Probing the heat during the PCCI beat: Determining PCCI engine temperatures using two-line thermometry

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Temperature is a key parameter for reaction progress during combustion, and as such its experimental determination has been a subject of considerable interest for many years. The aim of our present project is to study the 2-D temperature field in a realistic heavy-duty Diesel engine under the conditions of premixed charge compression ignition (PCCI) combustion. Two-line OH Laser Induced Fluorescence (LIF) thermometry will be used, in combination with spontaneous Raman scattering as an independent calibration. Here, we discuss the initial test measurements performed on a high-pressure high-temperature gas cell, and the selection of OH line pairs for thermometry. In addition, we will discuss Raman scattering temperature measurements that were carried out in a realistic engine.

Introduction

Over the years, laser diagnostics is widely used in combustion science, research and development to investigate transient phenomena without influencing the system under study by inserting probes and surfaces[1]. Laser-induced fluorescence (LIF) is frequently used for remote detection of concentration and temperature. Due to the relatively strong signals, high spatial and temporal resolution can be achieved. Within the duration of a single laser pulse (typically a few nanoseconds) volume elements in the sub-millimetre range can be observed. With illumination by laser light sheets extended two-dimensional cross-sections through the process under study can be excited and resulting signal light can be imaged on the chip of a CCD (charge-coupled device) camera. Because imaging techniques require strong signals, laser-induced fluorescence is most frequently used for this purpose.

Apart from LIF, linear or spontaneous Raman scattering provides a number of advantages for the diagnostics of combustion flames: it offers good spatial resolution; all molecular species with local abundances larger than 10 ppm can, in principle, be probed[2]; the relation between observed intensities and local molecular densities is linear, greatly simplifying abundance calibration by a single comparison to a known reference; and it covers a wide spectral range including the fingerprint of many molecular species using the same instrument within the same experiment, employing just one single laser at a fixed excitation frequency.

In our present work, we have used both LIF and spontaneous Raman scattering approaches for the quantitative local temperature field measurements both in a high pressure cell and in a realistic diesel engine, respectively.

Experiment and Results

In our first approach using LIF, temperatures can be obtained by performing excitation scans, whereby the laser is tuned across a series of absorption lines thereby probing the ground state rotational population distribution. For a pair of lines (two-line LIF), the relative ground state populations can be determined and related to temperature via the Boltzmann distribution. To this end several aspects, like Vibrational Energy Transfer (VET), Rotational Energy Transfer (RET), electronic quenching and absorption coefficients have to be taken into account. In addition, criteria for the selection of the set of peaks have to be included. First, the lines need to be isolated so that even at high pressures no overlap with neighboring peaks is present. Preferably, the two transitions should go to the same upper state to avoid errors due to differences in quenching. Finally the ground state rotational number N'' of the involved transitions should be between 2 and 13 [3].

The two-line LIF method is still under investigation. To test our method of temperature analysis, an optically accessible high-pressure cell in which temperatures of 1100 K and pressures of 5 MPa can be reached has been installed. In the cell, thermal dissociation of water vapor takes place thereby creating OH radicals. Using a thermocouple, placed into the cell as a reference, estimations of temperature errors of the two-line LIF method can be determined and further investigated. Currently the $Q_2(10)$ and $Q_1(11)$ lines, which have almost the same upper state, are under investigation. These lines have been observed in the test cell for pressures up to 0.5 MPa. An example of a spectrum for lower pressure (0.17 MPa) is given below (figure 1).

