Experimental Investigations on Exhaust Emissions of Low Grade Semi Adiabatic Diesel Engine Fuelled With Linseed Oil and Its Biodiesel

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Abstract: Investigations were carried out to determine exhaust emissions of a low grade low heat rejection (LHR) diesel engine with ceramic coated cylinder head [ceramic coating of thickness 500 microns was done on inside portion of cylinder head] with different operating conditions [normal temperature and pre-heated temperature] of linseed oil and its biodiesel with varied injector opening pressure and injection timing. Exhaust emissions of particulate emissions and nitrogen oxide (NO_x) levels were evaluated at different values of brake mean effective pressure (BMEP) of the engine. Comparative studies were made with conventional engine (CE) with crude vegetable oil and its biodiesel and also with diesel operation with similar working condition. Particulate emissions decreased while NO_x levels increased with engine with LHR combustion chamber with biodiesel in comparison with CE. Biodiesel operation on both versions of engine showed reduction of particulate emissions and increase of NOx levels, in comparison with crude vegetable oil.

Keywords: biodiesel; Crude vegetable oil; exhaust emissions; LHR combustion chamber.

1.INTRODUCTION

Vegetable oils are promising substitutes for diesel fuel, as they are renewable in nature and properties are comparable to diesel fuel in scenario of depletion of fossil fuels and ever increase of fuel prices in International Market and increase of pollution levels with fossil fuels. 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 and hinted that vegetable oil would be the future fuel [1]. Several researchers experimented the use of vegetable oils as fuel on conventional engines and reported that the performance was poor, citing the problems of high viscosity, low volatility and their polyunsaturated character. [2] [3] [4] [5] [6].These problems can be solved to some extent, if neat vegetable oils are chemically modified (esterified) to bio-diesel. Experiments were conducted on conventional diesel engine with biodiesel operation. They reported that biodiesel increased efficiency marginally and decreased particulate emissions and increased oxides of nitrogen.[7] [8] [9] [10] [11] [12] [13] [14] [15]. The drawbacks (high viscosity and low volatility) of biodiesel call for LHR engine which provide hot combustion chamber for burning these fuels which got high duration of combustion.

The concept of engine with LHR combustion chamber is to minimize heat loss to the coolant by providing thermal insulation in the path of the coolant thereby increases the thermal efficiency of the engine. Several methods adopted for achieving LHR to the coolant are i) using ceramic coatings on piston, liner and cylinder head (low grade LHR combustion chamber) ii) creating air gap in the piston and other components with low-thermal conductivity materials like superni (an alloy of nickel), cast iron and mild steel etc. (medium grade LHR combustion chamber) and iii) combination of low grade and medium grade LHR combustion chamber resulted in high grade LHR combustion chamber. Investigations were carried out on engine with low grade LHR combustion chamber with neat diesel operation and it was reported that ceramic coatings provided adequate insulation and improved brake specific fuel consumption (BSFC). [16] [17] [18]. Experiments were extended to crude vegetable oils and biodiesel with LHR engine with ceramic coated cylinder head. They reported that peak BTE increased by 3–5%, particulate emissions decreased by 15–20% and NO_x levels increased by 25–30% with LHR engine with crude vegetable oil in comparison with conventional engine with crude vegetable oil operation [19] [20] [21] [22] [23] [24] [25]. They reported that peak BTE increased by 5–7%, particulate emissions decreased by 20–25% and NO_x levels increased by 30–35% with LHR engine with biodiesel in comparison with conventional engine with biodiesel operation [26] [27] [28]..

However, comparative studies were not made with diesel operation working on similar conditions.

Experiments were conducted on preheated vegetable oils [temperature at which viscosity of the vegetable oils were matched to that of diesel fuel]. [29] [30] [31] [32]. 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 [33]. 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.[34] [35] [36]. They reported that particulate emissions decreased with increase of injector opening pressure.

The present paper attempted to study exhaust emissions of engine with LHR combustion chamber which contained ceramic coated cylinder head fuelled with different operating conditions of crude linseed oil and its biodiesel with varied injector opening pressure and injection timing and compared with CE with biodiesel operation and also with mineral diesel operation working on similar working conditions.

2. MATERIAL AND METHOD

2.1 Preparation of biodiesel

The chemical conversion of esterification reduced viscosity four fold. Linseed oil contains up to 70 % (wt.) free fatty acids. The methyl ester was produced by chemically reacting crude linseed oil with methanol in the presence of a catalyst (KOH). A two–stage process was used for the esterification of the crude linseed oil [37]. The first stage (acid-catalyzed) of the process is to reduce the free fatty acids (FFA) content in linseed 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 linseed oil to methanol was 9:1 and 0.5% catalyst (w/w). In the second stage (alkali-catalyzed), the triglyceride portion of the linseed 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.

