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A Review on the Different Geometries of Combustion Chamber in CI Engines on Performance, Ignition and Emission

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Abstract One of the important issues that today are considered by researchers as a research field is the study of combustion chamber in a variety of internal combustion engines. Different designs for the diesel engine combustion chamber are planned for this purpose. Open combustion chamber or direct injection and combustion chamber divided or indirect injection. Open combustion chamber or direct injection, which is widely used in heavy and industrial engines, and the combustion chamber divided in small engines with high revolution. The geometry of the combustion chamber in diesel engines (combustion ignition) has studied and discussed.

Keywords: *combustion chamber, direct injection, emissions, pollutants, internal combustion engine*

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1. Introduction

Awareness of increased pollution around the world has led researchers to adopt a new strategy to improve the emission and efficiency of internal combustion engines, especially diesel engines. Therefore, any documentary improvements in the fuel mix and air inside the cylinder can significantly improve combustion, then improve the engine efficiency and reduce the level of emission of propellants. For this reason, changes in the combustion chamber have been given particular attention by a large number of researchers over the past decade. [1] Emissions of greenhouse gases and severe NOx emissions led the IMO specifically refer to NOx in the revision in Annex VI MARPOL, which was implemented for engines installed on ships built on or after January 1, 2011. [2]

From all parts of the engine, the design of the combustion chamber (CC) has a significant impact on the propagation, emission and impact properties of the engine. The design part of the CC includes type of CC wall material, valve position, different air volume in different parts of the CC such as the piston bowl, the distance between the cylinder head and the piston, slope of valve and other. Research in the field of CC has been carried out over the past five decades and the compression ratio of CC to 14 to 24: 1 is the result of natural breathing of engines [3]. In general, the movement of air in the cylinder of diesel engines is accompanied by rotation, crushing and turbulence, which has a major impact on the air-fuel mixing, and combustion operation. Generally, the production of air rotary motion is due to the good design of the suction valve. The good design of the suction valve makes the higher rotation and helps to improve combustion.

Also, along with air movement, fuel spray features such as injection hole diameter, injection pressure, spray angle, and spraying time have a significant effect on the combustion of a diesel engine. [4]. Whatever, the sprayed jet fuel combustion fuel has more time to penetrate into the combustion chamber, the more air can be sprayed into the jet, much more areas are formed from the air mixture with the fuel vapor and the process of mixing with the larger pre-mix is more favorable [5]. Since, with the design of a suitable combustion chamber, it can achieve significant benefits in terms of reducing emissions, without having a significant effect on the efficiency of the engine, optimizing the combustion chamber shape is the su This type of same simulation models are performed for managing to predict the effect of combustion chamber geometry on the physical and chemical processes occurring inside the combustion chamber, without the need to use empirical relationships, for example in phenomenological models. Deyreisi et al [6,7] in the design of the combustion chamber, the piston bowl type, have also considered the effect of a variety of geometry of the piston bowl on the efficiency and combustion parameters, namely, the brake thermal efficiency (BTE), the brake specific fuel consumption (BSFC), exhaust gas temperature (EGT), Heat release rate (HRR) and the pressure and emission of pollutants [8]. Some studies carried out on the effect of combustion engine geometry on the CI engine efficiency and exhaust emissions will be discussed as follows (Lee et al., 2014). [9]. The numerical simulation of the combustion chamber in a hemisphere (HCC), shallow depth (SCC) and omega (OCC) was performed using the KIVA-4 CFD software at a constant compression ratio of 18.5. The results showed that the SCC and OCC combustion chambers produce higher NOx pollutants at low and high engine speeds. The combination of spray and improved geometry of the piston bowl had a positive effect on emission reduction (Kozus et al., 2015). [10] Empirical analysis with single injection and two injections strategies in three different piston bowel geometries resulted in the results of reducing NOx and the release of soot with low and partial loading conditions in the double-acting injection strategy. Jaichandar et al. [11] studied the effect of spraying time and geometry of the bowl with two different configurations. They showed that the brake thermal efficiency has increased by 5.64%, while when the TCC geometry (toroidal combustion chamber) was used instead of the HCC (hemisphere combustion chamber), the the brake specific fuel consumption was reduced by 4.6%. Kun Lin Tay et al [12] investigated the combustion properties in a direct injection compression engine (DICI) with a combination of kerosene and diesel fuel, using different geometries of the piston bowl along with different injection rates. In total, three geometries of the combustion bowl, namely the Omega Combustion chamber (OCC), shallow depth combustion chamber (SCC), and shallow depth Re-entrant combustion chamber (SRCC), along with six different ramps, gasoline + kerosene injection rates, gasoline injection rates and pure kerosene were used. They observed that SRCC geometry with the shortest throat length has the highest turbulence kinetic energy (TKE).

