Spray Modelling for Gasoline Direct Injection Applications

The gasoline direct injection (GDI) system is a promising technology that helps the engine to run at a higher compression ratio and achieve a higher volumetric efficiency compared with the port fuel injection (PFI) engines. The atomization of the fuel spray mainly influences the combustion performance of a GDI engine. GDI often operates at a higher injection pressure than PFI systems, which is believed to lead to better spray atomization. It implies that finer droplets lead to faster vaporization and better air-fuel mixing. In this work, an eight-holed counter bore GDI injector from Engine Combustion Network (ECN) called "Spray G" is considered. The simulations were carried out using the standard rate of injection (ROI) based Eulerian-Lagrangian approach, using the isooctane as the fuel. These simulations were carried out using the RNG k-ε turbulence model. However, the other turbulence models, such as the standard k-ε turbulence model and LES-based different sub-grid models, were also considered in this study under non-flashing conditions.

Firstly, numerical investigations were conducted under non-flashing operating conditions. It has been observed from the literature that the validation of Spray G is carried out mostly by varying the turbulence model constants and/or by an unusually wide spray cone angle. Most of the studies in the literature validated their model setups using the old spray penetration data from the ECN database. In recent years, the ECN database has provided new sets of penetration data which are deemed more reliable. Therefore, this study uses the latest data on spray penetrations from ECN for model validation and experimental findings on suction velocity and local droplet diameter. From the literature, it has been observed that validating these three parameters together is challenging. The validation studies were carried out by considering the KH-RT breakup length model. Several parametric studies were carried out by varying the KH model size constant (B_1)and the RT model breakup length constant (C_{bl}). Under non-flashing conditions, using the RNG k-ε turbulence model, the following model constants were recommended: B_1 as 32 and C_{bl} as 16. The predicted results showed reasonable agreement with the experimental data in terms of spray penetrations, prediction of suction velocity at 15 mm below the injector tip, and prediction of local droplet diameter at 15 mm below the injector tip.

Flash-boiling is a non-equilibrium phenomenon often occurring in a GDI engine during part load and idle operating conditions. Engine computational fluid dynamics (CFD) deal with a range of length-scales and multiple sub-models, and hence, often simplified models with reasonable assumptions are preferred to address rather complex phenomena. The literature review indicated the lack of a simplified engineering-level model to account for flashing sprays in engine CFD. To overcome this problem, a flash vaporization model based on the relevant non-dimensional numbers was developed and implemented in this study. Parametric studies were carried out to optimize the developed flash vaporization and breakup model constants under flash-boiling conditions. The results obtained from this parametric study were compared with the experimental data from ECN. It has been observed that the predicted results are within the range of the experimental observations in terms of spray penetration, spray width, and Sauter mean diameter (SMD).

Further, numerical studies were conducted to study the application of alternative fuels on a GDI injector under non-flashing and flashing conditions. Under non-flashing conditions, the blend of alternative fuels such as ethanol and methanol with isooctane has lower liquid penetration than the pure isooctane fuels spray. Numerical studies indicated that fuel properties such as the latent heat of vaporization and density were dominant. Additionally, on mixing of alcohol fuels with the isooctane, the charge cooling effect is observed through these studies. Local cooling of air-fuel mixtures by 30-40 K is observed when the alcohol content of the blend is increased. Furthermore, simulations were conducted under similar flash-boiling operating conditions, using ethanol and methanol as fuels, using the validated model setup of flash vaporization and modified breakup constants. Since ethanol and methanol's physical and saturation properties differ from the isooctane fuel, the fuel spray behaved differently. Compared with the experimental data, the predicted results of ethanol and methanol spray also achieved a reasonable agreement.

The developed flash vaporization model and the suggested breakup model constants were implemented in a GDI engine combustion under flashing conditions. These models were implemented using the CONVERGE user-defined functions (UDFs) so that the model constants and modelling approach would adapt based on the change in the surrounding conditions of the spray.