Low-Temperature Plasma-Assisted Combustion Kinetics of Methanol

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Abstract: A low-temperature plasma (LTP) coupled flow reactor investigates methanol pyrolysis and oxidation from 520-1250 K. Modelling studies confirm LTP-driven radical formation and synergistic NO effects accelerate fuel consumption, sustain overall reactivity and improve ignition. These findings highlight LTP's potential to enhance the operability of combustion devices using sustainable fuels.

1. Introduction

The effectiveness of low-temperature plasmas (LTPs) in enhancing the basic combustion phenomena is well-documented, with demonstrated improvements in ignition, flammability limits, chemical reactivity, flame stability, and emissions [1]. However, a complete understanding of the underlying processes responsible for such enhancements are not fully understood. Contributing factors include the production of radicals and electronically excited or charged species that increase chemical reactivity, electronic energy transfer leading to rapid heating, plasma-induced hydrodynamic instabilities, and ionic wind effects that accelerates flame development. For practical applications, fundamental understanding of the plasma coupling effects on chemical reactivity is critical to optimize LTP-based technologies for next generation combustion devices designed for sustainable fuels (e.g. biofuels, ammonia, hydrogen). In this study, purpose-built experiments and numerical modeling tools are employed to investigate LTP effects on enhancing the chemical reactivity of methanol.

2. Methods

A custom-built plasma-coupled flow reactor (PFR) is employed to investigate methanol pyrolysis and oxidation under near-isothermal conditions (520–1250 K, 0.5 bar). Plasma generation occurs through nanosecond-duration (~15 ns) high-voltage (~14 kV) pulses, delivering 120 pulses at ~0.73 W of power. Species are analysed at the reactor outlet using GC/MS and FTIR diagnostics. To interpret experimental results, a 0D numerical model is used, capturing the time-dependent electric field (E/n) within the plasma and accounting for the varying time scales of plasma (~ns) and neutral (~ms) chemistries. Further details can be found in [2]

3. Results and Discussion

Figure 1 compares experimental and numerical results for the LTP oxidation of methanol. LTP effects significantly lower the onset temperature for near-complete methanol consumption - roughly 200 K below the onset of thermal reactions. For T < 1000 K, local plasma timescales enhance O-atom radicals through collisional quenching with excited-N_2^*. At discharge timescales, these elevated radical pools drive neutral reactions that both propagate and recycle radicals (OH and H) to sustain overall reactivity and prevent radical flux termination. Specific radical flux propagation is shown to vary by
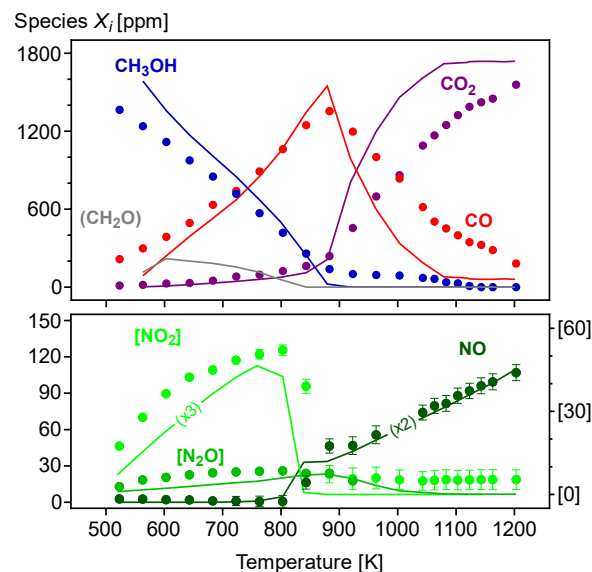

Fig. 1. Reactivity plot of methanol oxidation in air comparison experimental data (data points) and numerical model predictions (solid lines)

temperature. Enhanced N-atom densities from electron-impact reactions enhance NO_2 and N_2O formation for $T <$ 900 K. The presence of NO potentially provides synergist chemical effects (i.e. $NO+HO_2 = NO_2+OH$) to enhance propagation of H/OH radicals and effect overall chemical reactivity and ingntion.

4. Conclusion

Studies demonstrate LTP chemical effects on methanol reactivity as function of temperature. Enhanced radical generation affected by plasma processes enable sustained reactivity at T < 1000 K. Modeling results reveal synergistic chemical effects with enhanced NO formation due to the plasma. Current mechanism development efforts demonstrate satisfactory agreement with experimental results. Efforts are ongoing to reconcile model to improve predictive capabilities.

Acknowledgements

References

[1] Y. Ju. et al., Prog. Energy. Comb. 48 (2015) 21-83.
[2] N. Tsolas, et al., Combust. Flame 255 (2023) 112876.