Effect of combustion chamber geometries in biodiesel fueled CI engine: A comprehensive review

V Praveena$^{1,*}$, N S Aswin$^2$, R Vishnu Balaji$^2$ and S Srikrishna$^2$

$^{1,2}$Department of Mechanical Engineering, SRM Institute of Science and Technology, Chennai, Tamil Nadu, India

*Corresponding author: praveena.v@ktr.srmuniv.ac.in

Abstract. Depleting fossil fuels and raise in prices day by day has paid attention to alternative fuels. Emissions are the major concern in biofuels. Stringent future emissions norms can be met with implementation of key technologies. Performance of a biodiesel fueled CI engine can be improved by some modifications in the engine. One such is the combustion chamber geometry. This paper summarizes the results of different types of combustion chamber geometry with various biodiesel. The variations in performance parameters, emissions (UBHC, CO, NOx, smoke) and combustion parameters are also discussed in detail. The summary shows that suitability of alternative fuels can be improved by selecting the proper combustion chamber geometry.

Keywords: Combustion Chamber Geometry, Biodiesel, Emissions, Performance.

1. INTRODUCTION

Automotive sector consumes major portion of energy and contributes to atmospheric pollution. Bharath stage VI norms lays pressure on transport sectors in reducing emissions. This creates an urge for development of new technologies. Vegetable and animal fat oils are feasible alternatives for use in diesel engines, provided their high viscosity is corrected through methods like transesterification and preheating [1]. Other than low viscosity, these fuels suffer from low calorific value and volatility issues. These problems affect injection characteristics, air fuel mixing phenomena and combustion process of a biodiesel fueled diesel engine. Biodiesel possess advantages like renewability, local availability, high cetane number and less cost [2, 3]. Investigation in the past few years show that except NOx, all other emissions such as CO, UBHC and PM are reduced in biodiesel combustion [4, 5, 6 and 7]. Use of additives to improve the efficiency and decrease the emissions is less effective. Hence modification in engine by changing combustion chamber geometry is a good option. The combustion phenomena of fuel are dependent on motion of air and fuel entering the combustion chamber. The combustion chamber helps in providing proper type of rotational motion to the fuel (swirl and tumble).

Fuel rotates parallel to the cylinder axis in swirl motion whereas tumble initiates the vortex motion to the flow. The objective of this article is to summarize the available combustion chamber geometries for different biodiesel and its effect on combustion, performance and emissions from CI engine.
2. COMBUSTION CHAMBER GEOMETRY TYPES

Direct injection and indirect injection combustion chamber are the two types in use. The requirements for a good combustion chamber geometry are improved air fuel mixing, good scavenging, less heat loss, complete utilization of air and fast burning rate.

2.1 Hemispherical combustion chamber (HCC)

It has a domed cylinder head (Figure 1(a)). Combustion takes place in small squish. The depth ratio is varied to give better performance. It is advantageous over a non-cross flow cylinder head. The top of the piston is in the shape of half a sphere. It provides higher surface to volume ratio. Both the intake and exhaust valves are inclined, increasing valve port area that results in higher volumetric efficiency. It consists of semi-swirl injection port with an inclined centrally located injector. This type is not suitable for biodiesel due to its high viscosity and difficulty in atomization resulting in high BSFC.

2.2 Toroidal combustion chamber (TCC)

Motion is very significant in this type of chamber (Figure 1(b)). Better air movement in combustion chamber results in better combustion. The cone angle varies from 150 to 160 degrees. TCC prevents the flame from spreading over to the squish region. This results in better mixture formation of fuel air combinations. There is better swirl and tumble motion in this case.

2.3 Cylindrical combustion chamber (CCC)

It is a modified conical chamber with a truncated cone of base angle 90 degrees (Figure 1(c)). Swirl is produced by making 180 degrees turn of the total circumference.

2.4 Square combustion chamber

It has a narrow squish region (Figure 1(d)). Squish motion initiates swirling motion into the bowl. The exhaust emissions can be considerably amended than the conventional combustion chamber.

Figure 1. Schematic representation of different types of combustion chambers. (a) HCC (b) TCC (c) CCC (d) SCC [27]
3. EFFECT OF COMBUSTION CHAMBER GEOMETRY VARIATION ON PERFORMANCE PARAMETERS

3.1 BSFC
BSFC determines the amount of fuel supplied to the engine for developing the required brake power. Investigations carried over a period conclude that BSFC of engine increases with proportional increase of biodiesel or any alternate liquid fuel. Mohamed et al.[8] carried out experiments on a constant speed diesel engine fueled with various blends of soybean methyl ester. They found that BSFC increased for all blend proportions of SME and was 14.65% higher than diesel. The heating values of methyl esters are less than diesel and they cause an increase in BSFC.

