A Review On Computational Investigation Of Bowl Type Combustion Chamber Direct Ignition C.I Engine

Dr. Sk Abdul Siddhique[1], Raffi Mohammed[2], Sk. Abdul Azeez[3]
[1] Faculty, Dept of Mechanical Engineering
[2, 3]Dept of Mechanical Engineering
[1] King Khalid University
[2, 3]Ramachandra College of Engineering, A.P., India

Abstract*- In this review article studied on Direct Injection Diesel combustion, the processes from ignition to pollutant formation are strongly influenced by the in-cylinder flow process. There is a need to clearly understand the fluid dynamics of in-cylinder flow in Internal Combustion engines. In DI diesel engines, the air-fuel mixing and subsequent combustion is controlled by the flow field in the cylinder and fuel injection characteristics. Fuel spray break-up, evaporation, and fuel vapour -air mixing prior to ignition are all mainly dependent upon the local flow fields in the nearby fuel droplets. In the present study 5.2kW single cylinder, four stroke direct ignition diesel engine is selected to investigate. This system is having a hemi spherical shaped combustion chamber with single injector having three 0.3mm nozzles. These experimental results are used to validate the CFD tool Diesel- RK software. It was observed that the flow pattern obtained in the analysis was in good agreement with experimental data. In this research paper, later flow analysis was conducted on four combustion chamber geometries Toroidal, Shallow Depth, Re-entrant and Double wedge shallow are considered for investigation.*

Keywords- Direct injection (DI), EGR, Combustion chamber geometry, Compression Ignition, Computational Fluid Dynamics (CFD).

I. INTRODUCTION

Direct injection diesel engines are an important choice as prime mover in applications like on-road, off road, marine and industrial usage. Diesel engine processes shows complex feature compared to any other mechanical equipment. The combustion characteristics of DI diesel engine are greatly influenced by the air motion inside the cylinder. Over last one centaury, in spite of these complexities, IC engines continued to develop, as our knowledge of engine processes has increased. The environmental constraints on engines have become stringent during the recent years. Last three decades, high growth in engine research and development has witnessed with the key issues like, market competitiveness, stringent emission norms and efficiency. The air motion in a diesel engine generally caused either by the intake port during induction or by combustion chamber geometry during compression stroke. The shape of bowl in the piston and intake system controls the turbulence level and fuel air mixing of DI diesel engine. The variation of bowl shape, valve profile, intake system etc lead to a change in the flow field inside the engine.

Results and Discussion:

1.1 Multiple Injection Systems:

An experimental study was conducted on a six cylinder heavy duty diesel engine to investigate the impact of multiple injections as well as the coupling effects of multi-injection and EGR on diesel emissions and performance. The engine was operated at 1849 rpm, for three loads: BMEP 1.55 MPa, 1.17 MPa and 0.38 MPa were tested, which represent 100%, 75% and 25% load of the maximum load at this engine speed. The multiple injection strategies include single pilot injection, double pilot injection, post injection as well as pilot-main-post injection. Finally, the combination effects of multi-injection and EGR were evaluated to further reduce emissions. At high load, single pilot injection cannot effectively reduce emission. Only when pilot-main injection intervals are large, can smoke reduction be achieved. However, CO increases with enlarged intervals, without significant impact on NOx and BSFC. At low load, relatively small intervals can simultaneously reduce NOx, CO and BSFC. Double pilot injection shows a similar influence with single pilot injection. However, it seems that double pilot injection could reduce smoke and an increase of NOx. In this sense, it seems that double pilot injection can improve in-cylinder air utilization, promoting fuel-air mixing process and get better fuel-air mixture (1).

Experimental investigation was performed to study the effect of multiple injections strategies on emission and combustion characteristics in single cylinder Direct injection optical engine .The engine was operated at 1200 rpm under fired condition. Multiple injection strategies such as single pilot injection and double pilot injection were studied. Single pilot injection quantity varied by 10%, 30% and 50% of total fuel quantity and double pilot varied by 15%, 25% of total injection quantity for each pilot injection. Double-pilot injection found to reduce NOx and smoke emissions by 73% and 84%, respectively, compared to single pilot injection because of better premixed mixture formation when double-pilot injection is used. Double-pilot injection can reduce HC emissions by approximately 50% compared to single-pilot injections, due to shortened spray tip penetration resulting in a reduced amount of wall-wetted fuel. With single pilot injection a significant reduction of NOx and smoke can be achieved when pilot injection timing is advanced over 40° CA BSOI because of combustion with partial premixed charge compression ignition (PCCI)(2).

