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Effect of Cylindrical Combustion Chamber Shape on the Performance and Emission Characteristics of C.I. Engine Operated on Pongemia

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Abstract – The use of biodiesel blends in the diesel engine decreases the exhaust emissions (except NOx) but the performance of the engine is found to decrease. This is due to poor air mixing and insufficient turbulence. The performance of the engine can be improved by improving the mixing quality of biodiesel spray with air which can be achieved by modifying the shape of the combustion chamber. The present work investigates the effect of varying the combustion chamber geometry on the performance and emission characteristics of biodiesel operated diesel engine. Engine tests have been carried out on a single cylinder –four stroke direct injection diesel engine using various blends of Pongamia oil methyl esters (POME) with standard diesel as a fuel and with two types of combustion chambers namely hemispherical combustion chamber (HCC) and a cylindrical combustion chamber (CCC). For comparison, the compression ratio of the engine is kept constant. The test results showed that brake thermal efficiency obtained for hemispherical combustion chamber is higher than that obtained using cylindrical combustion chamber. Significant improvement in reductions of Carbon Dioxide (CO2), carbon monoxide (CO) was observed for hemispherical combustion chamber as compared to the cylindrical combustion chamber. However oxides of nitrogen were slightly higher for hemispherical combustion chamber. The unburnt hydrocarbon (UBHC), oxides of nitrogen (NO_x) and CO emissions are reduced in CCC shape compared to HCC shape.

Keywords: Combustion Chambers, Engine, Emission, Pongamia, Biodiesel.

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1. INTRODUCTION

The advantages of biodiesels are that they are renewable, can be produced locally, cheap, higher lubricity, higher cetane number, and minimal sulphur content and less pollutant for environment compared to diesel fuel. On the other hand, 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. For all the above reasons, it is generally accepted that blends of diesel fuel, with up to 20% bio-diesels, can be used in existing diesel engines. Various researchers [1, 2] have shown that biodiesel fuel exhibits physical, chemical and thermodynamic properties which are similar or some even better than to those of petroleum diesel fuel. However certain properties such as viscosity, calorific value, density and isothermal compressibility of biodiesel differ from petroleum diesel fuel. These properties strongly affect injection characteristics, air–fuel mixing characteristics and thereby combustion characteristics of biodiesel in a diesel engine

The inferior performance of biodiesel operated diesel engine in comparison with conventional diesel fuelled diesel engine is mainly due to change in fuel properties, engine design and operating parameters. To achieve improved performance and further reductions in emissions, rapid and better air–biodiesel mixing is the most important requirement. The mixing quality of biodiesel spray with air can be generally improved by selecting the best injection parameters and better design of the combustion chamber.

S. Jaichandar et al.[3] investigated the effect of varying the combustion chamber geometry on the performance of a diesel engine using 20% Pongamia Oil Methyl Ester in terms of brake specific fuel consumption, brake thermal efficiency as well as exhaust emissions and combustion characteristics without altering the compression ratio of the engine. The test results showed that brake thermal efficiency for Torroidal combustion chamber is higher than the shallow depth and hemispherical combustion chambers. Significant improvement in reduction of particulates, carbon monoxide and unburnt hydrocarbons is observed for Torroidal combustion chamber compared to the other two. However oxides of nitrogen were slightly higher for Torroidal combustion chamber. The combustion analysis shows improved characteristics for Torroidal combustion chamber compared to baseline engine at all loads of operation.S. Jaichandar et al. [4] the experiments were performed using a DI (direct injection) diesel engine equipped with a conventional jerk type injection system and pistons having HCC (hemispherical combustion chamber) and TRCC (Torroidal re-entrant combustion chamber) geometries. The combined effect of varying, injection pressure and combustion chamber geometries, on the combustion, performance and exhaust emissions, using a blend of 20% POME (pongamia oil methyl ester) by volume in diesel was evaluated. The test results showed that improvement in terms of brake thermal efficiency and specific fuel consumption for Toroidal reentrant combustion chamber (TRCC) operated at higher injection pressure. Substantial improvements in reduction of emissions levels were also observed for TRCC operated at higher injection pressure. However improved combustion, due to better air motion inside the cylinder and high pressure injection, increased the oxides of nitrogen (NOx). Increasing injection pressure decreased ignition delay, and increased peak in-cylinder pressure and maximum heat release rate.S. Jaichandar et al. [5] investigated that the test results for re entrant type combustion chambers fuelled with 20% POME and PBDF were compared with baseline engine having hemispherical open type combustion chamber operated with PBDF and 20% POME blend. The test results showed that substantially higher brake thermal efficiency and lower specific fuel consumption for Torroidal Re-entrant Combustion Chamber compared to baseline engine fuelled with 20% POME. Sharp reduction of particulates, CO and UBHC were observed for TRCC compared to the other two. However oxides of nitrogen (NOx) were higher for TRCC. The combustion analysis shows that, the ignition delay is lower for TRCC compared to baseline engine and the peak pressure is also higher at full load. Venkata Ramesh Mamilla et al. [6] evaluated the performance and emission characteristics fuelled with Jatropha oil (JTME), and its blends (20%, 40%, 60%, 80% and 100%). The performance parameters are analyzed include Brake thermal efficiency whereas exhaust emissions include oxides of nitrogen, HC, Smoke and CO. The results of the experiment in each case were compared with baseline data of diesel fuel. It concluded that lower blend of biodiesel 20% JTME act as best alternative fuel among all tested fuel at full load condition.

