Abstract

The Direct Injection Spark Ignition (DISI) engine is a promising technology that aims to reduce emissions and improve fuel economy, offering a viable solution to current environmental concerns. The liquid fuel atomization and spray mixing process in a DISI engine are crucial stages before combustion, directly impacting subsequent events and engine performance. Fuel injection in a DISI engine typically operates at higher pressures. The atomization process in a DISI engine may occur due to non-flashing or flashing conditions based on the fuel temperature and chamber pressure. Therefore, it is vital to comprehend the physics involved in the atomization process from the start to the end of injection.

The study focuses on analyzing the spray formation in the near-nozzle region during the early and post-injection stages of development using a single-hole direct injection atomizer system with gasoline (G100) and ethanol-gasoline (E85) blended fuels. The research utilized a Galilean-type beam expander and an achromatic lens in conjunction with an LED light and a high-speed camera to observe and analyze the microscopic details of the spray in the near-nozzle region. Additionally, a laser-based technique was employed to investigate the macroscopic morphology of the spray and measure parameters such as liquid penetration, cone angle, and width.

Three different shapes, spheroids, cylindrical, and steeple, were visualized experimentally during the evolution of the fuel jet under different fuel injection and chamber pressures. A transition in shape from the steeple-to-spheroid shape was detected. It was observed that the velocity of the emerged jet is affected by its evolved shapes, attributing to differences in the initial breakup characteristics and shot-to-shot variation in the spray at a given condition. The velocity of the cylindrical-shaped jet was 14% and 42% higher than the steeple and spheroid-shaped jets, respectively.

The Rayleigh-Plesset equation describes the reason for an increase in the spheroidal-shaped jet velocity by 84% when the chamber pressure (P_{ch}) is reduced from 0.6 to 0.1 MPa. It was observed that the cylindrical and the steeple-shaped jets pertain to a higher tendency to atomize during the initial stage of evolution compared to the spheroidal jet. The average jet velocities and liquid penetrations in the near-nozzle region for E85 and G100 were estimated.

The Ohnesorge and Reynolds number of the emerged liquid jets were estimated to describe the breakup regime of the jet during the initial stage. Spray during the initial stage at

2 MPa injection pressure shows second wind-induced breakup under 0.6 MPa P_{ch}. A transition between second-wind and atomization breakup for jets under 0.03 and 0.05 MPa P_{ch}. The jet experiences atomization breakup under 0.1 MPa P_{ch}. The effect of the injection pressure and chamber temperature were also studied.

The post-injection liquid sheet formation near the nozzle exit was observed. Results show that the size of the liquid sheet depends on the liquid-to-gas density ratio (ρ_{lg}). The size of the sheet for E85 fuel at ρ_{lg} of 2363 was found to be 6 mm, which was reduced by 75 % with a reduction in ρ_{lg} by 95 %. The chamber temperature increased from 303 K to 363 K, ρ_{lg} increased from 702 to 842, and a reduction in the liquid sheet was observed from 2.5 mm to 1.8 mm, respectively. The necking phenomenon of the liquid sheet was observed at the nozzle tip before the sheet detached and disintegrated into droplets. The necking length for the E85 was compared with gasoline fuel.

The transitional flashing jet acquired spheroid, cylindrical, and steeple shapes similar to non-flashing sprays. An orbicular-shaped structured jet was observed during flare flashing at 0.03 MPa chamber pressure and 363 K fuel temperature. It exhibits rapid axial momentum, resulting in a Reynolds number of 8.0×10^4, which is 1.3 times and 2.15 times higher than the transitional and non-flashing, respectively. Additionally, it has an estimated nucleation rate of $3.22 \times 10^{-2}\, m^{-3}s^{-1}$ using classical nucleation theory, which is 10 times higher than the transitional flashing, leading to improved atomization. However, spray collapse was observed under flare flashing with a reduction in P_{ch}, attributed to local condensation and subsequent pressure drop in core of the spray. Under flare flashing at a fuel temperature of 403 K, the Ohnesorge number is 2.95×10^{-3}, which is 0.8 times and 0.7 times lower than the fuel at 383 K and 363 K, respectively. The nucleation rate for flare flashing increases with higher fuel temperature, leading to improved atomization and a reduced likelihood of spray collapse. Post-injection spray structures in the near-nozzle show a transition from coarse to fine and dilute to densely populated with changes in the degree of superheating.

The macroscopic spray morphology for the flare flashing condition was compared using different imaging techniques including laser based diffused back illumination (DBI), LED based Mie scattered, and 1-Phase structured laser illumination planar imaging (1P-SLIPI), to demonstrate the advantage of SLIPI over conventional imaging to identify dense and dilute region within the spray.