**Summary of ECN7 Gasoline Topics**

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

**Brandon Sforzo, Argonne National Laboratory**

The objective of topic 7 is to investigate the internal and near-nozzle flow of a spray G injector. Internal flow and mechanical dynamics, detailed geometry, 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. Originally, the goals set for topic 7 included exploring multi-component fuels and the effects of multiple injections, though this was de-emphasized for this presentation.

Participation in the topic was very encouraging and each contribution has the capacity for deeper presentation beyond the summary of the topic.

Main points from Topic 7 were:

* 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
* Neutron imaging shows internal pintle motion and armature dynamics during and after injection – a time-resolved data set available for fluid-structure interaction
* Backlit microscopy and x-ray radiography illustrate near-nozzle plume expansion for G2 condition
* Nominal geometry simulations of the G2 condition generally under-predict plume expansion and interaction when compared to imaging and x-ray data
	+ Fuel mass peak concentrations are also much higher for simulations than x-ray radiography measurements
* Internal nozzle dynamics resulting from the real-geometry features improves the behavior of the initial plume expansion
* 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
* The new Flash-boiling mass exchange implemented in AVL FIRE, based on Hertz-Knudsen model compares well to expansion and mass distribution from experiments
* Future interests include CFD validation against USAXS atomization data, studies with multi-component fuels, and multiple-injections

Input from the Beekast survey provided:

* The conditions of greatest interest are (ordered): G2, G-M1 (multiple injections), and G3
* Most people haven’t had the opportunity to use the Gen 3.2 geometry, but there is a split in agreement that it is readily usable or that the filesize is still too large
* More realistic fuels/blends are of high interest, including E00 and other gasoline surrogates
* A high interest in developing models for capturing break-up and flash-boiling
* High interest in light-based diagnostic development, with general support for a mixed diagnostic approach

**Topic 8: Evaporative Spray G (external, plume interaction, flash boiling)**

**Tommaso Lucchini, Politecnico di Milano,**

**Louis Marie Malbec, IFPEN**

1) Most of the ECN-7 issues on spray G were (almost sorted out):

* CFD models improved their predictive capability when simulating single-component fuels
* consistency in terms of model validation achieved by a new post-processing approach based on paraview, python and vtk
* a lot of experimental data now available in the ECN website
* CFD contributors finally simulating not only Spray G1 but also other conditions

2) Multi-component evaporation requires to improve the existing models

3) Experimental considerations

* New techniques are available to help xp/cfd comparisons based on physical criteria:
	+ DBIEI tomography for liquid phase: gives access to single spray information
	+ Projected Schlieren for vapor phase: allows to build a “schlieren-like” image with cfd results
* E00 should be a hot topic for next ECN work
	+ E00 has shown a huge effect on spray collapse
	+ E00 exhibits preferential vaporization, that needs to be further investigated

3) Beekast survey reported that:

* Priority for ECN-8 is modeling multi-component evaporation
* Conditions of interest are mainly G3 and G2 since they are representative of spray evolution for current generation of GDI engines
* Validation target: droplet size, liquid volume fraction, liquid and vapor penetration, velocity field
* More attention to be given to E00 fuel and suggestion for experiments with single hole injector
* Suggested experimental activity on measurement of the mixture fraction field

**Topic 9: Spray G in Engines**

**Benjamin Böhm and Cooper Welch, Darmstadt University**

In topic 9, the spray development in engines was investigated. The aim was to investigate the influence of the turbulent in-cylinder flow, the continuously changing geometry, and the thermodynamic conditions inside the cylinder on the development of the spray. This represents a significant difference compared with the conditions in constant volume chambers.

The spray G injector has been implemented in 3 engines for which first experimental data are available. These include spray visualizations using both Mie scattering and DBI as well as flow field measurements using PIV. The work is focused on late injection during compression (G1) and early injection during the intake stroke G3 and G2 (flashboiling). From the simulation side, two studies have been devoted to this topic.