J. Li, W.M. Yang [7] studied the effects of piston bowl geometry on combustion and emission characteristics of a diesel engine fueled with biodiesel under medium load condition. Three different bowl geometries namely: Hemispherical Combustion Chamber (HCC), Shallow depth Combustion Chamber (SCC), and the baseline Omega Combustion Chamber (OCC) were created with the same compression ratio of 18.5. Also, the simulation results indicate that I terms of performance SCC is favorable at low engine speed; whereas at high engine speed, OCC is preferred As a consequence, SCC will generate relatively higher NO compared to other two piston bowl designs at low engine speed condition. Similarly, the high performance of OCC bowl geometry could result in a high NO emission at high engine speed condition.

From the summary of literature review we found that there will be a minimum research work carried on Cylindrical combustion chamber shape in terms of performance and emissions characteristics hence we selected this cylindrical combustion chamber shape as a main part of our work.

2. PROPERTIES OF FUELS USED

In India, usage of non-edible oils for the production of biodiesel is found to be best suited when considering the deficit supply of edible oils and their cost of production. Among the non-edible oils, Tree Borne Oil seeds (TBOs) like jatropha and pongamia gain importance. PongamiaPinnata, an excellent shrub having natural spread across the globe, is one of the promising biofuel crop ideally suitable for growing in the wastelands. Greater potential exists in India for bringing millions of hectares of wasteland under extensive plantation of pongamia, virtually converting unproductive lands into green oil fields. Pongamia seeds contain 30–40% oil. To prepare POME, the transesterification reaction was performed on raw pongamia oil. Transesterification is a chemical process of transforming large, branched, triglyceride molecules of vegetable oils and fats into smaller, straight chain molecules, almost similar to diesel fuel. The process takes place by the reaction of raw pongamia oil with methyl alcohol in the presence of catalyst. The properties of pongamia biodiesel with standard diesel are as follows in Table 1.

Figure. 1 Pongamia Tree, biodiesel and Seed

The properties of the fuels used in the study like Flash point, Fire point, Density and Calorific value of the fuel were calculated under laboratory conditions in Energy conversion laboratory of the college.

Table 1. Properties of diesel, biodiesel from pongamia and its blend.

Properties	Diesel	B20	B40	B60	B80	B100
Density (kg/m^3)	830	820	842	851	868	894
Specific gravity	0.83	0.82	0.842	0.851	0.868	0.894
Flash point(^{0}C)	63	83	89	110	118	180
Fire point (^{0}C)	66	95	100	124	145	195
Calorific Value (KJ/kg)	42000	41618	39380	38100	37880	37150

It is found that the viscosity and density is comparatively higher for biodiesel than the diesel and also the calorific value is comparatively lesser than that of the diesel. The flash point and fire point is also higher for biodiesel than the diesel. The calorific value is found to be 37MJ for biodiesel using Bomb calorimeter in laboratory conditions [8]. The effect of higher density and viscosity on the performance and emission characteristics was studies and tabulated.