Rakopoulos et al [13] conducted an experimental study to evaluate the the combustion efficiency and the characteristics of the exhaust gases emission. They tested diesel fuel mixture with 8%, 16% and 24% of the ethylene ether (DEE) volume in the combustion chamber of the four-stroke, single cylinder diesel engine, high-speed injection Direct (HSDI). The engine worked with different three loads, therefore fuel consumption, exhaust emissions and gases emissions such as nitrogen oxide, carbon monoxide and leak hydrocarbons was measured.

Nagarsheth and Gossay [14] used two different types of TBC combustion chambers TBC to analyze the diesel cycle, their diesel motor was made using TBC ceramic materials. The concept of an adiabatic engine was used to save energy loss and also to reduce emissions of exhaust gases. The self-regulated diesel combustion chamber components, such as upper surface of piston, engine head cylinder, valves and liners, were completely coated with two better materials such as TBC materials such as MgZrO3 and YSZ, in both cases, the TBC NiCAlY coating band was used for better mechanical strength. The analysis of diesel combustion periods was carried out and various combustion results, such as cylinder pressure, mass fraction, heat emission and pressure diagrams were given. Yousefi et al. [15] has compared combustion used and exhaust emissions for the same ratio for two HCCI engines with and without the primary combustion chamber. The results of the HCCI engine combustion were shown. The HCCI engine, with its initial combustion chamber (MK.V comet), tolerated the wrong process, while the HCCI engine without an initial combustion chamber (modified chamber) experienced a complete combustion. The HCCI engine was more advanced with higher combustion chamber, heat release rate (HRR), as well as had higher the start of combustion (SOC) and indicated mean effective pressure (IMEP) compared to another motor. Wei et al. [16] in order to better utilize the air in the combustion chamber and improve the quality of the mixture of fuel and air, has been proposed increased combustion efficiency and reduced emissions, a new rotary combustion chamber system in DI engines (direct injection). The spray was simulated inside the cylinder and examined at different angles of the injector nozzle with AVL-FIRE code.

As it is known, the combustion chamber geometry plays an important role in the combustion, efficiency and diffusion of CI engines. The combustion chamber geometry provides the conditions for an appropriate mixture of air and fuel before combustion. Typically combustion chambers, in addition to the upper space of TDC cylinder, located on the piston crown (Piston bowl) and cylinder head (primary combustion chamber) are designed in a variety of ways. In general, the purpose of this study is to review the geometries in the combustion chamber in order to determine the suitability of pure and combustible fuel types and its effect on combustion, efficiency and emissions.

2. Combustion Chamber

Depending on the speed of the engine, the geometry of the combustion chamber will change. For low-speed engines (less than 1500 rpm) and medium speed (1500-3000 rpm), the direct ignition chamber is used and for high-speed engines (above 3000 rpm), an indirect combustion chamber is used.

The design of the combustion chamber has two philosophies: first, the design with the high air velocity, second, with the low air velocity in the cylinder. In the rotational design of the first case, there are fewer holes in the engine and deep piston bowl, while in the second case there are more holes in the injector and the small bowl piston. However, the entire volume of CC is inside the main cylinder and direct fuel is injected into this volume. Some of the common geometries used are described below:

3. Different Geometries of the Combustion Chamber

Square combustion chamber: When using the square bowl combustion chamber of Figure 1, it is designed on the piston crown. The air movement in the square bowl leads to rotate and during compression creates a turbulent environment, especially in corner areas.

Hemi-spherical combustion chamber: Their name represents the concept of a combustion chamber at the cylinder head or at the top of the piston. Figure 2 shows space which is close to half the butter (hemi + -sphere + -aic), although in practice it is generally less than half of that. HCC combustion chamber of the cylinder head was used in 1901. [18] In this combustion chamber, the depth to diameter ratio can be different, but this does not apply to the proper use of biodiesel fuel as a suitable combustion fuel. Therefore, BSFC increases and BTE decreases when working with biodiesel in this type of combustion chamber.

