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Influence of Injection Timing on Exhaust Emissions of Di Diesel Engine with Air Gap Insulation with Linseed Biodiesel

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Abstract

Investigations were carried out to study exhaust emissions of a medium grade low heat rejection (LHR) diesel engine consisting of air gap insulated piston with superni (an alloy of nickel) crown and air gap insulated liner with superni insert with different operating conditions [normal temperature and pre–heated temperature] of linseed biodiesel with varied injection timing. Exhaust emissions of particulate emissions and nitrogen oxide (NO_x) levels were evaluated at different values of brake mean effective pressure (BMEP) of the engine. Comparative studies were made with conventional engine (CE) with biodiesel and also with mineral diesel operation with similar working condition. The optimum injection timing was 31^o bTDC (before top dead centre) with conventional engine while it was 29^o bTDC for engine with LHR combustion chamber with biodiesel operation. Particulate emissions decreased while NO_x levels increased with engine with LHR combustion chamber with biodiesel in comparison with CE.

Keywords: *Crude vegetable oil; biodiesel; exhaust emissions; LHR combustion chamber.*

1. Introduction

Vegetable oils are promising substitutes for diesel fuel, as they are renewable in nature and properties are comparable to diesel fuel in scenario of depletion of fossil fuels and ever increase of fuel prices in International Market and increase of pollution levels with fossil fuels. The idea of using vegetable oil as fuel has been around from the birth of diesel engine. Rudolph diesel, the inventor of the engine that bears his name, experimented with fuels ranging from powdered coal to peanut oil and hinted that vegetable oil would be the future fuel [1]. Several researchers experimented the use of vegetable oils as fuel on conventional engines. They reported that the performance was poor, citing the problems of high viscosity, low volatility and their polyunsaturated character. [1–3].These problems can be solved to some extent, if neat vegetable oils are chemically modified (esterified) to bio-diesel. Experiments were conducted on conventional diesel engine with biodiesel operation. They reported that biodiesel increased efficiency marginally and decreased particulate emissions and increased oxides of nitrogen.[4–6]. The drawbacks (high viscosity and low volatility) of biodiesel call for LHR engine which provide hot combustion chamber for burning these fuels which got high duration of combustion.

The concept of engine with LHR combustion chamber is to minimize heat loss to the coolant by providing thermal insulation in the path of the coolant thereby increases the thermal efficiency of the engine. Several methods adopted for achieving LHR to the coolant are i) using ceramic coatings on piston, liner and cylinder head (low grade LHR combustion chamber) ii) creating air gap in the piston and other components with low-thermal conductivity materials like superni (an alloy of nickel), cast iron and mild steel etc. (medium grade LHR combustion chamber) and iii) combination of low grade and medium grade LHR combustion chamber resulted in high grade LHR combustion chamber.

Studies were made on medium grade LHR engine with biodiesel with varied injection timing and injection timing. They reported that performance was improved, decreased particulate emissions, increased NO_x levels in comparison with neat diesel operation on CE. [7–11] Experiments were conducted on preheated biodiesel in order to equalize their viscosity to that of mineral diesel may ease the problems of injection process [12–14]. Investigations were carried out on engine with preheated vegetable oils. It was reported that preheated biodiesel marginally increased thermal efficiency, decreased particulate matter emissions and NO_x levels, when compared with normal biodiesel.

The present paper attempted to study exhaust emissions of engine with LHR combustion chamber which contained air gap insulated piston and air gap insulated liner with different operating conditions of linseed biodiesel with varied injection timing and compared with CE with biodiesel operation and also with mineral diesel operation working on similar working conditions.

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2. Material and Method

2.1 Preparation of biodiesel

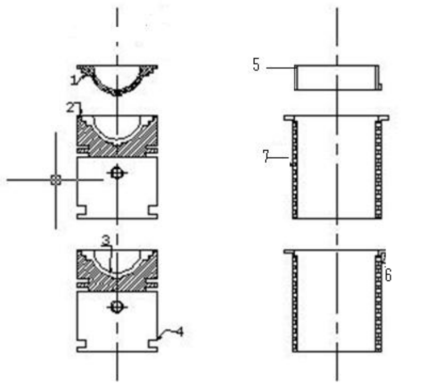
The chemical conversion of esterification reduced viscosity four fold. Linseed oil contains up to 70 % (wt.) free fatty acids. The methyl ester was produced by chemically reacting crude linseed oil with methanol in the presence of a catalyst (KOH). A two–stage process was used for the esterification of the crude linseed oil [5, 15]. 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. Molar ratio of linseed oil to methanol was 9:1 and 0.5% catalyst (w/w). 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 (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.

