Experimental Investigations On Performance Parameters Of Semi Adiabatic Diesel Engine with Mahua Biodiesel

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ABSTRACT

In the scenario of depletion of fossil fuels, the search for alternative fuels has become pertinent. Vegetable oils are promising substitutes for diesel fuels. Biodiesels derived from vegetable oils present a very promising alternative to diesel fuel since biodiesels have numerous advantages compared to fossil fuels as they are renewable, biodegradable, provide energy security and foreign exchange savings besides addressing environmental concerns and socio-economic issues. Experiments were conducted to determine performance parameters of a low heat rejection (LHR) diesel engine with different operating conditions [normal temperature and pre-heated temperature] of mahua biodiesel with varied injection timing and injector opening pressure. LHR engine consisted of air gap insulated piston, air gap insulated liner and ceramic coated cylinder head. Performance parameters of brake thermal efficiency, brake specific energy consumption, exhaust gas temperature, coolant load and volumetric efficiency were determined at various values of brake mean effective pressure of the engine fuelled with biodiesel. Comparative studies on exhaust emissions were made with diesel working on similar conditions. Performance parameters improved x with biodiesel operation on LHR engine over conventional engine. They further improved with increase of injector opening pressure, advanced injection timing and preheating of biodiesel.

KEYWORDS: Alternative fuels, vegetable oils, biodiesel, performance parameters

1.INTRODUCTION

The rapid depletion of petroleum fuels and their ever increasing costs have lead to an intensive search for alternate fuels. It has been found that the vegetable oils are promising substitute, because of their properties are similar to those of diesel fuel. They are renewable and can be easily produced. Rudolph Diesel, the inventor of the diesel engine that bears his name, experimented with fuels ranging from powdered coal to peanut oil [1].Several researchers experimented the use of vegetable oils as fuel on diesel engine and reported that the performance was poor, citing the problems of high viscosity, low volatility and their polyunsaturated character. [2–7]. The drawbacks associated with crude vegetable oil for use in diesel engine of high viscosity and low volatility were reduced to some extent, if crude vegetable oils are chemical converted into biodiesel. Experiments were conducted with biodiesel in conventional engine. [8–11].They reported that marginal improvement of performance and reduction of particulate emissions and increase of nitrogen oxide levels with biodiesel operation in comparison with diesel operation on conventional engine.
Experiments were conducted on preheated vegetable oils [temperature at which viscosity of the vegetable oils were matched to that of diesel fuel]. [12–15]. They reported that preheated vegetable oils decreased pollution levels of particulate emissions and NO_x emissions.

By controlling the injector opening pressure and the injection rate, the spray cone angle is found to depend on injector opening pressure [16]. Few investigators reported that injector opening pressure has a significance effect on the performance and formation of pollutants inside the direct injection diesel engine combustion.[17–21]. They reported that particulate emissions decreased with increase of injector opening pressure.
The other important engine variable to improve the performance of the engine is injection timing. Performance improved or deteriorated depending on whether injection timing was advanced (injection timing away from TDC) or retarded (injection timing towards TDC). Recommended injection timing was defined by the manufacturer that it is the timing at which maximum thermal efficiency was obtained with minimum pollution levels from the engine.

Investigations were carried out on single cylinder water cooled vertical diesel engine with brake power 3.68 kW at a speed of 1500 rpm with varied injection timing from 27–34^o bTDC [21]. They reported reduction of particulate emissions with advanced injection timing.

The drawbacks associated with biodiesel (high viscosity and low volatility) call for hot combustion chamber, provided by low heat rejection (LHR) combustion chamber. The concept of the engine with LHR combustion chamber is reduce heat loss to the coolant with provision of thermal resistance in the path of heat flow to the coolant. Three approaches that are being pursued to decrease heat rejection are (1) Coating with low thermal conductivity materials on crown of the piston, inner portion of the liner and cylinder head (low grade LHR combustion chamber); (2) air gap insulation where air gap is provided in the piston and other components with low-thermal conductivity materials like superni (an alloy of nickel),cast iron and mild steel(medium grade LHR combustion chamber);and (3).high grade LHR engine contains air gap insulation and ceramic coated components.

Experiments were conducted on engine with high grade LHR combustion chamber with biodiesel. It consisted of an air gap (3 mm) insulation in piston as well as in liner and ceramic coated cylinder head. The engine was fuelled with biodiesel with varied injector opening pressure and injection timing [22–28]. They reported from their investigations, that engine with LHR combustion chamber at an optimum injection timing of 28^o bTDC with biodiesel increased brake thermal efficiency by 10–12%, at full load operation–decreased particulate emissions by 45–50% and increased NO_x levels, by 45–50% when compared with mineral diesel operation on CE at 27^o bTDC.
The present paper attempted to determine the performance parameters of the LHR engine. It contained an air gap (3.0 mm) insulated piston, an air gap (3.0 mm) insulated liner and ceramic coated cylinder head with mahua biodiesel with different operating conditions with varied injection timing and injector opening pressure. Results were compared with CE with biodiesel and also with diesel at similar operating conditions.

