Performance and Emission Analysis of a CI Diesel Engine for Varied Combustion Chamber Designs using Biodiesel as Substitute Fuel

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Abstract: The energy consumption of the nation is increased exponentially in last few years. The transportation and power generation are the main sectors to utilize energy and mainly depends on petroleum products. But these petroleum products are exhaustive in nature which led to search for alternative fuel. Biodiesel is one of the alternative fuel to replace diesel fuel. However one has to come across in economical and technical aspects to use biodiesels. In this connection combustion chamber design modification is adopted to improve the engine performance and emission parameters. Hence in this investigation various combustion chamber designs viz., Hemispherical combustion chamber (HCC), Toroidal combustion chamber(TCC) and Re-entrant combustion chamber(RECC) are used with Black Sesame methyl ester as fuel. The performance parameters like mechanical efficiency, brake thermal efficiency, indicated thermal efficiency and specific fuel consumption are evaluated. The emission parameters such as NOx, unburnt hydrocarbons, carbon monoxide and carbon dioxide are determined. From the experimental results the improved performance and reduced emissions are recorded for Toroidal combustion chamber.

***Keywords* —Biodiesel, combustion chamber design, performance, emissions and Black Sesame methyl ester.**

I. INTRODUCTION

In Power generation and transportation sectors, diesel engine plays a vital role due to their high brake thermal efficiency. However there is stipulate for lesser noise & vibration, better performance, lower emissions. Further the fossil fuels reserves are decreasing rapidly due to more utilization of petroleum products. To overcome these difficulties attention is focused on new renewable biodiesel [3].

Biodiesel is characterized as the mono-alkyl ester of stretched series fatty acids, Fatty Acid methyl esters (FAME) and Fatty acid ethyl esters (FAEEs) derivative from animal or plant sources. An early technique to produce FAMEs is a base catalyzed transesterification. In this process basic catalyst, anhydrous methanol and several sources of oil were used to make biodiesel in 20 to 25 min. A simple glass beaker is used to collect the biodiesel, the biodiesel floats on the top of the byproducts [11].

A variety of conventional and non-conventional crops were used for making biodiesel, as well as used oil from the frying industry, soybean oil, rapeseed oil, sesame oil, safflower oil, palm oil etc were also used for preparation of biodiesel [13]. Sesame (Sesamumindicum) is an important food, oil medicinal and religious crop in India [10]. Sesame seeds are available in different colors .i.e. brown, red, yellow, black and white. The white or pale grayish ivory color seeds are most usage in food, religious and medical purpose [14].

Mainly the black sesame seeds are used to produce biodiesel. The dark colored and black sesame seeds are highly cultivated in Southeast Asia and china. 6.1 million tones of sesame seeds produced in the world led by India, Tanzania, sudan, Nigeria, china and Myanmar in the year 2016 [15].

Optimization for the qualitative and quantitative analysis on making of biodiesel from sesame seed oil, the base catalyzed transesterification was used. The results shows for the conversion of crude sesame oil to biodiesel was 72.56% and 75.45% at 6:1 methanol to oil ratio with 0.34% NaOH and 0.67% KOH catalyst respectively at 60-650C for qualitative certification [12].

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Experiments were conducted on four stroke constant speed air cooled single cylinder DI standard diesel engine using Jatropha methyl ester with toroidal, spherical and re-entrant combustion chamber geometries. From the results it was concluded that the toroidal combustion chamber brake thermal efficiency is 33.92% high correlated to remaining two piston configurations. Further investigations were carried out and observed that unburnt hydrocarbon, carbon monoxide and smoke density were slightly lesser using toroidal piston configuration compared to other piston geometries [8].

Sprayed tendency and piston geometry plays a vital role in the combustion chamber design. It was effected the emission, combustion and performance parameters of the standard engine. Further it was also found that Toroidal Re-entrant combustion Chamber provides better air fuel mixing in the combustion chamber. The heat release rate, cylinder pressure and peak pressure were increased; the ignition delay was decreased by using Re-entrant combustion chamber configuration compared to remaining piston configurations [7].

The shallow depth combustion chamber gave better performance correlated to hemispherical combustion chamber and omega type combustion chamber. Similarly higher heat release rate, more cylinder pressure and high combustion temperature were also observed by using shallow depth combustion chamber. The shallow depth combustion chamber particularly appropriate for low speed engine operating conditions [2], [5].

