



## Experimental Study of the Effects of Biodiesel on the Performance of a Ceramic Coated diesel engine

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The uses of biodiesel are increasingly popular because of their low impact on environment. However, it causes combustion problems in conventional diesel engine[CE]. Hence it is proposed to use the biodiesel in low heat rejection (LHR) diesel engines with its significance characteristics of higher operating temperature, maximum heat release, and ability to handle the lower calorific value (CV) fuel etc.. In this work, biodiesel from linseed was used as sole fuel in both versions of the combustion chamber. Engine with LHR combustion chamber was developed with ceramic coating on inside portion of cylinder head by partially stabilized zirconia of 0.5 mm thickness. The experimental investigations were carried out on a four stroke, single cylinder, DI 3.68 kW at a speed of 1500 rpm, In this investigation, comparative studies on performance parameters was made on CE and engine with LHR combustion chamber with different operating conditions of biodiesel with varied injector opening pressure and injection timing. CE showed compatible performance while LHR combustion chamber showed improved performance with biodiesel operation in comparison with pure diesel operation on CE.

**KEYWORDS:** Alternate Fuels, Vegetable Oils, Biodiesel, LHR combustion chamber, Performance parameters.

### I. INTRODUCTION

The paper is divided into i) Introduction, ii) Materials and Methods, iii)Results and Discussions, iv) Conclusions, Future scope of work, v) Acknowledgements followed by References.

Introduction deals with investigations carried out by researchers in the work related to the authors or brief literature review. .

This section deals with need for alternate fuels in diesel engine, problems with use of crude vegetable oil in diesel engine, advantages of use of preheated vegetable oil in diesel engine, use of biodiesel in diesel engine, effect of increase of injector opening pressure and advanced injection timing on the performance of the diesel engine, concept of engine with LHR combustion chamber, advantages of LHR combustion chamber, classification of engines with LHR combustion chamber, use of diesel, crude vegetable oil and biodiesel in engine with LHR combustion chamber, research gaps and objectives of the investigations.

It has been found that the vegetable oils are promising substitute, because of their properties are similar to those of diesel fuel and they are renewable and can be easily produced.

Rudolph Diesel, the inventor of the diesel engine that bears his name, experimented with fuels ranging from powdered coal to peanut oil. Several researchers [1-3] experimented the use of vegetable oils as fuel on diesel engine and reported that the performance was poor, citing the problems of high viscosity, low volatility and their polyunsaturated character.

Viscosity can be reduced with preheating. Experiments were conducted [4] on preheated vegetable [temperature at which viscosity of the vegetable oils were matched to that of diesel fuel] oils and it was reported that preheated vegetable oils improved the performance marginally. The problems of crude vegetable oils can be solved, if these oils are chemically modified to bio-diesel.

Bio-diesels derived from vegetable oils present a very promising alternative to diesel fuel since biodiesels have numerous advantages compared to fossil fuels as they are renewable, biodegradable, provide energy security and foreign exchange savings besides addressing environmental concerns and socio-economic issues. Experiments were carried out [5-6] with bio-diesel on direct injection diesel engine and it was reported that performance was compatible with pure diesel operation on conventional engine.

The other important engine variable to improve the performance of the engine is injection timing. Investigations were carried out [7-9] on single cylinder water cooled vertical diesel engine with brake power 3.68 kW at a speed of 1500 rpm with varied injection timing from 27-34°bTDC. It was reported from their investigations that performance of the engine improved with advanced injection timing. However, it increased NOx emissions and decreased smoke levels.

Sound levels determine the phenomena of combustion in engine whether the performance was improving or deteriorating. Studies were made [22-24] on sound levels with convention engine with vegetable oils and it was reported from the studies, that performance deteriorated with vegetable oil operation on conventional engine leading to produce high sound levels.

The drawbacks associated with biodiesel for use in diesel engine call for low heat rejection (LHR) combustion chamber.

The concept of LHR combustion chamber is to reduce heat loss to coolant by providing thermal insulation in the path of heat flow to the coolant. LHR combustion chambers are classified depending on degree of insulation such as low grade, medium grade and high grade insulated combustion chamber. Several methods adopted for achieving low grade LHR combustion chamber are using ceramic coatings

on piston, liner and cylinder head. Medium grade LHR combustion chamber provide an air gap in the piston and other components with low-thermal conductivity materials like superni, cast iron and mild steel etc. High grade LHR combustion chamber contain ceramic coatings on engine components and air gap insulated components.

LHR combustion chamber with ceramic coating of thickness in the range of 500 microns on the engine components with pure diesel operation [25-27] provided adequate insulation and improved brake specific fuel consumption (BSFC) in the range of 5-7%. The investigations on low grade LHR combustion chamber consisting of ceramic coating on cylinder head were extended to crude vegetable oil [28-29] and biodiesel [30]. It was revealed from their investigations that ceramic coated LHR combustion chamber marginally improved brake thermal efficiency, decreased smoke levels by 30% and increased NOx levels by 40%.

Little literature was available on comparative studies of conventional diesel engine and ceramic coated LHR combustion chamber with different operating conditions of the biodiesel with varied injection timing and injector opening pressure. Hence it was attempted here to determine performance parameters with linseed oil based biodiesel with CE and LHR combustion chamber with varied injector opening pressure and injection timing.

