EFFECT OF PISTON BOWL GEOMETRY AND DIFFERENT INJECTION PRESSURE ON THE PERFORMANCE, EMISSION, AND COMBUSTION CHARACTERISTICS OF DIESEL ENGINE USING BIODIESEL BLEND

by

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The shape of the piston cavity, variable injection pressure and variable compression ratio are main input parameters to give better atomization of fuels and high swirling induction that improves the Diesel engine performance, combustion, and emissions characteristics. In this study, the engine test was carried out to improve the combustion, performance, and emissions with the use of two different pistons namely hemispherical shaped piston (standard engine), and toroidal cavity piston with varied injection pressures in a single-cylinder direct injection Diesel engine using 25% of corn oil methyl ester-diesel blend (COME25). Initially, the piston bowl was modified to toroidal combustion chamber with tangential cut on circumference of the piston crown in a standard piston of hemispherical type combustion chamber. The engine speed, compression ratio, and injection timing were kept constant and the results of toroidal combustion chamber compared with base engine piston of hemispherical combustion chamber using diesel and COME25 fuel. The results showed that the toroidal combustion chamber has improved performance, combustion and emissions with the exception of NO_x emissions.

Key words: *piston, injection pressure, toroidal combustion chamber, performance, emissions, combustion, corn oil methyl ester*

Introduction

Due to the fast development of the country, needs more energy in all areas of industries like manufacturing, automotive, power plants, and energy sectors. This paves the way of production of renewable energy sources like solar energy, wind energy, biomass, and biofuels. Nowadays, vehicle population is increasing day by day due to the increases the population of the country. These automotive vehicles run by Diesel engine and produces high brake thermal efficiency (BTE) and emits more exhaust emissions, which will degrade the environment around us. So that the government imposing the stringent emission regulations, this have focused attention to the researchers to search for an alternative to petroleum fuels such as biomass and biodiesel. Biodiesel are produced from vegetable oil and it is environment friendly, biodegradable and renewable in nature. The properties of vegetable oils are almost similar to those of diesel fuel and hence it can be used as fuel for Diesel engines. Vegetable oils used in engines

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increase the brake specific fuel consumption (BSFC) and emissions such as CO, unburnt HC, and smoke opacity compared to pure diesel due to their properties such as lower heating value, high viscosity, poor atomization and low volatility [1, 2].

The viscosity of vegetable oil can be reduced by converting of vegetable oil into biodiesel by transesterification process. Biodiesel is a clean and environmental friendly fuel and it does not contain any sulphur content [3, 4]. Many researchers were carried out the combustion, performance and emission characteristics of a Diesel engine using biodiesel and its diesel blends without modifications of the engine. They reported that decrease in BTE, increase in NO_x emissions and reduction in particulate matter, CO, and HC emissions when compared to diesel [5, 6]. Celik and Simsek [7] and Kannan and Anand [8] studied the performance of Diesel engine with the effect of injection pressure in a Diesel engine using biodiesel/diesel blends. Their results revealed that the specific fuel consumption and brake power (BP) of the 25% biodiesel blend were found to be same as that of diesel fuel at 220 bar injection pressure. The HC, CO, and smoke emissions were reduced and the NO_x emission increased at full load. Moreover, significant reductions in CO, HC, and smoke emissions were observed when running with optimum injection pressure (220 bar) instead of the original injection pressure (200 bar).

Arumugam *et al*. [9] produced the rice bran oil methyl ester and test in a Diesel engine using of rice bran oil methyl ester with ethanol at various proportions such as 1%, 3%, and 5% by volume basis. The results showed that the increase in biodiesel concentration in the fuel blend influences CO_2 and NO_x emissions and decreases the CO and HC emissions. It is also reported that emission of ethanol-B20ROME blends, reduces CO_2 and NO_x which are the major contributors to global warming. With the addition of ethanol by 1, 3, and 5% to B20ROME, the NO_x emission levels were reduced significantly compared to that of B20ROME blend. Senthil *et al.* [10] studied the performance, emission, and combustion characteristics of single cylinder direct injection (DI) Diesel engine annona methyl ester as a fuel with the addition of anti oxidents such as p-phenylenediamine, a-tocopherol acetate, 1,4-dioxane, and l-ascorbic acid. Results showed that anti-oxidant additives are very effective in controlling the NO_x emission. Among different antioxidant additives, 0.010%-m concentration of p-phenylenedimine additive is optimum for NO_x emission reduction up to 42.15% when compared to that of neat biodiesel.

