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Performance Evaluation of Rice Brawn Oil in Low Grade Low Heat Rejection Diesel Engine

M.V.S. Murali Krishna[1], N. Durga Prasada Rao[2], A. Anjeneya Prasad[3] and P.V. K. Murthy[4]
[1]*Mechanical Engineering Department, Chaitanya Bharathi Institute of Technology,*
Gandipet, Hyderabad-500 075, Andhra Pradesh, India
[2]*Hindustan Aeronautics Limited, Bangalore- 560017*
Mechanical Engineering Department, J.N.T. U. College of Engineering, Hyderabad- 500 085, Karnataka, India
[3] *Vivekananda Institute of Science and Information Technology, Shadnagar, Mahabubnagar-509216, Andhra Pradesh, India*

ABSTRACT *- Investigations were carried out to evaluate the performance of a medium 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 rice brawn oil (CRBO) 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 deteriorated performance, while LHR engine showed compatible performance with CRBO operation at recommended injection timing and pressure and 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. The optimum injection timing was 32^{o}bTDC for CE while it was 29^{o}bTDC with LHR engine with CRBO operation. Peak brake thermal efficiency increased by 7%, smoke levels decreased by 2%, NOx levels increased by 24% and sound intensity decreased by 12% with CRBO operation on LHR engine at its optimum injection timing when compared with diesel operation on CE at manufacturer's recommended injection timing of 27^{o}bTDC. (Before top dead centre)*

Key words: *Crude Rice Brawn Oil, CE, LHR engine, Fuel Performance, Exhaust Emissions, Sound Intensity, Combustion Characteristics.*

I Introduction

The rapid depletion of petroleum fuels and their ever increasing costs have lead to an intensive search for alternate fuels. Among various possible options, vegetable oils and alcohols are promising substitutes of fossil diesel fuels. Alcohols have low cetane number and engine modification is necessary for use in diesel engines. That too, most of the alcohols produced are diverted to Petro-chemical industries. On the other hand, the properties of the vegetable oils are similar to those of diesel fuel and they are renewable and 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.

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.

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]. The process of converting the oil into methyl esters or biodiesel was carried out [6] by heating the crude oil at around 60-70^{o}C with the methanol in the presence of the 0.5% of catalyst (Sodium hydroxide) based on weight of the oil for about 3 hours. At the end of the reaction, excess methanol was removed by distillation and glycerol, which separates out was removed. The methyl esters were treated with dilute acid to neutralize the alkali and then washed to get free of acid, dried and distilled to get pure vegetable oil esters. These biodiesels have low viscosity and low molecular weight compared to crude vegetable oil. Investigations were carried out [7-14] 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 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.

Experiments were conducted on LHR engine [15] with cylinder head, valves and pistons of the engine coated with plasma spray zirconium with the thickness of 0.5 mm and it was reported that In comparison to CE, SFC was decreased by 6 %, and BTE was increased by 2%. The available exhaust gas energy of the LHR engine was 3–27% higher for the LHR engine compared to the standard (STD) Diesel engine.
Tests were performed [16] on a six cylinder, direct injection, turbocharged diesel engine whose pistons were coated with a 350 microns thickness of $MgZrO_3$ over a 150 micron thickness of NiCrAl bond coat. $CaZrO_3$ was employed as the coating material for the cylinder head and valves. The results showed that 1–8% reduction in BSFC could be achieved by the combined effect of the thermal barrier coating (TBC) and injection timing. On the other hand, NOx emissions were obtained below those of the base engine by 11% for 18^{o}bTDC injection timingIt was [17] explained that compared with CE, LHR engine with ceramic coating on piston crown and inner side of cylinder head with pure diesel operation, the engine power was increased by 2%, the engine torque was increased by 1.5–2.5 %, and SFC was decreased by 4.5–9 %.

Biodiesel was used as fuel in LHR engine with ceramic coating on engine components. Experiments were conducted [18] on LHR diesel engine with ceramic coated material MgO–ZrO2 on cylinder head, exhaust, and inlet valves while the piston surface was coated with ZrO2 with canola methyl and reported that increase in engine power and decrease in specific fuel consumption, as well as significant improvements in exhaust gas emissions and smoke density with LHR engine when compared with conventional engine.
Experiments were conducted [19] on LHR engine with ceramic coated piston crown, liner and inner surface of cylinder head with palm oil based bio-diesel and reported that LHR engine reduced smoke and marginally increased NOx emissions and thermal efficiency Experiments were conducted [20] on LHR engine with ceramic coating (thickness- 500 microns) on piston crown, cylinder head, valves and cylinder liner with jatropha oil based bio-diesel and reported improvement in the efficiency and pollution levels except NOx emissions .

