International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 7, Issue 7, July 2017)

# Comparative Study on the Modified Combustion Chamber Geometries in Diesel Engine for Using Biodiesel to Achieve Emissions Standards

Palash Chakma[1], Haeng Muk Cho[2]

[1]*Research Assistant,* [2]*Professor, Division of Mechanical and Automotive Engineering, Kongju National University, 275, Budae-dong, Cheonan-si, Chungcheongnam-do 331-717, South Korea*

***Abstract*— In diesel engine, fuel is injected into the engine cylinder near the end of the compression stroke. Combustion in diesel engines is very complex and until recently, its detailed mechanisms were not well understood. Biodiesel has properties comparable to ultra-low sulfur diesel; however certain properties of biodiesel such as viscosity, calorific value, density and volatility differ from ultra-low sulfur diesel and thereby affect combustion and performance in a diesel engine. The present studies the effect of varying the combustion chamber geometry namely Hemispherical, Toroidal, Shallow depth, Re-entrant and Cylindrical on the combustion and emissions characteristics of a diesel engine for using biodiesel and have been considered and results obtained from experimental analysis were discussed. Toroidal combustion chamber shows higher brake thermal efficiency than for the others. Meanwhile, carbon monoxide and unburnt hydrocarbons is observed for toroidal combustion chamber compared to the others and thereby particulates reduction is improved significantly. However nitrogen oxides were slightly higher for toroidal combustion chamber. The combustion analysis shows improved characteristics for toroidal combustion chamber compared to diesel engine at all loads of operation. Finally we concluded that modification in combustion chamber could help slightly to use biodiesel in diesel engine.**

***Keywords*— Combustion chamber, Biodiesel, Emissions, Combustion, Engine**

## I. Introduction

The applications of diesel engine such as transportation, agriculture and power generation sectors are becoming more popular in the worldwide due to their higher efficiency, power output, less fuel consumption, lower emissions, and durability as compared to gasoline engines over the past few decades. Keeping in the mind, the fossil fuel reserves are limited and environmental effects, the use of eco-friendly fuels (biodiesel) could be a suitable diesel oil substitute for diesel engines [1]. For this reason, the reduction of harmful emissions, improvement of fuel consumption and without scarifying engine performance many studies have been trying to develop of next generation technologies for diesel engines is progressing steadily. However, the properties of biodiesel such as viscosity, calorific value, density, and volatility differ which is comparable to ultra-low sulfur diesel.

In this context, the momentum is gathering to find the alternative source of fuel with modification of engine [2-3]. The main advantages of biodiesels are renewable, can be produced locally, low price, better lubricity, higher cetane number, and low sulfur content and environmentally friendly compared to diesel fuel. As per previous studies, use of biodiesels as fuel in diesel engines causes several problems, namely poor fuel atomization and low volatility originated from their high viscosity, high molecular weight and density [4]. On the contrary, their disadvantages include the higher viscosity and pour point, and lower calorific value and volatility. Moreover, their oxidation stability is lower, they are hygroscopic, and as solvents may cause corrosion in various engine components. Considering the above reasons, it is recommended that blends of diesel fuel, with up to 20% bio-diesels, can be used in existing diesel engines without any modification [5]. In addition, most of the studies indicated that carbon monoxide (CO), unburned hydrocarbon (UHC) and particular matters (PM) emissions were reduced, whereas nitrogen of oxides (NOx) and fuel consumption slightly increased in biodiesel-fueled diesel engines [6]. Combustion chamber geometry plays an important role in boosting the in-cylinder air motion which in turn in air-fuel mixing and combustion process [7]. The researchers are still working on various techniques such as pre-combustion, post-combustion and engine design modification to enhance better performance and reduce exhaust emissions and also to reduce the severity of the frightening situation and to mitigate the impact of the fuel problem [8]. The motion of fuel in the combustion chamber is turbulent, transient and three dimensional. The gas motion is unstable during intake and compression [9]. It is so desired that the fuel that enters the chamber undergoes a rotational motion in the cylinder. There are two types of rotational motion in the fuel – swirl and tumble [10–12]. In swirl motion, the fuel rotates parallel to the axis of the cylinder and in a tumble; it goes perpendicular to the axis of the cylinder. Swirl motion helps in enhancement of flame speed and combustion rate in the cylinder. Tumble is the vortex motion generated by flow through intake valves and its real application is in pent roof type CC used in four valve spark-ignition engines.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 7, Issue 7, July 2017)

There is another type of motion called as 'squish' which occurs in piston bowl type geometries. Here, the fuel goes radially inward during the compression stroke. Thus, the optimized bowl geometries allowed the reduction of engine emissions and better engine performances compared to original combustion chambers [13]. So, either improves the fuel properties or change the design parameter of the engine can be improved the performance of diesel engines operating with biodiesel. But, due to the duration of feedstocks, it's not so easy to improve the fuel properties and it also not much effective for decreasing the dependency on diesel if some additives will also be used to improve the properties of the fuel. Then, by changing in combustion chamber geometry and injection parameters are quite good options to improve the performance of the engine. Also, the performance and efficiency of the engine depend on the motion of air-fuel mixture inside the chamber has a profound effect on combustion rate of fuel. So, the purpose of this paper is to study of different kinds of modified combustion chamber geometries affects air-fuel mixing and its impact on the combustion, performance, and emissions.

## II. Factors To Be Considered For Better Combustion

The design of combustion chamber of diesel engine is different than any other combustion chambers. Usually heat loss, nozzle design and utilization of air are major requirements. Following are the factors to be considered for designing the combustion chamber which is described in Figure 1.

