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Potential of a Low Heat Rejection Diesel Engine with Crude Pongamia Oil

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ABSTRACT

Investigations are carried out to evaluate the performance of a low heat rejection (LHR) diesel engine consisting of air gap insulated piston with 3-mm air gap, with superni 2/4(an alloy of nickel) crown and air gap insulated liner with superni insert with different operating conditions of crude pongamia oil (CPO) with varied injection pressure and injection timing. Performance parameters of are determined at various magnitudes of brake mean effective pressure. Pollution levels of smoke and oxides of nitrogen (NOx) are recorded at the peak load operation of the engine. Combustion characteristics at peak load operation of the engine are 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 improved performance with CPO operation at recommended injection timing and pressure and the performance of both version of the engine is improved with advanced injection timing and at higher injection pressure when compared with CE with pure diesel operation. Peak brake thermal efficiency increased by 5%, smoke levels decreased by 4% and NOx levels increased by 40% with CPO operation on LHR engine at its optimum injection timing, when compared with pure diesel operation on CE at manufacturer's recommended injection timing.

Keywords: **Crude pongamia oil, LHR engine, Performance, Pollution levels, Combustion characteristics.**

1.INTRODUCTION

In the scenario of increase of vehicle population at an alarming rate due to advancement of civilization, use of diesel fuel in not only transport sector but also in agriculture sector leading to fast depletion of diesel fuels and increase of pollution levels with these fuels, the search for alternate fuels on has become pertinent for the engine manufacturers, users and researchers involved in the combustion research. It is well known fact that about 30% of the energy supplied is lost through the coolant and the 30% is wasted through friction and other losses, thus leaving only 30% of energy utilization for useful purposes. In view of the above, the major thrust in engine research during the last one or two decades has been on development of LHR engines. Several methods adopted for achieving LHR to the coolant are i) using ceramic coatings on piston, liner and cylinder head ii) creating air gap in the piston and other components with low-thermal conductivity materials like superni, cast iron and mild steel etc. Through ceramic coatings provided insulation and improved brake specific fuel consumption (BSFC), peeling of coating was reported by various researchers [1-4] after certain hours of duration. Creating an air gap in the piston involved the complications of joining two different metals. Though Parker et al. [5] observed effective insulation provided by an air gap, the bolted design employed by them could not provide complete sealing of air in the air gap. Dhinagar et al. [6] applied different degrees of insulation like ceramic coated cylinder head, air gap insulated piston and air gap insulated liner and conducted experiments with pure diesel operation and reported LHR version of the engine improved the performance. Rama Mohan [7] made a successful attempt of screwing the crown made of low thermal conductivity material, nimonic (an alloy of nickel) to the body of the piston, by keeping a gasket, made of nimonic, in between these two parts. Low degree of insulation provided by these researchers

[7] was not able to burn low cetane fuels of vegetable oils.

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. Experiments were conducted [11-15] with CE with vegetable oils and reported that performance was deteriorated with CE.

Bhaskar et al. [17] conducted experimental investigations on jatropha oil with LHR engine, which consisted of ceramic-coated cylinder head and air gap cylinder liner and reported that performance was improved and pollution levels of hydrocarbon and smoke decreased with LHR version of the engine with jatropha oil when compared with CE with pure diesel operation. Ignition improvers to jatropha oil further improved the performance and reduced the pollution levels. S.Jabez Dhinagar et al [18] tested three vegetable oils, neem oil, rice bran oil and karanja oil in LHR engine and reported that performance of vegetable oils was improved with pre-heating. Hanbey Hazar [19] conducted investigations on LHR engine with the cylinder head, exhaust, and inlet valves of a diesel engine were coated with the ceramic material MgO–ZrO2 by the plasma spray method, while the piston surface was coated with ZrO2. Thus, a thermal barrier was provided for the elements of the combustion chamber with these coatings. Using identical coated and uncoated engines, the effects of canola methyl ester produced by the transesterification method, and ASTM No. 2D fuel on engine performance and exhaust emissions were studied. Tests were performed on the uncoated engine, and then repeated on the coated engine and the results were compared. An increase in engine power and decrease in specific fuel consumption, as well as significant improvements in exhaust gas emissions and smoke density, were observed for all test fuels used in the coated engine compared with that of the uncoated engine. Rajendra Prasath et al. [20] conducted experiments on LHR engine with partially stabilized zironia coating on inside potion of cylinder head with bio-diesel and reported that performance was improved with LHR engine.

Little literature is available in evaluating the performance of LHR engine with air gap piston and air gap liner with superni (an alloy of nickel, a low thermal conductivity material) with varying engine parameters at different operating conditions of the vegetable oil. The present paper attempts to evaluate the performance of LHR engine, which contains air gap piston with superni crown and air gap insulated liner with superni insert with different operating conditions of CPO with varying engine parameters of change of injection pressure and timing and compared with CE at recommended injection timing and injection pressure.

