Particle Reduced, Efficient Gasoline Engines

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Publishable Summary

In direct-injection gasoline engines, evaporating fuel wall-films and the subsequent inhomogeneities of the air-fuel mixture near those films make the formation of polycyclic aromatic hydrocarbons (PAH) and soot in subsequent combustion likely. Different optical techniques are needed to visualize the links of this process chain, such as the spray, film formation, evaporation, combustion, and the formation of PAH and eventually soot. This part of the PaREGEn project develops diagnostic techniques for the visualization of evaporating fuel wall-films as a source of PAH and soot in direct-injection spark ignition (DI SI) engines. The work is mainly carried out in a model experiment at the University of Duisburg-Essen (UDE), which is based on the combustion chamber of a DI SI engine. In our model experiment, a mixture of isooctane (surrogate fuel) and toluene (fluorescent tracer) is injected by a multi-hole injector into an optically accessible flow channel. Heated air flows from the top to the bottom through the channel. Combustion is initiated by a spark plug within the ignitable fuel/air-mixture cloud. Depending on the injected fuel mass, some of the fuel impinges on the quartz-glass wall on the opposite side from the injector and forms a wall film. Laser-induced fluorescence (LIF) at 266 nm excitation wavelength is used to visualize the liquid spray and image the fuel-film thickness spatially and temporally resolved. Additionally, the concentration of the fuel vapour, indicating inhomogeneities in the fuel distribution, is imaged by LIF. Both measurement techniques are applied with and without combustion for different injection durations.

Fuel-film imaging is also carried out in an optically accessible research engine at and by BOSCH under motored conditions. Here, the fuel-film thickness is investigated for different injection pressures and crank angles.

Based on laser-induced fluorescence imaging of a tracer added to a non-fluorescing surrogate fuel, a procedure for spray visualization and quantification of liquid fuel-film thickness on transparent surfaces was developed. The basic strategy is pulsed excitation at 266 nm followed by spectrally separated broadband detection of the red-shifted LIF signal with a UV-sensitive camera. For the fuel-film imaging, fluorescence is then related to absorption in the film, which again is related to film thickness. However, while it is quite easy to obtain qualitative images, quantification requires further investigations.

The quantification of the fuel vapour concentration or the fuel-film thickness requires preparatory measurements. In a first step a background image needs to be subtracted from the particular raw image, showing the spray or fuel-film. Also, the spatial non-uniformity of the exciting laser beam and detection efficiency needs to be taken into account. Therefore, a so called “flat-field correction” evens out the effect of the inhomogeneous excitation energy. Then, the signal intensity of the corrected image needs to be related to the parameter of interest, such as mole fraction or film thickness by performing suitable calibration measurements. Apart from these steps, the photophysical properties of the tracer need to be considered.

For the spray visualization, two out of six spray cones are visualized by a laser sheet excitation at different stages during and after the injection. The iso-octane-toluene mixture contains 10 % toluene. During the injection period, the droplet size decreases. Additionally, evaporation into the heated air increases so that discrimination between liquid droplets and already evaporated fuel is not possible. The signal intensity can be qualitatively related to the fuel concentration. At 1 ms after the end of the injection some fuel is still traveling through the channel while another fraction impinges on the quartz wall on the opposite side of injector and accumulates to a fuel-film. At 7 ms after the end of the injection the majority of the fuel, which does not wet the quartz wall, is in a gaseous state within the channel. This makes the determination of the fuel vapour mole fraction possible. Nevertheless, there are some fuel droplets within the channel, which make the determination of the fuel vapour mole fraction inaccurate.

The wall-film formation is imaged orthogonally to the plane the fuel impinges on. In this experiment 1 % of toluene is dissolved in iso-octane. A wall-film is imaged in two different stages after the end of the injection with and without combustion in a close-up view. The wetted area decreases only slightly between the two

considered time steps and is almost not influenced by the combustion. Apparently, the wall-film temperature increases only slightly through the heat transfer from the hot burnt gas and the quartz wall to the liquid fuel.