The brake thermal efficiency was increased and total fuel consumption was decreased using Toroidal Re-entrant piston geometry operated at 220 bar pressure correlated to standard engine. Further the unburnt hydrocarbon, carbon monoxide and smoke density were significantly minimized by utilizing Toroidal Re-entrant combustion chamber. The nitrogen oxide pollutants were enhanced with TRCC [9].

Numerical and experimental investigations were carried out on stationary direct injection diesel engine with modified combustion chamber designs. From the investigation it was observed that the cylinder pressure was increased slightly with modified piston geometry. The specific fuel consumption was lower for Toroidal combustion chamber at 100% load condition. The soot emissions were decreased about 8% correlated to standard piston geometry. The nitrogen oxide emissions were increased about 30% compared to base piston configuration [6].

The experimental work carried out on DICI engine with two different pistons viz., deep bowl and toroidal combustion chambers (DBCC & TCC) associated with standard piston combustion chamber (SPCC). The tests were conducted at ordinary atmospheric conditions without modifications on engine compression ratio and different blends of grape seed oil methyl esters (GOME) biodiesel (B25, B50, B75 & b100) by volume with three piston configurations. From this work it was recorded that the DBCC has shown good combustion parameters compared to both TCC and SPCC for all GOME blends. For the TCC and B25 blend the emissions such as unburnt hydrocarbons, carbon monoxide and smoke were reduced by 4.6%, 30.7% and 9.2% respectively. While at the same blend for TCC the brake thermal efficiency was 4.7% higher than SPCC diesel [1].

The experimental investigations were conducted on 4-stroke single cylinder water cooled DICI engine in dual fuel mode using producer gas and Honge Methyl Ester (HOME), varying nozzle geometry (Different no of holes and hole diameters), and injection pressure varied in first phase. In the final phase of work the optimized combustion chamber is selected based on the performance to suite for the optimal nozzle geometry. Here in this work two different types of combustion chambers such as re-entrant and hemispherical geometries were used. The 4hole 0.25mm nozzle orifice; re-entrant combustion chamber and 230bar injection pressure have shown better performance [4].

II. Experimental Setup

A four stroke single cylinder water cooled diesel is used to conduct experiments as shown in fig 2. The engine specifications are indicated in table 1. A five gas exhaust analyzer is used to measure the pollutant parameters such as carbon dioxide, oxygen, carbon monoxide, hydrocarbon and nitrogen oxide. Fuel measurement is determined by using burette. K-type thermocouples are used to measure the temperatures at all locations of the engine. Combustion analysis is analyzed by IC engine software. The cylinder pressures at different crank angles are evaluated by using crank angle and piezo electric sensors. The standard test engine is made to run at constant speed of 1500 rpm and it is connected with eddy current dynamometer for applying loads on the engine. The engine overheating is prevented by water circulation. The water jacket temperature and calorimeter water temperatures are measured by temperature sensors. By using flow sensors the air and fuel flow rate are analyzed. The entire engine set up is connected to computer set up.

The engine is modified with different piston geometries such as Toroidal configuration and Re-entrant piston configuration. Black sesame methyl ester is used as a fuel. The biodiesel properties are shown in table 2.

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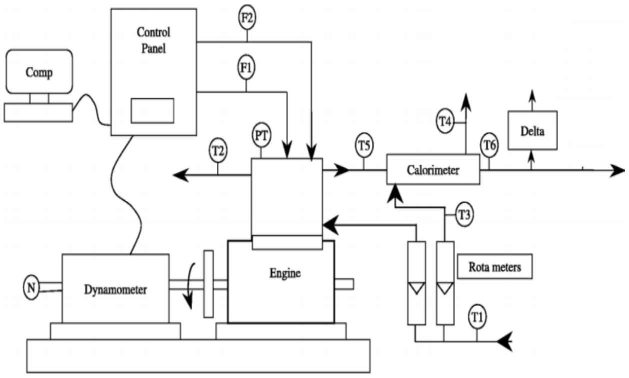

