INFLUENCE OF INJECTION TIMING ON PERFORMANCE PARAMETERS OF HIGH GRADE SEMI ADIABATIC DIESEL ENGINE WITH COTTON SEED BIODIESEL

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ABSTRACT

As a renewable, sustainable and alternative fuel for compression ignition engines, biodiesel instead of diesel has been increasingly fueled to study its effects on engine performances and emissions in the recent 10 years. But these studies have been rarely reviewed to favor understanding and popularization for biodiesel so far in conventional diesel engines. Biodiesels derived from vegetable oils present a very promising alternative for diesel fuel, since they have numerous advantages compared to fossil fuels. They are renewable, biodegradable, provide energy security and foreign exchange savings besides addressing environmental concerns and socio–economic issues. However drawbacks associated with biodiesel of high viscosity and low volatility which cause combustion problems in CI engines, call for engine with hot combustion chamber. They have significant characteristics of higher operating temperature, maximum heat release, and ability to handle low calorific value fuel. Investigations were carried out to evaluate the performance with low heat rejection combustion chamber with cotton seed biodiesel with

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varied injection timing It consisted of an air gap insulated piston with superni (an alloy of nickel) crown , an air gap insulated liner with superni insert and ceramic coated cylinder head. Comparative studies were made for engine with LHR combustion chamber and conventional engine at manufacturer's recommended injection timing (27^o bTDC) and optimum injection timing with biodiesel operation. Engine with LHR combustion chamber with biodiesel showed improved performance at 27^o bTDC and at optimum injection timing over CE .

Key words: Vegetable oil, Biodiesel; Conventional engine, LHR combustion chamber; Fuel performance; Injection timing

1.INTRODUCTION

Fossil fuels are limited resources; hence, search for renewable fuels is becoming more and more prominent for ensuring energy security and environmental protection. It has been found that the vegetable oils are promising substitute for diesel fuel, because of their properties are comparable to those of diesel fuel. They are renewable and can be easily produced. When Rudolph Diesel, first invented the diesel engine, about a century ago, he demonstrated the principle by employing peanut oil. He hinted that vegetable oil would be the future fuel in diesel engine [1]. Several researchers experimented the use of vegetable oils as fuel on conventional engines (CE) and reported that the performance was poor, citing the problems of high viscosity, low volatility and their polyunsaturated character. It caused the problems of piston ring sticking, injector and combustion chamber deposits, fuel system deposits, reduced power, reduced fuel economy and increased exhaust emissions [1–5].

The problems of crude vegetable oils can be solved to some extent, if these oils are chemically modified (esterified) to biodiesel. Studies were made with biodiesel on CE [6–10]. They reported from their investigations that biodiesel operation showed comparable thermal efficiency, decreased particulate emissions and increased nitrogen oxide (NO_x) levels, when compared with mineral diesel operation.

Increased injector opening pressure may also result in efficient combustion in compression ignition engine [11–12]. It has a significance effect on performance and formation of pollutants inside the direct injection diesel engine combustion. Experiments were conducted on engine with biodiesel with increased injector opening pressure. They reported that performance of the engine was improved, particulate emissions were reduced and NO_x levels were increased marginally with an increase of injector opening pressure.

The drawbacks associated with biodiesel (high viscosity and low volatility) call for hot combustion chamber, provided by low heat rejection (LHR) combustion chamber. The concept of the engine with LHR combustion chamber is reduce heat loss to the coolant with provision of thermal resistance in the path of heat flow to the coolant. Three approaches that are being pursued to decrease heat rejection are (1) Coating with low thermal conductivity materials on crown of the piston, inner portion of the liner and cylinder head (low grade LHR combustion chamber); (2) air gap insulation where air gap is provided in the piston and other components with low-thermal conductivity materials like superni (an alloy of nickel),cast iron and mild steel (medium grade LHR combustion chamber);and (3).high grade LHR engine contains air gap insulation and ceramic coated components.