## II. MATERIALS AND METHODS

This section contains fabrication of engine with LHR combustion chamber, preparation of biodiesel, properties of biodiesel, description of the schematic diagram of experimental set up, specifications of experimental engine, specifications of sound analyzer and definitions of used values. The inner side portion of cylinder head was coated with partially stabilized zirconium (PSZ) of thickness of 500 microns in order to convert conventional diesel engine to low heat rejection (LHR) combustion chamber. The chemical conversion of esterification reduced viscosity four fold. Linseed oil contains up to 72.9 % (wt.) free fatty acids [32]. The methyl ester was produced by chemically reacting the linseed oil with an alcohol (methyl), in the presence of a catalyst (KOH). A two-stage process was used for the esterification [34-35] of the waste fried vegetable oil. The first stage (acid-catalyzed) of the process is to reduce the free fatty acids (FFA) content in linseed oil by esterification with methanol (99% pure) and acid catalyst (sulfuric acid-98% pure) in one hour time of reaction at 55°C. In the second stage (alkali-catalyzed), the triglyceride portion of the linseed oil reacts with methanol and base catalyst (sodium hydroxide-99% pure), in one hour time of reaction at 65°C, to form methyl ester 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 methyl ester (or biodiesel) produced from linseed oil was known as linseed oil biodiesel (LSOBD). The physic-chemical properties of the crude linseed oil and biodiesel in comparison to ASTM biodiesel standards are presented in Table-1

**Table.1. Properties of test fuels**

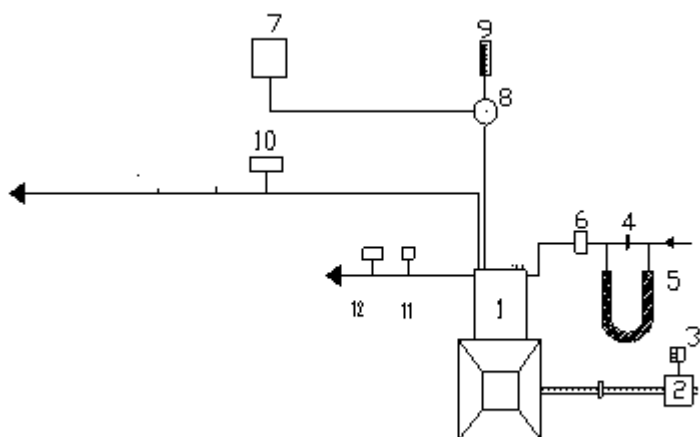
Property	Units	Diesel	Biodiesel	ASTM D 6751-02
Carbon chain	--	C <sub>8</sub> -C <sub>28</sub>	C <sub>16</sub> -C <sub>24</sub>	C <sub>12</sub> -C <sub>22</sub>
Cetane Number		55	55	48-70
Density	gm/cc	0.84	0.87	0.87-0.89
Bulk modulus @ 20Mpa	Mpa	1475	1850	NA
Kinematic viscosity @ 40°C	cSt	2.25	4.5	1.9-6.0
Sulfur	%	0.25	0.0	0.05
Oxygen	%	0.3	10	11
Air fuel ratio ( stoichiometric)	--	14.86	14.2	13.8
Lower calorific value	kJ/kg	42 000	38000	37 518
Flash point (Open cup)	°C	66	180	130
Molecular weight	--	226	280	292
Preheated temperature	°C	--	60	--
Colour	--	Light yellow	Yellowish orange	---

The test fuels used in the experimentation were pure diesel and linseed oil based biodiesel. The schematic diagram of the experimental setup with test fuels is shown in Figure 1. The specifications of the experimental engine are shown in Table-2. The combustion chamber consisted of a direct injection type with no special arrangement for swirling motion of air. The engine was connected to an electric dynamometer for measuring its brake power. Burette method was used for finding fuel consumption of the engine. Air-consumption of the engine was measured by an air-box method (Air box was provided with an orifice meter and U-tube water manometer). The naturally aspirated engine was provided with water-cooling system in which inlet temperature of water was maintained at 80°C by adjusting the water flow rate. 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 (to vary the length of plunger of pump barrel) in between the pump body and the engine frame, to vary the injection timing and its effect on the performance of the engine was studied, along with the change of injector opening pressure from 190 bar to 270 bar (in steps of 40 bar) using nozzle testing device. The maximum injector opening pressure was restricted to 270 bar due to practical difficulties involved. Exhaust gas temperature was measured with thermocouples made of iron and iron-constantan.

Table.2. Specifications of the test engine

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
Rated speed ( constant)	1500 rpm
Fuel injection system	In-line and direct injection
Compression ratio	16:1
BMEP @ 1500 rpm	5.31 bar
Manufacturer's recommended injection timing and pressure	27°bTDC × 190 bar
Dynamometer	Electrical dynamometer
Number of holes of injector and size	Three × 0.25 mm
Type of combustion chamber	Direct injection type
<b>Fuel injection nozzle</b>	<b>Make: MICO-BOSCH No- 0431-202-120/HB</b>
<b>Fuel injection pump</b>	<b>Make: BOSCH: NO- 8085587/1</b>

Different operating conditions of the biodiesel were normal temperature and preheated temperature. Different injector opening pressures attempted in this experimentation were 190 bar, 230 bar and 270 bar. Various injection timings attempted in the investigations were 27-34°bTDC.