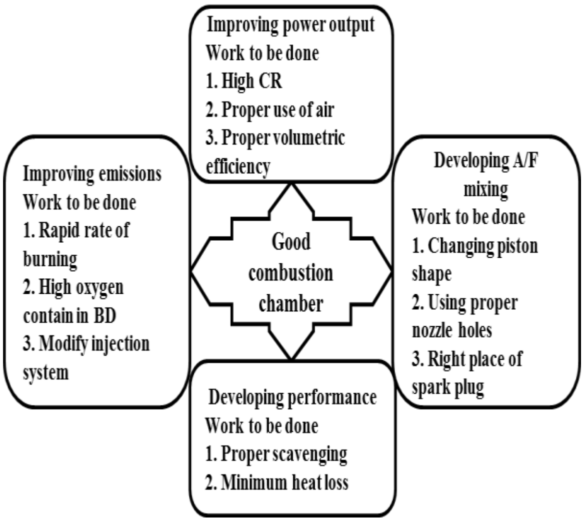



**Figure 1: The basic requirements of the combustion chamber**

Also, Primary Considerations in the Design of Combustion Chambers for C.I Engines: High thermal efficiency, Ability to us of less expensive fuel, Ease of starting, Ability to handle variations in speed, Smoothness of separation, Low exhaust emission, Nozzle design, High volumetric efficiency and High brake mean effective pressure [34].

## III. Combustion Chamber Arrangements And Various Shapes

The design of combustion chamber has an important influence upon the engine performance and its knock properties. The design of combustion chamber involves the shape of the combustion chamber, the location of the sparking plug, turbulence of air and the disposition of inlet and exhaust valves as shown in Figure 2. Because of the importance of combustion chamber design, it has been a subject of considerable amount of research and development in the last fifty years. It has resulted in raising the compression ratio from 4:1 before the First World War period to 8:1 to 11:1 in present times with special combustion Chamber designs and suitable anti-knock fuels. To provide proper mixing of fuel and air in short time is the main function of combustion chamber in diesel engine. The spray cone gets disturbed due to air motion and turbulence inside when the liquid fuel is injected into combustion chamber. The onset of combustion will cause an added turbulence that can be guided by the shape of the combustion chamber, makes it necessary to study the combustion design. Usually for low (rpm>1500) and medium speed (1500<rpm>3000) direct injection type combustion chamber and for high speed (rpm<3000) indirect combustion chamber is widely used.

The table 1 shows that cetane number of all the oils is slightly lower than the diesel indicating that straight vegetable oil (SVO) are the potential substitute of diesel but the viscosity ranging from 27.2 (linseed oil) to maximum of 51.15 $mm^2/sec$ (tallow oil) is considerably higher than diesel which indicates that there is a need to bring the viscosity of oil near to the diesel either by physical or chemical modification producing the resulting product as perfect substitute of diesel in all respect. The cold flow properties of SVO are lower than diesel indicating that performance of oil as fuel is difficult at low temperature due to its solidification as compared to diesel.

IJETAE
EXPLORING RESEARCH AND INNOVATIONS

**International Journal of Emerging Technology and Advanced Engineering**
**Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 7, Issue 7, July 2017)**

**TABLE I**
**DIFFERENT KIND OF BIODIESEL PROPERTIES AND THEIR ESTERS [32]**

| Type of biodiesel oil | Cetane number | Heating value (Kj/kg) | Viscosity (mm²/s) | Cloud point (℃) | Pour point (℃) | Flash point (℃) | Density (Kg/㎥) |
|---|---|---|---|---|---|---|---|
| Castor oil | NA | 39500 | 297(38°C ) | NA | -31.7 | 260 | 961 |
| Coconut oil | NA | NA | NA | NA | NA | NA | 924.27 |
| Cottonseed oil | 41.8 | 39468 | 33.5(38°C) | 1.7 | -15 | 234 | 925.87 |
| Linseed oil | 34.6 | 39307 | 27.2(38°C ) | 1.7 | -15 | 241 | 929.07 |
| Olive oil | NA | NA | NA | NA | NA | NA | 918 |
| Palm oil | 42 | NA | NA | NA | NA | NA | 910.1 |
| Peanut oil | 41.8 | 39782 | 39.6 (38°C) | 12.8 | -6.7 | 271 | 914 |
| Rapeseed oil | 37.6 | 39709 | 37.0 (38°C) | -3.9 | -31.7 | 246 | 920 |
| Sesame oil | 40.2 | 39349 | 35.5 (38°C) | -3.9 | -9.4 | 260 | 922 |
| Soybean oil | 37.9 | 39623 | 32.6(38°C ) | -3.9 | -12.2 | 254 | 997.5 |
| Sunflower oil | 37.1 | 39575 | 37.1 (38°C) | 7.2 | -15 | 274 | 920 |
| Tallow oil | NA | 40054 | 51.15(40°) | NA | NA | 201 | 820 |
| Jatropha oil | 51 | 39700 | 51 (30℃) | 16 | NA | 242 | 932 |
| Pongamia oil | 51 | 46000 | 55.1(30℃) | 23 | NA | 110 | 884 |
| Diesel | 47 | 45343 | 2.7 (38°C) | -15 | -33 | 52 | 870.2 |

