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Effect of piston bowl geometry on the performance of a diesel engine using Corn biodiesel and its diesel blends

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Abstract: In this study, the performance and emission characteristics of a single cylinder diesel engine with the effect of piston bowl geometry [hemisherical cavity piston (HCP) and toroidal cavity piston(TCP)] using diesel and corn oil methylester and its diesel blends have been ivestgated under different loading conditions. The refined corn oil was converted into corn oil methyl ester by transesterification process and then used to prepare biodiesel/diesel blends. Then the base engine hemispherical cavity piston is machined to make toroidal type piston without affecting its cavity volume and without affecting the compression ratio of the engine. The engine tests were conducted with neat corn oil methyl ester (B100) and 25% blend with diesel (B25) in a diesel engine with hemispherical cavity piston (HCP) and toroidal cavity piston (TCP). The results showed that the brake thermal efficiency of neat corn oil biodiesel and its blends for toroidal cavity piston operation was increased and the CO, HC and smoke emissions were decreased at full load. The NOx emissions were slightly increased for corn oil methy ester and its diesel blends with toroial piston operation compared with diesel fuel with HCP operation.

1. Introduction

As the decreasing trend of world global petroleum reserves and environmental degradation resulting from the combustion of petroleun fuels in transport vehicle and power plant becomes more apparent, so it is necessary to find alternative sources of energies like biofuels and biomass. Biofuels is the only viable choice of renewable energy for use in transport vehicle that do not require any hardware modifications in vehicle design. But some biomass alternatives such as ethanol, methanol and biodiesel derived from food crops such as sugarcane and vegetable seeds. The raw vegetable oil is extracted from vegetable oil seeds by crushing and other methods. The properties of raw vegetable are closer to diesel fuel except its kinematic viscosity. The kinematic viscosity of raw oil is reduced by transesterification process to convert into vehetable oil methyl ester.

In the last two decades, many researchers have studied that biodiesel fuels produce no sulfur dioxide and less aromatic hydrocarbon emissions. They are renewable, less toxic, and biodegradable and their combustion characteristics are comparable with with petroleum diesel fuels [1- 3]. In addition to that the biodiesel properties are similar to that of petroleum diesel fuels and they can be used as sole fuel or blended with diesel in diesel engines without any modification [4, 5]. The use of raw vegetable oils used as fuel for diesel engines without modification causes some amage to parts of the engine and also, the performance is greatly affected [6,7]. Various researchers have conducted experiments to study the performance and emission characteristics of diesel engine when vegetable oils, blends of vegetable oil and its derivatives are used as fuel and it has been found to be economical and competitive compared to petroleum diesel fuel [8–11].

Forson et al. [12] have invstigated that diesel engine running with Jatropha oil and diesel blends produces a closer performance and emissions characteristics to diesel for lower blend concentration of jatropha oil. Pramanik [13] conducted the performance tests using blends of diesel and Jatropha oil in a single-cylinder CI engine. The results showed that specific fuel consumption and the exhaust gas temperature were reduced due to decrease in viscosity of the vegetable oil. Therefore, the main objective of the present study is to decrease the viscosity of jatropha curcas oil by blending with diesel and to evaluate the engine performance and emission characteristics without any substantial hardware modifications.

2 Materials and Methods

2.1 Preparation of corn oil methylester (COME)

Corn oil was selected for this study and it is converted into its methyl ester by the transesterification process. In transesterification reaction, the molar ratio of methanol to Corn oil was 5:1 and 1% mass of KOH to cotton seed oil was used. The reactions were taken for two hours at reaction temperature 65˚C. After the end of the reaction, the mixtures were kept at the ambient temperature for eight hours and then the settled glycerin layer was drained off. After decantation of glycerol, the methyl ester was washed with distilled water to remove excess methanol. The properties of Corn oil methyl ester (COME) were found out and compared with diesel fuel. The comparison shows that the Corn seed oil methyl ester properties have relatively closer to properties of diesel fuel. The properties of diesel, corn oil and its methyl ester are listed in Table.1.

Two test fuels have been prepared with neat COME (B100) and B25 (25% diesel:75% CME by vol) for the experiments. Initially, the tests were conducted in a base engine with HCC piston using, B25 and B100 with standard injection pressure and injection timing. and the results compared with diesel fuel. In the second stage, the engine tests were carried out at with B25% and B100 on modified engine having TCC piston with different operating conditions and the results were compared with diesel fuel.