Combustion of the fuel depends on various factors like, injection pressure, shape of piston cavity, spray pattern, air swirl, quantity of fuel injected, and *etc*. Ellis [11] studied the effective air and fuel mixing is significantly increased by modifying the combustion chamber by suitable piston bowl can significantly increased the peak pressure heat release rate (HRR), Montajir *et al*. [12] have attempted to achieve improvement in mixture formation by changing the combustion chamber geometry. They found that the reentrant cavity with round lip produces larger spray volumes and wider spray spreading. They found that introduction of a bottom corner radius helps to disperse the fuel accumulated at the bottom corner and the spray volume increases.

Gnanamoorhi, *et al.* [13] studied the effect of combustion chamber geometry on performance, combustion and emissions of ethanol-diesel blend in a Diesel engine. It is reported that the toroidal combustion chamber creates better turbulence, squish, and swirl at high compression ratios of 19.5 : 1 compared to that of hemispherical cavity combustion chamber. It is also reported that the BTE for toroidal combustion chamber is 33% and the peak pressure in the cylinder as well as peak HRR is also increased. Further, it is also concluded that 60% of CO emission, 20% of HC emission, 40% of NO_x emission, and 90% in smoke emissions were reduced for toroidal combustion chamber, compared to that of hemispherical combustion chamber. Viswanathan *et al.* [14] investigated the performance and emission characteristics of 20% orange oil methyl ester and 80% diesel in hemispherical combustion chamber and toroidal combustion chamber. It is reported that NO_x and HC emission is reduced in toroidal combustion chamber engine. However, smoke emission is found to be lower in hemispherical combustion chamber engine.

Rajan and Kumar [15] tested the performance of a Diesel engine using jatropha methyl ester with internal jet using and reported that the BTE was improved and the exhaust gas emissions are reduced significantly at full load due to enhancement of turbulence motion of air by the internal jets. Saito *et al*. [16] compared conventional combustion chambers and re-entrant combustion chambers in terms of the combustion process, engine performance, and NO_x and smoke emissions for Diesel engine. It was reported that re-entrant combustion chamber, enhanced combustion because of the higher in-cylinder velocity accompanied by increased turbulence.

Li *et al*. [17] numerically studied of the effects of piston bowl geometry on combustion and emission characteristics of a Diesel engine fueled with biodiesel and its diesel blends. They reported that CO emissions were lower and NO emissions were higher for omega combustion chamber operation with biodiesel. Prasad [18] studied the effect of high swirl inducing piston to reduce exhaust emissions numerically. They found that an injection timing of 8.6 °CA bTDC was found to be optimum and it leads to a 27% reduction in NO_x emissions and 85% reduction in soot levels as compared to the base engine.

Jaichandar and Annamalai [19] studied the effect of injection pressure and reentrant combustion chamber using 20% pongamia biodiesel in a Diesel engine. They reported that CO, unburnt HC, and smoke were reduced and NO emission was increased for reentrant combustion chamber with increased injection pressure of 220 bar due to improved combustion. The BTE is increased and BSFC decreased for biodiesel as compared to hemi spherical bowl geometry of the piston for Diesel engine. Hence, the objective of the research work is to investigate the combined effect of varying injection pressure and combustion chamber geometry on the performance of a 25% corn biodiesel blend in a diesel engine and the results were compared to Diesel and the the 25% corn biodiesel blend.

Materials and methods

Production of corn oil methyl ester

In this study, corn biodiesel-diesel blend were used as alternative to diesel fuels. Raw corn oil was esterified by transesterification process. In trans esterification reaction, the molar ratio of methanol to corn oil was 5:1 and 1% mass of potassium hydroxide (KOH) was added with methanol. The methoxide solution and corn oil mixture are heated and the reactions were taken for two hours at a reaction temperature 65 °C. After the end of the reaction, the mixtures were kept at the ambient temperature for 8 hours and then settled in a separating flask. Two layers were formed in the flask. The top layer is a biodiesel and the bottom layer is a glycerin and then the 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 and compared with diesel fuel. The properties of COME are relatively closer to diesel fuel. The properties of diesel, corn oil, and its methyl ester are listed in tab.1.

Experimental set-up

The experimental test was conducted in a single cylinder, 4-stroke, air cooled and constant speed DI Diesel engine. The specifications of test engine are listed in tab. 2. The engine was coupled with an electrical dynamometer with load bank acting as a variable load system. The fuel injection timing of 23 °C was kept constant throughout the experiment.

