Studies of carbon monoxide emission using Mid-IR QCLAS in methane flames stabilized by nanosecond pulsed discharges

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Atmospheric pressure Nanosecond Repetitively Pulsed (NRP) discharges are used for the stabilization of lean flames, which are less polluting. The understanding of plasma-flame stabilization mechanisms is a current challenge for the scientific community. Here, Mid-IR Quantum Cascade Laser Absorption Spectroscopy (QCLAS) at 2055.4 cm^{-1} was used to measure carbon monoxide densities emitted by plasma assisted methane-air flames. We discuss the challenges associated with the diagnostic techniques and we present measurements of carbon monoxide emissions with and without NRP.

Lean combustion is known to produce fewer pollutants, in particular lower NOx emissions. The drawback of lean combustions is the occurrence of flame instabilities that can lead to flame extinction, hence to unburned hydrocarbons (loss of energy) and the release of pollutants. Nanosecond repetitively pulsed (NRP) discharges have been successfully applied for lean flame ignition and stabilization [1,2]. The use of NRP discharges is a very promising approach, the discharge power being less than one percent of the flame power. Here, lean CH_4-air premixed flames were stabilized by the NRP discharges generated by 10-ns high-voltage pulses (5-10 kV) at pulse repetition frequencies of 30 kHz.

Carbon monoxide is one major combustion intermediate species. Its presence in the exhaust gases is an indication of combustion incompleteness. The first investigations on CO densities in post-flame with and without NRP discharge were performed using Mid-IR QCLAS (QMACS). The presence of high water density (main combustion product) at high temperature (500 – 2000 K) makes the CO detection by Mid-IR absorption techniques very challenging. Through spectral simulations, we have found that interferences of CO lines with water vapor lines are minimal for the CO rovibrational transition P_{21} of the fundamental band at 2055.4003 cm^{-1}. Another difficulty is definition of absorption length for open space experiments. In addition (absorption being a line-of-sight integration technique), analysis must take into account the presence of large temperature and density gradients over the laser beam path. To overcome these difficulties we applied an Abel inversion to the lateral absorbance measurements to obtain local absorption coefficients. Furthermore, we use the measured radial temperature profile to obtain the line strength radial profile, and finally this was used to convert the absorption coefficients into absolute densities. A typical radial CO density is shown in figure 1.

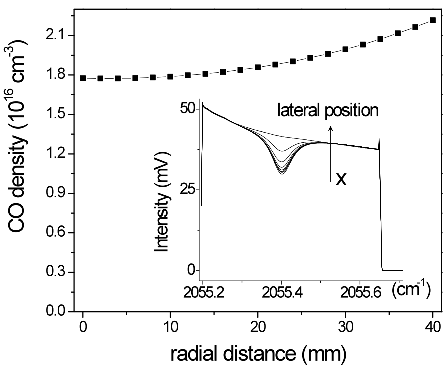

Fig. 1: *CO-density function of radial distance. The inset represents absorption lines at various lateral locations.*

A first set of experiments was performed in the burned-gas region, with the flame confined in a metallic tube of 50-cm length and 8-cm diameter. Single and multi-pass absorption systems were used. The amount of CO decreases by about three orders of magnitude in lean flames compared with rich flames. Using NRP discharges in lean conditions, no significant changes of CO density were observed, whereas in rich conditions an increase of about 20-30 % of the CO density was measured. The second set of experiments was performed for the same plasma and flame conditions without the confinement tube. Using NRP discharges the largest change was obtained for the lean condition at equivalence ratio of 0.7. A factor three increase of the CO density and gas temperature was measured. This demonstrates that the use of NRP discharges at the lean flammability limit enhances substantially the combustion degree.

References

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