International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

Investigations of Exhaust Emissions of Di Diesel Engine Fuelled with Crude Rice Bran Oil

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Accepted 15 May 2016, Available online 23 May 2016, **Vol.6, No.3 (June 2016)**

Abstract

Investigations were carried out to determine exhaust emissions of a conventional diesel engine with different operating conditions [normal temperature and pre-heated temperature] of rice bran oil in crude form with varied injection timing and injector opening pressure. Exhaust emissions [particulate emissions and oxides of nitrogen(NO_x)] were determined at various values of brake mean effective pressure of the engine fuelled with diesel and crude rice bran oil. Comparative studies on exhaust emissions were made with diesel working on similar conditions. Particulate emissions increased, while NOx levels decreased with crude vegetable oil operation. Exhaust emissions improved with increase of injector opening pressure, advanced injection timing and preheating of vegetable oil.

***Keywords**: Alternative fuels, vegetable oils, exhaust emissions*

Introduction

The rapid depletion of petroleum fuels and their ever increasing costs have led 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 and 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 [Matthias Lamping *et al*, 2008]. 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. [A.K. Agarwal,2006; P.K. Devan et al, 2009; A.K.Agarwal *et al,* 2010; R.D.Misra *et al,* 2010; N.Venkateswara Rao *et al,* 2013; Avinash Kumar Agarwal et al, 2013]

Experiments were conducted on preheated vegetable oils [temperature at which viscosity of the vegetable oils were matched to that of diesel fuel]. [S.Bari *et al*, 2002; Nwafor et al, 2003; M. Senthil Kumar *et al*, 2005; D. Agarwal *et a*l, 2007]. 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 [J.B. Heywood, 1988]. 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.[I.Celikten, 2003; Y.Cingur, 2003; D.Hountalas *et al,* 2003; B.K. Venkanna *et al*, 2010]. 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.[N.Venkateswara Rao *et al,* 2013; Chandrakasan et al, 2012] They reported that performance of the engine improved with advanced injection timing, increased NOx emissions and decreased particulate emissions.

Little literature was available on comparative studies on exhaust emissions with crude rice bran oil with diesel engine. Hence an attempt was made here to determine exhaust emissions with crude rice bran oil at different operating conditions with varied injection timing and injector opening pressure.

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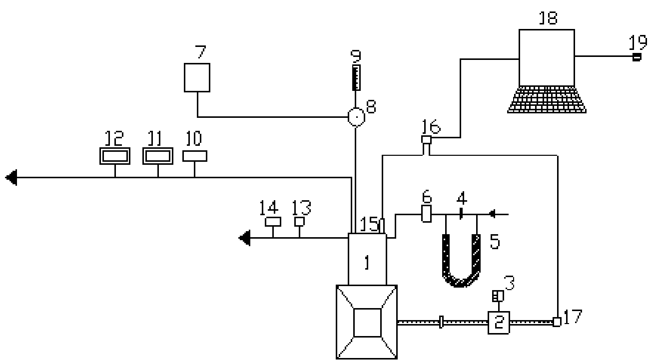
Table 1 Properties of Test Fuels

Property	Units	Diesel(DF)	Crude Vegetable oil (CRBO)	ASTM Standard
Carbon chain	--	C_8-C_{28}	C_{12}-C_{20}	
Cetane Number		55	45	ASTM D 613
Density	gm/cc	0.84	0.90	ASTM D 4809
Bulk modulus @ 20Mpa	Mpa	1475	2050	ASTM D 6793
Kinematic viscosity @ 40^{o}C	cSt	2.25	4.5	ASTM D 445
Sulfur	%	0.25	0.4	
Oxygen	%	0.3	0.2	
Air fuel ratio (stochiometric)	--	14.86	15.5	
Lower calorific value	kJ/kg	42 000	39000	ASTM D 7314
Flash point (Open cup)	^{o}C	66	190	ASTM D93
Molecular weight	--	226	290	
Preheated temperature	^{o}C	--	85	--
Colour	--	Light yellow	Dark yellow	---

