

Final Report:

Diagnostics for Combustion and Ignition Enhancement Using the Non-Equilibrium Plasma

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14. ABSTRACT A Particle Imaging Velocimetry (PIV) system, an Imaged Intensified CCD (ICCD) camera (PI-MAX), an infrared laser diode, an oscilloscope, and a boxcar Integrator were purchased for the diagnostics of combustion and ignition enhancement using the non-equilibrium plasma and for the species measurements in non-premixed flames using JP-8 surrogate fuels. The systems were integrated into the existing Nd-YAG and Cobra-Stretch dye lasers, as well as the plasma assisted combustion burners. OH concentrations, O ₃ and O(¹ D) emissions, temperature distributions in plasma assisted combustion were measured by using the planar laser induced fluorescence, emission spectroscopy, and Rayleigh scattering. The flow field and flame speeds of surrogate fuel-air premixed flames were measured by using the PIV system. A new diagnostic method for simultaneous measurement of flow velocity and temperature by using PIV technique together with nanophosphor emissions is under development. The purchased experimental equipment significantly increased the experimental capabilities for quantitative measurements of intermediate species in plasma assisted combustion and contributed to the advancement of fundamental understanding of non-equilibrium plasma assisted combustion.					
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Itemized Expenses of Installed Equipment

<u>Item #</u>	<u>Equipment Description</u>	<u>Company</u>	<u>Cost</u>
1	PIV System	TSI Inc.	64,282.34
2	ICCD Camera (PI-MAX)	Princeton Instruments Inc.	49,424.70
3	High Energy Tunable Laser Mirror	CVI Laser LLC.	618.49
4	Oscilloscope/Multimeter	Newark In One	7753.50
5	Laser Diode and Driver	Thor Labs	4041.19
6	Photosensor Module	Hamamatsu Photonic Systems	921.86
7	Boxcar Integrator (Stanford Research Systems)	PCHem Labs	1450.00
8	Other Diagnostic Materials (lens, filters, mirrors)	N/A	4186.35
		Total	132,678.43

1. Particle Imaging Velocimetry (PIV) System (Item # 1)

The PIV system is utilized to measure the velocity field of a counterflow burner for both plasma-assisted combustion and JP-8 surrogate fuels. In order to have reliable experimental results for the counterflow configuration, it is necessary to have a uniform velocity profile at the nozzle exit. Figure 1 shows a photo of the counterflow burner integrated with heaters that allow the use of liquid fuels through the vaporization. A photo of the PIV system and the velocity profiles taken with this system are shown in Fig. 2. The evaluated result shows that the velocity profile at the nozzle exit has uniformity.