In this study, for the first time, fly ash was used [21] as a thermal barrier coating material for engine combustion chamber elements such as cylinder head, cylinder liner, valves and piston crown face to a thickness of 200 μm by using plasma spray coating method and experiments were carried out on LHR diesel engine fueled by methyl ester of rice bran, pongamia oil and its blend (20% by volume) with diesel. An increase in engine power and decrease in specific fuel consumption, as well as significant improvements in exhaust gas emissions (except NOx) were observed for all test fuels used in LHR engine when compared with that of the CE. Experiments were conducted [22] with pongamia oil and jatropha oil based biodiesel in high grade LHR engines and reported performance improved with LHR engine.

The present paper attempted to evaluate the performance of LHR engine, which contained ceramic coated cylinder head with different operating conditions of CRBO 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.

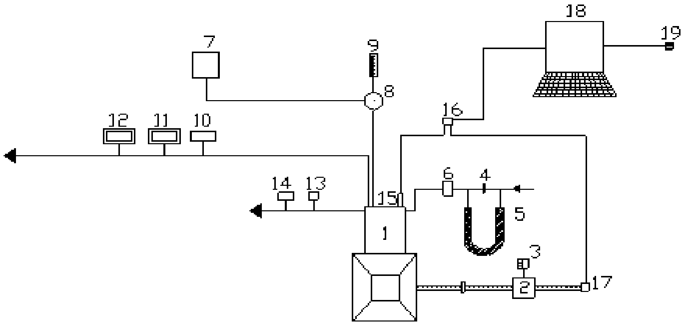
II METHODOLOGY

The properties of CRBO and diesel fuel were presented in Table 1.

Table 1. Properties of test fuels

Test Fuel	Viscosity at 25^{o}C (Centi-poise)	Density at 25 ^{o}C	Cetane number	Calorific value (kJ/kg)
Diesel	12.5	0.84	55	42000
CRBO	80	0.90	45	39000

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 crude rice brawn oil (CRBO) is shown in Figure 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^{o}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^{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. 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. 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.

III Results and Discussion

3.1 Performance Parameters

Figure 3 indicates that CE with CRBO showed the deterioration in the performance for entire load range when compared with the pure diesel operation on CE at recommended injection timing. 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 CRBO provided a possible explanation for the deterioration in the performance of the engine with CRBO operation. In addition, less air entrainment by the fuel spay suggested that the fuel spray penetration might increase and resulted in more fuel reaching the combustion chamber walls. Furthermore droplet mean diameters (expressed as Sauter mean) were larger for CRBO leading to reduce the rate of heat release as compared with diesel fuel. This also, contributed the higher ignition (chemical) delay of the CRBO due to lower cetane number.

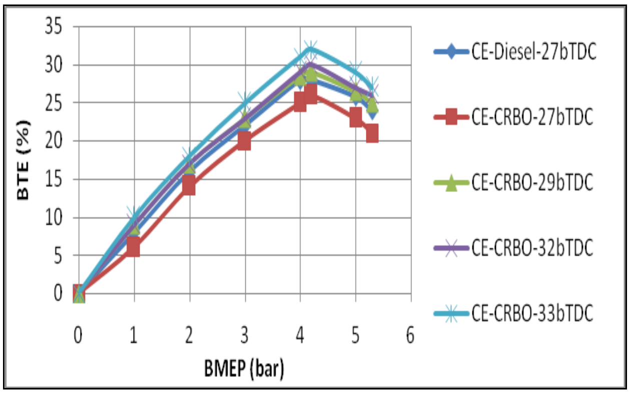


Fig. 2 Variation of brake thermal efficiency (BTE) with brake means effective pressure (BMEP) in conventional engine (CE) at different injection timings with crude rice brawn oil (CRBO) operation.

