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STUDIES ON EXHAUST EMISSIONS OF DI DIESEL ENGINE WITH LOW GRADE LHR COMBUSTION CHAMBER FUELLED WITH LINSEED BIODIESEL

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ABSTRACT

Investigations were carried out to study exhaust emissions of a low grade low heat rejection (LHR) diesel engine with ceramic coated cylinder head [ceramic coating of thickness 500 microns was done on inside portion of cylinder head] with different operating conditions [normal temperature and pre-heated temperature] of linseed biodiesel with varied injector opening pressure and 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. Particulate emissions decreased while NO_x levels increased with engine with LHR combustion chamber with biodiesel in comparison with CE.

KEYWORDS: Biodiesel, Crude Vegetable Oil, Exhaust Emissions, LHR Combustion Chamber

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 and 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 and it was 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. Investigations were carried out on engine with low grade LHR combustion chamber with neat diesel operation and it was reported that ceramic coatings provided adequate insulation and improved brake specific fuel consumption (BSFC). [7–8].

Studies were made on ceramic coated diesel engines with biodiesel and reported that performance was comparable, particulate emissions decreased while NO_x levels increased in comparison with neat diesel operation on CE. [9–11] However, comparative studies were not made with mineral diesel operation working on similar conditions.

The present paper attempted to study exhaust emissions of engine with LHR combustion chamber which contained ceramic coated cylinder head fuelled with different operating conditions of linseed biodiesel with varied injector opening pressure and injection timing and compared with CE with biodiesel operation and also with mineral diesel operation working on similar working conditions.

MATERIAL AND METHOD

Preparation of Biodiesel

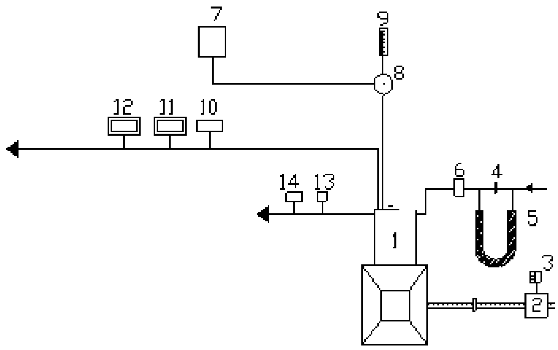
The chemical conversion of esterification reduced viscosity four fold. Linseed oil contains up to 70 % (wt.) free fatty acids. The methyl ester was produced by chemically reacting crude linseed oil with methanol in the presence of a catalyst (KOH). A two–stage process was used for the esterification of the crude linseed oil [12]. 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°C (Centi-Stroke)	Specific Gravity at 25°C	Cetane Number	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

Experimental Set-Up

Partially stabilized zirconium (PSZ) of thickness 500 microns was coated on inside portion of cylinder head. Experimental setup used for study of exhaust emissions on low grade LHR diesel engine with linseed biodiesel in Figure 1 The specification of the experimental engine is shown in Table 2 The engine was connected to an electric dynamometer (Kirloskar make) for measuring its brake power. Dynamometer was loaded by loading rheostat. The naturally aspirated engine was provided with water-cooling system in which outlet temperature of water is maintained at 80°C by adjusting the water flow rate. Injector opening pressure was changed from 190 bar to 270 bar using nozzle testing device. The maximum injector opening pressure was restricted to 270 bar due to practical difficulties involved. Injection timing was changed by inserting copper shims between pump body and engine frame. Exhaust emissions of particulate matter and nitrogen oxides (NO_x) were recorded by smoke opacity meter (AVL India, 437) and NO_x Analyzer (Netel India; 4000 VM) at various values of BMEP of the engine.



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,

Figure 1: 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

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). The injection pressures were varied from 190 bar to 270 bar. Various test fuels used in the experiment were biodiesel and diesel.

RESULTS AND DISCUSSIONS

Fuel Performance

The optimum injection timing was 31^{o} bTDC with CE, while it was 30^{o} bTDC for engine with low grade LHR combustion chamber with mineral diesel operation [9, 10].

From Figure 2, 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° 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° bTDC, when compared with diesel operation at 27° bTDC.