Table 1: Properties Test Fuels

Test Fuel	Viscosity at 25^{o}C (Centi-Stroke)	Specific gravity at 25^{o}C	Cetane number	Lower Calorific value (kJ/kg)
Diesel	2.5	0.82	51	42000
Biodiesel (BD)	3.7	0.90	55	41000
ASTM Standard	ASTM D 445	ASTM D 4809	ASTM D 613	ASTM D 7314

2.2 Fabrication of LHR engine

The low heat rejection diesel engine contains a two part piston (Fig.1) – the top crown made of low thermal conductivity material, superni was screwed to aluminum body of the piston, providing a 3mm air gap in between the crown and the body of the piston by placing superni gasket in between piston crown and body of the piston. A superni insert was screwed to the top portion of the liner in such a manner that an air gap of 3mm is maintained between the insert and the liner body.



1.Superni crown with threads, 2. Superni gasket, 3. Air gap in piston, 4. Body of the piston, 5. Superni insert with threads 6. Air gap in liner, 7. Body of the liner

Fig.1 Assembly of the air gap insulated piston and air gap insulated liner

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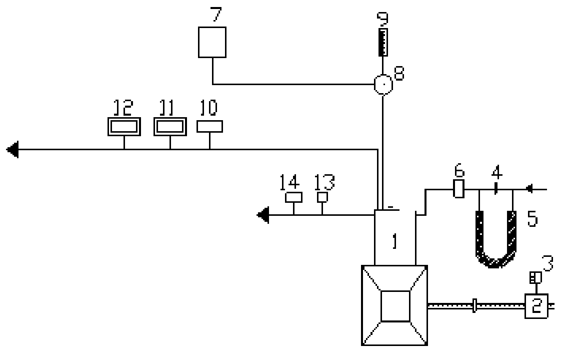
2.3. Experimental Set-up

The test fuel used in the experimentation was neat diesel. The schematic diagram of the experimental setup with diesel operation is shown in Fig. 2. The specifications of the experimental engine are shown in Table-2. Experimental setup used for study of exhaust emissions on low grade LHR diesel engine with linseed biodiesel in Fig.2 The specification of the experimental engine (Part No.1) is shown in Table.2 The engine was connected to an electric dynamometer (Part No.2. Kirloskar make) for measuring its brake power. Dynamometer was loaded by loading rheostat (Part No.3). The combustion chamber consisted of a direct injection type with no special arrangement for swirling motion of air. Burette (Part No.9) method was used for finding fuel consumption of the engine with the help of fuel tank (Part No7) and three way valve (Part No.8). Air-consumption of the engine was measured by air-box method consisting of an orifice meter (Part No.4), U-tube water manometer (Part No.5) and air box (Part No.6) assembly.



1.Engine, 2.Electical Dynamo meter, 3.Load Box, 4.Orifice meter, 5.U-tube water manometer, 6.Air box, 7.Fuel tank, 8, Three way valve, 9.Burette, 10. Exhaust gas temperature indicator, 11.AVL Smoke meter, 12.Netel Chromatograph NOx Analyzer, 13.Outlet jacket water temperature indicator, 14. Outlet-jacket water flow meter,

Fig.2 Experimental Set-up

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
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^{o}bTDC × 190 bar
Dynamometer	Electrical dynamometer
Number of holes of injector and size	Three × 0.25 mm
Type of combustion chamber	Direct injection type

