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Original Research Article

Comparative evaluation of pongamia biodiesel with open and re-entrant combustion chambers in a DI diesel engine

S.Jaichandar[1], K.Annamalai[2] and P.Arikaran[1]

[1] Dept. of Mechanical Engineering, Easwari Engineering College, Chennai, Tamilnadu, India
[2]Dept. of Automobile Engineering, Madras Institute of Technology, Anna University, Chennai, Tamilnadu, India

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Abstract

The influence of 20% blend of Pongamia Oil Methyl Ester (POME20) as alternative diesel fuel has been studied using a kirloskar made single cylinder, four stroke, direct injection diesel engine. Without altering the compression ratio of the engine, the piston's combustion chamber geometry was modified to have Shallow depth combustion chamber, Toroidal combustion chamber, Shallow depth re-entrant type combustion chamber and Toroidal re-entrant type combustion chamber from the standard Hemispherical open type combustion chamber. Performance and emission tests were conducted for these five types of combustion chamber geometries to study the performance characteristics such as brake thermal efficiency, brake specific fuel consumption and emission characteristics such as unburned hydrocarbons, carbon monoxide, oxides of nitrogen and smoke emissions. The test results showed that substantially higher brake thermal efficiency and lower specific fuel consumption for toroidal re-entrant type combustion chamber. Sharp reduction of particulates, carbon monoxide and unburnt hydrocarbons were observed for toroidal re-entrant type combustion chamber compared to the other two. On the other hand oxides of nitrogen (NOx) were higher for toroidal re-entrant type combustion chamber.

Keywords: Biodiesel, Diesel Engine, Combustion Chamber, Performance, Emissions.

Nomenclature

POME	Pongamia Oil Methyl Ester
IC	Internal Combustion
DI	Direct Injection
BSFC	Brake Specific Fuel Consumption
BTE	Brake Thermal Efficiency
UBHC	Unburned Hydrocarbons
CO	Carbon Monoxide
NOx	Oxides of Nitrogen
HCC	Hemispherical Combustion Chamber
TCC	Toroidal Combustion Chamber
SCC	Shallow-Depth Combustion Chamber
TRCC	Toroidal Re-Entrant Combustion Chamber
SRCC	Shallow-Depth Re-Entrant Combustion Chamber

* Corresponding Author

E-mail: jcdhanesh@gmail.com

1. Introduction

Growing concern regarding energy resources and the environment has increased interest in the study of alternative sources of energy. Meanwhile, engineers and researchers have intensified their efforts into radically improving traditional energy conversion machines such as the internal combustion engine with the goal of lowering its exhaust emissions and fuel consumption using alternate fuels.

To meet increasing energy requirements, there has been growing interest in alternative fuels like vegetable oils to provide a suitable diesel oil substitute for IC engines [1]. Vegetable oils present a very promising alternative to diesel oil since they are renewable and have similar properties. A lot of research work has been carried out to use vegetable oil both in its neat form and modified form. Different vegetable oils both edible and non-edible such as soybean oil [2-4], sunflower oil [5-8], palm oil [9], mahua oil [10], karanja oil [11], castor oil, jatropha oil [12-13], rapeseed oil[14-15], have been considered as alternative fuels for diesel engines. Studies such as Lary et al [16] have shown that the usage of vegetable oils in neat form is possible but not preferable. The high viscosity of vegetable oils and the low volatility affects the atomization and spray pattern of fuel, leading to incomplete combustion and severe carbon deposits, injector choking and piston ring sticking. The transesterification is the commonly used commercial process to produce clean and environmental friendly vegetable oil called biodiesel [17].

A great deal of experiments has been carried out to date to study the biodiesel fueled engine performance and emission levels without any modification to the engine. Herchel TC Machacon et al [18] evaluated performance and emission characteristics of coconut oil diesel fuel blends without any engine modifications. Increased coconut oil percentage in diesel fuel resulted in increased brake specific fuel consumption and decreased brake mean effective pressure. Barsic NJ and Humke AL [19-20] 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. On the other hand not much investigation has been carried out on performance and emission studies of biodiesel as diesel engine fuel in a direct injection diesel engine using different combustion chambers. Since biodiesel properties are different from diesel it is necessary to seek the optimum combination of elements of parts and factors related to the combustion in engines in order to enhance the performance of the engine.

