CARS temperature measurements in a turbulent gaseous diffusion flame

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CARS TEMPERATURE MEASUREMENTS IN A TURBULENT GASEOUS DIFFUSION FLAME

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A CARS (Coherent anti-Stokes Raman Spectroscopy) system for performing temperature measurements in turbulent flames is described, emphasising theory and potential problems. The experimental burner, a unusual form of an idealized industrial burner, generated axi-symmetric flows through a concentric tube arrangement, illustrated schematically in Figure 1. Air in the centre tube was ringed in a propane sheath, which itself was ringed in another air sheath. The Reynolds number of the centre air jet was 20,000, taken with respect to the inner pipe diameter. Preliminary CARS temperature measurements in this burner are presented both as averaged temperatures and as histograms.

To accurately fit theoretical and experimental CARS spectra in diffusion flames it is necessary to account for changes in the nonresonant susceptibility. CARS spectra taken near the propane injector exhibited a large nonresonant background and temperatures derived from these spectra, neglecting the variation in nonresonant susceptibility, were much higher than those obtained with thermocouples. To accurately fit theoretical and experimental CARS spectra it was necessary to vary the nonresonant contribution, particularly in the known fuel-rich zones of the flame. To accomplish this the theoretical spectra were stored in two parts so that individual CARS spectra can be reconstructed for any value of C, where C is the ratio of the N_2 mole fraction to the third order nonresonant susceptibility (in units of 10^{-15} cm 3/erg). For pure nitrogen C was set to 120 (its maximum value), while for air C=93. In stoichiometric combustion of propane/air C was 59 for the reactants and 70 for the products.

In the brush of the flame large temperature fluctuations were noticed using the thermocouple. To accommodate the large variation in CARS signals encountered in turbulent combustion it is generally necessary to extend the dynamic range of the intensified linear photodiode array (IPDA) detectors. The detectors, which have an analog to digit range of 16 bits or 64K ADC counts with a noise count of 1 to 2, exhibit nonlinear behaviour for signals > 10K counts. To use the region of high counts it is necessary to characterise the nonlinearity and correct for it in software.

Further increases in the dynamic range are possible by using a 10:1 beam splitter incorporated in the fibre-optic link between the CARS generation region and the CARS spectrometer. Using the two fibre tips as inputs to the spectrometer results in two CARS spectra side by side on the IPDA; one being 10 times the intensity of the other. For very large CARS signals, when the more intense spectrum is heavily saturated, the weaker signal can be analyzed.

With these improvements, single pulse CARS measurements have successfully been performed in the turbulent flame burner. An example of the CARS temperature measurements in histogram form is shown in Figure 2.

A further concern in CARS temperature measurements is the effect of spatial averaging in the CARS sample volume. Because the CARS intensity varies as the square of number density, a pocket of cooler gas in the CARS sample volume makes a much larger contribution to the total intensity than an identical region of hotter gas. This can lead to temperature biasing effects where the best-fit CARS temperatures could be much lower than a simple linear average temperature over the two regions. Since the CARS intensity varies as L^2, where L is the interaction length, if half the interaction region is filled with cold gas this will result in a CARS intensity that is 1/4 that expected from a uniformly filled sample region.

Preliminary results from an analysis of the CARS intensities as a function of temperature indicate that temperature biasing resulting from spatial averaging is not a serious problem in these flames. The observed dependence of experimental CARS intensities with temperature is shown to be in good agreement with that predicted for a uniformly filled sample region.

With the previously noted improvements to the CARS system single pulse CARS measurements have been analyzed to obtain the best-fit values of temperature and C. CARS measurements were made at five heights (20, 50, 80, 140, and 200 mm) from the burner centreline over the full extent of the flame. In the fuel rich regions of the flame the C value has been used to estimate the propane to nitrogen ratio.

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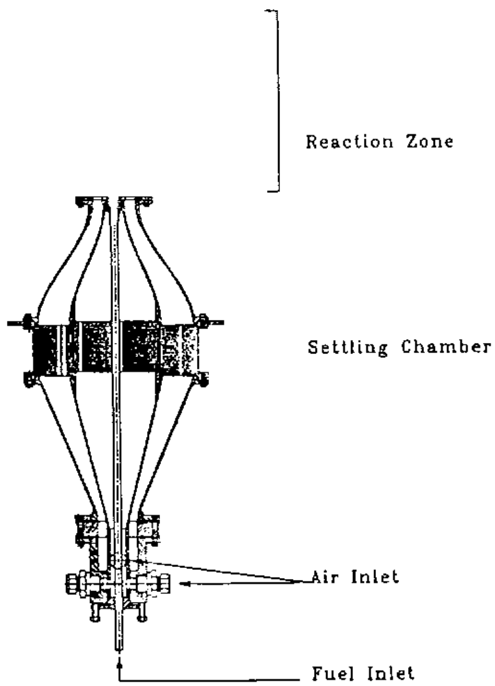

Figure 1 Schematic Diagram of Experimental Burner

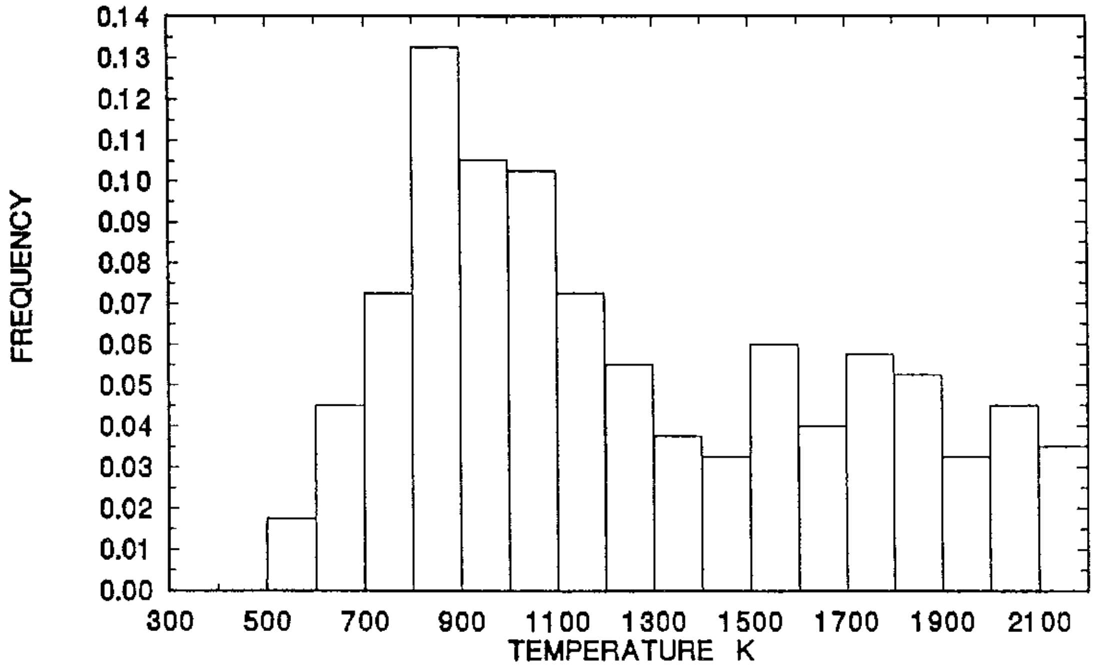

Figure 2 Temperature Histogram in Turbulent Flame Burner

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The Combustion Institute
Canadian Section

1991 SPRING TECHNICAL MEETING

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