1.Engine, 2.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.Outlet jacket water temperature indicator, 12. Outlet-jacket water flow meter,

Figure 1.Schematic Diagram of Experimental Set-up

### 3. RESULTS AND DISCUSSION

Results and discussion were made in two parts such as

1. Determining optimum injection timing with CE and engine with LHR combustion chamber,
- 2) determining the exhaust emissions

The performance of diesel fuel in conventional engine and LHR combustion chamber was taken from Reference [34]. The optimum injection timing with conventional engine was 31°bTDC, while with LHR combustion chamber it was 30°bTDC.

#### 3.1 Determination of Optimum injection timing

The performance of diesel fuel in CE and LHR combustion chamber was taken from Reference [31]. The optimum injection timing with conventional engine with pure diesel operation was 31°bTDC, while it was 30°bTDC for LHR combustion chamber.

Comparative studies were made between CE and LHR combustion chamber with different operating conditions of the biodiesel with varied injection timing and injector opening pressure. The results were compared with standard diesel under the same conditions.

#### 3.2 Performance Parameters

From Figure 2 indicate that at recommended injection timing, engine with biodiesel showed the compatible performance for entire load range when compared with the pure diesel operation. This may be due to the difference of viscosity between the diesel and biodiesel and calorific value of the fuel. The reason might be due to (1) higher initial boiling point and different distillation characteristics, (2) higher density and viscosity leads to narrower spray cone angle and higher spray penetration tip, leading to inferior combustion compared to neat diesel [35]. However, higher density of biodiesel compensates the lower value of the heat of combustion of the biodiesel thus giving compatible performance with engine. Biodiesel contains oxygen molecule in its molecular composition. Theoretical air requirement of biodiesel was low [Table.1] and hence lower levels of oxygen were required for its combustion. Brake thermal efficiency increased with the advanced injection timing with conventional engine with the biodiesel at all loads. This was due to initiation of combustion at earlier period and efficient combustion with increase of air entrainment [31] in fuel spray giving higher brake thermal efficiency. Brake thermal efficiency increased at all loads when the injection timing was advanced to 31°bTDC with the engine at the normal temperature of biodiesel. The increase of brake thermal efficiency at optimum injection timing over the recommended injection timing with biodiesel with conventional engine could be attributed to its longer ignition delay and combustion duration [31].

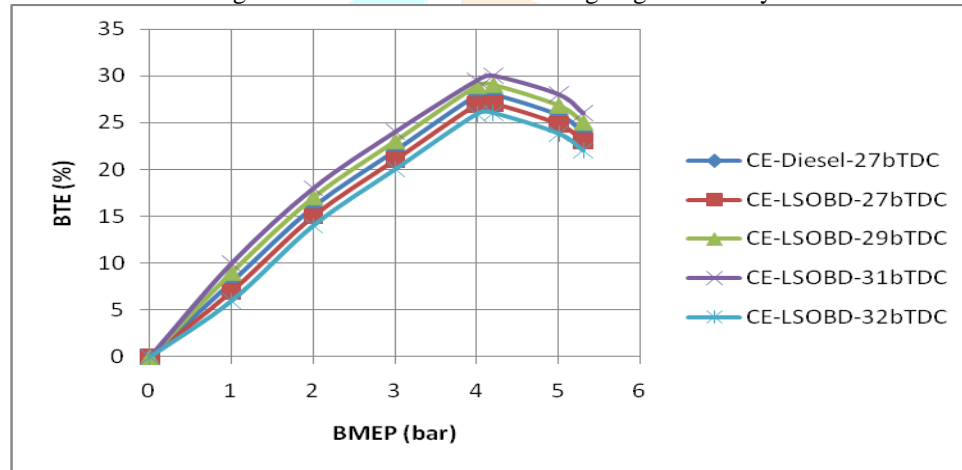


FIGURE 2. Variation of brake thermal efficiency (BTE) with brake mean effective pressure (LDOBD) in conventional engine (CE) at different injection timings with biodiesel (LSOBD) operation.

Similar trends were noticed with preheated biodiesel. Preheating of the biodiesel reduced the viscosity, which improved the spray characteristics of the oil, causing efficient combustion thus improving brake thermal efficiency.

From Figure 3, it is observed that LHR version of the engine at recommended injection timing showed the improved performance at all loads compared with CE with pure diesel operation. High cylinder temperatures [31] helped in improved evaporation and faster combustion of the fuel injected into the combustion chamber. Reduction of ignition delay of the vegetable oil in the hot environment of the LHR combustion chamber improved heat release rates and efficient energy utilization. The optimum injection timing was found to be 30°bTDC with LHR combustion chamber with different operating conditions of biodiesel operation. Since the hot combustion chamber of LHR combustion chamber reduced ignition delay and combustion duration and hence the optimum injection timing was obtained [31] earlier with LHR combustion chamber when compared to conventional engine with the biodiesel operation.

