Raman spectroscopy

Citation for published version (APA):

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.
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Raman spectroscopy

Rovibrational temperature determination of a plasma assisted premixed flame

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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 527 nm and is measured with an 2400 g/mm spectrograph and iCCD camera, see Figure 2.

Temperature modelling

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

\[
I_{i,j} = C \frac{h}{8\varepsilon_0 \Delta \sigma} (\sigma_L - \Delta \sigma)^4 \frac{d\sigma}{d\Omega} N_{i,j} P
\]

\[
N_{i,j} = g_j \exp\left(\frac{\hbar E_{i,j}(\nu)}{kT_{rot}}\right) N_T
\]

\[
N_{i,j} = \frac{g_j \exp\left(-\frac{\hbar E_{i,j}(\nu)}{kT_{rot}}\right) + \exp\left(-\frac{\hbar E_{i,j}(\nu)}{kT_{rot}}\right)}{\exp\left(-\frac{\hbar E_{i,j}(\nu)}{kT_{rot}}\right) + \exp\left(-\frac{\hbar E_{i,j}(\nu)}{kT_{rot}}\right)} N_T
\]

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 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 \( \text{N}_2 \) has been used to determine the flame temperatures with and without plasma. The results are presented in Figure 4 and 5.

Conclusions

- With Raman spectroscopy temperature dependent scattered \( \text{N}_2 \) 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


This work is part of the research programme “Making plasma assisted combustion efficient” with project number 16488, which is partly financed by the Dutch Research Council (NWO).