3. EXPERIMENTAL METHODOLOGY

The engine chosen to carry out experimentation was a single cylinder, compression ignition, direct injection engine. It was a naturally aspirated, four strokes, water cooled, and vertical engine. As shown in figure. 2 experimental set up, this engine can withstand higher pressures and is used extensively in agriculture and industrial sectors. The engine operates at a constant speed of 1500 rpm. The engine also had a overhead valve arrangement. The valves are operated by push rods and a camshaft. The water required for the engine cooling was forced by a water pump through the water jacket. The specification of engine is shown in Table 2.

Figure. 2 Experimental test engine

Table 2: Engine specifications

Sl. No	Parameters	Specification
1	Type of engine	Kirloskar make Single cylinder four stroke direct injection diesel engine
2	Nozzle opening pressure	200 to 205 bar
3	Rated power	5 HP @1500 RPM
4	Cylinder diameter (Bore)	80 mm
5	Stroke length	110 mm
6	Compression ratio	17.5 : 1
7	Displacement volume	660cc
8	Arrangement of valves	Over head
9	Combustion chamber	Open chamber (Direct injection)
10	Cooling type	Water cooled
11	Loading	Mechanical type loading dynamometer

The selection of biodiesel is usually based on availability of biodiesel; the pongemia methyl ester used for the experimentation. The various blends are prepared in laboratory like B20, B40, B60, B80& B100, we found the various fuel properties of prepared blends and standard diesel in laboratory using the Abel's apparatus and Saybolt's viscometer, the properties are shown in table 1.The experimentations are carried out with hemispherical combustion chamber shape for standard diesel, B20, B40, B60, B80 & B100 fuels with 0%, 25%, 50%, 75% and 100% engine loading with help of mechanical loading type of dynamometer and emission readings are noted with help of Gas Analyzer. The piston shape is changed to cylindrical shape without altering the volume by filling the molten aluminum and machining process shown in figure 3. The cylindrical piston assembled in to base line engine set up. The same experimentation will be repeated with cylindrical combustion chamber shape as carried to hemispherical combustion chamber shape without changing the compression ratio. Finally compared the performance and emission characteristics of cylindrical piston geometry with baseline hemispherical piston geometry. The two combustion chamber geometry shown in figure 4 and figure 5 respectively namely hemispherical combustion chamber and cylindrical combustion chamber shapes.

Figure 3. Preparation of cylindrical combustion shape

3.1 Design of Hemispherical piston geometry

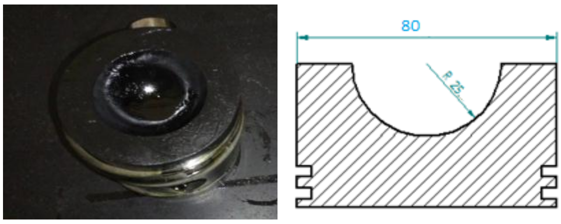

Fig. 4 Hemispherical combustion chamber shape

The figure 4 shows the hemi spherical combustion chamber shape and having the 80 mm bore diameter with 25 mm radius.

3.2 Design of Cylindrical piston geometry

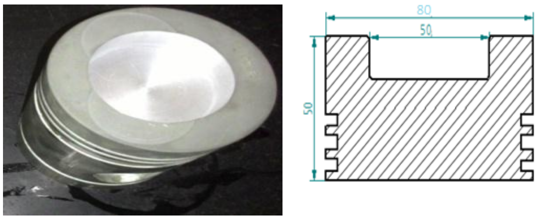

Fig.5 Cylindrical combustion shape

4. RESULTS AND DISCUSSION

In this experiment we investigated the Comparison between the two shapes of combustion chambers in terms of performance characteristics and emission characteristics at full load condition of diesel engine are as follows.

