DIRECT INJECTION SPARK IGNITION FUEL SPRAY CHARACTERIZATION UNDER SIMULATED INJECTION STRATEGIES

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This Thesis Is Dedicated to my Mom and Dad

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by

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Executive Summary

The work contained here characterizes the instantaneous fuel spray structure of a dense, transient spray under non-motored, simulated injection strategies. These strategies utilize the variation and control of in-cylinder pressure to simulate in-cylinder density at the time of injection in the motored case, and temperature of the fuel as well as that of a simulated piston. Experiments were performed using a single production DISI fuel injector within a controlled environment. The controlled environment is contained within a sealed quartz cylinder, which eliminates piston and air motion and allows for independent variation of various experimental parameters such as in-cylinder pressure, piston temperature, and fuel temperature. Axial flow visualization, PIV, and IR imaging experiments were performed for the single injector, with one fuel rail pressure and the simulation of four before top dead center (BTDC) conditions. Two parameters were varied in the experiments: piston surface temperature and fuel temperature with a single boundary condition of piston location (related to in-cylinder pressure through a simple model). It is anticipated that these results will be used within an optical engine to assist in the determination of the optimal injection strategies for reducing fuel impingement on piston surfaces to improve combustion efficiency. These results may also be used to advance injector design to reduce hydrocarbon emissions in DISI engines.

Overall, the use of a simulated piston had very little effect on overall fuel spray structure. The penetration distances and spray cone angles for the piston and no piston

cases are nearly identical for the four BTDC cases. The introduction of the piston caused a 1.8% decrease, 1.1% increase, and a 0.84% decrease in overall penetration distance for the 60° BTDC, 80° BTDC, and 100° BTDC cases, respectively. The introduction of the piston also caused a 2.0% decrease, 4.4% increase, and no change in developed spray angle for the 60° BTDC, 80° BTDC, and 100° BTDC cases, respectively at 1.4 ms after the SOF. Although the use of the simulated piston appears to not alter the spray structure, fuel spray structure is strongly affected by injection timing (and hence, the in-cylinder pressure). In general, the size of the hollow cone decreases as in-cylinder pressure increases. The overall size of the spray becomes increasingly compact as in-cylinder pressure increases. The boundary condition of varying piston location had no effect on fuel spray structure until impact occurs in the piston case. Standard deviation of the penetration distance was found to generally increase as time after the SOF increases.

A statistical analysis was performed on the piston/no piston data in order to better analyze the overall data set. It was concluded that the use of the simulated piston caused no statistical difference in penetration distance of the clump between the two cases (piston and no piston). It was also found that the use of the simulated piston caused no statistical difference in exit spray angle between the two cases (piston and no piston). All three factors (BTDC condition, time after SOF, and the use of the simulated piston condition) had a statistically significant effect on developed spray angle at the 95.0% confidence level.

Fuel spray structure using piston surface and fuel temperature variation is also nearly identical. The overall results reveal nearly identical penetration distances for the ambient and heated fuel cases. The use of higher piston surface temperatures with ambient fuel tended to increase penetration distances while the increase of piston surface temperature using heated fuel (90°C) decreased overall penetration distances. It was also found that as piston surface and fuel temperature increased, developed spray cone angle generally decreased. In 86% of the trials for the 60° BTDC, 80° BTDC, and 100° BTDC cases, developed cone angle decreased as a function of increasing piston surface and fuel temperature. Developed cone angle increases were found at all experimental cases for BDC. Knowledge of the instantaneous DISI fuel spray must be understood for the development of mixture preparation strategy and engine controls.

The fuel spray impingement investigation found that increasing piston surface temperature has a direct effect on piston wetting. The amount of fuel present on the piston surface decreases as piston surface temperature increases. The amount of fuel impinging upon the piston surface increases as time after the SOF increases. A simple technique was developed to better analyze fuel wetting on the piston surface. This technique subtracts the pixel values of one image from another to obtain qualitative data on piston surface wetting. PIV showed that the use of a heated piston had no significant impact on the velocities of the impinging fuel clump for the two times after the SOF used in this work. The clump velocity does appear to be time-dependent, with decreasing clump velocity as time after injection increases (due to increased drag). It was found that

increasing time after the SOF from 1.4 ms to 2 ms decreased velocities (by nearly a factor of three) and reduced overall clump size. A preliminary technique using infrared (IR) imaging revealed a significant change in piston surface temperature with the impact of fuel droplets and wetting of the piston surface is not uniform due to the impinging fuel jet characteristics. Since the most interesting operating mode for DISI engines is late injection, knowledge of the complex interactions involved in piston surface impingement is important in reducing hydrocarbon emissions for future DISI engine design.

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