Spray A Combustion Session

Group Leader: Lyle M. Pickett (Sandia National Laboratories).
Contributors: Tim Bazyn and Glen C. Martin (Caterpillar), Louis-Marie Malbec, Laurent Hermant, Gilles Bruneaux (IFPEN), Michele Bardi, Julien Manin, and Raúl Payri (CMT), Lyle M. Pickett and Caroline L. Genzale (Sandia National Laboratories)

Experimental Approaches

The processes that drive ignition and combustion for Spray A include all of those discussed previously, including careful gas and fuel temperature control as well as the vaporization, mixing, and penetration. However, ignition and lift-off length are expected to have a very high sensitivity to temperature (exponential). Combustion experiments are therefore expected to provide increased scrutiny about the similarity in operation between different facilities.

Direct luminosity imaging using high-speed cameras is the preferred method for ignition detection, at least for second-stage high-temperature ignition. Imaging of 310-nm emission using intensified cameras for detection of OH* chemiluminescence is the preferred technique for lift-off length measurement, although high-speed imaging at other wavelengths is also possible. Schlieren imaging can also be used to detect cool-flame and high-temperature ignition (SAE 2010-01-2106). The table below summarizes the approaches used to date at various institutions for Spray A.

	type	*injector*	*310 nm transient*	*310 nm time-ave*	*<450 nm*	*<600 nm*	*Natural unfilt.*	*Schlieren*
IFPEN	preburn	676	few	X			X	
Sandia	preburn	677	few	X	X	X		X
CAT	flow	677/678		X	X	X		X
CMT	flow	675	X	X			X	

Light imaging is the most straightforward option for comparison between facilities because flow-type vessels do not have controlled pressure rise from which to extract heat-release rate. The pressure rise from closed-volume, preburn-type vessels may be analyzed with respect to simultaneous light imaging, but care must be taken to account for small levels of heat release and speed of sound correction for the pressure wave. Preburn vessels also have residual CO2 and H2O, presenting compositional differences compared to flow vessels diluted with only N2.

Findings

- Luminosity imaging is sufficient for detection of ignition using non-intensified high-speed cameras, but exposure times greater than about 50 μs are necessary (and full-open lenses). Short-wave-pass filtering is recommended after ignition, because of the intense soot luminosity.
- Luminosity imaging with sensitivity for soot luminosity (1-5 μs, low f/#) does not have dynamic range to measure first high-temperature chemiluminescence.
- Schlieren imaging shows appearance of a cool-flame (first stage-ignition) at approximately 250 μs ASI. No measurement of cool-flame chemiluminescence was attempted.
- High-temperature (second-stage ignition) occurs at approximately 400 μs ASI at Caterpillar and Sandia, with an uncertainty of approximately 50 μs based on the camera framing period. Luminosity imaging for ignition at IFPEN and CMT was inconclusive because of limited camera sensitivity. However, indications are that ignition delay was slightly shorter at IFPEN and higher, at CMT.

- After correction for time delay based on the ignition location and the pressure transducer, the measured pressure rise correlates well with the luminosity increase. This measured pressure rise provides further information about heat release not attainable in open flow vessels.
- Time-averaged profiles of 310-nm emission show a “leveling-off” or “knee” followed by a decline of intensity with increasing axial distance. The decline is not as sharp at higher wavelength (<450 nm).
- Using the “leveling-off” as a threshold to define quasi-steady lift-off length, the order in lift-off length follows a similar trend between institutions as ignition delay. Where shorter ignition delays are measured, the lift-off length is less. The mean lift-off length value between institutions is approximately 17 mm, with variation of about ±1.5 mm. This difference is more significant than the statistical uncertainty at any institution, and likely indicates systematic temperature differences.
- No trends with respect to ignition or lift-off length could be associated with preburn vs flow vessels, suggesting that minor species or inert major species are not as significant as other variables.
- When ambient temperature is intentionally varied, and lift-off length is analyzed in the same way, the measured lift-off lengths over a range of temperature are in good agreement between institutions, including both preburn or flow vessels.

Overall, these results show that comparable combustion data can be generated in different types of combustion vessels. Combustion results perhaps even show less variation between facilities than spray liquid length, for example. Ultimately this suggests that Spray A datasets between flow vessels and preburn vessels can be linked, and future research may be leveraged.

Recommendations & Future Investigation

The recommendations for future ECN combustion methodology are:

- Use the measured “leveling-off” high-temperature chemiluminescence (imaging line-of-sight) as a reference. Use 50% of this value as a threshold when defining ignition delay and lift-off length. This luminosity intensity reference is orders of magnitude higher than cool-flame chemiluminescence and orders of magnitude weaker than soot luminosity, but it must be determined for the specific imaging arrangement. The reference can be measured for Spray A with sufficient sensitivity by permitting soot luminosity to saturate the imaging system after high-temperature ignition.
- For specific conditions, perhaps not at Spray A, determine the leveling-off value and base lift-off length upon this value. Further research is needed to determine how the leveling-off value depends upon wavelength.
- Use two high-speed pressure transducers of different gain settings in constant-volume chambers, with the high-gain transducer reset shortly before ignition to provide a sensitive measurement of ignition and pressure rise due to the spray.
- Use LIF of formaldehyde and OH to more precisely define first- and second-stage ignition. Couple these measurements to high-speed luminosity and schlieren imaging for greater understanding of routine high-speed diagnostics.
- For modeling purposes, axial profiles of ground-state OH may be used to define lift-off length. However, future models should incorporate emission from excited electronic-state OH, including chemical reactions that include OH* emission for a better match to the experiment.
- Moving beyond the Spray A temperature of 900 K, let ambient temperature be a part of future parametric studies. For example, Spray A-800 K, Spray A-950 K, and so forth. Post recommended temperature targets on the ECN website.