INFLUENCE OF COMBUSTION CHAMBER BOWEL GEOMETRY ON COMBUSTION, PERFORMANCE AND EMISSION CHARACTERISTICS OF A DIESEL ENGINE USING GRAPE SEED OIL METHYL ESTER

by

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In this paper, the combustion, performance and emission characteristics of a single cylinder diesel engine was investigated using two combustion chamber geometries such as toroidal combustion chamber and standard piston combustion chamber in a 5.2 kW single cylinder diesel engine. The experiments were carried out at an ambient temperature of 30 ± 2 °C. The performance was observed at no load 20, 40, 60, and 80%, and full load operating conditions. The results showed that the GOME 25 operated with toroidal combustion chamber has improved combustion, performance, and emission characteristics when compared to standard piston combustion chamber. The GOME 25 has improved brake thermal efficiency by about 23, 13.6, 10.6, 9.9, and 10.9% when compared to standard piston combustion chamber operated with diesel at no load, 20, 40, 60, 80, and 100% loading conditions, respectively. The smoke density and CO were reduced by about 14.8% and 38%, respectively. The NO_x emission operated with GOME 25 using toroidal combustion chamber was increased by about 36% when compared to standard piston combustion chamber with diesel. The heat release rate of GOME 25 with toroidal combustion chamber was observed to be better when compared to diesel with standard piston combustion chamber. The results confirmed that toroidal combustion chamber piston is a good option for the use of GOME 25 blend.

Key words: *emission, combustion, performance, grape seed oil methyl ester25*

Introduction

The diesel engines are widely used in public transport vehicles, power generation and agricultural sector as its good torque characteristics are high when compared to petrol engines. The fast depletion of conventional fuel resources and its negative impact on environmental have created research interest on development of renewable energy sources to substile for diesel [1]. During the last decades, many research and development have been reported on

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the use of new vegetable oils as additives with diesel [2]. A summary of research investigation reported on the use of bio diesel are presented in this section [3-12].

The research and development investigations confirm that, the biodiesel is biodegradable, free of sulphur with enriched oxygen and renewable in nature [3]. Moreover, the biodiesel blends have benefits such as, reduced emissions, minimum engine wear with less lubricant consumption and good thermal efficiency compared to diesel [4]. The use of biodiesel has certain drawbacks such as, poor storage stability, higher viscosity, increased NO_x emissions and cold flow properties when compared to diesel [5]. These drawbacks are overcome by selecting an appropriate raw material for production of biodiesel [6]. The comprehensive review papers on research and developments of biodiesel confirm that, biodiesel blends produce higher oxides of nitrogen and carbon-dioxide better than to diesel as its higher cetane number and enriched oxygen, which leads to improved combustion [7]. However, biodiesel blends have less carbon-monoxide and hydrocarbon emissions [8]. The biodiesel blends have less sulphur dioxide emissions due to the absence of sulphur [9]. The reported reviews confirmed that, it is possible to blend 20% of vegetable oils with diesel, which can be used as an alternative without modifications in existing diesel engines [10-12]. It is observed that, there is no specific research on the use of toroidal combustion chamber (TCC) for the use of GOME 25 has been reported. Hence, in this research work, the possibility of using GOME 25 with TCC is explored at different loading conditions.

Production and characterization of grape seed oil methyl ester

The GOME transesterification process utilizing a methanol in the incidence of KOH substance to break the molecules in to methyl ester such as, potassium hydroxide to chemically breakdown the particle as molecule of the grape seed oil in to methyl esters of the grape seed oil through glycerol as by-product. Initially, the grape seed oil was heated to 70 °C. At that point, the substance was blend with methanol to break up and incorporated to the warmed grape seed oil to the reactor, after the blend was enthused around one hour at a stirred temperature of around 70 °C. It was moved to another vessel glycerol settled down at the bottom and methyl ester float on top of the vessel and then glycerol was drained out.

