ABSTRACT

Title of Dissertation: MEASUREMENT AND SIMULATION OF SUPPRESSION EFFECTS IN A BUOYANT TURBULENT LINE FIRE

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An experimental and numerical study of turbulent fire suppression is presented. For this work, a novel and canonical facility has been developed, featuring a buoyant, turbulent, methane or propane-fueled diffusion flame suppressed via either nitrogen dilution of the oxidizer or application of a fine water mist. Flames are stabilized on a slot burner surrounded by a co-flowing oxidizer, which allows controlled delivery of either suppressant to achieve a range of conditions from complete combustion through total flame quenching. A minimal supply of pure oxygen is optionally applied along the burner to provide a strengthened flame base that resists liftoff extinction and permits the study of substantially weakened turbulent flames. The carefully designed facility features well-characterized inlet and boundary conditions that are especially amenable to numerical simulation.

Non-intrusive diagnostics provide detailed measurements of suppression behavior, yielding insight into the governing suppression processes, and aiding the development and validation of advanced suppression models. Diagnostics include oxidizer composition analysis and spray characterization measurements to determine suppression potential, flame imaging to quantify visible flame structure, luminous and radiative emissions measurements to assess sooting propensity and heat losses, and species-based calorimetry to evaluate global heat release and combustion efficiency. Novel generalized calorimetry formulations are developed and presented, which are applicable to both the diluted oxidizer and water mist configurations.

Nitrogen suppressed flames experience notable suppression effects, including transition in color from bright yellow to dim blue, expansion in flame height and structural intermittency, and reduction in radiative heat emissions. Mist suppressed flames experience similar structural intermittency and reduction in luminosity, but do not transition in color from yellow to blue. For both suppressants, the measured combustion efficiency remains close to unity, and only near the extinction limit do the flames abruptly transition from complete combustion to total extinguishment.

Measurements are compared with large eddy simulation results obtained using the Fire Dynamics Simulator, an open-source computational fluid dynamics software package. Comparisons of experimental and simulated results are used to evaluate the performance of available models in predicting flame extinction. Simulations in the present configuration highlight the issue of spurious reignition that is permitted by the classical eddy-dissipation concept for modeling turbulent combustion. To address this issue, simple treatments to prevent spurious reignition are developed and implemented. Simulations incorporating these treatments are shown to produce excellent agreement with the measured data, including the global combustion efficiency.