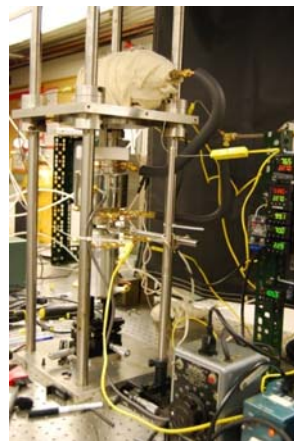


Figure 1: Direct photo of counterflow burner

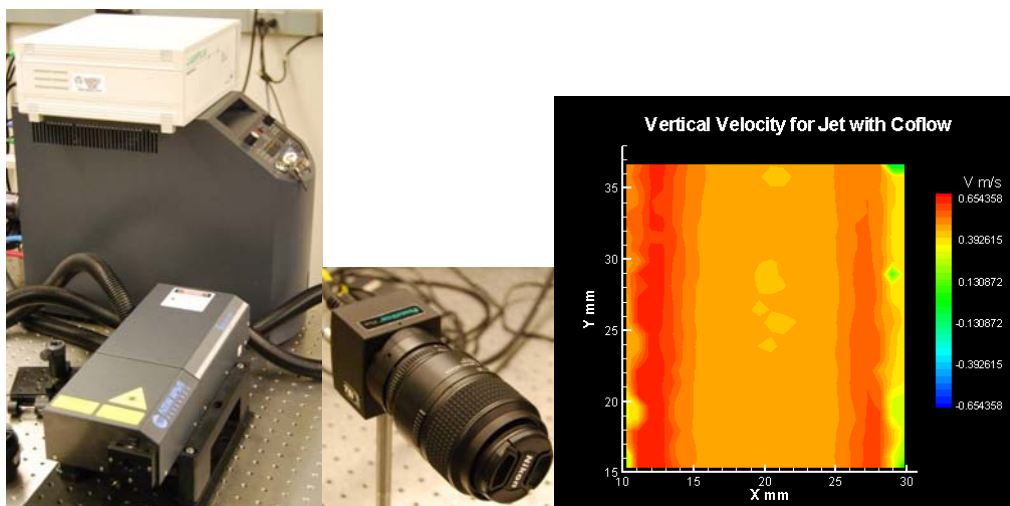


Figure 2: Direct photos of the PIV system and velocity profile measured by PIV in the counterflow burner

2. Hamamatsu Photosensor High Power Laser Diode Driver (Items # 5 and 6)

The diode laser is being used as a near-infrared light source for the excitation of upconversion nanophosphors. The luminescence of these particles can enable simultaneous measurements of flow velocity and temperature. The photosensor (Item # 6) is being used to collect the emission spectrum from the nanophosphors. The upconversion nanophosphors use host materials of Yttrium Oxide (Y_2O_3) and Sodium Yttrium Fluoride (NaYF_4) that are doped with Lanthanoids of Ytterbium (Yb), Thulium (Tm) and Erbium (Er).

3. PI-Max ICCD Camera (Item # 2)

OH PLIF

The Princeton Instruments PI-Max ICCD camera is used to image laser-induced fluorescence (LIF) in order to measure OH concentrations in plasma-assisted counterflow flames and surrogate fuel diffusion flames. To determine the proper laser excitation wavelength for OH LIF, a boxcar integrator (Item # 7) is integrated with the laser system. Figures 4 and 5 show, respectively, pictures of measured OH fluorescence from plasma-assisted counterflow diffusion flames and the comparison between measured and predicted OH concentrations. The camera also is used to understand the kinetic coupling between alkane and aromatic fuels via OH production and consumption in flames to construct a rigorous surrogate model for JP-8 fuels.

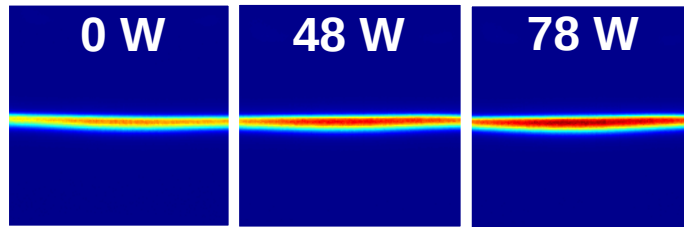


Figure 3: OH laser-induced fluorescence images of plasma-assisted counterflow methane-air diffusion flames at plasma powers of 0, 48, and 78 W, respectively.

