Comparative Performance of Ceramic Coated Diesel Engine with Mohr Oil in Crude and Biodiesel Form

T. Ratna Reddy, M.V.S. Murali Krishna, Ch. Kesava Reddy, P.V.K.Murthy

Abstract*— Investigations were carried out to evaluate the performance of a low grade low heat rejection (LHR) diesel engine with ceramic coated cylinder head with 3-mm air gap with different operating conditions [normal temperature and pre-heated temperature] of crude mohr oil (CMO) and mohr oil based biodiesel (MOBD) with varied injection pressure and injection timing. Performance parameters of brake thermal efficiency, exhaust gas temperature, volumetric efficiency and sound intensity were determined at various values of brake mean effective pressure (BMEP).Exhaust emissions of smoke and oxides of nitrogen (NOx) were recorded at the various values of BMEP. Combustion characteristics at peak load operation of the engine were measured with TDC (top dead centre) encoder, pressure transducer, console and special pressure-crank angle software package. Conventional engine (CE) showed compatible performance, while LHR engine showed marginally increased performance with vegetable oils (CMO & MOBD) operation at recommended injection timing and pressure. The performance of both version of the engine improved with advanced injection timing and at higher injection pressure when compared with CE with pure diesel operation.

***Keywords*—Crude Mohr oil, Bio-diesel, CE, LHR engine, Fuel Performance, Exhaust Emissions, Combustion Characteristics.**

I. INTRODUCTION

The search for alternate fuels has become pertinent, as fossil fuels are depleting, the pollution levels with fossil fuels are increasing and also there is increase of burden on economy sector of Govt. of India. Vegetable oils and alcohols are promising substitutes of fossil diesel fuels as they are renewable in nature. Alcohols have low cetane number and engine modification is necessary for use in diesel engines. That too, most of the alcohols produced are diverted for Petro-chemical industries in India. On the other hand, the properties of the vegetable oils are similar to those of diesel fuel and they can be easily produced. Rudolph diesel, the inventor of the engine that bears his name, experimented with fuels ranging from powdered coal to peanut oil.

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Several researchers [1-5] 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. Not only that, the common problems of crude vegetable oils in diesel engines are formation of carbon deposits, oil ring sticking, thickening and gelling of lubricating oil as a result of contamination by the vegetable oils. These problems can be solved, if neat vegetable oils were chemically modified to bio-diesel [6]. These biodiesels have low viscosity and low molecular weight compared to crude vegetable oil. Investigations were carried out [7-11] on biodiesel in CE and reported compatible performance with biodiesel in comparison with pure diesel operation on CE. The drawbacks of crude vegetable oil and biodiesel call for LHR engine.

The concept of LHR engine is to minimize heat loss to the coolant by providing thermal insulation in the path of the heat flow to the coolant. LHR engines were classified depending on degree of insulation as low grade LHR engines, medium grade LHR engines and high grade LHR engines. Low grade LHR engines consisted of thermal coatings on piston, liner and cylinder head with low thermal conductivity materials, medium grade LHR engines provide an air gap in the piston and other engine components with superni (an alloy of nickel), cast iron and mild steel etc., while high grade LHR engine was the combination of low and medium grade LHR engines.

Ceramic coatings provided adequate insulation, improved brake specific fuel consumption (BSFC) as reported by various researchers. However previous studies [12-14] with pure diesel in LHR engine with ceramic coated components revealed that the thermal efficiency variation of LHR engine not only depended on the heat recovery system, but also depended on the engine configuration, operating condition and physical properties of the insulation material. Crude vegetable oil was used [15] in LHR engine with ceramic coated cylinder head and reported that marginal improvement in thermal efficiency and it increased with advanced injection timing and with increase of injection pressure. Biodiesel was used [16-18] as fuel in LHR engine with ceramic coating on engine components and reported that biodiesel operation increased the performance marginally and decreased smoke levels increased NOx levels. . The present paper attempted to evaluate the performance of LHR engine, which contained ceramic coated cylinder head with different operating conditions of MOBD with varying engine parameters of change of injection pressure and timing and compared with pure diesel with CE at recommended injection timing and injection pressure.

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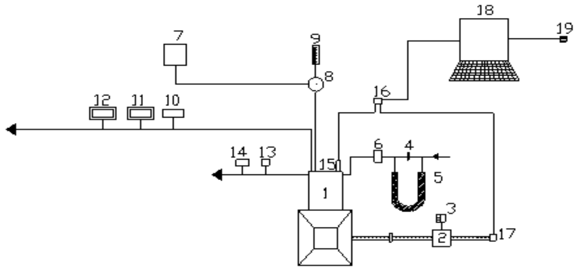
II. METHODOLOGY

The properties of test fuels were presented in Table I along with diesel fuel.

Table I Properties of test fuels

Test Fuel	Viscosity at 25°C (Centi-poise)	Density at 25°C	Cetane number	Calorific value (kJ/kg)
Diesel	12.5	0.84	55	42000
Crude mohr oil (CMO)	120	0.91	45	38000
Biodiesel (MOBD)	53	0.87	55	37500

Partially stabilized zirconium (PSZ) of thickness 500 microns was coated on inside portion of cylinder head. Experimental setup used for the investigations of LHR diesel engine with MOBD is shown in Fig.1



1.Engine, 2.Electical Dynamo meter, 3.Load Box, 4.Orifice 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 meter, 12.Netel Chromatograph NOx Analyzer, 13.Outlet jacket water temperature indicator, 14. Outlet-jacket water flow meter, 15.Piezo-electric pressure transducer, 16.Console, 17.TDC encoder, 18.Pentium Personal Computer and 19. Printer.

