A Review on Fuel Atomization in IC Engines

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Abstract

The present research work shows that the number of nozzle holes is to be one among the key parameters for controlling the mixing rate of the air-fuel and increase in the number of nozzle holes promotes the evaporation and atomization of the fuel, in turn the rate of combustion. If this nozzle hole number exceeds a particular value adverse effects on combustion as well as on emissions would take place. Performance can also be improved by modifying the fuel injector with varying its inclination angle and even by varying the nozzle hole diameter. With modifications in the fuel injector it is possible to obtain proper air fuel mixture, HCCI and in turn complete combustion which can used even for the high viscosity biofuels. It is possible to reduce the harmful emissions like CO, NOx, HC with this modification in the fuel injector.

Keywords: Bio fuels, Emissions, HCCI, IC engines, Nozzle

I Introduction

Rudolf Diesel in 1893 invented Diesel engine which is also known as compression ignition engine. Air is compressed and the air temperature that rises is solely responsible for initiating the ignition. Then fuel is injected into the combustion chamber. Highest thermal efficiency is the most important factor that increased its usage. Its usage is found in almost all the fields including on-road and off-road vehicles ranging from light duty to heavy duty. Increased usage of diesel engines has attracted many researchers to work on them, so as to improve their performance. The air that is introduced into the combustion chamber is compressed with a compression ratio ranges between 15:1 and 22:1. At the end of compression, fuel is injected into the combustion chamber.

There are two variants DI-direct injection and IDI indirect injection diesel engines. In case of DI diesel engines, fuel is injected through the injectors mounted at the top of the combustion chamber. The fuel is injected into the bowl (integral part of piston). Combustion process starts with certain delay called ignition delay. Whereas, in IDI diesel engines; fuel is injected into a pre-chamber. Here, the combustion starts at pre-chamber and extends to main chamber. DI engines are found to be more fuel efficient than IDI engines. Modern diesel engines are powered with common rail systems. This system provides a separate pulsing high pressure fuel supply to individual fuel injectors. Solenoid drives the plunger that ensures the injection of fuel (appropriate time, quantity and pressure). Common rail system uses a reservoir called, accumulator which stores fuel at high pressure. The fuel is supplied to the injectors through a common rail. Valves of the fuel injectors are controlled with electric actuators. This ensures the production of square injection pulse. This system improves the fuel atomization, which in turn improves the engine performance.

II Parameters for fuel atomization

Moon *et al*., (2007) [1] have made an attempt to explore the spray characteristics of a swirl type injector for a direct injection SI engines. A extremely inclined nozzle was used for the test. The obtained results were compared with the conventional and the L-stip nozzle. An open hollow cone spray is observed for the 70 degree taper angle. The taper angle should be optimized to avoid the formation of rich areas and to increase the spray volume. Improvement in the atomization was observed for a high fuel temperature injection.

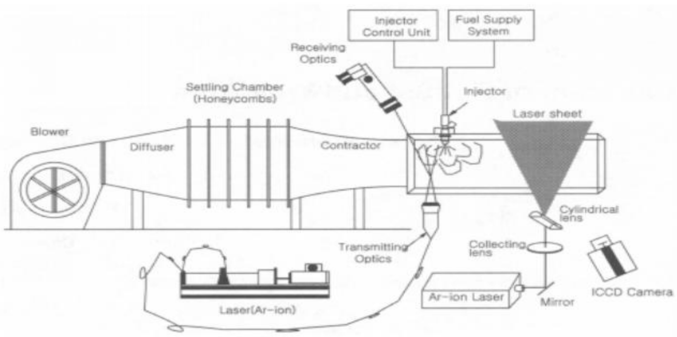

Fig 1: Experimental setup with inclined nozzle

Das *et al*., (2009) [2] have described a correlation study on fuel spray pattern recognition of multi-hole injectors for gasoline direct injection (GDI) engines. Spray pattern is characterized by penetration length, which represents the distance of maximum droplet concentration from the axis of the injector. Five fuel injectors with different numbers and sizes of nozzle holes were considered in this study. Experimental data and CFD modelling results were used separately to develop regression models for spray patter-nation. These regressions predict the influence of a number of injector operating and design parameters, including injection system operating pressure, valve lift, injector hole length-to-diameter ratio (l/d) and the orientation of the injector hole. The regression correlations provided a good fit with both experimental and CFD spray simulation results. Thus CFD offers a good complement to experimental validation during development efforts to meet a desired injector spray pattern.

