An Experimental Study on A CI Engine Fuelled With Soapnut Oil-Diesel Blend with Different Piston Bowl Geometries

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Abstract

The present work investigates the effect of varying the combustion chamber geometry on the performance, emission and combustion characteristics of a C.I. Engine using biodiesel. Engine tests have been carried out using a blend of 20% soapnut oil methyl ester (SOME) and diesel as fuel and with two types of combustion chambers namely Hemispherical combustion chamber, Toroidal combustion chamber without altering the compression ratio of the engine. The test results showed that brake thermal efficiency for toroidal combustion chamber is higher than for the other type of combustion chamber. Significant improvement in reduction of particulates, carbon monoxide and unburnt hydrocarbons is observed for toroidal combustion chamber compared to the hemispherical combustion chamber. However oxides of nitrogen were slightly higher for toroidal combustion chamber. The combustion analysis shows improved characteristics for toroidal combustion chamber compared to baseline engine at all loads of operation.

Index Terms: *Biodiesel, Diesel engine, Combustion chamber Performance, and Emissions etc…*

1. INTRODUCTION

The fossil fuels are depleting rapidly and the prices are going up day by day. As a result alternative fuels have received much attention due to its ability to replace fossil fuels. Moreover, the environmental issues concerned with the exhaust gases emission by the usage of fossil fuels also encourage the usage of alternative fuels such as biodiesel. In this context, there has been growing interest on alternative fuels like vegetable oils to provide a suitable diesel oil substitute for internal combustion engines. The main drawback of vegetable oils is associated with their high viscosity, 15–20 times greater than the standard diesel fuel. Thus, although short-term tests using neat vegetable oils showed promising results, problems appeared after the engine had been operated for longer periods. Researchers have suggested different techniques for reducing the viscosity of the vegetable oils. The different techniques are blending with diesel fuel, micro-emulsification with methanol or ethanol, thermal cracking, and conversion into Biodiesels through the transesterification process. Among these transesterification process is most widely used.

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 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. Some researchers have studied the performance and emission characteristics of a DI naturally aspirated diesel engine using 100% sun flower oil, 100% peanut oil and 50% (by vol.) mixtures of either sun flower oil or peanut oil with No. 2 diesel oil. They observed that the engine power and thermal efficiency decreased, specific fuel consumption was increased by 10% and emissions increased marginally. The attributed reasons were higher densities, higher viscosities, relatively lower heating values and thermal cracking of the vegetable oil fuel droplets at elevated temperatures. 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. To realize the full potential of biodiesel use in internal combustion engines, in addition to injection parameters, investigations on any modifications of engine design, particularly combustion chamber may be required, since the properties of biodiesel are different from diesel. Researchers have reported that the combustion and emission formation, particularly the increase of NOx emissions by application of biodiesel varies significantly with different combustion systems and different combustible mixture formation strategies. As the piston bowl geometry design affects the air–fuel mixing and the subsequent combustion and pollutant formation processes in a DI diesel engine an attempt has been made here to investigate the effects of combustion chamber geometries on biodiesel fuelled diesel engine. In this experimental investigation, engine tests were carried out using two types of open combustion chamber geometries to compare the performance, emission and combustion characteristics of 20% blend of SOME with baseline diesel.

2. Experimental setup

The test engine used was the Kirloskar, single cylinder four-stroke water cooled diesel engine developing 5.2 kW at 1500 rpm. The detailed technical specifications of the standard engine are given. This engine was coupled to an eddy current dynamometer with a control system. The cylinder pressure was measured by a piezoelectric pressure transducer fitted on the engine cylinder head and a crank angle encoder fitted on the flywheel. Both the pressure transducer and encoder signal were connected to the charge amplifier to condition the signals for combustion analysis using SeS engine combustion analyzer. The engine combustion analyzer is used to evaluate and determine power cylinder combustion characteristics such as ignition delay, start of combustion, estimated end of combustion, mass fraction burnt, heat release rate and pressure and volume variations with respect to crank angle. UBHC and CO were measured using a CRYPTON 5 gas analyser. NOx emissions were measured using SIGNAL heated vacuum NOx analyser. The smoke intensity was measured with the help of the AVL 437C Smoke meter.