Fig. 1 Experimental Set-up

CE had an aluminum alloy piston with a bore of 80-mm and a stroke of 110-mm. The rated output of the engine was 3.68 kW at a speed of 1500 rpm. The compression ratio was 16:1 and manufacturer's recommended injection timing and injection pressures were 27°bTDC and 190 bar respectively. The fuel injector had 3-holes of size 0.25-mm. The combustion chamber consisted of a direct injection type with no special arrangement for swirling motion of air. The engine was connected to 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 air-box method. The naturally aspirated engine was provided with water-cooling system in which inlet temperature of water was maintained at 60°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 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 injection pressures from 190 bar to 270 bar (in steps of 40 bar) using nozzle testing device. The maximum injection pressure was restricted to 270 bar due to practical difficulties involved. Exhaust gas temperature (EGT) was measured with thermocouples made of iron and iron-Constantan. Emission levels of smoke and NO_x were recorded by AVL smoke meter and Netel Chromatograph NOx analyzer respectively at various values of BMEP. Sound intensity was measured with Sound analyzer at different values of BMEP. Piezo electric transducer, fitted on the cylinder head to measure pressure in the combustion chamber was connected to a console, which in turn was connected to Pentium personal computer. TDC encoder provided at the extended shaft of the dynamometer was connected to the console to measure the crank angle of the engine. A special P-θ software package evaluated the combustion characteristics such as peak pressure (PP), time of occurrence of peak pressure (TOPP), maximum rate of pressure rise (MRPR) and time of occurrence of maximum rate of pressure rise (TOMRPR) from the signals of pressure and crank angle at the peak load operation of the engine. Pressure-crank angle diagram was obtained on the screen of the personal computer. The accuracy of the instrumentation used was 0.1%. The test fuels used in the experimentation were CMO and MOBD at different operating conditions. The configurations in the experimentation were CE and LHR engine.

III. RESULTS AND DISCUSSION

A. Performance Parameters

From Fig. 2, it indicates that biodiesel in CE showed compatible performance for the for entire load range when compared with the pure diesel operation on CE at recommended injection timing. This was due to low calorific value of biodiesel and difference of viscosity between diesel and biodiesel caused compatible performance with CE. BTE increased up to 80% of the full load and later it decreased in CE with biodiesel operation. This was due to increase of fuel conversion efficiency up to 80% of the full load and increase of friction power beyond 80% of the load. As the injection timing was advanced with CE with biodiesel, BTE increased at all loads. This was due to initiation of combustion at earlier period and efficient combustion with increase of air entrainment in fuel spray giving higher BTE. BTE increased at all loads when the injection timing was advanced to 31°bTDC in the CE at the normal temperature of biodiesel. The increase of BTE at optimum injection timing over the recommended injection timing with biodiesel with CE was attributed to its longer ignition delay and combustion duration.

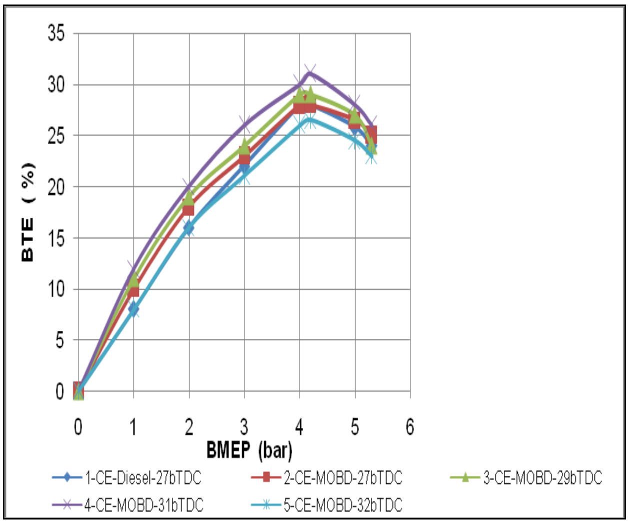


Fig.2. Variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) in conventional engine (CE) at different injection timings with mohr oil based bio diesel (MOBD) oil operation

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Curves from Fig. 3 indicate that CE operated with crude mohr oil (CMO) showed deteriorated performance for the for entire load range when compared with the pure diesel operation on CE at recommended injection timing.

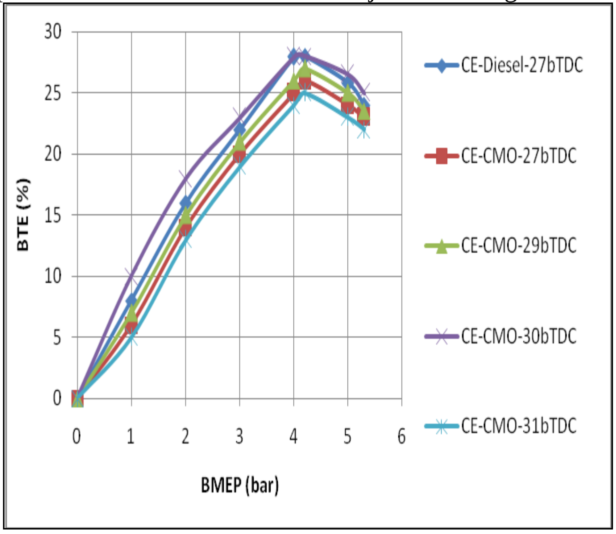

Fig.3. Variation of BTE with BMEP in CE at different injection timings with crude mohr oil (CMO) operation

Although carbon accumulations on the nozzle tip might play a partial role for the general trends observed, the difference of viscosity between the diesel and crude vegetable oil provided a possible explanation for the deteriorated performance with crude vegetable oil operation. BTE increased with the advancing of the injection timing with CE with crude vegetable oil at all loads, when compared with CE at the recommended injection timing and pressure. Crude vegetable oil has loner duration of combustion and longer ignition delay. Hence advancing of injection timing helped the initiation of combustion, when the piston was at TDC. BTE increased at all loads when the injection timing was advanced to 30°bTDC in the CE at the normal temperature of CMO. The optimum injection timing (30°bTDC) with CE with crude vegetable oil was less than that of biodiesel (31°bTDC). Higher cetane number of the fuel permitted higher value of advanced injection timing.

Curves from Fig. 4 indicate that LHR version of the engine showed improvement in the performance for entire load range compared with CE with pure diesel operation.