Kasiraman et al. [9] investigated the performance of cashew nut shell oil and found that BSFC is 15.72 MJ/kWh for CSNO and 11.9 MJ/kWh for diesel fuel. Poor combustion of CSNO is because of higher viscosity (55cst) and lower calorific value of 35.8 MJ/kg. Celebi et al.[10] carried out experiments on high viscous biodiesel fuels like Pongamia Pinnata and Tung oils. They found that BSFC of diesel is 12.37% lower than Tung biodiesel and 17.53% lower than Pongamia Pinnata biodiesel. Trial runs on different compression ration also gave results which followed a similar pattern. Ozer at al. [11] studied the effects of Canola biodiesel blends and found that BSFC tended to increase with percentage of blend. The maximum rise in BSFC was 6.56% with B20 blend at the high load. Modification of Combustion chamber geometry has resulted in decrease in BSFC when compared to the conventional design.

Chandrasekhar et al[12] investigated the effect of multi- chambered piston in a Jatropha biodiesel fueled CI engine. They found that BSFC for CR= 17.5 and injection pressure of 200 bar is 0.40 kg/kWhr and 0.38 kg/kWhr for standard piston and modified piston. A slight improvement is seen in case of modified piston. Jaichandran et al.[13] carried out experiments with 20% POME using HCC, TCC and SCC( Shallow depth). The BSFC for TCC, SCC and HCC were 0.275, 0.302 and 0.288. Also, BSFC of diesel was lesser in case of TCC when compared to HCC. Ravichandran et al [14] investigated the effect of hemispherical cavity piston and toroidal shaped piston in a CI engine fueled with corn biodiesel. BSFC was slightly less for toroidal shape (0.304 kg/kWhr) whereas it was 0.312 kg/kWhr for HCC. Modification in the nozzle tip hole has resulted in appreciable changes in fuel consumption. Group hole type nozzle helps in proper circulation of injected fuel in the bowl regions, thereby improving BSFC [15].

3.2 BTE
Researchers studied the effect of combustion chamber geometry on BTE and reported that they contribute to an appreciable extent for improving the BTE. Investigations on biodiesel over a period report that BTE for biodiesel is lower than that of diesel fuel due to lower heating value, higher viscosity and higher volatility [16]. Banapurmath et al [17] carried out experiments on Mahua and Neem biodiesel and showed that TCC geometry gave better performance compared to cylindrical and Trapezoidal, since there was increased swirl motion and better mixing of air fuel mixture [17]. Ravichandran et al has found that TCC was able to give 3.33% higher BTE than HCC. TCC provided a better combustion phenomenon for corn biodiesel [14]

Chandrasekhar et al [12] compared conventional and modified piston for 3 ranges of injection pressure (175, 200 and 225 bar). Injection pressure of 200 bar produced higher BTE due to decreased physical delay period. BTE was 30.30% in case of TCC for engine fueled with 20% POME, whereas the BTE was 29.3% for SCC (Shallow depth) at same loading conditions [13].
4. EFFECT OF COMBUSTION CHAMBER GEOMETRY VARIATION ON EMISSION PARAMETERS

4.1 NOx

Investigators demonstrate that any biodiesel results in an increase in NOx emission for all ranges of load. This is attributed to the cetane no. of biodiesel and degree of unsaturation [18]. Researchers carried out emission test on biodiesel and found that amount of NOx produced varied for different combustion chamber geometry. Lalvani et al.[19] conducted experimental study on 20% adelfa biodiesel using conventional and turbulence induced piston geometry. The NOx emission was 747.27% volume for turbulence induced piston at 200 bar, which is higher than diesel (694.57% vol). TCC provides better turbulence of air and also prevents the flame from spreading over to the squish region. This increases the combustion chamber temperature. 20% POME shows 712 ppm of NOx for HCC and 738 ppm of NOx for TCC [13]. Multi hole nozzle raises the combustion chamber temperature by providing high HRR. Hence, they emit higher NOx compared to conventional hole nozzle [15]. Modification in the bowl distance from the center affects the NOx emission. A considerable rise in temperature is caused due to this design [20].