2. 1 Engine modifications

Development of biodiesel fuelled direct-injection diesel engine requires modifications to fuel injection system and to the combustion chamber, since they strongly influence both the engine performance and the pollutant emissions. Mixture formation within the engine cylinder mainly depends upon shape of the combustion chamber in a direct injected diesel engine. In direct injection diesel engines a single combustion chamber with different piston bowl shapes such as cylindrical, square, hemispherical, shallow depth, and toroidal have been used. In the present investigation, to investigate the effects of combustion chamber geometry on performance, combustion and emission characteristics of biodiesel fuelled direct injection diesel engine the piston bowl geometry was modified to have Toroidal Combustion Chamber (TCC) and from the baseline Hemispherical Combustion Chamber (HCC).

Table-1: Standard engine specifications.

Make	**Kirloskar TV1**
Type	Vertical diesel engine, four stroke, water cooled, single cylinder
Displacement	661cc
Bore and stroke	87.5 mm and 110 mm
Compression ratio	17.5:1
Fuel	Diesel
Rated brake power	5.2 kW @ 1500 rpm
Ignition system	Compression ignition
Injection timing	23_bTDC (rated)
Injection pressure	200 bars
Combustion chamber	Hemispherical combustion chamber

For all the combustion chamber configurations, bowl volume was kept constant so that compression ratio was the same for all the investigated chambers.

HCC also gives small squish. However the depth to diameter ratio can be varied to give any desired squish to give better performance. But the TCC provides a powerful squish along with the air movement similar to that of familiar smoke ring. Due to powerful squish there is a better utilization of oxygen in TCC. The engine is equipped with a MICO in-line injection pump, which pressurize the fuel and injects at a pressure of 200 bars. A three-hole injector is used, which injects the fuel in the form of fine spray to ensure good fuel atomization. The fuel is injected into the centrally positioned open combustion chambers made in the piston crown. Squish and swirl air motion induced by the combustion chamber enables fast evaporation of highly atomized fuel and fast mixing of fuel vapours with air which ensures complete combustion. Fig. 3 shows the shapes and dimensions of three combustion chamber geometries used.

2.2 Test method

Two fuels were tested in this study: diesel fuel and a blend of 20% SOME fuel by volume in the diesel fuel. The test was conducted by starting the standard engine with diesel fuel only. After the engine was warmed up, it was then switched to 20% SOME blend. Then the engine tests were carried out at various loads with 20% SOME blend and diesel on modified engine having TCC. The engine tests were carried out at 0%, 25%, 50%, 75% and 100% load. In order to have meaningful comparison of emissions and engine performance, investigation was carried out at same operating conditions i.e. engine speed, torque, air–fuel ratio and peak conditions were maintained.

3. Results and Discussion

3.1 Brake thermal efficiency (BTE)

The comparison of BTE of standard engine and modified engine with diesel with diesel and 20% SOME.BTE of 20% SOME is lower (22.5%) compared to that of diesel (26.5%) with standard engine having HCC.

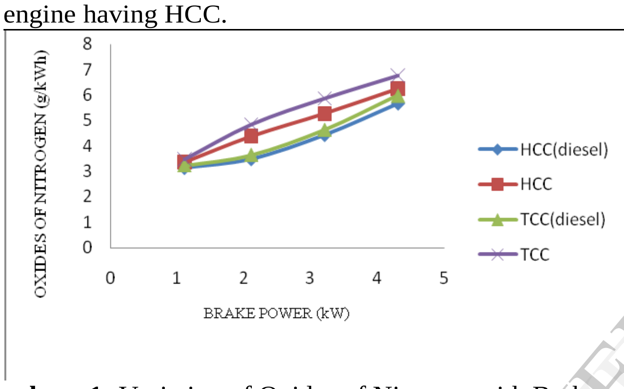

chart-1: Variation of Oxides of Nitrogen with Brake power.

Since the engine is operated under constant injection timing and SOME has a smaller ignition delay, combustion is initiated much before TDC is reached. This increase compression work and more heat loss and thus reduce the BTE of the engine. On the other hand BTE for TCC (27.4%) is higher when compared to the other types of combustion chambers at all loads when operated with 20% SOME. This may be due to better mixture formation of SOME and air, as a result of better air motion in TCC, which leads to better combustion of the biodiesel and thus increases the BTE.