The naturally aspirated engine was provided with water-cooling system in which outlet temperature of water is maintained at 80^{o}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. The naturally aspirated engine was provided with water-cooling system in which outlet temperature of water is maintained at 80^{o}C by adjusting the water flow rate, which was measured by water flow meter (Part No.14). Exhaust gas temperature (EGT) and coolant water outlet temperatures were measured with thermocouples made of iron and iron-constantan attached to the exhaust gas temperature indicator (Part No.10) and

outlet jacket temperature indicator (Part No.13) Copper shims of suitable size were provided 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.
Exhaust emissions of particulate matter and nitrogen oxides (NO_x) were recorded by smoke opacity meter (AVL India, 437) (Part No.11) and NO_x Analyzer (Netel India; 4000 VM) (Part No.12) at full load operation of the engine. Table 3 shows the measurement principle, accuracy and repeatability of raw exhaust gas emission analyzers/ measuring equipment for particulate emissions and NO_x levels. Analyzers were allowed to adjust their zero point before each measurement. To ensure that accuracy of measured values was high, the gas analyzers were calibrated before each measurement using reference gases.

Table 3: Specifications of the Smoke Opacimeter (AVL, India, 437). And NO_x Analyzer (Netel India ;4000 VM))

Pollutant	Measuring Principle	Range	Least Count	Repeatability
Particulate Emissions	Light extinction	1–100 %	0.1% of Full Scale (FS)	0.1% for 30 minutes
NO_x	Chemiluminiscence	1–5000 ppm	0.5 % F.S	≤0.5% F.S

2.4 Operating Conditions:

The different configurations used in the experimentation were conventional engine and engine with LHR combustion chamber. The various operating conditions of the vegetable oil used in the experiment were normal temperature (NT) and preheated temperature (PT–It is the temperature at which viscosity of the vegetable oil is matched to that of diesel fuel, 80^{o}C). Various test fuels used in the experiment were biodiesel and diesel.

3. Results and Discussion

3.1 Fuel Performance

The optimum injection timing was 31^o bTDC with CE, while it was 29^o bTDC for engine with low grade LHR combustion chamber with mineral diesel operation [16].
From Fig.3, it is observed CE with biodiesel at 27^o bTDC showed comparable performance at all loads due to improved combustion with the presence of oxygen, 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. This was due to low calorific value and high viscosity of biodiesel. CE with biodiesel operation increased BTE at all loads with advanced injection timing, when compared with CE with biodiesel operation at 27^o bTDC. This was due to initiation of combustion at early period and increase of resident time of fuel with air leading to increase of peak pressures. CE with biodiesel operation increased peak BTE by 7% at an optimum injection timing of 31^o bTDC, when compared with diesel operation at 27^o bTDC.

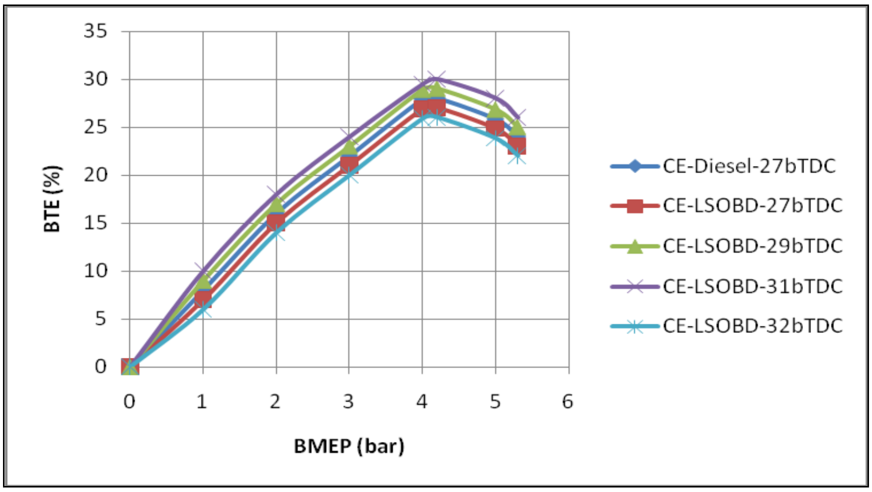


Fig 3 Variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) in conventional engine (CE) and with various injection timings at an injector opening pressure of 190 bar with linseed biodiesel (LSOBD)

Curves in Fig.4 indicate that LHR version of the engine at recommended injection timing showed the improved performance at all loads compared with CE with neat diesel operation. High cylinder temperatures helped in improved evaporation and faster combustion of the fuel injected into the combustion chamber.