Fig: 1 Test Engine Layout

Fig: 2 Test Engine Setup

(a) HCC

(b) TCC

(c) RECC

Fig:3 Types of combustion chambers

S.No.	Parameter	Specification
1	Make	:Apex innovations Ltd.
2	No. of cylinders	:1
3	No of strokes	:4
4	Cylinder bore	:87.5mm
5	Stroke length	:110mm
6	Connecting rod length	:234mm
7	Orifice diameter	:20mm
8	Compression ratio	:12:1 – 17.5:1
9	Power	:5.2kw
10	Speed	:1500 rpm
11	Fuel	:Diesel
12	Injection pressure	:180bar
13	Injection point variation	:0 to300 BTDC
14	Dynamo meter type	:Eddy current
15	Dynamo meter arm length	:185mm

Table 1 Engine Specification

S.No.	Property	ASTM Standard	BSME	Biodiesel limit (ASTMD6751)
1	Kinematic Viscosity @ 400C in CSt	ASTM D 445	2.49	1.9 to 6.0
2	Density @300C (gm/ml)	ASTM D 1298	0.894	0.85 to0.89
3	Flash Point in °C	ASTM D 92	164	100 to 180
4	Fire Point in °C	ASTM D 92	180	
5	Calorific Value (MJ/kg)	ASTM D 5865	39.15	Min 35
6	Cetane Number	ASTM D 613	46	44 to 49

Table 2 Properties of BSME

III. 3. RESULTS AND DISCUSSION

3.1 EFFECT OF DIFFERENT ENGINE PERFORMANCE PARAMETERS ON DIESEL ENGINE

The graph is plotted between Brake power Vs Brake thermal efficiency as shown in fig.4. For Toroidal Black sesame methyl ester (TBS), brake thermal efficiency is higher than remaining piston configurations and is about 27.9%. The lowest brake thermal efficiency is recorded for Re-entrant Black Sesame methyl ester (REBS) and is about 24.5%. The brake thermal efficiency for TBS is increased about 3.3% compared to standard diesel with standard piston. This is owing to prevention of the air squish motion above the piston crown.

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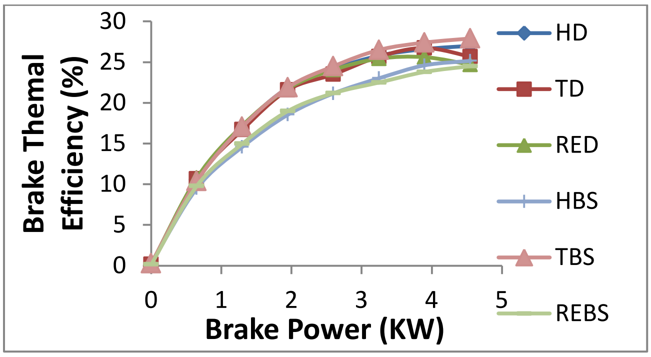

Fig: 4 Brake Power Vs Brake Thermal Efficiency

Figure.5. Shows the variation of brake power and indicated thermal efficiency. It is observed that the toroidal black sesame methyl ester(TBS), indicated thermal efficiency is lower than standard diesel at part load condition. The ITE for Hemispherical black sesame methyl ester(HBS) is higher compared to remaining piston configuration with biodiesel. This is due to better mixing combination of air and biodiesel in the combustion chamber. The indicated thermal efficiency for diesel is increased about 4.04% correlated to hemispherical black sesame methyl ester.

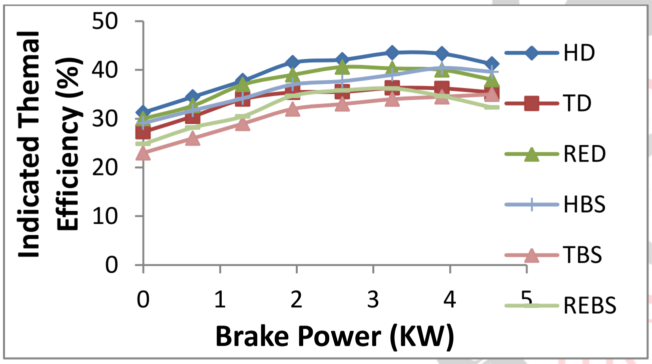

Fig: 5 Brake Power Vs Indicated Thermal Efficiency

The graph is plotted between brake power and mechanical efficiency as shown in fig.6. The mechanical efficiency gradually increases from no load condition to full load condition. From the graph it is observed that Toroidal black sesame methyl ester mechanical efficiency is high compared to all piston configurations and is about 79.71%. The lowest mechanical efficiency is recorded for hemispherical black sesame methyl ester and is about 63.51%. The mechanical efficiency of TBS is 21.6% high compared to standard diesel with base engine. This is due to longer flame propagation of the biodiesel.

