**Minutes of ECN 8 Gasoline Topics**

**Topic 7: Internal & Near-nozzle Flow**

**Brandon Sforzo, Hengjie Guo; Argonne National Laboratory**

The objective of topic 7 is to investigate the internal and near-nozzle flow of a spray G injector. Mechanical dynamics, detailed geometry, evidence of tip wetting, and spray morphology at different conditions were the focus of experiments. Simulations were focused on the G2 condition using the nominal or informed (Gen 3.2) geometry, and exploring the effects of multi-component fuels.

Experimental contributions in the topic was limited, though there were several simulation contributions. Each contribution has the capacity for deeper presentation beyond the summary of the topic.

Main points from Topic 7 were:

* Several multi-component fuels were explored by different institutions and their properties presented
* As previously presented, a CFD-ready X-ray CT scanned geometry of Spray G #28 is available, named the Gen 3.2 geometry
* Pintle motion measurements show agreement in motion between G1, G2, and G3 conditions
* Spray radiography for several conditions illustrates the expansion effect at the G2 flash boiling condition and the enhancement caused by multi-component fuels
* X-ray imaging illustrates tip wetting occurring for G2 with less wetting observed at the G3 condition
* Nominal geometry simulations of the G2 condition generally under-predict plume expansion and interaction when compared to imaging and x-ray data
* At mild flashing conditions, the standard HRM model underestimates the phase-change in the near nozzle region, and adjustments to the time constant improve the expansion behavior
* A mixing-driven vaporization (MDV) model has been developed and implemented into CONVERGE by Argonne, extending the capability of HRM from flash boiling to evaporation
* A turbulence pressure correction was implemented into CONVERGE via a hidden feature which promotes vaporization and improves the prediction from HRM
* Modeling capability of tip wetting and multi-component vaporization is available in AVL FIRE

Future goals:

* The current implementation of multi-component HRM needs to be improved, and a multi-component mixing-driven vaporization model is being developed by ANL
* Better match towards X-ray measurements of fuel mass per unit volume in the near-nozzle region is still required
* Additional checks, finalization, publish/release of x-ray data

**Topic 8 : Evaporative sprays**

**T. Lucchini, Department of Energy, Politecnico di Milano**

Investigation of the fuel air mixing process via experimental and numerical models was the main objective of the topic. In particular, the distribution of liquid volume fraction was extensively investigated, considering that it is strongly related with the spray morphology and its dependency on the different ambient conditions. There was one experimental contribution (SANDIA) which provided a very large amount of data available for the validation and four different institutions (SANDIA, Politecnico di Milano, University of L’Aquila, Argonne National Laboratoris) providing simulated results. A consistent post-processing methodology developed by SANDIA allowed a consistent and very wide comparison between computed and experimental data.

Key messages:

Relevant improvements were achieved with new experimental techniques allowing a detailed characterization of multi-component evaporation, plume-to-plume dispersion;

Simulations seem to correctly predict spray evolution under “conventional” conditions (without flash-boiling and considering a single-component fuel), while spray collapse and multi-component evaporation still require modeling improvements.

Additional comments:

Merit function has a great potential for a comprehensive validation of computed data. Inclusion of both liquid and vapor results in its expression will make possible to make it more general;

Modeling spray collapse under flash boiling conditions requires to improve the description of the atomization and breakup processes, accounting for the additional instabilities produced by bubble formation inside the droplets;

Multi-component evaporation seems to be affected by the spray-gas interaction, and this aspect should be better predicted also with the help of suitable experimental investigations.

**Topic 9: Spray G in Engines**

**Benjamin Böhm, TU Darmstadt**

The aim of this topic was to investigate the influence of the turbulent in-cylinder flow and the constantly changing geometry and thermodynamic conditions inside the cylinder on the development of Spray G. This represents a significant difference to the conditions within constant volume chambers. In this Topic there were experimental contributions from two institutions and numerical simulations from four institutions. The work included Spray G1, G2, and G3 conditions, with a clear focus on early injection G3. The study of the interaction of the spray with the turbulent flow was performed in a flow bench configuration and in two engines. The experimental data now include measurements of the mixing field using laser-induced fluorescence (LIF) in addition to spray visualizations and flow field measurements using particle image velocimetry (PIV). In addition to measurements in motored engine operation, first measurements in fired operation have been shown.