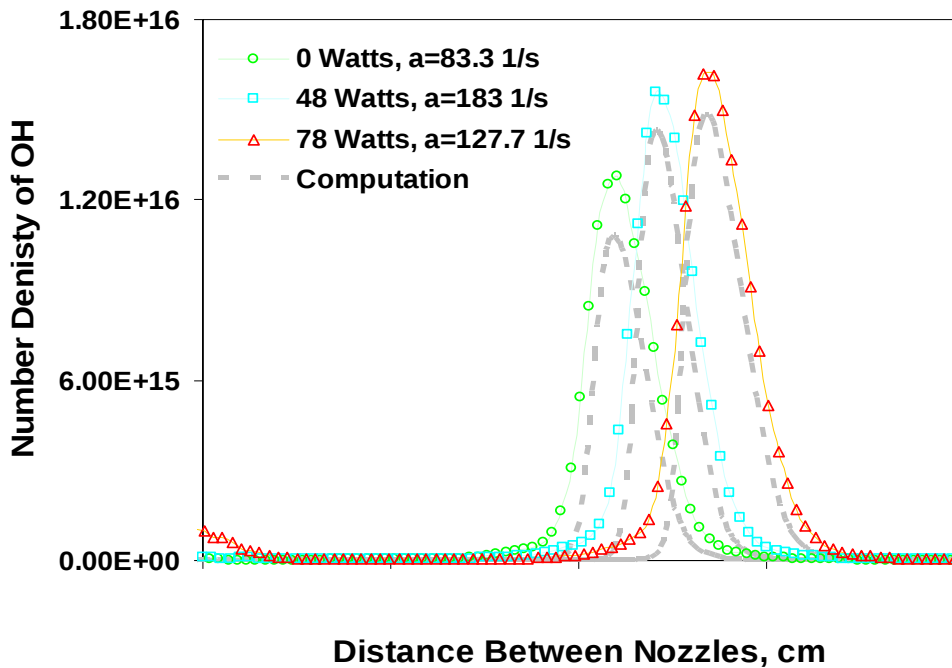


Figure 4: Comparison between measured and computed OH concentrations in plasma assisted counterflow methane-air diffusion flames

Plasma Emission

The PI-Max ICCD camera also was used to image the emission from plasma-discharged gases to identify relative concentrations and quenching rates of plasma-produced oxygen species, such as atomic and singlet oxygen. The emission of the plasma-discharged gases at different plasma powers is shown in Fig. 5, along with a plot of the intensities that were measured in the flow tube pictured on the right side of the figure from bottom to top.