The film imaging technique is also applied in an optically accessible motored DI SI engine. The engine experimental work is published in [1]. The experiments feature a central mounted injector, actuated at gas-exchange top dead centre (TDC) when the piston is close to the injector and fuel impingement can be expected. Iso-octane with 0.5 % toluene were used as a surrogate fuel, injecting at 50, 100, and 200 bar rail pressure into air fed to the engine running whilst at 600 rpm with 1 bar intake pressure. While it was difficult to ascertain when exactly all droplets had either impinged or were evaporated, fuel-film formation appeared to be mostly complete 10 to 15° CA after the end of injection. From this time on, the "fingerprint" of the 6-hole injector could be seen clearly as six distinct lobes of film on the piston top. Consistent with recent work in a constant-pressure vessel, the film was thickest at its outer edge for all conditions and increasing rail pressure did not necessarily decrease piston wetting. Instead, at 50 and 100 bar the initial film had nearly equal total mass, but further increase to 200 bar rail pressure decreased the fuel mass deposited on the piston. The evaporation history was then very similar for 50 and 200 bar. The thinner film finished evaporation earlier, as expected.

In the future, the influence of temperature on the LIF signal is going to be investigated and corrected for in the wall-film imaging. Additionally, wall-imaging in the flow channel will be carried out for a longer period and the air temperature will be increased to enhance evaporation. Furthermore, the total fuel-film mass of the evaporating wall-film will be investigated. Injection, combustion, and the evaporation of the wall-film into the hot burnt gas will be visualized by Schlieren imaging in the optically accessible flow channel. Afterwards, we will visualize the formation of soot precursors (PAH) and soot with LIF at 355 nm excitation wavelength and laser-induced incandescence (LII), respectively. Flame imaging of the natural flame luminosity (chemiluminescence from radicals and incandescence from soot) has already been carried out with different filters to identify sooting regions during combustion. The results from different diagnostic techniques will provide further understanding of the soot particle formation processes. Empirical correlation factors can be derived from quantitative results that will be used in predictive models for combustion concept design. In the end, the developed diagnostic techniques and the gathered knowledge will be transferred to optically accessible research engines.

The gathered information, presented in this report, is used as validation data for 3D simulations in Task 1.4, carried out by the project partners ETH, BOSCH, and LOGE. In particular, ETH will use the data for a validation of sub-models for spray and wall-films in Sub-task 1.4.2. Information about the experimental setup, the operating and boundary conditions of the optically accessible flow channel have already been delivered to ETH. Images of the spray propagation in the flow channel can be used to validate results from numerical simulations, such as the depth of penetration, at different points during injection. The fuel vapour imaging provides information about the distribution and the mole fraction of fuel vapour within the flow channel. Results from the wall-film imaging validate numerical simulations of fuel-film formation, such as film thickness or location, in the flow channel and the optical engine. While very detailed results from the wall-film imaging in the optical engine are already available, a more detailed fuel-film imaging in the flow channel will be carried out. Detailed results from combustion imaging are available but beyond the scope of this report and will be shown subsequently.

Furthermore, the experimental setup, the operating conditions and suitable tracers, developed in Sub-task 1.3.1, will be transferred as an input to the Sub-tasks 1.3.3 the imaging of combustion, soot and soot precursors, 1.3.4 the endoscopic imaging, and 1.4.1 optical diagnostics and in-cylinder characterization.

Appendix A – Acknowledgement

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Project partners:

#	Partner	Partner Full Name
1	RIC	RICARDO UK LIMITED
2	DAI	DAIMLER AG
3	JLR	JAGUAR LAND ROVER LIMITED
4	BOSCH	ROBERT BOSCH GMBH
5	FEV	FEV EUROPE GMBH
6	JM	JOHNSON MATTHEY PLC
7	HON	HONEYWELL, SPOL. S.R.O.
8	JRC	JOINT RESEARCH CENTRE – EUROPEAN COMMISSION
9	UNR	UNIRESEARCH BV
10	IDIADA	IDIADA AUTOMOTIVE TECHNOLOGY SA
11	SIEMENS	SIEMENS INDUSTRY SOFTWARE SAS
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15	RWTH	RWTH AACHEN UNIVERSITY
16	UFI	UFI FILTERS SPA
17	UOB	UNIVERSITY OF BRIGHTON
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