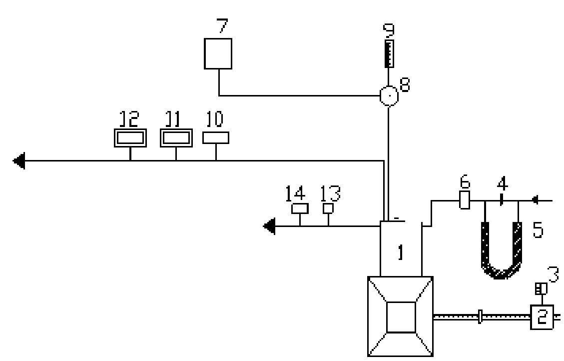
Table.1.

Properties Test Fuels

Test Fuel	Viscosity at 25ºC (Centi-Stroke)	Specific gravity at 25ºC	Cetane number	Lower Calorific value (kJ/kg)
Diesel	2.5	0.82	51	42000
Crude Vegetable oil (LSO)	4.5	0.92	45	41500
Biodiesel (BD)	3.7	0.90	55	41000
ASTM Standard	ASTM D 445	ASTM D 4809	ASTM D 613	ASTM D 7314

2.2 Experimental Set-up

Partially stabilized zirconium (PSZ) of thickness 500 microns was coated on inside portion of cylinder head. Experimental setup used for study of exhaust emissions on low grade LHR diesel engine with linseed biodiesel in Fig.1 The specification of the experimental engine is shown in Table.2 The engine was connected to an electric dynamometer (Kirloskar make) for measuring its brake power. Dynamometer was loaded by loading rheostat. The naturally aspirated engine was provided with water-cooling system in which outlet temperature of water is maintained at 80ºC by adjusting the water flow rate. 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. Injection timing was changed by inserting copper shims between pump body and engine frame. 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 various values of BMEP of the engine.



1.Engine, 2.Electical Dynamo meter, 3.Load Box, 4.Orifice meter, 5.U-tube water manometer, 6.Air box, 7.Fuel tank, 8, Three way valve, 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,

Fig.1. Experimental Set-up

Table.2

Specifications of the 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
Dynamometer	Electrical dynamometer
Number of holes of injector and size	Three × 0.25 mm
Type of combustion chamber	Direct injection type

2.3 Operating Conditions

The different configurations used in the experimentation were conventional engine and engine with LHR combustion chamber. The various operating conditions of the vegetable oil used in the experiment were normal temperature (NT) and preheated temperature (PT–It is the temperature at which viscosity of the vegetable oil or biodiesel is matched to that of diesel fuel,). The injection pressures were varied from 190 bar to 270 bar. Various test fuels used in the experiment were biodiesel and diesel.

3. RESULTS AND DISCUSSION

3.1 Fuel Performance

The optimum injection timing was 31° bTDC with CE, while it was 30° bTDC for engine with low grade LHR combustion chamber with diesel operation [38].

From Fig.2, it is observed CE with biodiesel at 27° bTDC showed comparable performance at all loads due to improved combustion with the presence of oxygen, when compared with mineral diesel operation on CE at 27° bTDC. CE with biodiesel operation at 27° bTDC decreased peak BTE by 3%, when compared with diesel operation on CE. This was due to low calorific value and high viscosity of biodiesel. CE with biodiesel operation increased BTE at all loads with advanced injection timing, when compared with CE with biodiesel operation at 27° bTDC. This was due to initiation of combustion at early period and increase of resident time of fuel with air leading to increase of peak pressures. CE with biodiesel operation increased peak BTE by 7% at an optimum injection timing of 31° bTDC, when compared with diesel operation at 27° bTDC

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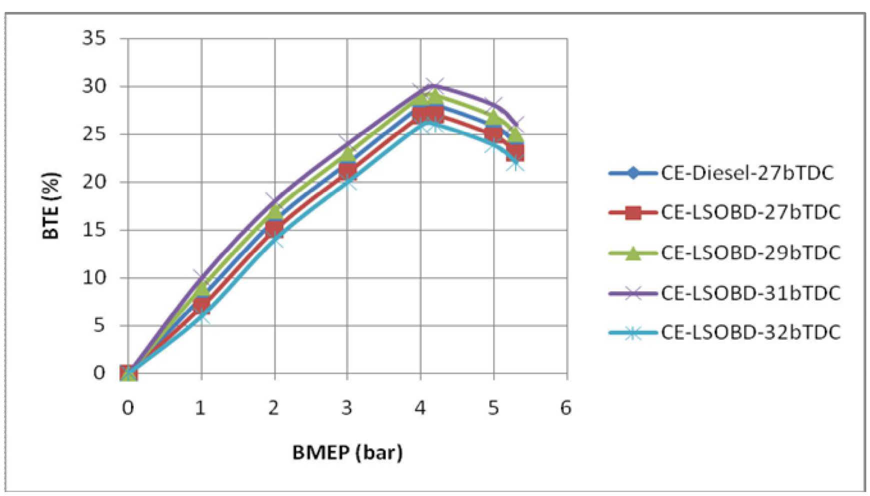

