



ELSEVIER



CrossMark

Available online at www.sciencedirect.com

ScienceDirect

Proceedings of the Combustion Institute 35 (2015) 1649–1656

Proceedings
of the
Combustion
Institute

www.elsevier.com/locate/proci

Reaction zone visualisation in swirling spray *n*-heptane flames

R. Yuan^{a,*}, J. Kariuki^a, A. Dowlut^b, R. Balachandran^b,
E. Mastorakos^a

^a*Hopkinson Laboratory, Engineering Department, University of Cambridge, CB2 1PZ, United Kingdom*

^b*Mechanical Engineering Department, UCL, London WC1E 7JE, United Kingdom*

Available online 26 June 2014

Abstract

Joint PLIF measurements of CH₂O and OH were performed in a swirl-stabilized *n*-heptane spray flame at conditions close to extinction. Simulations of laminar counterflow heptane flames at different strain rates showed that the heat release could be approximately represented by the product CH₂O × OH, but also that this product cannot visualise the heat release at the lean side of stoichiometry. The simulations suggest that the outline of CH₂O regions in PLIF images could be an approximate indicator of the stoichiometric mixture fraction iso-line. Due to the intense turbulence and local extinction, individual PLIF images show a very variable behaviour. They indicate rich zones, reaction sheet breaks, lift-off, and they suggest that this flame is mostly of non-premixed character. The mean heat release rate as represented here is consistent with inverse Abel-transformed OH* chemiluminescence imaging. The usefulness of this technique for spray flames is discussed.

© 2014 The Combustion Institute. Published by Elsevier Inc. All rights reserved.

Keywords: Extinction; Swirl; Formaldehyde fluorescence; Heptane spray

1. Introduction

Local extinction is an important limiting factor for lean combustion. Knowledge of the structure of the flame close to blow-off is important from a practical perspective, but also from the viewpoint of validating advanced turbulent combustion models. In gas turbines and industrial furnaces, the flame is virtually always stabilised by swirl. It can be argued that we know little

about the fundamental processes of extinction of spray flames in recirculation zones, as we do not have the same degree of information as we do for gaseous flames [1–4]. Cavaliere et al. studied *n*-heptane spray flames and saw local extinction holes present along the flame sheet and randomly-occurring lift-off [5]. These observations were based on 5 kHz OH-PLIF, which cannot reveal with certainty whether a flame is extinguished or not. In particular, the OH signal alone may not reveal whether the flame is of premixed character (and therefore there may be OH in the post-flame gases) or of non-premixed character (and therefore the OH is found roughly along the stoichiometric contour only).

* Corresponding author.

E-mail address: ry235@cam.ac.uk (R. Yuan).

As a second scalar for flame structure studies, formaldehyde (CH_2O) has been used extensively. CH_2O is produced in the low temperature oxidation process and consumed in the subsequent high temperature oxidation. Formaldehyde LIF was used for autoignition of methane jets [6], methanol, ethanol and acetone spray jet flames [7,8], and diesel fuel [9–11] and n-heptane [11,12] in HCCI engines. Najm et al. [13] conducted detailed chemical kinetic computations of methane premixed flame and found that the concentration of formyl radical (HCO) is very well correlated with flame heat release rate. They also point that the production of HCO is directly dependent on the availability of its precursor CH_2O ($\text{CH}_2\text{O} \xrightarrow{\text{OH,H}_2\text{O,M}} \text{HCO}$). However, as the PLIF of HCO is difficult for single shot imaging diagnostics when applied to fully turbulent flows due to its short fluorescence lifetime and low concentrations [13], the product of simultaneous OH and CH_2O PLIF was considered as an alternative. Simultaneous CH_2O and OH imaging and then taking the product $X_{\text{CH}_2\text{O}} \times X_{\text{OH}}$ (X being the mole fraction, taken as proportional to the PLIF signal intensity) has been used successfully as a marker of heat release in non-premixed and premixed flames [14–17]. Even when quantitative imaging has not been possible, the qualitative comparison of CH_2O and OH regions has been very fruitful. Medwell and Dally [18] discussed formaldehyde in MILD combustion conditions, while Masri and co-workers looked at simultaneous CH_2O and OH in jet flames of ethanol, methanol and acetone [7,8] and very interesting comments on the nature of the reaction zones in these spray flames could be made.