2.EXPERIMENTAL PROGRAMME

Fig.1gives the details of insulated piston and insulated liner employed in the experimentation. LHR diesel engine contains a two-part piston; the top crown made of low thermal conductivity material, superni-90 screwed to aluminum body of the piston, providing a 3mm-air gap in between the crown and the body of the piston. The optimum thickness of air gap in the air gap piston is found to be 3-mm [7], for better performance of the engine with superni inserts. A superni-90 insert is screwed to the top portion of the liner in such a manner that an air gap of 3-mm is maintained between the insert and the liner body. At 500^{o}C the thermal conductivity of superni-90 and air are 20.92 and 0.057 W/m-K respectively. The properties of vegetable oil are shown in Table-1.

TABLE-1.
PROPERTIES OF THE NON-EDIBLE VEGETABLE OIL AND DIESEL

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**
Pongamia oil (crude)	**125**	**0.91**	**48**	**37100**

Experimental setup used for the investigations of LHR diesel engine with crude pongamia oil (CPO) is shown in Fig.2. CE has an aluminum alloy piston with a bore of 80 mm and a stroke of 110mm. The rated output of the engine is 3.68 kW at a rate speed of 1500 rpm. The compression ratio is 16:1 and manufacturer's recommended injection timing and injection pressures are 27^{o}bTDC and 190 bar respectively. The fuel injector has 3-holes of size 0.25-mm. The combustion chamber consists of a direct injection type with no special arrangement for swirling motion of air. The engine is connected to electric dynamometer for measuring brake power of the engine. Burette method is used for finding fuel consumption of the engine. Air-consumption of the engine is measured by air-box method. The naturally aspirated engine is provided with water-cooling system in which inlet temperature of water is maintained at 60^{o}C by adjusting the water flow rate. Engine oil is provided with a pressure feed system. No temperature control is incorporated, for measuring the lube oil temperature. Copper shims of suitable size are provided in between the pump body and the engine frame, to vary the injection timing and its effect on the performance of the engine is 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 is restricted to 270 bar due to practical difficulties involved. Exhaust gas temperature (EGT) is measured with thermocouples made of iron and iron-constantan. Pollution levels of smoke and NO_x are recorded by AVL smoke meter and Netel Chromatograph NOx analyzer respectively at the peak load operation of the engine. Piezo electric transducer, fitted on the cylinder head to measure pressure in the combustion chamber is connected to a console, which in turn is connected to Pentium personal computer. TDC encoder provided at the extended shaft of the dynamometer is connected to the console to measure the crank angle of the engine. A special P-θ software package evaluates 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 is obtained on the screen of the personal computer

3.RESULTS AND DISCUSSION

3.1Performance Parameters

The variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) in the conventional engine (CE) with CPO, at various injection timings at an injection pressure of 190 bar, is shown in Fig.3. The variation of BTE with BMEP with pure diesel operation on CE at recommended injection timing is also shown for comparison purpose. CE with vegetable oil 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 vegetable oil provided a possible explanation for the deterioration in the performance of the engine with vegetable oil operation. The amount of air entrained by the fuel spray is reduced, since the fuel spray plume angle is reduced, resulting in slower fuel- air mixing. 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) are larger for vegetable oil leading to reduce the rate of heat release as compared with diesel fuel. This also, contributed the higher ignition (chemical) delay of the vegetable oil due to lower cetane number. According to the qualitative image of the combustion under the crude vegetable oil operation with CE, the lower BTE is attributed to the relatively retarded and lower heat release rates. BTE increased with the advancing of the injection timing in CE with the vegetable oil at all loads, when compared with CE at the recommended injection timing and pressure. This is 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 is advanced to 32^{o}bTDC in the CE at the normal temperature of vegetable oil. The increase of BTE at optimum injection timing over the recommended injection timing with vegetable oil with CE could be attributed to its longer ignition delay and combustion duration. BTE increased at all loads when the injection timing is advanced to 32^{o}bTDC in CE, at the preheated temperature of CPO. That, too, the performance is improved further in CE with the preheated vegetable oil for entire load range when compared with normal vegetable oil. Preheating of the vegetable oil 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.

The variation of BTE with BMEP in the LHR engine with CPO, at various injection timings at an injection pressure of 190 bar, is shown in Fig.4. LHR version of the engine showed the marginal improvement in the performance for entire load range compared with CE with pure diesel 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 vegetable oil in the hot environment of the LHR engine improved heat release rates and efficient energy utilization. Preheating of vegetable oil improves performance further in LHR version of the engine. The optimum injection timing is found to be 30^{o}bTDC with LHR engine with normal CPO. Since the hot combustion chamber of LHR engine reduced ignition delay and combustion duration and hence the optimum injection timing is obtained earlier with LHR engine when compared with CE with the vegetable oil operation.

Injection pressure is varied from 190 bars to 270 bars to improve the spray characteristics and atomization of the vegetable oils and injection timing is advanced from 27 to 34^{o}bTDC for CE and LHR engine. Table-2 shows the variation of BTE with injection pressure and injection timing at different operating conditions of CPO with different configurations of the engine. BTE increases with increase in injection pressure in both versions of the engine at different operating conditions of the vegetable oil.

