Effect of fuel properties on primary breakup and spray formation studied on a gasoline 3-hole nozzle

L. Zigan*, I. Schmitz, M. Wensing and A. Leipertz
Lehrstuhl für Technische Thermodynamik, Universität Erlangen-Nürnberg
Erlangen Graduate School in Advanced Optical Technologies (SAOT)
Am Weichselgarten 8, D-91058 Erlangen, Germany

Abstract

The initial conditions of spray atomization and mixture formation are significantly determined by the turbulent nozzle flow. In this study the effect of fuel properties on primary breakup and macroscopic spray formation was examined with laser based measurement techniques on a 3-hole nozzle in an injection chamber. Two single component fuels (n-hexane, n-decane), which are representative for high and low-volatile fractions of gasoline with sufficient large differences in viscosity, surface tension and volatility were studied. Integral and planar Mie-scattering techniques were applied to examine the macroscopic spray structures. To characterize the microscopic spray structure close to the nozzle orifice a high resolving long distance microscope was used. For deeper insight into primary breakup processes with effects on global spray propagation the range of Reynolds- (8,500-39,600) and Weber-numbers (15,300-44,500) was extended by variation of the fuel temperature (25°C, 70°C) and injection pressure (5 MPa, 10 MPa). Significant differences in microscopic spray behavior were detected at valve opening and closing conditions, whereas during the quasi-stationary main injection phase the spray parameters cone angle and radial spray width virtually converged for the different fuels. The radial spray width at nozzle orifice as well as the microscopic cone angle decrease by trend with higher Reynolds- and Weber numbers at early injection phases. This leads to higher macroscopic spray propagation for higher Reynolds- and Weber-Numbers. The fine scale analysis showed chaotic structure of the disintegrating jet at the beginning injection phase with massive ligament formation. Its dependency on fuel temperature and injection pressure is discussed in detail.

Introduction

Direct Injection Spark Ignition (DISI) engines require fast fuel atomization and evaporation with a reproducible placement of fuel vapor close to the spark plug to ensure a stable ignition of the air/fuel mixture. With the application of modern regenerative and synthetic fuels the mixture formation appeared to be different compared to gasoline, mainly due to changed evaporation behavior of high and low boiling fuel fractions [1, 2]. The initial conditions of spray atomization and mixture formation are significantly determined by the design of the nozzle and the resulting turbulent nozzle flow, which is also dependent on fuel properties. Especially for diesel-injection at elevated pressures the influence of cavitation on the spray breakup was studied [3, 4, 5, 6]. In [6, 7] transparent two-dimensional model nozzles and large scale nozzles were used to analyze the onset of cavitation. However, for real-size gasoline multi-hole nozzles for Direct Injection there is a lack of data concerning impact of fuel properties and varied boundary conditions on nozzle outflow and macroscopic spray behavior. Fundamental studies of fuel-dependent nozzle and spray behavior are required for optimization of spray guided direct injection concepts especially in combination with modern synthetic and regenerative fuels. The application of simplified model fuels gives deeper insight in spray-sub processes with a high relevance for modeling approaches. In this study a 3-hole research injector was examined in a injection chamber with Mie-imaging techniques to study fuel impact as well as the influence of injection pressure and fuel temperature on primary breakup and macroscopic spray behavior.

Materials and Methods

The spray experiments were conducted in an optical accessible injection chamber. Two single component fuels (n-hexane, n-decane) with large differences in viscosity, surface tension and volatility were studied. The range of the fuel properties is representative for a multi-component gasoline fuel. Furthermore, fuel temperature (25°C, 70°C) and injection pressure (5 MPa, 10 MPa) were varied to affect atomization by systematically changing the Reynolds- (8,500-39,600) and Weber-numbers (15,300-44,500) for an increased insight into spray sub-processes. Chamber pressure was set to 0.1 MPa to decrease the influence of back-pressure on primary atomization. The spray process was examined with laser based macroscopic and microscopic imaging techniques. To characterize the global spray propagation, integral Mie-Imaging with flash lamps was applied. Planar laser-light

* Corresponding author: lars.zigan@cbi.uni-erlangen.de

sheet imaging gives information about the macroscopic structures of single liquid jets. With the application of a long-distance microscope the jet disintegration at the nozzle orifice was studied in detail in a region of 1.7x1.4 mm (see Figure 1). Average images and fuel probability density distributions were calculated from 32 single images for each time step. Furthermore, spray cone angle and radial spray width at the outlet of the nozzle were evaluated for microscopic images and spray length for the macroscopic images of the sprays.