In a DI diesel engine the conventional combustion chamber has been optimized for combustion of diesel fuel, including improvement of mixing between injected fuel and in-cylinder air, and not for biodiesel. Study on any modification of engine system including combustion chamber may be required, because the properties, evaporation and combustion characteristics of biodiesel are apparently different from diesel. Therefore it is expected that the combustion chamber, especially piston cavity may need to be optimized in terms of mixing and combustion of biodiesel and air mixture. The present work aimed at investigating this experimentally using a biodiesel derived from Pongamia Oil i.e Pongamia Oil Methyl Ester in a DI diesel engine.

2. Experimental Apparatus and Methods

2.1. Experimental setup

The test engine used was the Kirloskar,

single cylinder four-stroke water cooled engine developing 5.2 kW at 1500 rpm. The detailed technical specifications of the standard engine are given in Table 1. 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 combustion analyser. 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. Figure 1 shows the schematic diagram of the experimental set up.

Table 1. Standard engine specifications

Make	Kirloskar TV1
Type	Vertical diesel engine, 4stroke, water cooled, single cylinder
Displacement	661 cc
Bore & Stroke	87.5 mm & 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 bar

Table 2. Properties of Diesel, biodiesel from Pongamia and its blend

OIL PROPERTIES	*Diesel*	*POME*	*POME* **20**
Kinematic Viscosity (cSt)	2.9	5.46	3.49
Density (Kg/m^3)	850	898	862
Calorific Value (MJ/kg)	44.12	39.15	43.126
Flash Pt °C	76	196	91
Cloud Pt °C	6.5	10.2	7.1
Pour Pt °C	3.1	4.2	3.6

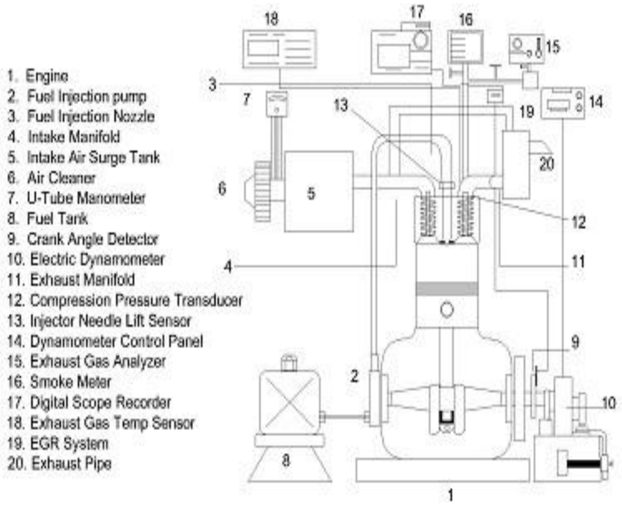

Fig.1. Schematic diagram of experimental setup

2.2. Engine modifications

In the present investigation, to compare the effect of different combustion chambers on biodiesel fueled engine performance, the combustion chamber geometry was modified to have Toroidal open type Combustion Chamber (TCC), Shallow depth open type Combustion Chamber (SCC), Toroidal Re-entrant Combustion Chamber (TRCC) and Shallow depth Re-entrant Combustion Chamber (SRCC) from the standard Hemispherical open type Combustion Chamber (HCC). For all the combustion chamber configurations, bowl volume was kept constant so that compression ratio was the same for all the investigated chambers. Figure 2 shows the shapes and dimensions of five combustion chamber geometries used.

2.3. Test method

For the experimentation the standard diesel and a blend of 20% POME by volume in the diesel were used as fuel. Properties of 100% POME and 20% POME are compared with standard diesel fuel in Table 2. The test was first conducted for the base engine having HCC with standard diesel; it was then switched to 20% POME blend. Then tests were carried out for the modified engine having SCC, TCC, SRCC and TRCC using 20% POME blend. 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.