4.1 Specific Fuel Consumption

From the figures 6 and 7 we observed that the variation of SFC with brake power for HCC and CCC shapes. The SFC increases from 0.26 kg/kw-hr to o.29 kg/kw-hr with increase in blend for HCC shape and for CCC shape it varies from 0.29 kg/kw-hr to 0.334 kg/kw-hr with increasing the blend. The SFC increases for biodiesel in both the shapes due to lower calorific value, however the SFC is more in CCC shape compared to HCC shape due to poor mixing quality in modified shape.

4.2 Brake Thermal Efficiency

From the figures 8 and 9 we observed that the variation of Brake thermal efficiency with brake power for HCC and CCC shapes. The BTE increases from 32.79 % to 34. 69 % with increase in blend for HCC shape, it increases from 29.31 % to 30.48%, however the decrease in BTE is observed for CCC shape for pure biodiesel (B100). This is due to improved combustion characteristics in HCC shape.

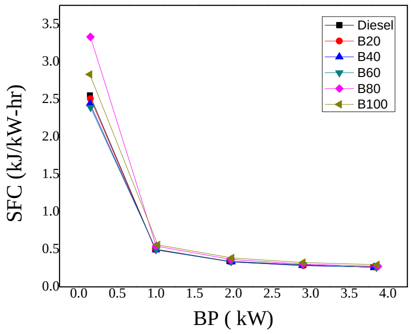

Figure 6. Variation of SFC with BP for HCC shape

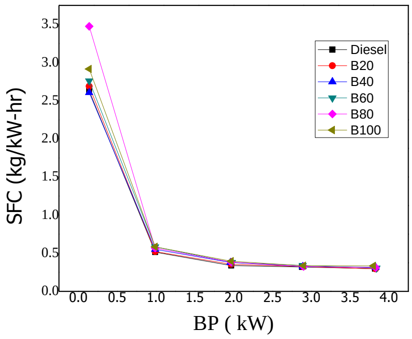

Figure 7. Variation of SFC with BP for CCC shape

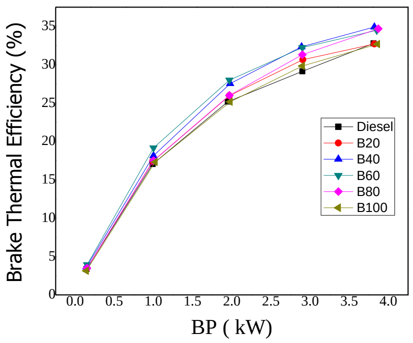

Figure 8. Variation of BTE with BP for HCC shape

4.3 Carbon monoxide

From the figures 10 and 11 we observed that the variation of carbon monoxide with brake power for HCC and CCC shapes. The percentage of CO emission decreases from 0.225 to 0.009 for HCC shape, for CCC shape it varies from 0.743 to 0.031 but the percentage of CO emission decreases up to B40 blend and thereafter it increases with increasing the blend for HCC shape. Whereas the percentage of CO emission decreases up to B80 blend and thereafter it increases with increasing the blend for CCC shape. However the percentage of CO is more in HCC compared to CCC shape at 50% load condition due to minimum swirl in CCC shape at full load condition.

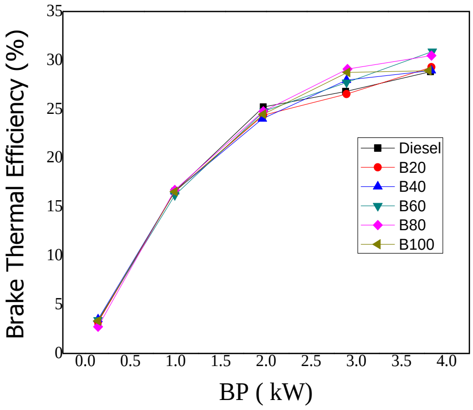

Figure. 9. Variation of BTE with BP for CCC shape

4.4 Carbon dioxide

From the figures 12 and 13 we observed that the variation of carbon dioxide with brake power for HCC and CCC shapes. The parentage of CO2 is more in CCC shape compared to HCC shape due to improve combustion in HCC shape.