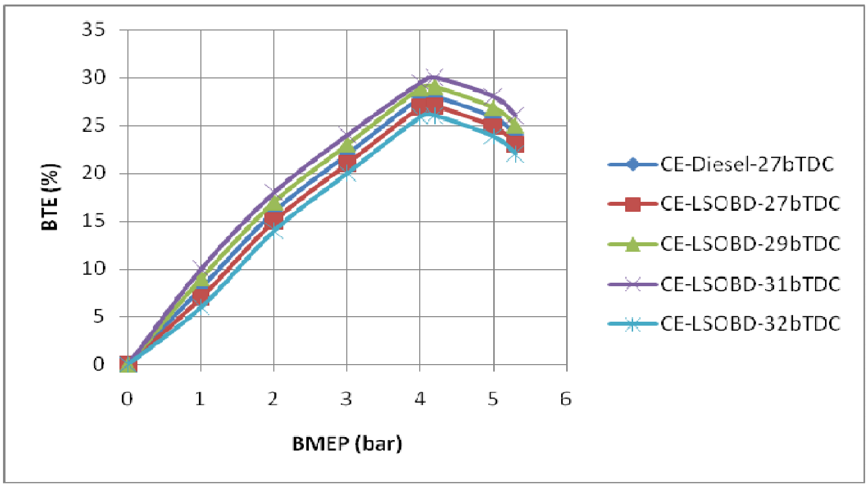


Figure 2: Variation of Brake Thermal Efficiency (BTE) with Brake Mean Effective Pressure (BMEP) in Conventional Engine (CE) and with Various Injection Timings at an Injector Opening Pressure of 190 Bar with Biodiesel

Curves in Figure 3 indicate 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 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 earlier with LHR combustion chamber when compared to conventional engine with the biodiesel operation.

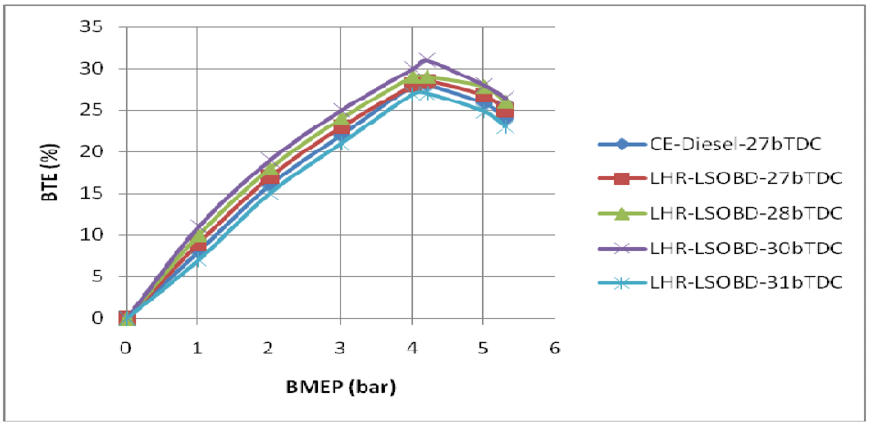


Figure 3: Variation of Brake Thermal Efficiency (BTE) With Brake Mean Effective Pressure (BMEP) in LHR Combustion Chamber at Different Injection Timings with Biodiesel (LSOBD) Operation

3.2 Exhaust Emissions

From Figure 4, 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.

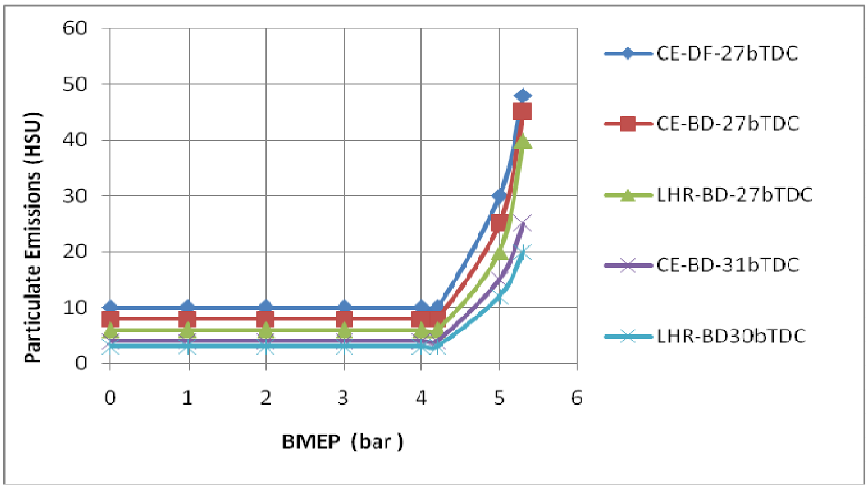


Figure 4: Variation of Particulate Emissions in Hartridge Smoke Unit (HSU) with Brake Mean Effective Pressure (BMEP) in Conventional Engine (CE) and Engine with LHR Combustion Chamber at Recommended Injection Timing and Optimum Injection Timing and at an Injector Opening Pressure of 190 Bar with Biodiesel (BD)

From Figure 4, 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.