Fig.2. Variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) in conventional engine (CE) and with various injection timings at an injector opening pressure of 190 bar with biodiesel

Curves in Fig.3 indicate that LHR version of the engine at recommended injection timing showed the improved performance at all loads compared with CE with pure diesel operation. High cylinder temperatures helped in improved 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 combustion chamber improved heat release rates and efficient energy utilization. The optimum injection timing was found to be 30ºbTDC with LHR combustion chamber with different operating conditions of biodiesel operation. Since the hot combustion chamber of LHR combustion chamber reduced ignition delay and combustion duration and hence the optimum injection timing was obtained earlier with LHR combustion chamber when compared to conventional engine with the biodiesel operation.

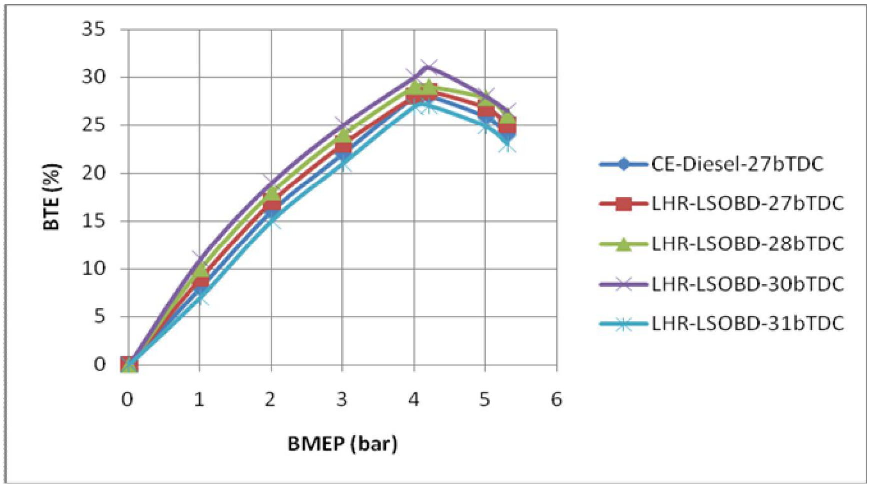

Fig.3 Variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) in LHR combustion chamber at different injection timings with biodiesel (LSOBD) operation.

Similarly the optimum injection timing with CE with crude vegetable oil was found to be 32ºbTDC, while it was 31º bTDC for LHR engine

3.2 Exhaust Emissions

Particulate emissions and NOx are the emissions from diesel engine cause health hazards like inhaling of these pollutants cause severe headache, tuberculosis, lung cancer, nausea, respiratory problems, skin cancer, hemorrhage, etc. [39] [40] [41]. The contaminated air containing carbon dioxide released from automobiles reaches ocean in the form of acid rain, there by polluting water. Hence control of these emissions is an immediate task and important.

Fig. 4 shows variation of particulate emissions with brake mean effective pressure (BMEP) with biodiesel operation with both versions of the engine at recommended injection timing and optimum injection timing. From Fig.4, 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.

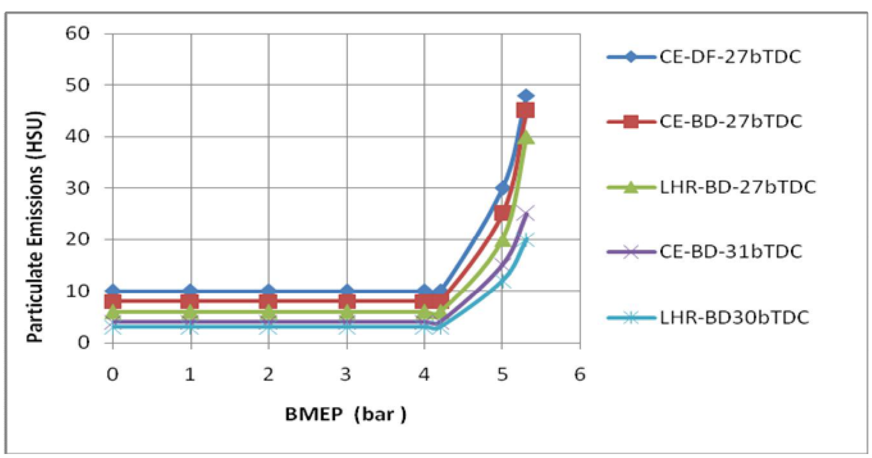

Fig.4. Variation of particulate emissions in Hartridge smoke unit (HSU) with brake mean effective pressure (BMEP) in conventional engine (CE) and engine with LHR combustion chamber at recommended injection timing and optimum injection timing and at an injector opening pressure of 190 bar with biodiesel (BD)

From Fig.4, it is noticed that particulate emissions at all loads reduced marginally with CE with biodiesel operation in comparison with diesel operation on CE. Improved combustion with improved cetane number and also with presence of oxygen in composition of fuel might have reduced particulate emissions. Particulate emissions further reduced with engine with LHR combustion chamber when compared with CE. Improved combustion with improved heat release rate might have reduced particulate emissions. Particulate emissions at full load reduced with advanced injection timing with both versions of the combustion chamber. Increase of resident time and more contact o fuel with air leading to increase atomization might have reduced particulate emissions.