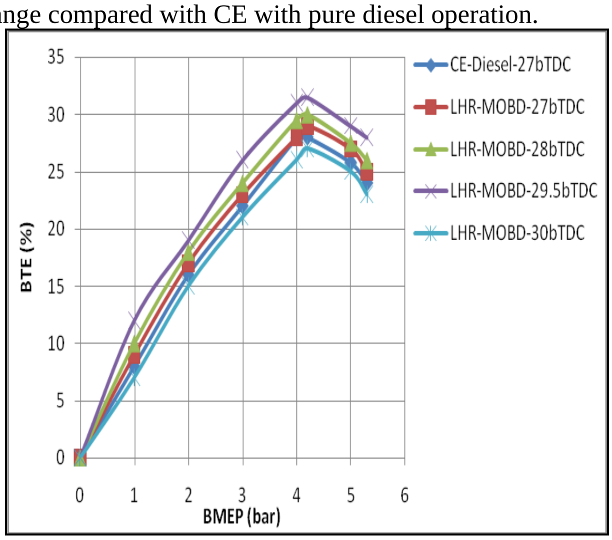

Fig. 4 Variation of BTE with BMEP in LHR engine at different injection timings with mohr oil based biodiesel (MOBD) operation.

High cylinder temperatures helped in better evaporation and faster combustion of the fuel injected into the combustion chamber. Reduction of ignition delay of the MOBD oil in the hot environment of the LHR engine improved heat release rates and efficient energy utilization. Preheating of MOBD improved performance further in LHR version of the engine. The optimum injection timing was found to be 29.5°bTDC with LHR engine with normal MOBD. Since the hot combustion chamber of LHR engine reduced ignition delay and combustion duration and hence the optimum injection timing was obtained earlier with LHR engine when compared with CE with the MOBD operation.

From Fig.5, it is noticed that LHR engine showed compatible performance wth crude mohr oil (CMO) at all loads when compared with CE with pure diesel operation. This was due to reduction of ignition delay of the vegetable oil in hot environment provided by LHR engine. When the injection timing was advanced to 28.5bTDC, the performance of LHR engine was further improved at all loads. This was because of initiation of combustion at the early stage. Hence the optimum ignition timing was found to be 28.5 b TDC with LHR engine with CMO operation.

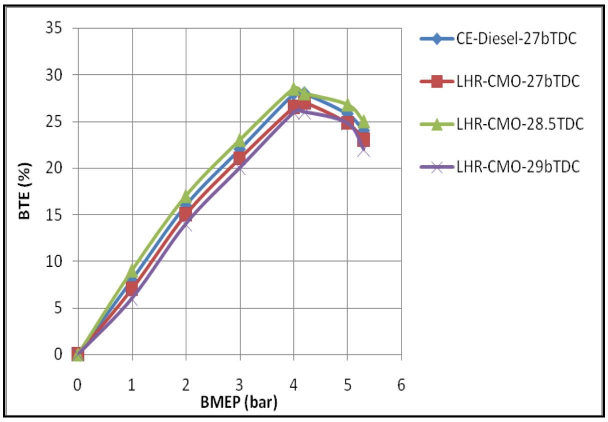

Fig.5 Variation of BTE with BMEP in LHR engine at different injection timings with crude mohr oil (CMO) operation.

Injection pressure was varied from 190 bars to 270 bars to improve the spray characteristics and atomization of the MOBD and injection timing was advanced from 27 to 34°bTDC for CE and LHR engine. From Table II, it was evident that BTE increased with increase in injection pressure in both versions of the engine at different operating conditions of the vegetable oils (CMO & MOBD). The improvement in BTE at higher injection pressure was due to improved fuel spray characteristics. However, the optimum injection timing was not varied even at higher injection pressure with LHR engine, unlike the CE. Hence it was concluded that the optimum injection timing was 31°bTDC at 190 bar, 30°bTDC at 230 bar and 29°bTDC at 270 bar for CE with biodiesel operation. The optimum injection timing was 30°bTDC at 190 bar, 29.5°bTDC at 230 bar and 28.5°bTDC at 270 bar for CE with crude vegetable oil (CMO) operation. The optimum injection timing for LHR engine was 28.5°bTDC irrespective of injection pressure. Peak BTE was higher in LHR engine when compared with CE with different operating conditions of the MOBD. Biodiesel showed marginally improved performance when compared with crude vegetable oil in both versions of the engine at different operating conditions of the vegetable oils.

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This is due to improved combustion with improved cetane rating of the biodiesel.

Table II Data of Peak BTE

Injection Timing (° bTDC)	Test Fuel	Peak BTE (%)											
		Conventional Engine (CE) Injection Pressure (Bar)						LHR Engine Injection Pressure (Bar)					
		190		230		270		190		230		270	
		NT	PT	NT	PT	NT	PT	NT	PT	NT	PT	NT	PT
27	DF	28	--	29	---	30	--	29	--	30	--	30.5	--
	CMO	26	27	27	28	28	29	27	28	28	29	29	30
	MOBD	28	29	29	30	30	31	29	30	30	31	31	32
28.5	CMO	26.5	27.5	27.5	28.5	28.5	29.5	28	29	29	30	30	31
	MOBD	28.5	29.5	29.5	30.5	30.5	31.5	29	30	30	31	31	32
29.5	CMO	27	28	28	29	27	28	--	--	--	--	--	-
	MOBD	29	30	30	31	31	32	31.5	32	32	32.5	32.5	33
30	CMO	28	29	27	28	26	27	-	--	--	--	-	-
	MOBD	30	31	31	32	30.5	31	27	28	27.5	28	27.6	28
31	CMO	27	28	26	27	25	26	--	--	--	--	--	--
	MOBD	31	32	30.5	31.5	30	31	27					

DF-Diesel Fuel, MOBD- Mohr oil based bio-diesel NT- Normal or Room Temperature , PT- Preheat Temperature

From Table III it is evident that BSEC at peak load reduced with the increase of injection pressure and with the advancing of the injection timing at different operating conditions of the vegetable oils (CMO & MOBD). This was due to initiation of combustion and with improved spray characteristics. Preheating of the vegetable oils improved the performance in both versions of the engine compared to the vegetable oils at normal temperature. Preheating reduced the viscosity of the bio-diesel, which reduced the impingement of the fuel spray on combustion chamber walls, causing efficient combustion thus improving BSEC. Biodiesel showed marginally lower BSEC at peak load in comparison with CMO at different operating conditions with different versions of the engine. Esterification reduced the viscosity and increased the cetane number with which combustion was improved and caused release of efficient energy.

