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Experimental Investigation of Combustion Species Radiation to Evaluate Equivalence Ratio in a Surface Flame Burner

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ABSTRACT: In the present research, combustion species were investigated in perforated natural gas burner based on flame emission spectroscopy. An experimental investigation is performed on a new burner test rig which is one of the most popular burners used in condensation boilers through a spectrometer-fiber optic to get the flame emission of a perforated burner. Combustion species H_2O*, OH*, CH*, C_2* and CO_2* are detected from their chemiluminescence The emission of CO_2* which has the main role in heat release rate of burner was investigated for different equivalence ratios (Φ) and burner powers of 11-16 kW showing an intensity peak in the range of Φ between 0.78 to 0.85 that corresponds to the maximum heat release rate. Emission of OH* was also investigated being the main indicator of NO regarding its producing mechanism. Its maximum was found at the range of at Φ=0.78 to 0.85 for different burner powers. A similar experiment showed that OH*/CH* intensity ratio was independent of burner power as is confirmed by previous researchers. One could infer the equivalence ratio from the flame emission.

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1. INTRODUCTION

The analysis of spontaneous light emitted by flames is the basis of many diagnostic techniques, designed to determine a wide range of combustion variables, in some cases with excellent spatial or temporal resolutions [1]. Experimental methods used to detect combustion species include intrusive and non-intrusive techniques. Intrusive approaches for combustion diagnostics are typically based on techniques where a mechanical probe is inserted directly into a region of interest. The most undesirable property of intrusive probes – that is, a local interaction with the combustion gases to be analyzed – remains unavoidable [2]. This interaction induces inadvertent reactions and disturbance on the flame shape. The spectroscopy of flames is the most common approach among the non-intrusive techniques. The advent of modern spectrometers, with built-in Charge-Coupled Device (CCD) detectors during recent decades, has encouraged researchers to apply this technology to monitor the combustion performance of bench-scale and laboratory flames [3].

Non-intrusive measurements include passive (non-laser based) and active (laser-based) methods. Despite their advantages in precise measurements, active methods need complicated apparatus (including lasers, high-speed cameras, lenses, filters, and signal amplifiers). In contrast, Flame Emission Spectroscopy (FES) is a passive approach based on acquiring radiation from a burner flame over a wide spectral region and is characterized by its low cost and robustness against the environmental disturbances [4].

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2. EXPERIMENTAL SETUP

A schematic diagram of the experimental apparatus is shown in Fig. 1. Two distinct gas lines, including natural gas (16 mbar-g) and airlines are provided in order to prepare aimed stoichiometric ratios. The composition of natural gas is given in Table 1. The air is supplied by a 0.75 kW side channel blower with an output pressure of 40 mbar-g. A venturi-type mixer is implemented to control the mixing process that conducts the air-gas mixture to a multi-hole cylindrical burner with the maximum thermal power of 26kW.

The spectrometer is connected to a computer to collect the intensity-wavelength diagram of each test. In order to reduce background noise, a black graphite plate is installed behind the burner, all tests are carried out in the night, and background emission is subtracted in spectrometer software while conducting each test.

3. RESULTS AND DISCUSSION

The obtained spectrum, in each case, consists of chemiluminescent species which are detected form their corresponding wavelengths and thermal radiation of the burner surface. In order to distinguish these two emission sources, burner emission was recorded in a time interval in which the burner is suddenly turned off. As a result, surface thermal radiation was found to be mostly in the IR region far from chemiluminescence peaks.

The peak values presented in this figure are related to chemiluminescent species OH*, CH*, C_2* emitting at wavelengths 310, 431, 516 and 471 nm respectively (the