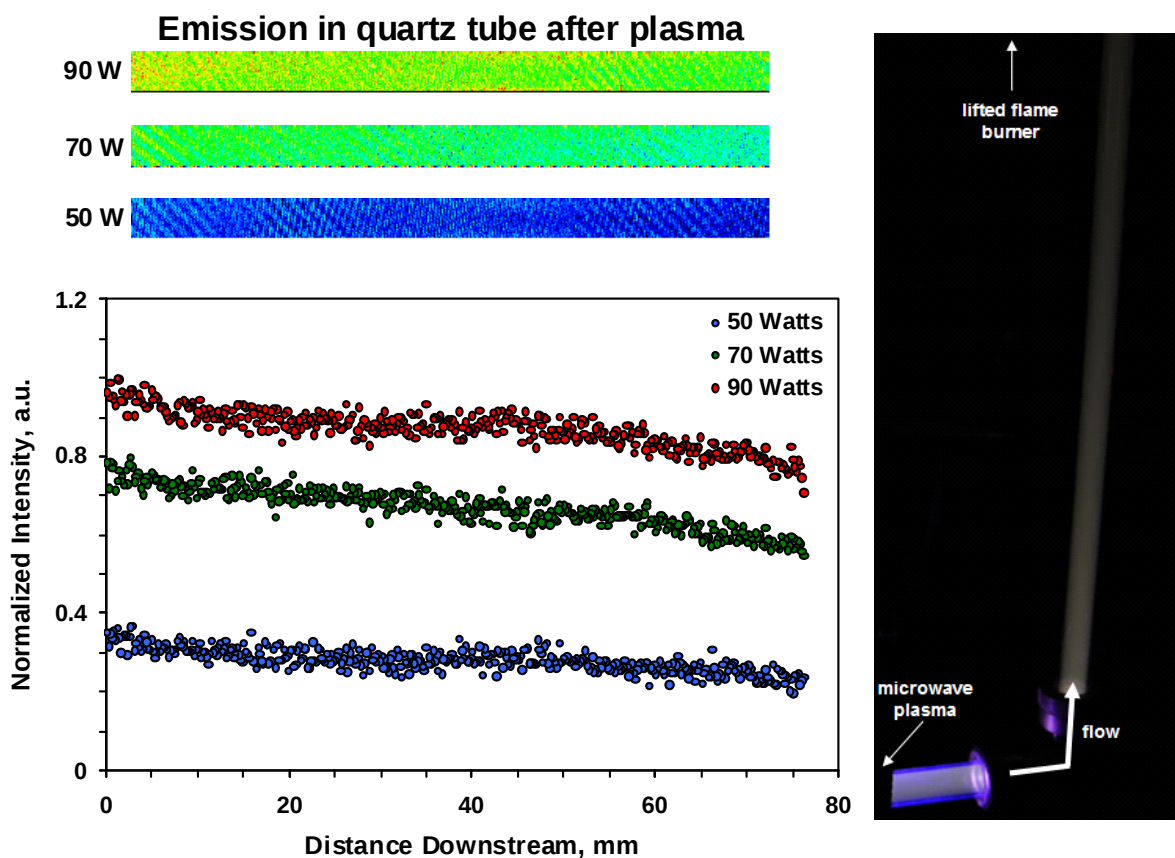


Figure 5: Plasma Emission in Afterglow

Rayleigh Scattering

To determine the temperature profile in the counterflow diffusion flame, Rayleigh scattering has been measured with the PI-MAX ICCD camera. The second harmonic of the Nd:YAG laser was used as a light source, and the high energy tunable laser mirrors (Item # 3) were utilized to align the laser beam and introduce the laser beam into the counterflow diffusion flame. Figure 6 shows a photo of the PI-MAX ICCD camera and experimental setup for Rayleigh scattering.

To calculate the temperature from the Rayleigh scattering, images were taken in both cold and reacting flows. After accounting for the background noise, the temperature profile can be evaluated by dividing these two images. Figure 7 shows the Rayleigh scattering images of cold flow, reacting flow, and the evaluated temperature profiles, respectively.

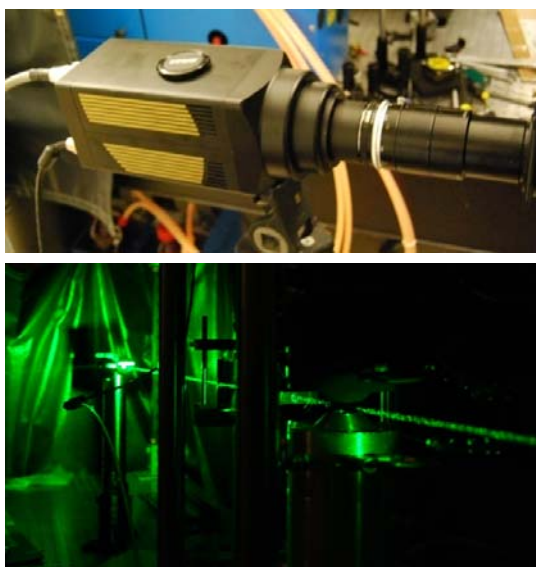


Figure 6: Photos of the PI-MAX ICCD camera and experimental setup for Rayleigh scattering