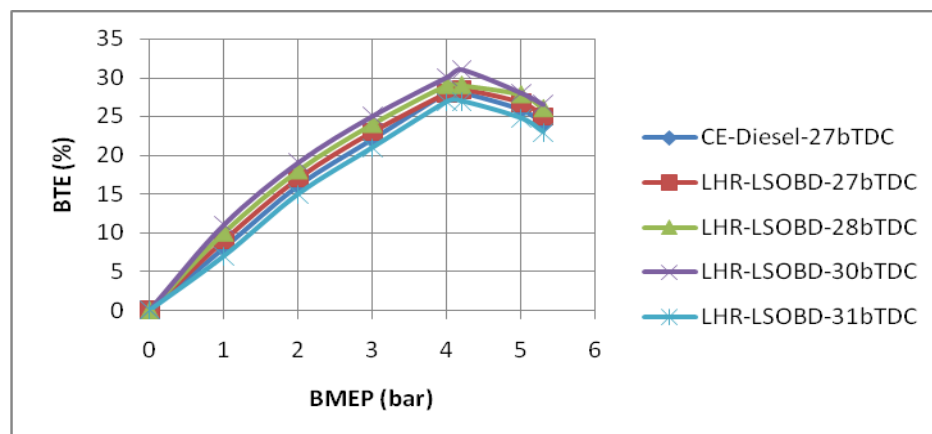


FIGURE 3. Variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) in LHR combustion chamber at different injection timings with biodiesel (LSOBD) operation.

Part load variations were very small and minute for the performance parameters and exhaust emissions. The effect of varied injection timing on the performance was discussed with the help of bar charts while the effect of injector opening pressure and preheating of biodiesel was discussed with the help of Tables.

From Figure.4, it was noticed that peak brake thermal efficiency(BTE)with engine with LHR combustion chamber with pure diesel operation was lower in comparison with conventional engine at recommended (2%) and optimized injection timings (6%). Engine with LHR combustion chamber [31] with pure diesel operation deteriorated the performance in comparison with conventional engine. As the combustion chamber was insulated to greater extent, it was expected that high combustion temperatures would be prevalent in LHR combustion chamber. It tends to decrease the ignition delay thereby reducing pre-mixed combustion as a result of which, less time was available for proper mixing of air and fuel in the combustion chamber leading to incomplete combustion, with which peak BTE decreased. More over at this load, friction and increased diffusion combustion resulted from reduced ignition delay.

Peak BTE with LHR combustion chamber with biodiesel operation was higher in comparison with conventional engine at recommended and optimized injection timings.

This was due to higher degree of insulation provided in the piston, liner (with the provision of air gap with superni-90 inserts) and cylinder head reduced the heat rejection leading to improve the thermal efficiency. This was also because of improved evaporation rate of the biodiesel. High cylinder temperatures [31] helped in improved evaporation and faster combustion of the fuel injected into the combustion chamber. Reduction of ignition delay of the vegetable oil in the hot environment of the engine with LHR combustion chamber improved heat release rates and efficient energy utilization.

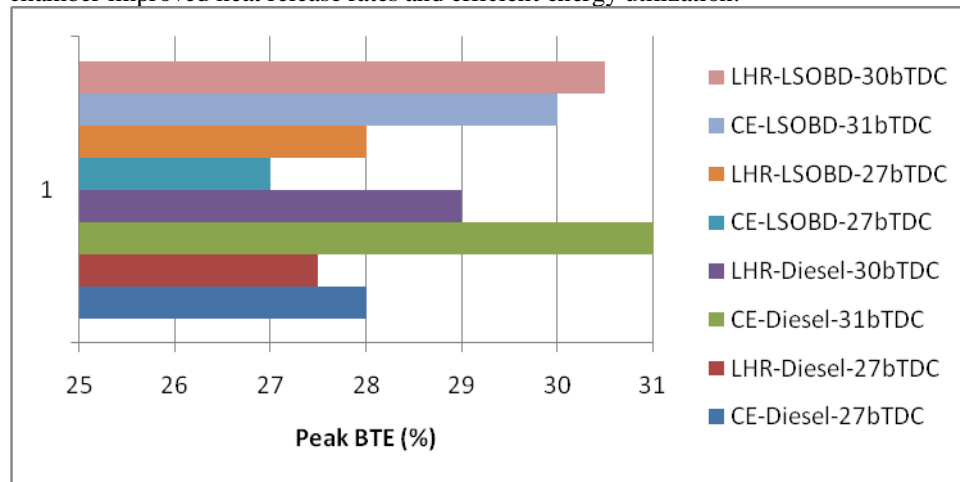


Figure. 4. Bar charts showing the variation of peak brake thermal efficiency (BTE) with test fuels at recommended and optimized injection timings at an injector opening pressure of 190 bar in Conventional engine and ceramic coated LHR combustion chamber.

Injector opening pressure was varied from 190 bar to 270 bar to improve the spray characteristics and atomization of the test fuels and injection timing is advanced from 27 to 34°bTDC for CE and LHR combustion chamber. As it is observed from Table.4, peak brake thermal efficiency increased with increase in injector opening pressure at different operating conditions of the biodiesel.