TABLE -2
THE VARIATION OF PEAK BTE WITH INJECTION TIMING AND INJECTION PRESSURE IN THE CONVENTIONAL AND LHR ENGINES AT DIFFERENT OPERATING CONDITIONS OF THE VEGETABLE OIL

Injection Timing (^{o} bTDC)	Test Fuel	Peak BTE (%)											
		Conventional Engine						LHR Engine					
		Injection Pressure (Bars)						Injection Pressure (Bars)					
		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	--
	CPO	25	26	26	27	27	28	29	29.5	29.5	30	30	30.5
30	DF	29	---	30	--	30.5	--	29.5	--	30.5	--	31	--
	CPO	26.5	27	27	27.5	28.5	29	29.5	30	30	30.5	30.5	31
31	DF	29.5	--	30	--	31	--	30	--	31	--	31	--
	CPO	27.5	28	28.5	29	28	28.5	--	--	--	---	--	--
32	DF	30		30.5		30.5							
	CPO	28.5	29	28	28.5	27.5	28	--	--	--	--	--	--
33	DF	31		31		30	---	--	--	--	--	--	-

DF-Diesel Fuel, CPO-Crude Pongamia Oil, NT- Normal or Room Temperature , PT- Preheat Temperature

The improvement in BTE at higher injection pressure is due to improved fuel spray characteristics. However, the optimum injection timing is not varied even at higher injection pressure with LHR engine, unlike the CE. Hence it is concluded that the optimum injection timing is 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 is 30^{o}bTDC irrespective of injection pressure. Peak BTE is higher in LHR engine when compared with CE with different operating conditions of the vegetable oils.

Fig.5 shows the variation of the exhaust gas temperature (EGT) with BMEP in CE and LHR engine with CPO at normal temperature at the recommended and optimized injection timings at an injection pressure of 190 bar. CE with CPO 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. Ignition delay in the CE with different operating conditions of vegetable oil increased the duration of the burning phase. LHR engine recorded lower value of EGT when compared with CE with vegetable oil operation. This is due to reduction of ignition delay in the hot environment with the provision of the insulation in the LHR engine, which caused the gases expand in the cylinder giving higher work output and lower heat rejection. This showed that the performance is improved with

LHR engine over CE with vegetable oil 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 vegetable oil. Preheating of the vegetable oil further reduced the magnitude of EGT, compared with normal vegetable oil in both versions of the engine. Table-3 shows the variation of EGT with injection pressure and injection timing at different operating conditions of CPO with different configurations of the engine. EGT decreases with increase in injection pressure and injection timing with both versions of the engine, which confirms that performance is increased with injection pressure. Preheating of vegetable oil decreases EGT in both versions of the engine.

TABLE-3

THE VARIATION OF EGT AT THE PEAK LOAD WITH INJECTION TIMING AND INJECTION PRESSURE IN THE CONVENTIONAL AND LHR ENGINES AT DIFFERENT OPERATING CONDITIONS OF THE VEGETABLE OIL

Injection timing (° b TDC)	Test Fuel	EGT at the peak load (°C)											
		Conventional Engine						LHR Engine					
		Injection Pressure (Bars)						Injection Pressure (Bars)					
		190		230		270		190		230		270	
		NT	PT	NT	PT	NT	PT	NT	PT	NT	PT	NT	PT
27	DF	425	--	410	---	395	--	475	---	460	--	445	--
	CPO	525	500	500	490	490	465	470	465	465	460	460	455
30	DF	410	---	400	--	385	---	455	---	450	--	445	--
	CPO	500	490	490	480	425	415	465	460	460	455	455	450
31	DF	400	---	390	--	375	---	450	---	445	---	440	---
	CPO	465	460	425	415	435	425						
32	DF	390		380		380		29	--	30	--	30.5	--
	CPO	425	415	435	425	445	435	-------	---	---	----	---	-
	EPO	410	400	400	390	410	400	--	-	--	-----	---	--
33	DF	375	---	375	---	400	--	--	--	--	---	--	--
	EPO	400	390	410	400	420	410	--	--	--	--	--	--

DF-Diesel Fuel, CPO-Crude Pongamia Oil, NT- Normal or Room Temperature , PT- Preheat Temperature

Fig.6 shows the variation of the volumetric efficiency (VE) with BMEP in CE and LHR engine with CPO at the recommended and optimized injection timings at an injection pressure of 190 bar. VE decreased with an increase of BMEP in both versions of the engine. This is due to increase of gas temperature with the load. At the recommended injection timing, VE in the both versions of the engine with CPO operation decreased at all loads when compared with CE with pure diesel operation. This is 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 CPO. This is 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. Table-4 shows the variation of VE with injection pressure and injection timing at different operating conditions of CPO with different configurations of the engine.