Table 3. Data of BSEC at Peak Load Operation

Injection Timing (°bTDC)	Test Fuel	BSEC (kW/ kW)											
		CE Injection Pressure (Bars)						LHR Engine Injection Pressure (Bars)					
		190		230		270		190		230		270	
		NT	PT	NT	PT	NT	PT	NT	PT	NT	PT	NT	PT
27	DF	4.00	--	3.92	--	3.84	--	4.16	---	4.08	--	4.00	--
	CMO	4.62	4.2	4.2	3.98	3.98	3.94	4.00	3.96	3.96	3.92	3.92	3.88
	MOBD	3.96	3.92	3.92	3.88	3.88	3.84	3.84	3.80	3.80	3.76	3.76	3.72
28.5	CMO	4.58	4.54	4.54	4.50	4.50	4.46	3.98	3.94	3.94	3.90	3.90	3.86
	MOBD	3.92	3.88	3.88	3.84	3.84	3.80	3.80	3.76	3.76	3.72	3.72	3.68
29.5	CMO	4.4	4.0	4.0	3.96	3.96	3.92	4.00	3.96	3.96	3.92	3.92	3.88
	MOBD	3.88	3.84	3.84	3.80	3.80	3.76	3.78	3.74	3.74	3.70	3.70	3.66
30	CMO	4.0	3.96	4.2	3.98	3.98	3.94	4.0	3.96	3.96	3.92	3.92	3.88
	MOBD	3.84	3.80	3.80	3.76	3.82	3.78	--	--	--	--	--	--
31	CMO	4.2	3.98	4.0	3.96	4.2	3.98	--	--	--	--	--	--
	MOBD	3.80	3.76	3.82	3.78	3.84	3.80	---	---	--	---	--	--

Figure 6 indicates that CE with MOBD at the recommended injection timing recorded higher EGT at all loads compared with CE with pure diesel operation.

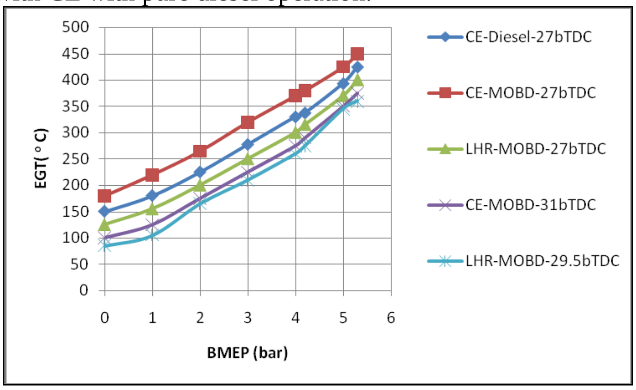

Fig.6 Variation of exhaust gas temperature (EGT) with BMEP in CE and LHR engine at recommend injection timing and optimized injection timings with MOBD operation.

Lower heat release rates and retarded heat release associated with high specific energy consumption caused increase in EGT in CE. Ignition delay in the CE with different operating conditions of MOBD increased the duration of the burning phase. LHR engine recorded lower value of EGT when compared with CE with MOBD operation. This was due to reduction of ignition delay in the hot environment with the provision of the insulation in the LHR engine, which caused the gases expanded in the cylinder giving higher work output and lower heat rejection. This showed that the performance improved with LHR engine over CE with MOBD operation. The magnitude of EGT at peak load decreased with advancing of injection timing and with increase of injection pressure in both versions of the engine with MOBD. Preheating of MOBD further reduced the magnitude of EGT, compared with normal MOBD in both versions of the engine.

From the Table IV, it is evident that EGT decreased with increase in injection pressure and injection timing with both versions of the engine, which confirmed that performance increased with increase of injection pressure. Preheating of MOBD decreased EGT in both versions of the engine.

Table IV Data of EGT at peak load operation

Injection timing (° b TDC)	Test Fuel	EGT at the peak load (°C)											
		CE Injection Pressure (Bar)						LHR Engine Injection Pressure (Bar)					
		190		230		270		190		230		270	
		NT	PT	NT	PT	NT	PT	NT	PT	NT	PT	NT	PT
27	DF	425	--	410	---	395	--	460	---	450	--	440	--
	CMO	500	470	470	440	440	410	475	450	450	425	425	400
	MOBD	450	425	425	400	400	375	420	400	400	380	380	360
28.5	CMO	480	450	450	420	420	390	460	440	440	420	420	410
	MOBD	435	410	410	390	390	375	390	370	370	350	350	330
29.5	CMO	460	430	430	400	400	370	480	460	460	440	440	420
	MOBD	425	400	400	375	375	350	360	340	340	320	320	300
30	CMO	430	400	400	370	370	400	--	--	--	--	--	-
	MOBD	400	375	375	350	400	375	--	--	--	--	--	-
31	CMO	450	430	440	410	450	430	--	--	--	--	--	-
	MOBD	375	350	400	375	425	400	-	-	-	-	-	-

EGT was lower with biodiesel in both versions of the engine when compared to CMO operation. This was due to improvement of cetane number of the vegetable oil with the esterification, which leads to improved combustion and reduced EGT.

Curves from Fig. 7 indicate that that coolant load (CL) increased with BMEP in both versions of the engine with test fuels. However, CL reduced with LHR version of the engine with biodiesel operation when compared with CE with pure diesel operation. Heat output was properly utilized and hence efficiency increased and heat loss to coolant decreased with effective thermal insulation with LHR engine. However, CL increased with CE with bio-diesel operation in comparison with pure diesel operation on CE.

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This was due to concentration of fuel at the walls of combustion chamber. CL decreased with advanced injection timing with both versions of the engine with test fuels. This was due to improved air fuel ratios.