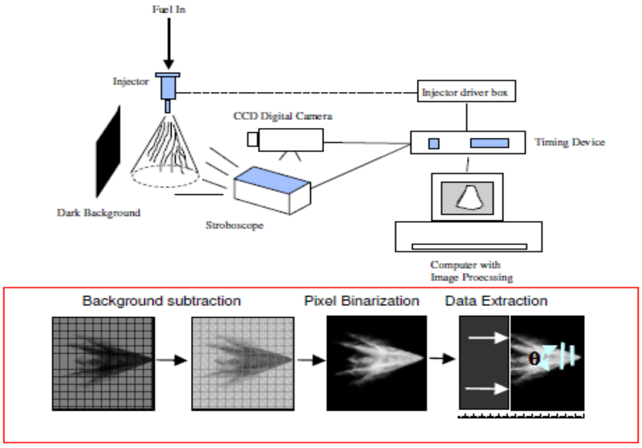

Fig 2: Digital spray imaging setup and resultant analysis

Malbec *et al*., (2010) [3] have investigated on the air entrainment of multihole Diesel injection using high speed particle image velocimetry (PIV). A multi hole common rail injector with an injection pressure of 100MPa was used for the study. The sprays are observed in a high pressure, high temperature cell that reproduces the thermodynamic conditions which exist in the combustion chamber of a diesel engine during injection. Typical ambient temperature of 800K and ambient density of 25kg/m^3 are chosen for the experiment. The air entrainment was studied with the PIV technique, giving access to the velocity fields in the surrounding air and/or in the interior of two neighboring jets. High attainment rate of 5000 Hz, corresponding to 200 μs between two following image pairs was obtained by a high-speed camera coupled with a high-speed Nd-YLF laser. The effect of neighbouring jets interaction was studied by comparing four injectors with different numbers of holes (4, 6, 8 and 12) with similar static mass flow rate per hole. The results show that both the maximum air entrainment level and the total mass of entrained air are similar for all the injectors, and therefore are not affected by neighbouring jets in the conditions studied. However the transient behaviour of the air entrainment process is affected when the number of holes is high, hence when two neighbouring jets are near (12 holes nozzle): the air entrainment reaches a maximum at later timings compared to the other nozzles. An analysis of the velocity fields between the two jets shows that this result might be due to the air flow inertia generated when the two jets are near. The transient behaviour after the end of injection (EOI) was also studied using the 4-holes injector. The results showed a very rapid decrease of the mean axial velocity near the nozzle after the EOI. The air entrainment becomes maximum at a given position and this position propagates downstream towards the jet tip.