For the same physical properties, as injector opening pressure increased droplet diameter decreased influencing the atomization quality, and more dispersion of fuel particle, resulting in turn in better vaporization, leads to improved air-fuel mixing rate, as extensively reported in the literature [16-18,35]. In addition, improved combustion leads to less fuel consumption.

Performance improved further with the preheated biodiesel when compared with normal biodiesel. This was due to reduction in viscosity of the fuel. Preheating of the biodiesel reduced the viscosity, which improved the spray characteristics of the oil causing efficient combustion thus improving brake thermal efficiency. The cumulative heat release was more for preheated biodiesel [35] than that of biodiesel and this indicated that there was a significant increase of combustion in diffusion mode [35]. This increase in heat release [35] was mainly due to better mixing and evaporation of preheated biodiesel, which leads to complete burning.

TABLE.4 DATA OF PEAK BRAKE THERMAL EFFICIENCY (BTE) AND

BRAKE SPECIFIC ENERGY

## CONSUMPTION AT FULL LOAD OPERATION

Injection Timing (°bTDC)	Test Fuel	Peak BTE (%)						Brake Specific Energy Consumption at peak load operation ( kW/kW)					
		Injection Pressure (Bar)						Injection Pressure (Bar)					
		190		230		270		190		230		270	
		NT	PT	NT	PT	NT	PT	NT	PT	NT	PT	NT	PT
27(CE)	DF	28	--	29	---	30	--	4.0	--	3.96	--	3.92	--
	LSOBD	27	27.5	27.5	28	28.5	29	4.02	3.96	3.96	3.94	3.94	3.96
27(LHR)	DF	27.5	--	28	--	29	--	4.3	--	4.2	--	4.1	--
	LSOBD	28	28.5	28.5	29	29	29.5	3.84	3.80	3.80	3.76	3.76	3.72
30(LHR)	DF	29		29.5		30		3.80		3.76		3.72	
	LSOBD	30.5	31	31	31.5	32	32.5	3.72	3.68	3.68	3.64	3.64	3.60
31(CE)	DF	31		31.5		32		3.6	--	3.7	--	3.8	---
	LSOBD	30	30.5	30.5	31	31	31.5	3.82	3.78	3.86	3.82	3.90	3.86

DF- Diesel fuel, LSOBD Biodiesel, NT- Normal temperature , PT- Preheated temperature

Generally brake specific fuel consumption, is not used to compare the two different fuels, because their calorific value, density, chemical and physical parameters are different. Performance parameter, BSEC, is used to compare two different fuels by normalizing brake specific energy consumption, in terms of the amount of energy released with the given amount of fuel.

From Figure.5, it was evident that brake specific energy consumption with LHR combustion chamber with pure diesel operation was higher in comparison with conventional engine at recommended (8%) and optimized injection timings (6%). This was due to reduction of ignition delay with pure diesel operation with LHR engine as hot combustion chamber was maintained by engine with LHR combustion chamber.

With biodiesel operation, BSEC was lower with LHR combustion chamber at recommended injection timing (5%) and at optimized injection timing (3%) in comparison with conventional engine.

BSEC was higher with conventional engine due to higher viscosity, poor volatility and reduction in heating value of biodiesel lead to their poor atomization and combustion characteristics. The viscosity effect, in turn atomization was more predominant than the oxygen availability [35] in the blend leads to lower volatile characteristics and affects combustion process. BSEC was improved with LHR combustion chamber with lower substitution of energy in terms of mass flow rate.

BSEC decreased with advanced injection timing with test fuels. This was due to initiation of combustion and substitution of lower energy as seen From the Figure.6.

BSEC of biodiesel is almost the same as that of neat diesel fuel as shown in Figure.6. Even though viscosity of biodiesel is slightly higher than that of neat diesel, inherent oxygen of the fuel molecules improves the combustion characteristics. This is an indication of relatively more complete combustion [35].

From the Table.4 it is noticed that BSEC at full load operation decreased with increase of injector opening pressure with different operating conditions of the test fuels. This was due to increase of air entrainment [35] in fuel spray giving lower BSEC.

BSEC decreased with the preheated biodiesel at full load operation when compared with normal biodiesel. Preheating of the biodiesel reduced the viscosity, which improved the spray characteristics of the oil.

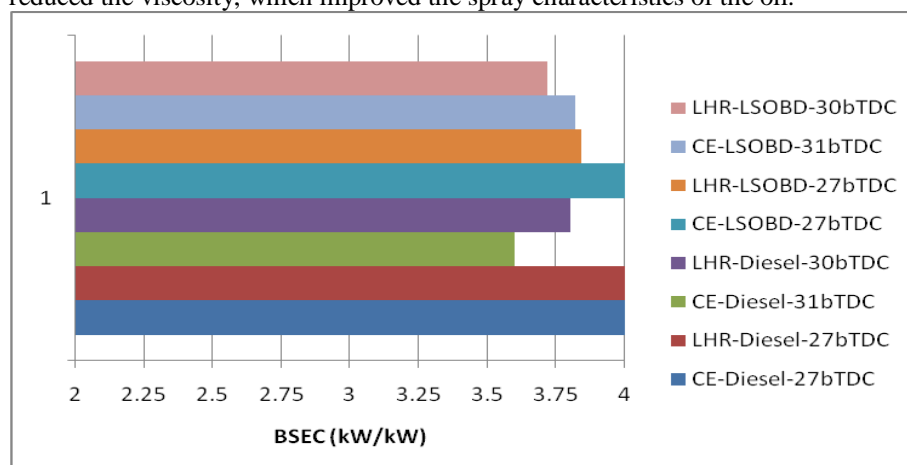


Figure. 5. Bar charts showing the variation of brake specific energy consumption (BSEC) at peak load operation with test fuels at recommended and optimized injection timings at an injector opening pressure of 190 bar in CE and LHR combustion chamber.