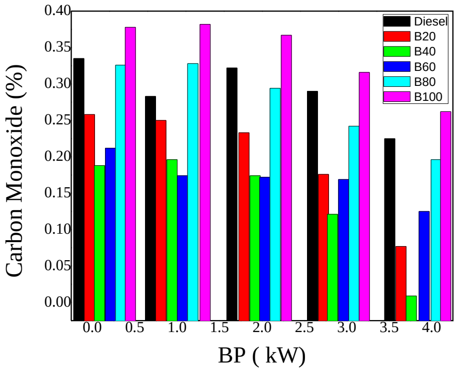

Figure 10. Variation of CO with BP for HCC shape

4.5 Unburnt hydrocarbons

From the figures 14 and 15 we observed that the variation of unburnt hydrocarbons with brake power for HCC and CCC shape. The UBHC emission decreases as load increases in both shape due to to high content of oxygen in pongemia biodiesel and better air swirl but comparatively UBHC emission reduces up to 50 % load condition and thereafter increases in CCC shape.

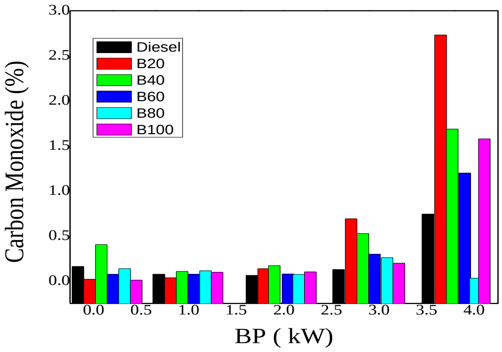

Figure 11. Variation of CO with BP for CCC shape

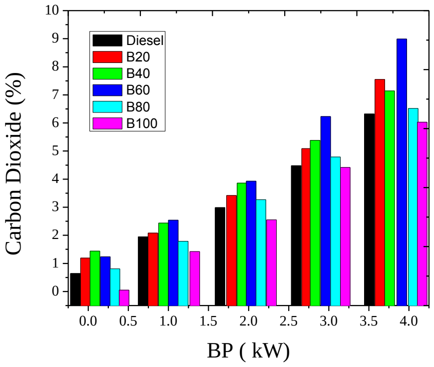

Fig. 12. Variation of CO_2 with BP for HCC shape

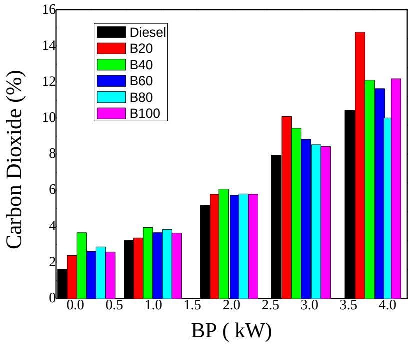

Figure. 13. Variation of CO_2 with BP for CCC shape

4.6 *Oxygen*

From the figures 18 and 19 we observed that the variation of oxygen with brake power for HCC and CCC shapes. The parentage of oxygen utilization is more in CCC shape compared to HCC shape during combustion, hence due to better combustion most of emission characteristics are reduced in CCC shape.

4.7 *Oxides of nitrogen*

From the figures 16 and 17 we observed that the variation of oxides of nitrogen with brake power for HCC and CCC shapes. the better air fuel mixing and faster combustion process in both combustion chamber shapes the NOX level increases in both the shapes. The NOx emission decreases from 2103ppm to 1914 ppm as blend increases for HCC shape, it varies from 1529 ppm to 1296 as increase in blend for CCC shape. However the 40 % of NOx emission has reduced in CCC shape comparatively HCC shape due to low temperature attained in combustion chamber.