Figure 1. Square combustion chambers

Toroidal combustion chamber: The brittle motion in TCC is better than that of another, so the better air flow in this combustion chamber causes a more favorable combustion. The TCC combustion compartment has a cone angle of 150 to 160 degrees as shown in Figure 3.

Shallow depth CC combustion chamber: This type of combustion chamber is used more frequently in low-speed diesel engines, they are usually designed with a low-depth hole and a large diameter hole on the piston crown. The SCC efficiency in a combustion which uses biodiesel fuel is relatively better than HCC, as shown in Figure 4.

Cylinder combustion chamber: It has a cylindrical hole in the piston crown and can be modified as a cone, that is, a short cone with a base angle of 90 degrees. (Figure 5).

Indirect injection combustion chamber: Combustion in an indirect combustion chamber is divided into two parts: One part in the cylinder head and another one in main cylinder. The fuel is injected into the combustion chamber section in the cylinder head. The combustion chamber geometry is presented in Figure 6.

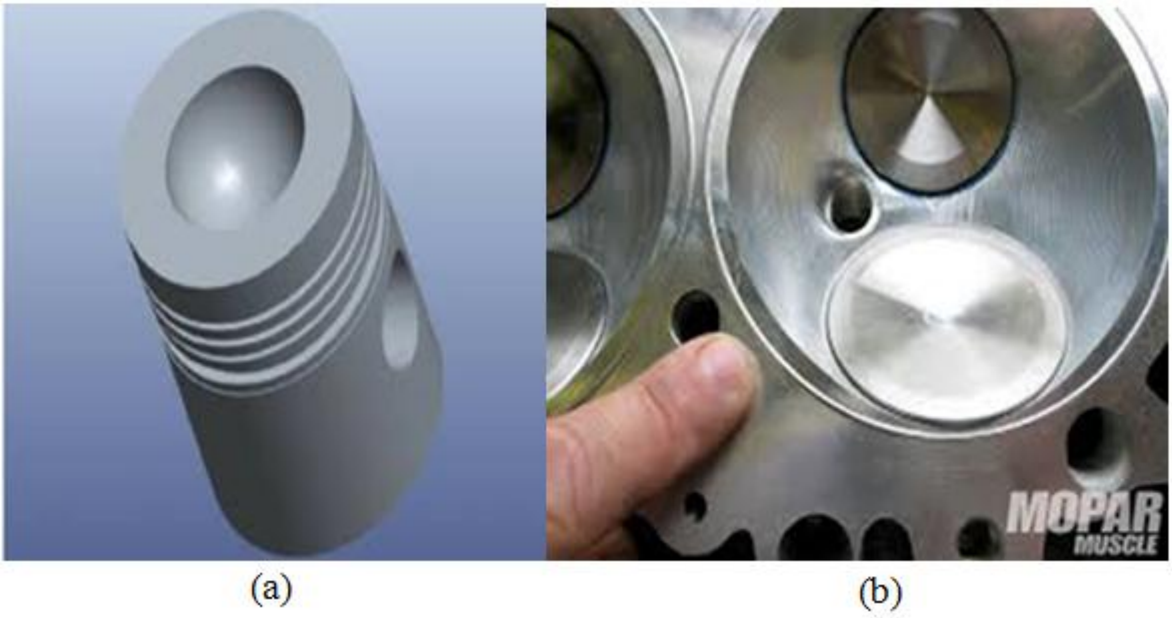


Figure 2. (a) Hemispheric combustion chambers, (b) Piston crown in cylinder head

Figure 3. Torodial CC combustion chamber

Figure 4. An example of an SCC combustion chamber

Figure 5. Two piece piston design – base piston and 4 piston crown inserts with squish area of 25%, 30%, 35% and 40%

Swirl CC combustion chamber: The swirl-combustion chamber (Figure 6) is mainly used in small CI engines with a cylinder diameter of less than 100 mm. This chamber is spherical and the first half of the combustion starts from there and the second half in the piston crown. Loss of heat from this type of combustion chamber was more than direct CC.

