International Journal of Thermal Technologies

E-ISSN 2277 – 4114
Available at http://inpressco.com/category/ijtt/

Research Article

Experimental Investigations on Exhaust Emissions of Low Heat Rejection Diesel Engine with Crude Mahua Oil

T. Ratna Reddy[#], Maddali V S Murali Krishna[#*] and Ch.. Kesava Reddy[!]

[#]Department of Mechanical Engineering, Chaitanya Bharathi Institute of Technology, Hyderabad- 500 075, Telangana India
[!]Department of Mechanical Engineering, Mahatma Gandhi Institute of Technology, Hyderabad- 500 075, Telangana India

Accepted 11 Sept 2016, Available online 25 Sept 2016, **Vol.6, No.3 (Sept 2016)**

Abstract

Vegetable oils present a very promising alternative for diesel fuel, since they have numerous advantages compared to fossil fuels. They are renewable, biodegradable and provide energy security, foreign exchange savings besides addressing socio–economic issues. However drawbacks associated with crude vegetable oils of high viscosity and low volatility which cause combustion problems in CI engines, call for engine with hot combustion chamber. They have significant characteristics of higher operating temperature, maximum heat release, and ability to handle low calorific value fuel. Investigations were carried out to determine exhaust emissions with low heat rejection diesel engine with crude mahua oil. It consisted of an air gap insulated piston, an air gap insulated liner and ceramic coated cylinder head with different operating conditions of mahua oil with varied injection timing and injector opening pressure. Exhaust emissions were determined at various values of brake mean effective pressure of the engine. Comparative studies on exhaust emissions were made for LHR engine and CE at manufacturer's recommended injection timing (27^o bTDC) and optimum injection timing with vegetable oil operation. LHR engine with crude oil showed reduction of particulate emissions at 27^o bTDC and at optimum injection timing over CE.

Keywords: *Vegetable oils, LHR combustion chamber; Fuel performance; Exhaust emissions.*

1. Introduction

Fossil fuels are limited resources; hence, search for renewable fuels is becoming more and more prominent for ensuring energy security and environmental protection. It has been found that the vegetable oils are promising substitute for diesel fuel, because of their properties are comparable to those of diesel fuel. They are renewable and can be easily produced. When Rudolph Diesel, first invented the diesel engine, about a century ago, he demonstrated the principle by employing peanut oil. He hinted that vegetable oil would be the future fuel in diesel engine [Venkanna, *et al.,* 2009].Several researchers 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. It caused the problems of piston ring sticking, injector and combustion chamber deposits, fuel system deposits, reduced power, reduced fuel economy and increased exhaust emissions [Venkanna *et al*., 2009; Acharya *et al*., 2009; Misra *et al*., 2010; Soo Young, *2011;* Avinash *et al.,* 2013].

Experiments were conducted on preheated vegetable oils in order to equalize their viscosity to that of mineral diesel may ease the problems of injection process [Pugazhvadivuand *et al.,* 2005; ; Agarwaland *et al.,* 2007; Hanbey Hazar *et al.,* 2007]. Investigations were carried out on engine with preheated vegetable oils. They reported that preheated vegetable oils marginally increased thermal efficiency, decreased particulate matter emissions and NO_x levels, when compared with normal vegetable oil.

Increased injector opening pressure may also result in efficient combustion in compression ignition engine [Celikten, 2003; Avinash *et al,* 2013]. It has a significance effect on performance and formation of pollutants inside the direct injection diesel engine combustion. Experiments were conducted on engine with crude vegetable oil with increased injector opening pressure. They reported that performance of the engine was improved, particulate emissions were reduced and NO_x levels were increased marginally with an increase of injector opening pressure.

The drawbacks associated with vegetable oil (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)

*Corresponding author: **Maddali V S Murali Krishna**

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 crude vegetable oil. 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 crude vegetable oil with varied injector opening pressure and injection timing [Chowdary, *et al*., 2012, Kesava Reddy *et al*., 2012; Janardhan *et al*., 2012; Janardhan *et al*., 2013; Subba Rao et., 2013]. They reported from their investigations, that engine with LHR combustion chamber at an optimum injection timing of 29 bTDC with crude vegetable oil increased brake thermal efficiency by 8–10%, at full load operation–decreased particulate emissions by 20–250% and increased NO_x levels, by 40–45% when compared with neat diesel operation on CE at 27° bTDC.