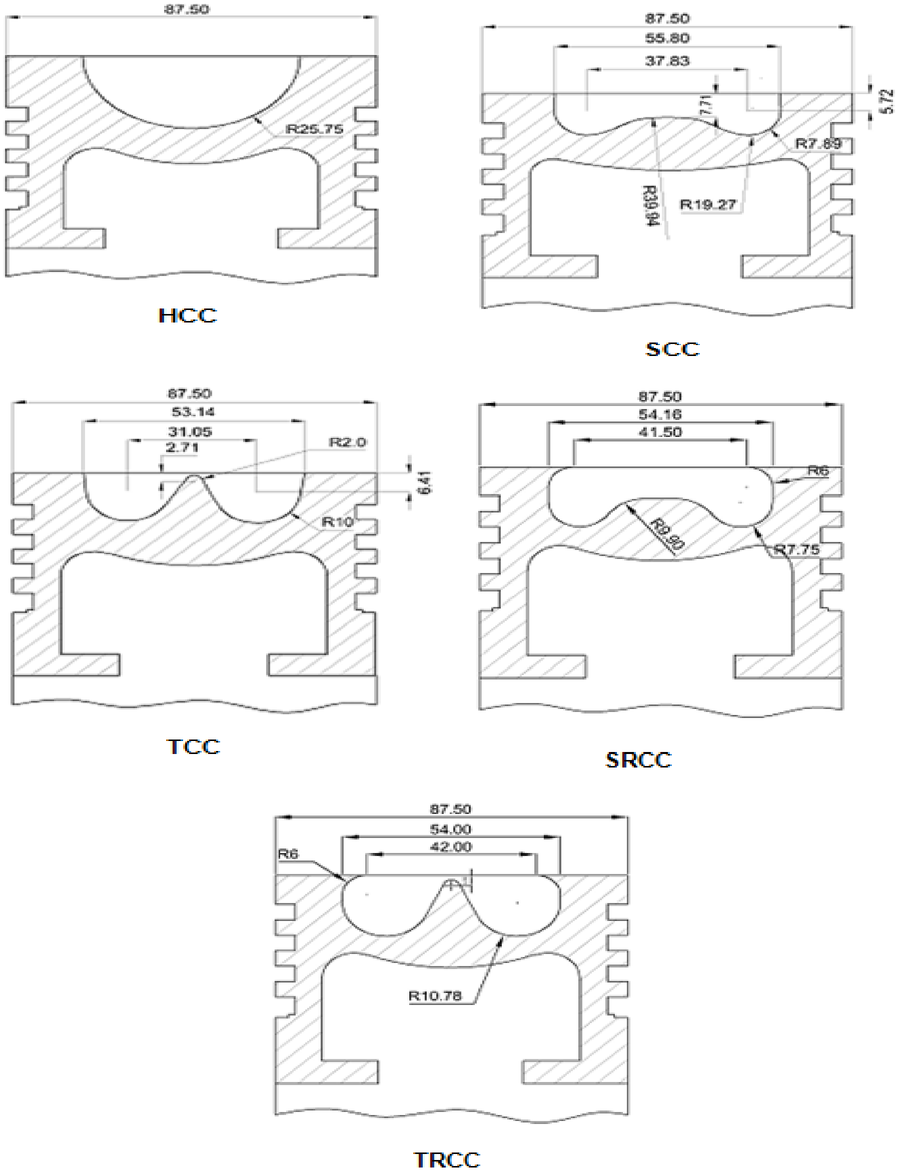

Fig. 2. Schematic diagram combustion chambers employed

3. Results and Discussion

The performance and emission characteristics of the base engine with HCC and modified engine with TRCC and SRCC were measured, analysed and compared for brake specific fuel consumption, brake thermal efficiency, unburnt hydrocarbon, carbon monoxide, oxides of nitrogen and smoke emissions.

3.1 Performance Analysis

3.1.1. Brake specific fuel consumption (BSFC)

Figure 3 shows the variations of BSFC of 20 percent POME, for the operation of the engine with five types of combustion chambers. BSFC for POME20 was slightly higher than that of diesel at all loads for all combustion chambers. This may be attributed to the lower calorific value of

POME than that of conventional diesel. Similarly the BSFC for open combustion chambers such as SCC, HCC and TCC is higher than that for re-entrant combustion chambers such as SRCC and TRCC. The higher specific fuel consumption for open combustion chambers may be attributed to poor air fuel mixing, which leads to poor combustion and thus increases the specific fuel consumption. Compared to HCC, the BSFC for the modified re-entrant combustion chambers viz. SRCC and TRCC was lower by 7% and 13.9% respectively at full load operation with POME20.

3.1.2. Brake thermal efficiency (BTE)

Figure 4 shows the comparison of brake thermal efficiency with respect to load on the engine for five types of combustion chambers. Brake thermal efficiency for TRCC is higher when compared to the other four types of combustion chambers at all loads. This may be due to better mixture formation of POME and air, caused by better air motion in TRCC. Improved mixture formation, leads to better combustion of the biodiesel and thus increases the brake thermal efficiency. At all loads the BTE for SCC is lower than that of other combustion chambers. The BTE for SRCC lies between those of TRCC and TCC at all loads. BTE for TRCC (33.09% at full load) was higher, when compared to the other types of combustion chambers at all loads with POME20.

