Combustion and Flame 156 (2009) 2264–2275

Contents lists available at ScienceDirect

Combustion and Flame

journal homepage: www.elsevier.com/locate/combustflame

Measurements of soot, OH, and PAH concentrations in turbulent ethylene/air jet flames

Seong-Young Lee [a,*], Stephen R. Turns [b], Robert J. Santoro [b]

[a] Department of Mechanical Engineering-Engineering Mechanics, Michigan Technological University, 1400 Townsend Drive, Houghton, MI 49931, USA
[b] Department of Mechanical and Nuclear Engineering, Pennsylvania State University, University Park, PA 16802, USA

ARTICLE INFO

Article history:
Received 28 February 2009
Received in revised form 4 June 2009
Accepted 4 September 2009
Available online 30 September 2009

Keywords:
Soot
OH
PAH
Zone thickness
Interaction length
Turbulent flame
Laser diagnostics

ABSTRACT

This paper presents results from an investigation of soot formation in turbulent, non-premixed, C_2H_4/air jet flames. Tests were conducted using a H_2-piloted burner with fuel issuing from a 2.18 mm i.d. tube into quiescent ambient air. A range of test conditions was studied using the initial jet velocity (16.2–94.1 m/s) as a parameter. Fuel-jet Reynolds numbers ranged from 4000 to 23,200. Planar laser-induced incandescence (LII) was employed to determine soot volume fractions, and laser-induced fluorescence (LIF) was used to measure relative hydroxyl radical (OH) concentrations and polycyclic aromatic hydrocarbons (PAHs) concentrations. Extensive information on the structure of the soot and OH fields was obtained from two-dimensional imaging experiments. Quantitative measurements were obtained by employing the LII and LIF techniques independently. Imaging results for soot, OH, and PAH show the existence of three soot formation/oxidation regions: a rapid soot growth region, in which OH and soot particles lie in distinctly different radial locations; a mixing-dominated region controlled by large-scale motion; and a soot-oxidation region in which the OH and soot fields overlap spatially, resulting in the rapid oxidation of soot particles. Detailed quantitative analyzes of soot volume fractions and OH and soot zone thicknesses were performed along with the temperature measurement using the N_2-CARS system. Measurements of OH and soot zone thicknesses show that the soot zone thickness increases linearly with axial distance in the soot formation region, whereas the OH zone thickness is nearly constant in this region. The OH zone thickness then rapidly increases with downstream distance and approximately doubles in the soot-oxidation region. Probability density functions also were obtained for soot volume fractions and OH concentrations. These probability density functions clearly define the spatial relationships among the OH, PAH concentrations, the soot formation, and oxidation processes.

1. Introduction

The current interest in high-performance, low-emissions gas turbine and diesel engines underscores the need for research on soot formation processes. In these applications, soot formation is frequently a limiting factor in performance and operability. Although recent research has provided significant data concerning the basic mechanisms for controlling soot formation and destruction, many questions remain. In particular, there is the need to understand soot formation and destruction in turbulent, non-premixed combustion environments. Currently available data for turbulent, non-premixed flames are quite limited. This state of affairs results from the difficulty of making in situ measurements in an environment dominated by large fluctuations in the velocity field and the various scalars of interest, e.g., temperature and species concentrations. Such measurements, however, are of great interest for both combustion science and practical applications. Information on soot is critically needed to better understand the elementary combustion process. This information in turn can be applied to practical devices to reduce pollutant formation without compromising combustion efficiency.

Prior studies associated with soot measurements in turbulent diffusion flames sought to identify soot formation mechanisms under various conditions [1–8]. Many of these experiments, however, were conducted using line-of-sight extinction/absorption methods that result in a path integrated measurement.

To improve spatial resolution, planar imaging of laser light scattering has been used to obtain qualitative [9] and quantitative [10] characterization of the fluctuations, intermittency, and integral scales of the soot field within turbulent, non-premixed jet flames. However, two-dimensional laser light scattering methods can not

* Corresponding author. Address: Department of ME-EM, Michigan Technological University, 802 R.L. Smith Building, 1400 Townsend Drive, Houghton, MI 49931-1295. Fax: +1 (906) 487 2822.
E-mail address: sylee@mtu.edu (S.-Y. Lee).

0010-2180/$ - see front matter © 2009 The Combustion Institute. Published by Elsevier Inc. All rights reserved.
doi:10.1016/j.combustflame.2009.09.005