Table 1. Diesel and GOME 25 properties

Fuel	Diesel fuel	GOME 25%
Specific gravity at 15 °C	0.835	0.845
Kinematic viscosity at 40 °C [cSt]	3.24	3.52
Lower heating value [$kJkg^{-1}$]	44,645	44,038
Flash point [°C]	55	80
Fire point [°C]	58	83
Density@15C [gcm^{-3}]	0.835	0.847
Calculated cetane index	50	51
Pour point [°C]	–23	–15

A washing procedure was carried out to eliminate unreached reminder of methanol and catalyst utilizing purified water and air. Then, a purification procedure on around 110 °C was applied to removing water in the GOME. Finally, GOME was drain out and cool down. The trans-esterification process used for extract of GOME is defined in fig. 1. The properties of GOME 25 and diesel are displayed in tab. 1.

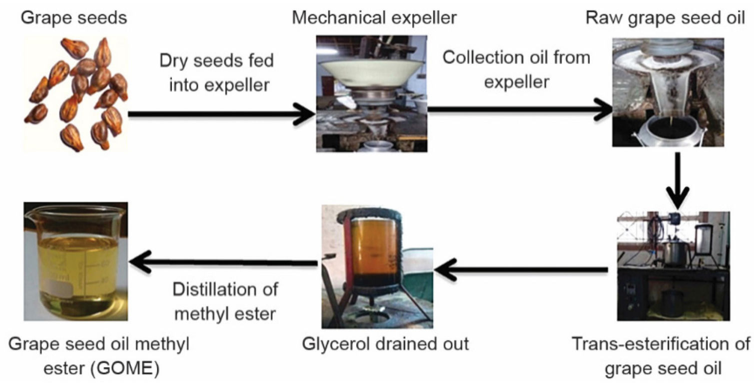

Figure 1. Generation of grape seed oil methyl ester GOME flow chart

Experiments

The schematic and photographic views of experimental set-up are shown in figs. 2 and 3, respectively, and its specification are given in tab. 2.

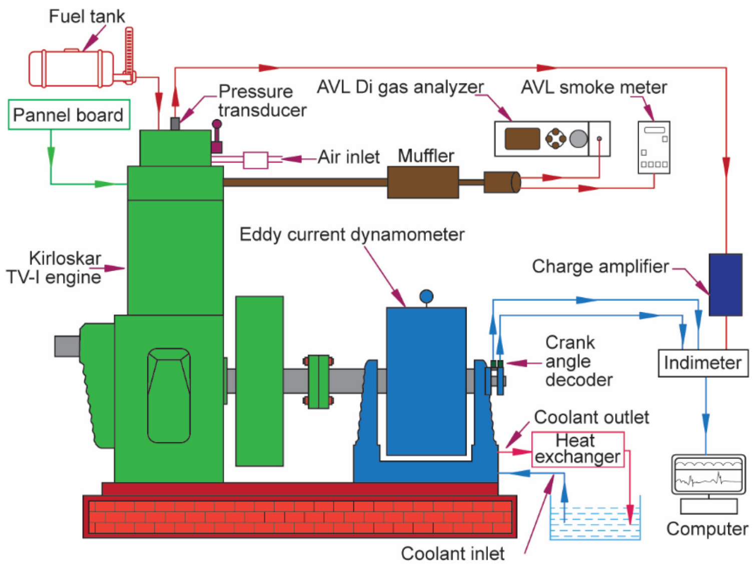

Figure 2. Schematic drawing of the investigational set-up

Experimental set-up

The experimental set-up consists of a 5.2 kW, single cylinder, water cooled engine connected with an eddy current dynamometer to load the engine. The experimental set-up is placed inside an environmental chamber maintained at 30±2 °C. The experimental set-up is equipped with necessary measuring instruments to measure the fuel consumption, engine load, speed, temperatures at typical locations, cooling water flow rate through the engine and

