Proposed for Presentation at
The Annual Conference on Fire Research
Gaithersburg, MD, October 28-31, 1996

Absorption/Emission Spectroscopy Measurements of Soot Volume Fraction and Soot Emission in Large Fires*

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The hazard posed by a large, fully turbulent (i.e. > 1.3m diameter) hydrocarbon fuel fire is defined by the history of the net heat flux from the fire to the system of interest. Due to the large amounts of soot (~10-15% total yield, [1]) and the relatively low velocities (on the order of 1-10 meter/second [2]) which characterize these fires, heat fluxes incident on most systems of interest are primarily due to participating media radiative transport. It is therefore necessary for the temperature of the *media* (as opposed to the temperature of a thermocouple exposed to the media) and the media radiative properties to be known within a hemispherical region with a minimum diameter of 4 optical path lengths to determine the heat flux at a point in the fire. Radiative emission and absorption from small (10-100 nm), spherical soot particles are thought to dominate radiative transport within the flame zone of large fires. Radiative scattering (as occurs in highly agglomerated soot, [3]) and gas band emission and absorption (as becomes increasingly important for smaller flames [4]) are typically neglected. Although the radiative transport depends on the knowledge of soot absorption and emission within the fire, relevant data have not been obtained for large fires. Data are therefore needed to validate soot generation and combustion submodels presently employed in fire field model. Due to the turbulent nature of these environments, highly time-resolved measurements are required.

To satisfy these requirements, a new optical fiber-based soot probe has recently been developed at Sandia in collaboration with En'Urga, Inc. and Purdue University to perform highly-transient measurements of the soot extinction coefficient, soot emission temperature, and soot volume fraction. The fundamental technique has been employed previously [5] in laboratory scale fires. A description of the technique employed in large fires, as well as recently acquired data, are presented. These data lend unique insight into the actual soot radiative properties and temperature which could previously only be indirectly inferred from "grab samples" (which tend to suffer from low sampling rates and alteration of soot topography in transit) or estimated based on combined thermocouple temperature and heat flux data.

Soot extinction coefficients are determined by measuring the attenuation of laser light though a small, cylindrical (~1.2 cm dia. X 2.5 cm long) sample volume. The soot emission temperature is measured using the ratio of the intensities at the 900nm and 1000nm wavelengths. Soot volume fraction can be

*This work was supported by the Sandia Model Validation Project, the Sandia Engineering Sciences Research Foundation, and the Defense Nuclear Agency and was performed at Sandia National Laboratories, Albuquerque, NM, managed by Lockheed-Martin Corp. for the U.S. Department of Energy under Contract DE-AC04-94AL85000

obtained from the soot probe data in two different manners. By assuming that the soot particles are small and round (thought to be a reasonable assumption in the interior of the flame zone but presently not validated) the soot volume fraction can be determined directly from the soot extinction measurements and the tabulated soot indices of refraction [6]. The relative strength of the intensities at 900 and 100 nm can also be used to calculated the soot volume fraction subject to the same assumption, but also subject to the assumption that the temperature is uniform throughout the sample volume.

Presently, the soot diagnostic technique uses two water-cooled, insulated, probe heads equipped with collimating and focusing lenses and a nitrogen purge to avoid soot deposition. The two-probe system allows simultaneous stationary and traversing measurements to be performed for spatial distribution data to be inferred. Stainless-steel fiber optic bundles (100 m length, capable of being immersed in water for the last 25 m) transmit the signal to and from the probe head from portable (0.6 m X 1.0 m) sending and receiving optics boxes. Portable, rack-mounted signal processing hardware is employed in conjunction with a high speed data acquisition system or a portable lap-top computer which is used to digitize and store the data.

Newly acquired data for 5 m diameter pool fires obtained using this technique will be presented. These data render the following advances in our understanding of large fires:

- Unique characterization of soot radiative properties in large fires.
- Assessment of soot volume fraction as needed for comparison with soot generation and combustion models.
- Assessment of small-scale variations in soot temperature.
- Characterization of the differences inherent in thermocouple temperature and actual emission temperature.
- An assessment of the time scales associated with radiative emission for the purposes of assessing the effects of radiative turbulence in large fires.
- The time-resolved correlation between soot volume fraction and soot emission temperature.

Further studies are expected to focus on in-situ soot measurements in larger (18.9 m diameter) fires, fires which include the effects of winds, and in the vicinity of engulfed, objects. The end goal is to advance our understanding of the dominant physical phenomena and to improve the fidelity of fire simulations through physically-based models which are validated with full-scale data.

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