The present paper attempted to determine the exhaust emissions 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 crude mahua oil with different operating conditions with varied injection timing and injector opening pressure. Results were compared with CE with vegetable oil and also with diesel at similar operating conditions.

2. Material and method

2.1 Preparation of Oil

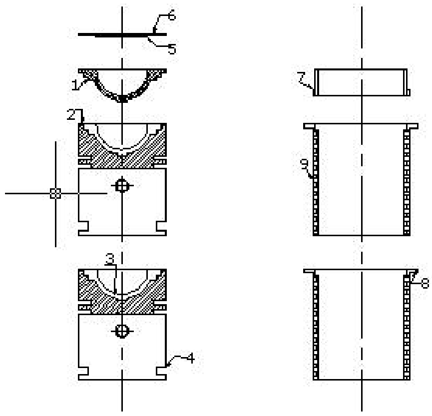
Mahua seeds have approximately 27% (w/w) oil content. Oil is obtained by crushing the seeds of plant. The properties of the Test Fuels used in the experiment were presented in Table-1.

Table.1 Properties of test fuels

Property	Units	Diesel (DF)	Crude Vegetable oil	ASTM Standard
Carbon Chain	--	C_8–C_{28}	C_{16}–C_{24}	---
Cetane Number	-	51	45	ASTM D 613
Specific Gravity at 15°C	-	0.8275	0.92	ASTM D 4809
Bulk Modulus at 15°C	MPa	1408.3	1350	ASTM D 6793
Kinematic Viscosity @ 40°C	cSt	2.5	54.44	ASTM D 445
Air Fuel Ratio (Stoichiometric)	--	14.86	13.5	--
Flash Point (Pensky Marten's Closed Cup)	° C	120	170	ASTM D93
Cold Filter Plugging Point	° C	Winter 6° C Summer 18°C	5° C	ASTM D 6371
Pour Point	° C	Winter 3°C Summer 15°C	0°C	ASTM D 97
Sulfur	(mg/kg,max)	50	55	ASTM D5453
Low Calorific Value	MJ/kg	42.0	38	ASTM D 7314
Oxygen Content	%	0.3	---	--

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 °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



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

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

Table.2 Specifications of Test Engine

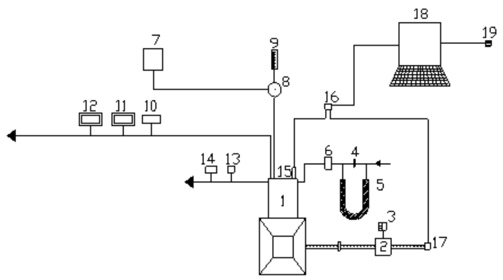
Description	Specification
Engine make and model	Kirloskar (India) AV1
Maximum power output at a speed of 1500 rpm	3.68 kW
Number of cylinders ×cylinder position× stroke	One × Vertical position × four-stroke
Bore × stroke	80 mm × 110 mm
Engine Displacement	553 cc
Method of cooling	Water cooled
Rated speed (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°bTDC × 190 bar
Number of holes of injector and size	Three × 0.25 mm
Type of combustion chamber	Direct injection type

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

2.3 Experimental set–up

The schematic diagram of the experimental setup used for the investigations on the engine with LHR combustion chamber with mahua oil 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 vegetable oil to the required levels (120°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°C by adjusting the water flow rate. The water flow rate was measured by means of analogue water flow meter, with accuracy of measurement of ±1%.



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, Pre-heater 9.Burette, 10. Exhaust gas temperature indicator, 11.AVL Smoke opacity meter,12. Netel Chromatograph NO_x Analyzer, 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.

Fig.2 Schematic diagram of experimental set–up

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%.

Exhaust emissions of particulate matter and nitrogen oxides (NO_x) were recorded by smoke opacity meter (AVL India, 437) and NO_x Analyzer (Netel India;4000 VM) at 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.