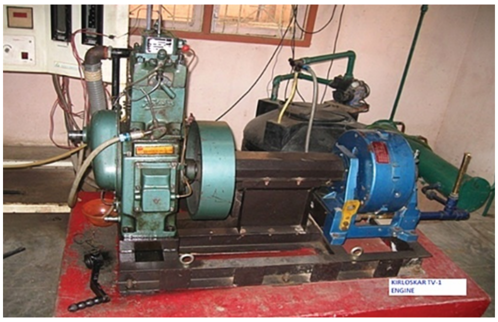

Figure 3. Photographic view of the Kirloskar TV-1 engine

air intake. All the measurements were interfaced with a computer through a data acquisition system. The engine emissions were measured by tapping fuel gas from engine exhaust. The pressure inside the combustion chamber was measured using piezoelectric pressure transducer fitted in the cylinder head with the sensitivity of 16:11 pC/bar.

Instrumentation

Temperatures at typical locations were measured using k-type thermocouples. The engine speed was measured by magnetic pickup instrument linked to frequency meter. The smoke intensity was quantified by smoke meter (AVL 437) and other emissions such as CO, NO_x and HC were quantified by gas analyzer (AVL 444) (tab. 2).

Table 2. Test engine specification

Make	Kirloskar-TV 1
Type	Four stroke, compression ignition, direct injection, constant speed, vertical, water cooled
Number of cylinder	One
Bore	87.5 mm
Stroke	110 mm
Compression ratio	17.5:1
Rated power	5.2 kW
Rated speed	1500 rpm
Dynamometer	Eddy current
Fuel injection timing	23° bTDC
Injection pressure	220 bar
No. of nozzle holes	3

Experimental procedure

The fuel consumption, exhaust emissions and smoke density were measured no load, 20, 40, 60, and 80% and full load conditions. The fuel consumption was measured using burette and stop watch. Three trial experiments were made and the average values were considered for discussion. For every test with different fuel blends, the combustion data were observed and recorded in the personal computer. Initially, the engine was allowed to run 30 minutes to attain steady state conditions. The initial warm-up has reduced the transient errors in the experimental observations. Two combustion chamber geometries such as standard piston combustion chamber (SPCC) and TCC were selected for experimental investigation. Initially, SPCC was selected and engine performance was observed for diesel. Further the experimental procedure has been repeated for GOME blends and same procedure followed by TCC. The schematic illustration of two combustion chamber geometry are given in fig. 4.

During experimental observations, engine load, engine speed, fuel consumption, emission parameters, combustion characteristics were measured.

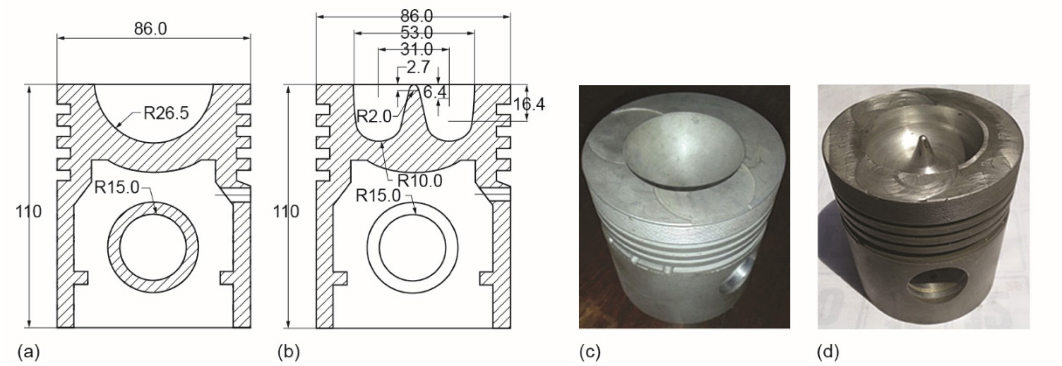

Figure 4. Piston details; (a), (b) schematic diagram different combustion chamber geometries, (c), (d) photographical view of different combustion chamber geometries; (a), (c) standard piston combustion chamber; (b), (d) toroidal combustion chamber; dimensions in mm

Uncertainties analysis

The errors in measuring instruments will influence the reliability of performance assessment. Hence, the uncertainty analysis was carried out to quantify the errors in performance calculations. The uncertainties in the calculated parameters were estimated by following equation according to Holman. The uncertainties and accuracies of the various instruments used are given in tab. 3.