An investigation has performed on the effect of multiple injection strategies in a Heavy-Duty Diesel Engine using optical measurements and CFD-Simulations. The multiple representative interactive flamelets (mRIF) model with a detailed diesel surrogate chemistry implemented in the CFD code STAR-CD was used in the numerical study. The multiple injection strategies include single injection, one pilot plus main injection and three pilot plus main injection. Optical engine tests were performed with multiple advanced pilot injections and the data acquired were compared with CFD simulations. When one or more advanced pilot injections were applied there is a shorter delay from start of injection (SOI) of the main injection to diffusion combustion starting. More soot is formed in the beginning of the combustion of the main injection. However, since less fuel is injected in the main injection the soot formation ends at an earlier crank angle degree (CAD), and net soot oxidation begins sooner. Engine-output NOx levels are reduced. Advanced pilot injections can be applied without a fuel consumption penalty. CO emissions are increased by around 80%. The key to reducing both soot and NOx emissions by applying pilot injections is that the pilot injected fuel should not ignite before sufficient mixing/lean-out occurs. Hence, substantial heat releases prior to the main injection must be prevented (3).

1.2 Combustion Chamber Geometry:

A computational investigation has carried out to study the effects of bowl geometry, fuel spray targeting, and swirl ratio for low-temperature combustion in a heavy-duty diesel engine. Multi-objective genetic algorithm optimization code was used to optimize the design parameter and modified version of the KIVA-3V code was used to simulate engine process. Combustion chamber bowl dia (60% – 80%of cylinder dia),bowl bottom dia (40% - 60% of bowl dia), Pip height (0% - 60% of bowl depth),injector spray half angle 50° to 85° and swirl ratio of 0.5 to 4.5 were taken for optimization. An optimal combination of spray targeting, swirl ratio and bowl geometry exist to simultaneously minimize emissions formation and improve soot and CO oxidation rates. Spray targeting was found to have a significant impact on the emissions and fuel consumption performance, and was furthermore found to be the most influential design parameter. Variations in spray targeting were found to largely affect pre-combustion mixing processes and charge preparation, resulting in marked effects on soot formation levels. Swirl ratio was found to alter both pre-combustion mixture preparation and late-cycle oxidation processes, while bowl geometry was found to predominantly affect mixing processes through an interaction with swirl ratio levels. The effect of bowl geometry was manifested mainly as an interaction with swirl ratio levels. Large diameter bowls were seen to require higher swirl levels in order to achieve similar soot reduction benefits seen in small bowl designs. Small bowl designs were observed to be more sensitive to variations in swirl, than large bowl designs (4).

A combined experimental and numerical study was conducted on combustion and exhaust gas emissions in a passenger car diesel engine by optimizing the combustion chamber design. Two re-entrant bowl with re-entrant ratio of 1.3 and 1.13 and a Toroidal combustion chamber were considered for their numerical study. The KIVA – 3V code used for Numerical simulation. They found that the modified re-entrant (re-entrant ratio of 1.13) bowl cavity showed a favourable performance in fuel distribution and mixing due to a compromise between equivalence ratio distribution and turbulence intensity distribution. They also observed that the modified re-entrant bowl cavity (re-entrant ratio of 1.13) showed low soot production and better re-combustion due to the high combustion temperature, while other two combustion chamber cavities did not fare well in soot re-burn. The modified re-entrant bowl cavity (re-entrant ratio of 1.13) showed high indicated thermal efficiency (40.46%) than other two combustion chamber geometries. Further experimental investigation was carried out in modified combustion chamber geometry to study the effect of injection pressure, pilot injection quantity and EGR rate on combustion and emission performance. The premixed compression ignition (PCI) combustion was applied at 1/8 and 2/8 load and partially premixed compression ignition (Pa-PCI) combustion was applied at 3/8 load. The injection pressure varied from 40MPa, 80, MPa and 120Mpa.The results showed that, by introducing Pa-PCI combustion to medium load, up to 88% improvement of NOx emission was achieved. The EGR application improved the thermal efficiency and emission at full load condition. The larger boost pressure is required as the EGR amount increases to improve the intake air quantity (5).