Pre combustion chamber: In this combustion chamber, Figure 6b, the primary chamber in the cylinder head and the cylinder chamber are connected to a number of holes and the fuel is injected by the nozzle at a pressure of less than 450 psi. The main compartment (before combustion) contains a volume of 40% of the total volume where the combustion starts and initially the air enters it and then through the holes into the cylinder. This movement creates a severe turbidity in the air and leas to better mix with fuel and more favorable combustion.

4. Strategies to Improve Combustion, Efficiency and Emission Reduction

In this section, we review the methods that resolved the problems that occurred in the initial start (cold) and the release of pollutants and the analysis of the combustion engine chambers:

Multiple injections in cold start: Multiple injection strategies with different injection rates were used to improve diesel performance. Shooting flame and pressure inside combustion chamber showed that the multi-injection strategy is better than single injection under cold start conditions. The amount of pressure variation inside the combustion chamber with the multi-injection strategy is almost twice as likely as single-injection cases [23].

EGR: With the return of a percentage of the engine's exhaust gases to the inlet valves of the cylinders to reduce emissions, it was found that the use of EGR above 20 to 40 percent of the engine output volume reduced the smoke mass in the combustion chamber. Increased EGR also reduced greenhouse gas emissions. To obtain smoke and NOx information at three levels of EGR, 0.2, 0.3 and 0.4, the result is that using higher EGR values reduces NOX. [24]

Piezoelectric pressure sensor: Pressure inside the cylinder is one of the most valuable signals used to detect combustion in IC motors. The piezoelectric pressure sensor has fast response speed, light weight, small size and low sensitivity to environmental conditions. They are widely used to measure the cylinder pressure of the engine combustion chamber. [25]. Agarwal et al. [26] using a piezoelectric pressure sensor, investigated the digital signal processing of the cylinder pressure information for combustion detection in the combustion chamber of the HCCI engine.

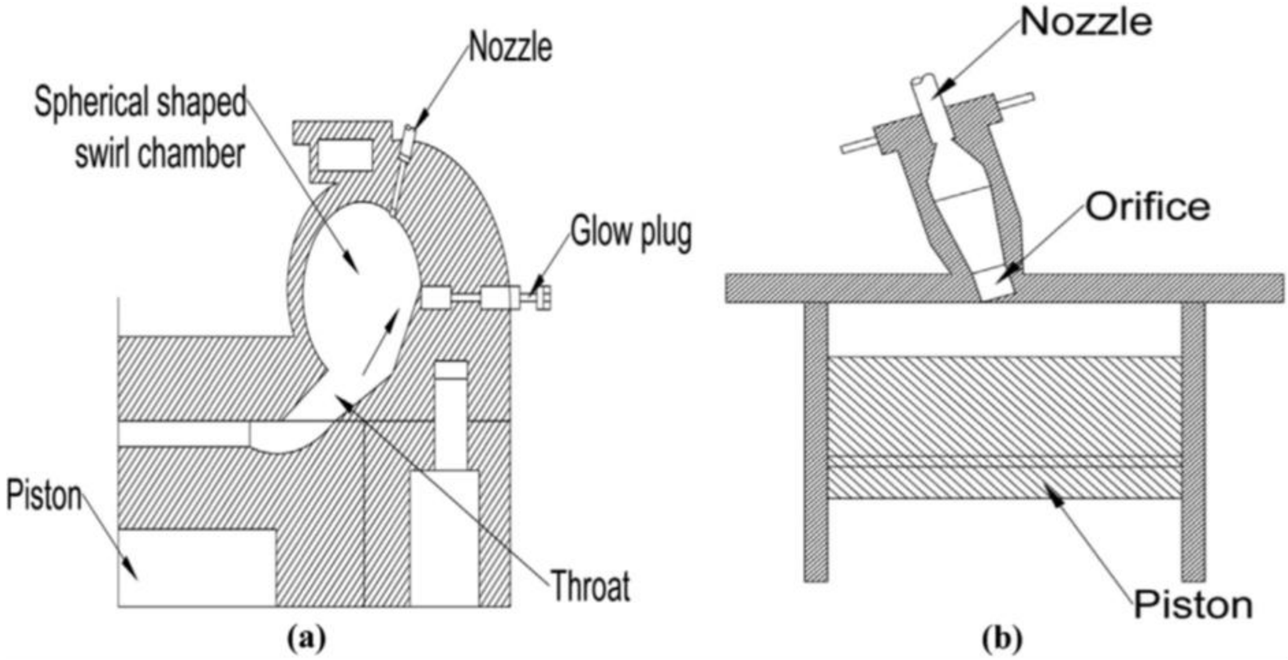


Figure 6. Schematic diagram of different In-direct injection combustion chambers used. (a) Swirl combustion chamber (b) pre-combustion chamber