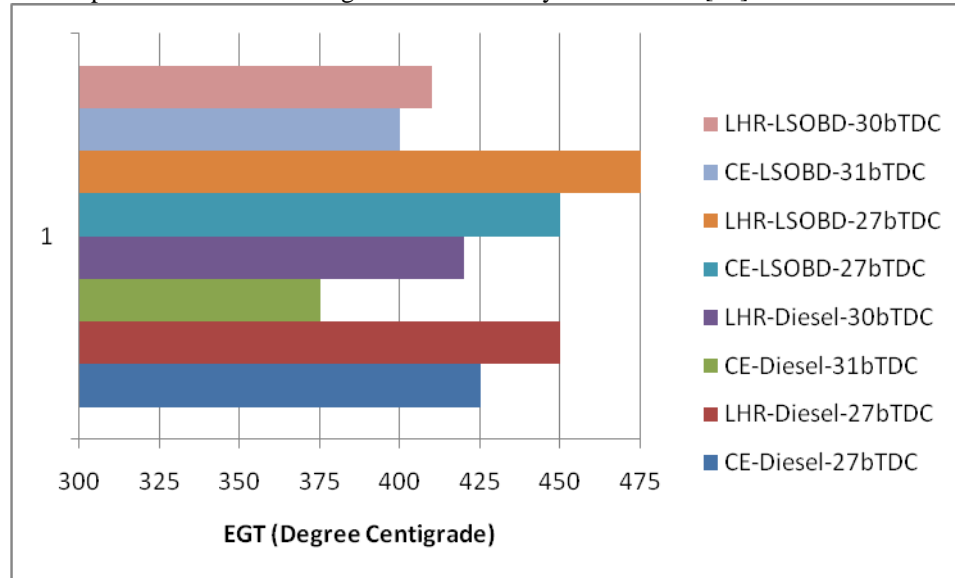
From Figure.6, it was observed that exhaust gas temperature (EGT) with engine with LHR combustion chamber with pure diesel operation was higher in comparison with conventional engine at recommended (6%) and optimized injection timings (12%).

This was due to reduction of ignition delay with pure diesel operation with LHR engine as hot combustion chamber was maintained by engine with LHR combustion chamber. This indicated that heat rejection was restricted through the piston, liner and cylinder head, thus maintaining the hot combustion chamber as result of which the exhaust gas temperature increased.

EGT with engine with LHR combustion chamber with biodiesel operation was marginally higher in comparison with conventional engine at recommended (6%) and optimized injection timings (3%). This was due to reduction of ignition delay in the hot environment with the provision of the insulation in the LHR combustion chamber, which caused the gases expand in the cylinder giving higher work output and lower heat rejection.

EGT decreased with advanced injection timing with test fuels as seen from the Figure. 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 in the value of EGT.

Though the calorific value (or heat of combustion) of fossil diesel is more than that of biodiesel ; the density of the biodiesel was higher therefore greater amount of heat was released in the combustion chamber leading to higher exhaust gas temperature with conventional engine, which confirmed that performance was compatible with conventional engine with biodiesel operation in comparison with pure diesel operation. Similar findings were obtained by other studies [21].



**Figure. 6.** Bar charts showing the variation of exhaust gas temperature (EGT) at peak load operation with test fuels at recommended and optimized injection timings at an injector opening pressure of 190 bar in conventional engine and LHR combustion chamber.

From the Table.5, it is noticed that the exhaust gas temperatures of preheated biodiesel were higher than that of normal biodiesel, which indicates the increase of diffused combustion [35] due to high rate of evaporation and improved mixing between methyl ester and air. Therefore, as the fuel temperature increased, the ignition delay decreased and the main combustion phase (that is, diffusion controlled combustion) increased [35], which in turn raised the temperature of exhaust gases. The value of exhaust gas temperature decreased with increase in injector opening pressure with test fuels as it is evident from the Table.5. This was due to improved spray characteristics of the fuel with increase of injector opening pressure. Exhaust gas temperature was lower with diesel operation with conventional engine when compared with biodiesel operation, while EGT was lower with LHR combustion chamber with biodiesel operation in comparison with diesel operation. Hence conventional engine was more suitable for diesel operation, while LHR combustion chamber was suitable for biodiesel operation.