KIVA-GA computer code was used to optimize the combustion chamber geometry of a DI diesel engine. The optimization was simultaneously performed for different engine operating conditions, i.e. load and speed (1500, 2000 and 4000rpm) and the corresponding fitness values were weighted according to their occurrence in the European Driving Test. The evaluation phase of the genetic algorithm was performed by simulating the behaviour of combustion chamber geometry with a modified version of the KIVA3V code. The measure of design fitness includes NOx, unburned HC and soot emissions, as well as fuel consumption. The goal of the optimization process was to select a chamber giving the best compromise of the selected fitness functions. Five different combustion chamber geometry were considered for their study. For all the combustion chamber configurations, bowl volume and squish-to bowl volume ratio were kept constant so that the compression ratio was the same for all combustion chambers. Their results showed that to reduce NOx emissions, the combustion chamber should be narrow and deep with a shallow re-entrance and a low protuberance on the cylinder axis while the spray should be oriented towards the bowl entrance. As far as soot is concerned, chambers characterized by a large throat radius and a very small re-entrance were found. The inclination of the bowl bottom tends to be reduced up to flat-bottom (6).

Numerical analysis was carried out on air motion in three different shapes of combustion chambers viz. central projection, shallow W, and pataloid type to reduce the NOx and smoke emissions. The experimental analysis was carried out on a single cylinder diesel engine with central projection chamber to validate the numerical analysis. It was found out that optimizing combustion chamber geometry, aimed at reinforcing the diffuse combustion at the later combustion period and to get the trade-off of fuel consumption, NOx and smoke emissions. The results showed that engine with central projection chamber provide high swirl ratio (4.7) than other two chambers. Central projection chamber with retarded injection timing (10 deg BTDC) has large reduction in NOx and slight rise in fuel consumption and smoke emission (7).

1.3 In-cylinder fluid flows:

Investigation has been done the flow field behaviour in a light duty diesel engine equipped with a re-entrant bowl in piston combustion chamber. The tests were carried out at 1000, 1500 and 2000 rpm. LDA system was adopted to measure the flow. Tangential and radial components of the air velocity were obtained at different crank angles. The mean motion, integral time scale and Reynolds shear stress were estimated by applying an ensemble averaging technique. The tangential velocity (swirl) increased during the compression stroke as the piston approached the TDC and showed approximately the same trend at all engine speeds producing a direct scaling to piston speed. Radial inward motion could be observed during the last part of compression; a peaking squish velocity was reached before TDC. The turbulence integral time scale showed a global decrease along the compression stroke towards an almost constant value during the first 20º of the expansion. Moreover the integral time scale showed an approximate inverse scaling trend with engine speed. The Reynolds shear stresses increased at the end of compression reaching a maximum of about 0.35 at 1000 rpm. Therefore the transport of momentum caused by Reynolds shear stresses at the end of compression stroke tends to be much more effective than molecular transport, allowing efficient energy transfer from mean motion to turbulent flow (8).

Combined experimental and computational investigation of the flow fields in a DI Diesel engine was carried out. Two engine speeds (1200 rpm and 1800 rpm) were studied, but special emphasis was accorded to the effect of the bowl-in-piston geometry: flat or W shaped bowls, with or without re-entrant. The internal air motion was characterized experimentally using back-scatter LDV measurements in a motored single cylinder engine. Simulations were performed with a modified version of KIVA II code taking into account the optical piston elasticity due to the high pressure. The study provided a better understanding of the piston bowl shape effects on the flow fields in DI diesel engines. The measured turbulence level was higher in a ‘W’ shaped than in a flat bowl, which was not observed in the calculations. In a ‘W’ shaped bowl the simulation showed that the swirl number within the re-entrant bowl increased again at the beginning of the expansion stroke. The trend seemed to be confirmed by local measurements. The role of the re-entrant was to increase both swirl number and turbulence level around TDC. A good agreement between numerical results and experimental data was found comparing spatial profiles and temporal evolutions of mean and turbulent velocities. Despite the flow complexity in the studied geometries the turbulence level was predicted with a satisfactory accuracy particularly in flat bowls. However, according to the experimental data there was a higher turbulence level near the wall of the bowl at TDC, which was not reproduced in the simulations. The effect of engine speed was well simulated: both mean velocity and fluctuation intensity scale with engine speed (9).