A strong influence of the turbulent flow on the formation of the spray has been observed. For early injection cases, the sprays/droplets are blown away by the directed in-cylinder flow. Thus, the spray appears strongly asymmetric in contrast to the observations in the constant volume chambers. This influence is increased with increasing engine speed, which is associated with an increase in flow velocity. Furthermore, the spray angle has been shown to vary significantly in comparison with the constant volume chamber data. On the contrary, for G1 the in-cylinder flow and the upward-moving piston leads to a reduction in spray collapse, which is opposite the effect observed in early injection. Simulations have shown that the air entrainment in the individual spray plumes depend on the local turbulent flow field, which is why the opening angle of the individual plumes in experiments is still of utmost interest for comparison with simulations.

The accompanying audience survey has shown that besides the in-cylinder conditions (pressure and temperature), the spray plume angle is the most interesting parameter for validation purposes, followed by the mean flow field, the spray shape, and the turbulent kinetic energy. In terms of operating conditions, there is great interest for future work in multiple injections and flashboiling (G2). However, the need for characterization with longer injections was also seen, which is necessary to realize a stoichiometric mixture for the fired case. Interest in G1 and G3 was less pronounced.

In the end, the proposal to define a single-hole injector in addition to spray G was discussed. This offers the experimental advantage of determining the spray plume angle unambiguously, which has been considered an important parameter for validation since ECN 6. Furthermore, spray-wall interactions can be investigated in much more detail, as this configuration significantly reduces the experimental challenges (visual obstruction by the liquid phase and soot). Closing 7 holes to turn spray G into a single-hole injector was questioned, as this would undoubtedly change the flow within the injector, which would subsequently affect the formation of the spray. Consequently, further characterization of the processes in the injector would be necessary.

In summary, it can be said that the spray G investigations in engines have picked up speed. Available spray measurement data are currently still limited to simple visualizations, but will be supplemented in the future by measurements of mixture formation using laser-induced fluorescence. On the simulation side, more activities can be expected in the future.

**Topic 10: Spray G wall impact and combustion**

**Michele Bardi, IFPEN**

The objective of topic 10 is to investigate the spray wall interaction of a spray G injector in inert and reacting environment. The physics of liquid film and the soot formed due to its combustion are the main focus of the topic.

Due to the recent definition of the topic the contributions received are still sparse without either a common reference condition or significant overlaps among the activities of the participating labs. However, much interest in the topic has been shown and both the exchange among participants and the analysis of the contributions enabled to give an important step forward.

The main outcome of the workshop concerning topic 10 are:

* Three main phenomenological areas can be identified in the topic: 1) spray wall impact characterization (e.g. macroscopic spray definition, mixing field, etc.); 2) Liquid film formation and evaporation; 3) soot formation and oxidation. In each of the 3 areas different contributions have been received and they are described in the presentation
* Mixing field of an impinging spray G injector has been quantitatively characterized by Argonne via X-ray radiography. Also high definition impinging imaging have been collected for laterl wall impact.
* A first 3D simulation of an impinging spray G has been carried out at Argonne by replicating in CFD the experimental setup of the X ray experiments on ConvergeTM
* Liquid film formed by an impinging spray G injector in inert conditions has been quantitatively characterized by IFPEN. Also the first reacting spray G impinging experiments have been carried out;
* Experimental evidences from Sandia, IVG and IFPEN indicate a long persistence of the liquid film after the premixed combustion;
* 1D simulations (from Oakland university and IFPEN) indicated the importance of the correct prediction of film-wall heat exchange and the correct wall temperature prediction;
* Data on wall heat flux are available from Istituto Motori (inert spray G wall impingement) and will be available from Sandia and Oakridge future experiments thanks to a new heat flux probe
* ORNL will carry out Spray G liquid film measurement with a non-optical diagnostic (Neutron absorption) and on a metal substrate to provide a further comparison for optical experiments.
* Future experiments in Darmstadt engine will enable overlap between topic 9 and 10
* Two reference conditions have been defined representative of cold start cases:



* The Beekast survey also highlighted some future direction:
	+ Soot formation temperature is considered the most representative parameter to target for CV vessel experiments. O2 concentration is the second one.
	+ Fuel and surface rugosity are indicated as the most interesting parametric variations to be explored. Turbulence, Flame adiabatic temperature, Injection – flame time lag, and wall material.
	+ The location of soot formation and the determination of a “formation distance” is considered as an important validation measurement for CFD models.