Table 1. The properties of diesel, corn oil, and its methyl ester and its blend

Properties	Diesel	Corn oil	COME	COME25	Test method
Density	830	880	860	840	P16
Kinematic Viscosity at 40 °C [cSt]	3.2	23	5.2	4.2	P25/D445
Calorific value [MJkg^{-1}]	43	36	39	37.5	D5865
Flash point, [°C]	51	170	125	110	P21/D93
Cloud point, [°C]	6.5	12	10.2	7.1	D2500
Cetane No.	45	40	52	47	D2500
Acid value, [mg KOHkg^{-1}]	0.1	5.06	0.42	0.15	P1/D664
Carbon residue, [%mass]	0.1	1.2	0.0035	0.015	–

Table 2. Specifications of test engine

Engine	Kirloskar-AV1
Type	4S, vertical
Bore, [mm]	87.5
Stroke, [mm]	110
Rated power, [kW]	4.44
Displacement, [cm^3]	661
Compression ratio	17.5:1
Injection timing, [°CA]	23° bTDC
No. of nozzle hole	3 holes
Nozzle diameter, [mm]	0.2
Nozzle opening pressure range, [bar]	200-280 bar

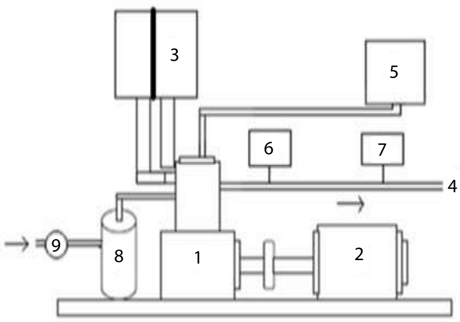

Figure 1. Schematic view of test engine;
1 – engine, 2 – dynamometer, 3 – fuel tank, 4 – exaust pipe, 5 – data aquisition system, 6 – gas analyser, 7 – smoke gun, 8 – surge tank, 9 – air-flow meter

A three-hole injector injects the fuel into the centrally positioned combustion chamber made in piston crown. The standard Diesel engine has hemispherical cavity piston (HCP) and the modified engine has toroidal cavity piston (TCP). The schematic diagram of experimental set-up is shown in fig. 1. The CO, CO_2, HC, and NO emissions were measured by AVL-444 gas analyzer and smoke intensity was measured by AVL 437 smoke meter. The engine speed measures with the help of digital tachometer, fuel tank connected with calibrated glass burette to measure mass of fuel for experiment, engine intake air supply is connected with air box to measure mass of air consume during the experiment, K-type thermocouple with digital temperature indicator was used to measure the inlet and outlet cooling water temperatures and exhaust temperature.

Cylinder pressure and HRR were measured by a piezoelectric pressure transducer fitted on engine cylinder head and a CA encoder fitted on flywheel. Both pressure transducer and encoder signals were connected to charge amplifier to condition the signals for combustion analysis using AVL (Indi meter) combustion analyzer. The uncertainties computed for the measured quantities are given in tab. 3. Initially the performance, emission and combustion tests were carried out using diesel and COME25 at various loads for standard engine having HCP and standard injection pressure of 200 bar. Then the same tests were conducted for the modified engine having TCP with diesel and COME25 at various nozzle opening pressures like

220 bar, 240 bar, and 260 bar, and fuel injection timing of 23 °bTDC were kept constant. The engine tests were carried out at 0%, 25%, 50%, 75%, and 100% load.

Table 3. Accuracies of measured parameters

Parameters	BTE	EGT	CO	HC	NO	Smoke	Pressure	SPEED
% of accuracy	±0.5	±0.5	±0.3	±0.5	±0.2	±0.8	±1.0	±1.0

Engine modifications

In the present investigation, effects of combustion chamber geometries on performance, combustion and emission characteristics of biodiesel fueled Diesel engine were studied. The piston bowl geometry was modified to have toroidal cavity combustion chamber (TCP) from the standard hemispherical cavity combustion chamber (HCP). For both the combustion chamber configurations, bowl volume was kept constant so that compression ratio was the same as for the standard engine.