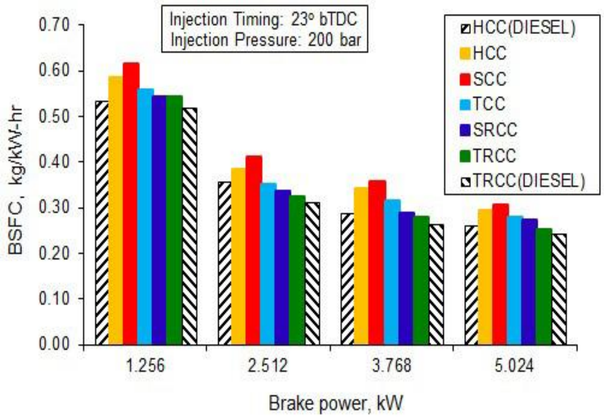

Fig. 3. Variations of BSFC

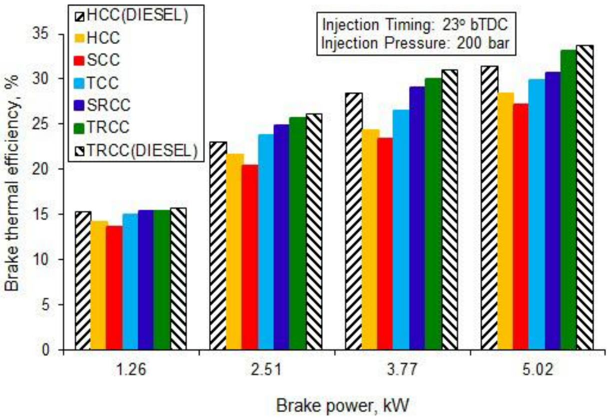

Fig. 4. Comparisons of BTE

3.2. Emission Analysis

3.2.1. Unburnt hydrocarbons emission (UBHC)

Figure 5 shows the variations of UBHC emissions with load for five types of combustion chambers. UBHC emissions were reduced over the entire range of loads for all types of combustion chambers fuelled with POME20 when compared to diesel operation. Moreover, the UBHC emissions for re-entrant combustion chambers are compared with the open combustion chambers. UBHC emissions are reduced over the entire range of loads for re-entrant combustion chambers such as TRCC and SRCC. This may be due to better combustion of POME caused by better mixture formation of air and POME due to improved swirl motion of air. There was a reduction of 20.7% UBHC emissions for the TRCC compared to baseline HCC, when tests were carried out with POME20.

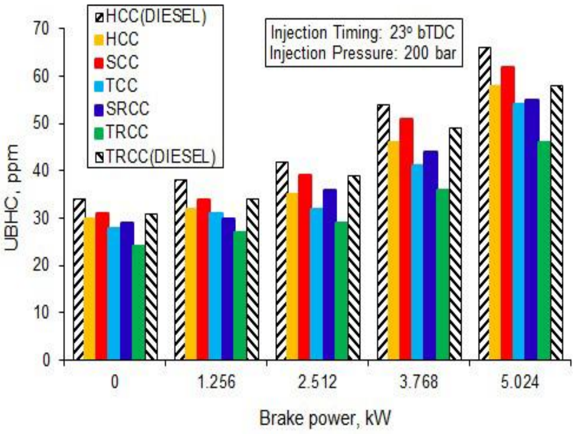

Fig. 5. Variations of UBHC Emissions

3.2.2. Carbon monoxide emission (CO)

Figure 6 shows the comparison of CO emissions with respect to load, for five types of combustion chambers. Carbon monoxide emissions are greatly reduced with the addition of POME to diesel. This shows that CO emissions are greatly reduced with the addition of POME to diesel. In addition it is found that CO emissions further decreased with the re-entrant combustion chambers than with the open combustion chambers. Higher air movement in TRCC lead to better combustion of fuel resulting in the decrease in CO emissions. Secondly increase in the proportion of oxygen in POME promotes further oxidation of CO during the engine exhaust process. Reduction in CO emissions is a strong advantage in favour of POME. There was a reduction of 44.5% CO emissions for the TRCC compared to baseline HCC, when tests were carried out with POME20.

3.2.3. Nitrogen oxides emission (NOx)

Figure 7 shows the variations of oxides of nitrogen emissions with load for five types of combustion chambers.