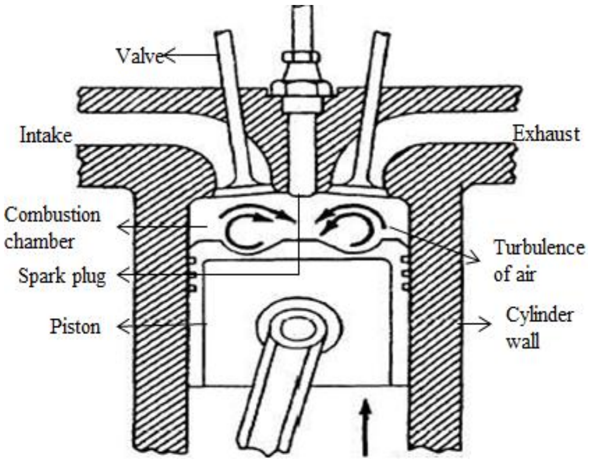



**Figure 2: Schematic of combustion chamber arrangements [34]**

*Direct injection type—* Basically it is designed for high swirl (piston has deep bowl with fewer holes in the injector) and low swirl (piston has shallow bowl with more holes in the injector). Nevertheless, in this type the entire volume of combustion chamber is located in the main cylinder and fuel is injected into this volume.

It is also known as an open combustion chamber. Here are some chambers shapes are discussed below:

*Hemispherical combustion chamber:* It gives small squish in Figure 2(a). However, the depth to diameter ration for a cylindrical chamber can be varied to give any desired squish to give better performance.

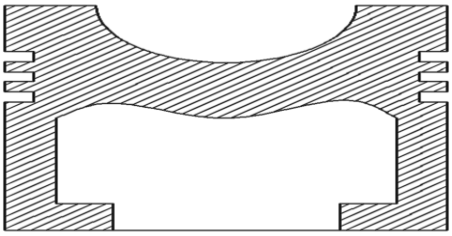
*Toroidal combustion chamber:* The idea behind this shape is to provide a powerful squish along with the air movement, similar to that of the familiar smoke ring, within the toroidal chamber in Figure 2(b). Due to powerful squish the mask needed on inlet valve is small and there is better utilization of oxygen. The cone angle of spray for this type of chamber is 150° to 160°.

*Shallow depth combustion chamber:* In shallow depth chamber the depth of the cavity provided in the piston is quite small shown in Figure 2(c). This chamber is usually adopted for large engines running at low speeds. Since the cavity diameter is very large, the squish is negligible.

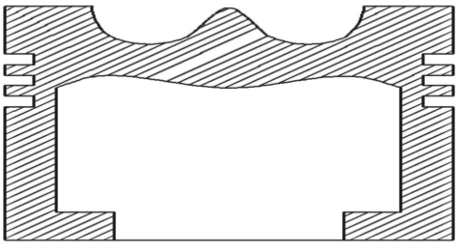
*Re-entrant combustion chamber:* The swirling motion into the chamber during the compression stroke creates a turbulent environment especially in the corner regions while using a re-entrant combustion chamber with a narrow squish region and strong squish forces in Figure 2(d).

**International Journal of Emerging Technology and Advanced Engineering**
**Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 7, Issue 7, July 2017)**

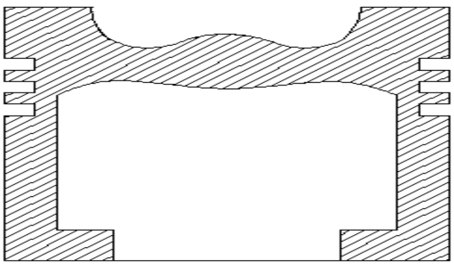
Cylindrical combustion chamber: This design was attempted in recent diesel engines in Figure 2(e). This is a modification of the cylindrical chamber in the form of a truncated cone with base angle of 30°. The swirl was produced by masking the valve for nearly 180° of circumference and squish can also be varied by varying depth.



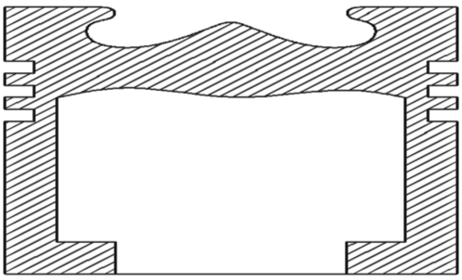
**(a) Hemispherical**



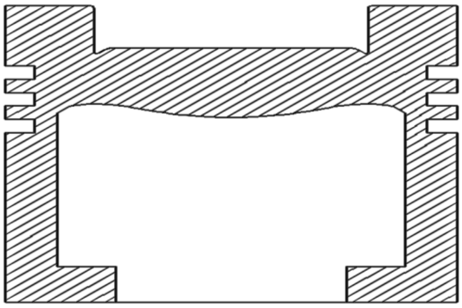
**(b) Toroidal**



**(c) Shallow depth**



**(d) Re-entrant**



**(e) Cylindrical**

**Figure 2: Schematic diagram of direct injection combustion chambers**

*Indirect injection type—* A divided chamber is defined as one in which the combustion space is divided into two or more distinct compartments connected by restricted passages. This creates considerable pressure differences between them during the combustion process.

*Swirl combustion chamber:* Swirl chamber consists of a spherical shaped chamber separated from the engine cylinder and located in the cylinder head as shown in Figure 3(a) and about 50% of the air is transferred during the compression stroke. A throat connects the chamber to the cylinder which enters the chamber in a tangential direction so that the air coming into this chamber is given a strong rotary movement inside the swirl chamber and after combustion, the products rush back into the cylinder through same throat at much higher velocity. This type of combustion chamber finds its application where fuel quality is difficult to control, where reliability under adverse conditions is more important than fuel economy. The use of single hole of larger diameter for the fuel spray nozzle is often important consideration for the choice of swirl chamber engine.