Experiments were conducted on engine with high grade LHR combustion chamber with biodiesel. It consisted of an air gap (3 mm) insulation in piston as well as in liner and ceramic coated cylinder head. The engine was fuelled with biodiesel with varied injector opening pressure and injection timing [13–19]. They reported from their investigations, that engine with LHR combustion chamber at an optimum injection timing of 28^o bTDC with biodiesel increased brake thermal efficiency by 10–12%, at full load operation–decreased particulate emissions by 45–50% and increased NO_x levels, by 45–50% when compared with mineral diesel operation on CE at 27^o bTDC. The present paper attempted to determine the performance of the engine with high grade LHR combustion chamber. It contained an air gap (3.2 mm) insulated piston, an air gap (3.2 mm) insulated liner and ceramic coated cylinder head with cotton seed biodiesel with different operating conditions with varied injection timing and injector opening pressure. Results were compared with CE with biodiesel and also with diesel at similar operating conditions.

2. MATERIAL AND METHOD

Cottonseeds have approximately 18% (w/w) oil content. India's cottonseed production is estimated to be around 35% of its cotton output (approximately 4.5millionmetric tons). Approximately 0.30 million metric ton cottonseed oil is produced in India and it is an attractive biodiesel feedstock [8]

2.1 Preparation of biodiesel

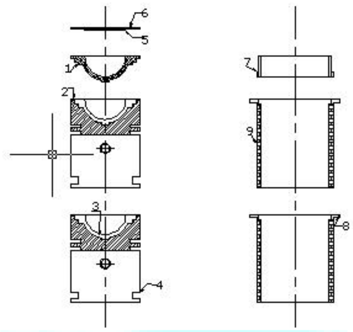
The chemical conversion of esterification reduced viscosity four fold. Crude cotton seed oil contains up to 70% (by wt.) unsaturated fatty acids. The methyl ester was produced by chemically reacting crude cotton seed oil with methanol in the presence of a catalyst (KOH). A two–stage process was used for the esterification of the crude cotton seed oil [8]. The first stage (acid-catalyzed) of the process is to reduce the free fatty acids (FFA) content in cotton seed oil by esterification with methanol (99% pure) and acid catalyst (sulfuric acid-98% pure) in one hour time of reaction at 55°C. Molar ratio of cotton seed oil to methanol was 9:1 and 0.75% catalyst (w/w). In the second stage (alkali-catalyzed), the triglyceride portion of the cotton seed oil reacts with methanol and base catalyst (sodium hydroxide–99% pure), in one hour time of reaction at 65°C, to form methyl ester (biodiesel) and glycerol. To remove un–reacted methoxide present in raw methyl ester, it is purified by the process of water washing with air–bubbling. The properties of the Test Fuels used in the experiment were presented in Table-1. [8].

Table.1 Properties of test fuels [8]

Fuel	Specific Gravity at 15^{o} C	Cetane Number	Low Calorific Value (kJ/kg)
Diesel	0.82	51	42000
Biodiesel	0.86	56	39900
ASTM Standard	ASTM D 4809	ASTM D 613	ASTM D 7314

2.3 Engine with LHR combustion chamber

Fig.1 shows assembly details of insulated piston, insulated liner and ceramic coated cylinder head. Engine with LHR combustion chamber contained a two–part piston ; the top crown made of superni was screwed to aluminium body of the piston, providing an air gap (3.2 mm) in between the crown and the body of the piston by placing a superni gasket in between the body and crown of the piston.