5. The Effect of Combustion Chamber Geometry on Combustion, Performance and Emissions

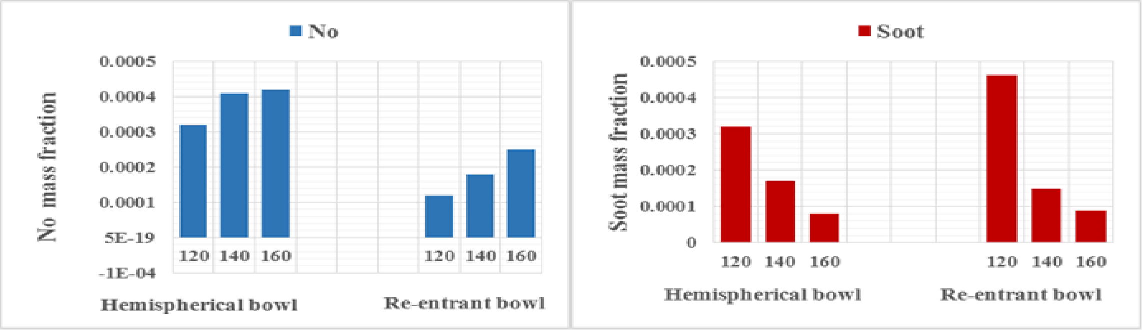
In this section, we refer to studies on the effect of various CC geometries on the various characteristics of the CI engines (combustion, performance and emission parameters).

The impact of the engine piston bowl area on the combustion performance of greenhouse gases examined. The volume of the piston bowl was different and 25%, 30%, 35% and 40% of the total area of the piston. The tests were performed with a single-cylinder diesel engine with a compression ratio of 10: 1 in 1500 rpm with 100% open throttle and the results were analyzed. It was observed that an increase in the piston bowl above 30% of the piston area resulted in instability in the combustion.

However, a significant increase was observed in the brake and brake thermal efficiency power in the ratio of equivalence between 0.7 and 0.9 for the piston bowl of 30%. The HC emission level for the piston bowl was 30%, compared with 25%, 35% and 40%, respectively. There was a significant increase in NO emission in the piston bowl 30% and 25% compared to 35% and 40%. In short, the 30% piston bowl improved combustion performance and reduced emissions.

Dinesh Kumar Soni1, Rajesh Gupta. [27] in his article examined the effect of combustion chamber process on two samples of re-entrant and hemispherical piston bowls to improve the combustion process and the amount of greenhouse gases emission in different spray angles (120°, 140° and 160°) using the AVL FIRE software and trading CFD code, they concluded that at the spray angle of 160, the result is better than the other spray angles. In the case of NO and Soot emission with the spray angle of 120° and 160° respectively had the lowest amount as presented in Figure 7.