TABLE-4
THE VARIATION OF VOLUMETRIC EFFICIENCY (VE) AT THE PEAK LOAD WITH THE INJECTION TIMING AND INJECTION PRESSURE IN THE CONVENTIONAL AND LHR ENGINES, AT DIFFERENT OPERATING CONDITIONS OF THE VEGETABLE OIL

Injection timing (^{o}bTDC)	Test Fuel	Volumetric efficiency (%)											
		Conventional Engine						LHR Engine					
		Injection Pressure (Bars)						Injection Pressure (Bars)					
		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	--
	CPO	78.5	79.5	79.5	80.5	80.5	81.5	75.5	76.5	76.5	77.5	77.5	78.5
30	DF	86	--	87	--	88	---	80	--	82	--	83	--
	CPO	79	80	80	81	81	82	77	77.5	78.5	79.5	79.5	80.5
31	DF	87	--	87.5	--	89	--	82	--	83	--	84	--
	CPO	79.5	80.5	80.5	81.5	81.5	82.5	-	--	--	--	--	-
32	DF	87.5	--	88	--	87	--	-	--	-	--	--	-
	CPO	80	81	81	82	82	83	--	--	--	--	--	--
	EPO	81	82	82	83	83	84	--	--	--	-	---	--
33	DF	89	--	89	--	86	--	--	--	--	--	--	--

DF-Diesel Fuel, CPO-Crude Pongamia Oil, NT- Normal or Room Temperature , PT- Preheat Temperature

VE increased marginally with the advancing of the injection timing and with the increase of injection pressure in both versions of the engine. This is due to better fuel spray characteristics and evaporation at higher injection pressures leading to marginal increase of VE. This is also due to the reduction of residual fraction of the fuel, with the increase of injection pressure. Preheating of the vegetable oil 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.

3.2 POLLUTION LEVELS

Fig.7 shows the variation of the smoke levels with BMEP in CE and LHR engine with vegetable oil operation at the recommended and optimized injection timings at an injection pressure of 190 bar. Drastic increase of smoke levels is observed at the peak load operation in CE at different operating conditions of the vegetable oil, compared with pure diesel operation on CE. This is 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 is also due to decrease of air-fuel ratios and VE with vegetable oil compared with pure diesel operation. Smoke levels are related to the density of the fuel. Since vegetable oil has higher density compared to diesel fuels, smoke levels are higher with vegetable oil. 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 vegetable oil compared with the CE. Density influences the fuel injection system. 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 oil. This is due to i) the reduction of density of the vegetable oils, as density is directly proportional to smoke levels, ii) the reduction of the diffusion combustion proportion in CE with the preheated vegetable oil, iii) the reduction of the viscosity of the vegetable oil, with which the fuel spray does not impinge on the combustion chamber walls of lower temperatures rather than it directs into the combustion chamber.

Table-5 shows the variation of smoke levels with injection pressure and injection timing at different operating conditions of CPO with different configurations of the engine. 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 oil. This is 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-5

THE VARIATION OF SMOKE INTENSITY AT THE PEAK LOAD OPERATION OILS WITH THE INJECTION TIMING AND INJECTION PRESSURE IN THE CONVENTIONAL AND LHR ENGINES, AT DIFFERENT OPERATING CONDITIONS OF THE VEGETABLE OIL

Injection timing (^{o}bTDC)	Test Fuel	Smoke intensity (HSU)											
		Conventional Engine						LHR Engine					
		Injection Pressure (Bars)						Injection Pressure (Bars)					
		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	--
	CPO	70	65	65	60	60	56	65	60	60	55	55	50
30	DF	36	--	34	--	32	--	45	--	42	--	41	--
	CPO	67	64	64	61	61	58	47	45	45	43	43	41
31	DF	33	---	32	--	30	--	43	--	41	--	40	--
	CPO	64	61	61	58	58	55	--	--	--	--	--	--
32	DF	32	--	31	--	32	--	--	--	--	---	--	--
	CPO	60	57	57	54	54	51	--	--	--	--	---	-
33	DF	30	---	30	--	35	--	-	--	--	--	--	--

DF-Diesel Fuel, CPO-Crude Pongamia Oil, NT- Normal or Room Temperature , PT- Preheat Temperature

Fig.8 shows the variation of the NOx levels with BMEP in CE and LHR engine with vegetable oil at the recommended and optimized injection timings at an injection pressure of 190 bar. NOx levels are lower in CE while they are higher in LHR engine at different operating conditions of the vegetable oil at the peak load when compared with diesel operation. This is due to lower heat release rate because of high duration of combustion causing lower gas temperatures with the vegetable oil operation on CE, which reduced NOx levels. Increase of combustion temperatures with the faster combustion and improved heat release rates in LHR engine cause higher NOx levels. As expected, preheating of the vegetable oil further increased NOx levels in CE and reduced the same in LHR engine when compared with the normal vegetable oil. This is due to improved heat release rates and increased mass burning rate of the fuel leading to increase 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.

Table-6 shows the variation of NOx levels with injection pressure and injection timing at different operating conditions of CPO with different configurations of the engine. NOx levels increased with the advancing of the injection timing and with increase of injection pressure in CE with different operating conditions of vegetable oil. Residence time and availability of oxygen had increased, when the injection timing is advanced with the vegetable oil operation, which caused higher NOx levels 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 causes the increase the gas temperatures marginally thus leading to increase in NOx levels as the availability of oxygen and increase of gas temperatures are the two factors responsible for formation of NOx levels. However, marginal decrease of NOx levels is observed in LHR engine, due to decrease of combustion temperatures**,** which is evident from the fact that thermal efficiency is increased in LHR engine due to the reason sensible gas energy is converted into actual work in LHR engine, when the injection timing is advanced and with increase of injection pressure.