1.S1. 1.Piston crown with threads,

2. Superni gasket,

3. Air gap in piston,

4. Body of piston,

5. Ceramic coating on inside portion of cylinder head,

6. Cylinder head

7.Superni insert with threads,

8.Air gap in liner

9.Liner

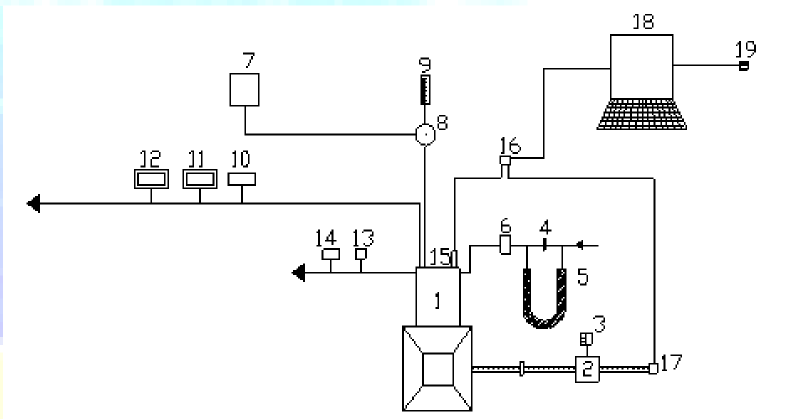
Fig.1 Assembly details of air gap insulated piston, air gap insulated liner and ceramic coated cylinder head

A superni insert was screwed to the top portion of the liner in such a manner that an air gap of 3.2 mm was maintained between the insert and the liner body.

At 500^{o}C the thermal conductivity of superni and air are 20.92 and 0.057 W/m–K. Partially stabilized zirconium (PSZ) of thickness 500 microns was coated by means of plasma coating technique. The combination of low thermal conductivity materials of air, superni and PSZ provide sufficient insulation for heat flow to the coolant, thus resulting in LHR combustion chamber.

2.4 Experimental set–up

The schematic diagram of the experimental setup used for the investigations on the engine with LHR combustion chamber with cotton seed biodiesel is shown in Fig.2. Specifications of Test engine are given in Table 2. The engine was coupled with an electric dynamometer (Kirloskar), which was loaded by a loading rheostat. The fuel rate was measured by Burette. The accuracy of brake thermal efficiency obtained is ±2%. Air-consumption of the engine was obtained with an aid of air box, orifice flow meter and U–tube water manometer assembly. The naturally aspirated engine was provided with water–cooling system in which outlet temperature of water was maintained at 80°C by adjusting the water flow rate. The water flow rate was measured by means of analogue water flow meter, with accuracy of measurement of ±1%.



1.Four Stroke Kirloskar Diesel Engine

2.Kirloskar Electical Dynamometer

3.Load Box

4.Orifice flow meter

5.U-tube water manometer

6.Air box

7.Fuel tank

8, Pre-heater

9.Burette

10. Exhaust gas temperature indicator

11.AVL Smoke opacity metet

12. Netel Chromatograph NO_x Analyzer

13.Outlet jacket water temperature indicator

14. Outlet-jacket water flow meter

15.AVL Austria Piezo-electric pressure transducer

16.Console

17.AVL Austria TDC encoder

18.Personal Computer

19. Printer.

Fig.2 Schematic diagram of experimental set–up

Description	Specification
Engine make and model	Kirloskar (India) AV1
Maximum power output at a speed of 1500 rpm	3.68 kW
Number of cylinders ×cylinder position× stroke	One × Vertical position × four-stroke
Bore × stroke	80 mm × 110 mm
Engine Displacement	553 cc
Method of cooling	Water cooled
Rated speed (constant)	1500 rpm
Fuel injection system	In-line and direct injection
Compression ratio	16:1
BMEP @ 1500 rpm at full load	5.31 bar
Manufacturer's recommended injection timing and injector opening pressure	27^obTDC × 190 bar
Number of holes of injector and size	Three × 0.25 mm
Type of combustion chamber	Direct injection type

Engine oil was provided with a pressure feed system. No temperature control was incorporated, for measuring the lube oil temperature. Copper shims of suitable size were provided in between the pump body and the engine frame, to vary the injection timing. Injector opening pressure was changed from 190 bar to 270 bar using nozzle testing device.