4.2 HC

The oxygen content of biodiesel is higher compared to diesel. This results in decreased UBHC emissions in biodiesel. When air swirl is improved by suitable modifications in combustion chamber geometry, near complete combustion occurs, thereby reducing UBHC emissions [21]. Emission test on 20% POME on 3 different Combustion chamber geometry showed 54 ppm for TCC and 58 ppm for SCC. Highest emissions were observed for SCC, then HCC and the least was TCC. This is attributed to the better swirl and good mixing of air and fuel [13] Multihole nozzle provides lower HC emissions than the conventional type. This effect was demonstrated by varying the size of nozzle hole and configuration [15]. Research findings of Banapurmath et al[17] goes in hand with the results of Jaichandran et al[13]. Neem and Mahua biodiesel blends produced less HC emissions for TCC geometry due to better turbulence and minimized heat loss [17]

4.3 CO

Insufficient amount of oxygen during combustion results in CO formation. Since biodiesel contains more oxygen atoms, the CO % produced is always less compared to diesel [22].POME biodiesel produced 0.143% by volume of CO emission for TCC, which was recorded as the least among all CC geometry types. Improved combustion phenomena and increased oxygen content are the reasons for reduced CO [13]. Findings of Banapurmath et al.[17] also matches with the prior investigator. CO emission in increasing order for various combustion chamber geometry are TCC, CCC, HCC and TrCC. Mamilla et al.[23] studied the effect of Re-entrant and toroidal combustion chamber on a JTME blend with diesel. They found least CO emissions of 0.24% volume was produced by TCC geometry.

4.4 Smoke

Generally, biodiesel emit less PM due to high oxygen content in the biodiesel molecules. Near complete combustion of fuel leads to less PM and smoke. Banapurmath et al [17] et al has tested NOME and MOME using 3 shapes of combustion chamber geometry and found that TCC produced the least smoke opacity. Trapezoidal CC produced the highest smoke opacity. Smoke emission decreased to a significant extent in TCC while fueling the CI engine with 20% POME [13].

5. EFFECT OF COMBUSTION CHAMBER GEOMETRY VARIATION ON COMBUSTION PHENOMENA

The type of combustion chamber geometry determines the combustion parameters such as cylinder pressure, HRR and ignition delay. Biodiesels generally require higher injection pressure to produce fine atomization and improved combustion. Selecting a suitable geometry instead of standard hemispherical combustion chamber, helps in attaining improved combustion at low injection pressure itself. TRCC
produced high peak pressure when compared to HCC while fueling with 20% POME [24]. Also, modified combustion chamber helps in betterment of HRR. Modifying the bowl piston resulted in better swirl, tumble and therefore better combustion in this combustion chamber [25]. The knocking phenomena of a diesel engine depend upon the ignition delay. Jaichandar et al. [26] conducted experiments on 20% POME for different combustion chamber and found that re-entrant combustion chamber resulted in lower ID periods. This is attributed to the increase in cylinder temperature and improved air fuel mixing. TCC shape resulted in lower ID when compared to HCC, CCC and TrCC. Also, increase in BP, produces less ignition delay because of increased cylinder temperature [17].

6. CONCLUSION

In this study, a summary of modified combustion chamber with biodiesel and its effect on performance, emission and combustion phenomena are given. The results of various investigations of the above researchers are summarized as follows:

- Suitable combustion chamber geometry helps in improving swirl, tumble and squish motion inside the combustion chamber. Based on the properties of biodiesel, the appropriate combustion chamber geometry can be chosen.
- Momentum of air is the best in toroidal re-entrant combustion chamber and the least in square combustion chamber.
- Size and number of holes in the nozzle determines BSFC and BTE.
- Emissions like CO, UBHC and smoke are less for toroidal re-entrant combustion chamber and NOx emissions are high for toroidal re-entrant combustion chamber.