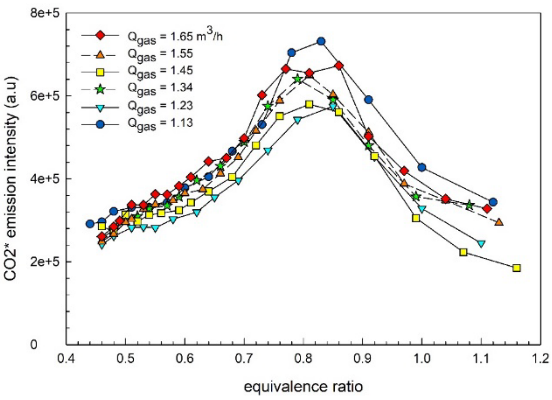

Fig. 1. CO_2* intensity ratio variation with *Φ*

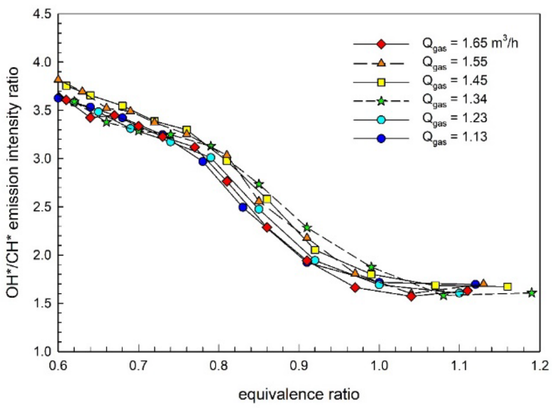

Fig. 2. OH*/CH* intensity ratio variation with *Φ*

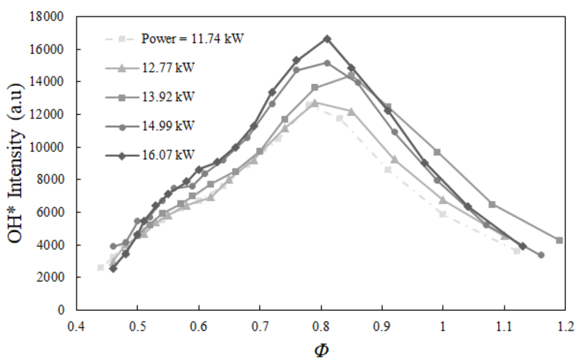

Fig. 3. OH*/CH* intensity ratio variation with *Φ*

last two wavelengths are for C_2*). There is a background emission for CO_2* in the wavelength band of 350-600 nm (integrated over this range, CO_2* emission accounts for its chemiluminescence) [5].

The OH* is one of the main species which plays an essential role in combustion processes. Figure 5 shows the time-averaged variation of OH* emission intensity versus equivalence ratio which shows a maximum in the lean burning region of *Φ*=0.77 to 0.85 (for all fuel flow rates). Furthermore, increasing the fuel flow rate enhances the OH* intensity peak, meaning an increase in heat release rate (a similar result was reported by Higgins et al. for their coarse grid burner). As the fuel flow rate increases from 1.13 m^3/h to 1.65 m^3/h (46% rise) OH* intensity soars to 1.45 of its initial value at φ=0.8.

Chemiluminescence of CO_2* is analyzed showing the heat release rate trend (as illustrated in Fig. 1). The peak intensity for different fuel flow rates is in the range of 0.78<*Φ*<0.85 showing a promising similarity with that of OH*. Comparing Fig. 3 and Fig. 1 and considering OH* and CO_2* as an indicator of heat release rate (according to [5]), the equivalence ratio range of 0.78<*Φ*<0.85 is reported as maximum heat release rate region and therefore, optimal thermal performance range.

Fig. 2 shows the variation of the intensity ratio of OH*/CH* versus equivalence ratio for different fuel flow rates. The intensity ratio can be used as a tool to evaluate the thermal burner equivalence ratio from its emission. Similar attempts have been made in another application confirming the monotonic trend for OH*/CH*. Present results indicate that OH*/CH* is almost independent (up to 17% relative difference) of burner power and could be regarded as an index by which one could get to equivalence ratio through OH*/CH*.

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4. CONCLUSIONS

An experimental study is conducted to investigate the optimum equivalence ratio range in maximum heat release rate and energy transfer for a multi-hole cylindrical burner using a flame emission spectroscopy approach, which is an optical, non-intrusive technique. The burner which is widely used in condensing gas boilers is investigated by OH* and CO_2* chemiluminescence intensity at different fuel flow rates and equivalence ratios. The two species emissions had a similar peak range of *Φ*=0.78-0.85 that corresponded to the burner maximum heat release rate. The OH*/CH* intensity ratio showed a power-independent variation versus *Φ*. Using the proposed correlation, one could obtain *Φ* from burner spectral emission. In targeted fuel flow rates, burner surface temperature showed a peak at *Φ*=0.82 that was in accordance with the equivalence ratio at the maximum heat release rate.

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