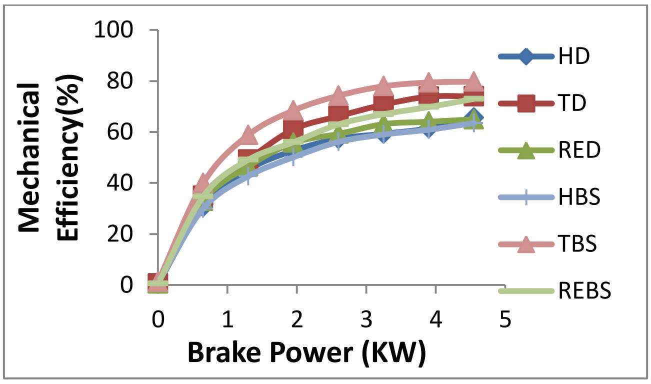

Fig: 6 Brake Power Vs Mechanical Efficiency

The variation of specific fuel consumption with brake power is shown in fig.7. From the graph it is observed that the specific fuel consumption gradually decreases from no load to 30% of the rated load condition. After 30% of the rated load condition there is no much variation in the SFC. The lowest specific fuel consumption noted for TBS is 0.251 kg/kWh correlated to all other piston configurations. This is due to high cylinder temperature and pressure. The specific fuel consumption for hemispherical black sesame methyl ester is high and is about 0.394 kg/kWh compared to remaining piston configurations.

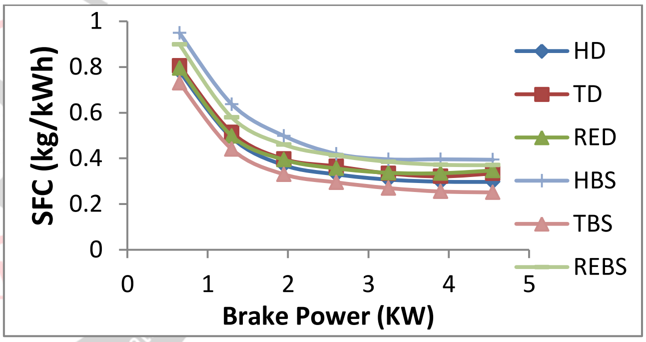

Fig: 7 Brake Power Vs Specific Fuel Consumption

Figure.8. shows the variation between brake power and carbon monoxide emissions. From the plotted graph it is observed that there is no much variation from zero load to 35% rated load. After the 35% of the rated load the CO emissions are increased drastically. The lowest CO emissions are recorded for TBS compared to all piston configurations and are about 0.6%. This is mainly due to complete combustion of the biodiesel. The CO emission for HD is high correlated to all other piston configurations and is about 1.42%.

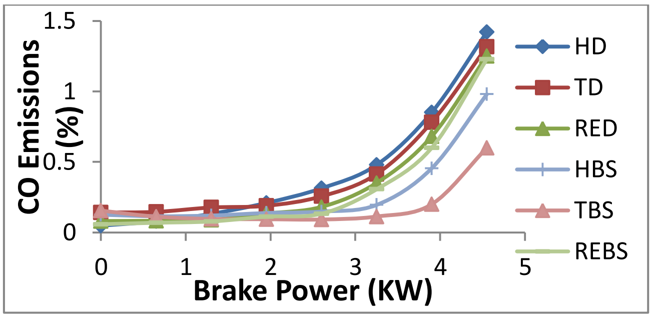

Fig:8 Brake Power Vs CO Emissions

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The graph is plotted between brake power and carbon dioxide emission levels as shown in figure.9. From the graph it is identified that the CO2 emissions are increased linearly from no load to rated load condition. The carbon dioxide emission levels are high for hemispherical diesel compared to all other piston configurations. The lowest CO2 emissions are recorded for REBS correlated to remaining piston configurations.