2.4Test Conditions

Test fuels used in the experiment were neat diesel and crude vegetable oil. Various configurations of the engine were conventional engine and engine with LHR combustion chamber. Different operating conditions of the vegetable oil 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° 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°bTDC, while it was 28°bTDC for engine with LHR combustion chamber with diesel operation [Murali Krishna, 2004; Murali Krishna *et al*., 2014]. Fig.3 shows variation of brake thermal efficiency with brake mean effective pressure (BMEP) in conventional engine with crude vegetable oil at various injection timings.

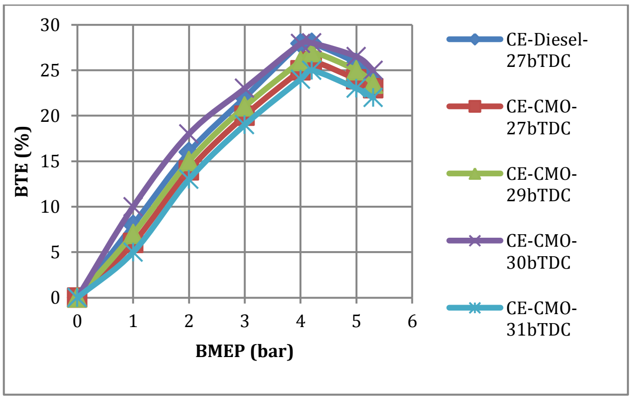


Fig. 3 Variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) in conventional engine (CE) with crude vegetable oil at various injection timings at an injector opening pressure of 190 bar

The trend exhibited by the CE with crude mahua oil was similar to that of the CE with neat diesel fuel. However, the CE with crude mahua showed the deterioration in the performance at all loads when compared to the neat diesel operation.

Although carbon accumulations on the nozzle tip might play a partial role for the general trends observed, the difference of viscosity between the diesel and crude mahua oil provided a possible explanation for the deterioration in the performance of the engine with crude mahua oil operation. According to the qualitative image of the combustion under the crude vegetable oil operation with CE, the lower BTE was attributed to the relatively retarded, lower heat release rates and calorific value. Murali Krishna observed the same trends with the crude jatropha oil at the normal temperature with the CE. Murali Krishna observed that the peak thermal efficiency with crude jatropha oil operation on CE was deteriorated by 14% while the author noticed it as 7%, when compared to neat diesel operation on the CE. This was due to higher calorific value of mahua oil employed by the author in CE.

BTE increased with the advanced injection timing with CE with crude vegetable oil at all loads, when compared with CE at the recommended injection timing and pressure. Increase of contact period of fuel with air might have improved combustion with vegetable oil in CE with advanced injection period. This was because of increase of contact period of fuel with air leading to improve atomization. Hence advancing of injection timing helped the initiation of combustion, when the piston was at TDC. BTE increased at all loads when the injection timing was advanced to 30°bTDC in the CE at the normal temperature of crude mahua oil (CMO).

Fig.4 shows variation of brake thermal efficiency with brake mean effective pressure (BMEP) in engine with LHR combustion chamber with crude vegetable oil at various injection timings. This curve followed similar trends with Fig.3. From Fig.4, it is observed that at 27° bTDC, engine with LHR combustion chamber with crude vegetable oil showed the improved performance at all loads when compared with diesel operation on CE. High cylinder temperatures helped in improved evaporation and faster combustion of the fuel injected into the combustion chamber. Reduction of ignition delay of the crude vegetable oil in the hot environment of the engine with LHR combustion chamber might have improved heat release rates. Engine with LHR combustion chamber with crude vegetable oil increased peak BTE by 8% at an optimum injection timing of 29° bTDC in comparison with neat diesel operation on CE at 27° bTDC.