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
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	5.31 bar
Manufacturer's recommended injection timing and pressure	27^{o}bTDC × 190 bar
Dynamometer	Electrical dynamometer
Number of holes of injector and size	Three × 0.25 mm
Type of combustion chamber	Direct injection type
Fuel injection nozzle	Make: MICO-BOSCH No- 0431-202-120/HB
Fuel injection pump	Make: BOSCH: NO- 8085587/1



1.Engine, 2.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 meter, 12.Netel Chromatograph NOx Analyzer, 13.Outlet jacket water temperature

Fig.1 Experimental setup

2. Materials and Methods

The physic-chemical properties of the crude vegetable oil in comparison to ASTM standards are presented in Table-1. Schematic diagram of experimental setup used for the investigations on compression ignition diesel engine with crude vegetable oil (CRBO) is shown in Fig.1

The test fuels used in the experimentation were neat diesel and crude rice bran oil. The specifications of the experimental engine are shown in Table-2.

The combustion chamber consisted of a direct injection type with no special arrangement for swirling motion of air. The engine was connected to an electric dynamometer for measuring its brake power. Burette method was used for finding fuel consumption of the engine. Air-consumption of the engine was measured by an air-box method (Air box was provided with an orifice flow meter and U-tube water manometer). 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. Engine oil was provided with a pressure feed system. No temperature control was incorporated, for measuring the lube oil temperature. Copper shims of suitable size were provided in between the pump body and the engine frame, to vary the injection timing and its effect on the performance of the engine was studied, along with the change of injector opening pressure from 190 bar to 270 bar (in steps of 40 bar) using nozzle testing device. The maximum injector opening pressure was restricted to 270 bar due to practical difficulties involved. Exhaust gas temperature was measured with thermocouples made of iron and iron-constantan.

Exhaust emissions of smoke and NO_x were recorded by AVL (A company trade name) smoke meter and Netel Chromatograph (A company trade name) NOx analyzer respectively at full load operation of the engine. The specifications of the analyzers were given in Table-3.

Table 3 Specifications of Analyzers

Name of the analyzer	Measuring Range	Precision	Resolution
AVL Smoke meter	0-100 HSU	1 HSU	1 HSU
Netel Chromatograph NOx analyzer	0-5000 ppm	5 ppm	1 ppm

Various test fuels used in experimentation were neat diesel and crude rice bran oil Different operating conditions of the crude rice bran oil were normal temperature and preheated temperature. Different injector opening injector opening pressures attempted in this experimentation were 190 bar, 230 bar and 270 bar. Various injection timings attempted in the investigations were 27-34 °bTDC.

Recommended injection timing: It is the injection timing of the engine with maximum efficiency of the engine with minimum pollution levels.

Optimum injection timing: It is injection timing at which maximum thermal efficiency was obtained at all loads and beyond this injection timing, efficiency of the engine decreased.

3. Results and Discussion

3.1 Performance

Fig.2 indicates that variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) with conventional engine (CE) at various injection timing with crude vegetable oil at an injector opening pressure of 190 bar. From Fig.2 it is noticed that BTE increased up to 80% of BMEP (BMEP at full load=5.3 bar) and beyond that load it decreased with crude vegetable oil. Increase of fuel conversion efficiency and mechanical efficiency up to 80% of the full load might have improved the performance of the engine. Decrease of air fuel ratios and reduction of volumetric efficiency beyond 80% of the full load might have caused reduction in thermal efficiency. 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 vegetable oil provided a possible explanation for the deterioration in the performance of the engine with crude vegetable oil operation. Furthermore droplet mean diameters (expressed as Sauter mean) were larger for crude vegetable oil leading to reduce the rate of heat release as compared with diesel fuel. BTE increased with the advancing of the injection timing in engine with the crude vegetable oil at all loads, when compared with engine at the recommended injection timing and pressure.

