Engineering Sciences
Thermal Science

Laser Diagnostics Reveal the Nature of Fire

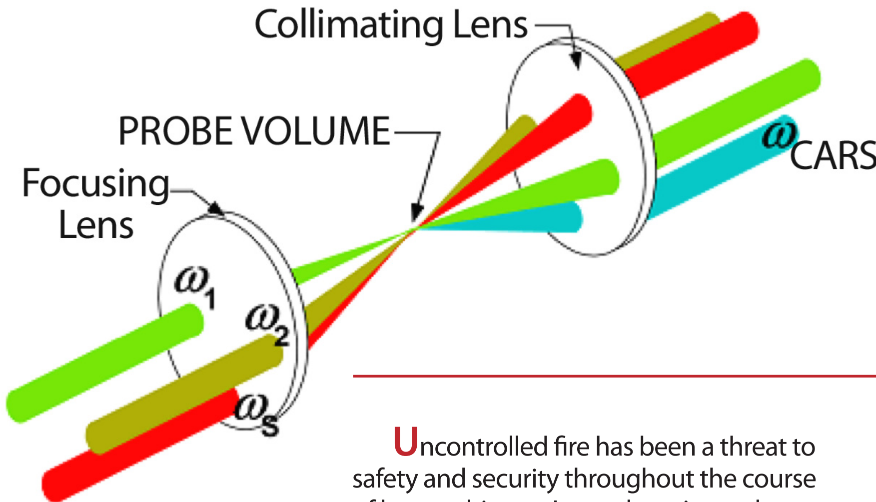

Figure 1: Arrangement of laser beams for a CARS measurement.

Temperature, composition and flow structure of fires

Uncontrolled fire has been a threat to safety and security throughout the course of human history. In modern times, the danger posed by a fire accident is a dominant threat to our nation's infrastructure and to the security of our weapon systems. At Sandia's Thermal Test Complex, scientists and engineers are utilizing the power of high-energy pulsed laser light to provide new insight into the nature of fire, with measurement times on the order of light speed, and measurement volumes comparable to the size of a human hair—extreme resolution which is needed to resolve the physics of the fundamental flame zones which are the "building blocks" of even the largest fires.

Coherent anti-Stokes Raman scattering (CARS) is a spectroscopic tool which provides simultaneous temperature and gas-concentration data by probing the energy contained in the vibrations and rotations of gas molecules in a fire. With CARS, three selected laser wavelengths, shown in red, green and yellow in Fig. 1, are mixed in a nonlinear fashion, resulting in the generation of a blue-shifted CARS signal beam in the measurement volume. The spectral content of the CARS beam reveals the presence of combustion gases as distinct peaks in the CARS spectrum, as shown in Fig. 2; the fire temperature and gas composition can be obtained from the shape and relative strengths of these peaks. For example, recent

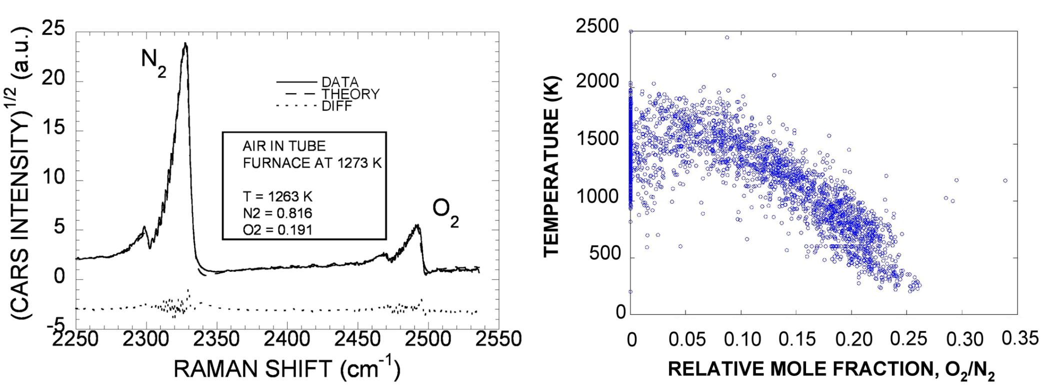

Figure 2: Left: CARS spectrum showing contributions from nitrogen and oxygen. Right: Temperature-oxygen correlation from a methanol fire.

For more information:

Technical Contacts:
Sean P. Kearney, Ph.D
505-844-6669
spkearn@sandia.gov

Timothy J. O'Hern, Ph.D.
505-844-9061
tjohern@sandia.gov

Science Matters Contact:
Alan Burns, Ph.D
505-844-9642
aburns@sandia.gov

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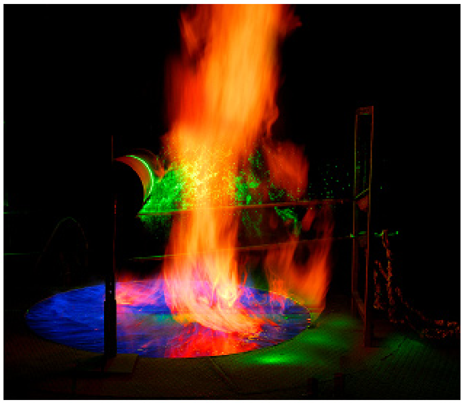

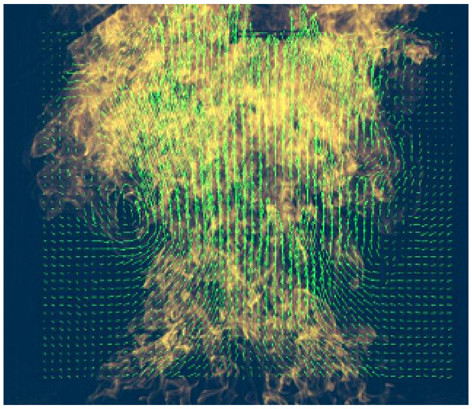

Figure 3: Left: PIV in a methanol fire. Green light from an Nd:YAG laser sheet can be seen scattering from PIV seed particles. Right: PIV-measured velocity field overlaid on visible image of soot emission from a methane fire.

experiments in a 2-m-diameter methanol pool fire revealed the correlation between temperature and oxygen content at a point in the middle of the pool (Fig. 2).

In order to reveal the nature of the complex turbulent flow field within a fire plume, Particle Image Velocimetry (PIV) is used. PIV provides a snapshot of the flow structure by tracking small, micron-scale particles which are introduced or "seeded" into the fire and follow the motion of the fire gases. The particles are illuminated for extremely short exposures to effectively "freeze" the particle motion using a 10-nanosecond laser light pulse that is formed into a two-dimensional light sheet. Laser illumination of particles in a 2-meter methanol fire is shown in Fig. 3. A picture of the velocity field is obtained by statistically correlating two successive freeze-frame particle images to track the particle motion between frames. A sample velocity field from a 1-m-diameter methane fire is also provided in Fig. 3, where the direction of gas motion is shown by green arrows whose length is proportional to the speed of the motion.

The high-fidelity experimental detail offered by these laser-diagnostic approaches is providing results which are used to validate the performance of advanced fire simulation tools being developed at Sandia. These state-of-the-art computer codes are used to perform high-consequence risk analysis for DOE weapon systems, military hardware and US critical infrastructure.

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