Computational study of stratified charge compression ignition engines with late injection under low-load conditions

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Abstract

The fuel stratification introduced by direct injection (DI) of iso-octane in an optically accessible homogeneous charge compression ignition (HCCI) engine is numerically investigated by using a multi-dimensional model. The primary purpose of the study is to provide an understanding of the effects of late DI on the in-cylinder fuel-air mixture distribution under low-load conditions. HCCI engines have the potential to provide high diesel-like efficiency with rather low harmful emissions of nitrogen oxides (NO_x) and soot. One of key hurdles, however, is the precise control of ignition timing and the rate of heat release or pressure-rise under a wide range of operating loads. At low loads, combustion efficiency is quite low and the associated carbon monoxide (CO) and unburned hydrocarbons (uHC) emissions are quite high. DI has the potential to improve the combustion efficiency and reduce emissions by introducing charge stratification to increase local combustion temperatures. To understand and optimise performance, detailed transient information about in-cylinder flow motions, fuel-air mixing, and mixture distributions is required.

In this study, the model is firstly validated by comparing the fuel distributions between calculations and experimental measurements made using planar laser induced fluorescence for three different injection timings (Hwang *et al.*, SAE2007-01-4130). The predicted fuel distributions at different injection timings show a good agreement with the measurements. It is found that with more retarded injection timing the fuel distribution is increasingly concentrated in the central region and less fuel in the crevice volume, corresponding to the potential improvement of the combustion efficiency and emissions of CO and uHC and a potential increase of NO_x emissions. The results emphasise the importance of the combustion efficiency versus NO_x trade-off and suggest that it is likely to be highly dependent on the details of the geometry and flow conditions. Generally, it is expected that the combustion efficiency/NO_x trade-off improves when fuel can be injected as late as possible with acceptable levels of NO_x emissions (Hwang *et al.*, SAE2007-01-4130). Therefore, techniques that can provide faster mixing have the potential for further improvement.

Then, the fuel distributions under different flow and injection parameters, such as swirl ratio, injection pressure and included angle of the spray, are studied. It is observed in the modelling that at a high injection pressure the trade-off between combustion efficiency and NO_x emission could be potentially improved. However, a high swirl ratio and a low injection pressure show adverse effects due to poor global mixing. The modelling results correctly match the phenomena observed in the experiments. Next, the influences of included angle of the spray are qualitatively investigated. It is shown in the modelling that with a high included angle, the spray shows prolonged vapour penetration and fuel mixture entering in the crevice volume even at late injection, leading to considerable reduction of combustion efficiency. For a low included angle of the spray, it is found that the global mixing was significantly slowed due to intensified wall impingement, resulting in a potential increase of NO_x emissions.

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