Fig.5. presents bar charts showing the variation of particulate emissions at full load with both versions of the engine with test fuels at recommended injection timing and optimum injection timing with test fuels. Biodiesel reduced particulate emissions at full load with CE by 6% at recommended injection timing and 20% at optimum injection timing with in comparison with diesel operation with CE. Biodiesel reduced particulate emissions at full load with LHR engine by 20% at recommended injection timing and 43% at optimum injection timing with in comparison with diesel operation on same version of the engine.

CE with crude vegetable oil increased particulate emissions at full load by 46% at recommended injection timing and 67% at optimum injection timing with in comparison with diesel operation on same version of the engine. Presence of fatty acids in the composition of crude vegetable oil, high value of C/H ratio (C= Number of carbon atoms, H= Number of hydrogen atoms in the composition of fuel) and high density of crude vegetable oil leads to the formation of drastic increase of particulate emissions. LHR engine with crude vegetable oil reduced particulate emissions at full load by 46% at recommended injection timing and 25% at optimum injection timing with in comparison with diesel operation on same version of the engine. This showed that LHR engine was more suitable for crude vegetable oil and biodiesel as it effectively reduced particulate emissions.

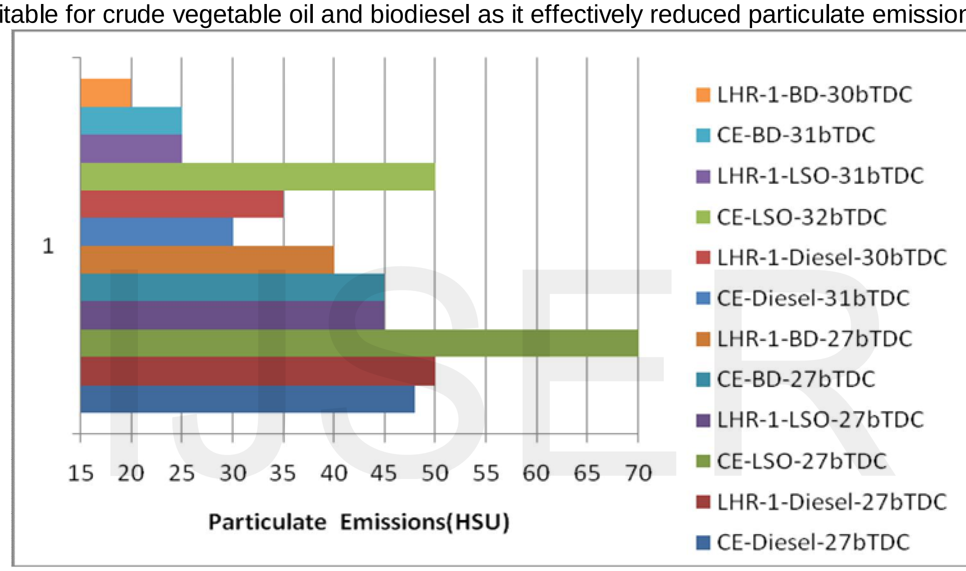

Fig.5. Bar charts showing the variation of particulate emissions at full load with both versions of the engine at recommended injection timing and optimum injection timing with test fuels.

Fig. 6 shows variation of nitrogen oxide levels with brake mean effective pressure (BMEP) with biodiesel operation with both versions of the engine at recommended injection timing and optimum injection timing.

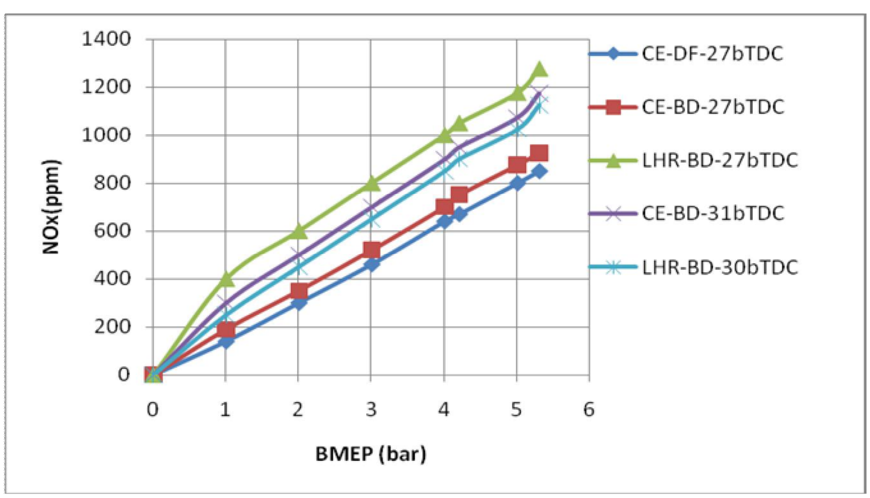

Fig.6 Variation of nitrogen oxide levels with brake mean effective pressure (BMEP) in conventional engine (CE) and engine with LHR combustion chamber at recommended injection timing and optimum injection timing and at an injector opening pressure of 190 bar with biodiesel (BD)