Table. 1 Properties of diesel, Corn oil and its methylester

Properties	Diesel	Corn oil	Corn oil methyl ester
Kinematic Viscosity (cSt)	2.9	35	4.52
Density (kg/m3)	830	896	860
Calorific value (MJ/kg)	42.5	36.3	38.82
Flash point	56	176	165

2.2 Experimental Setup

In this experimental work, a Kirloskar make single cylinder, four-stroke, compression ignition (CI), air cooled diesel engine was used. The specifications of test engine are given in Table.1. The test engine was coupled with electrical dynamometer with load bank to apply the brake load to the engine. The schematic of experimental set up is shown in Fig.1. Two separate fuel tanks are used for diesel and biodiesel. The fuel flow was measured with the help of burette and stopwatch. The standard Kiroskar engine has Hemispherical Combustion Chamber (HCC) with overhead valve arrangements operated by push rods. The exhaust gas emissions like CO, HC and NOx were measured by AVL-444 five gas analyser and smoke intensity was measured by AVL 437C Smoke meter. The accuracy of the gas anlyser is given in Table .2. The modifications of the piston made without altering compression ratio of engine, piston's combustion chamber geometry (Fig. 2) with Toroidal Combustion Chamber (TCC) from the base ENGINE piston cavity HCC. HCC also gives small squish. However, depth to diameter ratio can be varied to give any desired squish to give better performance. But the toroidal piston provides a powerful squish along with the air movement inside the combustion chamber, resulting in better utilization of oxygen in the toroidal combustion chamber. [v.ganesan]