In this paper, we use simultaneous CH_2O and OH imaging in the stabilisation region of an n-heptane spray flame in a swirl-induced recirculation zone, a configuration of great relevance to gas turbine combustion, and in particular for flames close to the stability (i.e., extinction) limits. Our specific objectives are: (i) to examine the performance of the CH_2O –OH technique for n-heptane; (ii) to visualise reaction zones in swirl spray flames; (iii) to examine how these zones are altered close to blow-off. The paper continues with a presentation of the experimental method, some results from laminar flame simulations, and typical images from the application of the technique.

2. Methods

An enclosed bluff-body swirling n-heptane spray flame was stabilized at two flow conditions: far from and close to blow-off. The burner (Fig. 1) was identical to the one examined previously by Cavaliere et al. [5], with the exception of a new atomiser giving a slightly narrower spray. Four

quartz plates formed the combustion chamber of 97 mm width square and 150 mm length. The air was supplied through a 350 mm long circular duct of $D = 37$ mm inner diameter fitted with a conical bluff body of diameter $d = 25$ mm. A 60° swirler provided strong swirl at the exit, which, together with the bluff body, contributed to the establishment of a recirculation zone. For information, see Ref. [19] for velocity measurements in this burner for the n-heptane case, which should not be too far from the present flame due to the dominance of the air flow. A pressurized atomizer (Lechler, #212.054.17.AC; a flow rate up to 0.45 g/s at 5 bar) was fitted inside the bluff-body holder, providing a hollow cone spray profile with a nominal spray angle 60° .

The air flow was dried and particle-filtered and supplied by an air compressor. The heptane was supplied from a nitrogen-compressed container. Air and fuel flow rates were metered separately using an Alicat mass flow controller (MFC 5, 1000 SLPM) and a Bronkhorst liquid flow controller (LIQUI-flow, L30, 0–2 g/s). The two flow conditions studied as well as the blow-off condition are listed in Table 1.

Two 10 Hz Nd:YAG lasers and one dye laser were used for the joint CH_2O and OH PLIF system [20]. The OH-PLIF was excited at 283 nm, while the CH_2O -PLIF was excited at 355 nm. The fluorescence of OH was captured in the range of 309–375 nm with WG305 and UG11 Schott glass filters applied. The fluorescence of CH_2O was captured in the range 375–610 nm using an intensified CCD camera through a filter set (laser line notch filter: OD > 4, 17.8 nm FWHM, GG395 and BG 40) to eliminate scattering, flame luminosity, and soot emission interference. A 355 nm laser line notch filter was added to the CH_2O camera to further cut-off any scattering of laser light by droplets. Because heptane (liquid and/or vapour) and PAH may also fluoresce in the range 350–600 nm [21,22], possible interference from fluorescence of vapour and liquid and of PAH could not be subtracted from the CH_2O signals. Some comments on the importance of this interference are made later based on laminar flame simulations and on some preliminary experiments. The nominal resolution of the imaging system was 0.05 mm/pixel. The gain of the image intensifier was 30,000 FL/FC and 80,000 FL/FC for CH_2O and OH, respectively. The laser powers were 12 mJ/pulse for OH PLIF and 300 mJ/pulse for CH_2O PLIF. The intensifiers were triggered off the Q switch of each laser with a gate of 220 ns. The CH_2O PLIF laser was triggered at 300 ns delay from the triggering of the OH laser. The laser pulse width was 10–12 ns.

Both OH and CH_2O PLIF images were transformed to be spatially aligned with each other on a pixel-by-pixel basis. The alignment needed to be precise and followed several stages. Firstly,

Download English Version:

<https://daneshyari.com/en/article/6679281>

Download Persian Version:

<https://daneshyari.com/article/6679281>

[Daneshyari.com](https://daneshyari.com)