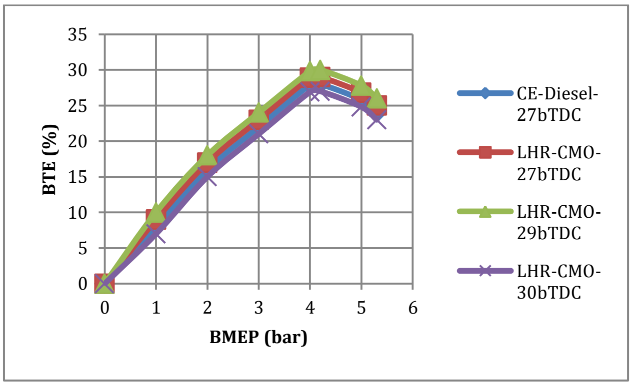


Fig.4 Variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) in engine with LHR combustion chamber with crude vegetable oil at various injection timings at an injector opening pressure of 190 bar.

Hot combustion chamber of LHR engine reduced ignition delay and combustion duration and hence the optimum injection timing (29° bTDC) was obtained earlier with engine with LHR combustion chamber when compared with CE (30° bTDC) with crude vegetable oil operation.

3.2 Exhaust Emissions

Particulate emissions and NO_x are the exhaust emissions from diesel engine cause health hazardslike inhaling of these pollutants cause severe headache, tuberculosis, lung cancer, nausea, respiratory problems, skin cancer, hemorrhage, etc. [Fulekar, 1999; Khopkar, 2010; Sharma, 2010]. In diesel engines, it is rather difficult to lower NO_x and particulate emissions simultaneously due to soot-NO_x tradeoff. High NO_x and particulate emissions are still the main obstacle in the development of next generation conventional diesel engines Therefore, the major challenge for the existing and future diesel engines is meeting the very tough emission targets at affordable cost, while improving fuel economy. They reported that fuel physical properties such as density and viscosity could have a greater influence on particular emission than chemical properties of the fuel [Avinash Kumar *et al*, 2013]. Fig.5 shows variation of particulate emissions with crude vegetable oil operation on both versions of the engine at recommended injection timing and optimum injection timing.

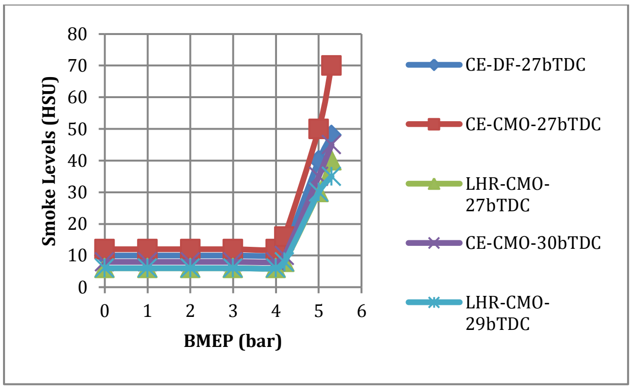


Fig.5 Variation of particulate emissions with brake mean effective pressure (BMEP) with crude vegetable oil with both versions of the engine at recommended injection timing and optimum injection timing.

From Fig.5, it is noticed that during the first part, particulate emissions were more or less constant, as there was always excess air present. However, at the higher load range there was an abrupt rise in particulate emissions due to less available oxygen, causing the decrease of air–fuel ratio, leading to incomplete combustion, producing more particulate emissions.

Particulate emissions were higher with crude vegetable oil with its higher density. Smoke levels were higher with vegetable oil due to presence of fatty acids. However, LHR engine reduced particulate emissions efficiency due to improved combustion and less amount of fuel accumulation on the hot combustion chamber walls of the LHR engine compared with the CE with diesel operation. Improved combustion with higher heat release rate decreased smoke levels with LHR engine. Particulate emissions deceased with advanced injection timing with both versions of the engine with vegetable oil operation Increased contact period of fuel with air and atomization might have improved combustion and hence lower particulate emissions.

Fig. 6 presents bar charts showing the variation of particulate emissions with different versions of the engine at recommended injection timing and optimized injection timing with crude mahua oil at an injection pressure of 190 bar.

