

Raman spectroscopy

Citation for published version (APA):

Pelders, J. E. H., Patel, R., Nijdam, S., & Dam, N. (2019). *Raman spectroscopy: rovibrational temperature determination of a plasma assisted premixed flame*. Poster session presented at Combura, Soesterberg, Netherlands.

Document status and date:

Published: 10/10/2019

Document Version:

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

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Raman spectroscopy

Rovibrational temperature determination of a plasma assisted premixed flame

J.E.H. Pelders, R. Patel, N.J. Dam and S. Nijdam

Introduction

To improve the lean flammability limit and combustion stability of premixed methane flames, plasma can be applied. Non-equilibrium plasma effects the flame through thermal, chemical and aerodynamic mechanisms. The thermal mechanism can be quantified by in-flame temperature measurements using Raman spectroscopy.

Experimental setup

- A flat flame burner with a high voltage electrode in the surface, which creates a nanosecond micro-discharge plasma in the gas channels has been designed by Elkholy [1], see Figure 1.
- Raman scattering induced by a Nd:YLF laser beam at 527nm and is measured with an 2400 g/mm spectrograph and iCCD camera, see Figure 2.

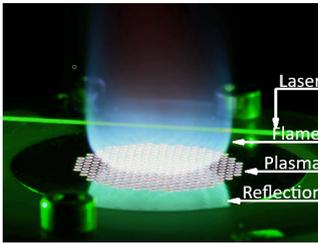


Figure 1: Flat flame burner

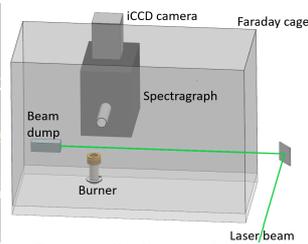


Figure 2: Optical setup

Temperature modelling

Raman spectrum intensity I can be modelled using a Boltzmann distribution (eq. 2) for the scattered population $N_{v,J}$ or a Treanor distribution (eq. 3) for a strong over-abundance of higher vibrational levels [2].

$$I_{v,J} = C \frac{h}{8\epsilon_0^2 \Delta\sigma_R} (\sigma_L - \Delta\sigma_R)^4 \frac{d\sigma_R}{d\Omega} N_{v,J} P \quad (1)$$

$$N_{v,J} = \frac{g_J \exp\left(-\frac{hcE_{vib}(v)}{kT_{vib}} - \frac{hcE_{rot}(v,J)}{kT_{rot}}\right)}{Q_{vib}(T_{vib})Q_{rot}(v, T_{rot})} N_T \quad (2)$$

$$N_{v,J} = \frac{g_J \exp\left(-\frac{hcE_{vib}(v=1)}{kT_{vib}} + \frac{hc(E_{vib}(v=1) - E_{vib}(v))}{kT_{rot}} - \frac{hcE_{rot}(v,J)}{kT_{rot}}\right)}{Q_{vib}(T_{vib}, T_{rot})Q_{rot}(v, T_{rot})} N_T \quad (3)$$

Symbol	Quantity	Unit	Symbol	Quantity	Unit
v	Vibrational level	-	$\frac{d\sigma_R}{d\Omega}$	Scattering cross-section	cm^{-1}
J	Rotational level	-	P	Laser power	W
C	Calibration constant	-	g	Degeneracy	-
h	Planck constant	J.s	k	Boltzmann constant	J/K
ϵ_0	Permittivity of vacuum	F/m	Q	Partition function	-
σ	Wavelength	nm	E	Internal energy of molecule	cm^{-1}

Results

The scattered emission of a $Q = 6$ L/min and $\phi = 0.83$ methane flame with and without a 3 kHz repetition rate plasma is measured in the centre of the flame at 3 mm

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above the burner, see Figure 3. Least squares fitting of the Boltzmann distribution model with variable T_{rot} and T_{vib} and measured Raman spectrum of N_2 has been used to determine the flame temperatures with and without plasma. The results are presented in Figure 4 and 5.

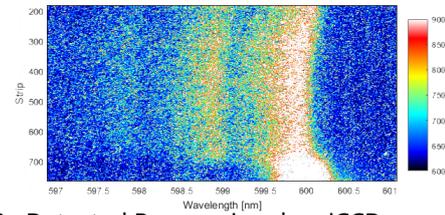


Figure 3: Detected Raman signal on iCCD camera of flame without plasma

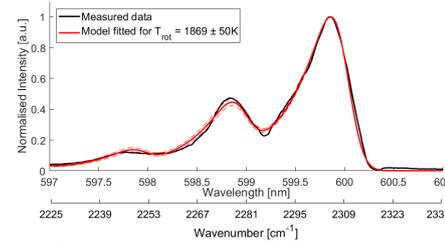


Figure 4: N_2 Raman spectrum of flame without plasma, captured in 1x1.000.000 gates

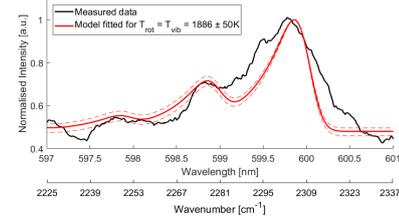


Figure 5: N_2 Raman spectrum of flame with plasma, captured in 5x100.000 gates

Conclusions

- With Raman spectroscopy temperature dependent scattered N_2 spectra can be measured and modelled using a Boltzmann and Treanor distribution with moderate accuracy.
- Signal quality is insufficient to measure significant change to the rotational and vibrational temperatures due to non-equilibrium plasma.

References

- [1] A.H.E. Elkholy et al (2018). Characteristics of a novel nanosecond DBD microplasma reactor for flow applications. *Plasma Sources Sci Technol.* **27**, 055014.
- [2] A. Lo et al (2012). Spontaneous Raman scattering: a useful tool for investigating the afterglow of nanosecond scale discharges in air. *Applied Physics B* . **107**, 229-242.

This work is part of the research programme "Making plasma assisted combustion efficient" with project number 16480, which is partly financed by the Dutch Research Council (NWO)