2. MATERIALS AND METHODS

2.1 Preparation Of Biodiesel

Mahua seeds have approximately 27% (w/w) oil content. Oil is obtained by crushing the seeds of plant. The chemical conversion of esterification reduced viscosity four fold. Crude mahua contains up to 70 % (wt.) free fatty acids. The methyl ester was produced by chemically reacting crude mahua oil with methanol in the presence of a catalyst (KOH). A two–stage process was used for the esterification of the crude mahua oil [10]. The first stage (acid-catalyzed) of the process is to reduce the free fatty acids (FFA) content in mahua oil by esterification with methanol (99% pure) and acid catalyst (sulfuric acid-98% pure) in one hour time of reaction at 55°C. Molar ratio of mahua oil to methanol was 9:1 and 0.75% catalyst (w/w). In the second stage (alkali-catalyzed), the triglyceride portion of the mahua oil reacts with methanol and base catalyst (sodium hydroxide–99% pure), in one hour time of reaction at 65°C, to form methyl ester (biodiesel) and glycerol. To remove un–reacted methoxide present in raw methyl ester, it is purified by the process of water washing with air–bubbling. The properties of the Test Fuels used in the experiment were presented in Table–1.

Table.1 Properties of test fuels

Property	Units	Diesel (DF)	Biodiesel(BD)	ASTM Standard
Carbon Chain	--	C_8–C_{28}	C_{16}–C_{24}	---
Cetane Number	-	51	55	ASTM D 613
Specific Gravity at 15^{o}C	-	0.8275	0.87	ASTM D 4809
Bulk Modulus at 15^{o}C	MPa	1408.3	1600	ASTM D 6793
Kinematic Viscosity @ 40^{o}C	cSt	2.5	5.44	ASTM D 445
Air Fuel Ratio (Stoichiometric)	--	14.86	12.5	--
Flash Point (Pensky Marten's Closed Cup)	^{o}C	120	150	ASTM D93
Cold Filter Plugging Point	^{o}C	Winter 6^o C Summer 18^{o}C	3^o C	ASTM D 6371
Pour Point	^{o}C	Winter 3^{o}C Summer 15^{o}C	0^{o}C	ASTM D 97
Sulfur	(mg/kg, max)	50	40	ASTM D5453

Low Calorific Value	MJ/kg	42.0	37.5	ASTM D 7314
Oxygen Content	%	0.3	12	--

2.2 Engine With LHR Combustion Chamber

Fig.1 shows assembly details of insulated piston, insulated liner and ceramic coated cylinder head.

Engine with LHR combustion chamber contained a two–part piston ; the top crown made of superni was screwed to aluminium body of the piston, providing an air gap (3.0 mm) in between the crown and the body of the piston by placing a superni gasket in between the body and crown of the piston. A superni insert was screwed to the top portion of the liner in such a manner that an air gap of 3.2 mm was maintained between the insert and the liner body. At 500 ^{o}C the thermal conductivity of superni and air are 20.92 and 0.057 W/m–K. Partially stabilized zirconium (PSZ) of thickness 500 microns was coated by means of plasma coating technique. The combination of low thermal conductivity materials of air, superni and PSZ provide sufficient insulation for heat flow to the coolant, thus resulting in LHR combustion chamber

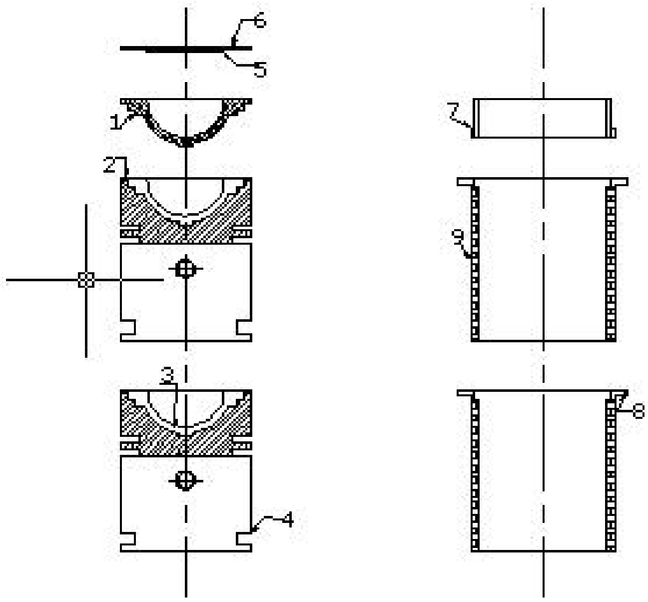

Fig.1 Assembly details of air gap insulated piston, air gap insulated liner and ceramic coated cylinder head

1.Supe 1. Piston crown with threads, 2. Superni gasket, 3. Air gap in piston, 4. Body of piston, 5. Ceramic coating on inside portion of cylinder head, 6. Cylinder head, 7.Superni insert with threads, 8.Air gap in liner, 9.Liner

2.3 Experimental set–up

The schematic diagram of the experimental setup used for the investigations on the engine with LHR combustion chamber with mahua biodiesel is shown in Fig.2. Specifications of Test engine are given in Table2.The engine was coupled with an electric dynamometer (Kirloskar), which was loaded by a loading rheostat. The fuel rate was measured by Burette. The accuracy of brake thermal efficiency obtained is ±2%. Provision was made for preheating of biodiesel to the required levels (90^{o}C) so that its viscosity was equalized to that of diesel fuel at room temperature. Air-consumption of the engine was obtained with an aid of air box, orifice flow meter andU–tube water manometer assembly. The naturally aspirated engine was provided with water–cooling system in which outlet temperature of water was maintained at 80^{o}C by adjusting thewater flow rate. The water flow rate was measured by means of analogue water flow meter, with accuracy of measurement of ±1%.

