Correlation of chemiluminescent signal and pollutant emission of a liquid-fueled turbulent swirl burner

Gyöngyvér Hidegh, Viktor Józsa

Budapest University of Technology and Economics, Faculty of Mechanical Engineering, Department of Energy Engineering, 1111 Budapest, Műegyetem rkp. 3., Hungary

Motivation

The pollutant emission standards push the development of real-time diagnostics and control systems of modern combustion chambers. The modern active online optical flame monitoring methods focus on the application of flame emission spectroscopy (FES) [1-5]. In practice, the potential appliances are the furnaces, boilers and gas turbines. Principally, for the sake of the compliance with the NO_X standards, lean and premixed combustion is applied [6,7]. However, it leads to an increased sensitivity for pressure waves and instabilities which may lead to flame blowout or flashback.

To ensure stable operation, equivalence ratio monitoring by FES is a promising method. Principally, the literature contains information on laminar premixed flames, especially methane-air flame [8,9]. Nevertheless, turbulent flames can also be monitored by FES, being a significant milestone towards practical applications [10]. As for steady liquid fuel combustion, the literature is rather limited, therefore, the present paper focuses on chemiluminescent and pollutant emissions of swirl combustion, utilizing liquid fuel.

Measurement setup

In this paper, a turbulent lean premixed prevaporized (LPP) swirl burner is investigated which was fueled with standard diesel oil (EN 590:2014), shown in Fig. 1. The burner was originally designed for the Capstone C-30 micro gas turbine. The length of the mixing tube is 75.5 mm; its inner diameter is 26.8 mm. On the mixing tube, there are fifteen rectangular holes with a 45° inlet angle in order to swirl the combustion air, and four other circular inlets to prevent flashback. It is equipped with a plain-jet airblast atomizer in which the annular air flow blows over the liquid jet at few hundred m/s velocity difference. The resulting interaction leads to the disruption of the jet into tiny droplets.

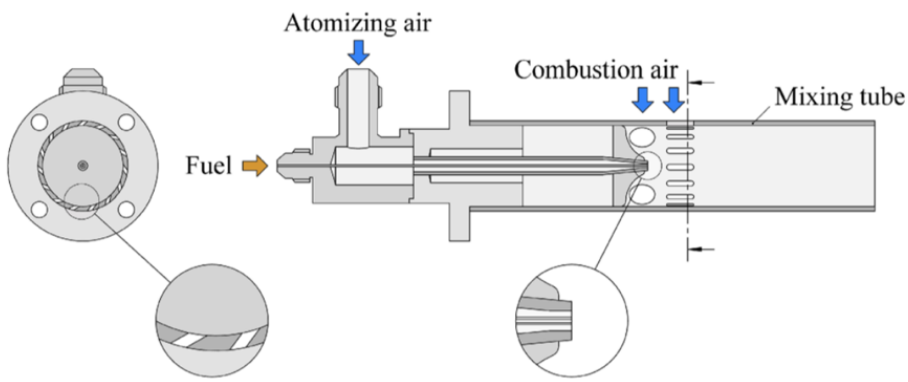

Fig. 1. Investigated LPP burner

The atmospheric test rig is shown in Fig. 2. It was designed for 15 kW combustion power; the combustion air was preheated to 400 °C to enhance the vaporization of the liquid fuel droplets. The combustion air flow rate, delivered by the fan into the preheater, was controlled by a frequency inverter, and therefore, the equivalence ratio. The lower limit of the air-to-fuel equivalence ratio, λ, was 0.7 in all cases. The higher limit was governed by flame blowout which occurred at λ = 1.2-1.8, depending on the setup. The lip of the burner was equipped with various quarls, which, besides their stabilizing effect, significantly affects pollutant emission [11]. The half-cone angle of the quarls was varied between 0 and 60° in 15° steps, where 0° means a simple extension of the mixing tube to compensate a possible shorter mixing tube of the baseline burner configuration. Six atomizing gauge pressures were examined in the range of p_g = 0.3–2.3 bar. The flue gas was sampled by a Testo 350 emission analyzer from the chimney hood through a steel sampling probe, which had five equidistant holes along the diameter of its pipe. The probe was 1 m above the burner, while the longest flame did not exceed 0.25 m measured from the burner lip, allowing ambient air entrainment.

