ECN2 Soot Session

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Summary

Soot was a new topic for ECN2, and soot measurement and modeling for ECN configurations are both in their early stages compared to spray and combustion characterization.

On the experimental side, Emre Cenker gave an overview of soot measurement issues and data that are available for the ECN configurations. The experiments targeted soot volume fraction measurements in Spray A, including variations in ambient temperature and ambient oxygen concentration, along the central axial cross section. Experiments also included the standard diagnostics to verify that the conditions corresponded to those of Spray A. A Laser Extinction Method (LEM) and Planar Laser Induced Incandescence (PLII) were coupled for quantitative spatially resolved measurements. LII images were taken after the start of injection where quasi-stationary combustion was established. In addition, by changing the LII timing relative to the injection timing, the temporal variation of the soot cloud was observed. Lift-off length measurements and flame luminosity imaging were also conducted for each boundary condition to interpret the soot measurements. Due to some inaccuracy in the Spray A characterization measurements, soot results presented at this workshop were acquired under slightly different ambient conditions compared to the nominal Spray A conditions: -1 kg/m^3 in ambient density, and +30 K in ambient temperature.

On the modeling side, Dan Haworth gave an introduction to soot physics and CFD-based soot modeling, including radiation heat transfer. Two groups submitted computed mean soot volume fraction data for Spray H (n-heptane). Both used semi-empirical two-equation soot models, but there were several important differences between the two sets of simulations. These included different gas-phase chemical mechanisms, different turbulence-chemistry interaction treatments (TCI neglected versus TCI accounted for using a CMC model), and different radiation models (radiation neglected versus radiation accounted for using an optically thin model), in addition to differences in the soot models themselves. Both models produced reasonable levels of soot compared to the experiments, and both captured the measured trends in soot volume fraction with variations in ambient O_2 level and ambient density.

Conclusions

The results on the experimental side show that Spray A is a moderately sooting jet where signal trapping is not significant, indicating greater potential for quantitative soot diagnostics. Maximum soot volume fractions of approximately 2-4 ppm are measured at near-Spray A conditions (21.8 kg/m^3, 930 K, 15% O_2), and are as high as 12 ppm at elevated temperature (1030 K). For the 1.5 ms nominal Spray A injection duration, the soot cloud remains transient. Therefore, a longer injection duration of 4 ms was used to analyze the soot structure in a quasi-steady mode. Variations of ambient temperature and oxygen concentration were carried out, and the effects on soot formation and oxidation were consistent with those in the literature.

On the modeling side, only Spray H soot results were submitted, as reliable gas-phase chemical mechanisms have been available for n-heptane for some time. Existing soot models are able to reproduce measured soot levels and trends with variations in ambient oxygen level and density for Spray H. However, because of the significant differences between the models, no definitive conclusions could be drawn regarding the relative merits of the different modeling approaches or which physical subprocesses are the most important. Some groups now are beginning to show promising combustion results for Spray A (n-dodecane) in the ignition and liftoff length session, and it is anticipated that soot modeling results should be forthcoming for Spray A.

Recommendations

- It has been shown that accuracy of ambient and boundary conditions in Spray A is crucial. It is therefore recommended that the temperature be characterized carefully and taken into account when monitoring the gas mixture of ECN pre-combustion vessels.

- Significant statistical error was observed in the present LII experiment. It was shown that jitter between the laser and the camera was very probably responsible for the majority of this error. It is therefore recommended for future ECN soot experiments to minimize the jitter and to take it into account in the LII calibration.

- For quasi-steady mode measurements, a longer injection duration such as 4 ms should be employed.

- The focus in soot modeling should shift to injectors and fuels for which new experimental measurements are being made: Spray A, in particular.

- To make progress in physical understanding and modeling, modelers should perform systematic parametric studies to isolate and quantify the effects of individual physical processes. For example, the importance of TCI (or of radiation) can be isolated by comparing results from a model that neglects TCI (or radiation) with results from a model that accounts for TCI (or radiation). The relative importance of individual soot subprocesses (e.g., nucleation, surface growth, agglomeration) can be established by varying soot model parameters.