Finally, it can be concluded that the re-entrant piston geometry is more reliable to reduce NO emissions; in addition, it can be used for a mass fraction of soot with a 160 ° spray angle. Taghavifar et al. [28] changed their piston structure by making changes in the combustion chamber depth and diameter. First, the bowl spacing from the HCP center from D1 to D4 in steps of 0.005 m (D1 = 0.045 m and D4 = 0.06 m), In the second case, the radius of the bowl ranges from R1 to R4 in steps of 0.001 m (R1 = 0.0047 m and R4 = 0.0077 m). In the first case, the spacing of the bowl from the HCP center from D1 to D4 in steps of 0.005 m (D1 = 0.045 m and D4 = 0.06 m), in the second case, the radius of the bowl from R1 to R4 in steps of 0.001 m (R1 = 0.0047 m and R4 = 0.0077 m). During all structural changes, four steps were considered. It was found that the increase in bowel movement (D1-D4) provides better uniformity in the air / fuel mixture, or the quality (equivalence ratio) or the quantitative (homogeneity ratio) that leads to increased pressure and HRR. However, the start of combustion has been postponed. At the end of the expansion stage, it will affect the engine performance and combustion heat with the delivery of less work. It was reported that at 10 degrees TDC at the angle of rotation of the crankshaft (CA ATDC) with increasing D in piston bowl, temperature and NOx emission will be reduced, it was reported that increasing the radius of the bowl is effective on the performance of the engine, despite the higher oxygen content and air availability with a higher bowel radius, it has adverse effects on the performance of the engine. This issue was in fact attributed to the lesser motion and torsional flow of the air in this model. Due to the larger area of the piston bowl associated with the R4 design, more heat from the piston wall was lost. Jaichandar and Annamalai investigated the biodiesel fuel features modified with a modified piston bowl without changing the engine compression ratio in the diesel engine DI [22]. They found in three ways of Torudyl input combustion chamber (TRCC) and Shallow depth Re-entrant Combustion chamber (SRCC) and hemispherical combustion chamber (HCC). In TRCC, compared to SRCC and HCC, the combustion was better at the maximum cylinder pressure due to better fuel mixing. Due to better air motion, the combustion delay for TRCC is lower than SRCC and HCC. Also, in the study of the specific fuel consumption of the BSFC, the specific fuel consumption for SCC has obtained (0.271 kg / kWh) and HCC, 288.0 kg / kg, TCC above 252.0 kg / kWh. Regarding gases emission, they also achieved the following results: unstable hydrocarbons emission (UBHC) for TRCC and SRCC is reduced compared to the HCC. CO emission by the addition of biodiesel POME is significantly reduced. CO emission from the TRCC engine was lower than two other combustion chambers. Emissions of greenhouse gases and NOx for the TRCC were higher than the base engine, which EGR system was proposed to solve the problem. In the case of the peak pressure, the peak pressure variation due to the braking power for the modified engine and the standard engine with DOME diesel fuel is 20% POME (Figure 8). It can be seen that the peak pressure for the 20% POME compared to the standard PBDF fuel is a bit low.



(a) (b)

Figure 7. Emissions at different spray angle (a) NO mass fraction (b) Soot mass fraction