*Pre combustion chamber:* Typical pre-combustion chamber consists of an anti-chamber connected to the main chamber through a number of small holes compared to the swirl chamber in Figure 3(b). The pre-combustion chamber is located in the cylinder head and its volume accounts for about 40% of the total combustion space. The fuel is injected into the pre-chamber at high velocity and the combustion is initiated. Thus it creates both strong secondary turbulence and distributes the flaming fuel droplets throughout the air in the main combustion chamber.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 7, Issue 7, July 2017)

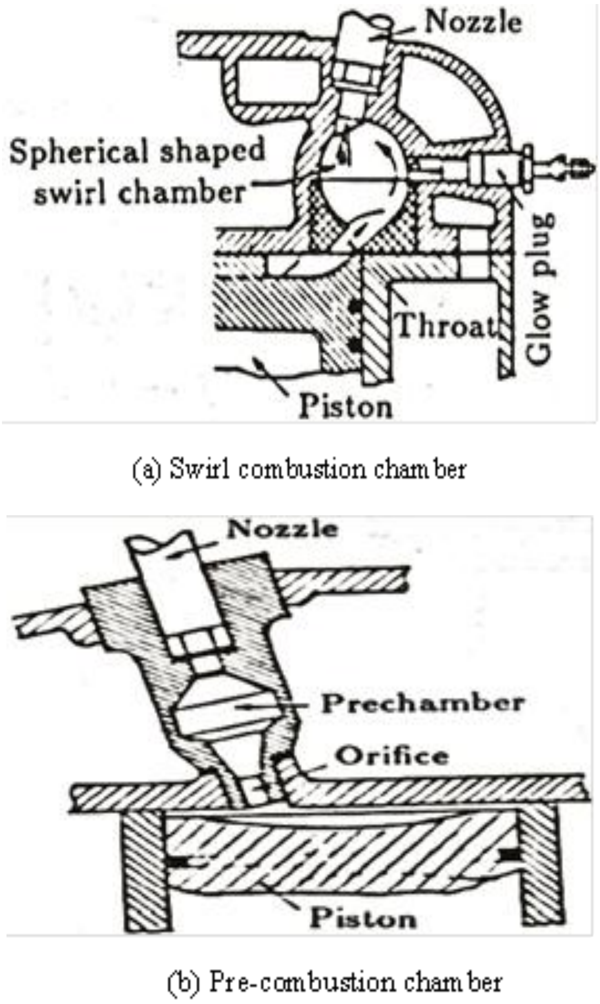



**Figure 3: Schematic diagram of indirect combustion chambers [33]**

## IV. Analysis Of Modified Combustion Chamber Geometry And Their Parameters

Combustion chamber has been modified without altering compression ratio. The analysis is mainly divided into three segments such as combustion parameters analysis, performance parameters analysis and emission parameters analysis. In this section effects of combustion chamber configurations and geometry on the performance of diesel engine are presented in following sections.

Pressure variation: High injection pressure is needed for making fine atomization of biodiesel droplet due to high surface tension and viscosity of biodiesel so that proper air fuel mixing takes place. Figure 4 shows the cylinder pressures of various combustion geometries such as hemispherical, shallow depth, re-entrant and toroidal have been analyzed. It is found that biodiesel has depressed cylinder pressure when compared to diesel due to more prominent viscosity.

Among all combustion chambers, the cylinder pressure trend of TCC with 20% POME is found closer to that of standard engine operated with diesel fuel and well above for SCC and HCC with 20% POME. This may be attributed to better combustion due to better air fuel mixing [5, 8]. The pressure for ROME–producer gas operation with TCC is higher compared to ROME producer gas operation with other combustion chamber shapes tested. It is perhaps due to relatively more complete combustion which is on account of the more eminent turbulent and swirl motion of air and the increase in the evaporation rate. The pressure for MOME biodiesel operation with TCC was higher compared to NOME biodiesel tested. Both test shows that the sharp increase in combustion acceleration shows increase in cylinder pressure during the piston's descent and that the combustion energy is efficiently converted into work [15-16]. Diesel also shows higher cylinder pressure due to higher calorific value and fine atomization of fuel.

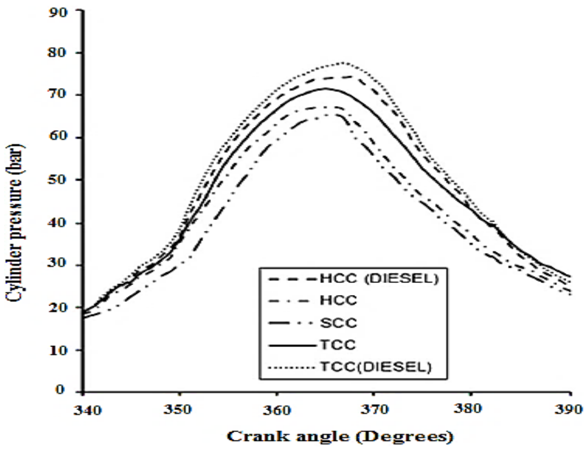



**Figure 4: Variations of cylinder pressure [5]**

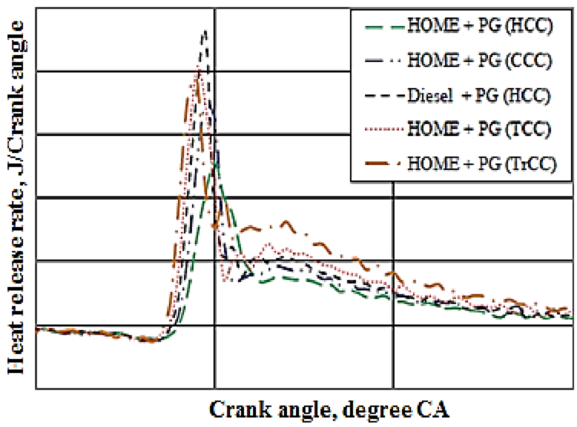



**Figure 5: Comparison of rate of heat release and crank angle [15]**

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 7, Issue 7, July 2017)