1.4 EGR and injection pressure:

Experimental investigation was conducted to study the effect of EGR and injection pressure on engine performance and emission. Single cylinder diesel engine with deep-bowl Toroidal type was considered for study. The engine was operated at a speed of 1800 rpm. Injection pressure varied from 60MPa to 150 MPa and EGR varied from 0% to 25%.The results showed that Increase in EGR fraction leads to reduction in NOx, but increases the Particulate matter (PM),Total hydro carbon (THC) and indicated specific fuel consumption (ISFC). Reduction of nozzle orifice size reduces the NOx without deterioration of PM at lower EGR rate. PM decrease with increase in injection velocity NOx increase with injection velocity (10).

The influence of injection pressure and swirl motion on fuel air mixing combustion was studied. The analysis was carried out on a single cylinder diesel engine with operating speed of 1500 rpm. The swirl ratio varied from 0.0 to 4.0 and the injection pressure varied from 20MPa to 30Mpa. The results showed that 1. Increase in swirl is beneficial only up to a certain level 2. For a given injection pressure, there exists an optimum swirl ratio (swirl ratio of 2 at 30MPa injection pressure). At values other than this the fuel air mixing and combustion deteriorates. 3. Increase in injection pressure improves the air entrainment, premixed fuel fraction and combustion rate leading to shorter combustion duration.4. The matching of swirl motion and injection pressure is desirable for improved engine performance and emissions characteristic (11).Experimental and numerical investigations were conducted to study the effect of multiple injections and EGR on engine emissions. A single cylinder diesel engine equipped with common rail injection system was taken for test. The KIVA-3V code was used for numerical simulation. Different multiple injection strategies such as single, double and triple injection system were studied. Dwell period between pilot and main injection was varied from 6 to 10 deg CA. The results showed that with the combined effect of EGR and multiple injections simultaneously reduce the cycle NOx and soot by 32%, 75% respectively. Also improve the fuel consumption by 12%.

II. CONCLUSION

Hence, all these parameters, in particular, combustion chamber configurations need more attention to meet the global trends in fuel consumption, performance and emissions. Further, investigations are necessary to meet the latest emission standards and to improve the performance of diesel engines. Recent developments in computational facility, Computational Fluid Dynamics (CFD), in particular, is very useful for understanding the processes involved and optimization of engine design with minimum cost and time.

This context related to present work is presented in the following sections. Controlled combustion in a diesel engine significantly increases efficiency and pollutant formation because of its heterogeneous in nature. Understanding about the in-cylinder fluid dynamics, fuel sprays and combustion will help in meeting tough challenges such as fuel economy and pollutant formation. Lot of experimental, CFD works had been reported in the past. From the available previous literature, a detailed review has been prepared on impact of combustion chamber shapes, in-cylinder flows, fuel sprays etc., in the following sections.

REFERENCES

[1] Yao Mingfa, Wang Hu, Zheng Zunqing, and Yue Yan, “Experimental Study of Multiple Injections and Coupling Effects of Multi-Injection and EGR in a HD Diesel Engine”, SAE Paper No. 2009-01-2807, 2009.

[2] Jinwoo Lee, Jinwoog Jeon, Jungseo Park, and Choongsik Bae, “Effect of Multiple Injection Strategies on Emission and Combustion Characteristics in a Single Cylinder Direct-Injection Optical Engine”, SAE Paper No. 2009-01-1354, 2009.

[3] Tobias Husberg , Ingemar Denbratt, and Anders Karlsson, “Analysis of Advanced Multiple Injection Strategies in a Heavy-Duty Diesel Engine using Optical Measurements and CFD-Simulations”, SAE Paper No.2008-01-1328, 2008.

[4] Genzale, C.L., Reitz, R.D. and Wickman, D. “A Computational Investigation into the Effects of Spray Targeting, Bowl Geometry and Swirl Ratio for Low-Temperature Combustion in a Heavy-Duty Diesel Engine”, SAE paper No. 2007-01-0119,2007.

[5] Takashi Kaminaga, and Jin Kusaka, “Improvement of Combustion and Exhaust Gas Emissions in a Passenger Car Diesel Engine by Modification of Combustion Chamber Design”, SAE Paper No.2006- 01-3435, 2006.

[6] De Risi, A., Donateo, T. and Laforgia, D. “Optimization of the Combustion Chamber of Direct Injection Diesel Engines”, SAE paper No. 2003-01-1064, 2003.