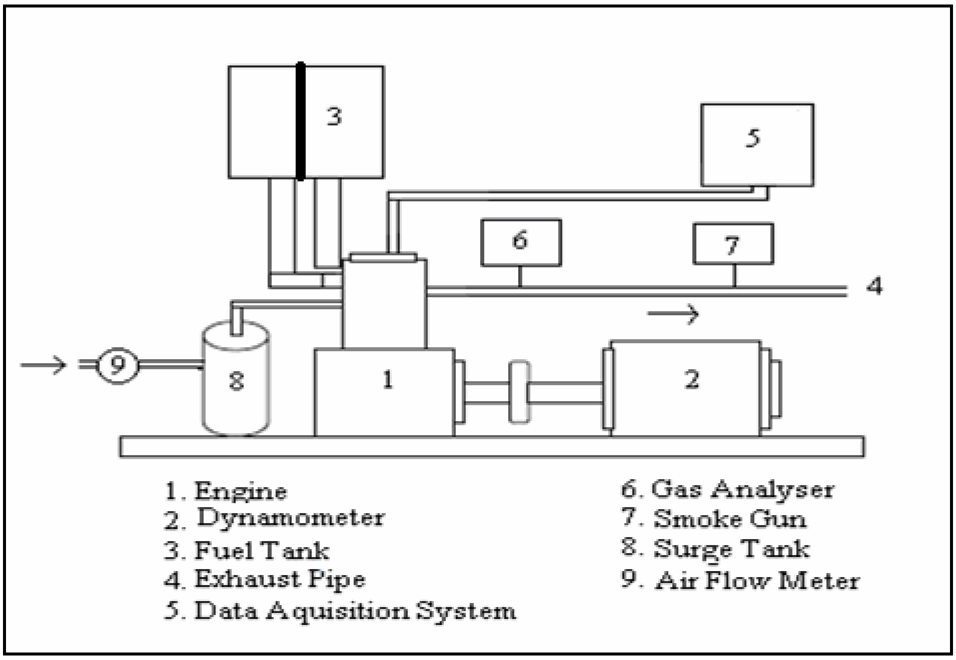

Fig.1 Schematic of experimental setup

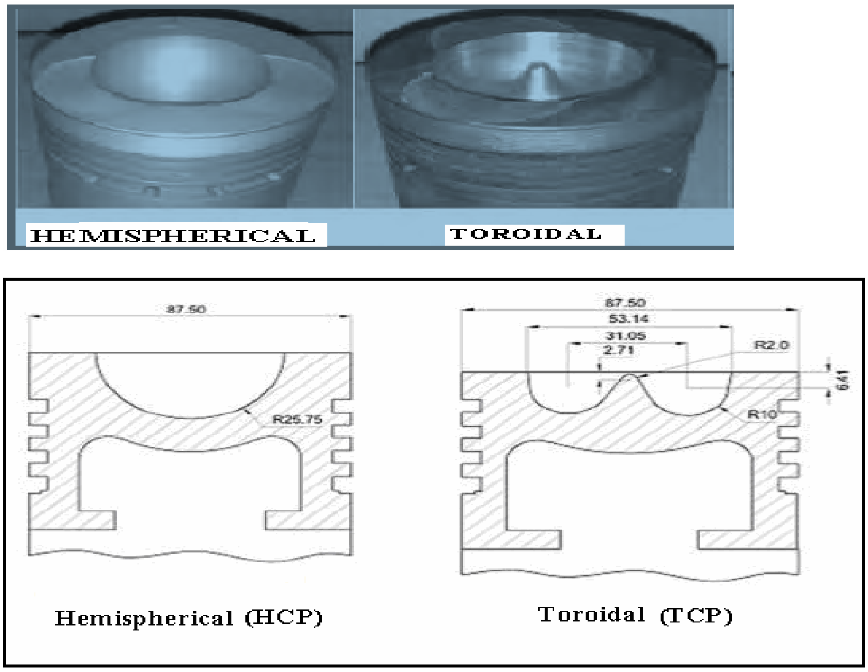

Fig. 2 Modification of Piston bowl (all dimensions in mm)

Table.2 Specifications of test engine

Engine	**Kirloskar, Vertical, single cylinder**
Bore (mm)	87.5
Stroke (mm)	110
Rated Power (Kw)	4.4
Speed (rpm)	1500
Injection pressure (bar)	200
Injection timing	23.4^{o} Btdc
Type of Cooling	Air
Dynamometer	Electrical

3 Results and Discussion

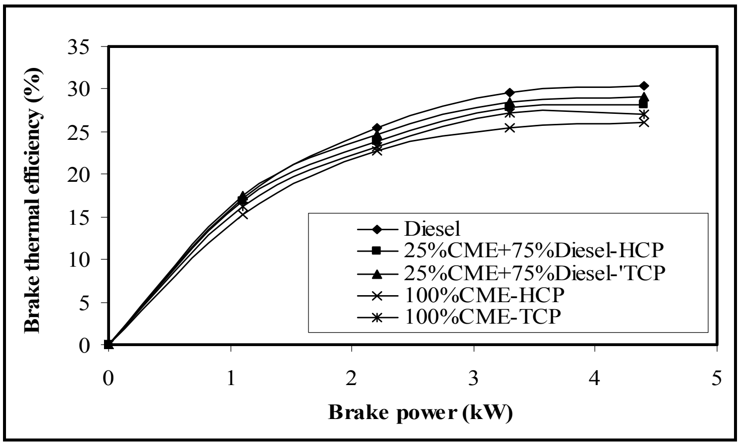

Fig.3 Brake thermal efficiency Vs BP

Figure. 3 shows the variation of brake thermal efficiency with brake power for diesel and corn oil methyl ester for both the piston operations. The brake thermal efficiency of B25 and B100 with base engine (having HCP piston) is lower compared to that of diesel. Since the engine is operated under constant injection timing and the COME has a smaller ignition delay. Due to this the combustion is initiated much before TDC is reached. This increases compression work and more heat loss and thus reduces BTE of engine. The BTE for TCP with B25 and B100 is higher than base engine with HCP piston at all loads. This may be due to air-fuel better mixture formation of B25 and B100 with air, as a result of better air motion in TCP piston, which leads to better combustion of COME and thus increases the brake thermal efficiency at full load. The BTE of B25 and B100 with TCP piston operation is increased by 3.6% and 3.33% respectively compared with the same fuel with HCP piston. The maximum efficiency obtained for B25 with TCC piston is 29.12%, wheras for HCP piston it is 28.14% at maximum load.