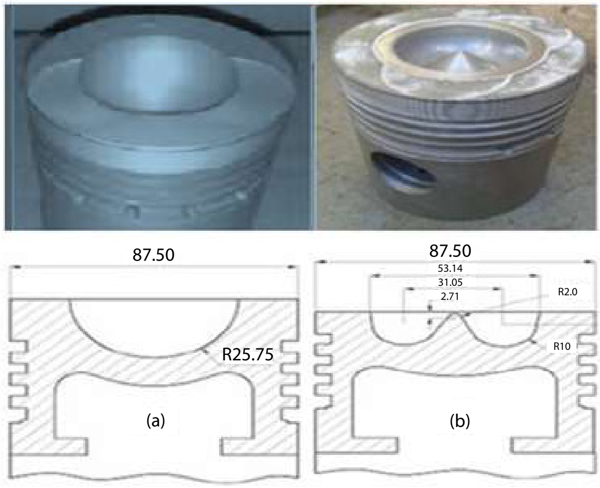

Figure 2. Modification of pistons; (a) HCP, (b) TCP

The photographic and cross-sectional view of both the pistons employed for this study are shown in fig. 2. The shape of the combustion chamber and the fluid dynamics inside the chamber are important in Diesel engine combustion. As the piston moves upward, the gas is pushed into the piston bowl. During this period squish and swirling action of air can be produced, which can improve the air/fuel mixture formation before ignition of the air/fuel mixture, resulting in complete combustion [20]. The injector opening pressure was varied by adjusting the spring tension of the injector by screwing or unscrewing the screw provided on the top of the injector. Then the experiments were carried out at different nozzle opening pressures of 200, 220, 240, and 260 bar for TCP at different load conditions.

Results and discussion

The performance and emissions characteristics of the base engine with HCP and modified engine with TCP at different injection pressures were determined and compared with pure diesel and COME25.

Combustion characteristics

The cylinder pressure variation in the cycle is the most important parameters in the analysis of the combustion characteristics of any fuel. The cylinder pressure variation with CA at full load for both the standard engine and modified engine with COME25 and pure diesel at different injection pressures is shown in fig. 3.

It is observed that the cylinder pressure was slightly lower for COME25 compared to that of pure diesel with the standard engine. This is due to poor mixing of COME25 with

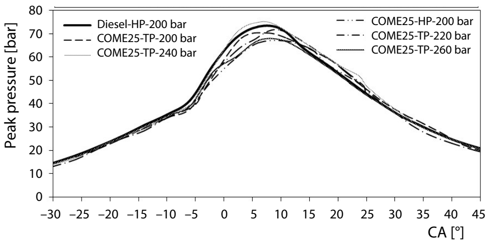

Figure 3. Variation of cylinder pressure with CA (*for color image see journal web site*)

air due to its higher viscosity and lower calorific value.The pressure variations of COME25 with TCP operation increases the cylinder pressure rise compared to HCP operation at the standard injection pressure of 200 bar. This may be due to better air motion by the TCP resulting in better combustion of COME25 at full load. It is observed that the cylinder pressure variations for COME25 is increased with increasing injection pressure from 200 bar to 220 bar and 240 bar pressure. This may be attributed to better atomization and vaporization of fuel and air mixture, resulting in better combustion of COME25 blend. It is also observed that the cylinder pressure was increases with an increase in injection pressures for the modified engine (TCP) with COME25 at all loads, which is higher than standard engine with HCP piston. This is attributed to better air motion was induced in the combustion chamber by the TCP, resulting in better combustion. However, cylinder pressure was decreased with modified engine having TCP for COME25 at 260 bar due to insufficient oxygen available for combustion when more fuel is injected at higher injection pressure of 260 bar at all loads, which results in poor combustion. The maximum cylinder pressure obtained for COME25 with TCP engine at 240 bar is 74 bar and for 220 bar is 71.5 bar at full load. The cylinder pressure for pure diesel and COME25 with HCP engine and standard injection pressure is 73 bar and 67 bar, respectively, at full load.

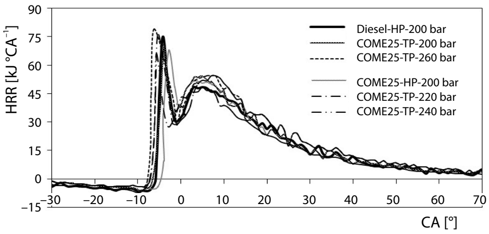

Figure 4 .Variation of heat release rate with crank angle (*for color image see journal web site*)

The comparison of the HRR curves for standard engine and modified engine with pure diesel and COME25 at different injection pressures is depicted in fig. 4. It is seen that the maximum HRR of COME25 blend was lower than that of pure diesel with the standard engine.