*Heat release rate:* The heat release rate is more as compared to conventional combustion chamber for biodiesel due to better in case of modified combustion chamber. In Figure 5, TCC shows higher heat release rate as compared to other combustion chambers during biodiesel operation. This is due to higher density and viscosity of biodiesel which leads to poor fuel atomization and mixing resulting in late burning and lower heat release. Retardation of injection timing decreases the ignition delay causing lower premixed combustion and lower peak heat release rate [17]. A study reported that the modified bowl piston gives higher HRR as compared with existing bowl piston due to higher atomization, volatility, vaporization of diesel and better swirl, squish and turbulence motion of A/F mixing in modified combustion chamber which results in the better combustion in combustion chamber [18]. Moreover, another study investigated the performance and emission of heavy duty diesel engine using three types of bowl geometries such as steeped, bathtub and stock. It is concluded that the HRR was slightly higher for stepped piston as compared to stock geometry while better combustion will be occurred in bathtub piston [19].

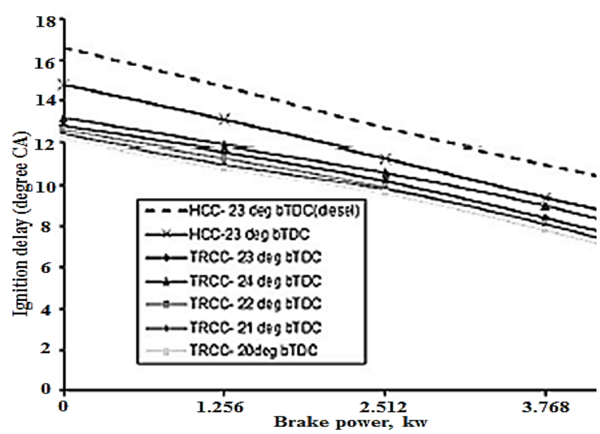



**Fig. 6 Variations of ignition delay [2].**

*Ignition delay:* The most important parameter in determining the knocking characteristics of diesel engines is called ignition delay. Most importantly it depends on some factors such as injection pressure, injection timing, compression ratio, cetane number and fuel properties. Hence, shorter ignition delay is created due to high cetane number and vice versa. Figure 6 shows that for re-entrant combustion chambers the ignition delay periods are lower compared to open type combustion chambers at all loads of operation. For all test fuels and combustion chamber geometries the reduction in ignition delay increases with the increase in load [2].

Authors investigated that the modified bowl of the combustion chamber by changing the bowl distance from $D_1$ to $D_4$ in 0.005m paces from the center and radius from $R_1$ to $R_4$ in 0.001m paces. It is found that combustion increases as bowl radius and wall diameter also increased. Moreover, outward movement of outer wall of the bowl has been created due to increase in ignition delay [20].

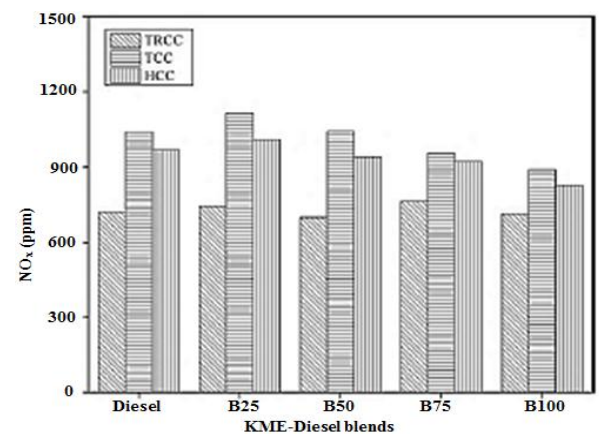



**Figure 7: NOx variation effects of different CC [22].**

*$NO_x$ emission:* Most of the researchers found that $NO_x$ emissions increases slightly in all types of combustion chamber geometry while operating with biodiesel instead of diesel and also the concentration of biodiesel in the blends affects the higher $NO_x$ emissions. Meanwhile, the load applied in the engine is one of the most important factors for increasing $NO_x$. Authors observed that the sensitivity of $NO_x$ with cetane number is high at low load compared to high load due to at high load maximum amount of fuel was injected and burn during controlled combustion period by which temperature of chamber was increased and $NO_x$ decreases [21]. From Figure 7, it is observed with various combustion chamber geometries for different test fuels with $NO_X$ emission at full load condition. The observed higher $NO_X$ emission for all test fuels with TCC than other geometries was held accountable due to the higher in-cylinder temperature in respect of better combustion [22]. Another study reported that $NO_x$ was much higher for SCC as compared to other geometries at 1200rpm engine speed due to combustion temperature was very high. But OCC produces much higher NOx emission and SCC produces low emission because SCC has longest duration of heat release and lowest rate of heat release when engine speed change from 1200rpm to 3600 [23].