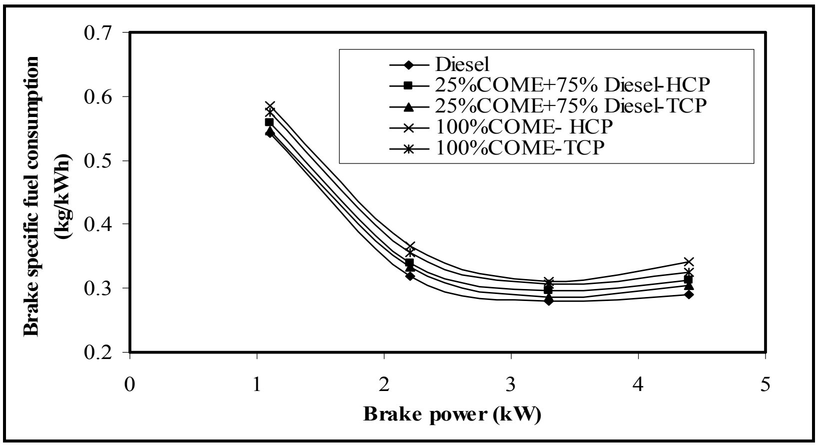

Fig.4 Brake specific fuel consumption Vs BP

The variation of brake fuel consumption (BSFC) with brake power for the test fuels with both the piston operations is shown in Figure. 4. At full load, the BSFC for B25 is slightly higher than that of diesel base engine with HCP piston at full load. This may be due to lower calorific value of COME compared with diesel fuel. The BSFC is slightly decreased when the engine is operatind with TCP piston using B25 and B100 biodiesel. The BSFC of B25 with TCP piston is 0.304kg/kWh and with HCC is 0.312kg/kWh, whereas for diesel with base engine is 0.291kg/kWh at full load. The BSFC of B100 with HCP and TCP is lower than that diesel fuel with base engine at full load.

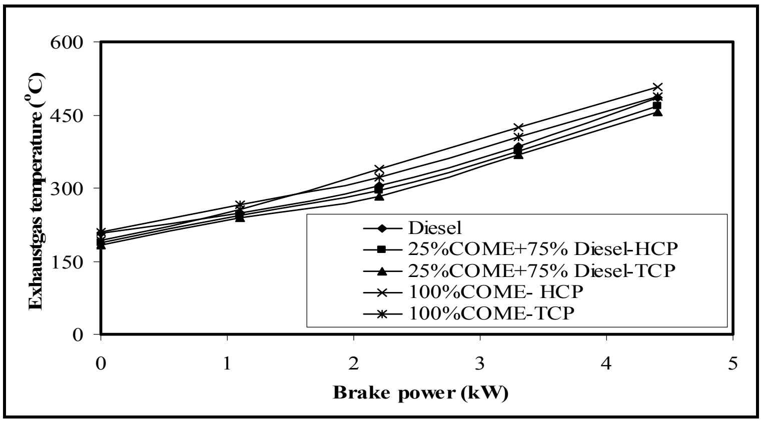

Fig.5 Exhaust gas temperature Vs BP

Figure 5 shows the exhaust gas temperature variations for the diesel and biodiesel blends for botn the piston operations. It is observed that exhaust gas temperature increases with increase in load for both the pistons for diesel and biodiesel and its blend. It is also observed that exhaust gas temperature increases for all fuels due to more amounts of fuel burns at higher loads. The exhaust gas temperature is slightly decreased for B25 and B100 with TCP piston operation compared with HCP piston. The increase in exhaust gas temperature may be due to better air motion in the TCP and higher oxygen content present in the biodiesel, resulting in better combustion, and thus decreases the exhaust gas temperature. The exhaust gas temperature for B25 and B100 with TCP is 455 and 489, whereas for HCP it is 468 and 507 respectively at full load.