TABLE-6
THE VARIATION OF NO_X LEVELS AT THE PEAK LOAD WITH THE INJECTION TIMING AND INJECTION PRESSURE IN THE CONVENTIONAL AND LHR ENGINES AT DIFFERENT OPERATING CONDITIONS OF THE VEGETABLE OIL

Injection timing (° b TDC)	Test Fuel	NOx levels (ppm)											
		Conventional Engine						LHR Engine					
		Injection Pressure (Bars)						Injection Pressure (Bars)					
		190		230		270		190		230		270	
		NT	PT	NT	PT	NT	PT	NT	PT	NT	PT	NT	PT
27	DF	850	----	890	----	930	---	1300	--	1280	--	1260	--
	CPO	740	760	750	770	780	800	1265	1250	1235	1220	1200	1185
30	DF	935	---	980	---	1020	--	1225	--	1205	--	1185	--
	CPO	790	805	810	825	820	840	1190	1170	1170	1140	1140	1120
31	DF	1020	---	1070	---	1190	---	1150	--	1130	--	1110	--
	CPO	850	865	870	885	880	900	--	--	--	--	--	-
32	DF	1105	----	1150	---	1235	---	--	--	--	--	--	--
	CPO	1000	1015	1020	1035	1030	1050	--	-	--	--	--	-
33	DF	1190	----	1230	---	1275	---	--	--	--	--	--	-

DF-Diesel Fuel, CPO-Crude Pongamia Oil, NT- Normal or Room Temperature , PT- Preheat Temperature

3.3 COMBUSTION CHARACTERISTICS

Table-7 presents the comparison on the magnitudes of PP, MRPR, TOPP and TOMRPR with the injection timing and injection pressure, at the peak load operation of CE and LHR engine with vegetable oil operation. Peak pressures are 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 is 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 oil is 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 oil operation. Higher injection pressure produces 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 is more with different operating conditions of vegetable oils in CE, when compared with pure diesel operation on CE. This is due to higher ignition delay with the vegetable oil when compared with pure diesel fuel. This once again established the fact by observing lower peak pressures and higher TOPP, that CE with vegetable oil operation showed the deterioration in the performance when compared with pure diesel operation on CE. Preheating of the vegetable oil showed lower TOPP, compared with vegetable oil at normal temperature. This once again confirmed by observing the lower TOPP and higher PP, the performance of the both versions of the engine is improved with the preheated vegetable oil compared with the normal vegetable oil. 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 are within the limits hence the vegetable oils could be effectively substituted for diesel fuel.

TABLE-7
VARIATION OF PP, MRPR, TOPP AND TOMRPR WITH INJECTION TIMING AND INJECTION PRESSURE AT THE PEAK LOAD OPERATION OF CE AND LHR ENGINE WITH VEGETABLE OIL 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/ CPO	CE	45.9	47.9	48.1	49.4	2.1	2.2	2.8	2.9	12	11	12	10	1	1	1	1
	LHR	58.8	59.7	62.1	63.8	3.2	3.3	3.4	3.5	11	10	10	9	1	1	1	1
30/CPO	LHR	60.5	61.8	64.1	64.8	3.3	3.4	3.5	3.6	10	9	9	9	0	0	0	0
32/CPO	CE	50.4	51.7			3.0	3.1			11	10			0	0		

CPO-Crude Pongmia Oil, CE-Conventional engine, LHR-Low heat rejection, NT-Normal temperature, PT-Preheated temperature,

4. CONCLUSIONS

Vegetable oil operation at 27^{o}bTDC on CE showed the deterioration in the performance, while LHR engine showed improved 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 is observed with the advancing of the injection timing and with the increase of injection pressure with the vegetable oil operation on both versions of the engine. CE with crude vegetable oil operation showed the optimum injection timing at 32^{o}bTDC, while the LHR engine showed the optimum injection at 30^{o} bTDC at an injection pressure of 190 bars. At the recommended injection timing and pressure, crude vegetable oil operation on CE increased smoke levels, decreased NOx levels, while LHR engine decreased smoke levels and increased NOx levels when compared with pure diesel operation on CE. Preheating of the crude vegetable oil decreased smoke levels marginally and increased NOx levels slightly in CE, while in the LHR engine preheating of the vegetable oils decreased smoke and NOx levels. CE with vegetable oil operation decreased smoke levels and increased NOx levels, while LHR engine decreased smoke and NOx levels with the advancing of the injection timing and increase of injection pressure. Lower peak pressures and more TOPP are observed with normal crude vegetable oil in CE. LHR engine with vegetable oil operation increased PP and decreased TOPP when compared with CE. Preheating increased PP and decreased TOPP when compared with normal vegetable oil operation on both versions of the engine. Lower peak pressures and lower peak gas temperatures are predicted in CE, while higher peak pressures and higher gas temperatures are in the LHR engine with crude vegetable oil operation at the recommended injection timing and pressure.