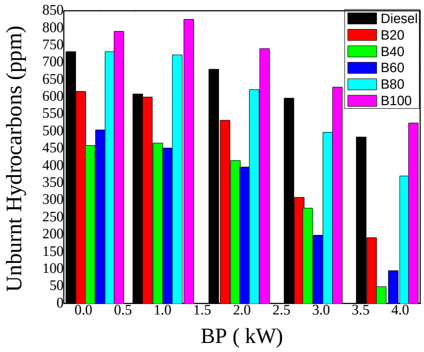

Figure. 14. Variation of UHC with BP for HCC shape

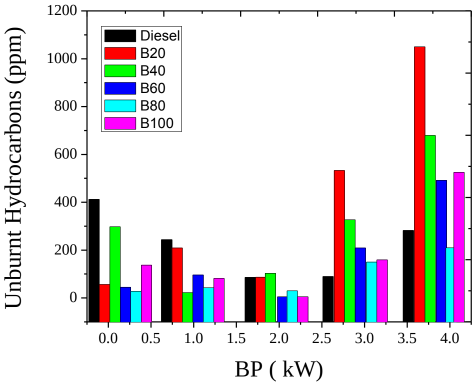

Figure 15. Variation of UHC with BP for CCC shape

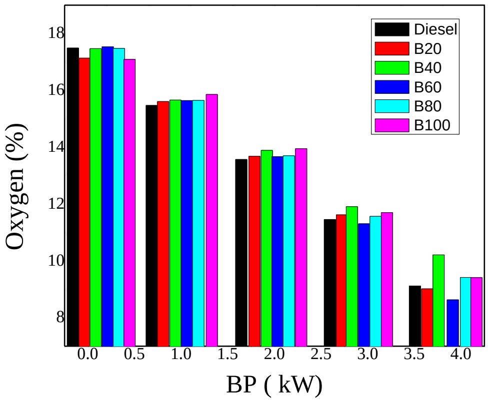

Figure. 16. Variation of O_2 with BP for HCC shape

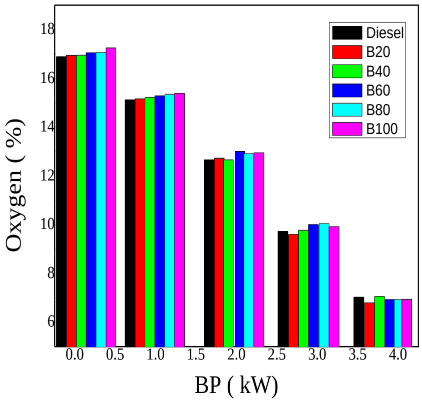

Figure 17. Variation of O_2 with BP for CCC shape

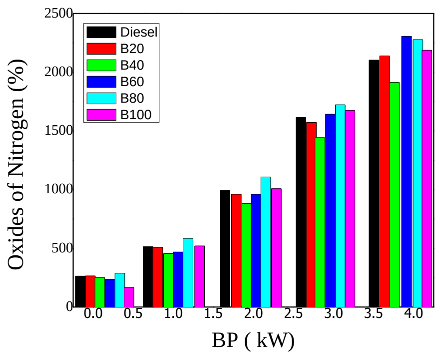

Figure. 18. Variation of oxides of Nitrogen with BP for HCC shape

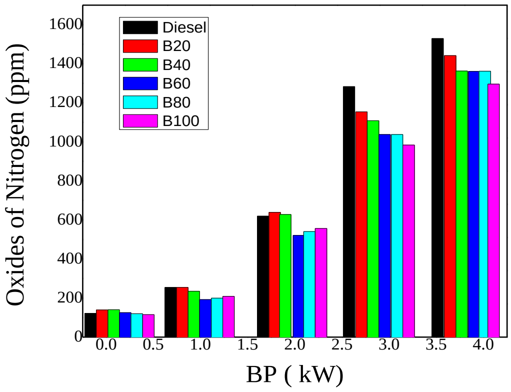

Figure. 19. Variation of oxides of Nitrogen with BP for CCC shape

5. CONCLUSIONS

The specific fuel consumption has shown reduction with increase in brake power for both combustion chamber shapes but it decreases in the case of hemispherical shape due to improved combustion. Brake thermal efficiency has improved with increase in brake power for both combustion chamber shapes and it is observed that among all blends B40 for hemispherical combustion chamber shape and B60 for cylindrical combustion chamber shape gives more efficiency. The Brake thermal efficiency increases with increase in blend for both combustion chamber shapes observed at all load. The cylindrical combustion chamber shape gives lower emissions as compared to base line hemispherical combustion chamber shape especially there is a 40 % of reduction in the NO_x for cylindrical combustion chamber shape as compared to the hemispherical combustion chamber shape. The cylindrical combustion chamber shape utilized more oxygen than that of hemispherical combustion chamber shape due to complete combustion in cylindrical combustion shape.

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