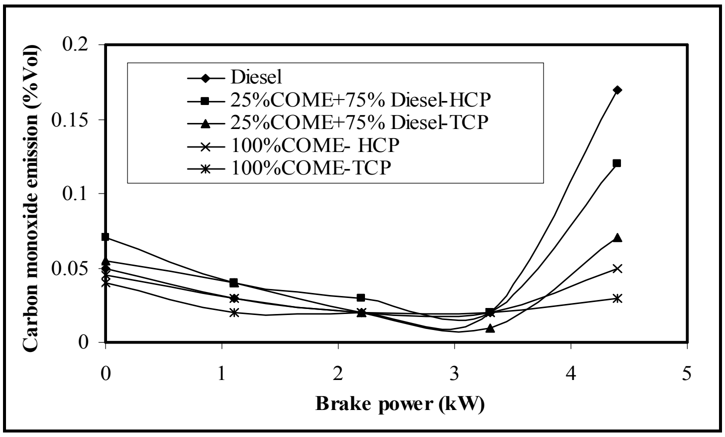

Fig.6 Carbon monoxide emission Vs BP

Figure 6 illustrates the variation of Carbon monoxide emissions with brake power for all test fuel with both the piston operations. The CO emissions for both the combustion chambers are not much different from those of diesel fuel at all loads. However, CO emissions of the B25 and B100 decreased significantly when compared with base line diesel fuel at full load. The CO emissions for B25 and B100 further decreased with TCP when compared to HCP at full load. This is due to higher air movement in TCP and presence of oxygen in the COME biodiesel, lead to better combustion of fuel, resulting in decrease in CO emissions. The maximum reduction in CO emission for B25 and B100 with TCP is 42% and 40% respectively when compared with HCP piston operation. The CO emission obtained for B25 and B100 with TCP is 0.07%Vol and 0.03%Vol, whereas with HCP it is 0.12%Vol and 0.05%Vol respectively at full load.

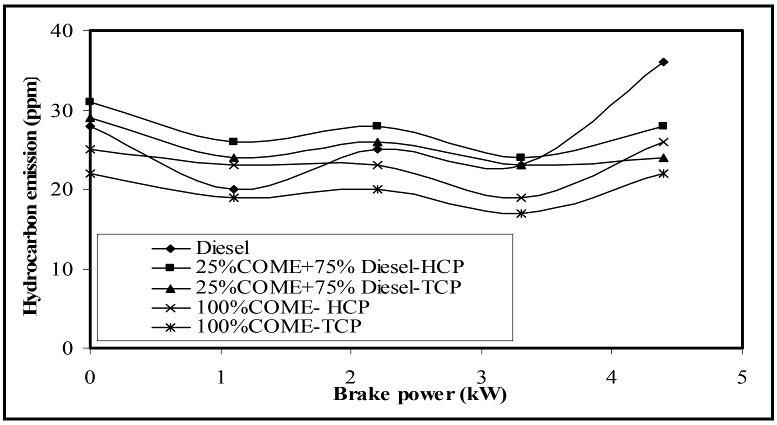

Fig.7 Hydrocarbon emission Vs BP

Figure 7 illustrates the variation of hydrocarbon emissions with brake power for all the test fuels with both the piston operations. The HC emissions of the B25 and B100 decreased significantly when compared with base line diesel fuel at full load. The HC emissions for B25 and B100 further decreased with TCP when compared to HCP at full load. This is due to improved swirl motion of air movement in TCP and presence of oxygen in the COME biodiesel, lead to better air-fuel mixture formation, resulting in complete combustion of fuel. The maximum reduction in HC emission for B25 and B100 with TCP is 14% and 15% respectively when compared with HCP piston operation. The HC emission obtained for B25 and B100 with TCP is 24ppm and 22ppm, whereas with HCP it is 28ppm and 26ppm respectively at full load.