Table.2 Specifications of Test Engine

The maximum injector opening pressure was restricted to 270 bar due to practical difficulties involved. Coolant water jacket inlet temperature, outlet water jacket temperature and exhaust gas temperature were measured by employing iron and iron-constantan thermocouples connected to analogue temperature indicators. The accuracies of analogue temperature indicators are ±1%.

3. RESULTS AND DISCUSSION

3.1 Performance parameters

Fig.3 presents bar charts showing the variation of peak brake thermal efficiency with both versions of the engine at recommended injection timing and pressure with biodiesel operation. It showed that CE with biodiesel at 27^{o} bTDC showed comparable performance. The presence of oxygen in fuel composition might have improved performance with biodiesel operation, when compared with diesel operation on CE at 27^{o} bTDC. CE with biodiesel operation at 27^{o} bTDC decreased peak BTE by 3%, when compared with diesel operation on CE. Low calorific value and high viscosity of biodiesel might have showed comparable performance with biodiesel operation in comparison with neat diesel.

From Fig.3, it is observed that at 27^{o} bTDC, engine with LHR combustion chamber with biodiesel showed the comparable performance when compared with diesel operation on CE. High cylinder temperatures helped in improved evaporation and faster combustion of the fuel injected into the combustion chamber.

The optimum injection timing with CE was 31^{o} bTDC, while it was 28^{o} bTDC for engine with LHR combustion chamber with diesel operation [20-21]. Similarly corresponding values for biodiesel were 31^{o} bTDC for CE 28^{o} bTDC for LHR engine[22].

CE with biodiesel operation showed improved performance over CE with diesel operation. The presence of oxygen in fuel composition might have improved performance with biodiesel operation, when compared with mineral diesel operation on CE at 27^o bTDC. CE with biodiesel operation at 27^o bTDC decreased peak BTE by 3%, when compared with diesel operation on CE. Low calorific value and high viscosity of biodiesel might have showed comparable performance with biodiesel operation in comparison with neat diesel. CE with biodiesel operation increased BTE at all loads with advanced injection timing, when compared with CE with diesel operation at 27^o bTDC. Initiation of combustion at early period and increase of contact period of fuel with air improved performance with biodiesel when compared with diesel operation at 27^o bTDC. CE with biodiesel operation increased peak BTE by 3% at an optimum injection timing of 31^o bTDC, when compared with diesel operation at 27^o bTDC.

From Fig.3, it is observed that at 27^o bTDC, engine with LHR combustion chamber with biodiesel showed the improved performance when compared with diesel operation on CE. High cylinder temperatures helped in improved evaporation and faster combustion of the fuel injected into the combustion chamber. Reduction of ignition delay of the biodiesel in the hot environment of the engine with LHR combustion chamber might have improved heat release rates. Engine with LHR combustion chamber with biodiesel operation increased peak BTE by 14% at an optimum injection timing of 28^o bTDC in comparison with mineral diesel operation on CE at 27^o bTDC. Hot combustion chamber of LHR engine reduced ignition delay and combustion duration and hence the optimum injection timing (28^o bTDC) was obtained earlier with engine with LHR combustion chamber when compared with CE (31^o bTDC) with biodiesel operation. From Fig.3, it is observed that engine with LHR combustion chamber with biodiesel operation increased peak BTE by 3% at 27^o bTDC and 10% at 31^o bTDC in comparison with CE with biodiesel operation at 27^o bTDC and at 31^o bTDC.