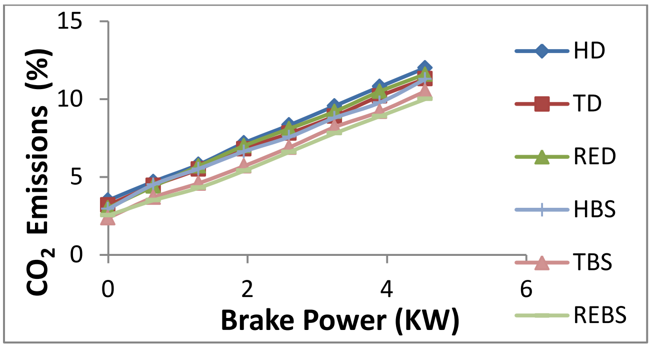

Fig:9 Brake Power Vs CO2 Emissions

Figure.10. shows the deviations between brake power and oxides of nitrogen emissions. From the graph it is found that the NOx pollutants are gradually increases from no load operation to 100% load operation. The NOx emissions for Hemi spherical black sesame methyl ester is high compared to remaining piston configurations. This is due to increased cylinder temperature. The oxides of nitrogen for hemispherical diesel is low correlated to biodiesel and other piston configurations.

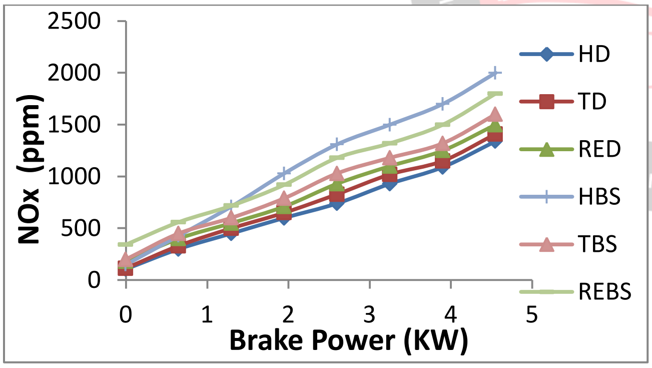

Fig: 10 Brake Power Vs NOX Emissions

The graph is drawn between brake power vs unburnt hydrocarbon emissions as shown in fig.11. From the graph it is concluded that the HC emissions for Toroidal diesel is more compared to all other piston profiles. The Toroidal black sesame methyl ester unburnt hydrocarbon emissions are low compared to remaining piston configurations. This is due oxygenated nature of biodiesel.

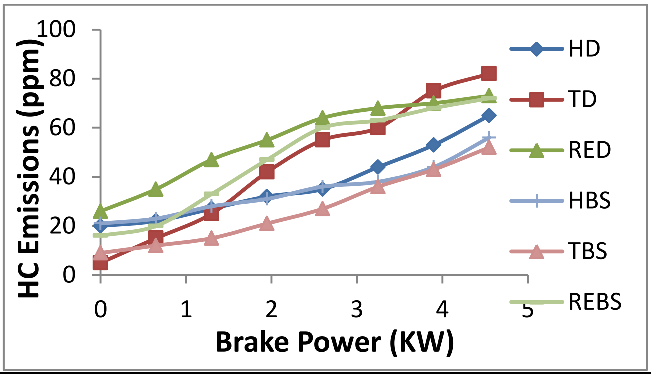

Fig: 11 Brake Power Vs HC Emissions

IV. CONCLUSION

The experiments are carried out on single cylinder four stroke direct injection water cooled diesel engine using different piston configurations with biodiesel. The following conclusions are drawn below.

- The BTE for Toroidal black sesame methyl ester is increased about 3.3% compared to standard diesel. This is due to proper air fuel mixing in the modified combustion chamber.
- The ME for Toroidal black sesame methyl ester is 21.6% high compared to standard diesel with base engine.
- .The SFC for Toroidal black sesame methyl ester is decreased compared to conventional engine. This is due to better flame propagation in the combustion chamber.
- The NOx emissions for Hemi spherical black sesame methyl ester is high compared to remaining piston configurations. This is due to increased cylinder temperature.
- The Toroidal black sesame methyl ester unburnt hydrocarbon emissions are low compared to remaining piston configurations. This is due oxygenated nature of biodiesel.

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