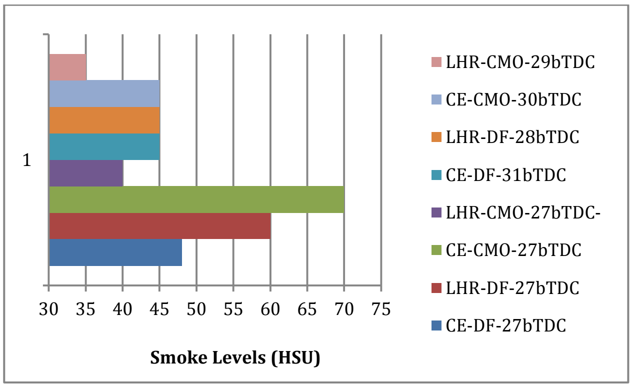


Fig.6 Bar chart showing the variation of particulate emissions at full load with crude mahua oil

CE with vegetable oil increased particulate emissions by 46% at recommended injection timing and 50% at optimum injection timing in comparison with neat diesel (DF) operation. LHR engine with vegetable oil decreased particulate emissions by 33% at recommended injection timing and 22% at optimum injection timing in comparison with neat diesel operation on same version of the engine. Cracking of fuel with reduction of ignition delay might have deteriorated the performance with LHR engine with diesel operation. CE with diesel operation decreased particulate emissions by 25% at recommended injection timing and 50% at optimum injection timing in comparison with LHR engine. Excessive temperatures m8ght have reduced ignition delay with LHR engine leading to deteriorate the performance of the engine. LHR engine with vegetable oil operation decreased particulate emissions by 42% at recommended injection timing and 33% at optimum injection timing in comparison with CE. This showed that LHR engine was more suitable to vegetable oil operation.

Table.4. shows data of smoke levels varied with injection pressure at different operating conditions of vegetable oil. Table.4. shows a decrease in particulate emissions with increase of injection timing and the injection pressure in both versions of the engine, with different operating conditions of the crude vegetable oil. Improvement in the fuel spray characteristics at higher injection pressures and increase of air entrainment, at the advanced injection timings, might have caused lower smoke levels. Preheating of the crude vegetable oil reduced particulate emissions in both versions of the engine, when compared with normal temperature of the crude vegetable oil.

Table.4 Data of particulate emissions at full load operation

Injection Timing (bTDC)	Test Fuel	Particulate Emissions at full load (Hartridge Smoke Unit)											
		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	--	60	--	55	--	50	--
	CMO	70	65	65	60	60	55	40	35	35	30	30	25
28	DF	---	---	---	---	---	---	45	---	40	---	35	----
29	CMO	---	----	---	---	---	---	35	30	30	25	25	20
30	CMO	45	40	50	45	55	50	---	---	---	---	---	---
31	DF	30	---	35	---	40	----	--	---	---	--	--	---

Reduction of density of the crude vegetable oil, as density was directly proportional to particulate emissions ii) the reduction of the diffusion combustion proportion in CE with the preheated crude vegetable oil, iii) the reduction of the viscosity of the crude vegetable oil, with which the fuel spray does not impinge on the combustion chamber walls of lower temperatures rather than it directed into the combustion chamber might have caused lower smoke levels. Density influences the fuel injection system. Decreasing the fuel density tends to increase spray dispersion and spray penetration. At the preheated condition, particulate emissions were observed to be less in comparison with normal condition of the crude vegetable oil, as the density decreased.

Fig.7. shows variation of nitrogen oxide (NO_x) levels with brake mean effective pressure with vegetable oil operation at an injection pressure of 190 bar. Fig.7 indicates for both versions of the engine, NO_x concentrations raised steadily as the fuel/air ratio increased with increasing BP/BMEP, at constant injection timing. At part load, NO_x concentrations were less in both versions of the engine. Availability of excess oxygen might have caused lower nitrogen oxide levels. At remaining loads, NO_x concentrations steadily increased with the load in both versions of the engine. This was because, local NO_x concentrations raised from the residual gas value following the start of combustion, to a peak at the point where the local burned gas equivalence ratio changed from lean to rich.