Table 3. Accuracy and uncertainty of the instruments

Instrument	Measurement	Accuracy	Uncertainty [%]
Burette	Fuel consumption	± 0.2 cm^3	± 1.5
Load cell	Loading device	± 10 N	± 0.2
Speed sensor	Speed	± 10 rpm	± 1.0
Temperature indicator	Temperature	± 2 °C	± 0.3
Exhaust gas analyzer	CO	± 0.02%	± 0.2
	HC	± 10 ppm	± 0.1
	NO_x	± 12 ppm	± 0.2
Smoke	Smoke density	± 1 HSU	± 1.0
Pressure transducer	Cylinder pressure	± 0.3 kg	± 0.3
Crank angle encoder	Crank angle	± 1°	± 1.0

Results and discussion

The results obtained from series of experiments conducted in a single cylinder four stroke diesel engine are presented in this section.

Combustion analysis

The combustion performance parameters such as, heat release and cylinder pressure are described in this sub section.

Heat release rate

In fig. 5, the net heat release rate for SPCC and TCC operated with diesel and GOME 25 at various loading conditions are illustrated. It was observed that, the heat release rate of SPCC operated with diesel was lower when compared to TCC operated with GOME 25 due to less ignition delay. This may be attributed to good air fuel mixing ensures better combustion. It is also observed that, the maximum heat release rate of about 118 kJ/m^{3}deg was observed for TCC worked with GOME 25, which is about 9% higher when compared to SPCC with diesel.

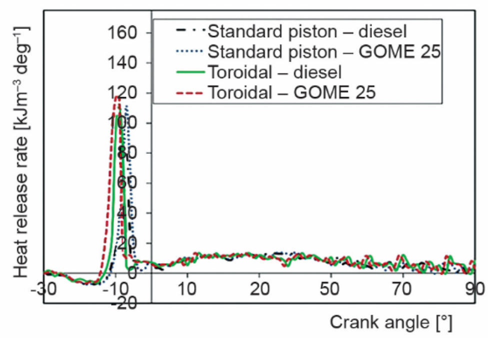

Figure 5. Crank angle *vs.* heat release rate

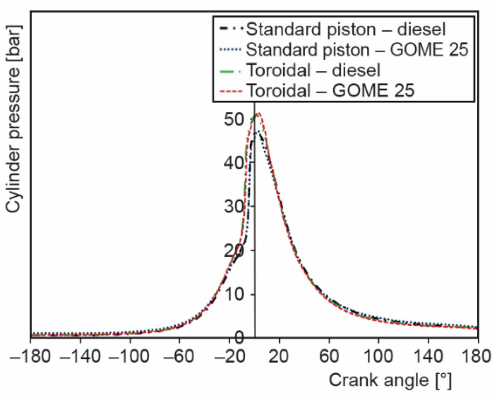

Figure 6. Crank angle *vs.* cylinder pressure

Cylinder pressure

In fig. 6, the cylinder pressure variations for TCC and SPCC are compared against crank angle. It was observed that, an increase of the premixed combustion and earlier rise in the peak pressure are attained for a TCC for both diesel and GOME 25 blend. The GOME 25 shows an early start of combustion compared with diesel due to reduction in ignition delay. The TCC has a high swirl speed, which creates a strong mixing of GOME-diesel blend. The turbulence level at begin of injection is higher in TCC than SPCC. An increased turbulence will develop the air entrainment under ignition situation and reduce the ignition delay. Moreover, an in-cylinder temperature and pressure has improved the air-fuel mixing and enhance the combustion processes. The GOME 25 have ensured better atomization and mixing capability by using TCC, which reduces the emission formation.

