THz spectroscopy through a high-pressure combustion system

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***Abstract*—We observe that the intensity of water vapour absorption lines in a combustion system containing a diffusion flame is highly dependent on the air flow rate. This implies that the recorded signal originates from (lower temperature) water vapour outside the volume of the flame. Seeding the flame enables water to be used as a fuel region marker.**

I INTRODUCTION and BACKGROUND

As an understanding of the complex processes of soot formation is required for optimization of combustion efficiency, there is a need to establish diagnostic techniques for the harsh environment of combustors burning liquid fuels. Heavily-sooted flames, produced by combustion at elevated pressures, are difficult to study using laser-based diagnostics as the flame is opaque to visible and near-infrared radiation. Reduced scattering at THz frequencies[1] offers the potential for chemical analysis via identification of high-energy rotational and low-energy vibrational absorption lines. Previous THz measurements through a long path-length of premixed propane-air flame, at atmospheric pressure, have been reported[2]. As well as lines characteristic of room-temperature water vapour[3], others were attributed to higher energy rotational states, and the temperature of the flame was calculated by analysis of their relative intensities. Extending the measurement range[4,5] allowed identification of rotational transitions from an excited vibrational level, with associated spectral line broadening. This paper presents results of terahertz time-domain spectroscopy (THz-TDS) measurements made through a stable, laminar diffusion flame from a burner that is contained within a water-cooled pressure chamber. Methane and air (co-flow) were delivered to the burner at a rate measured by flow meters. The TDS system is based on the generation of a THz pulse using an ultrafast (90fs) near-infrared laser, with coherent detection *via* electro-optic (EO) sampling. This arrangement provides THz radiation over the range 0.2-2.5THz with a maximum amplitude S/N of >2000. The 10mm diameter collimated THz beam is directed through the burner so that it passes through the flame region.

II. RESULTS

In agreement with previous reports, the relative intensities of water vapour lines from flame spectra differ from those of air at room temperature, as a consequence of the distribution of rotational state populations. However, it can be seen (Figure 1) that increasing the co-flow of air progressively reduces the absorption of THz radiation. Spectra calculated using the HITRAN 2004 database show (Figure 2) how the absorption coefficient of water falls by a factor of around 100 when the temperature is increased from 300K to 1800K.

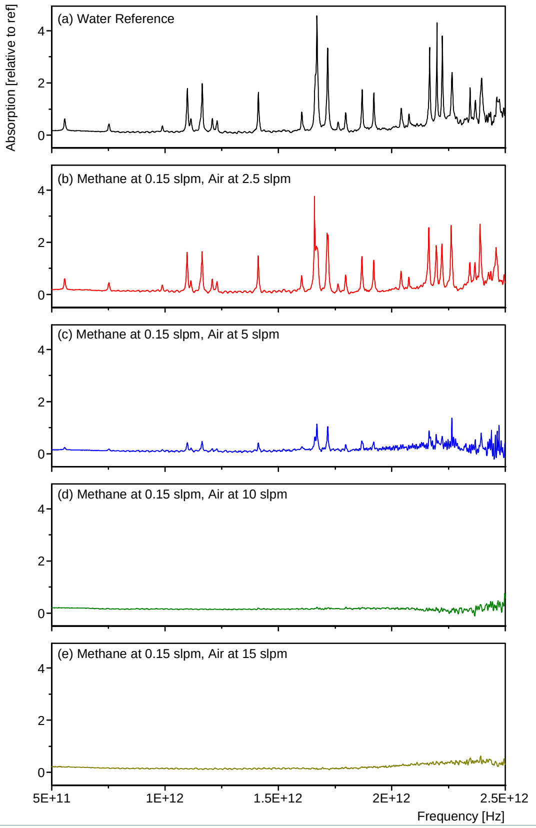

Figure 1: Absorption spectra (relative to purged reference) of (a) water reference and methane flames at 1 bar with a flow rate of 0.15 slpm and Air flow rates of ; (b) 2.5 slpm, (c) 5 slpm, (d) 10 slpm.

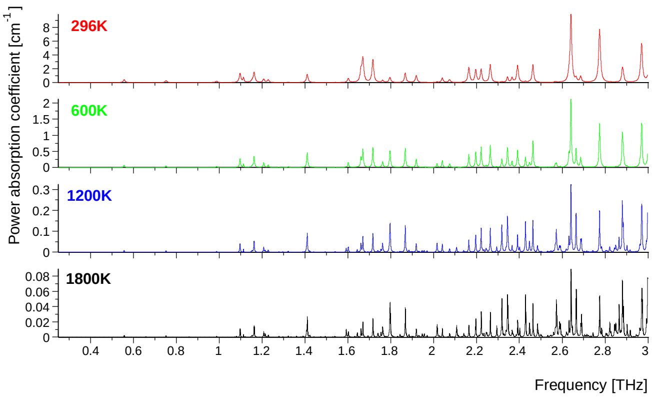

Figure 2: Calculated absorption spectra (using HITRAN) of water at 1 bar and temperatures of 296K, 600k, 1200K and 1800K.

Our results therefore suggest that the peaks recorded at lower air flow rates (2.5, 5 slpm) result from water that is outside the volume of the flame. At the higher flow rate (10 slpm) this

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lower temperature water is effectively purged from the THz beam path, leaving only higher temperature water that is more difficult to record with the current flame dimensions, water concentration, system bandwidth and detection sensitivity.

The fuel mixing process in a combustor is complex and not easily controlled; it is therefore important to understand the processes within the unburnt fuel-rich region of a flame. By seeding the fuel with excess water we observe that the spectra are more readily recorded at the higher air flow rates. Figure 3 shows the absorption spectra of a methane flame seeded with acetone containing 10% water.

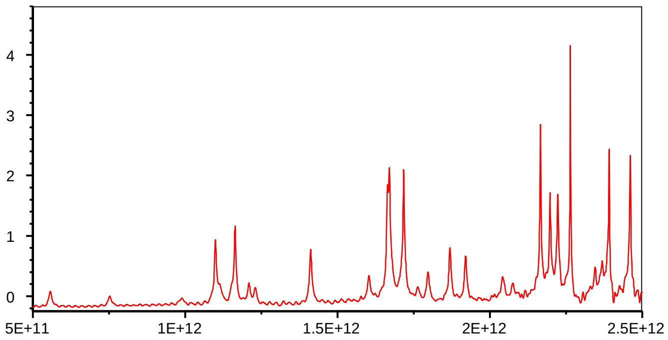

Figure 3: Absorption spectra recorded using a methane flame at 1 bar seeded with acetone containing 10% water with a flow rate of 0.15 slpm and air flow rate 15 slpm.

The results show no discernable peaks from acetone itself, but the water contained within the acetone is easily evident in the spectra, where no peaks are recorded for the same flame conditions, with no seeding.

We conclude that targeting higher frequency absorption lines (>3THz) using more powerful narrowband sources, will enable extraction of more specific combustion information. Also, for known conditions where water absorption does not occur, water can be used as a fuel region marker.

References

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