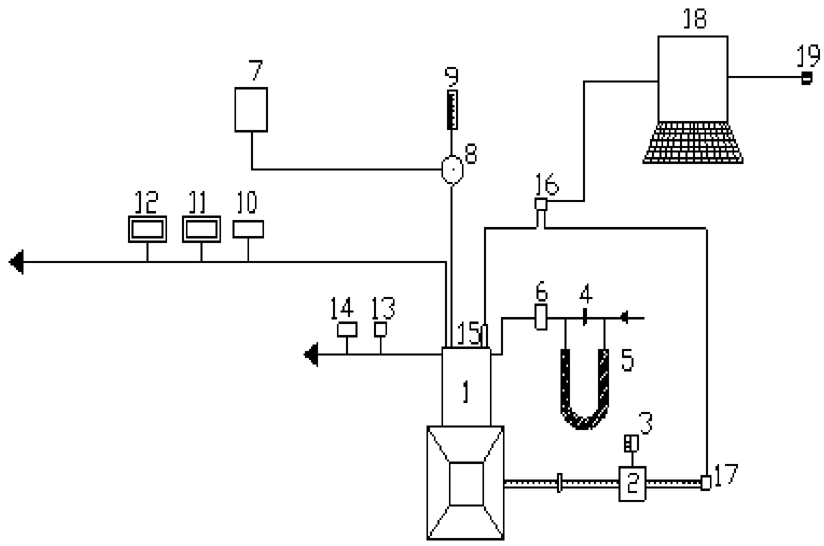

Fig.2 Schematic diagram of experimental set–up

1.Four Stroke Kirloskar Diesel Engine, 2.Kirloskar Electical Dynamometer, 3.Load Box, 4.Orifice flow meter, 5.U-tube water manometer, 6.Air box, 7.Fuel tank, 8, Preheater 9.Burette, 10. Exhaust gas temperature indicator, 11.AVL Smoke opacity meter,12. Netel Chromatograph NO_xAnalyzer, 13.Outlet jacket water temperature indicator, 14. Outlet-jacket water flow meter,15.AVL Austria Piezo-electric pressure transducer, 16.Console, 17.AVL Austria TDC encoder, 18.Personal Computer and 19. Printer.

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. Injector opening pressure was changed from 190 bar to 270 bar using nozzle testing device. The maximum injector opening pressure was restricted to 270 bar due to practical difficulties involved. Coolant water jacket inlet temperature, outlet water jacket temperature and exhaust gas temperature were measured by employing iron and iron-constantan thermocouples connected to analogue temperature indicators. The accuracies of analogue temperature indicators are ±1%.

Table.2 Specifications of Test Engine

Description	Specification
Engine make and model	Kirloskar (India) AV1
Maximum power output at a speed of 1500 rpm	3.68 kW
Number of cylinders ×cylinder position× stroke	One × Vertical position × four-stroke
Bore × stroke	80 mm × 110 mm
Engine Displacement	553 cc
Method of cooling	Water cooled
Rated speed (constant)	1500 rpm
Fuel injection system	In-line and direct injection
Compression ratio	16:1
BMEP @ 1500 rpm at full load	5.31 bar
Manufacturer's recommended injection timing and injector opening pressure	27^obTDC × 190 bar
Number of holes of injector and size	Three × 0.25 mm
Type of combustion chamber	Direct injection type

Exhaust emissions of particulate matterand nitrogen oxides (NO_x) were recorded by smoke opacity meter (AVL India, 437) and NO_x Analyzer (Netel India;4000 VM) at full load operation of the engine. Table 3 shows the measurement principle, accuracy and repeatability of raw exhaust gas emission analyzers/ measuring equipment for particulate emissions and NO_x levels. Analyzers were allowed to adjust their zero point before each measurement. To ensure that accuracy of measured values was high, the gas analyzers were calibrated before each measurement using reference gases.

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

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

2.4Test Conditions

Test fuels used in the experiment were neat diesel and biodiesel. Various configurations of the engine were conventional engine and engine with LHR combustion chamber. Different operating conditions of the biodiesel were normal temperature and preheated temperature. Different injector opening pressures attempted in this experiment were 190and 270 bar. Various injection timings attempted in the investigations were manufacturer's recommended injection timing (27^o bTDC) and optimum injection timing.. Each test was repeated twelve times to ensure the reproducibility of data according to uncertainity analysis(Minimum number of trials must be not less than ten).

3. RESULTS AND DISCUSSION

3.1 Performance Parameters

The optimum injection timing with CE was 31^{o}bTDC, while it was 28^{o}bTDC for engine with LHR combustion chamber with diesel operation [29]. Fig.3 shows variation of brake thermal efficiency with brake mean effective pressure (BMEP) in conventional engine with biodiesel at various injection timings. BTE increased up to 80% of the full load and beyond that load, it decreased with biodiesel operation at various injection timings. Increase of fuel conversion of efficiency up to 80% of full load and decease of mechanical efficiency and volumetric efficiency beyond 80% of the full load and were the responsible factors for variation of BTE with respect to BMEP. Curves in Fig.3 indicate that CE with biodiesel at 27^{o}bTDC showed comparable performance at all loads.