A vertically adjustable spectrometer was used for the FES measurement, manufactured by OpLab Ltd. The focal length of the 20 mm diameter quartz objective is 0.5 m, leading to a line of sight measurement with 5 mm diameter at the focus. The lower limit of the control volume was 2 mm above the burner or quarl lip in all the cases; this corresponds to the 0 mm measurement height. The device has an nMOS light detector with 1024 pixels. The diffraction grid determines the range of the spectrum, which was 260-580 nm, with the resolution of 0.3125 nm. The chemiluminescent intensity of OH*, CH* and C_2* was taken at 309, 430 and 516 nm, respectively.

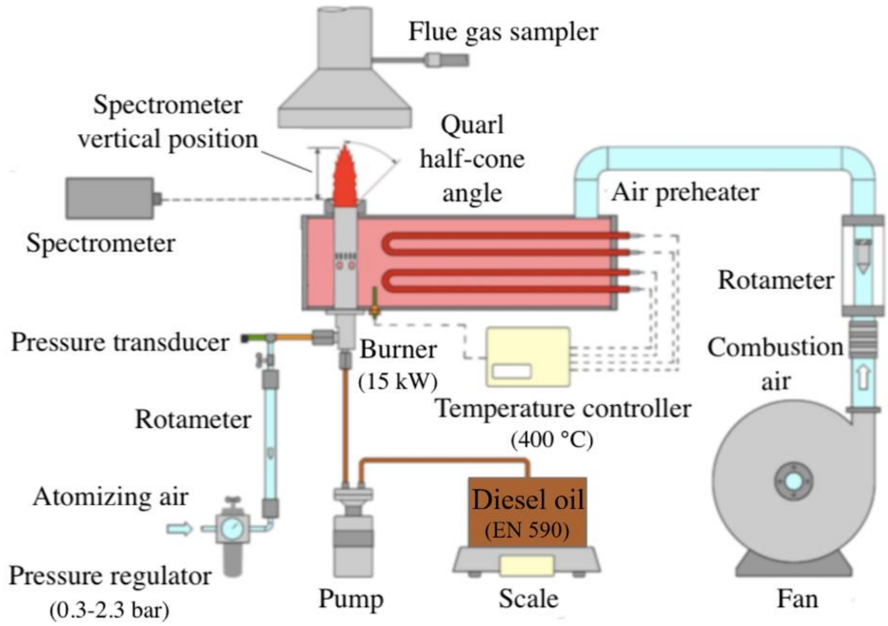

Fig. 2. Measurement setup.

Results and discussion

The uncertainty of the air-to-fuel equivalence ratio was lower than 7.3% in all the examined operating states, which decreased with increasing combustion air flow rates, and the average value was 6% in the investigated range. The highest uncertainty of CO and NO_X measurement did not exceed 19 and 5 ppm respectively. Since the emissions were corrected to 15% O_2, the combustion air flow rate influenced this uncertainty the most with average uncertainties of 7 ppm for CO and 4 ppm for NO_X.

The comparison of the CH*/C$_2$* chemiluminescent signal and pollutant emission applying the 45° half-cone angle quarl is presented in Fig. 3, as a function of p_g and λ, at 10 and 15 mm measurement height. Similar trends can be found for CO and NO$_X$ emission, and the CH*/C$_2$* intensity ratio at 10 mm height, where the combustion is lean (λ > 1.2), being independent of the atomizing pressure, principally governed by λ. At 15 mm height, the CH*/C$_2$* intensity ratio becomes sensitive to the atomizing pressure as well.