The key take-away messages from this topic were as follows:

* A strong influence of the turbulent flow on the spray shape was observed. The directional flow over the intake valves shifts individual spray plumes and leads to a reduced spray angle. On the one hand, this increases the penetration depth and, on the other, enhances the plume-to-plume interaction.
* The intake flow in tumble engines is redirected upward from the piston surface. This induces a flow that is opposite to the spray and results in a significant reduction in penetration depth compared to measurements in pressure chambers where there is no flow.
* While for multiple injections the injection quantity specified by the standard operating points can be nearly maintained, for single injection engine operation the quantity must be increased by a factor of nearly 3. This applies to the stoichiometric operation of the engines used which have a displacement ~ 0.5 l.
* The simulations shown reproduced the spray well in terms of penetration depth, but there are variations in terms of spray shape. The plumes show a lower dispersion. Therefore, there is still a need to measure the geometry of the individual plumes or alternatively the resulting mixing field for validation.
* To improve the specification of the initial boundary conditions for engine simulations, a direct numerical simulation (DNS) was presented that included the flow in the injector. It provided the droplet distribution close to the injector outlet for large eddy simulations (LES), in a region where sprays are very dense and measurements are difficult to perform and subject to high uncertainty.

Future directions:

* Borg Warner provides us with a new generation of injectors. There will be a multi-hole injector (8 holes) with a similar spray pattern as the Spray G injector and a single hole injector.
* The single hole injector will be used for further fundamental studies of the spray-turbulence interaction. This will allow the measurement of the plume opening angle, an interesting parameter for validation. The goal is to investigate model sensitivities in more detail.
* There is a strong interest in the community to look at new fuels. Besides ammonia and methanol, the strongest interest is currently in hydrogen. However, the question of the availability of suitable injectors must be clarified.

The reduction of particulate emissions is a highly topical issue. For this purpose, multiple injections are of interest, although the injection of small quantities at short intervals is experimentally very challenging. Furthermore, the investigation of the spray collapse as well as the injector tip as potential causes for particle emissions are of interest.

**Topic 10: Spray Wall impact and Combustion**

**Michele BARDI (IFPEN) / Logan WHITE (Sandia) / Meghnaa Dhanji (Sandia) /Tuan Nguyen (Sandia)**

The general aim of this topic to build a database of consistent data and to provide understanding for model development and validation following the “Spray A” approach.

Given the progress of the contributions to the topic the main objective of ECN 8 workshop is to provide a state of the art of the activities carried out on this topic by ECN community, in specific:

* Share recent advancement in the diagnostics related to liquid film, targeting cold-starts.
* Share the state of the art on understanding of the physical mechanisms involved of…
* Present the available CFD models results and a preliminary comparison with experimental results, focusing on film mass and heat transfer comparisons
* Set main challenges for future investigations

The key take-away messages from this topic were as follows:

* A certain consistency has been found for liquid film measurement by Sandia and IFPEN using different film diagnostics (LIF and UV absorption). For the reference conditions at 7ms ASOI the liquid film thickness was found to range from 4 to 8 µm by both institutions. For the conditions at lower temperature (cf to presentation for details) the liquid film ranged from 8 to 15µm. It is important to underline that LIF was applied at very high tracer concentration (~30 % mass).
* A novel technique Low Coherence interferometry (LCI) was put in place at Sandia and used for verification of LIF results. The approach enables to obtain a 1D liquid film measurement based on light interaction in the visible range, excluding absorption and fluorescence effects. The comparison with LIF results showed good consistency.
* A Multispectral/multiplexed UV abs was put in place at Duisburg university and showed the possibility of measuring liquid film also in presence of soot, and to characterize soot optical properties at the same time. Also, some discrepancies put in evidence when comparing inert vs reacting results, suggest the formation of other UV light - absorbing species (soot precursors) which are not present in inert cases.
* An important transient in LIF signal of liquid samples has been highlighted at Duisburg and related to oxygen quenching and to a oxygen degassing effect caused by laser pulses.
* First Heat-flux measurement for impinging spray G has been performed providing reference data
  + First comparisons with CFD results shows encouraging results
  + For the cold wall and cold fuel conditions, conductive cooling or heating of the wall upon fuel impingement is dependent on the ambient density
* Similar film evaporation dynamics are observed in different experiments (film shape, thickness) and data related to the first parametric variations are available
* Current SWI models can approximate fuel film thickness, but the predictions between model vary wildly. Future work should focus on accurately capture spatial film distribution.

The main future direction highlighted during the workshop discussions are:

* The need to continue the comparison of the experiments obtained in different Facilities (Sandia and IFPEN) to provide a more detailed comparison of the results
* Initiate a discussion between the different groups carrying out liquid film simulations and analyze the different sensitivity of the models to parametric variations.
* Investigate the behavior of different models in double injection cases where the discrepancies with experiments appears to become larger