Fig.6 indicates for both versions of the engine, NOx concentrations raised steadily with increasing BMEP at constant injection timing. At part load, NO_x concentrations were less in both versions of the engine. This was due to the availability of excess oxygen. 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. Curves in Fig.5 indicate that NO_x levels at all loads were marginally higher in CE, while they were drastically higher in engine with LHR combustion chamber at different operating conditions of the biodiesel at the full load when compared with diesel operation on CE. Presence of oxygen (10%) in the methyl ester, which leads to improvement in oxidation of the nitrogen available during combustion, raised the combustion bulk temperature responsible for thermal NO_x formation. Increase of combustion temperatures with the faster combustion and improved heat release rates associated with the availability of oxygen in LHR engine caused drastically higher NO_x levels in engine with LHR combustion chamber.
Fig. 7 presents bar charts showing the variation of NOx levels at full load with both versions of the engine with test fuels at recommended injection timing and optimum injection timing with test fuels.

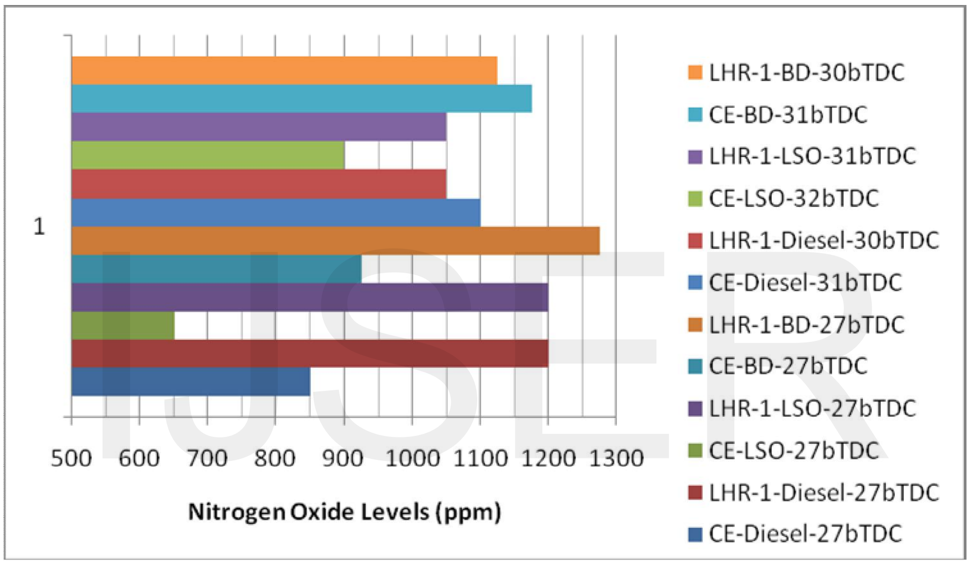

Fig.7. Bar charts showing the variation of nitrogen oxide levels at full load with both versions of the engine at recommended injection timing and optimum injection timing with test fuels

Biodiesel increased NO_x levels at full load with CE by 9% at recommended injection timing and 18% at optimum injection timing with in comparison with diesel operation with CE. Biodiesel increased NO_x emissions at full load with LHR engine by 6% at recommended injection timing and 7% at optimum injection timing with in comparison with diesel operation on same version of the engine.
CE with crude vegetable oil decreased NO_x emissions at full load by 24% at recommended injection timing and 23% at optimum injection timing with in comparison with diesel operation on same version of the engine. NO_x levels are lower with CE with vegetable oil because low heat release rate due to deterioration in combustion.
LHR engine with crude vegetable oil showed comparable NO_x emissions at full load at recommended injection timing and at optimum injection timing in comparison with diesel operation on same version of the engine.