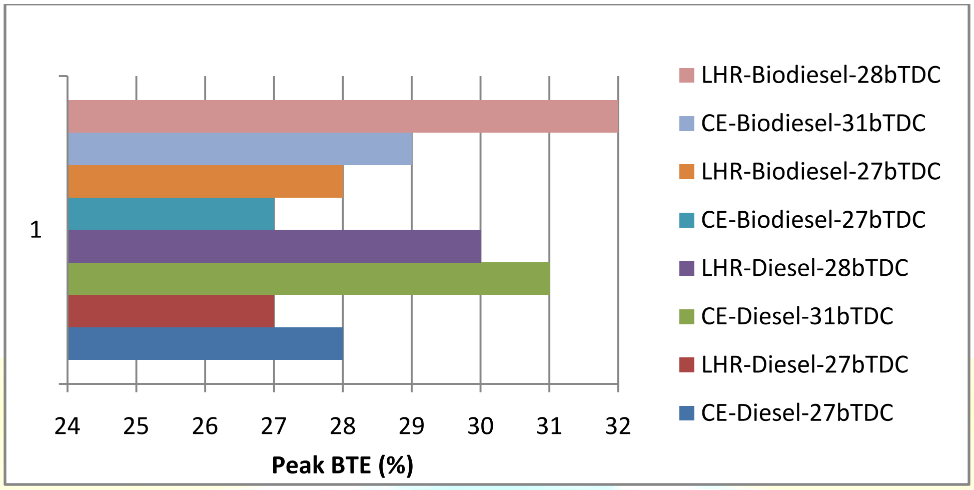


Fig.3 Bar charts showing the variation of peak brake thermal efficiency (BTE) with test fuels with conventional engine (CE) and engine with LHR combustion chamber at recommended and optimized injection timings at an injector opening pressure of 190 bar.

Engine with LHR combustion chamber with biodiesel operation showed higher peak BTE than diesel operation on same configuration of the engine. This showed that engine with LHR combustion chamber was more suitable for biodiesel.

Improved evaporation of biodiesel in hot environment provided by the engine with LHR combustion chamber might have improved peak thermal efficiency of the engine.

Fig.4 presents bar charts showing the variation of brake specific energy consumption (BSEC) at full load with test fuels. From Fig.4, it is shown that BSEC at full load decreased with advanced injection timing with test fuels. This was because of increase of resident time of fuel with air thus improving atomization and thus combustion. BSEC was comparable with biodiesel with CE at 27^o bTDC and 31^o bTDC, when compared with CE with diesel operation at 27^o bTDC and at 31^o bTDC. Improved combustion with higher cetane number and presence of oxygen in fuel composition with higher heat release rate with biodiesel may lead to produce comparable BSEC at full load. Engine with LHR combustion chamber with biodiesel decreased BSEC at full load operation by 6% at 27^o bTDC and 3% at 28^o bTDC, when compared diesel operation with engine with LHR combustion chamber at 27^o bTDC and at 28^o bTDC. This once again confirmed that engine with LHR combustion chamber was more suitable for biodiesel operation than neat diesel operation. Engine with LHR combustion chamber with biodiesel decreased BSEC at full load operation by 3% at 27^{o} bTDC and 2% at 28^{o} bTDC, in comparison with CE at 27^{o} bTDC and at 31^{o} bTDC with biodiesel.