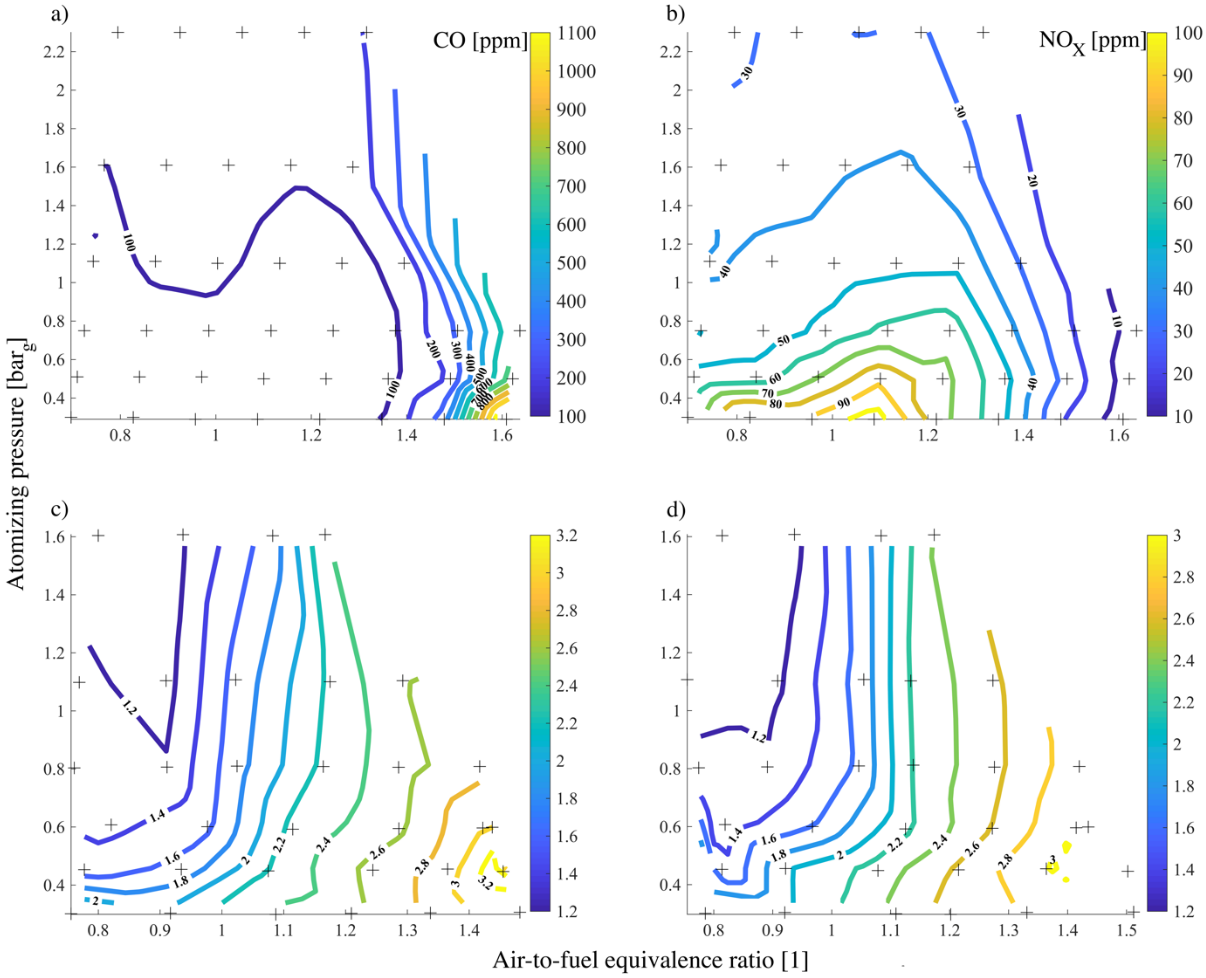

Fig. 3. CH/C$_2$* intensity ratio and pollutant emission with the 45° quarl: a) CO emission, b) NO$_X$ emission, c) CH*/C$_2$* intensity ratio at 15 mm height, d) CH*/C$_2$* intensity ratio at 10 mm height. The + signs indicate the measurement points.*

For each quarl at 25 and 20 mm height, the flame structure was more likely to alter during the combustion process than in the lower regions, therefore, these measurement results are less relevant from the point of view of the combustion control. At 15 mm height, a transitional region was observed, where the correlation between the CH*/C$_2$* signal and the pollutant emission has started to develop. For lean mixtures in the lower regions, at the detected 10, 5, and 0 mm heights the CH*/C$_2$* intensity ratio and the pollutant emission showed a similar trend in the function of the p_g and λ. The OH*/CH* and OH*/C$_2$* intensity ratios were also examined, but a notable correlation was found neither with the CO nor with the NO$_X$ emission trends.

Conclusion

The vertical positioning of the spectrometer up to 10 mm from the burner or quarl lip does not affect the measurement of the chemiluminescent signals. By focusing on the flame root of lean mixtures, the CH^*/C_2^* intensity ratio and pollutant emission trends are principally affected by the equivalence ratio, without a notable effect by the atomizing pressure.

Acknowledgements

This work has been supported by National Research, Development and Innovation Fund of Hungary project № OTKA-FK 124704, New National Excellence Program of the Ministry of Human Capacities project № ÚNKP-18-4-BME-195, and the János Bolyai Research Scholarship of the Hungarian Academy of Sciences.

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