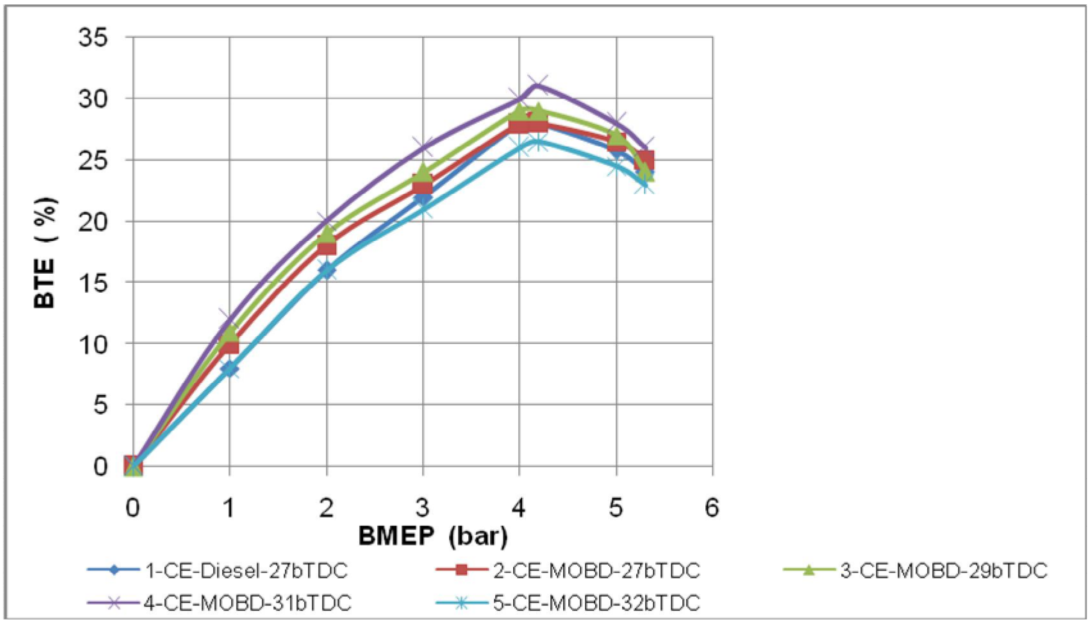

Fig. 3 Variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) in conventional engine (CE) with biodiesel at various injection timings at an injector opening pressure of 190 bar.

The presence of oxygen in fuel composition might have improved performance with biodiesel operation, when compared with mineral diesel operation on CE at 27^o bTDC. CE with biodiesel operation at 27^{o}bTDC decreased peak BTE by 3%, when compared with diesel operation on CE. Low calorific value and high viscosity of biodiesel might have showed comparable performance with biodiesel operation in comparison with neat diesel. CE with biodiesel operation increased BTE at all loads with advanced injection timing, when compared with CE with diesel operation at

27° bTDC. Initiation of combustion at early period and increase of contact period of fuel with air improved performance with biodiesel when compared with diesel operation at 27° bTDC. CE with biodiesel operation increased peak BTE by 3% at an optimum injection timing of 31° bTDC, when compared with diesel operation at 27° bTDC.

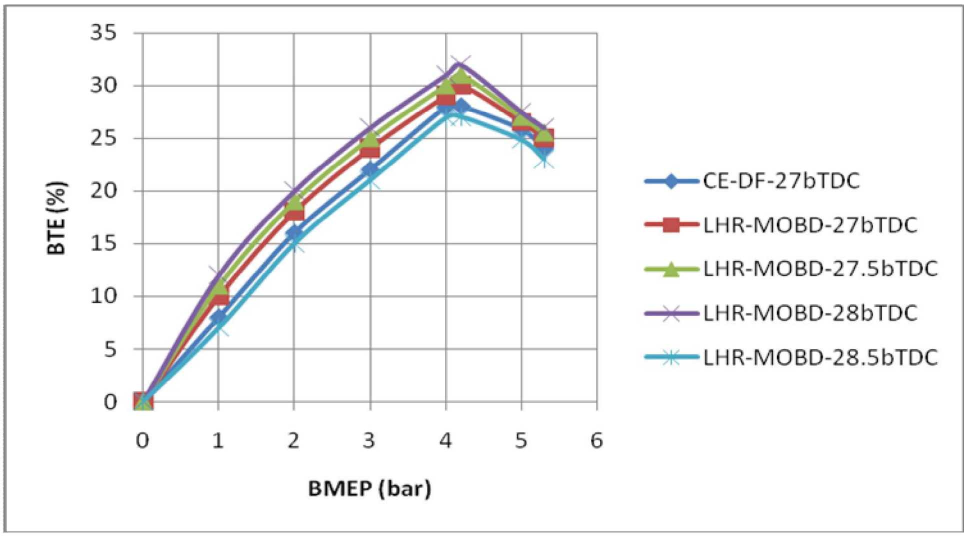

Fig.4. Variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) in engine with LHR combustion chamber with biodiesel at various injection timings at an injector opening pressure of 190 bar.

High cylinder temperatures helped in improved evaporation and faster combustion of the fuel injected into the combustion chamber. Reduction of ignition delay of the biodiesel in the hot environment of the engine with LHR combustion chamber might have improved heat release rates. Engine with LHR combustion chamber with biodiesel operation increased peak BTE by 14% at an optimum injection timing of 28° bTDC in comparison with mineral diesel operation on CE at 27° bTDC. Hot combustion chamber of LHR engine reduced ignition delay and combustion duration and hence the optimum injection timing (28° bTDC) was obtained earlier with engine with LHR combustion chamber when compared with CE (31° bTDC) with biodiesel operation.

Fig.5 presents bar charts showing the variation of peak BTE with different versions of the engine with biodiesel and neat diesel operation at recommended injection timing and optimum injection timing at an injection pressure of 190 bar. CE with biodiesel operation showed comparable peak BTE at recommended injection timing, and decreased it by 3% at optimum injection timing in comparison with neat diesel operation on same configuration of the engine. Presence of oxygen might have improved combustion with biodiesel operation. LHR engine with biodiesel operation increased peak PBTE at recommended injection timing by 11% and 7% at optimum injection timing in comparison with neat diesel operation on same configuration of the engine. This showed that LHR engine was more suitable for biodiesel operation. LHR engine increased peak BTE by 7% at recommended injection timing and 7% at optimum injection timing in comparison with CE with biodiesel operation. Improved heat release rate might have increased peak BTE with LHR engine.