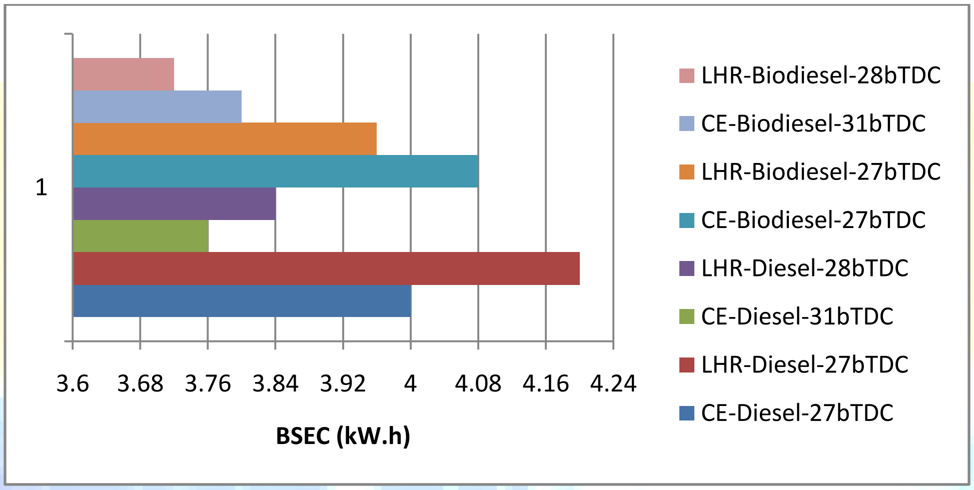


Fig.4.Bar charts showing the variation of brake specific energy consumption (BSEC) at full load operation with test fuels with both versions of the engine at recommended and optimized injection timings at an injector opening pressure of 190 bar.

Improved evaporation rate and higher heat release rate of fuel with LHR combustion chamber might have improved the performance with LHR engine.

Fig.5 presents bar charts showing variation of exhaust gas temperature (EGT) at full load with test fuels. From Fig.5, it is noticed that, exhaust gas temperature (EGT) at full load operation decreased with advanced injection timing with test fuels. This was because, when the injection timing was advanced, the work transfer from the piston to the gases in the cylinder at the end of the compression stroke was too large, leading to reduce EGT. CE with biodiesel operation increased EGT at full load operation by 6% at 27^{o} bTDC and 7% at 31^{o} bTDC in comparison with CE with neat diesel operation at 27 ^{o} bTDC and at 31^{o} bTDC. Though calorific value (or heat of combustion) of biodiesel is lower than that of diesel, density of biodiesel is higher, therefore greater amount of heat was released in the combustion chamber leading to produce higher EGT at full load operation with biodiesel operation than neat diesel operation. This was also because of higher duration of combustion of biodiesel causing retarded heat release rate. Similar findings were obtained by other researchers [6–8]. From Fig.5, it is noticed that engine with LHR combustion chamber with biodiesel operation increased EGT at full load operation by 5% at 27^{o} bTDC and 5% at 28^{o} bTDC, when compared with diesel operation on same configuration of the engine at 27^{o} bTDC and at 28^{o} bTDC.

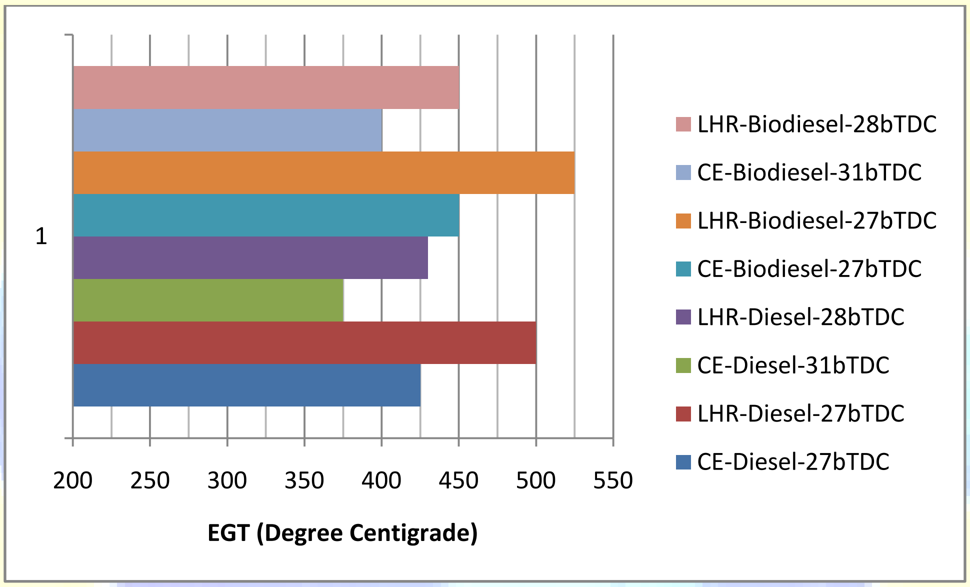


Fig.5Bar charts showing the variation of exhaust gas temperature (EGT) at full load operation with test fuels with both versions of the engine at recommended and optimized injection timings at an injector opening pressure of 190 bar.