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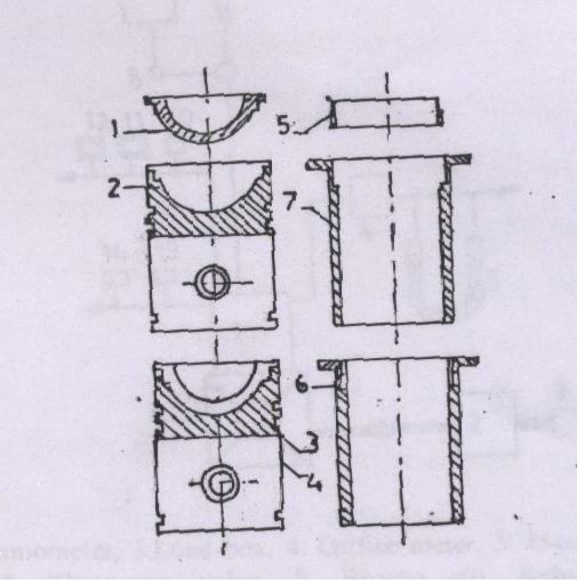
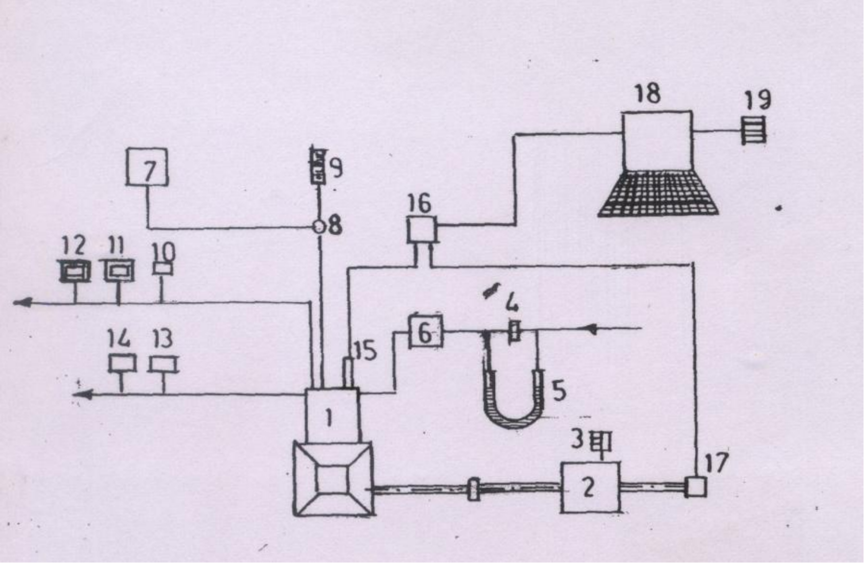


1. Crown
2. Gasket
3. Air gap
4. Body

5 Insert
6. Air gap
7. Liner

Insulated piston *Insulated liner*

Fig.1 Assembly details of insulated piston and insulated liner



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.2 Experimental Set-up

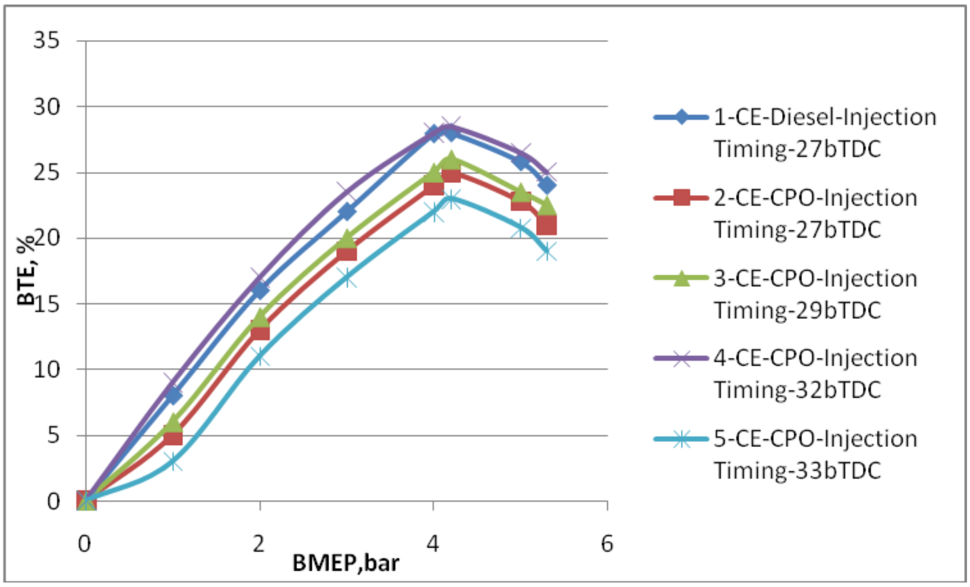


Fig.3 Variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) in conventional engine (CE) at different injection timings with crude pongamia oil (CPO) oil operation.