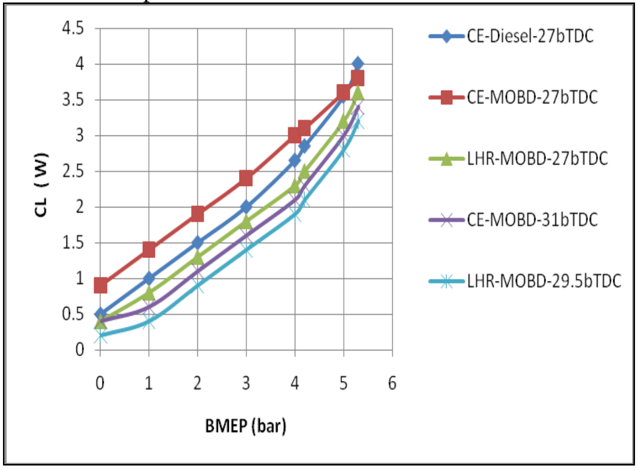

Fig.7 Variation of Coolant load (CL) with BMEP in both versions of the engine at recommended and optimized injection timings with mohr oil based bio-diesel (MOBD) operation at an injection pressure of 190 bar.

From Table V, it is noticed that CL decreased with advanced injection timing and with increase of injection pressure. This was because of improved combustion and proper utilization of heat energy with reduction of gas temperatures. CL decreased with preheated vegetable oils (CMO& MOBD in comparison with normal vegetable oils l in both versions of the engine. This was because of improved spray characteristics.

Biodiesel showed marginally lower CL in comparison with crude vegetable oil in both versions of the engine at different operating conditions. This was due to reduction of fuel deposits and fuel concentration at combustion chamber walls with biodiesel operation.

Table V Data of CL at peak load operation

Injection timing (°bTDC)	Test Fuel	Coolant Load (kW)											
		CE						LHR Engine					
		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	DF	4.0	---	3.8	--	3.6	---	4.5	---	4.3	--	4.1	---
	CMO	4.4	4.2	4.0	3.8	3.8	3.6	3.8	3.6	3.6	3.4	3.4	3.2
	MOBD	3.8	3.6	3.6	3.4	3.4	3.2	3.6	3.4	3.4	3.2	3.2	3.0
28.5	CMO	4.3	4.1	3.9	3.7	3.7	3.5	3.6	3.4	3.4	3.2	3.2	3.0
	MOBD	3.7	3.5	3.5	3.3	3.3	3.1	3.4	3.2	3.2	3.0	3.0	2.8
29.5	CMO	4.2	4.0	3.7	3.5	3.9	3.7	3.8	3.6	3.6	3.4	3.4	3.2
	MOBD	3.6	3.4	3.4	3.2	3.4	3.2	3.2	3.0	3.0	2.8	2.8	2.6
30	CMO	3.7	3.5	3.9	3.7	4.1	3.9	--	--	--	----	--	--
	MOBD	3.5	3.2	3.4	3.2	3.4	3.2	--	--	--	--	--	--
31	CMO	4.1	3.9	4.0	3.8	3.9	3.7						
	MOBD	3.4	3.2	3.4	3.2	3.6	3.4						

From Fig.8, it is noticed that volumetric efficiency (VE) decreased with an increase of BMEP in both versions of the engine. This was due to increase of gas temperature with the load. At the recommended injection timing, VE in the both versions of the engine with MOBD operation decreased at all loads when compared with CE with pure diesel operation. 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 with LHR engine. VE increased marginally in CE and LHR engine at optimized injection timings when compared with recommended injection timings with MOBD. This was due to decrease of un-burnt fuel fraction in the cylinder leading to increase in VE in CE and reduction of gas temperatures with LHR engine.

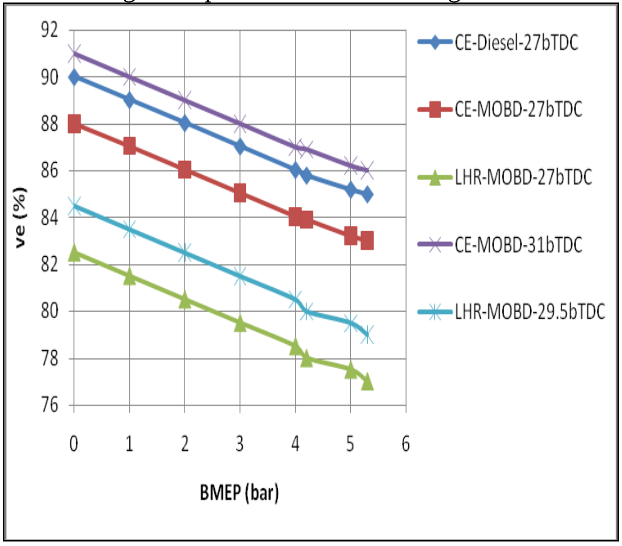

Fig.8 Variation of volumetric efficiency (VE) with BMEP in CE and LHR engine at recommend injection timing and optimized injection timings with mohr oil based bio-diesel (MOBD) operation.

From the Table VI, it could be observed that VE increased marginally with the advancing of the injection timing and with the increase of injection pressure in both versions of the engine. This was due to better fuel spray characteristics and evaporation at higher injection pressures leading to marginal increase of VE. This was also due to the reduction of residual fraction of the fuel, with the increase of injection pressure.Table-4 showed the variation of VE with injection pressure and injection timing at different operating conditions of vegetable oils (CMO & MOBD) with different configurations of the engine. Preheating of the vegetable oils marginally improved VE in both versions of the engine, because of reduction of un-burnt fuel concentration with efficient combustion, when compared with the normal temperature of vegetable oils. Biodiesel showed marginally higher VE than CMO operation on both versions of the engine at different operating conditions of the vegetable oils. This was because of improved combustion with cetane rating of the biodiesel.