3.2 Brake specific fuel consumption (BSFC)

The BSFC of standard engine and modified engine with diesel and 20% SOME. The brake specific fuel consumption for 20% SOME (0.288 kg/kW-h) is slightly higher than that of diesel (0.263 kg/kW-h) in the standard engine at full load.

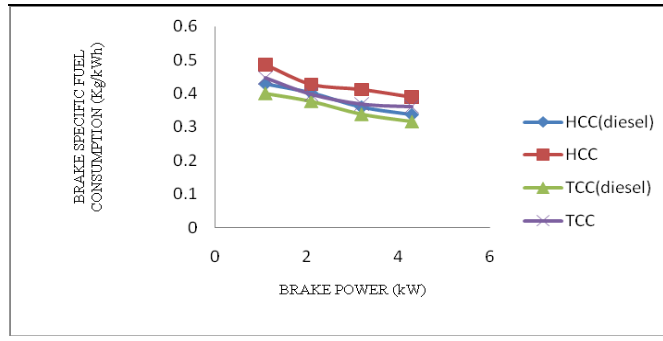

chart-2: Comparison of Brake specific fuel consumption with Brake power.

This may be attributed to the lower calorific value of SOME than that of convectional diesel. However the specific fuel consumption for HCC (0.288 kg/kW-h) is higher than that for TCC (0.275 kg/kW-h) when fuelled with 20% SOME. The higher fuel consumption for HCC may be attributed to poor air fuel mixing, which leads to poor combustion and thus increase the specific fuel consumption for HCC.

3.3 Oxides of nitrogen emission (NO_x)

NO_x is formed by chain reactions involving nitrogen and oxygen in the air. These reactions are highly temperature dependent. Since diesel engines always operate with excess air, NO_x emissions are mainly a function of gas temperature and residence time. The variations of oxides of nitrogen emissions for standard engine and modified engine with diesel and 20% SOME.

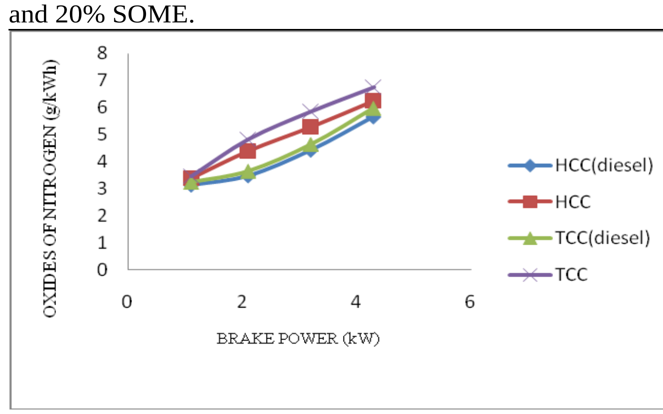

chart-3: Variation of Oxides of Nitrogen with Brake power.

The NO_x emissions were higher for TCC than the base engine when operated with 20% SOME. The reason for the increase in NO_x may be attribute to higher combustion temperatures arising from improved combustion due to mixture formation and availability of oxygen in SOME. Another reason for increased NO_x emissions may be attributed to that .a larger part of the combustion is completed before top dead centre for SOME and its blends compare diesel due to their lower ignition delay.

3.4 Hydrocarbon emission (HC)

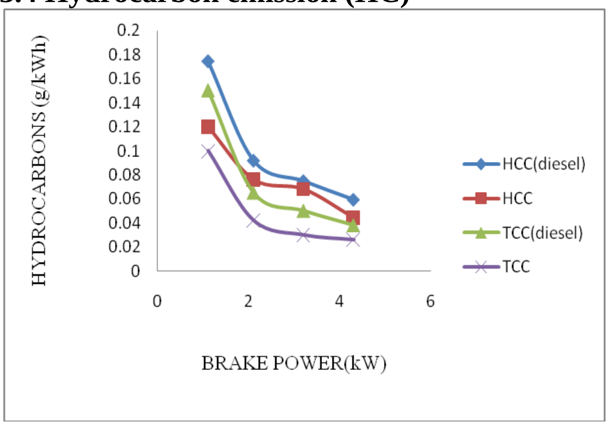

chart-4: Variation of Hydrocarbon with Brake power.