High duration of combustion due to high viscosity of biodiesel in comparison with diesel might have increased EGT at full load. Engine with LHR combustion chamber with biodiesel increased EGT at full load operation by 17% at 27^{o} bTDC and 13% at 28^{o} bTDC, in comparison with CE at 27^{o} bTDC and at 31^{o} bTDC. This indicated that heat rejection was restricted through the piston, liner and cylinder head, thus maintaining the hot combustion chamber as result of which EGT at full load operation increased with reduction of ignition delay. Similar observations were reported by previous researchers [20–21].

Fig.6 presents bar charts showing variation of coolant load with test fuels. CE with biodiesel increased coolant load by 3% at 27^o bTDC and 10% at 31^o bTDC when compared with neat diesel operation on CE at 27^o bTDC and 31^o bTDC as observed from Fig.6

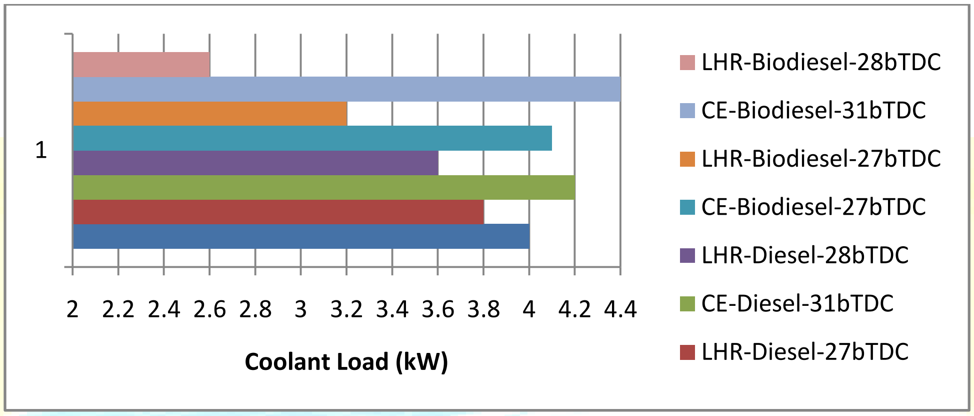


Fig.6 Bar charts showing the variation of coolant load at full load operation with test fuels with both versions of the engine at recommended and optimized injection timings at an injector opening pressure of 190 bar.

Increase of un–burnt fuel concentration at the combustion chamber walls may lead to increase of gas temperatures with biodiesel produced higher coolant load than diesel operation. Similar trends were reported in previous studies [21–22]. Coolant load at full load operation increased in CE, while decreasing the same in engine with LHR combustion chamber with advanced injection timing with biodiesel. In case of CE, un–burnt fuel concentration reduced with effective utilization of energy, released from the combustion, coolant load with test fuels increased marginally at full load operation, with an increase of gas temperatures, when the injection timing was advanced to the optimum value. The reduction of coolant load in engine with LHR combustion chamber might be due to the reduction of gas temperatures with improved combustion. Hence, the improvement in the performance of CE was due to heat addition at higher temperatures and rejection at lower temperatures, while the improvement in the efficiency of the engine with LHR combustion chamber was because of recovery from coolant load at their optimum injection timings with test fuels. Engine with LHR combustion chamber with biodiesel operation decreased coolant load operation by 16% at 27^o bTDC and 28% at 28^o bTDC, when compared diesel operation with same configuration of the engine at 27° bTDC and at 28° bTDC. More conversion of heat into useful work with biodiesel than diesel might have reduced coolant load with biodiesel. Fig.6indicates that engine with LHR combustion chamber with biodiesel decreased coolant load at full load operation by 7% at 27° bTDC and 41% at 28° bTDC, in comparison with CE at 27° bTDC and at 31° bTDC. Provision of thermal insulation and improved combustion with engine with LHR combustion chamber might have reduced coolant load with LHR engine in comparison with CE with biodiesel operation. Similar observations were reported by previous researchers. [20–21].