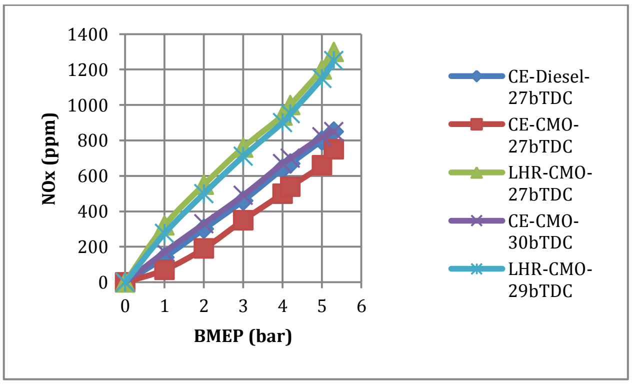


Fig.7 Variation of nitrogen oxide levels with brake mean effective pressure with vegetable oil operation

At full load, with higher peak pressures, and hence temperatures, and larger regions of close-to-stoichiometric burned gas, NO_x levels increased in both versions of the engine. Though amount of fuel injected decreased proportionally as the overall equivalence ratio was decreased, much of the fuel still burns close to stoichiometric. Thus NO_x emissions should be roughly proportional to the mass of fuel injected (provided burned gas pressures and temperature do not change greatly). It is noticed that NO_x levels were lower in CE while they were higher in LHR engine at different operating conditions of the crude vegetable oil at the full load when compared with diesel operation. Lower heat release rate with high duration of combustion caused lower gas temperatures with the crude vegetable oil on CE, which reduced NO_x levels. Increase of combustion temperatures with the faster combustion and improved heat release rates in LHR engine caused higher NO_x levels. NO_x levels increased with advanced injection timing with CE while they decreased with LHR engine with vegetable oil operation. Advanced injection timing might have increased gas temperatures with CE, while they decreased with LHR engine with improved oxygen fuel ratios.

Fig. 8 presents bar charts showing the variation of nitrogen oxide levels with different versions of the engine at recommended injection timing and optimized injection timing with crude mahua oil at an injection pressure of 190 bar. CE with vegetable oil decreased NO_x levels by 12% at recommended injection timing and 29% at optimum injection timing in comparison with neat diesel (DF) operation. Deteriorated combustion might have produced lower temperatures causing lower nitrogen oxide levels. LHR engine with vegetable oil increased nitrogen oxide levels by 4%at recommended injection timing and 4% at optimum injection timing in comparison with neat diesel operation on same version of the engine. Improved heat release rates might have produced higher NO_x levels with LHR engine with vegetable oil operation. LHR engine with diesel operation increased drastically NO_x levels by 53% at recommended injection timing and 14% at optimum injection timing in comparison with CE. Excessive temperatures m8ght have increased NO_x levels with LHR engine. LHR engine with vegetable oil operation increased NO_x levels by 80% at recommended injection timing and 52% at optimum injection timing in comparison with CE as in case of neat diesel operation.

Table.5 Data of nitrogen oxide levels at full load operation

Injection Timing (bTDC)	Test Fuel	Nitrogen oxide levels at full load (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	--	1250	--	1200	--
	CMO	750	700	800	750	850	800	1350	1300	1300	1250	1250	1200
28	DF	---	----	---	---	--	----	1250	---	1200	---	1150	---
29	CMO	---	---	----	---	---	----	1300	1250	1250	1200	1200	1150
30	CMO	850	800	900	850	950	900	---	--	--	---	---	---
31	DF	1100	----	1150	---	1250	-----	----	-----	-----	----	----	-----

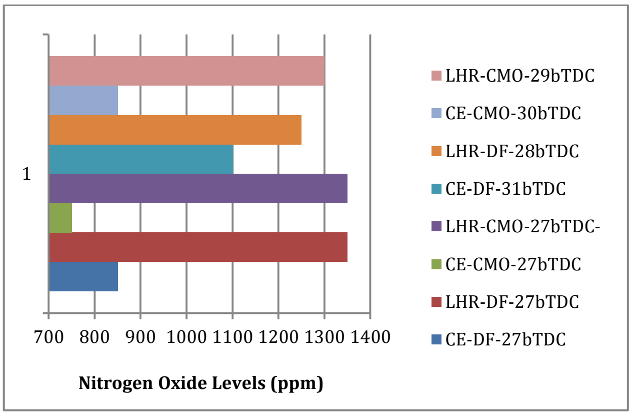


Fig.6 Bar chart showing the variation of nitrogen oxide levels at full load with crude mahua oil