According to the qualitative image of the combustion under the CRBO operation with CE, the lower BTE was attributed to the relatively retarded and lower heat release rates. BTE increased with the advancing of the injection timing in CE with the CRBO at all loads, when compared with CE at the recommended injection timing and pressure. 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 32°bTDC in the CE at the normal temperature of CRBO. The increase of BTE at optimum injection timing over the recommended injection timing with CRBO with CE could be attributed to its longer ignition delay and combustion duration. BTE increased at all loads when the injection timing was advanced to 32°bTDC in CE, at the preheated temperature of CRBO. That too, the performance improved further in CE with the preheated CRBO for entire load range when compared with normal CRBO. Preheating of the CRBO reduced the viscosity, which improved the spray characteristics of the oil and reduced the impingement of the fuel spray on combustion chamber walls, causing efficient combustion thus improving BTE. Curves from Figure 3 indicate that LHR version of the engine showed improvement in the performance for entire load range compared with CE with pure diesel operation.

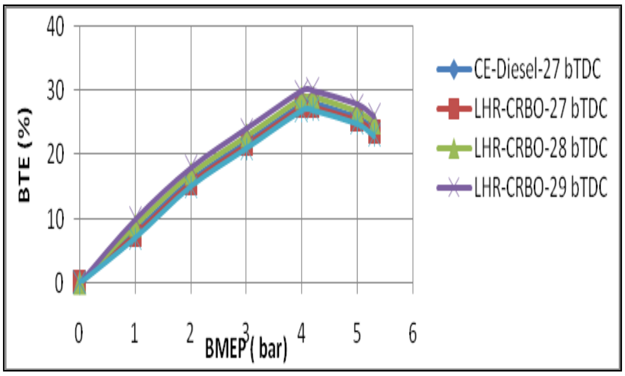


Fig. 3 Variation of BTE with BMEP in LHR engine at different injection timings with CRBO operation

High cylinder temperatures helped in better evaporation and faster combustion of the fuel injected into the combustion chamber. Reduction of ignition delay of the CRBO oil in the hot environment of the LHR engine improved heat release rates and efficient energy utilization. Preheating of CRBO improved performance further in LHR version of the engine. The optimum injection timing was found to be 29^{o}bTDC with LHR engine with normal CRBO. 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 CRBO operation.

It could be noticed from Figure 4, at optimum injection timing, BTE with LHR engine was higher than that of CE. Decrease of combustion duration and better evaporation rates would help in increasing the efficiency of LHR engine.

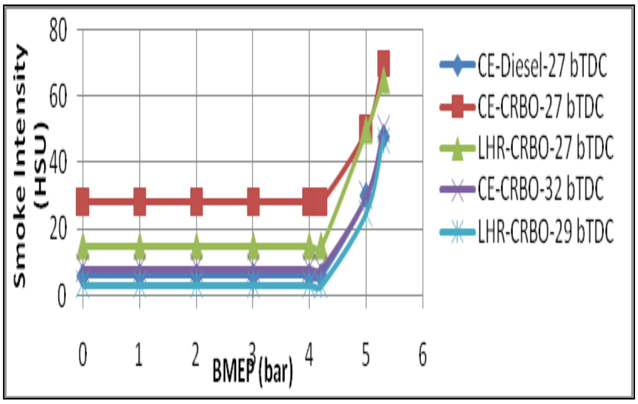


Fig. 4 Variation of BTE with BMEP in different versions of the engine at the recommended injection timing and optimum injection timing at an injection pressure of 190 bar with CRBO.

Injection pressure was varied from 190 bars to 270 bars to improve the spray characteristics and atomization of the CRBO and injection timing was advanced from 27 to 34^{o}bTDC for CE and LHR engine. From Table-2, it was evident that BTE increased with increase in injection pressure in both versions of the engine at different operating conditions of the CRBO. 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 32^{o}bTDC at 190 bar, 31^{o}bTDC at 230 bar and 30^{o}bTDC at 270 bar for CE. The optimum injection timing for LHR engine was 29^{o}bTDC irrespective of injection pressure. Peak BTE was higher in LHR engine when compared with CE with different operating conditions of the CRBO.