This may be attributed to shorter ignition delay for COME25 compared with that of pure diesel operation. In addition, the poor atomization characteristics of biodiesel due to higher viscosity and surface tension may be responsible for lower HRR. Further it is noticed that HRR during diffusion combustion phase of COME25 was slightly higher than that of pure diesel. It is observed that the HRR of COME25 is increased for TCP engine with an increase in injection pressure at full load due to better atomization and vaporization of biodiesel air mixture and shorter ignition delay, resulting in increased premixed combustion. It is also noticed that the HRR of COME25 was increased with an increase in injection pressures for the TCP engine as compared with HCP engine. This may be attributed to better air motion induced by TCP engine, resulting in increased HRR at full load. The maximum HRR was obtained for COME25 with 240 bar is 79.1 kJ/°CA at full load. The HRR for COME25 with standard combustion chamber is 68 kJ/°CA and for pure diesel it is 74.1 kJ/°CA at full load.

Ignition delay of fuel is a significant parameter in determining the knocking characteristics of compresion ignition engines. Figure 5 illustrated the variations of ignition delay for standard engine (HCP) and TCP engine with pure diesel and COME25 at different injection pressures. It is observed that the shorter ignition delay period was observed for COME25 compared to that of pure diesel with standard engine. This may be due to the higher cetane number of COME25 compared to pure diesel. It is also observed that for toroidal combustion chambers, the ignition delay periods were further lowered for COME25 compared to standard engine at all loads. This may be due to higher combustion chamber wall temperature and reduced exhaust gas dilution at higher loads. At higher injection pressures, the ignition delay further decreased as a result of increased in cylinder temperature due to improved air/fuel mixing and premixed combustion. The ignition delay obtained for COME25 with 240 bar is 6 °CA at full load. The ignition delay for COME25 with standard combustion chamber is 9 °CA and for pure diesel it is 10 °CA at full load [21].

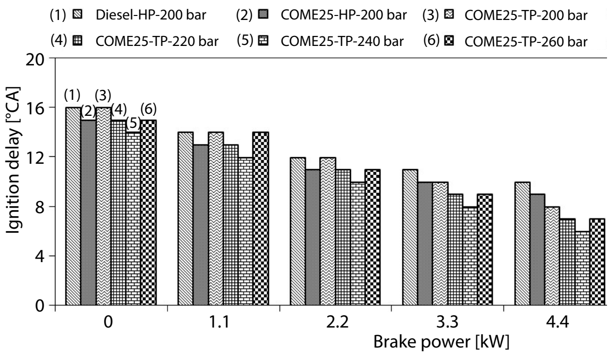

Figure 5. Variation of ignition delay with BP

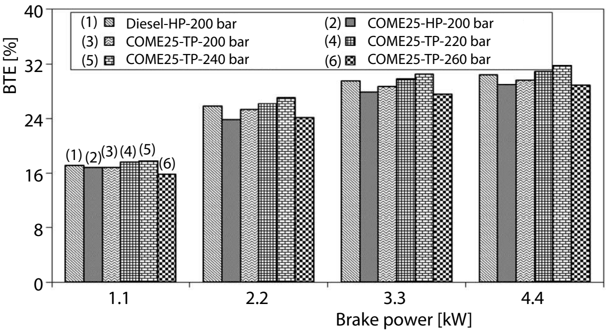

Figure 6. Variation of BTE with BP

Performance characteristics

The BTE describes the conversion of chemical energy of fuel into useful work. It is also indicate the combustion behavior of the engine to a greater extent [20]. Figure 6 depicts the variation of BTE of HCP engine and TCP engine with pure diesel and COME25 at different injection pressures. It is observed that the BTE increased with the increase in BP for diesel and COME25 for both the engines. The BTE of COME25 was lower (28.96%) compared to that of pure diesel (30.42%) with the standard engine having HCP piston.

The BTE obtained for COME25 with the TCP combustion chamber was increased (29.58%) compared to the standard engine operated with COME25 at full load. This may be attributed to better mixture formation of COME25 and air, as a result of better air motion in TCP combustion chamber. In addition, at higher injection pressure (240 bar), the BTE further increased (31.76%) for COME with TCP engine operation. This may be due to better atomization and air/fuel mixing as a result of better air motion, leads to complete combustion of COME25 blend. The BTE of COME25 at 260 bar injection pressure is decreased at all loads due to decrease in the droplet size of the fuel and all the fuel particles do not find the oxygen for combustion. A smaller fuel droplet will have lesser momentum that will affect fuel distribution in air with fuel. The decrease in relative velocity of fuel corresponding to air resulted in poor air entrainment leading to incomplete combustion [20].