Table.3 shows data of exhaust emissions at full load varied with injector opening pressure and at different operating conditions of the crude vegetable oil and its biodiesel. From Table.3, it is understood that particulate emissions decreased with preheating of crude vegetable oil and its biodiesel with both versions of the combustion chamber. This was because of reduction of density, viscosity of fuel and improved spray characteristics of fuel. From same Table, it is noticed that, particulate emissions decreased with increase of injector opening pressure in both versions of the engine with test fuels. Improved air fuel ratios with improved spray characteristics of the test fuels might have reduced particulate emissions.
Data in Table.3 shows that, NO_x levels decreased with preheating of crude vegetable oil and its biodiesel. As fuel temperature increased, there was an improvement in the ignition quality, which caused shortening of ignition delay. A short ignition delay period lowered the peak combustion temperature which suppressed NO_x formation. NO_x levels increased with an increase of injector opening pressure with different operating conditions of crude vegetable oil and its biodiesel with CE. Fuel droplets penetrate and find oxygen counterpart easily with the increase of injector opening pressure. Turbulence of the fuel spray increased the spread of the droplets which caused increase of gas temperatures marginally thus leading to increase in NO_x levels with CE. Marginal decrease of NO_x levels was observed in engine with LHR combustion chamber, due to decrease of combustion temperatures with improved air fuel ratios.

Table.3
Data of Exhaust Emissions

Injection timing (deg. bTDC)	Combustion chamber version	Test Fuel	Exhaust Emissions at full load operation							
			Particulate Emissions (HSU)				NO_x Levels (ppm)			
			Injector Opening Pressure (bar)				Injector Opening Pressure (bar)			
			190		270		190		270	
			NT	PT	NT	PT	NT	PT	NT	PT
27	CE	Diesel	48	___	34	___	850	__	950	__
	CE	BD	45	40	35	30	925	875	1025	975
	CE	LSO	70	60	50	40	650	600	550	500
	LHR	Diesel	50	__	40	__	1200	__	1100	__
	LHR	LSO	45	40	35	30	1200	1150	1100	1050
	LHR	BD	40	35	30	25	1275	1225	1175	1125
30	LHR	Diesel	35	__	25	__	1050	__	950	___
	LHR	BD	20	15	15	10	1125	1075	1025	975
31	CE	Diesel	30	__	35	__	1100	__	1200	__
	LHR	LSO	25	20	20	15	1050	1000	950	900
	CE	BD	25	20	35	30	1175	1225	1275	1225
32	CE	LSO	50	45	60	55	900	850	800	750

4.

SUMMARY

1. Biodiesel operation decreased particulate emissions at full load with CE by 36% at recommended injection timing and 50% at optimum injection timing in comparison with crude vegetable oil operation. LHR engine reduced particulate emissions at full load by 11% at recommended injection timing and 20% at optimum injection timing when compared with LHR engine with crude vegetable oil operation.
2. Biodiesel operation increased nitrogen oxide emissions at full load with CE by 42% at recommended injection timing and 31% at optimum injection timing in comparison with crude vegetable oil operation. LHR engine increased nitrogen oxide levels at full load by 6% at recommended injection timing and 7% at optimum injection timing when compared with LHR engine with crude vegetable oil operation
3. Advanced injection timing and increase of injector opening pressure improved exhaust emissions with crude vegetable oil operation and its biodiesel operation on engine with LHR combustion chamber.
4. Preheated crude vegetable oil and its biodiesel reduced particulate emissions and NO_x levels in both versions of the combustion chamber.

4.1. Research Findings

Exhaust emissions from engine with ceramic coated combustion chamber were studied with varied injector opening pressure and injection timing at different operating conditions of crude linseed oil and its biodiesel.

4.2Recommendations

Engine with low grade LHR combustion chamber gave higher levels of NO_x at full load operation, These emissions can be controlled by selective catalytic reduction technique [42].

4.3 Scientific Significance

Change of injection timing and injection pressure were attempted to reduce pollutants from the engine along with change of configuration of combustion chamber with different operating conditions of the crude vegetable oil and its biodiesel.

4.4 Social Significance

Use of renewable fuels will strengthen agricultural economy, which curbs crude petroleum imports, saves foreign exchange and provides energy security besides addressing the environmental concerns and socio-economic issues.

4.5 Novelty

Change of injection timing of the engine was accomplished by inserting copper shims between pump body and engine frame