TABLE -1 Data of peak BTE

Injection Timing (^{o} bTDC)	Test Fuel	Peak BTE (%)											
		Conventional Engine (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	28	--	29	---	30	--	29	--	30	--	30.5	--
	CRBO	26	27	27	28	28	29	27.5	28.5	28.5	29.5	29.5	30.5
29	DF	28.5	--	29.5	--	30.2		29.5	--	30.5	--	31	--
	CRBO	27	28	28	29	30	31	30	31	31	32	32	33
30	DF	29	---	30	--	30.5	--	29	--	30	--	30.5	--
	CRBO	28	29	29	30	30	31	27	28	28	29	29	30
31	DF	29.5	--	30	--	31	--	--	--	--	--	--	--
	CRBO	29	30	30	31	29	30	27	28	28	29	29	30
32	DF	30		30.5		30.5							
	CRBO	30	31	29	30	29	30	--	--	--	--	--	--
33	DF	31		31		30	---	--	--	--	--	--	-

DF-Diesel Fuel, CRBO- Crude rice brawn oil, NT- Normal or Room Temperature, PT- Preheat Temperature

Figure 5 indicates that CE with CRBO at the recommended injection timing recorded higher EGT at all loads compared with CE with pure diesel operation. Lower heat release rates and retarded heat release associated with high specific energy consumption caused increase in EGT in CE

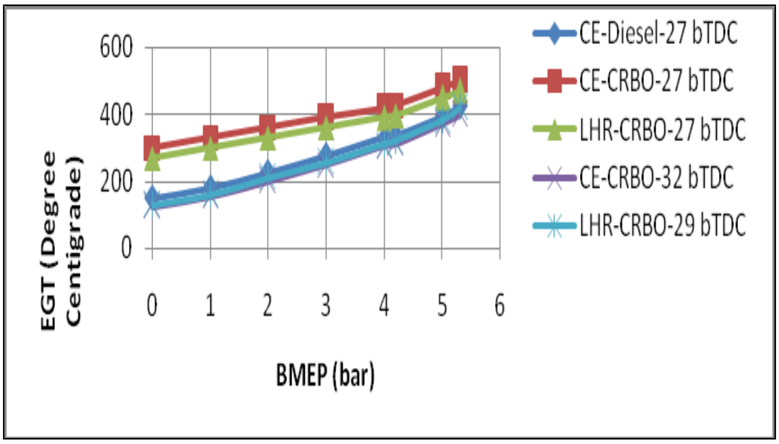


Fig.5 Variation of exhaust gas temperature (EGT) with BMEP in CE and LHR engine at recommend injection timing and optimized injection timings with CRBO operation.

Ignition delay in the CE with different operating conditions of CRBO increased the duration of the burning phase. LHR engine recorded lower value of EGT when compared with CE with CRBO 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 CRBO 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 CRBO. Preheating of CRBO further reduced the magnitude of EGT, compared with normal CRBO in both versions of the engine.

From the Table-3, 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 CRBO decreased EGT in both versions of the engine.

TABLE 3. Data of EGT at peak load operation

Injection timing (° b TDC)	Test Fuel	EGT at the peak load (°C)											
		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	425	--	410	---	395	--	460	---	450	--	440	--
	CRBO	500	475	475	450	450	425	470	450	450	430	430	410
29	DF							440		430		420	
	CRBO	475	450	450	425	425	400	420	400	400	380	380	360
30	DF	410	---	400	--	385	---	460	---	450	--	440	--
	CRBO	450	425	425	400	400	375	450	430	430	410	410	390
31	DF	400	---	390	--	375	---	450	---	445	---	440	---
	CRBO	425	400	400	375	400	375	-	-	-	-	-	-
32	DF	390		380		380							--
	CRBO	400	375	400	375	400	375	-------	---	---	----	---	-
33	DF	375	---	375	---	400	--	--	--	--	---	--	--

From Figure 6, 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 CRBO 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 CRBO. 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.

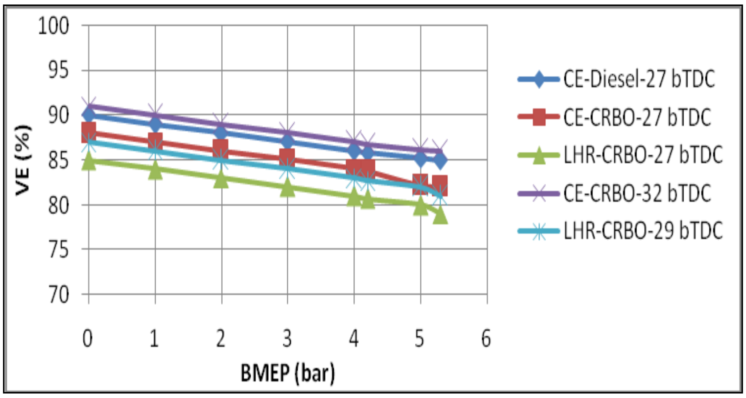


Fig. 6 Variation of volumetric efficiency (VE) with BMEP in CE and LHR engine at recommend injection timing and optimized injection timings with CPO operation.