The comparison of BSFC variations with BP for standard engine and modified engine (TCP) with pure diesel and COME25 at different injection pressures are illustrated in fig. 7. It is noticed that the BSFC increased for COME25 due to its lower calorific value and poor vaporization characteristics of COME25.

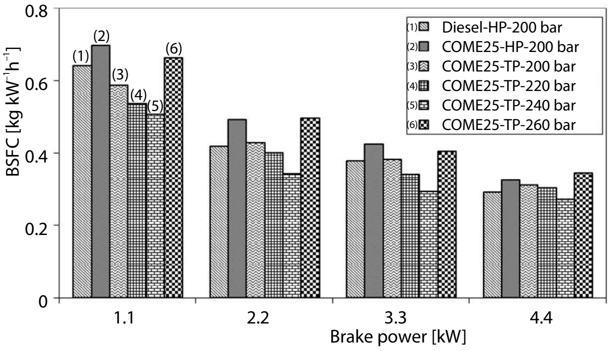

Figure 7. Variation of BSFC with BP

The specific fuel consumption of COME25 with TCP (0.312 kg/kWh) was lower than the standard engine having HCP (0.324 kg/kWh) with COME25 blend. This may be attributed to better atomization and vaporization of COME25 and better air/fuel mixing by the TCP combustion chamber, resulting in complete combustion of COME25 at full load. The BSFC of COME25 further decreased with increase in injection pressures at all loads for the TCP operation. This behavior can be attributed to improved air/fuel mixing due to better atomization and vaporization of the fuel that led to better combustion [20]. However, it is noticed that the BSFC is further increased with an increase in injection pressure was increased beyond 240 bar. This can be attributed to poor spray penetration and poor dispersion of the fuel and weak air entrainment, results in poor combustion [21].

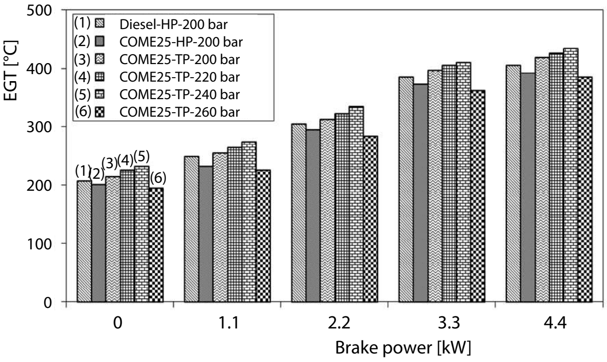

Figure 8. Variation of EGT

Figure 8 presents the comparisons of exhaust gas temperature (EGT) with BP for standard engine and modified engine with pure diesel and COME25 at different injection pressures. The EGT increased with engine load for both the engines. It is observed that the EGT of the COME25 blend was higher than that of pure diesel with standard engine having HCP. This may be attributed to slow combustion of high viscous COME25 at full load. The EGT is observed higher for COME25 with toroidal combustion chamber (TCP) compared to HCP engine with COME25 blend. This may be due to more complete combustion as a result of better air/fuel mixing and the presence of oxygen in the COME25 blend [20]. The EGT further increased with an increase in injection pressures due to predominant premixed and diffusion combustion phase. This could be attributed to better atomization, air/fuel mixing and vaporization of the COME25 fuel blend. The EGT of COME25 with TCP at 240 bar injection pressure is 434 °C and for HCP with diesel and COME25 at standard injection pressure is 405 °C and 392 °C, respectively, at full load [19].

Emission characteristics

Figure 9 depicts the comparisons of CO emissions with BP for both the combustion chambers at different injection pressures. The CO emissions for both the combustion chambers fueled with COME25 blend decreased significantly when compared with that of pure diesel. It is observed that CO emissions reduced for COME25 compared to pure diesel with standard engine. This may be due to more oxygen content present in the COME25 blend, resulting in better combustion. It is also noticed that the CO emission decreased for COME25 with TCP combustion chamber compared to HCP combustion chamber operation.