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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 29^o 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 earlier with LHR combustion chamber when compared to conventional engine with the biodiesel operation.

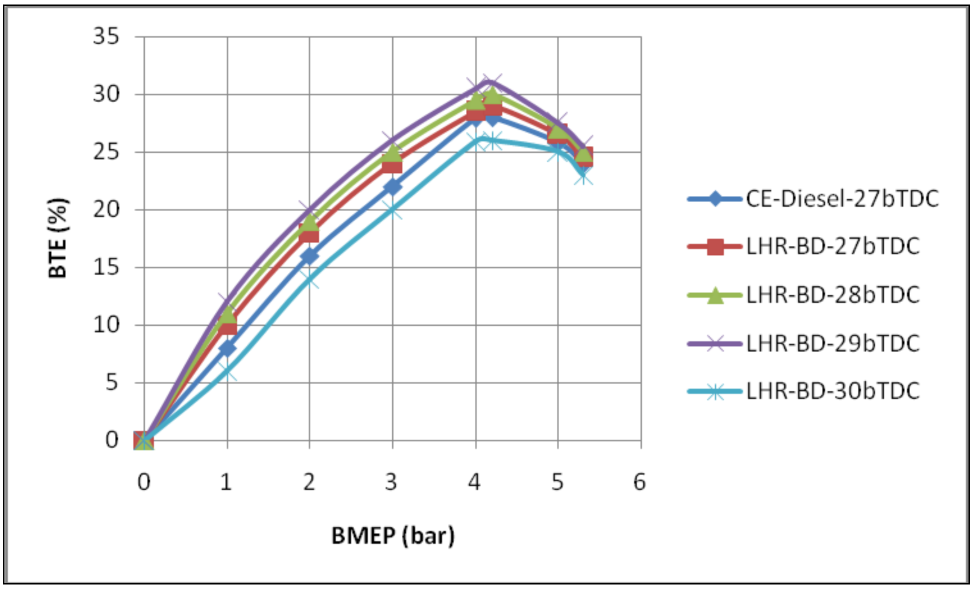

Fig.4 Variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) in LHR combustion chamber at different injection timings with biodiesel (BD) operation.

3.2 Exhaust Emissions

From Fig.5, it is noticed that during the first part, particulate emissions were more or less constant, as there was always excess air present. However, at the higher load range there was an abrupt rise in particulate emissions due to less available oxygen, causing the decrease of air–fuel ratio, leading to incomplete combustion, producing more particulate emissions.