**TABLE.5. DATA OF EXHAUST GAS TEMPERATURE (EGT) AND COOLANT LOAD AT FULL LOAD OPERATION**

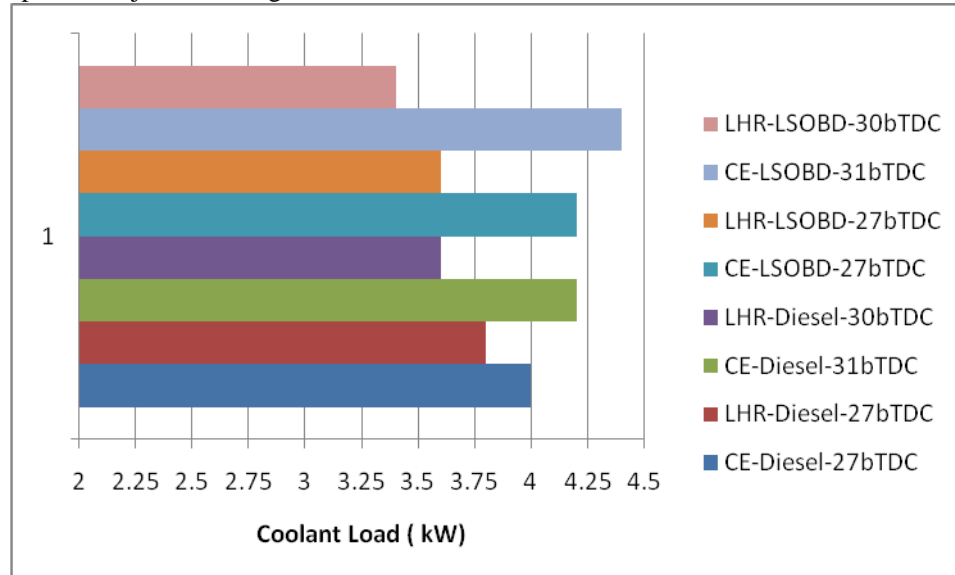
Injection Timing (%bTDC)	Test Fuel	EGT at peak load operation (degree centigrade)						Coolant load at peak load operation (kW)					
		Injector Opening Pressure (Bar)						Injector Opening Pressure (Bar)					
		190		230		270		190		230		270	
		NT	PT	NT	PT	NT	PT	NT	PT	NT	PT	NT	PT
27(CE)	DF	425	--	410	---	395	--	4.0	---	4.2	--	4.4	---
	LSOBD	450	490	410	450	370	410	4.2	4.0	4.4	4.2	4.6	4.4
27(LHR)	DF	450	--	430	--	410	--	3.8	--	3.6	--	3.4	--
	LSOBD	475	500	450	475	425	450	3.6	3.4	3.4	3.2	3.2	3.0
30(LHR)	DF	420	--	400	--	380	--	3.6	--	3.8	--	4.0	--
	LDOBD	410	430	440	470	460	480	3.4	3.2	3.2	3.0	3.0	2.8
31(CE)	DF	375	---	350	---	325	--	4.2	--	4.4	--	4.6	---
	LSOBD	400	440	420	460	440	420	4.4	4.2	4.6	4.4	4.8	4.6

DF- Diesel fuel, LSOBD Biodiesel, NT- Normal temperature , PT- Preheated temperature

Figure 7 indicates that coolant load with LHR combustion chamber with pure diesel operation was lower (5% and 14%) at recommended and optimized injection timings respectively in comparison with conventional engine. This was due insulation provided with LHR combustion chamber.

Coolant load with engine with LHR combustion chamber with biodiesel operation was lower at recommended (14% and optimized injection timings (23%) respectively in comparison with conventional engine. This was due insulation provided with LHR combustion chamber.

In case of conventional engine, un-burnt fuel concentration reduced with effective utilization of energy, released from the combustion, coolant load with test fuels increased marginally at peak load operation, due to un-burnt fuel concentration reduced with effective utilization of energy, released from the combustion, with increase of gas temperatures, when the injection timing was advanced to the optimum value. However, the improvement in the performance of the conventional engine was due to heat addition at higher temperatures and rejection at lower temperatures, while the improvement in the efficiency of the LHR combustion chamber was due to recovery from coolant load at their respective optimum injection timings with test fuels. Murali Krishna [31] noticed the similar trend at optimum injection timing with his LHR combustion chamber.



**Figure. 7. Bar charts showing the variation of coolant load at peak load operation with test fuels at recommended and optimized injection timings at an injector opening pressure of 190 bar in conventional engine and LHR combustion chamber.**