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REFERENCES

1. Deepak Agarwal, Lokesh Kumar and Avinash Kumar Agarwal. "Performance evaluation of a vegetable oil fuelled compression ignition engine," Renewable Energy, vol. 33, no. 6, pp 1147–1156, 2008.
2. P.K. Devan and N.V. Mahalakshmi, "Performance, emission and combustion characteristics of poon oil and its blends in a DI diesel engine," Fuel, vol. 88, pp 861-870, 2009.
3. S.K. Acharya, R.K. Swain and M.K. Mohanti, " 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, vol. 33, no. 1, pp 80-88, 2009.
4. R.D. Misra and M.S. Murthy, "Straight vegetable oils usage in a compression ignition engine—A review," Renew Sustain Energy Rev, vol. 14, pp 3005–3013, 2010..
5. No. Soo-Young, " Inedible vegetable oils and their derivatives for alternative diesel fuels in CI engines: A review, " Renew Sustain Energy Rev, vol. 15, pp 131–149, 2011.
6. Avinash Kumar Agarwal and Atul Dhar, " Experimental investigations of performance, emission and combustion characteristics of Karanja oil blends fuelled DICI engine," Renewable Energy, vol. 52, pp 283–291, 2013.
7. N. Venkateswara Rao, M.V.S. Murali Krishna and P.V.K. Murthy, "Comparative studies on exhaust emissions and combustion characteristics of tobacco seed oil in crude form and biodiesel form in direct injection diesel engine," International Journal of Mechanical and Production Engineering Research and Development, vol. 3, no. (4), pp 125-138, 2013.
8. D.Srikanth, M.V.S. Murali Krishna, P. Usha Sri and P.V. Krishna Murthy, "Performance evaluation of a diesel engine fuelled with cotton seed oil in crude form and biodiesel form," International Journal of Academic Research for Multidisciplinary, vol. 1, no. 9, ,pp 329-349, 2013.
9. B. Baiju, M.K. Naik and L.M. Das, "A comparative evaluation of compression ignition engine characteristics using methyl and ethyl esters of karanja oil, Renewable energy, vol. 34, pp 1616-1621, 2009.
10. A. Murugesan, C. Umarani, R. Subramanian and N. Nedunchezhian, "Bio-diesel as an alternate fuel for diesel engines," Renewable and Sustainable Energy Reviews, vol. 13, no.3, pp 653-662, 2009.
11. P.K. Sahoo, L.M. Das, M.K.G. Babu, P. Arora, V.P. Singh, N.R. Kumar and T.S. Varyani, "Comparative evaluation of performance and emission characteristics of jatropha, curanja and polanga based biodiesel as fuel in tractor engine," Fuel, 88(9), 1698-170, 2009.
12. P.K. Devan, and N.V. Mahalakshmi, "Performance, emission and combustion characteristics of a compression ignition engine using methyl ester of paradise oil- eucalyptus oil blends," Applied Energy, vol. 86, pp 675-680, 2009.
13. P.M. McCarthy, M.G. Rasul and S. Moazzem, " Analysis and comparison of performance and emissions of an internal combustion engine fuelled with petroleum diesel and different biodiesels, Fuel, vol. 90, pp 2147–2157, 2011.
14. Anirudh Gautam and Avinash Kumar Agarwal, " Experimental investigations of comparative performance, emission and combustion characteristics of a cottonseed biodiesel fueled four–stroke locomotive diesel engine," Int J Engine Res,14, pp 354-360, 2013.
15. Krishna Maddali and Chowdary R. Comparative studies on performance evaluation of waste fried vegetable oil in crude form and biodiesel form in conventional diesel engine, SAE Paper 2014–01–1947, 2014.
16. A. Parlak, H. Yasar and O. Idogan, " The effect of thermal barrier coating on a turbocharged Diesel engine performance and exergy potential of the exhaust gas. Energy Conversion and Management, vol. 46, no. 3, pp 489–499, 2005.
17. B. Ekrem, E. Tahsin and C. Muhammet, " Effects of thermal barrier coating on gas emissions and performance of a LHR engine with different injection timings and valve adjustments. Journal of Energy Conversion and Management, 47, pp 1298-1310, 2006.
18. M. Ciniviz, C. Hasimoglu, F. Sahin and M.S. Salman, "Impact of thermal barrier coating application on the performance and emissions of a turbocharged diesel engine. Proceedings of The Institution of Mechanical Engineers Part D-Journal Of Automobile Eng, vol. 222, no. D12, pp 2447–2455, 2008.
19. N. Venkateswara Rao, M.V.S. Murali Krishna and P.V.K. Murthy, " Comparative studies on exhaust emissions and combustion characteristics of ceramic coated diesel engine with tobacco seed oil based biodiesel," International Journal of Advanced Scientific & Technical Research, vol. 3, no.5, pp 334–349, 2013.
20. D. Srikanth, M.V.S. Murali Krishna, P. Usha Sri and P.V. Krishna Murthy, " Performance exhaust emissions, and combustion characteristics of cotton seed oil based biodiesel in ceramic coated diesel engine," International Journal of Mechanical Engineering, vol. 2, no.5, pp 67-82, 2013.
21. M.V.S. Murali Krishna, R.P. Chowdary, T.Kishen Kumar Reddy and P.V.K. Murthy, Performance evaluation of waste fried vegetable oil in la low grade low heat rejection diesel engine,"International Journal of Research in Mechanical Engineering and Technology, vol. 2, no.2, pp 35-43, 2012.
22. R.P. Chowdary, M.V.S. Murali Krishna and T.Kishen Kumar Reddy, "Studies on exhaust emissions from ceramic coated diesel engine with waste fried vegetable oil based biodiesel," International Journal of Mechanical Engineering and Technology, July, vol. 5, no.7,pp 127–135, 2014.
23. Ch. Kesava Reddy, M.V.S. Murali Krishna, P.V.K. Murthy and T. Ratna Reddy, "Performance evaluation of a low grade low heat rejection diesel engine with crude Pongamia oil," International Scholarly Research Network (ISRN) Renewable Energy, Article ID 489605, pp 1-10, 2012.
24. T. Ratna Reddy, M.V.S. Murali Krishna, Ch. Kesava Reddy and P.V.K. Murthy, "Studies on performance of ceramic coated diesel engine fuelled with crude mohr oil," International Journal of Engineering Sciences, vol. 2, no.4, pp 119-129, 2013.
25. T. Ratna Reddy, M.V.S. Murali Krishna, Ch. Kesava Reddy and P.V.K. Murthy, "Comparative performance of ceramic coated diesel engine with mohr oil in crude and biodiesel form," International Journal of Engineering and Advanced Technology, vol. 2, no. (3), pp 588-596, 2012.
26. N. Janardhan, M.V. S. Murali Krishna, P. Usha Sri and P.V.K. Murthy., "Performance, emissions and combustion characteristics with ceramic coated diesel engine with jatropha oil based biodiesel," International Journal of Energy and Technology, vol.5, no.21,pp 1-3, 2013.
27. D. Srikanth, M.V.S. Murali Krishna, P.Usha Sri and P.V.Krishna Murthy, "Performance exhaust emissions, and combustion characteristics of cotton seed oil based biodiesel in ceramic coated diesel engine,". International Journal of Mechanical Engineering, vol. 2, no. 5, 67-82.
28. N. Venkateswara Rao, M.V.S. Murali Krishna and P.V.K. Murthy. "Comparative studies on exhaust emissions and combustion characteristics of ceramic coated diesel engine with tobacco seed oil based biodiesel," International Journal of Advanced Scientific & Technical Research, vol. 3, no. 5, pp 334-349, 2013.
29. D. Agarwal and A.K. Agarwal, "Performance and emissions characteristics of jatropha oil (preheated and blends) in a direct injection compression ignition engine. Int. J. Applied Thermal Engineering, vol. 27, pp 2314-23, 2007.