Results and Discussion

In general, the injector is characterized by an unsteady spray behavior with a rapid atomization and intensive jet-to-jet interaction due to spray flapping. However, strong shot-to shot fluctuations were observed so that a statistical analysis was conducted. Large differences in microscopic spray behavior close to the nozzle were detected at valve opening and closing conditions, whereas during the quasi-stationary main injection phase after 400 µs the spray parameters virtually converged for all fuels and conditions. The radial spray width at nozzle exit as well as the microscopic cone angle decrease by trend with higher Reynolds- and Weber numbers at early injection phases. For an injection pressure of 10 MPa the radial spray width at nozzle outlet decreases approx. 25% when the Reynolds-number is increased by a factor of 3 and Weber-number by 1.5, respectively. Basically, this leads to increased macroscopic spray length of approx. 12% also at very early injection phases (e.g. for 200µs after start of injection) for higher Reynolds- and Weber-numbers. For an injection pressure of 5 MPa the microscopic spray width and near-nozzle spray cone is slightly reduced especially for higher Reynolds- and Weber-numbers under quasi-stationary conditions. The fine scale analysis showed chaotic structures of the disintegrating jet at early injection phases with massive ligament formation. Basically, for n-decane the breakup leads to large scale ligaments close to the nozzle with a higher probability than for the n-hexane spray especially at late quasi-stationary conditions.

Acknowledgement

The authors gratefully acknowledge the financial support for parts of this work from the Erlangen Graduate School in Advanced Optical Technologies within the framework of the German Excellence Initiative by the German Research Foundation (DFG).

References

[1] Kraemer, H., Einecke, S., Schulz, C., Sick, V., Nattrass, S. R., and Kitching, J. S., *Simultaneous Mapping of the distribution of different fuel volatility classes using tracer-LIF tomography in an IC engine.* SAE paper No. 982467, 1998.

[2] Zigan, L., Schmitz, I., Flügel, A., Wensing, M., and Leipertz, A., *Influence of fuel properties on spray formation and evaporation measured on a piezoelectric injector for second-generation gasoline direct injection. Injection systems for IC engines*, IMECHE, May 2009, London, pp. 193-202.

[3] Badock, C., Wirth, R., Fath, A., and Leipertz, A., *Investigation of cavitation in real size diesel injection nozzles. International Journal of Heat and Fluid Flow 20 (1999)* pp.538-544.

[4] Fath, A., Münch, K.-U., and Leipertz, A., *Spray Break-Up of Diesel Fuel Close to the Nozzle, Proc. ILASS'1996, pp. 59-64*.

[5] Payri, F., Bermúdez, V., Payri, R., Salvador, F.J., The influence of cavitation on the internal flow and the spray characteristics in diesel injection nozzles. Fuel 83 (2004), pp. 419-431.

[6] Andriotis, A., Gavaises, M., Arcoumanis, C., *Vortex flow and cavitation in diesel injector nozzles. J. Fluid Mech. (2008), vol. 610*, pp. 195–215

[7] Sou, A., Hosokawa, S., Tomiyana, A., Effects of cavitation in a nozzle on liquid jet atomization. International Journal of Heat and Mass Transfer 50 (2007), pp. 3575-3582

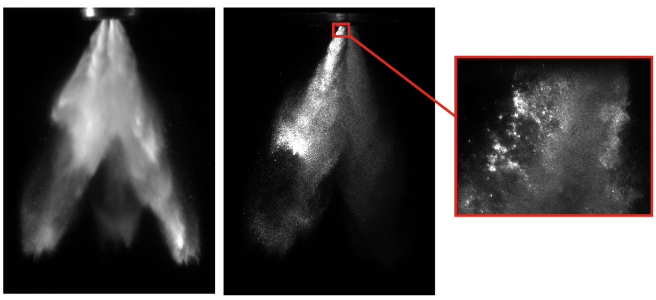

Figure 1. Global spray visualization with flash lamps (left), macroscopic laser light sheet illumination of one jet (middle) and microscopic detection of primary breakup at the nozzle outlet (right)