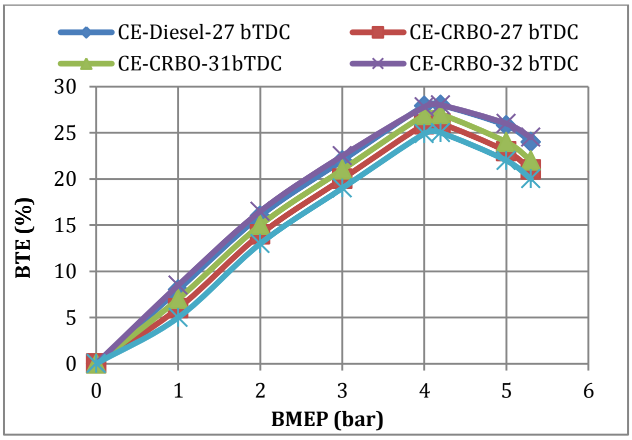


Fig.2 Variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) in conventional engine (CE) at different injection timings with crude rice brawn oil (CRBO) operation

Initiation of combustion at earlier period and efficient combustion with increase of air entrainment in fuel spray might have increased BTE with advanced injection timing. BTE increased at all loads when the injection timing was advanced to 32°bTDC in the CE at the normal temperature of CRBO.

Part load variations were very small and minute for the performance parameters and exhaust emissions. The effect of varied injection timing (advanced injection timing) on the performance with test fuels was discussed with the help of bar charts, while the effect of increase of injector opening pressure was discussed with the help of Tables.

Tabe.4 Data of exhaust emissions at full load operation

Injection Timing (° bTDC)	Test Fuel	Particulate emissions (Hartridge Smoke Unit)						NO_x Levels (ppm)					
		Injector Opening Pressure (Bar)						Injector Opening 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	--	850	----	900	----	950	---
	CRBO	65	60	60	55	55	50	700	650	750	700	800	750
31	DF	30	--	35	--	40	--	1100	--	1150	--	1200	--
32	CRBO	50	45	55	50	60	55	900	850	950	900	1000	950

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. [S.M. Khopkar, 2004; B.K.Sharma 2005]] 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.3 shows variation of particulate emissions with brake mean effective pressure (BMEP) at recommended injection timing and optimum injection timing with CE with crude vegetable oil operation. In the same graph, trends of diesel fuel were also given for the purpose of comparison.

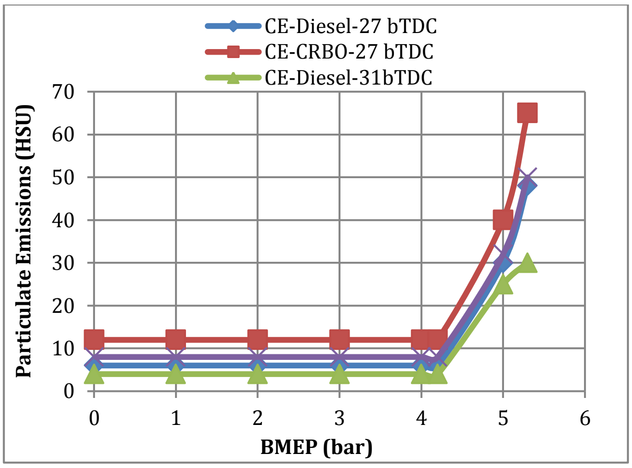


Fig.3 Variation of particulate emissions with brake mean effective pressure with test fuels in conventional engine (CE) with vegetable oil and diesel at recommended and optimum injection timing

From Fig.3, it is observed that drastic increase of particulate emissions at full load operation with vegetable oil (s) operation was observed compared with pure diesel operation. This was due to the higher value of ratio of C/H (C= Number of carbon atoms and H= Number of hydrogen atoms in fuel composition, higher the value of this ratio means, number of carbon atoms are higher leading to produce more carbon dioxide and more carbon monoxide and hence higher smoke levels) of crude vegetable oil (0.7) when compared with pure neat diesel (0.45). The increase of particulate emissions was also due to decrease of air-fuel ratios and volumetric efficiency with vegetable oil compared with neat diesel operation.