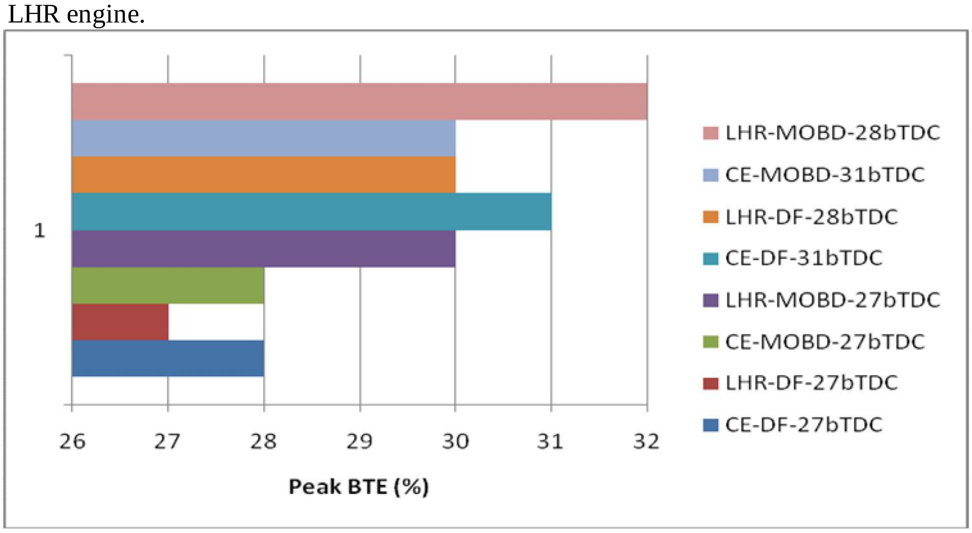

Fig.5. Bar charts showing the variation of peak brake thermal efficiency (BTE) with mahua oil biodiesel

Injection pressure was varied from 190 bars to 270 bar to improve the spray characteristics and atomization of the biodiesel and injection timing was advanced from 27 to 34^{o}bTDC for CE and LHR engine.Table.4 shows variation of peak BTE with injection pressure at different operating conditions of biodiesel. From Table-5.24, it is noticed that BTE increased with increase in injection pressure in both versions of the engine at different operating conditions of the mahua oil in biodiesel form.

The improvement in BTE at higher injection pressure might be 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 with biodiesel operation. the optimum injection timing was 31^{o}bTDC at 190 bar, 30^{o}bTDC at 230 bar and 29^{o}bTDC at 270 bar for CE. The optimum injection timing for LHR engine was 28^{o}bTDC irrespective of injection pressure with biodiesel. Peak BTE was higher in LHR engine when compared with CE with different operating conditions of the biodiesel.

Table.4 Data of peak BTE

Injection Timing (^{o} bTDC)	Test Fuel	Peak Brake Thermal Efficiency(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	--	27	--	28	--	29	--
	MOBD	28	29	29	30	30	31	30	31	31	32	32	33
28	DF	---	---	---	----	---	--	30	---	31	---	31.5	---
	MOBD	----	----	----	----	---	---	32	32.5	32.5	33	33	33.5
29	MOBD	28	29	29	30	30	31						
30	MOBD	29	30	30	31	29	30						
31	DF	31	---	30.5	---	30	--	---	----	------	----	------	---
	MOBD	30	31	31	32	30.5	31	---	---	---	--	--	---

From Table 4, it is noticed that the performance improved in both versions of the engine with the preheated biodiesel when compared with normal biodiesel. Preheating of the vegetable oil reduced the viscosity, which improved the spray characteristics of the oil thus improving peak BTE with preheated biodiesel.

Fig.5 presents bar charts showing the variation of brake specific energy consumption (BSEC) at full load with different versions of the engine with biodiesel and neat diesel operation at recommended injection timing and optimum injection timing at an injection pressure of 190 bar. BSEC at full load operation decreased with the advanced injection timing with both versions of the engine with biodiesel. Initiation of combustion at early period and improved atomization of fuel with air might have improved the performance with advanced injection timing. Initiation of combustion at earlier period and efficient combustion with the increase of air entrainment in fuel spray might have given lower BSEC at full load.Conventional engine with biodiesel operation increased BSEC at full load at recommended injection timing by 1% and increased it by 3% at optimum injection timing in comparison with neat diesel operation on same configuration of the engine. Though calorific value of the biodiesel was lower, its density was higher leading to give comparable heat release rate with diesel. Increase of centane number might have also contributed for improved performance with biodiesel. However, higher viscosity might have deteriorated the performance with biodiesel. LHR engine with biodiesel operation decreased BSEC at full load by 8% at recommended injection timing and 4% at optimum injection timing in comparison with neat diesel operation on same configuration of the engine. This showed that LHR engine was more suitable for biodiesel operation.

LHR engine decreased BSEC at full load by 2% at recommended injection timing and 1% at optimum injection timing in comparison with CE with biodiesel operation. Improved heat release rate might have decreased BSEC at full load with LHR engine.