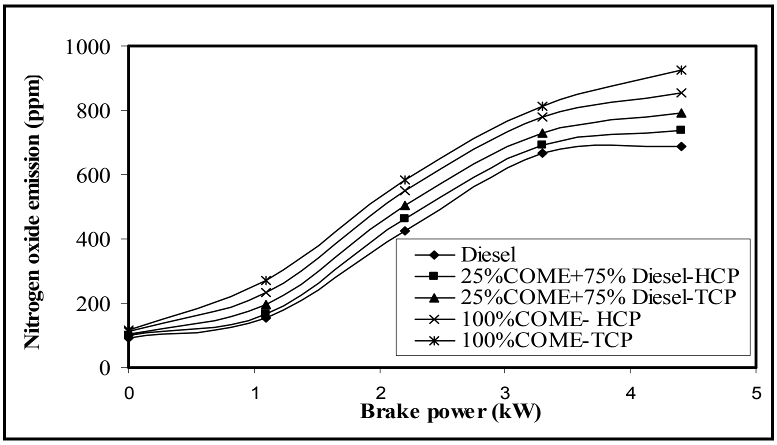

Fig. 8 Nitrogen oxide emission Vs BP

Figure 8 depicts the variation of nitrogen oxide emissions with brake power for all test fuel with both the piston operations. The NO emissions for B25 and B100 were higher for TCP piston than the base engine with HCP piston operation. The NO emissions increased by 7.2% and 9% for B25 and B100 with TCP compared with HCP operation. The reason for increase in NO emissions may be due to higher combustion temperatures by better mixture formation and availability of oxygen in COME resulting in improved combustion. The another reason for increased in NO emissions may be due to lower ignition delay resulting in larger part of combustion is completed before top dead center for biodiesel fuels compared to diesel[20]. So it is highly possible that higher peak cycle temperatures are reached for biodiesel fuels. However, the NO emission can be controlled by adopting exhaust gas recirculation (EGR). For B25 and B100 with TCP, the NO emission was 792 ppm and 843ppm compared to 739 ppm and 812ppm respectively for base engine with HCP at full load.

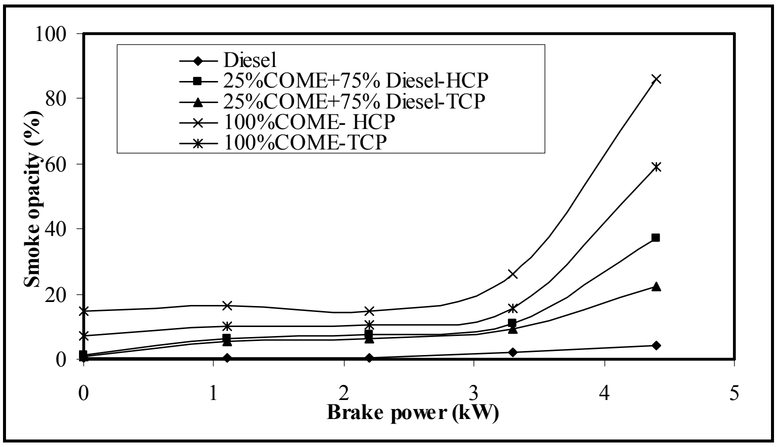

Fig.9 Smoke opacity Vs BP

The variation of smoke opacity with brake power for all the test fuels with both the piston operations is shown in Figure 9. At all loads, smoke opacity for biodiesel decreased significantly than diesel fuel with base engine. This may be due to presence of oxygen in biodiesel and its blend. This oxygen in the fuel leads to an improvement in diffusive combustion. Smoke emissions were found lower for TCP than HCP, due to more complete combustion due to better air motion by the TCC resulting in better air-fuel mixing, leads to complete combustion. The smoke emission is decreased by 40% and 32% for B25 and B100 respectively with TCP piston compared with HCP at full load. The smoke emission for B25 and B100 with TCC is 22.2% and 59%, whereas with HCP it is 37% and 86% respectively at full load.

4. Conclusions

The present study effect of piston bowl geometries on emissions in a single cyliner diesel engine. The performance and emission test results of two configurations of the diesel engine are reported.

- Improved air motion in TCP due to its geometry improves mixture formation, which increases BTE and lowers BSFC compared to HCP. Better combustion due to better air fuel mixing in TCP, gives maximum thermal efficiency for B25.
- The CO, HC and smoke emissions were lower TCP with B25 due to improved air-fuel mixing and higher oxygen content present in COME and better combustion compared to HCP type combustion chamber.
- The NO emissions were decreased for TCP due to better combustion and presence of oxygen content in COME results in increased combustion chamber compared with HCP type combustion chamber.
- Thus performance and emission characteristics of biodiesel from corn oil methylester and its blends can be improved by suitably designing the combustion chamber.

Abbreviations:

BP	ake power
HCP	emispherical cavity piston
TCP	oroidal cavity piston
COME	orn oil methyl ester
BTE	ake thermal efficiency
BSFC	ake specific fuel consumption
EGT	khaust gas temperature
CO	arbon monoxide
CO_2	arbon dioxide
HC	ydro carbon
NO	itrogen oxide

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