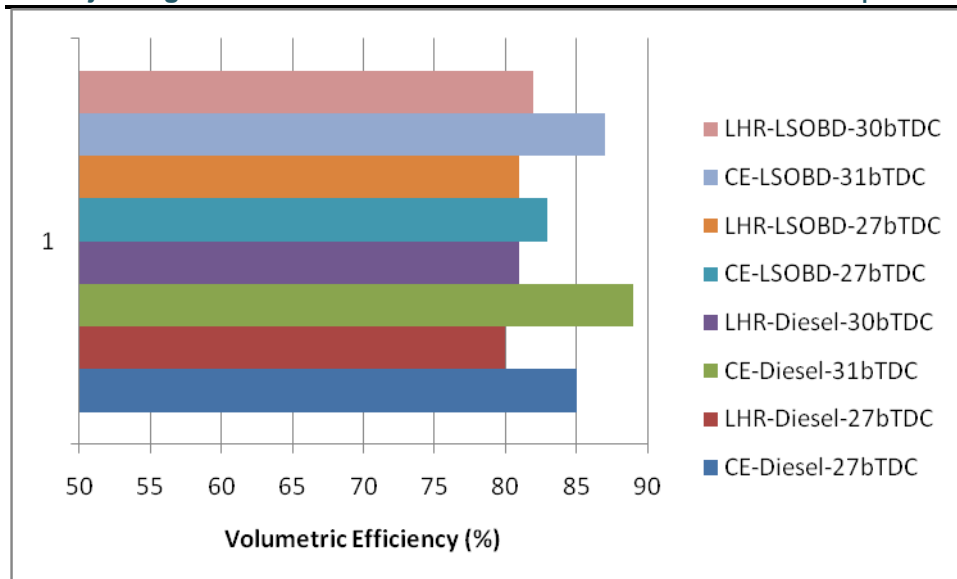
From Table.5, it is seen that coolant load increased marginally in the conventional engine while it decreased in the LHR combustion chamber with increase of the injector opening pressure with test fuels. This was due to the fact with increase of injector opening pressure with conventional engine, increased nominal fuel spray velocity resulting in improved fuel-air mixing with which gas temperatures increased. The reduction of coolant load in the LHR combustion chamber was not only due to the provision of the insulation but also it was due to better fuel spray characteristics and increase of air-fuel ratios causing decrease of gas temperatures and hence the coolant load.

Coolant load decreased marginally with preheating of biodiesel. This was due to improved air fuel ratios [31] with improved spray characteristics.

Figure 8 denotes that volumetric efficiencies were lower (6% and 9%) with LHR combustion chamber with pure diesel operation at recommended and optimized injection timings respectively in comparison with conventional engine.

Volumetric efficiency in the LHR combustion chamber decreased at full load operation when compared to the conventional engine at recommended and optimized injection timing with test fuels. This was due increase of temperature of incoming charge in the hot environment created with the provision of insulation, causing reduction in the density and hence the quantity of air. However, this variation in volumetric efficiency is very small between these two versions of the engine, as volumetric efficiency mainly depends [20] on speed of the engine, valve area, valve lift, timing of the opening or closing of valves and residual gas fraction rather than on load variation. Murali Krishna [35] also observed the similar trends in the value of volumetric efficiency.





**Figure. 8. Bar charts showing the variation of volumetric efficiency at peak load operation with test fuels at recommended and optimized injection timings at an injector opening pressure of 190 bar in conventional engine and LHR combustion chamber.**

With biodiesel operation, volumetric efficiencies were lower with LHR combustion chamber at recommended (3%) and optimized injection timings (6%) respectively in comparison with conventional engine.

Volumetric efficiency was higher with pure diesel operation at recommended and optimized injection timing with conventional engine in comparison with biodiesel operation. This was due to increase of combustion chamber wall temperatures with biodiesel operation due to accumulation of un-burnt fuel concentration. This was also because of increase of combustion chamber wall temperature as exhaust gas temperatures increased with biodiesel operation in comparison with pure diesel operation.

Volumetric efficiency increased marginally with both versions of the engine with test fuels with advanced injection timing. This was due to decrease of combustion chamber wall temperatures with improved air fuel ratios [34].

Preheating of the biodiesel marginally decreased volumetric efficiency, when compared with the normal temperature of biodiesel, because of reduction of bulk modulus, density of the fuel and increase of exhaust gas temperatures.

#### 4. CONCLUSIONS

Peak BTE with LHR combustion chamber with biodiesel operation was higher in comparison with conventional engine at recommended (4%) and optimized injection timings (2%).

BSEC was lower with LHR combustion chamber with biodiesel operation in comparison with conventional engine at recommended injection timing (5%) and optimum injection timing (3%).

EGT with LHR combustion chamber with biodiesel operation was marginally higher in comparison with conventional engine at recommended (6%) and optimized injection timings (3%).

Coolant load with LHR combustion chamber with biodiesel operation was lower (14% and 23%) at recommended and optimized injection timings respectively in comparison with conventional engine. This was due insulation provided with LHR combustion chamber.

Volumetric efficiencies were lower (3% and 6%) with LHR combustion chamber with biodiesel operation at recommended and optimized injection timings respectively in comparison with conventional engine.

With increase of injection pressure with both versions of the engine with test fuels. Peak brake thermal efficiency increased. At peak load operation- brake specific energy consumption decreased, exhaust gas temperature decreased, volumetric efficiency increased, coolant load increased (CE), and sound levels decreased.

With preheating of biodiesel with both versions of the engine- Peak brake thermal efficiency increased, at peak load operation- brake specific energy consumption decreased, exhaust gas temperature increased(CE), volumetric efficiency decreased(CE), coolant load decreased. LHR combustion chamber was more suitable for biodiesel operation than pure diesel operation.

#### 5. Research Findings and Future Scope of Work

Investigations on study of performance parameters with engine with ceramic coated LHR combustion were systematically carried out with varied injector opening pressure and injection timing with different operating conditions of the test fuels with various configurations of the combustion chamber.

Degree of insulation can further be increased in order to study performance parameters as low viscous fuels can be efficiently burnt in LHR combustion chamber.

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