30. M. Canaker, A.N. Ozsezen and A. Turkcan, “Combustion analysis of preheated crude sunflower oil in an IDI diesel engine,” Biomass Bio-energy, vol. 33, pp 760-770, 2009.
31. 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, 2010..
32. A.K. Agarwal and A. Dhar, “Experimental investigation of preheated Jatropha oil fuelled direct injection compression ignition engine: Part I, performance, emission and combustion characteristics. Journal of ASTM International 2010; vol. 7, pp 1-13, 2010.
33. J.B. Heywood, (1988), Fundamentals of Internal combustion engines, Tata McGraw Hills, NewYork.
34. S. Jindal, B.P. Nandwana, N.S. Rathore and V. Vashistha, “Experimental investigation of the effect of compression ratio and injector opening pressure in a direct injection diesel engine running on Jatropha methyl ester,” Applied Thermal Engineering, vol. 30, pp 442–448, 2010.
35. B.K. Venkanna and R.C. Venkataramana, “ Influence of fuel injection rate on the performance, emission and combustion characteristics of DI diesel engine running on calophyllum inophyllum linn oil (honne oil) / diesel fuel blend,” SAE Technical Paper No. 2010-01-1961, 2010.
36. Avinash Kumar Agarwal, Dhananjay Kumar Srivastava, Atul Dhar, et al. “Effect of fuel injection timing and pressure on combustion, emissions and performance characteristics of a single cylinder diesel engine,” Fuel vol. 111, pp. 374–83, 2013.
37. Md Nurun Nabi, S.M Najmul Hoque, “Biodiesel production from linseed oil and performance study of a diesel engine with diesel bio-diesel, Journal of Mechanical Engineering,’ vol. 39, no.1, 40-44, 2008.
38. M.V.S. Murali Krishna, N. Janardhan, Ch. Kesava Reddy and P.V.Krishna Murthy, “ Experimental investigations on DI diesel engine with different combustion chambers, British Journal of Applied Science & Technology, vol. 6, no. 3, pp 239–260, 2014..
39. M.H. Fulekar, “Chemical pollution – a threat to human life,” Indian Journal of Environmental Technology, vol. 1, pp 353-359, 1999.
40. S.M. Khopkar, “Environmental Pollution Analysis,” [New Age International (P) Ltd, Publishers, New Delhi], pp 180-190, 2010.
41. B.K. Sharma, “ Engineering Chemistry, [Pragathi Prakashan (P) Ltd, Meerut], pp 150-160, 2010.
42. N. Janardhan, P. Usha Sri, M.V.S. Murali Krishna and P.V.K. Murthy, “Performance of biodiesel in low heat rejection diesel engine with catalytic converter,” International Journal of Engineering and Advanced Technology, vol. 2, no.2, 97–109, 2012.