Fig.7shows bar charts showing variation of volumetric efficiency at full load with test fuels.

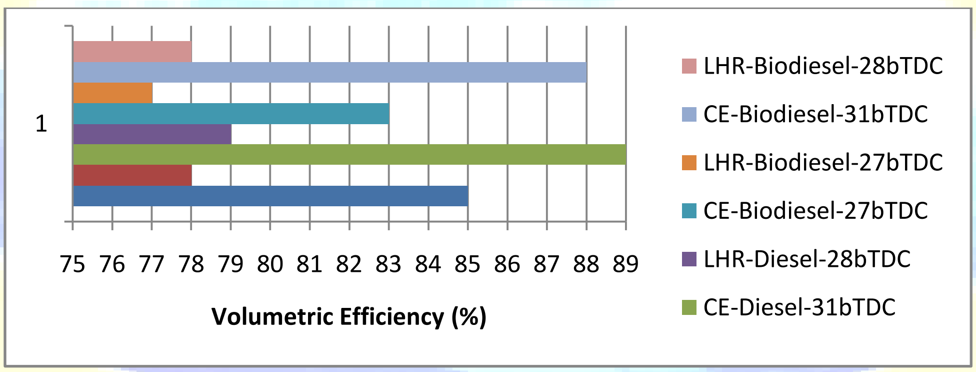


Fig.7 Bar charts showing the variation of volumetric efficiency at full load operation with test fuels with both versions of the engine at recommended and optimized injection timings at an injector opening pressure of 190 bar.

It indicates that CE with biodiesel operation decreased volumetric efficiency at full load by 2% at 27° bTDC and comparable at 31° bTDC, when compared with diesel operation on CE at 27° bTDC and 31° bTDC. Increase of EGT might have reduced volumetric efficiency at full load, as volumetric efficiency depends on combustion wall temperature, which in turn depends on EGT. Volumetric efficiency at full load operation improved marginally with advanced injection timing with test fuels with both configurations of the combustion chamber. Reduction of EGT at full load might have improved volumetric efficiency with test fuels. From Fig.9, it is noticed that volumetric efficiencies at full load operation on engine with LHR combustion chamber at

27^o bTDC and at 28^o bTDC with biodiesel were marginally lower than diesel operation on same configuration of the engine at 27^o bTDC and 28^o bTDC. Increase of EGT was responsible factor for it. Fig.7 indicates that engine with LHR combustion chamber with biodiesel decreased volumetric efficiency at full load operation by 7% at 27^o bTDC and 11% at 28^o bTDC, in comparison with CE at 27^o bTDC and at 31^o bTDC. The reduction of volumetric efficiency with engine with LHR combustion chamber was because of increase of temperatures of insulated components of LHR combustion chamber, which heat the incoming charge to high temperatures and consequently the mass of air inducted in each cycle was lower. Similar observations were noticed by earlier researchers [20–21].

SUMMARY

1. Engine with LHR combustion chamber is efficient for alternative fuel like biodiesel rather than neat diesel.
2. Engine with LHR combustion chamber with biodiesel improved its performance over CE at recommended injection timing and optimized timing.
3. The performance of the engine improved with advanced injection timing, with both versions of the combustion chamber with biodiesel.

Novelty

Engine parameters (injection timing) and different configurations of the engine (conventional engine and engine with LHR combustion chamber) were used simultaneously to improve performance of the engine. Change of injection timing was accomplished by inserting copper shims between pump frame and engine body.

Highlights

- Fuel injection pressure & timings affect engine performance and combustion parameters.
- Change of combustion chamber design improved the performance of the engine.

Future Scope of Work

Effect of preheating and injection pressure of the fuel can be studied on the performance, exhaust emissions and combustion characteristic of the engine.

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