A new set-up for single-shot measurements in turbulent flames by spontaneous Raman scattering - application in high pressure cryogenic flames

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The purpose of the present study is to develop a new experimental set-up for single-shot measurements from Spontaneous Raman Scattering in view of investigating turbulent flames at atmospheric pressure and more specifically two-phase flames under very high pressures as encountered in the MASCOTTE test bench of ONERA. The MASCOTTE test bench of ONERA is a cryogenic propellant combustion facility where high pressure flames (up to 6 MPa) are obtained by feeding a single-element injector with liquid oxygen (LOx) and hydrogen or methane. This test bench constitutes a challenging configuration to test a laser diagnostic owing to the intense flame emission, the high refractive index gradients, the presence of droplets, and the confinement (small chamber with very thick windows).

Demonstration of ability of Spontaneous Raman Scattering (SRS) to provide quantitative measurements of major species concentration and temperature in flames has been shown from several years. The main drawback of this method is its poor efficiency due to small Raman scattering cross sections, leading to low signal-to-noise ratio (SNR), especially in flames where the molecular density is low and where the Raman scattering is embedded in flame emission. Another drawback is the interference from radiations induced by the laser like Laser Induced Fluorescence (LIF) or stimulated Raman scattering. Therefore investigation of turbulent flames where temporal and spatial resolutions of the measurement are required, remains a delicate application for spontaneous Raman scattering. Pulsed high-power lasers are commonly used to get round the difficulty induced by the small Raman scattering cross section and the associated low signal levels, and to get a correct temporal resolution. The use of such lasers brings a new difficulty in avoiding generation of optical breakdown and non-linear radiation, like stimulated Raman scattering, in the tight beam focusing used to obtain correct spatial resolution.

The experimental set-up proposed in the present work consists of a new laser source providing high energy while keeping a moderate irradiance and an original collection system allowing the removal of interfering lights. The Raman scattering is induced by a Nd:YAG laser at 532 nm. It is not the most efficient wavelength to enhance Raman signal, but for investigation in high-pressure flames of MASCOTTE, UV excitation is not reliable solution as interference sources are numerous in this spectral range and due to a very strong flame self-emission of high pressure flame in UV. The principal specification of this Nd:YAG laser lies in its pulse duration of 106 ns (FWHM) at 532 nm, obtained thanks to a long laser cavity. This long pulse obtained by the long cavity keeps optical specifications and flexibility of use of standard Nd:YAG lasers. The energy thresholds for laser breakdown and stimulated Raman scattering obtained with this new laser is almost ten times higher than with 8ns-width Nd:YAG laser. In high pressure cryogenic flames, SRS signal is embedded in various lights. Removing these background emissions is the key to quantitative analysis. Contrary to Raman scattering measurements, most of these parasite emissions are unpolarized. The polarization property of Raman scattering can be used to subtract unpolarized light by collecting simultaneously the two polarization components of light. A new system of collection is proposed to split the two polarization components of collecting light, at each laser pulse, with an extinction ratio of 5.10^5:1, using only one spectrograph and one camera. For signal detection the fast gating capacity of a 512x512 pixels genIII ICCD is preferred to a back-illuminated CDD to limit the collection of flame spontaneous emission thanks to short gates. The Raman lines of different major species are collected simultaneously on the camera linked to an imaging spectrograph.

The feasibility of single-shot measurements in air has been demonstrated and the applicability of the measurements with this set-up in very luminous two-phase flames has been evaluated. Measurements have been performed in H2-Liquid Oxygen (LOx) and CH4-LOx flames under 6 MPa at two locations: one upstream localized at the averaged radial location of the flame and the other downstream beyond the flame tip. At each laser pulse, two spectra are collected : the s-polarization spectrum contains both Raman (rotational H_2, vibrational H_2 or CH_4, vibrational H_2O, vibrational O_2) and interfering emissions and the p-polarization spectrum contains only the interfering emissions and rotational H_2 Raman lines. The result of the subtraction of the two polarization components leads to partial Raman spectra which contains the ro-vibrational Stokes of O_2, H_2O and H_2, without rot-H2 lines detected but removed by the subtraction of spectra. On upstream spectra the presence of liquid phase near the probe volume probably arises the contribution of interfering emissions. Measurements at downstream location in LOx/H_2 flames show that instantaneous SRS measurements are easier than at upstream position because noise level is weaker. Nevertheless the strong laser-induced background (LIF and LII) brings the identification of the species lines difficult on the spectra of CH_4/LOx combustion at 6 MPa.