Fuel Distribution Measurements in a Model Low NOx Double Annular Combustor using Laser Induced Fluorescence

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Abstract

Planar laser induced fluorescence (PLIF) was employed in a three sector, low NOx double annular combustor in order to characterise the combusting fuel spray. Naphthalene was employed as a fluorescent agent in odourless kerosene in order to determine the behavior of the fuel vapour, and the light to medium fractions in the fuel spray, while 2,5 di-phenyl oxizol (ppo) was employed to determine the behavior of the heavy fractions in the fuel spray. Counter-swirl air blast atomizing fuel injectors employing a nominal fuel spray included cone angle of 90 deg were employed to inject the kerosene fuel into the double annular combustor. Radial and axial measurements were performed on the combusting spray. Spatial variations in fuel spray placement were observed, together with radial anisotropy.

Introduction

Legislative controls on emissions from gas turbine combustors has prompted considerable technical innovation, both in the design of new combustors (intended to meet the decreasing emissions limits), and in the development of new combustion diagnostics. These new diagnostics aim to generate an increase in quantitative information and understanding of gas turbine combustion and the subsequent generation of emissions.

Current experimental techniques employed to measure atomiser performance include mechanical patternators [1], Phase Doppler Anemometry (PDA) and Laser Sheet Imaging (LSI) [2]. Mechanical patternators cannot, however, be used in a combusting system, as the liquid fuel is consumed. Phase Doppler Anemometry is used to measure pointwise mean and standard deviation drop size, and mean and standard deviation drop velocity in low density sprays. PDA is unsuccessful, however, in measuring the drop size distribution in high density sprays. Laser Sheet Imaging is useful for the qualitative determination of fuel placement, spray isotropy, and spray cone angle, but exhibits a bias towards small drops in the spray field.

No diagnostic can currently measure or quantify the process of fuel spray evaporation. However, the spray cone angle, angle of spray dispersion, and spray penetration distance are indirect indicators of the process of fuel vapourisation. The spray cone angle and angle of spray dispersal also affects the combustion-acoustic coupling (rumble) in the combustor. 2psi - 3psi pressure oscillations in the combustor can cause rumble up to 200dB intensity.

This paper reports relative quantitative measurements of the liquid and vapour phase fuel distribution in a high pressure, three-sector low NOx double annular combustor using Planar Laser Induced Fluorescence (PLIF).

Experimental Method

The three-sector double annular combustor was radially staged, with twin counterswirl airspray fuel injectors, and a splitter to separate the pilot zone from the main zone. High pressure fused silica windows were placed on both sides adjacent to the pilot zone to provide optical access perpendicular to the direction of flow. There was a further fused silica window at the rear of the rig, to provide optical access towards the injectors.

The combustor was operated at a ground idle condition (P = 3.0 bar, T(inlet air) = 530K, air flow rate = 0.95 $kg.s^{-1}$, and fuel flow rate = 3.8 $g.s^{-1}$ per injector), and a higher fuel flow rate condition of 4.9 $g.s^{-1}$ per injector to simulate take-off. PLIF measurements were obtained in four planes (two radial planes, two axial planes) for the specified operating conditions.

Exxol D80 odourless kerosene produces approximately 1/50 the fluorescence emission of conventional kerosene. Naphthalene (boiling pt ~ 220^{o}C) was employed as a fluorescent seed in order to determine the beha-

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viour of the fuel vapour, and the light to medium fractions in the fuel spray. 2,5 Di-phenyl oxizol (ppo) (boiling pt ~ 350°C) was employed in order to determine the behavior of the heavy fractions in the fuel spray.

A Lambda Physik EMG-150 MSC laser operating in narrow band tunable mode at 308nm was used for the fuel PLIF tests. The excimer laser produced laser pulses of energy 165mJ, of approximately 20ns duration. The first and second planes of measurement (radial measurements) required the laser sheet to be directed through the side window, parallel with the injector surface, spaced 5mm and 10mm away from the injector surface respectively. The laser sheet was 37mm in height, and approximately 0.15mm wide in the measurement region. The visible fluorescence was imaged through the rear window using a Princeton Instruments ICCD camera with a 50mm f1.2 Nikon lens.

The third and fourth planes of measurement (axial measurements) required the laser sheet to be directed through the exhaust window. The laser sheet was 46mm in height, and approximately 0.25mm wide in the measurement region immediately downstream of the injector.