Particulate emissions were related to the density of the fuel. Since vegetable oil has higher density compared to diesel fuel, particulate emissions were higher with vegetable oil(s). Particulate emissions decreased at the respective optimum injection timing with test fuels. Increase of contact period of fuel with air might have increased atomization and caused reduction of particulate emissions. The optimum injection timing for diesel operation on CE was 31° bTDC (M.V.S. Murali Krishna *et al*, 2014].

Fig.4 presents bar charts showing the variation of particulate emissions at full load with crude vegetable oil and diesel at recommended injection timing and optimum injection timing with conventional engine.

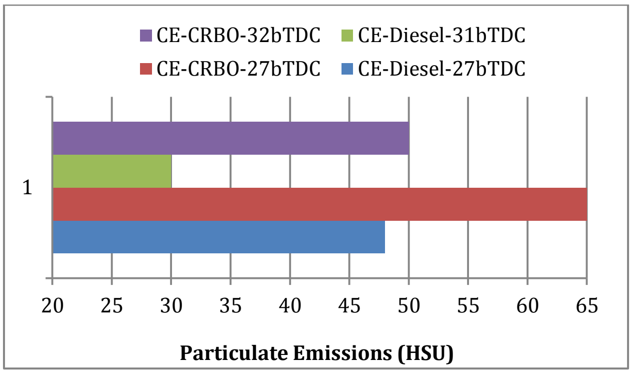


Fig.4 Bar charts showing the variation of particulate emissions in Hartridge smoke unit (HSU) at full load operation with test fuels at recommended and optimized injection timings at an injector opening pressure of 190 bar

Particulate emissions at full load increased by 35% at recommended injection timing and 67% at optimum injection timing with crude vegetable oil operation on CE in comparison with neat diesel (DF) operation. Table.4 shows data of particulate emissions varied with injector opening pressure at different operating conditions of the crude vegetable oil.

Data from Table 4 shows a decrease in particulate emissions with increase of injector opening pressure, with different operating conditions of the crude vegetable oil. Improvement in spray characteristics might have reduced particulate emissions.

Preheating of the vegetable oil reduced particulate emissions, when compared with normal temperature of the vegetable oil. This was due to i) the reduction of density of the vegetable oil , as density was directly related to particulate emissions, ii) the reduction of the diffusion combustion proportion with the preheated vegetable oil iii) the reduction of the viscosity of the vegetable oil , with which the fuel spray does not impinge on the combustion chamber walls of lower temperatures rather than it directed into the combustion chamber.

The different fatty acids present in the vegetable oil are palmic, steric, lingoceric, oleic, linoleic and fatty acids. These fatty acids increase particulate emissions and also lead to incomplete combustion due to improper air-fuel mixing.

Temperature and availability of oxygen are two favorable conditions to form NO_x levels. Fig.5 shows variation of NOx levels with brake mean effective pressure (BMEP) with crude vegetable oil operation with CE at recommended injection timing and optimum injection timing. At full load, NO_x levels increased with test fuels at recommended injection timing due to higher peak pressures, temperatures as larger regions of gas burned at close-to-stoichiometric ratios. From Fig.5, it is noticed that NOx levels were lower with crude vegetable oil operation at the full load when compared with diesel operation.

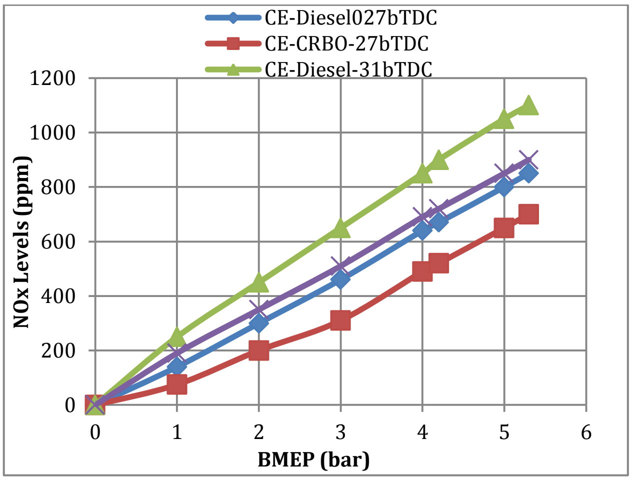


Fig.5 Variation of nitrogen oxide levels (NO_x) with brake mean effective pressure with test fuels in conventional engine (CE) with vegetable oil and diesel at recommended and optimum injection timing.