Table VI Data of Volumetric Efficiency at peak load operation

Injection timing (°bTDC)	Test Fuel	Volumetric efficiency (%)											
		CE						LHR Engine					
		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	DF	85	--	86	--	87	--	78	--	80	--	82	--
	CMO	81	82	82	83	83	84	76	77	77	78	78	79
	MOBD	83	84	84	85	85	86	77	78	78	79	79	80
28.5	CMO	81.5	82.5	82.5	83.5	83.5	84.5	77	78	78	79	79	80
	MOBD	83.5	84.5	84.5	85.5	85.5	86.5	78	79	79	80	80	81
29.5	CMO	82	83	83	84	82	81	76	77	77	78	78	79
	MOBD	84	85	85	86	86	87	79	80	80	81	81	82
30	CMO	83	84	82	83	81	82	--	--	--	--	--	--
	MOBD	85	86	86	87	85	86	--	--	--	--	--	--
31	CMO	82	83	81	82	80	81	--	--	--	--	--	--
	MOBD	86	87	85	86	84	85	--	--	--	--	--	--

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B. Exhaust Emissions

Fig.9 indicates that the value of smoke intensity increased from no load to full load in both versions of the engine. During the first part, the smoke level was more or less constant, as there was always excess air present. However, in the higher load range there was an abrupt rise in smoke levels due to less available oxygen, causing the decrease of air-fuel ratio, leading to incomplete combustion, producing more soot density. The variation of smoke levels with BMEP typically showed a U-shaped behavior due to the pre-dominance of hydrocarbons in their composition at light load and of carbon at high load. Drastic increase of smoke levels was observed at the peak load operation in CE at different operating conditions of the MOBD, compared with pure diesel operation on CE. This was due to the higher magnitude of the ratio of C/H of biodiesel (0.7) when compared with pure diesel (0.45). The increase of smoke levels was also due to decrease of air-fuel ratios and VE with MOBD compared with pure diesel operation. Smoke levels were related to the density of the bio-diesel. Since MOBD has higher density compared to diesel fuels, smoke levels are higher with MOBD. However, LHR engine marginally reduced smoke levels due to efficient combustion and less amount of fuel accumulation on the hot combustion chamber walls of the LHR engine at different operating conditions of the MOBD compared with the CE. Density influences the fuel injection system

.From Table VII, it is evident that smoke levels decreased with increase of injection timings and with increase of injection pressure, in both versions of the engine, with different operating conditions of the vegetable oils (CMO & MOBD). This was due to improvement in the fuel spray characteristics at higher injection pressures and increase of air entrainment, at the advanced injection timings, causing lower smoke levels. Decreasing the fuel density tends to increase spray dispersion and spray penetration. Preheating of the vegetable oils reduced smoke levels in both versions of the engine, when compared with normal temperature of the vegetable oils. This was due to i) the reduction of density of the MOBD, as density was directly proportional to smoke levels, ii) the reduction of the diffusion combustion proportion in CE with the preheated vegetable oils, iii) the reduction of the viscosity of the vegetable oils, with which the fuel spray does not impinge on the combustion chamber walls of lower temperatures rather than it directed into the combustion chamber. Biodiesel operation decreased sound levels marginally when compared with crude vegetable oil in both versions of the engine at different operating conditions of the vegetable oils. This was due to improved combustion with esterification of the vegetable oil.

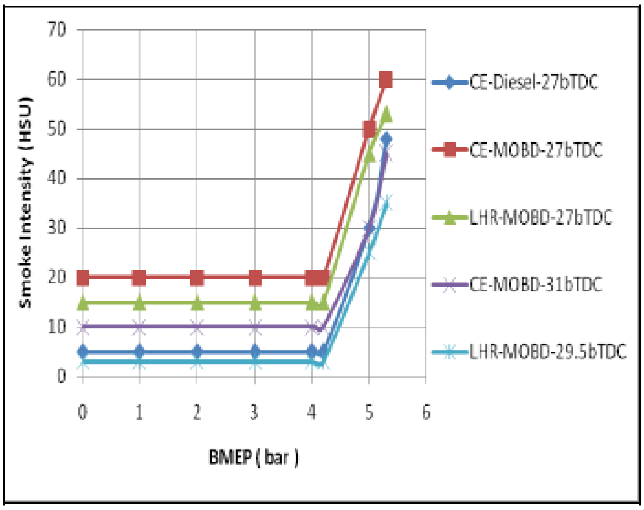

Figure.9. Variation of smoke intensity in Hartridge Smoke Unit (HSU) with BMEP in CE and LHR engine at recommend injection timing and optimized injection timings with MOBD

Table VII Data of Smoke Levels in Hartridge Smoke Unit (HSU) at peak load operation

Injection timing (°bTDC)	Test Fuel	Smoke intensity (HSU)											
		CE						LHR Engine					
		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	DF	48	--	38	--	34	--	55	--	50	--	45	--
	CMO	70	65	65	60	60	55	58	50	50	42	42	35
	MOBD	60	55	55	50	50	45	53	45	45	37	37	30
28.5	CMO	65	60	60	55	55	50	50	45	45	40	40	35
	MOBD	57	52	52	47	47	42	45	40	40	35	35	30
29.5	CMO	60	55	55	50	60	55	55	50	50	45	45	40
	MOBD	55	50	50	45	45	40	35	25	28	26	26	22
30	CMO	55	50	60	55	65	60	--	--	--	--	--	-
	MOBD	50	45	45	40	50	45	--	--	--	--	--	-
31	CMO	60	55	65	60	70	65	--	--	--	--	--	-
	MOBD	45	40	50	45	55	50	--	--	--	--	--	-

Fig.10 shows that NOx levels were lower in CE while they were higher in LHR engine at different operating conditions of the MOBD at the peak load when compared with diesel operation. This was due to lower heat release rate because of high duration of combustion causing lower gas temperatures with the MOBD operation on CE, which reduced NOx levels. Increase of combustion temperatures with the faster combustion and improved heat release rates in LHR engine caused higher NOx levels. As expected, preheating of the MOBD decreased NOx levels in both versions of the engine when compared with the normal MOBD. This was due to improved air fuel ratios and decrease of combustion temperatures leading to decrease NOx emissions in the CE and decrease of combustion temperatures in the LHR engine with the improvement in air-fuel ratios leading to decrease NOx levels in LHR engine.