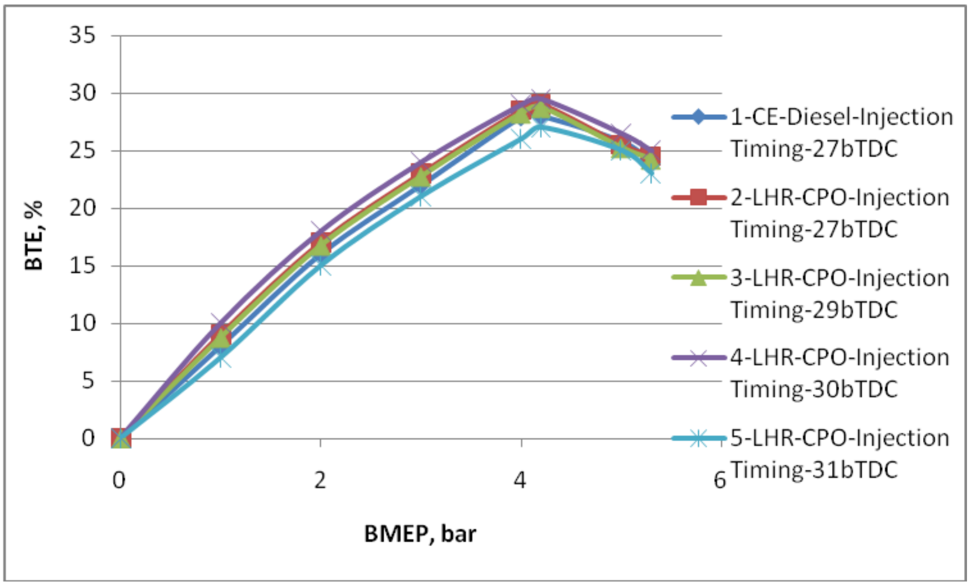


Fig.4 Variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) in low heat rejection (LHR) engine at different injection timings with crude pongamia oil operation (CPO).

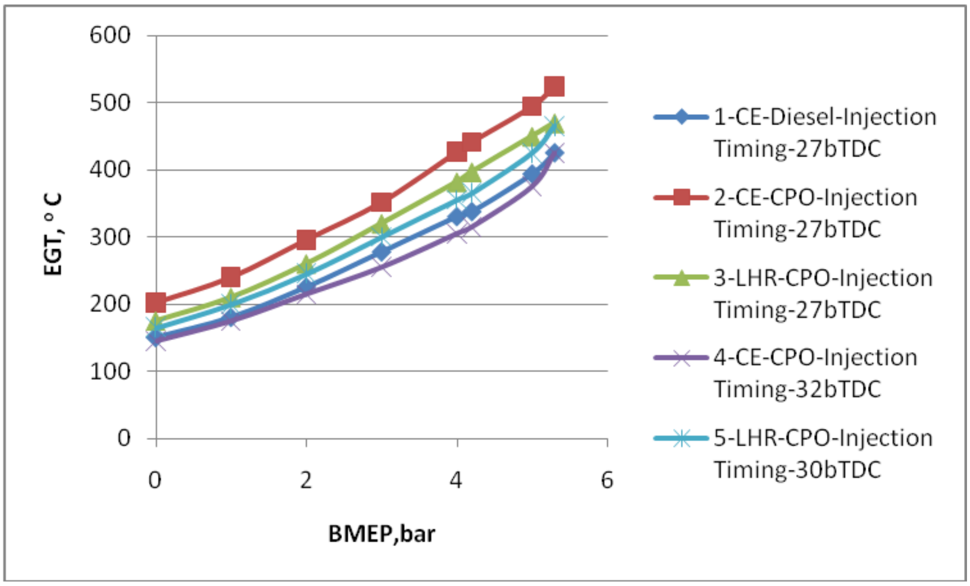


Fig.5 Variation of exhaust gas temperature (EGT) with brake mean effective pressure (BMEP) in conventional engine (CE) and low heat rejection (LHR) engine at recommend injection timing and optimized injection timings with crude pongamia oil (CPO) operation.

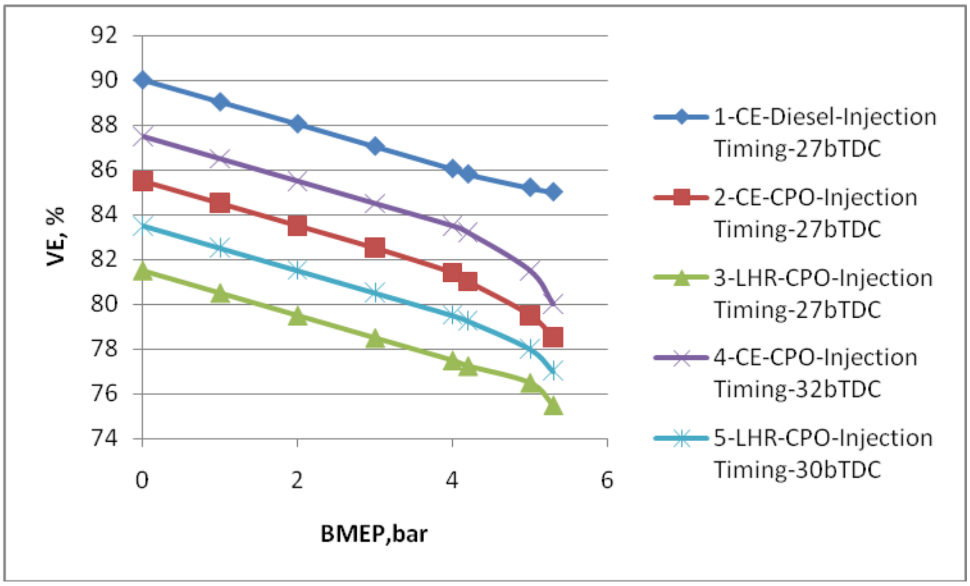


Fig.6. Variation of volumetric efficiency (VE) with brake mean effective pressure (BMEP) in conventional engine (CE) and low heat rejection (LHR) engine at recommend injection timing and optimized injection timings with crude pongamia oil (CPO) operation.