Lower heat release rate because of high duration of combustion (high viscous fuels) might have caused lower gas temperatures with the vegetable oil operation, which decreased NO_x levels. NO_x levels increased with advanced injection timing with test fuels. Residence time and availability of oxygen had increased, when the injection timing was advanced with test fuels, which caused higher NOx levels.

Fig.6 presents bar charts showing the variation of nitrogen oxide levels at full load with crude vegetable oil and diesel at recommended injection timing and optimum injection timing with conventional engine. From Fig.6, it is noticed that NOx levels decreased by 18% at recommended injection timing and 18% at optimum injection timing with CE with crude vegetable oil operation in comparison with neat diesel operation.

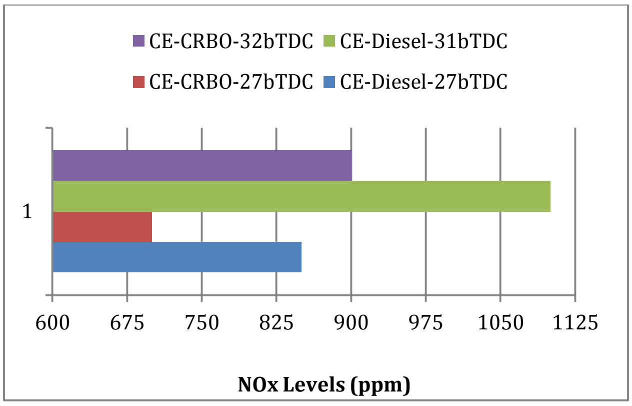


Fig.6 Bar charts showing the variation of nitrogen oxide levels (NO_x) at full load operation with test fuels at recommended and optimized injection timings at an injector opening pressure of 190 bar

From the Table 4, it is noted that NOx levels increased with increase of injector opening pressure with different operating conditions of vegetable oil.

NO_x slightly increased with test fuels as injector opening pressure increased. This was because of improved combustion causes higher peak brake thermal efficiency due to higher combustion chamber pressure and temperature, which leads to higher NO_x formation. This is an evident proof of enhanced spray characteristics, thus improving fuel air mixture preparation and evaporation process.

NOx levels decreased with preheating of the vegetable oil (s) as noticed from the Table.4. The fuel spray properties may be altered due to differences in viscosity and surface tension. The spray properties affected may include droplet size, droplet momentum, degree of mixing, penetration, and evaporation. The change in any of these properties may lead to different relative duration of premixed and diffusive combustion regimes. Since the two burning processes (premixed and diffused) have different emission formation characteristics, the change in spray properties due to preheating of the vegetable oil are lead to reduction in NO_x formation. As fuel temperature increased, there was an improvement in the ignition quality, which will cause shortening of ignition delay.

Conclusions

1) Particulate emissions at full load increased by 35% at recommended injection timing and 67% at optimum injection timing with crude vegetable oil operation on CE in comparison with neat diesel operation.

2) NOx levels decreased by 18% at recommended injection timing and 18% at optimum injection timing with CE with crude vegetable oil operation in comparison with neat diesel operation.
3) With increase of injector opening pressure, Smoke levels decreased and NOx levels increased with test fuels.
4) With preheating, decrease of smoke levels and NOx levels were observed with test fuels.

Research Findings and Suggestions

Comparative studies were made on exhaust emissions with different operating conditions of crude vegetable oil with varied injection timing and injector opening pressure in direct injection diesel engine.

Vegetable oil requires hot combustion chamber as they are highly 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 in this direction is necessary.

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, was greatly acknowledged.

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