The unburnt hydrocarbon emissions for TCC are compared with the baseline HCC fuelled using diesel and 20% SOME are shown. UBHC emissions are reduced over the entire range of loads for TCC and HCC when operated with 20% SOME. This may be due to better combustion of SOME, with better mixture formation of air and SOME, due to improved swirl motion of air. There is a reduction of 6% HC emissions for the TCC compared to baseline engine when tests are carried out with 20% SOME and 18% reduction with standard engine when fuelled with diesel at full load operation.

3.5 Carbon monoxide emission (CO)

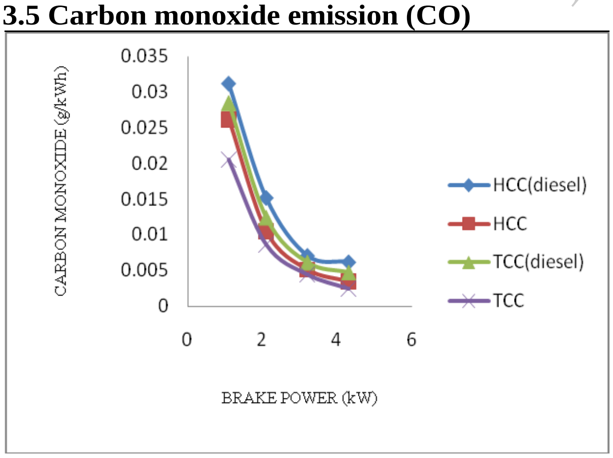

chart-5: Variation of Carbon monoxide with Brake power.

The comparison of CO emissions with brake power for two types of combustion chambers. At low and medium loads, CO emissions for the different combustion chambers were not much different from those of standard diesel. However, at full load, CO emission of the blend decreased significantly when compared with those of standard diesel. Carbon monoxide emissions are greatly reduced with the addition of SOME to diesel. It decreases with TCC than the other combustion chambers. Higher air movement in TCC and presence of oxygen in SOME, lead to better combustion of fuel resulting in the decrease of CO emissions.

3.6 Smoke Intensity

The smoke intensity comparison for two types of open combustion chambers with 20% SOME and diesel. At all loads, smoke emissions for blend decreased significantly when compared with those of standard diesel. The significant reduction in smoke emission may be due to presence of oxygen in biodiesel blend. Smoke is mainly produced in the diffusive combustion phase.

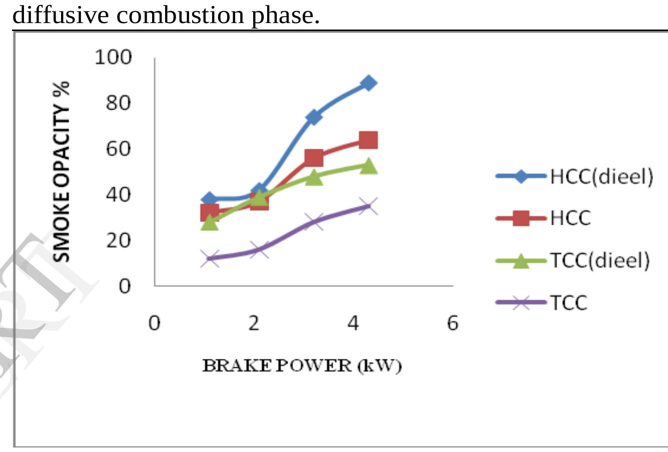

chart-6: Variation of Smoke opacity with Brake power.

The oxygenated 20% SOME fuel leads to an improvement in diffusive combustion. It is also observed that the smoke emissions were lower for TCC than HCC. Among all combustion chambers, TCC with 20% SOME gives 20% of reduction of smoke density when compared with standard engine with diesel operation. This may be due to more complete combustion due to better air fuel mixing and the presence of oxygen in the SOME.

3.7 Combustion Analysis

In the combustion characteristics of the soapnut oil-diesel blend and two types of combustion chambers were discussed in the following sections.