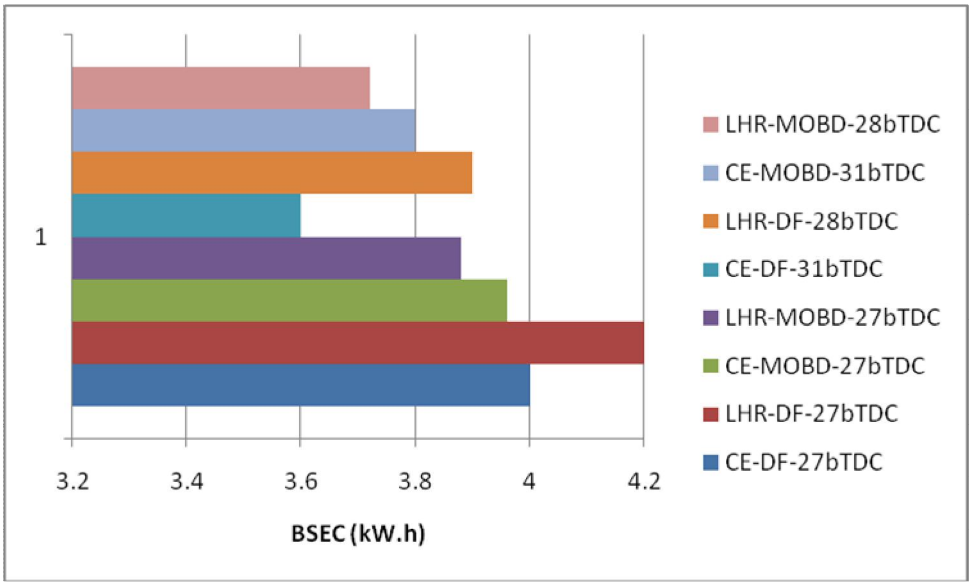

Fig.6. Bar charts showing the variation of brake specific energy consumption (BSEC) at full load with biodiesel operation (MOBD)

Table.5. shows variation of BSEC at full load with injection pressure at different operating conditions of the biodiesel. BSEC at full load decreased marginally with an increase of injection pressure and at preheated condition of biodiesel. Improved spray characteristics of the fuel might have reduced BSEC at full load with biodiesel. With increase of injection pressure, mean diameter of fuel particle decreases and hence less energy is required for its combustion.

Table.5 Data of BSEC at full load operation

Injection Timing (^{o}bTDC)	Test Fuel	Brake Specific Energy (BSEC) at full load operation (kW.h)											
		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	4.0	---	3.96	----	3.92	----	4.2	----	3.92	---	3.88	---
	MOBD	3.96	3.92	3.92	3.88	3.88	3.84	3.88	3.84	3.84	3.80	3.80	3.76
28	DF	---	---	---	---	---	---	3.90	---	3.86	---	3.82	--
	MOBD	----	----	---	---	---	---	3.76	3.72	3.72	3.68	3.68	3.64
31	DF	3.6	---	3.86	---	3.90	---	---	----	------	----	------	---
	MOBD	3.80	3.76	3.82	3.78	3.84	3.80	---	---	---	--	--	---

Fig.7. presents bar charts showing the variation of exhaust gas temperature (EGT) at full load with different versions of the engine with biodiesel and neat diesel operation at recommended injection timing and optimum injection timing at an injection pressure of 190 bar. EGT at full load decreased marginally with advanced injection timing with biodiesel and diesel operation. Initiation of combustion at early period and higher expansion of gases would lead to produce lower EGT with advanced injection timing Conventional engine with biodiesel operation increased EGT at full load by 6% at recommended injection timing and decreased 7% at optimum injection timing in comparison with neat diesel operation on same configuration of the engine. Heat release rate might be higher with biodiesel operation as its density was higher leading to produce higher EGT at full load. LHR engine with biodiesel operation decreased EGT at full load by 5% at recommended injection timing and 1% at optimum injection timing in comparison with neat diesel operation on same configuration of the engine, which again confirmed that LHR engine was more suitable for biodiesel operation. LHR engine increased EGT at full load by 6% at recommended injection timing and 6% at optimum injection timing in comparison with CE with biodiesel operation. Heat rejection was confined to insulating components leading to produce higher EGT at full load with LHR engine.

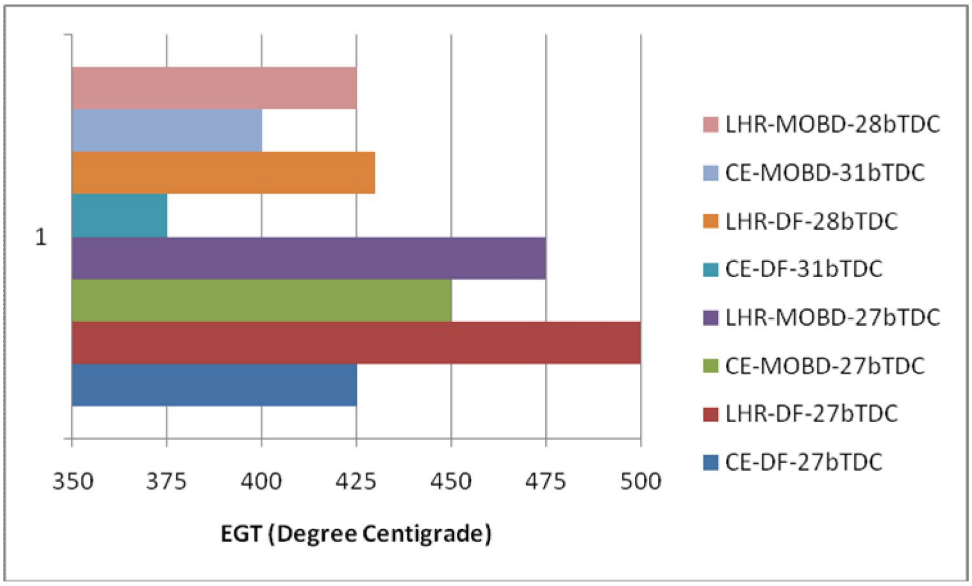

Fig.7. Bar charts showing variation of exhaust gas temperature (egt) at full load with mahua oil biodiesel (mobd)

Table.6. shows variation of EGT at full load with injection pressure with different operating conditions of the biodiesel. From Table-6, it is observed that EGT decreased with increase in injection pressure with both versions of the engine with biodiesel which confirmed that performance increased with increase of injection pressure. Preheating of the biodiesel increased EGT at full load with CE and reduced with LHR engine, compared with normal vegetable oil in both versions of the engine.