This may be due to higher air movement in TCP combustion chamber and also excess oxygen present in COME25 blend resulting further oxidation of CO during the engine exhaust stroke. Further reduction in CO emissions was observed with increase in injection pressure and it may be attributed to better atomization, evaporation of COME25 blend and leads to complete combustion [19]. There was a reduction of 44% CO emissions for the TCP engine compared to the standard engine when tests were carried out with COME25 with standard engine. The CO emission obtained for COME25 at 240 bar injection pressure is 0.04% and for standard engine with 200 bar pressure is 0.14% at full load.

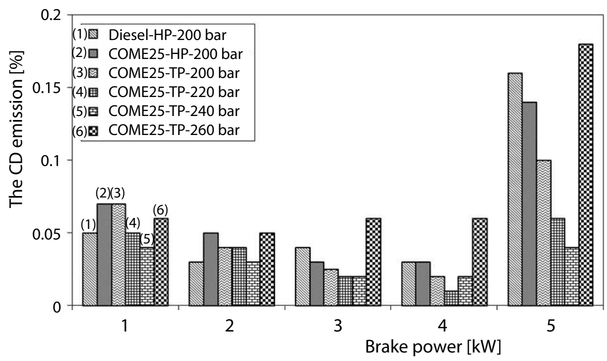

Figure 9. The CO emissions with BP

The variations of HC emission with BP for COME25 and pure diesel at different injection pressures for both the engine operations are illustrated in fig. 10. The HC emissions were increased with increase in load for COME25 compared to pure diesel with standard engine. This may be due to improper mixing of air COME25 blend resulting in increased HC emissions. It was also noticed that TCP combustion chamber emits lesser levels of HC compared to HCP combustion chamber. This may be attributed to better utilization of of air in the combustion chamber by the TCP combustion chamber as a result of improved swirl motion of air in the combustion chamber and also the presence of excess oxygen in COME25 fuel. Further increase in injection pressure, the formation of HC emission decreased due to better combustion and reduction in quench layer, due to increased cylinder wall temperature. It is also noticed that there is a reduction of 29% HC emissions for COME25 with TCP compared to the standard engine (HCP) and 43% reduction of HC emissions with pure diesel at full load. The maximum HC emission obtained for COME25 at 240 bar injection pressure is 32 ppm (200 bar) compared to 45 ppm (220 bar) and 56 ppm (260 bar) for COME25 and pure diesel using HCP engine with standard injection pressure at full load [18].

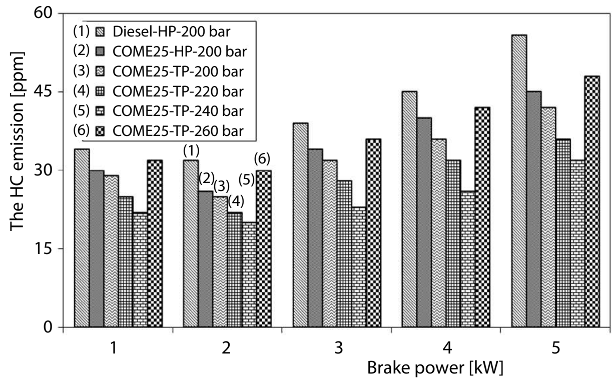

Figure 10. Variations of HC emissions with BP

Figure 11 shows the variations of NO emission with BP for both the engine with pure diesel and COME25 at different injection pressures. The NO emission is formed at higher combustion temperature and atmospheric nitrogen present in the air used for combustion. The NO emission for COME25 with standard engine higher than diesel due to excess oxygen present in the fuel, resulting in higher NO emission at all loads. In addition, larger part of the combustion may be completed before bTDC may be another reason for increase in NO emission. It is observed that the NO emission was increased for COME25 with TCP compared to standard engine hav-