Table.5 shows variation of nitrogen oxide levels with injection pressure with different versions of the engine with different operating conditions of the vegetable oil. Data in Table-5 shows that, NO_x levels increased with the advancing of the injection timing in CE with different operating conditions of crude vegetable oil. Residence time and availability of oxygen had increased, when the injection timing was advanced with these fuels, which caused higher NO_x levels in CE. However, NO_x levels decreased marginally with increase of injection timing with in LHR engine at different operating conditions of crude vegetable oil. Decrease of gas temperatures with the increase of air-fuel ratios might have reduced NOx levels with LHR engine. NOx levels increased with increase of injection pressure with CE, while they decreased with LHR engine with vegetable oil operation. 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 increase of gas temperatures marginally thus leading to in increase in NO_x levels with CE. [Rao, 2011; Heywood, 2013]. Marginal decrease of NO_x levels was observed in LHR engine, due to with 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**.** As expected, preheating of the crude vegetable oil decreased NO_x levels in both versions of the engine when compared with the normal vegetable oil. Improved air fuel ratios and decrease of combustion temperatures leading to decrease NOx emissions in the CE and LHR engine with vegetable oil operation.

Conclusions

1) Engine with LHR combustion chamber is efficient for alternative fuel like crude vegetable oil rather than neat diesel.
2) Engine with LHR combustion chamber with crude vegetable reduced particulate emissions and increased nitrogen oxide levels at full load operation over CE at recommended injection timing and optimized timing.
3) The exhaust emissions were improved with advanced injection timing, increase of injector opening pressure and with preheating with both versions of the combustion chamber with crude vegetable oil.

4.2 Novelty

Engine parameters (injection timing and injection pressure) fuel operating conditions (normal temperature and preheated temperature) and different configurations of the engine (conventional engine and engine with LHR combustion chamber) were used simultaneously to improve performance, exhaust emissions and combustion characteristics of the engine. Change of injection timing was accomplished by inserting copper shims between pump frame and engine body.

Highlights

- Fuel injection pressure & timings affect engine performance, exhaust emissions
- Exhaust emissions improve with preheating of crude vegetable oil

Future Scope of Work

Engine with LHR combustion chamber gave higher NO_x levels, which can be controlled by means of the selective catalytic reduction (SCR) technique using lanthanum ion exchanged zeolite (catalyst-A) and urea infused lanthanum ion exchanged zeolite (catalyst-B) with different versions of combustion chamber at full load operation of the engine [Janardhan, *et al*., 2012].

Acknowledgments

Authors thank authorities of Chaitanya Bharathi Institute of Technology, Hyderabad for providing facilities for carrying out this research work. Financial assistance provided by All India Council for Technical Education (AICTE), New Delhi is greatly acknowledged.

References

Venkanna, B.K., Venkataramana Reddy, C., Swati, B. and Wadawadagi. (2009), Performance, emission and combustion characteristics of direct injection diesel engine running on rice bran oil / diesel fuel blend. International Journal of Chemical and Biological Engineering, 2 (3),pp131-137.

Acharya, S.K., Swain, R,K. and Mohanti, M.K. (2009), The use of rice bran oil as a fuel for a small horse-power diesel engine. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 33 (1), pp 80-88,.

Misra, R.D. and Murthy, M.S. (2010), Straight vegetable oils usage in a compression ignition engine—A review. Renewable and Sustainable Energy Reviews*, vol.* 14,pp 3005–3013.

Soo-Young, No. (2011), Inedible vegetable oils and their derivatives for alternative diesel fuels in CI engines: A review. Renew Sustain Energy Rev, 15, pp 131–149.

Avinash Kumar Agarwal, and Atul Dhar, (2013), Experimental investigations of performance, emission and combustion characteristics of Karanja oil blends fuelled DICI engine, Renewable Energy, 52, pp 283–291.