Diffused combustion might have increased with preheating with CE while improved combustion with improved air fuel ratios might have decreased with LHR engine.

Table.6 Data of exhaust gas temperature at full load with biodiesel operation

Injection timing (° b TDC)	Test Fuel	Exhaust gas temperature (°C) at full load operation											
		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	--
	MOBD	450	475	425	450	400	425	475	450	450	425	425	400
28	DF	----	---	---	---	---	---	430	---	410	----	390	---
	MOBD	---	---	--	----	---	---	425	400	400	375	375	350
31	DF	375	--	380	---	400	---	---	---	--	---	--	---
	MOBD	400	425	425	450	450	475	---	---	--	---	--	---

Preheating of the biodiesel increased EGT at full load with CE and reduced with LHR engine, compared with normal vegetable oil in both versions of the engine.Diffused combustion might have increased with preheating with CE while improved combustion with improved air fuel ratios might have decreased with LHR engine.

Fig.8. presents bar charts showing the variation of volumetric efficiency at full load with different versions of the engine with biodiesel and neat diesel operation at recommended injection timing and optimum injection timing at an injection pressure of 190 bar. Volumetric efficiency at full load increased marginally with advanced injection timing with biodiesel and diesel operation. Reduction of EGT with advanced injection timing improved volumetric efficiency with both versions of the engine. Conventional engine with biodiesel operation decreased volumetric efficiency at full load by 2% at recommended injection timing and 4% at optimum injection timing in comparison with neat diesel operation on same configuration of the engine. Concentration of un-burnt fuel might have reduced volumetric efficiency with biodiesel operation. LHR engine with biodiesel operation increased volumetric efficiency by 3% at recommended injection timing and 2% at optimum injection timing in comparison with neat diesel operation on same configuration of the engine. Decrease of EGT might have increased volumetric efficiency with biodiesel operation on LHR engine in comparison with diesel operation. LHR engine decreased volumetric efficiency at full load by 4% at

recommended injection timing and 6% at optimum injection timing in comparison with CE with biodiesel operation. Heating of charge with insulated components of LHR engine resulted in reducing volumetric efficiency when compared with CE.

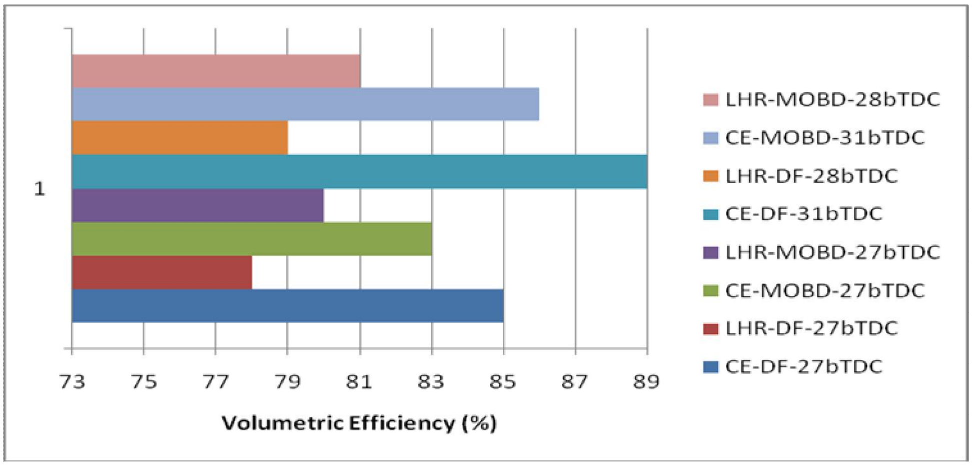

Fig.8.Bar charts showing variation of volumetric efficiency at full load with mahua oil biodiesel (mobd)

Table.7. presents variation of volumetric efficiency at full load with injection pressure with different operating conditions of biodiesel.

Tale.7 Data of volumetric efficiency at full load with biodiesel operation

Injection timing (^{o}bTDC)	Test Fuel	Volumetric efficiency (%) at full load operation											
		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	--
	MOBD	83	82	84	83	85	84	80	81	81	82	82	83
28	DF	---	---	---	---	---	--	79	---	80	----	81	----
	MOBD	---	---	--	--	---	---	81	82	82	83	84	85
31	DF	89	----	88	---	87	----	---	---	--	---	--	---
	MOBD	86	85	85	84	84	83	---	---	--	---	--	---

From Table.7, volumetric efficiency increased with increase of injection pressure in both versions of the engine with biodiesel and diesel. Improved fuel spray characteristics and evaporation at higher injection pressures might have increased volumetric efficiency. Reduction of residual fraction of the fuel might have also contributed in increasing volumetric efficiency with the increase of injection pressure. Preheating of the mahua oil in biodiesel form marginally decreased volumetric efficiency with CE, while it increased with LHR engine. EGT might have contributed for variation of volumetric efficiency with both versions of the engine.

