were analyzed. The controlling factors of emission intensity were also investigated. Moreover, the feasibility of using atomic emission spectroscopy to calculate flame temperature was evaluated.

2. Experimental system

2.1. Experimental setup

As shown in Fig. 1, the experiments were conducted in the bench-scale OMB gasifier which was operated under ambient atmosphere. Four burners were mounted oppositely with 90° between each other. The distance from the impinging plane to the endoscope is 600 mm, and the impinging plane refers to the horizontal plane where the four burners are located. The distance between two opposed burners is 300 mm. The burner structure in this work is similar to industrial burner, which has two coaxial channels and a cooling water channel. Central channel is for diesel that was transported by a gear pump. Annular channel is for oxygen supplied by Dewar tank. The furnace temperature was monitored by several B-type platinum-rhodium thermocouples.

Spectral measurement system includes two sections. One is a fiber-optic spectrometer consist of an optical fiber and a spectrometer (HR2500+, Ocean Optics, Inc.). The fiber probe was inserted into the port to collect spectral signals and a cooling jacket was used to protect probe. The spectral resolution of spectrometer is 0.15 ± 0.01 nm; spectral region is 200–900 nm; the view field of fiber-optic probe is 25°. The raw spectral data collected by spectrometer should be corrected using a standard light source. The detailed calibration procedure has been reported by Zhang et al. [25]

The other section is a high-resolution CCD camera (XCL-500, SONY) coupled with several bandpass filters and a high-temperature endoscope (CESYCO, Φ38 mm). The spatial resolution of the CCD camera is 2448 × 2048 pixels, the exposure time was 5 ms, the diaphragm was F/9. A cooling jacket including cooling water and purging gas (Ar) was used to protect the endoscope from high temperature and pollutants. The view field of endoscope is 45°. Moreover, the bandpass filters are placed in the endoscope and can cover the CCD camera sensor completely. In this work, the filters of central wavelengths at 580, 590, 600 nm were used to obtain Na^* emission distributions, and 760, 770, 780 nm filters were used to derive K^* emission distributions. The diameter of filters is 25 mm; FWHM is 10 nm; the peak transmission is approximately 50%.

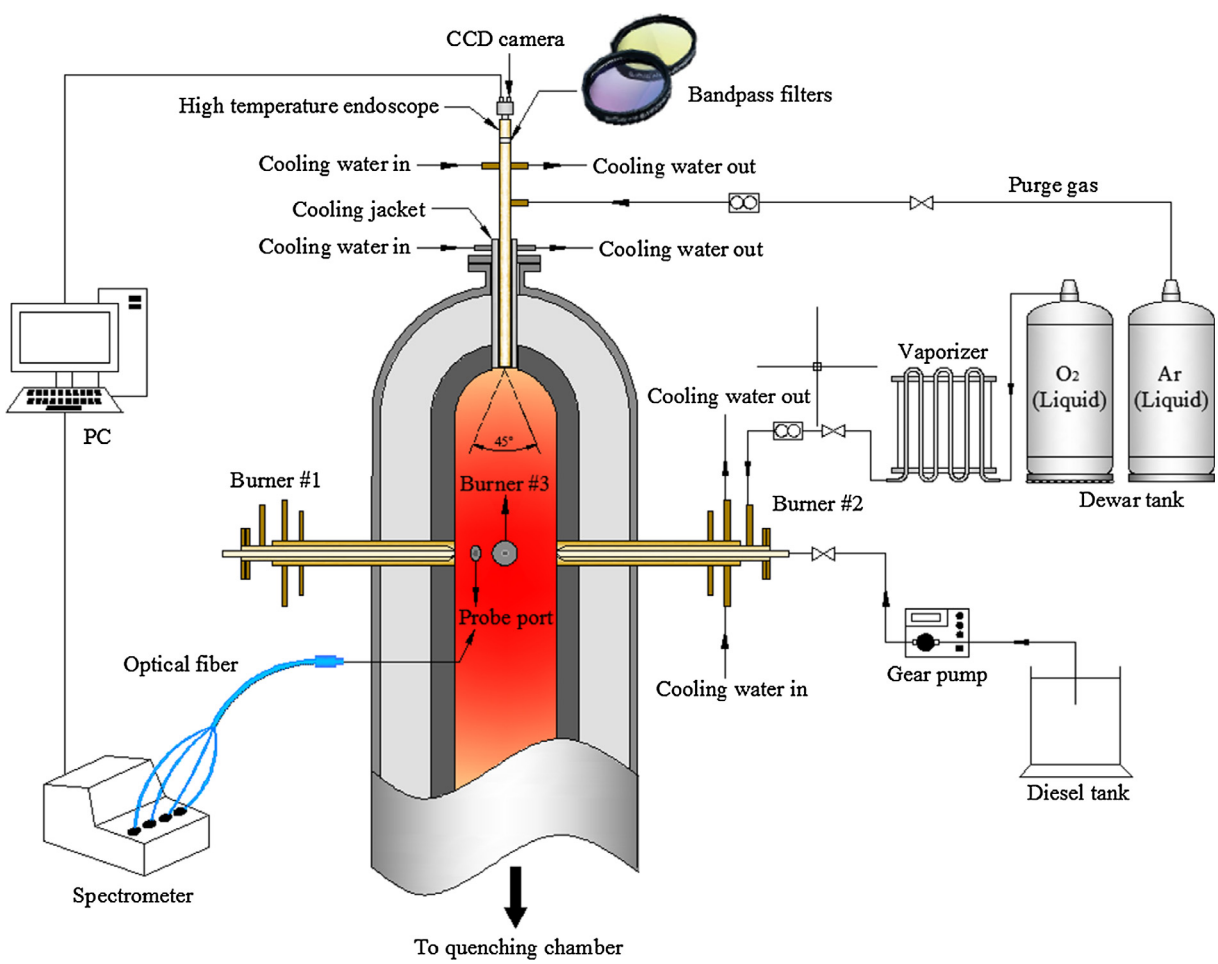

Fig. 1. Schematic of bench-scale OMB gasifier.