Also, It has been investigated the diesel engine running with combination of vegetable and fat oil and found out that oxides of nitrogen were highly increased for both fuel (neat or blended) because of increase in the temperature of combustion chamber due to high oxygen contents in biodiesel [24].

*CO emission:* Carbon monoxide is a toxic by-product and is formed due to incomplete combustion of fuel or lack of oxygen. But, in case of incomplete combustion, either due to low gas temperature or due to shortage of air, CO will be formed [25]. As biodiesel contains more oxygen than diesel, so the amount of CO emission decreases either the combustion chamber geometry is modified or not. But in case of modified TCC geometry, the CO emission is quite lesser than that of conventional HCC geometry due to complete combustion [13]. The variation of carbon monoxide (CO) emission levels for diesel shown in Figure 8. It is observed that incomplete combustion and associated lower BTE with respective configuration is responsible for this observed trend. However, HC and CO emission levels shows lower in TCC compared to other combustion chamber shapes. The cause of the incomplete combustion products for gasoline-diesel blends is the fact that longer ignition delay will produce more notable over-leaning in the cylinder. An experiment carried out using rapeseed oil in standard CI engine without any modification in CC geometry and found approximately a 50% decrease in CO emission as compared to diesel fuels [26]. Therefore, also several blends of rapeseed methyl ester have been tested with diesel and with and without use of catalytic converter in a turbocharged in engine. It is overserved that CO reduces about 47.6% without catalytic converter and reduces 33% with catalytic converter because of the percentage of oxygen molecules increase with BD and CO converted into $CO_2$ [27].

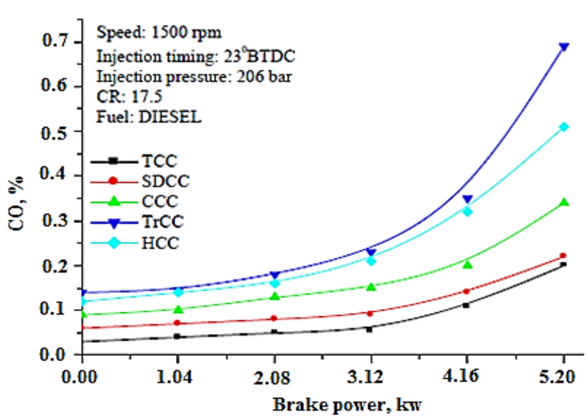



**Figure 8: Illustration of CO and BP with different CC [25]**

Carbon monoxide remains in the exhaust if the oxidation of CO to CO2 is not complete. This is because carbon monoxide is an intermediate product in the combustion process. Generally, this is due to lack of sufficient oxygen. The emission levels of CO from gasoline engine are highly dependent on A/F ratio. Also, Better carburetion and fuel distribution are key to low CO emission in addition to operating the engine at increased air-fuel ratio [35].

*Smoke emission:* Due to more oxygen content in the biodiesel molecules, the low levels of sulfur and higher cetane number, PM emissions generally reduce by using biodiesel as compared to diesel. Also the increase of oxygen content in the biodiesel contributed to complete fuel oxidation even in locally rich zones, leading to a significant decrease in PM and smoke. Further, due to high temperatures and available oxygen in the region could help mixing of air and fuel resulted in burning of particulate matter at the boundary of diffusive flame [28-30]. The variation of smoke opacity with brake power shows in Figure 9. It has been observed that smoke opacity for UOME was higher than diesel over the entire load range. Due to higher viscosity and higher free fatty acid content of biodiesel considered could lead to improper fuel air mixing. However, all the combustion chambers give higher smoke emission levels compared to TCC. It may be due to the fact that, the air-fuel mixing prevailing inside combustion chamber and higher turbulence resulted in better combustion and oxidation of the soot particles which further leads to reduction in the smoke emission levels. Moreover, one research showed the variation of smoke density with brake power and observed that TCC produce less smoke density as compare to TrCC, CCC, HCC because TCC generate high turbulence inside the combustion chamber which results oxidation of smoke particles and reduce smoke emission [16]. Also an experiment has investigated in three types of combustion chambers such as spherical, re-entrant and toroidal using 20% Jatropha methyl ester at different loads. The result shows that the reduction in smoke density was higher for toroidal combustion chamber than that of other types of geometry. The result shows that the smoke opacity for spherical, re-entrant and toroidal combustion chamber were 133 $mg/m^3$, 130 $mg/m^3$ and 126 $mg/m^3$ respectively. This decrement in smoke opacity is due to better turbulence in air-fuel mixture and higher oxygen content in the biodiesel [31].

*Blue smoke:* It results from the burning of engine lubricating oil that reaches combustion chamber due to worn piston rings, cylinder liners and valve guides.

IJETAE
EXPLORING RESEARCH AND INNOVATIONS

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 7, Issue 7, July 2017)

*White or cold smoke:* It is made up of droplets of unburnt or partially burnt fuel droplets and is usually associated with the engine running at less than normal operating temperature after starting, long period of idling, operating under very light load, operating with leaking injectors and water leakage in combustion chamber. This smoke normally fades away as engine is warmed up and brought to normal stage.

*Black or hot smoke:* It consists of unburnt carbon particles (0.5" 1 microns in diameter) and other solid products of combustion. This smoke appears after engine is warmed up and is accelerating or pulling under load [35].