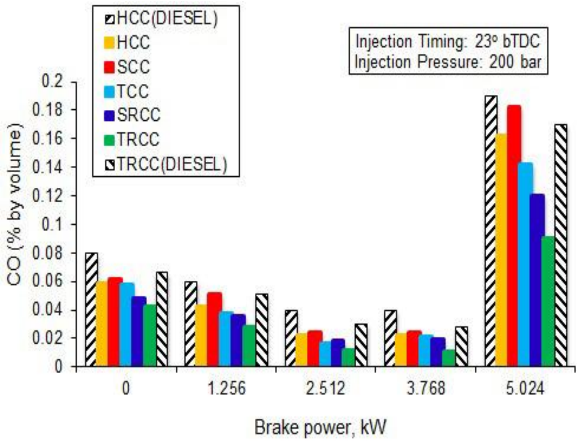

Fig. 6. Variations of CO Emissions

The NOx emissions were higher for re-entrant combustion chambers i.e for TRCC and SRCC than the open combustion chambers such as SCC, HCC and TCC. The reason for the increase in NOx could be the possibility of higher combustion temperatures arising from improved combustion due to better mixture formation and availability of oxygen in POME. However NOx can be controlled by adopting exhaust gas recirculation and by employing suitable catalytic converters. At full load, for the TRCC using POME20, the level of NO_x emission was 784 ppm compared to 712 ppm for standard engine having HCC. There was an increase of about 9.2% of NO_x emissions for TRCC compared to the baseline engine when fuelled with POME20 and 20.98% with standard diesel.

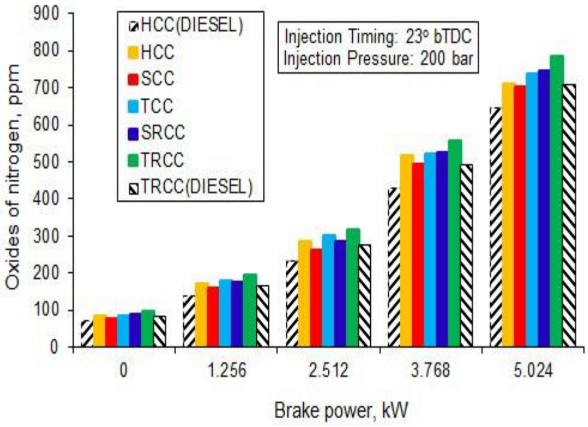

Fig. 7. Comparisons of NO_X Emissions

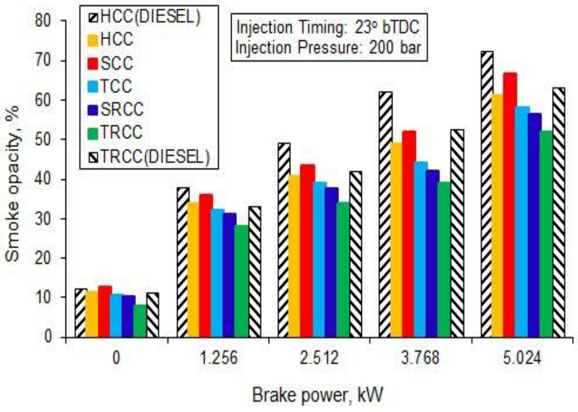

Fig. 8. Comparisons of Smoke Emissions

3.3.4. Smoke

The smoke intensity comparison for five types of combustion chambers is shown in Figure 8. At all loads and for all combustion chambers, smoke emissions for the blend decreased significantly when compared with those of diesel. The reduction in smoke emission may be due to the presence of oxygen in biodiesel blend. Further, it is also observed that the smoke emissions were lower for re-entrant combustion chambers than open combustion chambers. This was due to more complete combustion due to better air fuel mixing and the presence of oxygen in the POME. There was a reduction of 28.2% smoke emissions for the TRCC compared to baseline HCC, when tests were carried out with POME20.

4. Conclusion

In this experimental study a comparative evaluation of open (HCC, SCC and TCC) and re-entrant combustion chamber geometries (SRCC and TRCC) on the performance and emission characteristics of biodiesel operated DI diesel engine was investigated. The following conclusions were drawn from the experimental results.

1. The improved air motion in re-entrant combustion chambers due to its geometry improves the mixture formation which increases brake thermal efficiency and lowers the specific fuel consumption.
2. Due to higher oxygen content in the POME and better combustion as a result of improved mixture formation, the emissions of CO, UBHC and smoke were lower for re-entrant combustion chambers than the open combustion chambers.
3. Better combustion and presence of oxygen content in the POME results in increased combustion chamber temperature that produces higher oxides of nitrogen in re-entrant combustion chambers than the open combustion chambers.

The present analysis reveals that performance and emission characteristics of biodiesel from Pongamia oil can be improved by using a re-entrant combustion chamber than an open combustion chamber.

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