Rakopoulos, C.D., Rakopoulos, D.C., Hountalas, D,T, *et al.* (2008), Performance and emissions of bus engine using blends of diesel fuel with biodiesel of sunflower or cottonseed oils derived from Greek feedstock, Fuel, 87, pp 147–157.

Pugazhvadivuand, M., Jayachandran, K. (2005), Investigations on the performance and exhaust emissions of a diesel engine using preheated waste frying oil as fuel, Renew energy, 30(14), pp 2189-2202.

Agarwaland, D., Agarwal, A.K. (2007), Performance and emissions characteristics of jatropha oil preheated and blendsin a direct injection compression ignition engine, Appl. Therm. Eng, 27(13), pp 2314–2323.

Hanbey Hazar and Huseyin Aydin, Performance and emission evaluation of a CI engine fueled with preheated raw rapeseed oil (RRO)-diesel blends, Applied Energy, vol. 87, pp 786–790, 2007.

Celikten, I, (2003), An experimental investigation of the effect of the injection pressure on engine performance and exhaust emission in indirect injection diesel engines, Appl Therm Eng, 23, pp 2051–60.

Avinash Kumar Agarwal, Dhananjay Kumar Srivastava, Atul Dhar, *et al*., (2013), Effect of fuel injection timing and pressure on combustion, emissions and performance characteristics of a single cylinder diesel engine, Fuel, 111, pp 374–83.

Chowdary, R.P., Murali Krishna, M.V.S., Reddy, T.K.K. and Murthy,P.V.K. (2012). Performance evaluation of a high grade low heat rejection diesel engine with waste fried vegetable oil. International Journal of Engg & Technology, 2(3),March,440-450

Kesava Reddy, Ch., Murali Krishna, M.V.S., Murthy, P.V.K. and Ratna Reddy, T. (2012) Performance evaluation of a high grade low heat rejection diesel engine with crude pongamia oil. International Journal of Engineering Research and Applications, 2(5), 1505-1516.

Janardhan, N., Murali Krishna, M.V.S., Ushasri, P. and Murthy, P.V.K. (2012). Performance of a low heat rejection diesel engine with jatropha. International Journal of Engineering Inventions, 1(2), 23-35.

N. Janardhan, M.V.S Murali Krishna, P. Ushasri and P.V.K. Murthy. (2013). Performance of evaluation of a low heat rejection diesel engine with jatropha oil. International Journal of Engineering Research in Africa. 11,27-44.

Subba Rao, B., Ramjee, E., Murthy, P.V.K. and Murali Krishna, M.V.S. (2013), Studies on exhaust emissions and combustion characteristics of tobacco seed oil in crude form and biodiesel from a high grade low heat rejection diesel engine, International Journal of Industrial Engineering and Technology,3(1),pp 27-36..

Murali Krishna, M.V.S., Janardhan, N., Kesava Reddy, Ch. and Krishna Murthy, P.V.K. (2014), Experimental investigations on DI diesel engine with different combustion chambers, British Journal of Applied Science & Technology, 6 (3), pp239–260,2014.

Murali Krishna, M.VS. (2004), Performance evaluation of low heat rejection diesel engine with alternative fuels, PhD Thesis, J. N. T. University, Hyderabad, India.

Fulekar, M.H. (1999), Chemical pollution – a threat to human life, Indian Journal of Environmental Technology, 1, pp 353-359.

Khopkar, S.M. (2010), Environmental Pollution Analysis, [New Age International (P) Ltd, Publishers, New Delhi], pp 180-190.

Sharma, B.K. (2010), Engineering Chemistry, [Pragathi Prakashan (P) Ltd, Meerut], pp 150-160

Rao, P.V. (2011), Effect of properties of Karanja methyl ester on combustion and NO_x emissions of a diesel engine.J Petroleum Tech& Alternative Fuels, 2(5), pp 63–75.

Heywood, J.B. (2013), Internal Combustion Engine Fundamentals, McGraw-Hill Book Company, New Delhi.

Janardhan, N., Ushasri, P., Murali Krishna, M.V.S. and Murthy, P.V.K. (2012), Performance of biodiesel in low heat rejection diesel engine with catalytic converter. International Journal of Engineering and Advanced Technology, 2(2), pp 97-109.