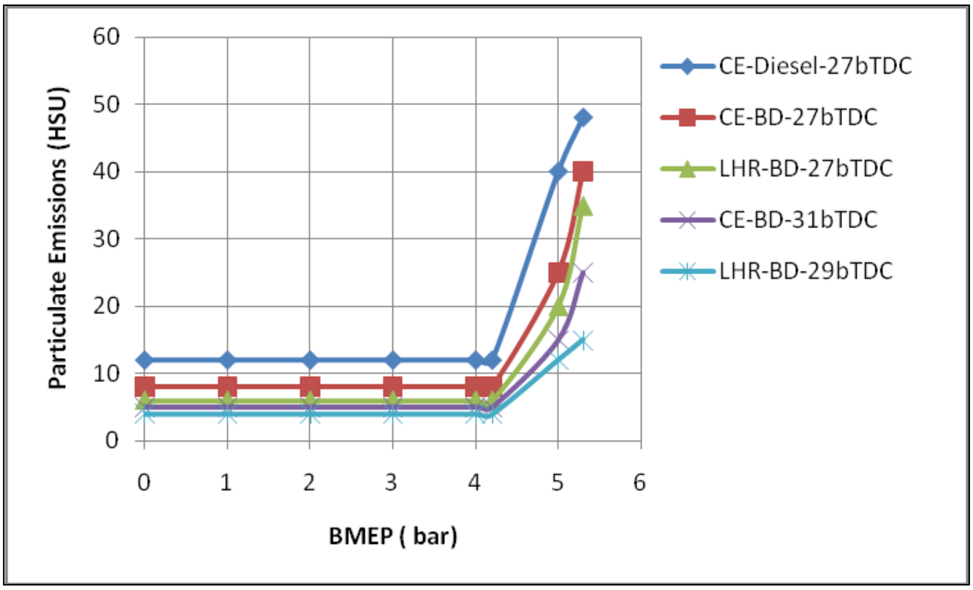

Fig.5 Variation of particulate emissions in Hartridge smoke unit (HSU) with brake mean effective pressure (BMEP) in conventional engine (CE) and engine with LHR combustion chamber at recommended injection timing and optimum injection timing and at an injector opening pressure of 190 bar with biodiesel (BD)

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From Fig.5, it is noticed that particulate emissions at all loads reduced marginally with CE with biodiesel operation in comparison with mineral diesel operation on CE. This was due to improved combustion with improved cetane number and also with presence of oxygen in composition of fuel. Particulate emissions further reduced with engine with LHR combustion chamber when compared with CE. This was due to improved combustion with improved heat release rate. Particulate emissions at full load reduced with advanced injection timing with both versions of the combustion chamber. This was due to increase of resident time and more contact o fuel with air leading to increase atomization.

Fig.6 indicates for both versions of the engine, NOx concentrations raised steadily with increasing BMEP at constant injection timing. At part load, NO_x concentrations were less in both versions of the engine. This was due to the availability of excess oxygen. At remaining loads, NO_x concentrations steadily increased with the load in both versions of the engine. This was because, local NO_x concentrations raised from the residual gas value following the start of combustion, to a peak at the point where the local burned gas equivalence ratio changed from lean to rich. Curves in Fig.6 indicate that NO_x levels at all loads were marginally higher in CE, while they were drastically higher in engine with LHR combustion chamber at different operating conditions of the biodiesel at the full load when compared with diesel operation on CE. This was also due to the presence of oxygen (10%) in the methyl ester, which leads to improvement in oxidation of the nitrogen available during combustion.

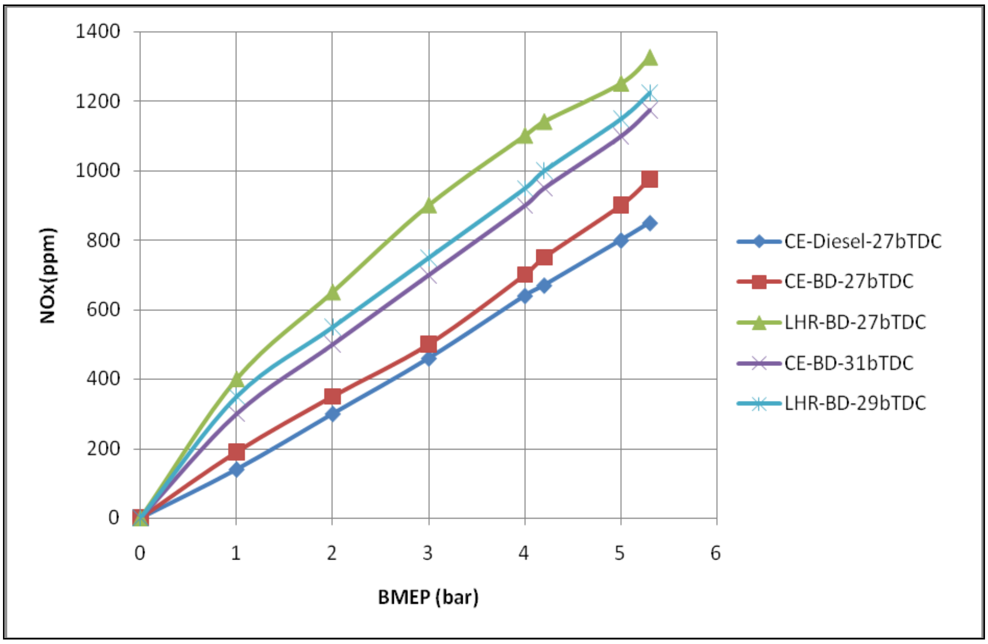

Fig.6 Variation of nitrogen oxide levels with brake mean effective pressure (BMEP) in conventional engine (CE) and engine with LHR combustion chamber at recommended injection timing and optimum injection timing and at an injector opening pressure of 190 bar with linseed biodiesel (BD)