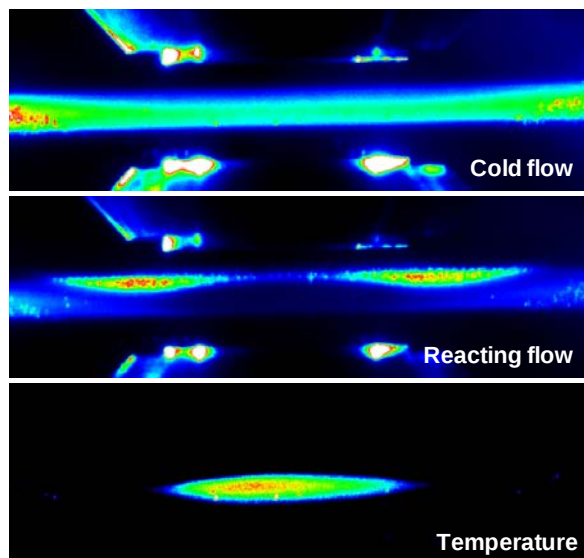


Figure 7: Rayleigh scattering images taken with the PI-MAX ICCD camera

4. Tektronix Oscilloscope and Photosensor (Item # 4)

The oscilloscope and photosensor are being used to measure the concentration of O_3 produced in a low-pressure plasma system. A one-pass absorption cell with plasma-activated oxygen/inert gas flow is used with a mercury light source on one side and a notch filter and photodiode (Figure 8). The reduction in light intensity transmitted through the cavity is a function of the number density and absorption cross section of O_3 . The output of the photodiode is read by the oscilloscope, and the concentration of O_3 in the system can be found through calculations using the absorption cross section of O_3 at the given excitation wavelength.

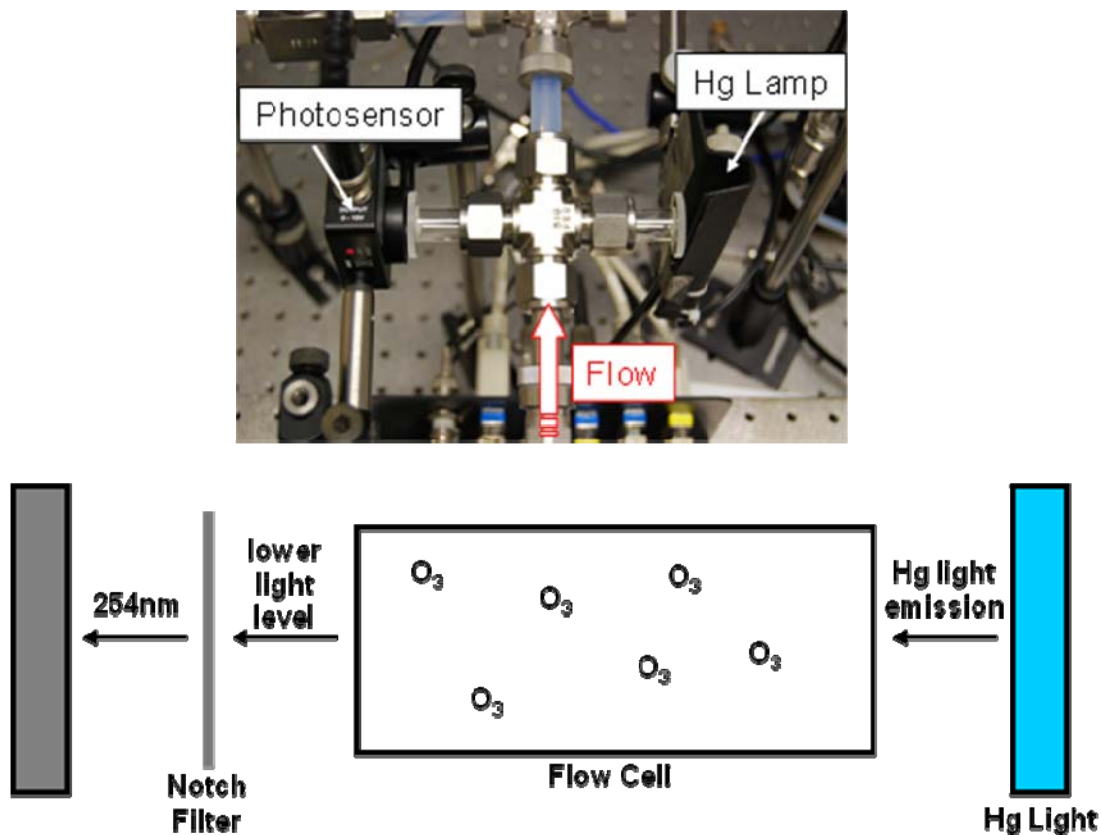


Figure 8: Ozone Absorption Cell System