From the Table-3, 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 CRBO with different configurations of the engine. Preheating of the CRBO 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 oil.

TABLE 4. Data of Volumetric Efficiency at peak load operation

Injection timing (^{o} 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	--
	CRBO	82	83	83	84	84	85	79	80	80	81	81	82
29	DF	85.5		86.5		87.5		78.5		80.5		82.5	
	CRBO	83	84	84	85	85	86	80	81	81	82	82	83
30	DF	86	--	87	--	88	---	76	--	77	--	78	--
	CRBO	84	85	85	86	86	87	79	80	80	81	81	82
31	DF	87	--	87.5	--	89	--	77		78	--	79	--
	CRBO	85	86	86	87	85	86	--	--	--	--	--	--
32	DF	87.5	--	88	--	87	--	-	--	-	--	--	-
	CRBO	86	87	85	86	84	85	--	--	--	--	--	--
33	DF	89	--	89	--	86	--	--	--	--	--	--	--

3.2 Exhaust Emissions

Figure 8 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 CRBO, compared with pure diesel operation on CE. This was due to the higher magnitude of the ratio of C/H of CPO (1.13) when compared with pure diesel (0.45). The increase of smoke levels was also due to decrease of air-fuel ratios and VE with CRBO compared with pure diesel operation. Smoke levels were related to the density of the fuel. Since CRBO has higher density compared to diesel fuels, smoke levels are higher with CRBO. 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 CRBO compared with the CE. Density influences the fuel injection system.

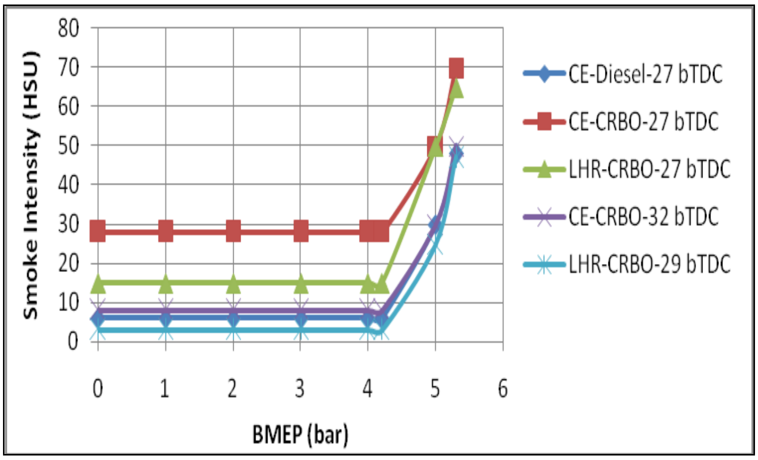


Fig.8. Variation of smoke intensity in Hartridge Smoke Unit (HSU) with BMEP in CE and LHR engine at recommend injection timing and optimized injection timings with CRBO

Decreasing the fuel density tends to increase spray dispersion and spray penetration. Preheating of the CRBO reduced smoke levels in both versions of the engine, when compared with normal temperature of the CRBO. This was due to i) the reduction of density of the CRBO, as density was directly proportional to smoke levels, ii) the reduction of the diffusion combustion proportion in CE with the preheated CRBO, iii) the reduction of the viscosity of the CRBO, with which the fuel spray does not impinge on the combustion chamber walls of lower temperatures rather than it directed into the combustion chamber.

From Table-4, 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 CRBO. 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.