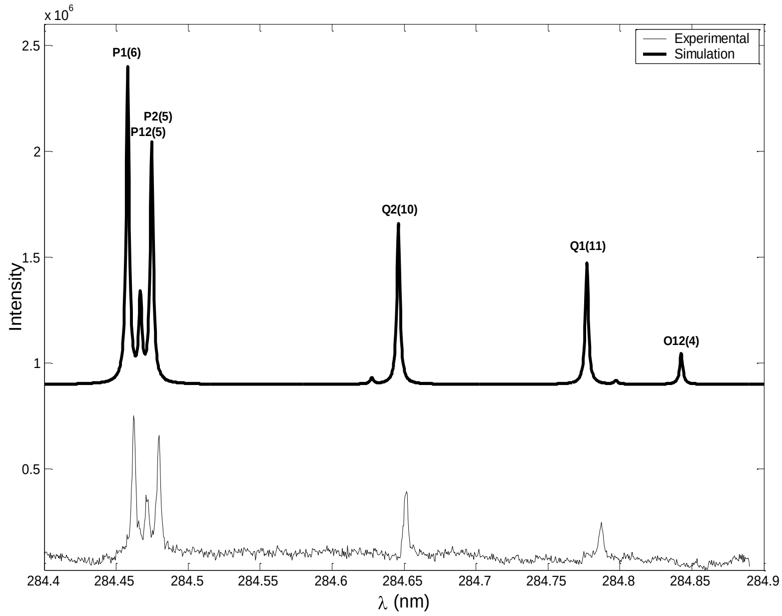

Figure 1: $Q_2(10)$ and $Q_1(11)$ lines observed in the test cell (P=0.17 Mpa, T=1064K).

In second approach, we have applied spontaneous Raman Scattering technique for quantitative temperature measurements in an optically accessible six-cylinder, heavy duty research engine for crank angles (CA) up to 30 ^{o} (BTDC and ATDC).

All our measurements have been performed using one cylinder of a heavy-duty Diesel engine (DAF Trucks, NL). A description of our optical research engine has been summarized in Ref [4]. An excitation wavelength of 532 nm was used to avoid fluorescence from trace lubricants and fuel compounds inside the engine. The Stokes and anti-Stokes spectra were recorded for compressed air without combustion. In addition, the fuel injector was also lifted to reduce elastic scattering from its tip. An averaged anti-Stokes and Stokes spectrum measured at top dead centre (TDC) is shown in figure 2. The temperature obtained from the signal ratio of these two is shown in figure 3.

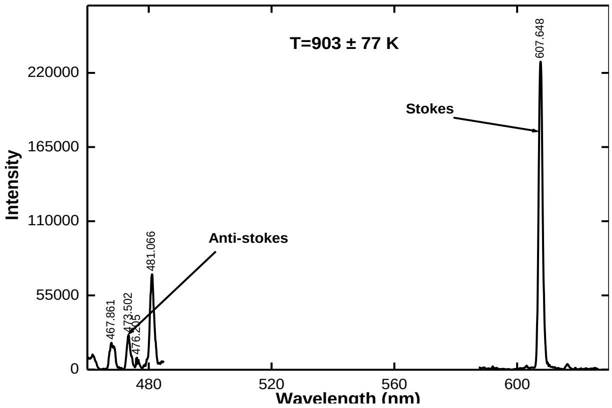

Figure 2: Averaged Raman spectrum measured at TDC. The resulting calculated temperature is 903±77K.

For different CA's, the measured quasi-local temperatures from the Raman spectra and the global temperature derived from pressure curves are compared and also shown in figure 3. An agreement of the temperature measurements using Raman and that obtained from the pressure curves is seen clearly up to 30 ^{o}CA. Further, we have observed a large discrepancy of temperature measurements from Raman scattering after 30 ^{o}CA (not shown in the figure). This could be due to the weak local strength of anti-Stokes signal which is difficult to observe after 30^o CA.

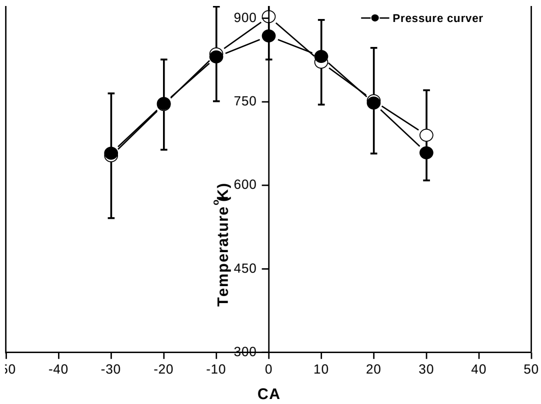

Figure 3: Comparison of Temperatures derived from Raman spectra and the pressure curves.

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