Performance characteristics

The performance parameters at five different boundary conditions are described in this subsection.

Brake thermal efficiency (BTE)

Figure 7 compares the variations brake thermal efficiency against brake power for GOME 25 blend and diesel using TCC and SPCC. The brake thermal efficiency of GOME 25 diesel blend using TCC was observed higher about 11% when compared to the SPCC using diesel. Additionally, it was observed that, an improved brake thermal efficiency of TCC using GOME 25 at all loading conditions when compared to diesel with SPCC for all loading conditions. The better mixing of GOME 25 and air will also be completed by way of producing TCC bowl. Further, the droplet collision is higher for the TCC resulted in higher oxygen content in GOME 25. An increase in surface area of TCC improves the vaporization and also ensures better turbulence inside the combustion chamber. At low operating loads, the BTE was increased for TCC when compared to the SPCC for diesel due to excessive vaporization and mixing with air. It ensures breaking-up of fuel molecules.

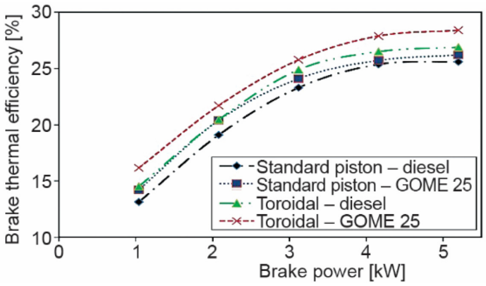

Figure 7. Brake power *vs.* brake thermal efficiency

Emission characteristics

Carbon monoxide emission

The CO emissions in both the SPCC and TCC with GOME 25 and diesel are compared in fig. 8. The CO is mostly formed due to the lack of oxygen quantity and incomplete combustion of fuel, which lowers the cylinder temperature, and increases the ignition delay. Utilising TCC, the spray penetration distance was reduced and increases the turbulence which improves the combustion chamber temperature and reduce the ignition delay. The CO emission were reduced due to improved oxidation. The carbon/hydrogen ratio of GOME 25 blend is lower when compared to diesel, which produces low CO emissions. The GOME 25 has additional oxygen composition within the fuel. The oxidation of O_2 molecule takings place at higher combustion temperature, which allows the entire response of all oxygen within the fuel at higher load and it significantly reduced the CO emissions. The CO emissions for SPCC and TCC using GOME 25 has significantly reduced when compared to diesel due to the presence of oxygen in GOME. This shows CO emissions were particularly reduced by about 38% (at full load conditions) using TCC operated in GOME 25 compared to the using SPCC with diesel.

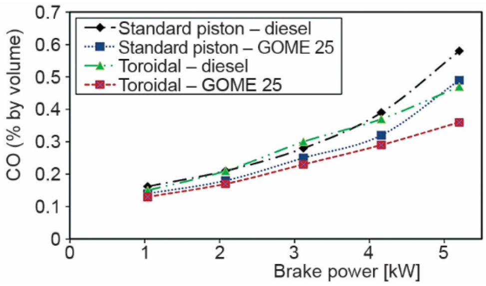

Figure 8. Brake power *vs.* carbon monoxide

Unburned hydrocarbon emission (UBHC)

The UBHC emissions with SPCC and TCC combustion chambers for diesel and GOME 25 diesel blend are compared in fig. 9. The UBHC emissions are reduced over the entire range of loads for TCC when compared to SPCC with diesel fuel and GOME 25 blends. The diesel fuel operation with SPCC and TCC were found to be 124.5 and 120.2 ppm at full load conditions. The GOME 25 diesel blend operation with SPCC and TCC were found to be