Fig.9. presents bar charts showing the variation of coolant load at full load with different versions of the engine with biodiesel and neat diesel operation at recommended injection timing and optimum injection timing at an injection pressure of 190 bar. Coolant load at full load increased marginally with CE, while it decreased with LHR engine with advanced injection timing with biodiesel and diesel operation. Increase of gas temperatures with CE while decreasing the same with LHR engine might be the reasons for variation of coolant load with CE and LHR engines as in case of crude vegetable oil operation. Conventional engine with biodiesel operation increased coolant load at full load by 5% at recommended injection timing and 5% at optimum injection timing in comparison with neat diesel operation on same configuration of the engine. Concentration of un-burnt fuel at combustion chamber walls might have increased gas temperatures with biodiesel operation. LHR engine with biodiesel operation decreased coolant load by 11% at recommended injection timing and 22% at optimum injection timing in comparison with neat diesel operation on same configuration of the engine. This showed that rejected heat might have converted into useful work with LHR engine with biodiesel operation leading to improve performance of the LHR engine with biodiesel operation. LHR engine decreased coolant load at full load by 11% at recommended injection timing and 30% at optimum injection timing in comparison with CE with biodiesel operation. Provision of thermal insulation might have reduced coolant load at full

load with HR engine in comparison with LHR engine. Reduction of gas temperatures with improved air fuel ratios might have reduced coolant load with LHR engine.

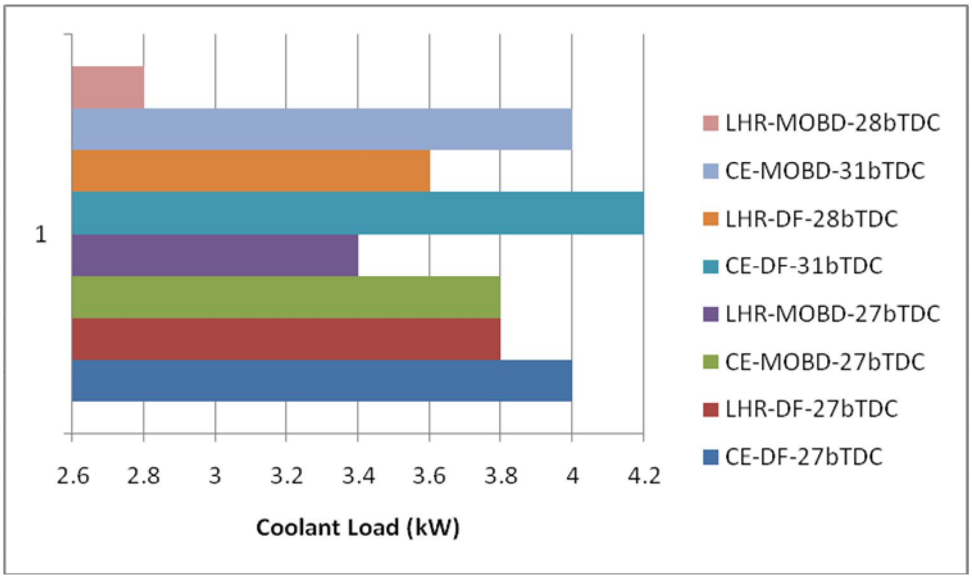

Fig.9. Bar charts showing variation of coolant load at full load with mahua oil biodiesel (MOBD)

Table.8 shows variation of coolant load with injection pressure with different operating condition of the biodiesel, which followed similar trends with crude vegetable oil operation. Coolant load at full load increased with CE, while decreasing with LHR engine with increase of injection pressure. Variation of gas temperatures with injection pressure caused variation of coolant load with both versions of the engine. Preheated biodiesel reduced coolant load with both version of the engine as in case of crude vegetable oil operation.

Table.8 Data of coolant load at full load with biodiesel operation

Injection timing (^{o} bTDC)	Test Fuel	Coolant Load (kW) at full load operation											
		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	---	3.8	---	3.6	--	3.4	---
	MOBD	3.8	3.6	3.6	3.4	3.4	3.2	3.4	3.2	3.2	3.0	3.0	2.8
28	DF	---	---	---	---	---	---	3.6	---	3.4	---	3.2	---
	MOBD	---	----	---	---	---	---	2.8	2.6	2.6	2.4	2.4	2.2
31	DF	4.2	---	4.4	----	4.6	----	---	---	--	---	--	---
	MOBD	4.0	3.8	4.2	4.4	4.4	4.6	---	---	--	---	--	---

4. CONCLUSIONS

1. The optimum injection timing with conventional engine (CE) was 31^o bTDC, while it was 28^o bTDC with low heat rejection (LHR) engine with biodiesel operation.
2. LHR engine increased peak BTE by 7% at recommended injection timing and 7% at optimum injection timing in comparison with CE with biodiesel operation.
3. LHR engine decreased BSEC at full load by 2% at recommended injection timing and 1% at optimum injection timing in comparison with CE with biodiesel operation
4. LHR engine increased EGT at full load by 6% at recommended injection timing and 6% at optimum injection timing in comparison with CE with biodiesel operation.
5. LHR engine decreased volumetric efficiency at full load by 4% at recommended injection timing and 6% at optimum injection timing in comparison with CE with biodiesel operation. .
6. LHR engine decreased coolant load at full load by 11% at recommended injection timing and 30% at optimum injection timing in comparison with CE with biodiesel operation

7. With preheating, and increase of injector opening pressure, performance parameters improved marginally with biodiesel operation on both versions of the engine. .

4.1.Research findings and suggestions

Comparative studies were made on performance parameters with different operating conditions of biodiesel with varied injection timing and injector opening pressure with LHR engine and conventional engine.

Biodiesel requires hot combustion chamber as they are moderate viscous, and non-volatile. Hence a low heat rejection diesel engine can be employed in order to burn them effectively, with its significance characteristics of higher operating temperature, maximum heat release, and ability to handle lower calorific value (CV) fuel etc. Hence further work on exhaust emissions is necessary.

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