TABLE 4. Data of Smoke Levels in Hartridge Smoke Unit (HSU) at peak load operation

Injection timing (^{o}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	--
	CRBO	70	65	65	60	63	60	65	60	60	55	55	50
29	DF	40	--	36	--	34		52		48		43	
	CRBO	68	64	63	59	60	57	47	45	45	40	40	35
30	DF	36	--	34	--	32	--	45	--	42	--	41	--
	CRBO	67	64	60	57	61	58	55	50	50	45	45	40
31	DF	33	---	32	--	30	--	43	--	41	--	40	--
	CRBO	60	57	57	54	54	60	--	--	--	--	--	-
32	DF	32	--	31	--	32	--	--	--	--	---	--	--
	CRBO	50	45	45	40	40	35	--	--	--	--	---	-
33	DF	30	---	30	--	35	--	-	--	--	--	--	--

Figure 9 shows that NOx levels were lower in CE while they were higher in LHR engine at different operating conditions of the CRBO 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 CRBO 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 CRBO decreased NOx levels in both versions of the engine when compared with the normal CRBO. 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.

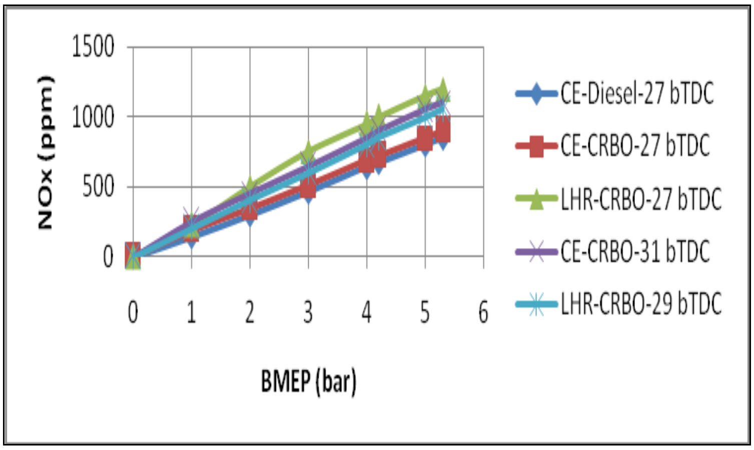


Fig.9. Variation of NOx levels with BMEP in CE and LHR engine at recommend injection timing and optimized injection timings with crude CPO operation.

From Table-5, it is noticed that NOx levels increased with the advancing of the injection timing in CE with different operating conditions of CRBO.

TABLE 5. Data of NOx levels at peak load operation

Injection timing (^{o} 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	--
	CRBO	900	850	850	800	800	750	1200	1150	1150	1100	1100	1050
29	DF	900	--	860	--	820	--						
	CRBO	950	900	900	850	850	800	1050	1000	1000	950	950	900
30	DF	935	---	900	---	860	--	1225	--	1205	--	1185	--
	CRBO	1000	950	950	900	900	850	1150	1100	1100	1050	1050	1000
31	DF	1020	---	980	---	940	---	1150	--	1130	--	1110	--
	CRBO	1050	1000	1000	950	950	900	--	--	--	--	--	--
32	DF	1105	----	1060	---	1020	---	--	--	--	--	--	--
	CRBO	1100	1050	1050	1000	1000	950	--	-	--	--	--	-
33	DF	1190	----	1150	---	1110	---	--	--	--	--	--	-

Residence time and availability of oxygen had increased, when the injection timing was advanced with the CRBO 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**.**

3.3 Sound Intensity

Hence if any fuel is being tested as an alternate fuel, sound intensity is to be checked with alternate fuels with varied engine conditions.

Figure 10 indicates at recommended injection timing, sound intensities drastically increased in CE with CRBO operation in comparison with CE with pure diesel operation. This was due to deterioration in the performance of CRBO operation on CE. High viscosity, poor volatility and high duration of combustion caused improper combustion of CRBO 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 CRBO. When injection timings were advanced to optimum, sound intensities were reduced for both versions of the engine, due to early initiation of combustion

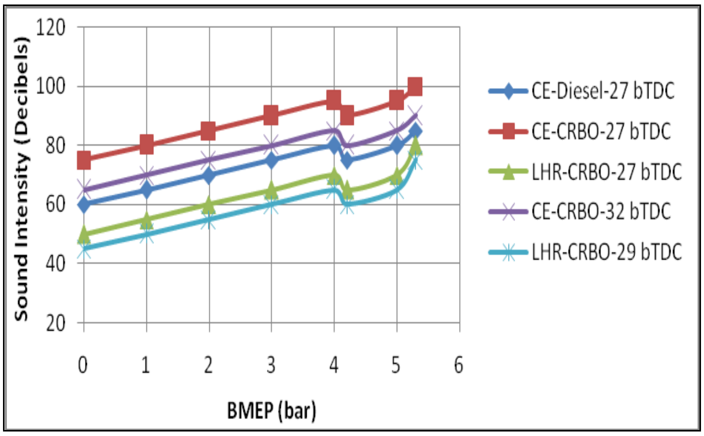


Fig. 10 Variation of sound intensity with BMEP in CE and LHR engine at recommend injection timing and optimized injection timings with CRBO

