Two-dimensional imaging of soot volume fraction and OH in turbulent jet diffusion flames spanning low to high mixing rates

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Simultaneous planar measurements of laser-induced incandescence (LII) and Laser-Induced Fluorescence of OH radical were carried out in turbulent jet flames from a simple jet, precessing jet and bluff body burner firing natural gas. These flames span a wide range of global mixing rates and sooting characteristics, and are selected because measurements of total NOx emissions, radiant fraction and global residence time are available. The paper focuses on the choice of experimental conditions required to obtain reliable measurements. However it also discusses key differences in the flames that are obtained.

Introduction

Soot formation and destruction in flames is of great significance due to its role in radiative heat transfer and hence its effect on flame temperature. The development of the Laser Induced Incandescence (LII) technique has enabled experimentalists of obtaining instantaneous two-dimensional images of soot volume fraction in turbulent environments with good temporal and spatial resolution. However the unsteady nature of these flames, combined with the coupled dependence of temperature, radiation, mixing rates and soot volume fraction mean that a detailed understanding also requires simultaneous information of other parameters. Unfortunately such simultaneous measurements are much more difficult in flames containing soot than in clean flames. This is because the scattering from soot particles and the fluorescence from soot precursors contaminate the signal used in the measurement of other parameters.

The aim of the present investigation is to image the location of soot sheets relative to the high-temperature reaction zone on an instantaneous basis. The OH radical, which forms on the fuel-lean side of the high-temperature zone, is deemed to be a reasonable marker for this purpose. Hence, measurement of LII is performed simultaneously with imaging of OH by laser Induced Fluorescence (LIF). The burners selected for the investigation are a simple jet flame, a bluff body flame, which is highly strained, and a precessing jet flame which produces a low strain flame dominated by buoyancy. These span a wide range of mean and instantaneous soot volume fraction at constant total heat output, and have practical relevance [1].

Experiment

LII imaging was conducted using the fundamental from a Nd:YAG laser (1064 nm) to avoid any interference of PAH LIF from soot precursors. The IR laser beam was expanded into a slightly diverging sheet of 85 mm width and a thickness of ~400 µm. This configuration was chosen to maximise the width from a 50 mm lens to facilitate the calculation of soot sheet dimensions, while ensuring that all of the sheet remained within the “plateau region” of the LII fluence curve. The OH radicals were excited with a 282.323 nm sheet from a tuneable Nd:YAG pumped-dye laser producing ~3 mJ/pulse. The two beams were carefully aligned to pass through the same optical train, although the wavelength dependence of the optics means that UV sheet is slightly larger and thinner than the IR. The LII and OH signals were collected on two intensified gated CCD cameras positioned diametrically opposite and perpendicular to the plane of the overlapped laser sheets. To reduce the interference of the OH signal from scattering, a narrow band interference filter with a centre wavelength at 310 nm was used in combination with a long pass glass filter with a cut-off wavelength at about 295 nm, A F1.2 UV lens was used to provide a strong OH signal. Both signals were detected with a gate width of 50 ns, with the LII delayed by 200 ns from the OH.

The paper will report on an assessment of the effects of soot volume fraction and Reynolds number on beam steering for both wavelengths. Since both diffraction and scattering are wavelength dependent, these effects are different in the two sheets, which affects the spatial coincidence of the two sheets, degrading spatial resolution.

The paper will also report briefly on the range and combinations of filters and fuels assessed in seeking to obtain a good OH signal. The simultaneous measurements become more difficult as soot volume fraction is increased due to the combined effects of increased scattering and an apparent reduction in OH concentration. This apparent reduction is presumably due to the combined effects of reduced temperature and modified chemical interactions.

References

1. Qamar, N.H., et al., Proc. Combust. Inst. **30**: 1493-1500 (2005).