Figure 5 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 Figure 5 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. 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

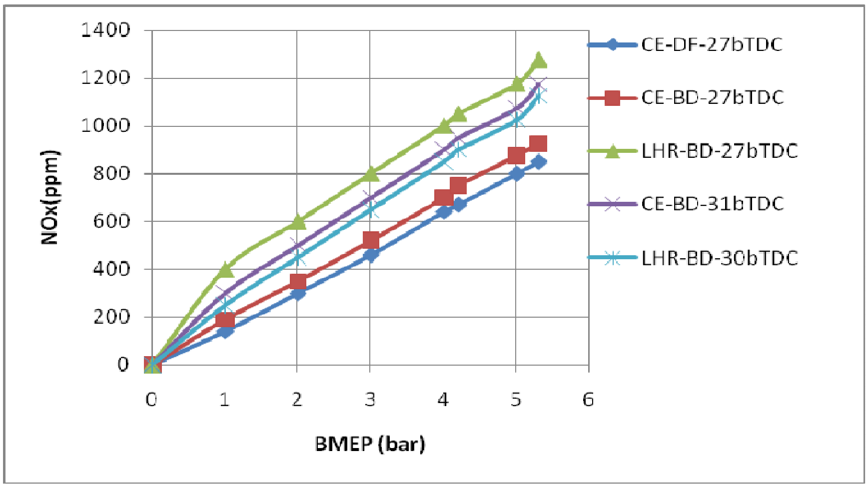


Figure 5: Variation of Nitrogen Oxide Levels with Brake Mean Effective Pressure (BMEP) in Conventional Engine (CE) and Engine with LHR Combustion Chamber at Recommended Injection Timing and Optimum Injection Timing and at an Injector Opening Pressure of 190 Bar With Biodiesel (BD)

From Table 3, 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. From same Table, it is noticed that, particulate emissions decreased with increase of injector opening pressure in both versions of the engine with test fuels. This was due to improved air fuel ratios with improved spray characteristics of the test fuels.

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. NO_x levels increased with an increase of injector opening pressure with different operating conditions of biodiesel with CE. Fuel droplets penetrate and find oxygen counterpart easily with the increase of injector opening pressure. Turbulence of the fuel spray increased the spread of the droplets which caused increase of gas temperatures marginally thus leading to increase in NO_x levels with CE. Marginal decrease of NO_x levels was observed in engine with LHR combustion chamber, due to decrease of combustion temperatures with improved air fuel ratios.

Table 3: Data of Exhaust Emissions with Biodiesel Operation

Injection Timing (Deg. BTDC)	Combustion Chamber Version	Test Fuel	Exhaust Emissions at Full Load Operation							
			Particulate Emissions (HSU)				No_x Levels (ppm)			
			Injector Opening Pressure (bar)				Injector Opening Pressure (bar)			
			190		270		190		270	
			NT	PT	NT	PT	NT	PT	NT	PT
27	CE	Diesel	48	—	34	—	850	—	950	—
	CE	BD	45	40	35	30	925	875	1025	975
	LHR	Diesel	50	—	40	—	1200	—	1100	—
	LHR	BD	40	35	30	25	1275	1225	1175	1125
30	LHR	Diesel	35	—	25	—	1050	—	950	—
	LHR	BD	20	15	15	10	1125	1075	1025	975
31	CE	Diesel	30	—	35	—	1100	—	1200	—
	CE	BD	25	20	35	30	1175	1225	1275	1225

SUMMARY

Advanced injection timing and increase of injector opening pressure 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 20% at 30^o bTDC in comparison with CE at 27^o bTDC and 31^o bTDC. It increased nitrogen oxide levels by 38% at 27^o bTDC, while decreasing them by 4% at 30^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 6% 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 20% at 27^o bTDC and 33% at 30^o bTDC in comparison with same configuration of the combustion chamber with diesel operation at 27^o bTDC and 30^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 7% at 30^o bTDC in comparison with same configuration of the combustion chamber with diesel operation at 27^o bTDC and 30^o bTDC.

Research Findings

Exhaust emissions from engine with ceramic coated combustion chamber were studied with varied injector opening pressure and injection timing at different operating conditions of linseed biodiesel.

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 [13].

Scientific Significance

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

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.

Novelty

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

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