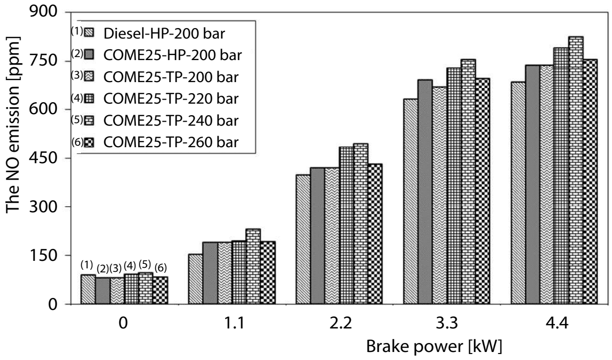

Figure 11. Variations of NO with BP

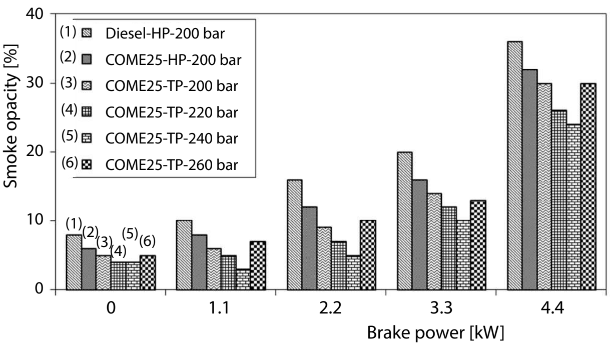

Figure 12. Variations of smoke opacity with BP

ing HCP. The reason for the increase in NO emission may be attributed to higher combustion temperatures arising from improved combustion and better mixture formation in TCP and availability of oxygen present in COME25 fuel. Another reason for increased NO emissions may be attributed to that, a larger part of the combustion was completed bTDC for COME25 blend compared to pure diesel due to their lower ignition delay [20]. Hence, it is highly possible that higher peak cycle temperatures were attained for COME25 compared to pure diesel. For the same reason, it is also observed that NO emission further increased with increase in injection pressure. At full load, the NO emissions obtained for COME25 with TCP at 200 bar and 240 bar injection pressure is 827 ppm and 786 ppm, respectively, compared to standard engine operated with pure diesel (686 ppm) at full load [19].

The smoke opacity variation for both the combustion chambers with pure diesel and COME25 at different injection pressures is depicted in fig. 12. The smoke opacity was decreased for COME25 blend upto the part load (75% load) and then it increases at full load due to improper mixing of COME25 and air at full load. At all loads and for both combustion chambers, smoke opacity for COME25 decreased significantly when compared to that of pure diesel.

The reduction in smoke emissions may be due to the presence of oxygen in biodiesel blend. It was also observed that the lower injection pressure operation resulted in higher smoke emissions than high injection pressure. At lower injection pressure, the atomization process was very poor. This resulted in bigger droplets and hence bigger core. It was found that smoke emissions were formed in the core region [20]. However, at a higher injection pressure of 240 bar, it was observed that lower smoke emissions were formed due to small size fuel droplets, better air/fuel mixing and complete combustion. Toroidal piston with 240 bar injection pressure provided 33% reduction of smoke opacity when compared with the standard engine fueled with COME25 and pure diesel. The maximum reduction of smoke opacity for COME25 at 240 bar injection pressure is 24% compared 32% at standard engine with COME25 and B25 at 200 bar injection pressure at full load. The similar trend is found by the researcher Kumar *et al.* [21].

Conclusions

The experiments were successfully conducted with the effect of injection pressure and combustion chamber geometry on the performance, emission, and combustion characteristics of a single cylinder 4-stroke Diesel engine using COME blend. The following conclusions were made from the experimental results:

- Air motion in TCP piston and increase in injection pressure resulting in high atomization of fuel inside the cylinder leads to uniform distribution of fuel with air and better combustion of fuel, which increases the BTE and lowers the specific fuel consumption compared to standard engine operated with HCP combustion chamber.
- The BTE was increased by 2.8% and 1.36% for COME25 with TCP combustion chamber at 240 bar injection pressure compared with HCP with standard engine for COME25 and pure diesel, respectively. The BSFC was decreased for COME25 with TCP with 240 bar by 16% compared to the same fuel with standard engine at full load operation.
- The NO_x emissions for TCP with COME25 was increased by 12% (81 ppm) and 20% (141 ppm) compared COME25 and pure diesel, respectively, and the smoke opacity also decreased for TCP compared with standard engine at full load.
- The CO and HC emission TCP with 240 bar injection pressure decreased by 43% and 44%, respectively, for COME25 compared to standard engine.
- The combustion parameters such as cylinder pressure, HRR, and ignition delay were improved for COME25 with TCP combustion chamber operation compared to standard engine.
- Finally, it is concluded that toroidal combustion chamber is more suitable for Diesel engine fueled with biodiesel blend based on the performance and combustion improvement and reduction in emissions of the Diesel engine.

Nomenclature

BP – brake power
BSFC – brake specific fuel consumption
BTE – brake thermal efficiency
CA – crank angle
COME – corn oil methyl ester
COME25 – 25% biodiesel + 75% diesel
DI – direct injection
EGT – exhaust gas temperature
HCP – hemispherical cavity piston
HRR – heat release rate
TCP – toroidal cavity piston

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