Table 6 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 6 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		95		95		90		85	
	CRBO	100	95	98	93	96	91	80	75	75	70	70	65
29	DF	83		81		79		90		85		80	
	CRBO	97	92	92	87	91	86	75	70	70	65	65	60
30	DF	80		78		77		87		82		77	
	CRBO	94	89	92	87	90	85	80	75	75	70	70	75
31	DF	78		77		75		84		79		74	
	CRBO	92	87	90	85	93	87	--	--	--	--	--	--
32	DF	76		75		76		80		75		70	
	CRBO	90	85	93	88	95	88						
33	DF	75		76		77							

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, CRBO 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 CRBO 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. Preheated CRBO reduced sound levels as preheated oil reduced viscosity and improved atomization characteristics of the fuel.

3.4 Combustion Characteristics

From Table-7, it could be observed peak pressures were lower in CE while they were higher in LHR engine at the recommended injection timing and pressure, when compared with pure diesel operation on CE. This was due to increase of ignition delay, as CRBO 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 CRBO 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 CRBO 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 CRBO. TOPP was more with different operating conditions of CRBO in CE, when compared with pure diesel operation on CE. This was due to higher ignition delay with the CRBO when compared with pure diesel fuel. This once again established the fact by observing lower peak pressures and higher TOPP, that CE with CRBO operation showed the deterioration in the performance when compared with pure diesel operation on CE. Preheating of the CRBO showed lower TOPP, compared with CRBO at normal temperature. 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 CRBO compared with the normal CRBO.

TABLE 7. Data of PP, MRPR, TOPP and TOMRPR at peak load operation

Injection timing (^{o}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/ CRBO	CE	47.9	49.8	48.8	50.8	2.1	2.2	2.8	2.9	11	10	11	10	1	1	1	1
	LHR	57.8	58.8	60.1	61.8	3.0	3.1	3.2	3.3	10	10	9	9	1	1	1	1
29/CRBO	LHR	60.7	61.8	62.1	63.8	3.4	3.6	3.6	3.78	8	8	8	8	0	0	0	0
32/CRBO	CE	53.3	54.4			3.4	3.6			9	9			0	0		

This trend of increase of MRPR and decrease of TOMRPR indicated better and faster energy substitution and utilization by CRBO, which could replace 100% diesel fuel. However, these combustion characters were within the limits hence the CRBO could be effectively substituted for diesel fuel

IV. Conclusions

CRBO operation at 27^{o}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 CRBO improved performance when compared with normal CRBO 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 CRBO operation on both versions of the engine. CE with CRBO operation showed the optimum injection timing at 32^{o}bTDC, while the optimum injection for LHR engine was at 29^{o}bTDC at an injection pressure of 190 bars. At the recommended injection timing and pressure, CRBO operation on CE increased smoke levels by 46% and NOx levels by 6% relatively, while LHR engine marginally decreased smoke levels compatibly but drastically increased NOx levels by 41% relatively when compared with pure diesel operation on CE. Preheating of the CRBO decreased smoke levels and NOx levels slightly in both versions of the engine. CE With CRBO operation decreased smoke levels and increased NOx levels, while LHR engine decreased smoke and NOx levels with the advancing of the injection timing. With increase in injection pressure, smoke and NOx

Levels decreased in both versions of the engine. At recommend injection timing, sound intensity increased by 18% with CRBO operation on CE while it decreased by 6% with LHR engine when compared with diesel operation on CE. Sound intensity decreased with advanced injection timing and increase of injection pressure with both versions of the engine at different operating conditions of the CRBO operation. Lower peak pressures and more TOPP were observed with normal CRBO in CE. LHR engine with CRBO operation increased PP and decreased TOPP when compared with CE. Preheating increased PP and decreased TOPP when compared with normal CRBO operation on both versions of the engine. Lower peak pressures were observed in CE, while higher peak pressures in the LHR engine with CRBO operation at the recommended injection timing and pressure.

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