Investigation of the Diesel spray atomization process with use of Phase Doppler Anemometry at high injection pressures and at engine-like gas density

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A series of experimental studies were carried out in a constant volume bomb (CVB) in order to assess the atomization process of a Diesel spray from a multi-hole injector at high injection pressures and under engine-like gas density. The microscopic Diesel fuel spray characteristics, namely the droplet velocities and diameters, were examined by applying the Phase Doppler Anemometry (PDA). The Diesel spray was injected into ambient and pressurized air, respectively. In case of pressurized conditions the bomb was charged with nitrogen gas up to 2.5 MPa. The injection pressures ranged from 30 to 160 MPa. The energizing time was set to 0.7, 1.2 and 2.0 ms, respectively, in order to study both, the transient and the quasi stationary injection phases. The measurements were carried out along the spray axis as well as at different radial positions at an axial distance of 40 mm from the nozzle exit.

The results show that the peak velocities increase as the injection pressure is increased. This is due to the fact that the higher pressure is transferred into higher kinetic energy. Furthermore the time from the first measured droplets to the start of the quasi steady period decreases as the fuel pressure is increased. This indicates that a higher pressure of the fuel leads to a shorter opening time of the needle. The corresponding droplet diameters perhaps do not show the intuitively expected results, which means that for all injection pressures at the second phase of the quasi stationary period the mean diameter increases. In addition, it was found that the mean droplet size increases as the injection pressure is increased. A possible explanation for this phenomenon is that the increased acceleration of the entrained gas leads to less aerodynamic forces acting on the subsequent droplets behind the spray tip. Hence, it can be assumed that a reduced droplet break-up takes place.

The effect of the energizing time on the microscopic spray characteristics was studied at ambient conditions. It was observed that with an energizing time of 0.7 ms the peak velocity is significantly lower than that with 1.2 and 2.0 ms. This can be explained by the fact that at short injection durations, where the limit of maximum needle lift is not reached, the flow is restricted over the whole injection event. On the contrary to that, by increasing the energizing duration (here: 1.2 ms and 2.0 ms), the needle reaches its maximum position so that possible cavitation effects and turbulence within the needle seat region are reduced. Hence, there are less pressure losses within the nozzle, resulting in increased peak velocities.

With an energizing duration of 2.0 ms significantly larger droplets were measured over the whole injection period than with 0.7 ms. It is thought that the induced turbulences in the sac hole, which are dominant at 0.7 ms over the whole injection event, are responsible for the enhanced droplet break-up.

The measurements to investigate the influence of the gas density on the spray characteristics were undertaken with an injection pressure of 80 MPa. It was found that the droplet velocity decreases dramatically when the back-pressure is increased from 0.1 MPa to 2.5 MPa. In addition, a steep velocity gradient at 0.1 MPa was observed, whereas the droplet velocity at 2.5 MPa air pressure indicate a small decrease with increasing radial distance from the spray axis. Noticeably larger droplets at a cell pressure of 2.5 MPa were measured. Especially along the spray axis the mean diameter at 2.5 MPa is on average 30% higher than that at 0.1 MPa. This increase in droplet size can be attributed to the increase of droplet coalescence.

The velocity and diameter profiles for the injection pressures 80 and 160 MPa at a back-pressure of 2.5 MPa are compared from measurements carried out at radial distances of 1 mm, 2 mm and 4 mm from the spray axis. The droplet velocities for the injection pressure of 160 MPa are significantly higher than those of 80 MPa. As far as the droplet diameter is concerned the trend is not as obvious. At a radial distance of 1 mm and 2 mm, respectively, the droplets injected with 160 MPa are larger than those with 80 MPa. Conversely, at 4 mm from the spray axis slightly smaller mean droplet diameter are obtained at 160 MPa injection pressure. At 160 MPa and at a radial distance of 6 mm similar droplet sizes were measured to those of 4 mm, whereas at 80 MPa no droplets were measured at all. Due to the fact that at a radial distance of 6 mm only at 160 MPa injection pressure droplets were measured it can be concluded that the spray dispersion angle at 160 MPa is wider than at 80 MPa. Near the spray axis (here: 0 - 2 mm) droplet coalescence seems to be the dominating effect, which leads to larger droplets at higher injection pressures. Towards the spray periphery the interaction with the surrounded gas increases, resulting in slightly smaller droplets at 160 MPa.