Experimental investigation on the spray behaviour for a hollow cone piezo injector with a multiple injection strategy

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Abstract

The traditional goal in engine development is the optimising of the fuel consumption while maintaining or improving performance [1]. One strategy to achieve this goal for spark ignition engines is gasoline direct injection. The injector technology has evolved rapidly and the recent introduction of the piezo hollow cone injector promises a very wide flexibility to cover many different engines requirements such as cold start, full load and stop and go driving. This work demonstrates the results of the spray analysis for a piezo hollow cone injector operating with a multiple injection strategy. Three optical techniques have been used to investigate the liquid phase (Mie scattering), vapour phase (shadowgraphy) and droplet size and velocity (2D PDA). It is shown that this injection strategy has a substantial influence on the spray penetration and the vapour phase distribution.

Introduction

In automotive engineering the fundamental goal is to reduce carbon oxide emissions. For Spark Ignition engines gasoline direct injection is, among other techniques, a powerful tool to achieve such goal. Regardless of whether a stratified or homogenous combustion, spark ignited or auto ignition concept is adopted, bringing the fuel directly into the cylinder offers a wide range of possibilities for CO_2 reduction [2]. Different injector types have been demonstrated since the introduction of gasoline direct injection engines. However, multi-hole injectors are beginning to show more wide spread application but with increasing fuel rail pressures there are issues to be addressed [3]. Another approach is the piezo activated, hollow cone injector. Due to the fast activation response of the piezo technology, this injector type offers a great potential for innovative injection strategies. One of these is pulsed, or multiple injection strategies. Instead of bringing in the fuel in one long injection period, the fuel delivery is separated into several shorter injections but with the total mass remaining the same.

Experimental Facilities and Methods

In the present work three complementary measurement techniques have been used and spray characterisation experiments have been carried out under engine like conditions at ETH Zürich and under atmospheric conditions at Loughborough University. In the high pressure, high temperature cell, HTDZ, in Zürich evaporating and non evaporating conditions have been explored, Table 1. Mie scattering was used to visualize the liquid phase in a cross section through the hollow cone spray. The light sheet was produced by an Ar^+ - laser operating in multiline mode with wavelengths between 476 and 514 nm. The scattered light was collected with a LaVision HSS 6 high speed camera with a resolution of 512×512 pixels and frame rate of 20 kHz, Figure 1 (blue path, camera 2).

Using this shadowgraphy setup it was also possible to investigate both the liquid and the vapour phase of the fuel simultaneously with the addition of a second laser. A Cavilux®Smart diode laser (690nm) was used with the beam expanded by a spherical lens and directed through the HTDZ after which it was refocused by an identical lens to cut off some of the refracted light in the focal point of the lens. A narrow band pass filter was used to filter out the scattered light of the Ar^+ - laser sheet. The light was collected by a second LaVision HSS 6 Camera, which was synchronised with the first camera, Figure 1 (red path, camera 1).

In the atmospheric spray rig at Loughborough University 2D phase Doppler anemometry measurements were performed to produce the droplet size and axial and radial velocity fields as function of time and space.The Siemens piezo injector was driven by a direct injection control unit, DICU, from ScienLab. The DICU allows a variation of needle lift and lifting speed. For the pulsed injection mode, the injection was split into five injections. Each pulse was 0.1 ms long and the piezo crystal was loaded with 0.5mC, which lifts the needle a bit less

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than half the maximum lift. The time between the pulses was 1.425ms. The gasoline was under a pressure of 12MPa.

Results and Discussion

The engineering goal was to produce a dense confined spray in the region just below the injector tip. With a multiple injection strategy this was readily achieved. Compared to a continuously propagating spray under a normal injection periods the sprays for each short injection literally come to a stand still once the injection pulse stopped. Due to the entrainment produced by the short injection pulse, a large toroidal recirculation zone is formed just below the nozzle. Its lifetime is sufficiently long so that the following droplets re-enforce the recirculation to confine the spray. The zones directly at the injector and below the recirculation are almost void of fuel droplets. These spray features can be seen on the Mie and shadowgraphy images combined in Figure 2 (left and right) taken in the HTDZ. The droplet velocity measurements and Mie imaging carried out under atmospheric conditions quantifies this behaviour, Figure 2 middle.

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References

[1] E. Schünemann, et al., *The BMW High Precision Injection Combustion as an Important Contribution to Efficient Dynamics*, in *Engine Combustion Processes.*

[2] W. Hübner, et al., *Influence of pre-injection on controlled auto-ignition combustion – a theoretical and experimental study*, in *THE SPARK IGNITION ENGINE OF THE FUTURE. 2009*, Universität Karlsruhe: Strasbourg.

[3] Jürgen Pfeil, et al., *Untersuchungen zur Hochdruckeinspritzung bei Ottomotoren mit strahlgeführter Direkteinspritzung*, in *Diesel- und Benzindirekteinspritzung V.* 2008, expert Verlag: Berlin.

Table 1. Specifications of the HTDZ

Parameter	Specification
Diameter/Width	Ø 110 mm /40 mm
Max. Temp.	300–700K (without precombustion)
Pressure (before comb.)	0.1 - 8 MPa
Pressure (after comb.)	20 MPa

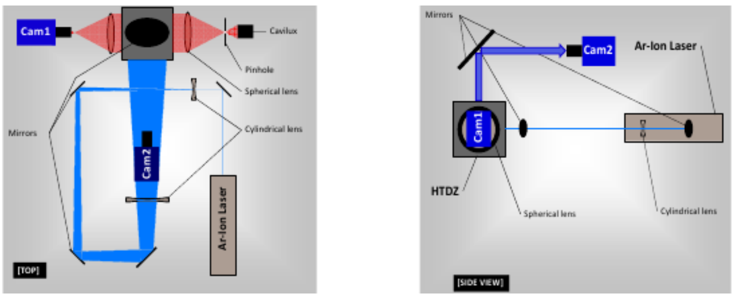

Figure 1. Sketch of the two measurement systems, the laser sheet for the Mie scattering (blue) and the shadowgraphie setup (red)

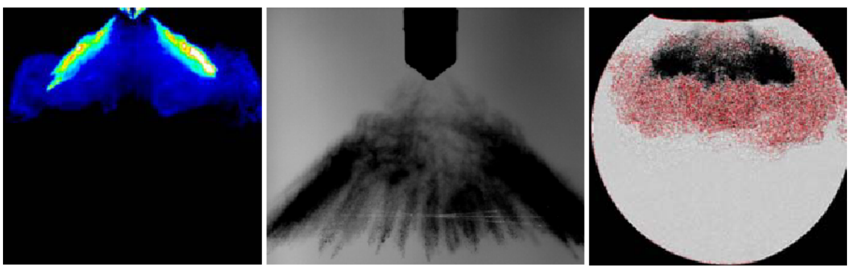

Figure 2. Pulsed injection: Mie image (left) under non evaporating conditions. Shadow imaging with crossed PDA- beams (Mie scattering) under atmospheric conditions (middle). Shadowgraphie image under evaporating conditions (right)