3.7.1 Pressure Crank Angle Diagram.

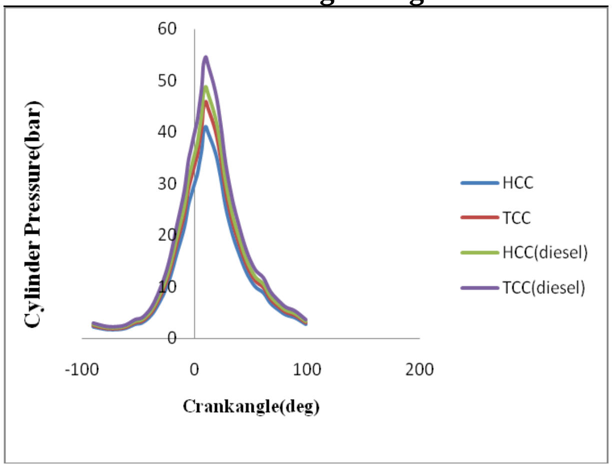

chart -7: Variation of cylinder pressure with Crank angle.

The pressure variations of two type of combustion chambers with 20% SOME and diesel is shown in figure.7. The pressure variations of two types of combustion chambers follow the similar pattern of pressure rise as that of diesel at all load conditions. However when compared to diesel, the value of pressure data of 20% SOME are lower for all types of combustion chamber. These distinct differences may be due to variations of viscosity and heating value of with the percentage of SOME in the fuel. The cylinder pressure trend of TCC with 20% SOME is found closer that of standard engine operated with diesel and above for HCC with 20% SOME. This may be attributed to better combustion due to better air fuel mixing.

3.7.2 Heat Release Rate

The maximum heat release rate of 20% SOME blend is lower than that of diesel in the standard engine. This may be attributed to shorter ignition delay for 20% SOME compared with that diesel. In addition the poor spray atomization characteristics of biodiesel due to higher viscosity and surface tension may be responsible for the lower heat release rate.

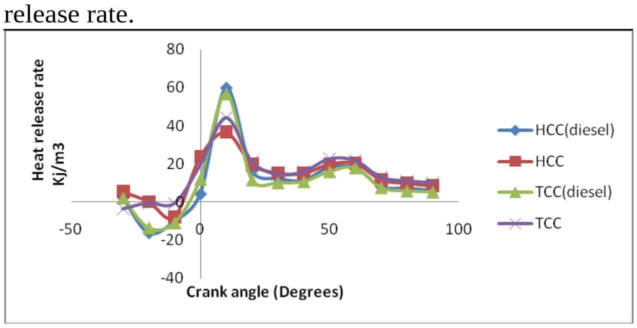

chart-8: Variation rate of heat release for different crank angle.

Further it has been noticed that heat release rate during diffusion combustion phase of 20% SOME is slightly higher than that of diesel. However the heat release rate curve for TCC fuelled with 20% SOME demonstrates similar but slightly lower than other open combustion chambers operated with 20% SOME. This may be attributed to improved air fuel mixing, evaporation and better combustion.

4. CONCLUSIONS

In this experimental study the effect of open combustion chamber geometries on performance and emission characteristics of biodiesel derived from soapnut oil was investigated. The following conclusions were drawn from the experimental results:

1. The improved air motion in TCC due to its geometry, improves the mixture formation of 20% SOME with air which increases brake thermal efficiency (27.4%) and lowers the specific fuel consumption (0.275 kg/kW-h) compared to HCC.
2. Due to higher oxygen content in the SOME and better combustion as a result of improved mixture formation, the emissions of CO, UBHC and smoke were lower for TCC than the other type of combustion chamber.
3. Better combustion and presence of oxygen content in the SOME results in increased combustion chamber temperature that produces higher oxides of nitrogen in TCC than HCC
4. Due to higher combustion chamber wall temperature, availability of oxygen with SOME and improved mixture formation due to better air motion, the ignition delay for TCC was found to be lesser compared to HCC.

Better combustion due to better air fuel mixing in TCC, gives maximum in cylinder pressure compared to HCC with 20% SOME. For all combustion chambers operated with 20% SOME decrease in premixed combustion and increase in diffused combustion was observed.

6. The present analysis reveals that performance, emission and combustion characteristics of biodiesel from soapnut oil can be improved by suitably designing the combustion chamber.

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