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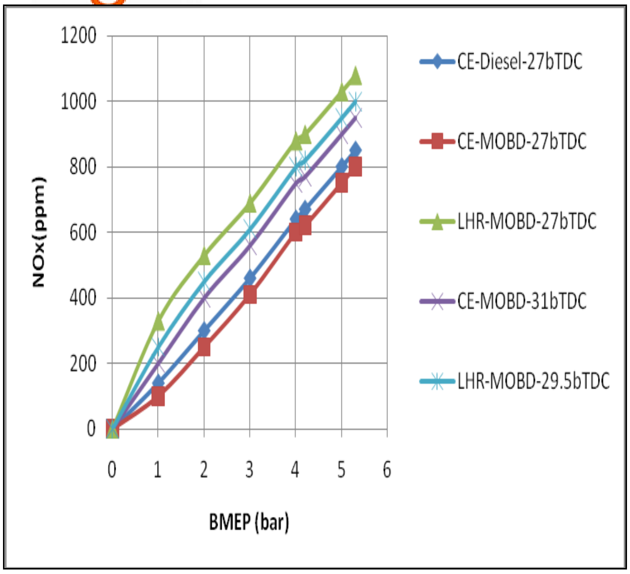

Fig.10 Variation of NOx levels with BMEP in CE and LHR engine at recommend injection timing and optimized injection timings with MOBD operation.

From Table VIII, it is noticed that NOx levels increased with the advancing of the injection timing in CE with different operating conditions of MOBD.

Table VIII Data of NOx levels at peak load operation

Injection timing (° b TDC)	Test Fuel	NOx levels (ppm)											
		CE						LHR Engine					
		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	DF	850	----	810	----	770	---	1300	--	1280	--	1260	--
	CMO	750	700	700	650	650	600	1030	950	950	900	900	850
	MOBD	800	750	750	700	700	650	1080	1000	1030	950	980	900
28.5	CMO	775	725	725	675	675	625	990	910	910	830	830	750
	MOBD	825	775	775	725	725	675	1040	960	960	880	880	800
29.5	CMO	800	750	750	700	700	650	--	--	--	--	--	--
	MOBD	850	800	800	750	750	700	1000	920	920	840	840	760
30	CMO	850	800	800	750	750	700	--	---	--	--	--	--
	MOBD	900	850	850	800	800	750	--	--	--	--	--	-
31	CMO	900	850	900	850	850	800	--	--	--	--	--	-
	MOBD	950	900	900	850	850	800	--	--	--	--	--	--

Residence time and availability of oxygen had increased, when the injection timing was advanced with the vegetable oils (CMO & MOBD) operation, which caused higher NOx levels in CE. However, NOx levels decreased with increase of injection pressure in CE. With the increase of injection pressure, fuel droplets penetrate and find oxygen counterpart easily. Turbulence of the fuel spray increased the spread of the droplets which caused decrease of gas temperatures marginally thus leading to decrease in NOx levels. Marginal decrease of NOx levels was observed in LHR engine, due to decrease of combustion temperatures**,** which was evident from the fact that thermal efficiency was increased in LHR engine due to the reason sensible gas energy was converted into actual work in LHR engine, when the injection timing was advanced and with increase of injection pressure**.** Biodiesel operation increased NOx levels marginally in comparison with crude vegetable oil operation on both versions of the engine at different operating conditions of the vegetable oils. This was because of improved heat release rates with efficient combustion of biodiesel produced marginally higher NOx levels than crude vegetable oil operation.

C. Sound Intensity

Hence if any fuel is to be tested as an alternate fuel, sound intensity is also to be checked with varied engine conditions. Fig.11 indicates at recommended injection timing, sound intensities drastically increased in CE with MOBD operation in comparison with CE with pure diesel operation. This was due to deterioration in the performance of MOBD operation on CE. High viscosity, poor volatility and high duration of combustion caused improper combustion of MOBD leading to generate high sound levels. LHR engine decreased sound intensity when compared with pure diesel operation on CE. This was because of hot environment in LHR engine improved combustion of MOBD. When injection timings were advanced to optimum, sound intensities were reduced for both versions of the engine, due to early initiation of combustion

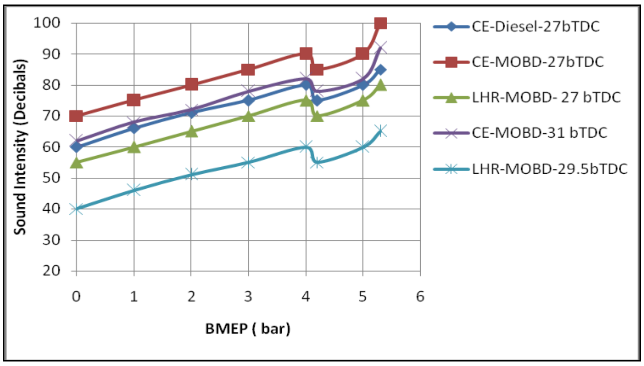

Fig.11 Variation of sound intensity with BMEP in CE and LHR engine at recommend injection timing and optimized injection timings with MOBD

Table IX denotes that the Sound intensity decreased with increase of injection pressure for both versions of the engine with the test fuels. This was due to improved spray characteristic of the fuel, with which there was no impingement of the fuel on the walls of the combustion chamber leading to produce efficient combustion.

Table IX Data of sound intensity at peak load operation

Injection timing (°bTDC)	Test Fuel	Smoke intensity (HSU)											
		CE						LHR Engine					
		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	DF	85		80		75		95		90		85	
	CMO	110	105	105	103	100	95	85	80	80	75	75	70
	MOBD	100	95	98	93	96	91	80	75	75	70	70	65
28.5	CMO	109	104	104	102	99	94	80	75	75	70	70	65
	MOBD	99	94	94	92	89	84	75	70	70	65	65	60
29.5	CMO	107	102	104	99	94	97	85	80	80	75	75	70
	MOBD	97	92	92	87	91	86	65	60	60	55	55	50
30	CMO	104	100	102	97	110	105	--	-	--	--	--	-
	MOBD	94	89	92	87	90	85	--	--	--	--	--	-
31	CMO	102	97	105	100	110	105	--	--	--	-	--	-
	MOBD	92	87	90	85	93	87	--	-	--	--	-	-

Sound intensity decreased with increase of injection pressure for both versions of the engine with the test fuels. This was due to improved spray characteristic of the fuel, with which there was no impingement of the fuel on the walls of the combustion chamber leading to produce efficient combustion.

At recommended injection timing, vegetable oils (CMO &MOBD) operation on CE produced high levels of sound intensity as combustion was deteriorated due to high viscosity and poor volatility of the fuel and high duration of combustion. However, LHR engine with vegetable oils operation produced low levels of sound intensity due to the efficient combustion in the hot environment provided by LHR engine. However, when injection timing was advanced to the respective optimum injection timing, combustion improved in both versions of the engine leading to generate low levels of sound.