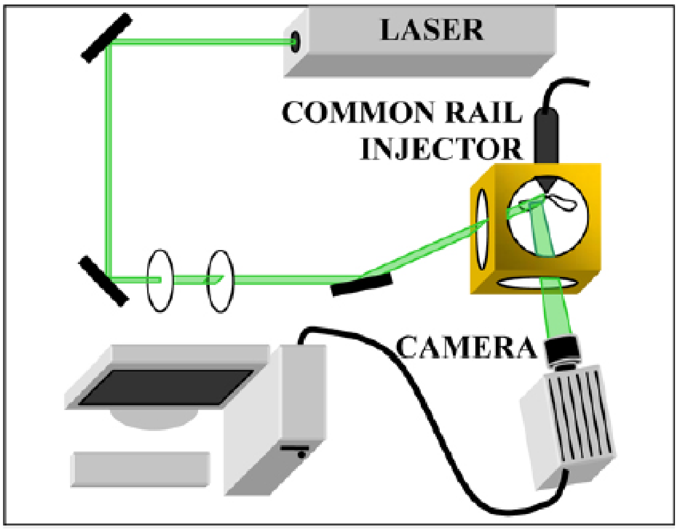

Fig 3: Experimental setup for PIV measurements

Matthias *et al*., (2012) [4] have demonstrated collaborative 3D-CFD and experimental efforts, majorly focused on optimizing the mixture stratification and the potential for high engine efficiency with low NOx emissions. Performance of the hydrogen engine was evaluated over a speed range from 1000 to 3000 rpm and a load range from 1.7 to 14.3 bar BMEP. Engine maps showed that the hydrogen direct injection engine operating above 35% brake thermal efficiency (BTE) over more or less 80% of the tested operating range. A more detailed characterization of engine efficiency is done by quantifying the effects of different loss mechanisms in the engine at relevant points throughout the engine map. The dominant loss mechanism was heat loss to the combustion chamber walls and as a function of both engine speed and load. There exists a trade-off between wall heat losses and other partial losses. As a result, the peak BTE was observed at 2000 rpm, 13.5 bars BMEP. A series of engine maps showed efficiency improvements due to optimal injection timing and also showed efficiency and NOx improvements due to injector nozzle design. The most promising engine configuration uses a 4-hole nozzle which showed improvement over the previous 5-hole nozzle. The final engine map showed a peak BTE of 45.5% and part-load BTE of 33.3%, demonstrating the ability of the hydrogen direct injection engine to exceed both U.S. DOE light-duty efficiency targets. The 4-hole nozzle also provides a mixture that is less potent for NOx than the 5-hole nozzle which correlates to a significant decrease in NOx emissions at the peak efficiency operating point. The corresponding map of NOx emissions was dominated by less than 0.10 g/kwh of NOx.

Wehrfritz A *et al*., (2011) [5] have studied numerically the influence of the number of fuel sprays in a single-cylinder diesel engine on mixing and combustion. The CFD simulations were carried out for a heavy-duty diesel engine with an 8 holes injector in the standard arrangement. The fuel spray mass-flow rate was obtained from 1D-simulations and was adjusted according to the number of nozzle holes to keep the total injected fuel mass constant. Two cases concerning the modified mass flow rate are studied. In the first case the injection time was decreased whereas in the second case the nozzle hole diameter was decreased. In both cases the nozzle holes (i.e. fuel sprays) was increased in several steps to 18 holes. Quantitative analysis were performed for the local air-fuel ratio, homogeneity of mixture distribution, heat release rate and the resulting in-cylinder pressure. The results showed that an increased number of fuel sprays leads to a more uniform fuel distribution, but also to a more incomplete combustion.

Dr. Hiregoudar yerrennagoudaru *et al*,. (2014) [6] conducted experiment by attaching different fin model to the existing fuel injector and with varying number of holes. It was found that 4 holes 10 fins nozzle design is given good result compared with other models. Better BSFC and break thermal efficiency was found.

Fig 4: Injectors with and without fin model

Dr. Hiregoudar yerrennagoudaru *et al*,. (2015) [7] conducted experiment by attaching straight projected and Z-shape fin model to the existing fuel injector and with varying number of holes. Experiments showed that using Z- type 7 projections fin model gave better result and HC, CO emissions were reduced. The purpose of using fin model to the injector stated in the work is to get fine spray.

Fig 5: Straight cut and Z type fin model

K Sengottaiyan *et al*,. (2017) [8] for reducing NOx emissions experiment was conducted using rotating injector in DI diesel engine. The investigation reveals reduced NOx emission and marginal improvement in the performance of the engine due to decrease in breakup length of spray and increase in the spray area during

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injection. The rotating spray makes co-swirl motion along with air swirl motion inside the cylinder at the end of the compression. The fi ner fuel is sprayed throughout the combustion chamber, enhancing the air fuel mixing process. It increases the burning rate and reduces the local concentration of the mixture. As a result, there is an improvement in performance and a simultaneous reduction in NOx emission from the engine.

Fig 6: Engine with Rotating Injector

III Conclusion

The present research paper revealed the progress made in the field of fuel spray and fuel atomization in diesel engines. From the survey it is observed that the initial air swirl, number of nozzle holes and the fuel injection time are controlling the quality of combustion. From the literature it is found that the engine performance depends on many interdependent parameters. They are engine efficiency, fuel economy, injection pressure, operating pressure, operating temperature, engine design, engine geometry, combustion process, compression ratio, nozzle geometry, injection orientation, injector location, injector geometry, injection strategies, geometry of the ports, bowl geometry, distribution of air fuel mixture within the chamber. In order to improve the engine performance, it is necessary to optimize all the above interdependent parameters. From the literature it is found that researchers have attempted with many combinations of the above stated parameters but not many with the combination of swirl, number of injector holes and the injection time. Swirl in diesel engines is an important parameter that affects the mixing of the air fuel ratio and the quality of combustion, in turn heat release, emissions and overall engine performance which can be attained by Number of nozzle holes of a fuel injector in diesel engines is another important parameter that affects the mixing of the air and fuel, in turn the quality of combustion. Fuel atomization can also be improved with various modifications in the injector.

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