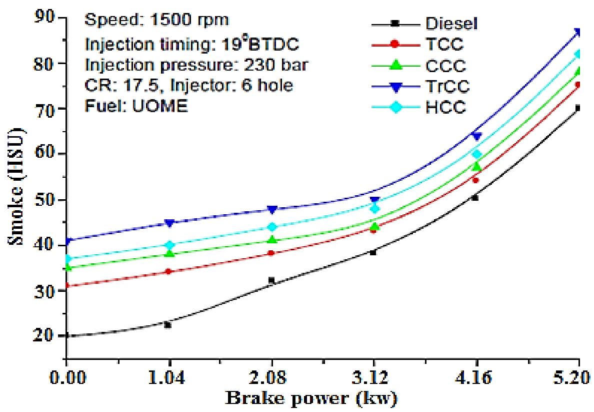



**Figure 9: Variation of smoke opacity with brake power [14]**

## V. CONCLUSION

Diesel engines have an excellent reputation for their low fuel consumption, reliability, and durability characteristics. They are also known for their extremely low hydrocarbon and carbon monoxide emissions. However, they have also been rejected by many for their odorous and sooty exhaust that is also characterized with high nitric oxide and particulate matter emissions. In this present work, modified combustion chamber geometry has been studied with biodiesel and also its factors, parameters have been discussed. The results can be acquired from this study may be summarized as follows.

1. To improve the performance of the engine by changing in combustion chamber geometry and injection parameters are quite good options. However, the use of different types of geometry could help to achieve the better air motion such as squish, swirl, tumble, turbulence and structure of bowl to justify the flow behavior inside the combustion chamber.
2. The change in bowl displacement demonstrates higher flow dynamic and engine performance change as compared two factors of bowl design. So, in order to acquire best efficiency that the users forecast on this element is highly recommended.
3. Ignition delay for open type combustion chamber are higher than re-entrant type geometry and the cylinder wall temperatures increases and exhaust gas dilution decrease at high loads for all geometry. It is also observed that TCC produces better air motion as compared to other geometry which results in acquired air fuel mixing and increases the combustion parameter.
4. It is also found that carbon monoxide, smoke and hydrocarbons was slightly lower for toroidal combustion chambers compared to the other but those are lower when compared to diesel. On the other hand, nitrogen oxides play just opposite role and vice versa. This may be attributed due to better swirl and turbulence motion which improve mixing of air and fuel and increase the temperature of the combustion chamber.
5. The combustion, performance and emission characteristics have been affected by the piston, piston bowl geometry and atomization of fuel in the combustion chamber. Also better turbulence kinetic energy and swirl found in re-entrant bowl geometry during compression stroke. For getting better momentum of air in combustion chamber in increasing order should be like this SqCC <HCC <CCC <SCC <TCC <TRCC.

*Acknowledgement*

This research was supported by The Leading Human Resource Training Program of Regional Neo industry through the National Research Foundation (NRF) of Korea funded by the Ministry of Science, ICT and future Planning (NRF-2016H1D5A1909917).

## REFERENCES

[1] V.S. Yaliwal, N.R. Banapurmath, N.M. Gireesh, R.S. Hosmath, Teresa Donateo, P.G. Tewari. Effect of nozzle and combustion chamber geometry on the performance of a diesel engine operated on dual fuel mode using renewable fuels. Renewable Energy 93 (2016) 483-501.

[2] S. Jaichandar, P. Senthil Kumar, K. Annamalai. Combined effect of injection timing and combustion chamber geometry on the performance of a biodiesel fueled diesel engine, Energy 47 (2012) 388-394.

[3] Hyung Jun Kim, Kwan Soo Lee, Chang Sik Lee. A study on the reduction of exhaust emissions through HCCI combustion by using a narrow spray angle and advanced injection timing in a DME engine. Fuel Processing Technology 92 (2011) 1756–1763.

[4] Murat Karabektas. The effects of turbocharger on the performance and exhaust emissions of a diesel engine fuelled with biodiesel. Renewable Energy 34 (2009) 989–993.

[5] S. Jaichandar, K. Annamalai. Effects of open combustion chamber geometries on the performance of pongamia biodiesel in a DI diesel engine. Fuel 98 (2012) 272–279.

[6] J. Li, W.M. Yang, H. An, A. Maghbouli, S.K. Chou. Effects of piston bowl geometry on combustion and emission characteristics of biodiesel fueled diesel engines. Fuel 120 (2014) 66–73.

[7] Amir Hasan Kakaee, Ali Nasiri Toosi, Babak Partovi, Amin Paykani. Effects of piston bowl geometry on combustion and emissions characteristics of a natural gas/diesel RCCI engine. Applied Thermal Engineering 102 (2016) 1462–1472

[8] B. Dhinesh, M. Annamalai, Isaac Joshua, Ramesh Lalvani, K. Annamalai. Studies on the influence of combustion bowl modification for the operation of Cymbopogon flexuosus biofuel based diesel blends in a DI diesel engine. Applied Thermal Engineering 112 (2017) 627–637.

[9] ARGS Raj, Mallikarjuna JM, Ganesan V. Energy efficient piston configuration for effective air motion CFD Study. Applied Energy 102 (2013) 347–54.

[10] Musa O, Xiong C, Changsheng Z, Li W. Effect of inlet conditions on swirling turbulent reacting flows in a solid fuel ramjet engine. Applied Thermal Engineering 25(113) (2017) 186–207.

[11] Bari S, Saad I. CFD modelling of the effect of guide vane swirl and tumble device to generate better in-cylinder air flow in a CI engine fuelled by biodiesel. Computational Fluids 84 (2013) 262–9.