Results and Discussion

Figure 1 (a) and (b) shows false colour images of the mean fluorescence obtained from (a) the naphthalene seed in the fuel vapour and spray, and (b) from the ppo seed in the fuel spray, along the combustor axis centering on the middle of the central injector. The spray cone angle observable from Figure 1(a) is approximately 80 deg, while the spray cone angle observable from Figure 1(b) is approximately 110 deg. This is a notable difference showing how the different fuel fractions comprising the kerosene behave spatially.

Figure 2 shows a false colour image of the radial fuel spray distribution obtained from the mean ppo fluorescence determined 10 mm downstream of the injector face. The image demonstrates the anisotropy associated with the counterflow air jets, and the placement of the fuel spray.

References

[1] Lefebvre, A.W., *Gas Turbine Combustion*, 2nd Edition, McGraw-Hill, 1999, pp243 – 250.

[2] eds. K. Kohse-Hoinghaus and J. Jeffries, *Applied Combustion Diagnostics*, Taylor and Francis, 2002, Chapter 15.

Figures

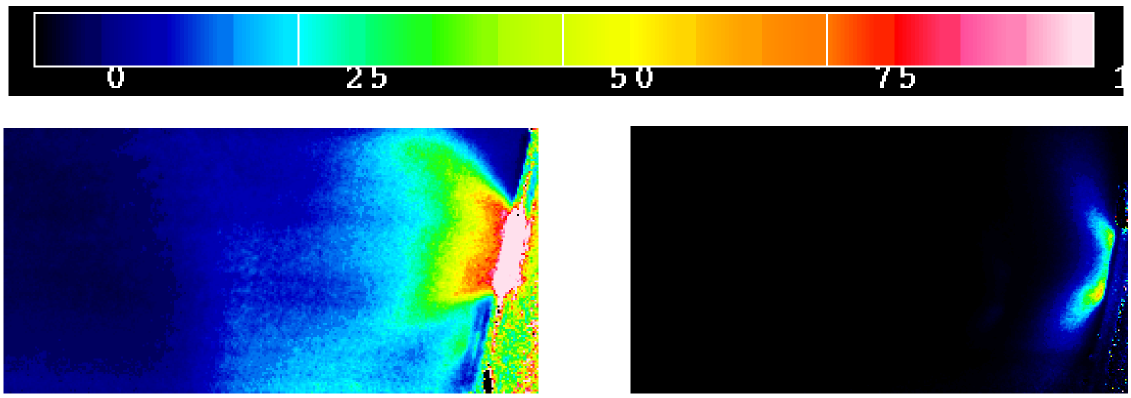

Figure 1 (a): mean naphthalene fluorescence in fuel spray, (b) mean ppo fluorescence in fuel spray

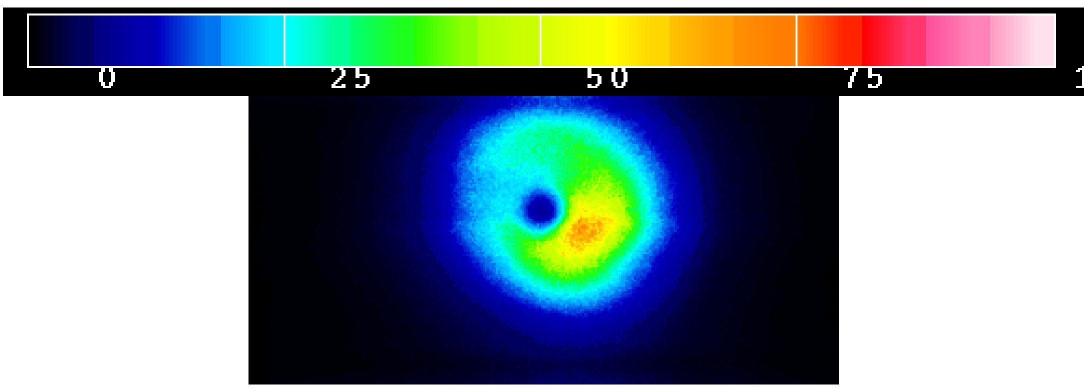

Figure 2: Radial fuel distribution obtained 10 mm downstream of the injector.