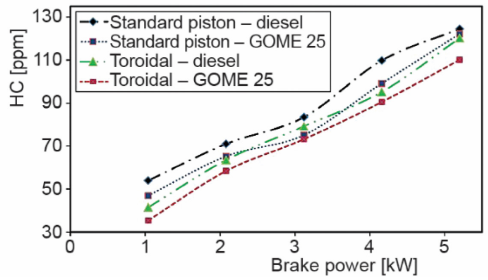

Figure 9. Brake power *vs.* unburned hydrocarbon

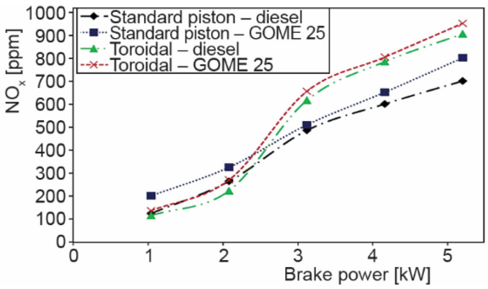

Figure 10. Brake power *vs.* NO_x

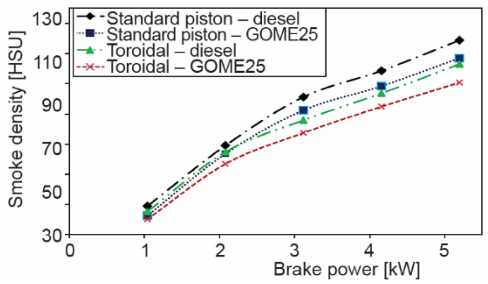

Figure 11. Brake power *vs.* smoke density

122 and 110 ppm at full load conditions. The UBHC for TCC operated with GOME 25 is lower by about 34% at 20% load and 11.5% at full load conditions when compared to SPCC, due to improved combustion of GOME 25 using TCC.

Oxides of nitrogen emission (NO_x)

The variation of oxides of nitrogen emissions for SPCC and TCC with diesel and GOME 25 are compared in fig. 10. The NO_x emissions were increased for TCC when compared to SPCC due to the rise in combustion temperatures. The NO_x can be controlled by TCC and by utilizing GOME 25. At full load conditions with GOME 25, for the TCC, the NO_x emission was 952 ppm compared to 701 ppm for SPCC using diesel. The NO_x emissions were found to be higher about 35% for TCC using GOME 25 when compared to SPCC using diesel at all loading conditions.

Smoke density

The smoke densities for SPCC and TCC for diesel and GOME 25 are compared in fig. 11. The presence of oxygen and hydrogen molecules in GOME 25 diesel blend has reduced the smoke emissions. It was also observed that, TCC operated with GOME 25 has about 15% reduction of smoke when compared with SPCC operated with diesel. It is observed that in TCC, better entrainment of the air reaches the maximum degree of similarity with fuel. The inadequate air-fuel mixing has leads to ignition delay. The high value of cetane number for GOME 25 has reduced the fuel consumption at all loading conditions.

Conclusions

The influences of combustion bowel geometry on combustion, performance, and emission characteristics of a single cylinder diesel engine were investigated and the following conclusions drawn.

- The heat release rate and cylinder pressure were found to be increased in the case of TCC using GOME 25.
- The brake thermal efficiency of GOME 25 blended fuel was observed to be higher when compared to diesel.
- Better air movement was observed in TCC, which ensures improved brake thermal efficiency and reduces the specific fuel consumption when compared to SPCC.

- The presence of oxygen content in GOME 25 has improved the combustion processes and reduced the emissions (in the case of TCC) such as smoke, UBHC, and CO when compared to SPCC. Moreover, the presence of oxygen in GOME 25 has increased combustion chamber temperature and produces higher NO_x in TCC than SPCC.
- Increase in combustion chamber temperature operating with TCC using GOME 25 has improved the mixture formation, which reduces the ignition delay compared with SPCC using diesel.
- Improved combustion due to mixing of better air and fuel in TCC was observed when compared to SPCC. The results confirmed that TCC geometry is found suitable for GOME 25.

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