This will raise the combustion bulk temperature responsible for thermal NO_x formation. Increase of combustion temperatures with the faster combustion and improved heat release rates associated with the availability of oxygen in LHR engine caused drastically higher NO_x levels in engine with LHR combustion chamber

From Table.4, it is understood that particulate emissions decreased with preheating with both versions of the combustion chamber. This was because of reduction of density, viscosity of fuel and improved spray characteristics of fuel.

Data in Table.3 shows that, NO_x levels decreased with preheating of biodiesel. As fuel temperature increased, there was an improvement in the ignition quality, which caused shortening of ignition delay. A short ignition delay period lowered the peak combustion temperature which suppressed NO_x formation

Table 4: Data of Particulate Emissions and NO_x levels at full load operation

Injection timing (deg. bTDC)	Combustion chamber	Test Fuel	Particulate Emissions (HSU)	NO_x Emissions (ppm)

	version		NT	PT	NT	PT
27	CE	Diesel	48	___	850	__
	CE	BD	40	35	975	925
	LHR	Diesel	55	__	1250	__
	LHR	BD	35	30	1325	1275
29	LHR	Diesel	40	__	1100	__
	LHR	BD	15	10	1225	1150
31	CE	Diesel	30	__	1100	__
	CE	BD	25	20	1175	1225

4. Summary

Advanced injection timing improved exhaust emissions with biodiesel operation on engine with LHR combustion chamber. Preheated biodiesel reduced particulate emissions and NO_x levels in both versions of the combustion chamber.

Comparison with CE with biodiesel

Engine with low grade LHR combustion chamber with linseed biodiesel decreased particulate emissions at full load operation by 11% at 27^o bTDC and 40% at 29^o bTDC in comparison with CE at 27^o bTDC and 31^o bTDC. It increased nitrogen oxide levels by 36% at 27^o bTDC, and 4% at 29^o bTDC in comparison with CE at 27^o bTDC and 31^o bTDC.

Comparison with mineral diesel operation

Conventional engine with biodiesel operation decreased particulate emissions at full load operation by 17% at 27^o bTDC and 17% at 31^o bTDC in comparison with CE at 27^o bTDC and 31^o bTDC with mineral diesel operation. Engine with LHR combustion chamber with biodiesel decreased particulate emissions at full load operation by 36% at 27^o bTDC and 63% at 29^o bTDC in comparison with same configuration of the combustion chamber with diesel operation at 27^o bTDC and 29^o bTDC.

Conventional engine with biodiesel operation increased nitrogen oxide levels at full load operation by 9% at 27^o bTDC and 7% at 31^o bTDC in comparison with CE at 27^o bTDC and 31^o bTDC with mineral diesel operation. Engine with LHR combustion chamber with biodiesel increased nitrogen oxide levels at full load operation by 6% at 27^o bTDC and 11% at 29^o bTDC in comparison with same configuration of the combustion chamber with diesel operation at 27^o bTDC and 29^o bTDC.

4.1. Research Findings

Exhaust emissions from engine with air gap insulation were studied with varied injection timing at different operating conditions of linseed biodiesel.

4.2 Recommendations

Engine with low grade LHR combustion chamber gave higher levels of NO_x at full load operation, These emissions can be controlled by selective catalytic reduction technique [7].

4.3 Scientific Significance

Change of injection timing was attempted to reduce pollutants from the engine along with change of configuration of combustion chamber with different operating conditions of the biodiesel.

4.4 Social Significance

Use of renewable fuels will strengthen agricultural economy, which curbs crude petroleum imports, saves foreign exchange and provides energy security besides addressing the environmental concerns and socio-economic issues.

4.5 Novelty

Change of injection timing of the engine was accomplished by inserting copper shims between pump body and engine frame

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