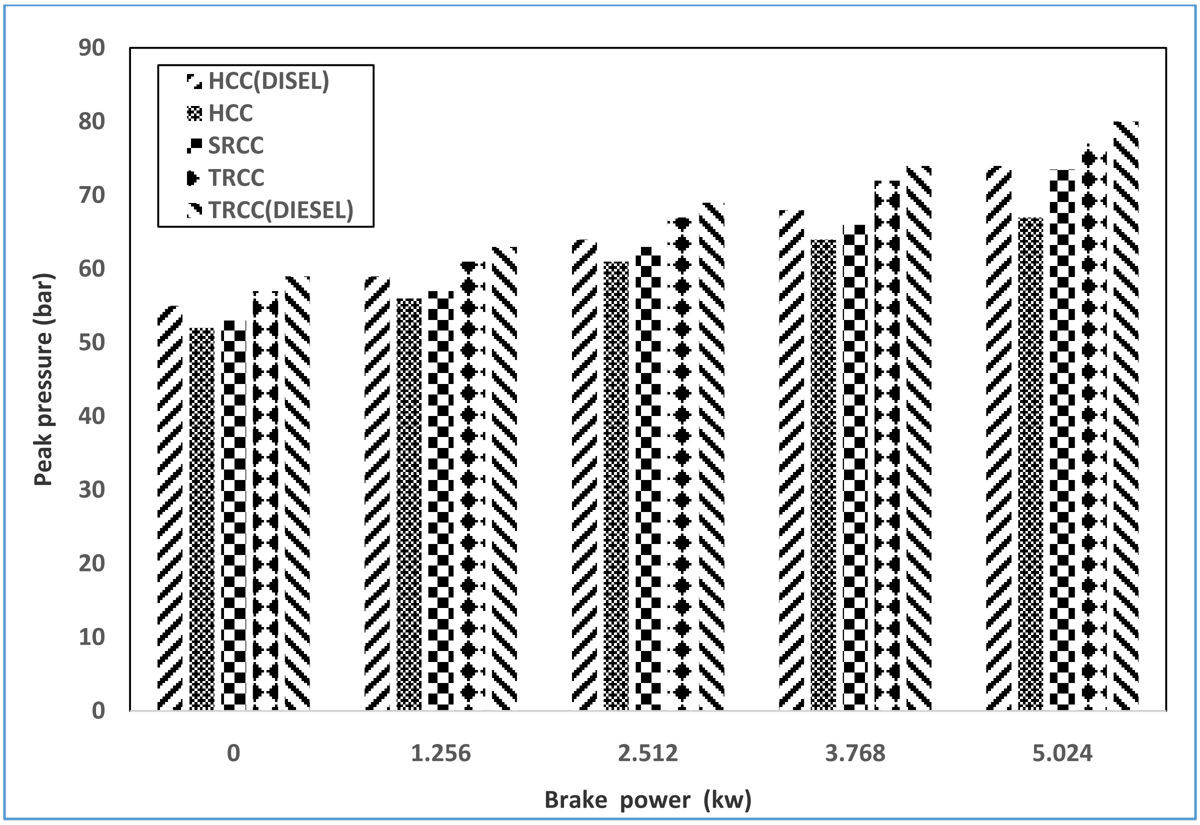


Figure 8. Variations of peak pressures

Saravanakumar et al. [29] have used the results of an empirical study of a single-cylinder CI engine with variable displacement compression ratio which B20 combination as a test fuel (CIME) was mixed with diesel fuel, in order to investigations in a hemispherical combustion chamber (HCC), also with the change in the HCC piston bowl geometry, a modified hemispherical combustion chamber (MHCC) was used. It was considered that CIME mixed with diesel (B20) caused better combustion and emission and under full load conditions, peak pressure B20 in MHCC was higher than HCC and diesel in HCC. This indicated that MHCC increased the pressure of 4.7% compared to diesel in HCC and reduced emissions by 35%, 13.8% and 34.1% were obtained respectively for CO, HC and soot.

Hu et al. [30] examined a medium-speed marine diesel engine with the effects of fuel injector matching and combustion chamber geometry on nitrogen oxide (NOx), steam and specific fuel oil consumption (SFOC) using a parametric study. The study was performed on four different engine loads, for example, at 25%, 50%, 75% and 100% of the engine's load. The parameters of the injection compared with the combustion chamber geometry had significant effects on the targets. The injection time had the greatest effect on the objectives, especially on the NOx emission. Later injections and lower rotation of the air reduced NOX emissions.

6. Conclusions

In the present study, we investigated different geometries of the combustion chamber in the CI engines and the effect of pure diesel and combined diesel fuel on performance, combustion and emission, and the most important results are as follows.

1. With changes in the combustion chamber geometry, and fuel spraying strategies, it is possible to achieve favorable conditions such as squish, swirl, tumble, and turbulence for combustion, performance and emission.
2. In the research on the geometry of the combustion chamber with the modified piston bowl in the MOTD, in three cases, the Toroidal Re-entrant Combustion Chamber (TRCC) and the shallow depth Re-entrant combustion chamber (SRCC) and hemispherical combustion chamber (HCC) in the TRCC compared with the SRCC and HCC has a maximum cylinder pressure and combustion delay for TRCC for TRCC was less than SRCC and HCC. Also, the BSFC for TRCC was more favorable. They also achieved the following results regarding the gases emission: The unstable hydrocarbons emissions (UBHC) for TRCC and SRCC is reduced compared to HCC. CO emission from the engine with TRCC was less than two other Combustion Chamber. Greenhouse gas emissions and NOx for TRCC was higher than others. EGR system was proposed to solve this problem.
3. By investigating the various geometries of the piston bowl, the TRCC model was more favorable for factors such as turbulence, kinetic energy and rotation in the compaction stage and the quality of air movement in the combustion chamber was reduced, respectively, by TRCC> TCC> SCC> CCC> HCC >SqCC
4. The most common and best software for simulating combustion chamber geometry was CFD code, bur

AVL FIRE and KIVA-CHEMKIN were used for the performance and analysis of combustion.

5. The small and large sizes of the piston bowl and the fuel sprayer nozzle nozzles for diesel and bio diesel have had a disproportionate effect on the combustion, the engine performance and emission which was determined with the percentages mentioned in the studies.
6. TBC ceramic materials can be used for better mechanical resistance in the combustion chamber and better results were obtained for different dimensions of combustion such as cylinder pressure, mass fraction, heat emission and volume and pressure diagram.

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