[12] Benajes J, Olmeda P, Martín J, Blanco-Cavero D, Warey A. Evaluation of swirl effect on the Global Energy Balance of a HSDI Diesel engine. Energy 122 (2017) 168–81.

[13] Seokhwon Lee, Joonho Jeon, Sungwook Park. Optimization of combustion chamber geometry and operating conditions for compression ignition engine fueled with pre-blended gasoline-diesel fuel. Energy Conversion and Management 126 (2016) 638–648.

[14] D.N. Basavarajappa, N. R. Banapurmath, S.V. Khandal, G. Manavendra. Effect of Combustion Chamber Shapes & Injection Strategies on the Performance of Uppage Biodiesel Operated Diesel Engines. Universal Journal of Renewable Energy 2 (2014) 67-98.

[15] Nataraj Kashipura, Banapurmath NR, Manavendra G, Nagaraj AM, Yaliwal VS, Vaibhav Kulkarni and Satish Gokak. Effect of Combustion Chamber Shapes on the Performance of Duel Fuel Engine Operated on Rice Bran Oil Methyl Ester and Producer Gas. Journal of Petroleum Environment Biotechnology 4(6) 2015.

[16] Banapurmath NR, Chavan AS, Bansode SB, Sankalp Patil1, Naveen G, Sanketh Tonannavar, Keerthi Kumar N andTandale MS. Effect of Combustion Chamber Shapes on the Performance of Mahua and Neem Biodiesel Operated Diesel Engines. Journal of Petroleum Environment Biotechnology 4(6) 2015.

[17] Sakthivel Gnanasekaran, Saravanan N., M. Ilangkumaran. Influence of injection timing on performance, emission and combustion characteristics of a DI diesel engine running on fish oil biodiesel. Energy 116 (2016) 1218-1229.

[18] Manikalihas P, Venkatachalam R, Kalil Rahiman M, Boopathi P, Bharathiraja M. Comparison study of existing bowl piston and modified bowl piston diesel engine performance emission and combustion characteristics by using diesel. Journal of Advance Chemistry 12 (2016) 5243–51.

[19] Benajes J, Pastor JV, García A, Monsalve-Serrano J. An experimental investigation on the influence of piston bowl geometry on RCCI performance and emissions in a heavy-duty engine. Energy Conversion Management 103(2015) 1019–30.

[20] Taghavifar H, Khalilarya S, Jafarmadar S. Engine structure modifications effect on the flow behavior, combustion, and performance characteristics of DI diesel engine. Energy Conversion Management 85 (2014) 8520–32.

[21] Li X, Gulder OL. Effects of fuel cetane number, density and aromatic content on diesel engine NOx emissions at different operating conditions. In: Proceedings of the fourth international symposium COMEDIA (1998)111–6.

[22] S. Vedharaj, R. Vallinayagam, W.M. Yang, C.G. Saravanan, P.S. Lee, Optimization of combustion bowl geometry for the operation of kapok biodiesel – Diesel blends in a stationary diesel engine. Fuel 139 (2015) 561–567

[23] Li J, Yang WM, An H, Maghbouli A, Chou SK. Effects of piston bowl geometry on combustion and emission characteristics of biodiesel fueled diesel engines. Fuel 120 (2014) 120 66–73.

[24] Graboski MS, McCormick RL. Combustion of fat and vegetable oil derived fuels in diesel engines. Progress Energy Combustion Sci 24(1998) 125–64.

[25] Ranganatha Swamy L., T.K. Chandrashekar, N.R. Banapurmath, P.Nashipudi, Effect of Injection Timing, Combustion Chamber Shapes and Nozzle Geometry on the Diesel Engine Performance, Universal Journal of Petroleum Sciences 2 (2014) 74-95

[26] Krahl J, Munack A, Schroder O, Stein H, Herbst L, Kaufmann A. Fuel design as constructional element with the example of biogenic and fossil diesel fuels. Int Comm Agric Eng 2005, [7: manuscript EE 04 008].

[27] Peterson CL, Reece DL. Emissions testing with blends of esters of rapeseed oil fuel with and without a catalytic converter. SAE paper 961114; 1996.

[28] Abu Jrai A, Yamin JA, Al-Muhtaseb AH, Hararah MA. Combustion characteristics and engine emissions of a diesel engine fueled with diesel and treated waste cooking oil blends. Chemical Engineering Journal 172 (2011) 129–36.

[29] Puhan S. Mahuaoil (Madhucaindica seed oil) methyl ester as biodiesel-preparation and emission characteristics. Biomass-Bioenergy 28(1) (2005) 87–93.

[30] Lapuerta M, Rodriguez-Fernandez J, Agudelo JR. Diesel particulate emissions from used cooking oil biodiesel. Bio-Resource Technology 99 (2008) 731–40.

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

[32] Gaurav Dwivedi, Siddharth Jain, M.P. Sharma. Diesel engine performance and emission analysis using biodiesel from various oil sources – Review. Journal of Materials and Environment Science 4 (4) (2013) 434-447.

[33] http://www.nitc.ac.in/dept/me/jagadeesha/Internal_Combustion_Engines/Chapter4.pdfhttps://www.waybuilder.net/sweethaven/MechTech/Automotive01/default.asp.

[34] https://www.slideshare.net/KDPatel9034/combustion-chamber-for-compression-ignition-engines

[35] http://pranesh.freeblog.biz/files/2013/07/ADVANCED-I.C.-ENGINES-BOOK.pdf