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Preheated vegetable oils reduced sound levels as preheated oil reduced viscosity and improved atomization characteristics of the fuel. Biodiesel operation decreased sound levels marginally when compared with crude vegetable oil in both versions of the engine at different operating conditions of the vegetable oils. This was due to improved combustion with esterification of the vegetable oil.

D. Combustion Characteristics

From Table X, it could be observed peak pressures were lower in CE while they were higher in LHR engine at the recommended injection timing and pressure, with vegetable oils (CMO & MOBD) operation when compared with pure diesel operation on CE. This was due to increase of ignition delay, as vegetable oils require large duration of combustion. Mean while the piston started making downward motion thus increasing volume when the combustion takes place in CE. LHR engine increased the mass-burning rate of the fuel in the hot environment leading to produce higher peak pressures. The advantage of using LHR engine for vegetable oils was obvious as it could burn low cetane and high viscous fuels. Peak pressures increased with the increase of injection pressure and with the advancing of the injection timing in both versions of the engine, with the vegetable oils operation. Higher injection pressure produced smaller fuel particles with low surface to volume ratio, giving rise to higher PP. With the advancing of the injection timing to the optimum value with the CE, more amount of the fuel accumulated in the combustion chamber due to increase of ignition delay as the fuel spray found the air at lower pressure and temperature in the combustion chamber. When the fuel- air mixture burns, it produces more combustion temperatures and pressures due to increase of the mass of the fuel. With LHR engine, peak pressures increases due to effective utilization of the charge with the advancing of the injection timing to the optimum value. The magnitude of TOPP decreased with the advancing of the injection timing and with increase of injection pressure in both versions of the engine, at different operating conditions of vegetable oils. TOPP was more with different operating conditions of MOBD in CE, when compared with pure diesel operation on CE. This was due to higher ignition delay with the vegetable oils when compared with pure diesel fuel. This once again established the fact by observing lower peak pressures and higher TOPP, that CE with vegetable oils operation showed the deterioration in the performance when compared with pure diesel operation on CE. Preheating of the vegetable oils showed lower TOPP, compared with vegetable oils at normal temperature.

Table X Data of PP, MRPR, TOPP and TOMRPR at peak load operation

Injection timing (°bTDC)/ Test fuel	Engine version	PP(bar)				MRPR (Bar/deg)				TOPP (Deg)				TOMRPR (Deg)			
		Injection pressure (Bar)				Injection pressure (Bar)				Injection pressure (Bar)				Injection pressure (Bar)			
		190		270		190		270		190		270		190		270	
		NT	PT	NT	PT	NT	PT	NT	PT	NT	PT	NT	PT	NT	PT	NT	PT
27/Diesel	CE	50.4	--	53.5	---	3.1	---	3.4	--	9	-	8	--	0	0	0	0
	LHR	48.1	--	53.0	--	2.9	--	3.1	--	10	--	9	--	0	0	0	0
27/CMO	CE	46.3	47.3	48.5	49.4	2.0	2.1	2.7	2.8	11	10	11	9	0	0	0	0
	LHR	55.5	57.5	58.6	59.6	3.0	3.1	3.3	3.4	10	9	9	8	0	0	0	0
27/ MOBD	CE	46.5	47.8	49.9	50.6	2.6	2.7	2.8	2.9	11	10	11	10	1	1	1	1
	LHR	57.5	58.6	60.6	61.8	3.3	3.4	3.6	3.7	10	9	10	9	1	1	1	1
28.5/CMO	LHR	60.7	61.7	61.1	63.8	3.4	3.5	3.5	3.6	8	8	8	8	8	0	0	0
29.5/MOB	LHR	61.7	62.8	63.1	64.8	3.5	3.6	3.6	3.78	8	8	8	8	0	0	0	0
30/CMO	CE	49.4	50.6	60.1	62.8	3.2	3.3	3.6	3.7	10	9	10	9	0	0	0	0
31/MOBD	CE	53.3	54.6	62.1	63.7	3.5	3.7	3.7	3.8	10	9	9	8	0	0	0	0

This once again confirmed by observing the lower TOPP and higher PP, the performance of the both versions of the engine improved with the preheated vegetable oils compared with the normal vegetable oils. MOBD showed improved combustion characteristics with both versions of the engine when compared with CMO operation. This was because of improved combustion with increased cetane rating of the fuel. This trend of increase of MRPR and decrease of TOMRPR indicated better and faster energy substitution and utilization by vegetable oils, which could replace 100% diesel fuel. However, these combustion characters were within the limits hence the vegetable oils could be effectively substituted for diesel fuel

IV. CONCLUSIONS

Vegetable oils (CMO & MOBD) at 27°bTDC on CE showed the deterioration in the performance, while LHR engine showed compatible performance, when compared with pure diesel operation on CE. Preheating of the vegetable oils improved performance when compared with normal vegetable oils in both versions of the engine. Improvement in the performance was observed with the advancing of the injection timing and with the increase of injection pressure with the vegetable oils operation on both versions of the engine. CE with MOBD operation showed the optimum injection timing at 31°bTDC, while the optimum injection for LHR engine was at 29.5°bTDC at an injection pressure of 190 bars. CE with CMO operation showed the optimum injection timing at 30°bTDC, while the optimum injection for LHR engine was at 28.5°bTDC at an injection pressure of 190 bars. Lower peak pressures and higher TOPP were observed with normal vegetable oils in CE. LHR engine with vegetable oils operation increased PP and decreased TOPP when compared with CE. Preheating increased PP and decreased TOPP when compared with normal MOBD operation on both versions of the engine. Lower peak pressures were observed in CE, while higher peak pressures in the LHR engine with vegetable oils operation at the recommended injection timing and pressure. At respective optimized injection timings, LHR engine with MOBD operation- peak BTE increased by 13%, at peak load operation- BSEC decreased by 5%, EGT decreased by 40°C, CL decreased by 11%, VE decreased by 3%, smoke levels decreased by 30%, compatible NOx emissions, sound intensity decreased by 19% when compared with LHR engine with CMO operation.

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