GRADUATE AERONAUTICAL LABORATORIES
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Excimer Laser System for Hydrocarbon-Radical imaging

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14. ABSTRACT

A semi-custom Nd:YAG pump and dye laser system was acquired for implementation of planar laser-induced fluorescence (PLIF) as one of the diagnostic techniques to be used in variable-pressure, hydrocarbon flame experiments. The research will include studies of hydrocarbons, both pure and mixtures, in a pressure range from 0.5 atm to 12 atm, through, but not limited to, two-dimensional imaging of CH and OH radical concentration profiles. The experimental data combined with numerical simulations will allow for the determination of flame properties such as ignition and extinction strain rates, laminar flame speeds, as well as the validation of chemical kinetic schemes in variable-pressure conditions.

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Abstract

A semi-custom Nd:YAG pump and dye laser system was acquired for implementation of Planar Laser Induced Fluorescence (PLIF) as one of the diagnostic techniques to be used in variable-pressure, hydrocarbon flame experiments. The research will include studies of hydrocarbons, both pure and mixtures, in a pressure range from 0.5 atm to 12 atm, through, but not limited to, two-dimensional imaging of CH and OH radical concentration profiles. The experimental data combined with numerical simulations will allow for the determination of flame properties such as ignition and extinction strain rates, laminar flame speeds, as well as the validation of chemical kinetic schemes in variable-pressure conditions.

1. Equipment description

The laser system is a semi-custom configuration. It was supplied by Spectra-Physics and is comprised of a pump Nd:YAG laser and a multi-stage dye laser.

1a. Pump laser

The Nd:YAG laser (Spectra-Physics, model PRO 290-50) includes the laser head, power supply, and remote-control module. The PRO 290-50 is configured for operation at 50Hz with an optics upgrade (NSI-5) for high-energy operation at 10Hz. It was supplied with the necessary dichroic separation optics to extract 532nm (beam-splitter assembly HIS-532) and 355 nm (beam-splitter assembly OP-355) output. Furthermore, it came with an internal water-cooled beam-dump (BD-6) and was upgrated with a high-efficiency harmonic generator (HG-4B1).

1b. Dye laser

The dye laser (Sirah for Spectra-Physics, model PrecisionScan-G) includes the laser head, two sets of associated dye circulators, and computer software for dye-laser control. The PrecisionScan-G was configured with single-grating broadband-linewidth resonator (LG), a preamplifier and one main amplifier; it was upgraded with a double-grating, narrow-linewidth sub-assembly (DG) and a second amplifier for high-energy operation, for a total of three dye cells.

The dye laser includes a wavelength-separation unit (WS-M), a frequency-conversion unit (basic FCU), and two harmonic-generation crystals for broad wavelength operation from 215 to 400nm (basic SHG 260 and upgrade SHG 220). Furthermore, the PresisionScan-G was upgraded with a closed-loop wavelength-stabilization system.

The system was ordered with one year of warranty. Components and upgrades were delivered, installed and tested (February 2000), except for the closed-loop stabilization system (delivery pending).

The original proposal specified an excimer-laser pump, followed by a dye laser. In reviewing possible laser systems for the intended experiments, it was decided that a higher-energy Nd:YAG pump laser, operating at either 10Hz, at high energy, or 50Hz, at lower energy, was better suited for the experiments. These two frequencies are well matched to the Cassini and KFS digital-imaging systems developed in-house under previous and current AFOSR support.[1] The difference in the acquisition cost was co-funded from AFOSR Grant F49620-98-1-0052.

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[1] DURIP Grant No. F49620-95-1-0199 and AFOSR Grant Nos. F49620-94-1-0353 and F49620-98-1-0052.

2. Research use of acquired equipment

The system described above is presently installed and tested. It is being integrated with an experimental configuration for the study of hydrodynamic, pressure, and chemical-kinetic effects on hydrocarbon flames whose goals include the validation of chemical-kinetic models of, initially, low-C hydrocarbon combustion.

Pending support for a major effort in this area (AFOSR proposal submitted), a parametric experimental study combined with extensive numerical simulations will determine the salient features of hydrocarbons throughout their ignition/extinction Z-curve. Flame properties such as ignition and extinction strain-rates as well as flame speeds will be determined as a function of:

- pressure (0.5 to 12 atm),
- fuel type,
- equivalence ratio, and
- ignition temperature.

Associated direct numerical simulations will be conducted along the stagnation streamline (1-D) for the full Navier-Stokes and energy equations, and will include detailed chemistry and detailed transport descriptions for multi-component chemically reacting systems. The experimental and numerical results will generate a comprehensive data library of flame properties of hydrocarbons at normal and elevated pressures that will allow for the validation of chemical kinetic schemes.

The recently acquired laser system is designed for operation at 258, 283, 308 and 389nm. These wavelengths have been documented [*e.g.*, Refs. 1-3] for UV excitation of hydrocarbon-flame radicals such as CH, OH and others in this wavelength range.

Two-dimensional imaging of CH and OH radical concentration profiles will be achieved with a detector system that will use 1024x1024 low-noise, high framing-rate CCD camera systems (Cassini or KFS, depending on laser pulse rate) developed in-house and undergoing continuous improvements.

In work in progress, preliminary experiments were performed to investigate several aspects of the future experimental effort. More specifically, computer-controlled software drivers were developed and tested extensively for an automated experimental procedure. This procedure is designed such that for each fuel type and fuel concentration, all information for ignition, extinction and flame propagation will be measured in a few seconds (20-40s). This approach will allow the time required to create a complete data base for each fuel to be reduced two to three orders of magnitude, when compared the traditional techniques employed, while providing excellent spatial and temporal resolution.

Sensitivity analysis was performed, through direct numerical simulations, to investigate the dependence of the spatial response of the radical concentration profiles to experimental parameters such as pressure, jet velocity, stagnation temperature, reduced kinetic rates, etc. It was found that there is a significant dependence to these characteristics.

Subsequently, theoretical and numerical calculations were performed for the optimization of the burner design and the accurate determination of hydrodynamic parameters such as velocity and velocity gradients, boundary layer and temperature corrections, etc. The experimental apparatus was optimized such that the overall accuracy of the acquired data will be in the range of 1-3%.

The optical and detection systems used for the radical imaging were designed and optimized to ensure the requisite resolution for the determination of the radical species concentration profiles.

Currently, exploratory experiments are in progress for the UV excitation of CH radicals in stagnation-type of flow of laminar hydrocarbon flames.

3. References

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3. Seitzman, J. M., Miller, M. F., Island, T. C. and Hanson, R. K., "Double pulsed imaging using simultaneous OH/acetone PLIF for studying the evolution of high-speed, reacting mixing layers," *Twenty-Fourth Symposium (International) in Combustion/The Combustion Institute,* 1743-1750 (1994).