7. REFERENCES

[1] Capuano D, Costa M, Fraia SD, Massarotti N, Vanoli L 2017 Direct use of waste vegetable oil in internal combustion engines, *Renew Sustain Energy Rev.* 69, 759–70.
[2] Ramadhas AS, Jayaraj S, Muraleedharan C 2004 Use of vegetable oils as IC engine fuel – a review, *Renew Energy* 29, 727–42.
[3] Singh P, Varun, Chauhan SR 2017 Feasibility of a new non-edible feedstock in diesel engine: investigation of performance, emission and combustion characteristics, *J Mech Sci Technol.* 31(4), 1979–86.
[4] Barsic NJ, Humke AL(1981), Performance and emission characteristics of a naturally aspirated diesel engine with vegetable oils – Part 1, *SAE paper no. 810262, 1173–87.*
[5] Barsic NJ, Humke AL, Vegetable oils 1981 diesel fuel supplement. *J Automob Eng.* 89(4), 37–41.
[6] Canakci M, Erdil A, Aracakioğlu E 2006 Performance and exhaust emissions of a biodiesel engine, *Appl Energy.* 83, 594–605.
[7] Praveena V, Leenus Jesu Martin M 2017 A review on various after treatment techniques to reduce NOx emissions in a CI engine, *Journal of the Energy Institute.* 1743-9671.
[8] Mohamed F, Dawody AL, Bhatti SK 2013 Optimization strategies to reduce the biodiesel NOx effect in diesel engine with experimental verification, *Energy Conversion and Management.* 68, 96-104.
[9] Kasiraman G, Nagalingam B, Balakrishnan M 2012 Performance, emission and combustion improvements in a direct injection diesel engine using cashew nut shell oil as fuel with camphor oil blending, *Energy.* 47, 116-124.
[10] Çelebi K. 2017 Evaluation of fuel consumption and vibration characteristic of a compression ignition engine fuelled with high viscosity biodiesel and hydrogen addition, *International Journal of Hydrogen Energy.*
[11] Özer Can, Erkan Öztürk, H. Serdar Yucesu 2017 Combustion and exhaust emissions of canola biodiesel blends in a single cylinder DI diesel engine, *Renewable Energy.* 109, 73–82.
[12] Rajashekar CR, Chandrashekar TK, Umashankar C, Kumar RH 2012 Studies on effects of combustion chamber geometry and injection pressure on biodiesel combustion, *Trans Can Soc Mech Eng.* 36(4), 429–38.
[13] Jaichandar S, Annamalai K 2012 Effects of open combustion chamber geometries on the performance of pongamia biodiesel in a DI diesel engine, *Fuel.* 98, 272–9.
[14] Ravichandran A, Rajan K, Narayanan MR, Kumar KS 2016 Effect of piston bowl geometry on the performance of a diesel engine using Corn biodiesel and its diesel blends, *Int J Chem Tech Res.* 9, 105–12.
[15] Park SW, Reitz RD 2008 Modeling the effect of injector nozzle-hole layout on diesel engine fuel consumption and emissions, *J Eng Gas Turbines Power*. 130(3), 1–10

[16] Aydin HS, Bayindir H 2010 Performance and emission analysis of cottonseed oil methyl ester in a diesel engine, *Renew Energy*. 35, 588–92

[17] Banapurmath NR, Chavan AS, Bansode SB, Patil S, Naveen G, Tonannavar S et al 2015 Effect of combustion chamber shapes on the performance of Mahua and Neem biodiesel operated diesel engines, *J Pet Environ Biotechnol*. 6(4), 1–7

[18] Chhina R, Verma SR, Sharda A 2005 Exhaust emission characteristics of an unmodified diesel engine operated on bio-diesel fuels, *J Agric Eng*. 42, 38–43

[19] Lalvani JIJ, Parthasarathy M, Dhinesh B, Annamalai K 2016 Pooled effect of injection pressure and turbulence inducer piston on performance, combustion, and emission characteristics of a DI diesel engine powered with biodiesel blend, *Ecotoxicol Environ Saf*. 134, 336–43

[20] Taghavifar H, Khalilarya S, Jafarmadar S 2014 Engine structure modifications effect on the flow behavior, combustion, and performance characteristics of DI diesel engine, *Energy Convers Manag*. 85, 20–32

[21] Yoon SH, Lee CS 2011 Experimental investigation on the combustion and exhaust emission characteristics of biogas-biodiesel dual-fuel combustion in a CI engine, *Fuel Process Technol*. 92(5), 992–1000

[22] Krahl J, Munack A, Schroder O, Stein H, Herbst L, Kaufmann A 2005 Fuel design as constructional element with the example of biogenic and fossil diesel fuels, *Int Comm Agric Eng*.

[23] Mamilla VR, Mallikarjun MV, Rao GLN 2013 Effect of combustion chamber design on a DI diesel engine fuelled with Jatropha methyl esters blends with diesel, *Procedia Eng*. 64, 479–90

[24] Jaichandar S, Annamalai K 2013 Combined impact of injection pressure and combustion chamber geometry on the performance of a biodiesel fueled diesel engine, *Energy*. 55, 330–9.

[25] Manikalihas P, Venkatachalam R, KalilRahiman M, Boopathi P, Bharathiraja M 2016 Comparison study of existing bowl piston and modified bowl piston diesel engine performance emission and combustion characteristics by using diesel, *J Adv Chem*. 12, 5243–51.

[26] Jaichandar S, Annamalai K 2012 Influences of re-entrant combustion chamber geometry on the performance of Pongamia biodiesel in a DI diesel engine, *Energy*. 44, 633–40.

[27] Varun, Paramvir Singh, Samaresh Kumar Tiwari, Rituparn Singh, Naresh Kumar 2017 Modification in combustion chamber geometry of CI engines for suitability of biodiesel: A review, *Renewable and Sustainable Energy Reviews*. 79, 1016-1033