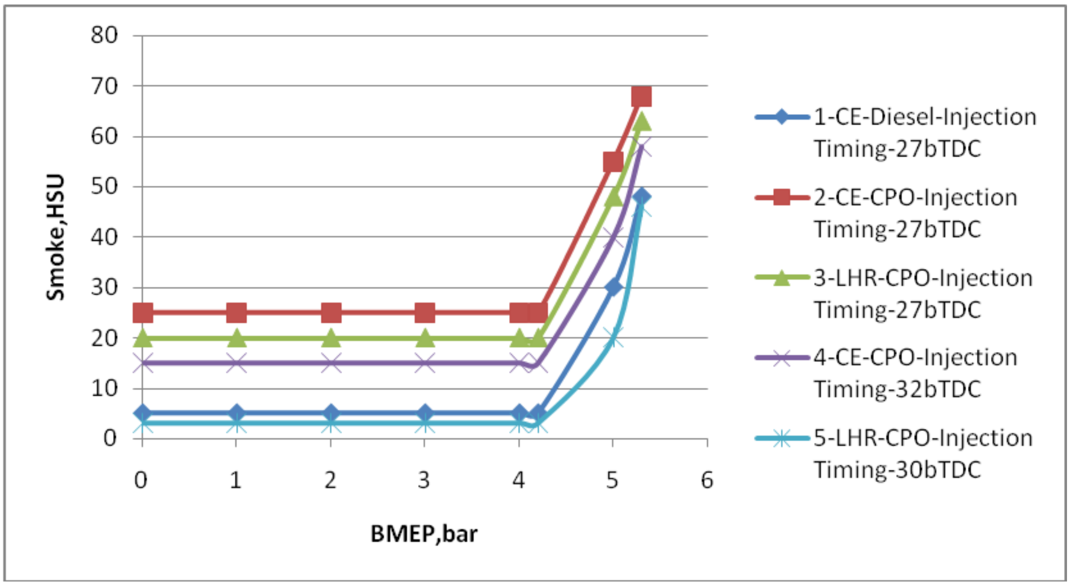


Fig.7. Variation of smoke intensity in Hartridge Smoke Unit (HSU) with brake mean effective pressure (BMEP) in conventional engine (CE) and low heat rejection (LHR) engine at recommend injection timing and optimized injection timings with crude pongamia oil operation (CPO).

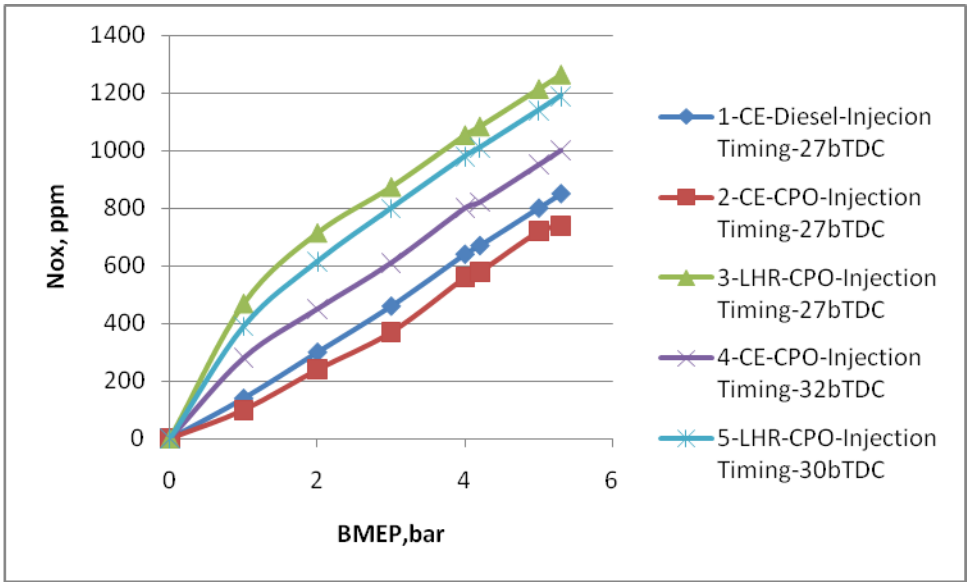


Fig.8. Variation of NOx levels with brake mean effective pressure (BMEP) in conventional engine (CE) and low heat rejection (LHR) engine at recommend injection timing and optimized injection timings with crude pongamia oil (CPO) operation.