Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Proceedings of the Combustion Institute 30 (2005) 727–734
Proceedings of the Combustion Institute
www.elsevier.com/locate/proci

Measurements and inverse calculations of spectral radiation intensities of a turbulent ethylene/air jet flame

Yuan Zheng, Jay P. Gore*

Maurice J. Zucrow Laboratories, School of Mechanical Engineering, Purdue University, West Lafayette, IN 47907, USA

Abstract

Fast (6250 Hz) line-of-sight measurements of infrared spectral radiation intensities (I_λ) from a luminous flame and a new deconvolution technique for the estimate of local scalar properties using inverse radiation calculations are reported. Time series data of I_λ for one diametric and nine chord-like radiation paths in a representative horizontal plane were measured. Statistical properties of I_λ, including mean, root mean square (rms), probability density function, autocorrelation coefficient, and power spectral density, were obtained from the time series data. The measured statistical properties of I_λ at two representative wavelengths, which are dominated by carbon dioxide (CO_2) and soot radiation, respectively, are reported. The autocorrelation coefficient data show large negative loops with repeatable zero crossings at 20 ms and minimum values as low as −0.2 at 30–40 ms. Radial distributions of mean and rms CO_2 mole fractions and temperatures were estimated using inverse calculations of mean I_λ at two different wavelengths dominated by CO_2 radiation in conjunction with the relationship of these quantities to mixture fractions. Soot volume fraction distributions were also estimated using inverse calculations of mean I_λ at a wavelength dominated by continuum soot radiation. The estimated local mixture fraction distributions were in reasonably good agreement with sampling data from similar flames. The calculated mean I_λ from 1.4 to 4.8 μm other than those used in the inverse calculations matched the experimental data well. The present method provides non-intrusive measurements of major gas species and temperature statistics in turbulent soot containing flames not accessible to other optical diagnostics.
© 2004 The Combustion Institute. Published by Elsevier Inc. All rights reserved.

Keywords: Flames; Non-intrusive diagnostics; Radiation; Turbulence

1. Introduction

Turbulent flows and luminous flames are commonly encountered in unwanted fires and industrial furnaces, where thermal radiation is the dominant heat transfer mode. Time series measurements of line-of-sight spectral radiation intensities (I_λ) contain detailed albeit convoluted information about participating scalar properties and their statistics in combustion environments. Recently, Zheng et al. [1,2] obtained comprehensive I_λ data on standard turbulent non-luminous flames [3] using a fast infrared array spectrometer (FIAS). The evaluations of molecular band radiation models and turbulence–radiation interaction effects were facilitated by the existence of a detailed scalar database from Sandia [3]. However, similar scalar property databases are not available

* Corresponding author. Fax: +1 765 494 9321.
E-mail address: gore@ecn.purdue.edu (J.P. Gore).

1540-7489/$ - see front matter © 2004 The Combustion Institute. Published by Elsevier Inc. All rights reserved.
doi:10.1016/j.proci.2004.08.255

for luminous soot containing flames and in fact the laser-based technologies used at Sandia require soot free flames. Few techniques such as cohesive anti-Stokes Raman spectroscopy may work for luminous flames but have certainly not been applied to heavily sooty flames such as ethylene/air and acetylene/air.

Measurements of soot volume fractions and temperatures in turbulent luminous flames have relied on intrusive optical sampling probe measurements [4–6]. Measurements of soot volume fractions using laser induced incandescence have been reported by others [7–9]. However, optical measurements of carbon dioxide (CO_2) concentrations using intrusive local emission measurements in luminous turbulent flames are not available except [10]. The availability of fast infrared array spectrometers and recently developed algorithms for spectral tomographic inversion allow the extension of this technique to simultaneous measurements of gas phase temperature and CO_2 concentrations. These extensions of scalar statistics and fast I_λ measurements to turbulent luminous flames can provide useful information for many engineering applications.

The FIAS acquires I_λ at 80 wavelengths (λ) at a scanning rate of 6250 Hz [1,11], and therefore time scales longer than 0.3 ms can be resolved. These unique features of FIAS provide good potential for the reconstruction of multiple scalar properties of turbulent flames using inverse I_λ calculations. Using tomographic reconstruction techniques, Best et al. [12] obtained distributions of temperatures and species (soot, carbon dioxide, and water vapor) concentrations in a round laminar ethylene/air flame. Measurements and inverse calculations of emission and transmission were conducted by these authors [12] at multiple wavelengths from 1.5 to 5 μm. In round turbulent jet flames, the distributions of instantaneous scalar quantities are no longer axi-symmetric. The distributions of statistical scalar properties, however, are still axi-symmetric. Zheng et al. [2] utilized this fact and reconstructed integral length and time scales of scalar fluctuations in non-luminous turbulent flames using inverse calculations of root-mean-square (rms) and autocorrelation coefficient of I_λ. Extensions of multi-wavelength tomographic inverse radiation calculation to turbulent luminous flames are very interesting, although more challenges are expected owing to the existence of soot particles.

In turbulent combustion environments, the mean radiation quantities are determined not only by the mean scalar quantities but also by their fluctuations. This is the result of turbulence–radiation interactions (TRI) as referred in the literature [13,14]. Thus, inverse calculations of mean I_λ at multiple wavelengths can be used to estimate both mean and fluctuating scalar properties provided that the effects of TRI are treated appropriately. To account for TRI in I_λ calculations, two-time/two-point scalar statistics are generally required [1]; therefore, the computations are more complicated than those utilizing only one-point statistics. Fortunately, computational studies on small-size turbulent non-luminous flames [15,16] indicated that the use of one-point statistics may be sufficient for mean I_λ calculations. Based on this, it is conjectured that mean I_λ calculations adapting one-point scalar statistics are also applicable to small turbulent luminous flames.

Motivated by this, the present study consisted of the following:

1. Time series of I_λ for diametric and many chord-like radiation paths were measured in a horizontal plane of a round turbulent ethylene/air jet flame using the FIAS. Mean, rms, probability density function (PDF), autocorrelation coefficient ($\rho(\Delta\tau)$), and power spectral density (PSD) of I_λ were obtained from the time series data. Experimental investigations of mean and PDF of I_λ for luminous turbulent flames were reported in the literature [17,18]. These studies, however, were limited to diametric paths only.
2. Local mean and rms temperatures and CO_2 mole fractions were estimated adapting a tomographic inversion in conjunction with the relationship of these quantities to mixture fraction (Z). The calculated mean I_λ at two different wavelengths (4.47 and 4.51 μm) dominated by CO_2 radiation were used to fit the measured mean I_λ iteratively for each radiation path from the flame edge to the axis.
3. The local soot volume fractions were estimated using tomographic inversion of emission intensities at 1.99 μm in conjunction with a form for the local relationship between soot volume fractions and mixture fractions.
4. Mean I_λ for all the radiation paths at 80 wavelengths were finally calculated by integration of the radiative transfer equation (RTE) including self-absorption. The scalar properties for the mean I_λ calculations were determined approximately using the local mean and rms mixture fractions along the radiation paths, in conjunction with presumed one-point PDFs of Z estimated from the CO_2 concentrations and temperatures.

2. Experimental method

The turbulent ethylene/air jet flame under consideration has a nominal Reynolds number of 15,200 based on exit velocity, cold gas properties, and fuel injector diameter. The jet burner, on which the ethylene (C_2H_4) flame is stabilized, is a long tube with an inner diameter (D) of 8 mm ta-

Download English Version:

https://daneshyari.com/en/article/9637396

Download Persian Version:

https://daneshyari.com/article/9637396

Daneshyari.com