

Research Article

# Experimental Investigations on Exhaust Emissions of Di Diesel Engine with Tobacco Seed Biodiesel with Varied Injection Timing and Injection Pressure

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## Abstract

*In the scenario of depletion of fossil fuels, the search for alternative fuels has become pertinent. Vegetable oils are promising substitutes for diesel fuels. Biodiesels derived from vegetable oils present a very promising alternative to diesel fuel since biodiesels have numerous advantages compared to fossil fuels as they are renewable, biodegradable, provide energy security and foreign exchange savings besides addressing environmental concerns and socio-economic issues. Experiments were conducted to determine exhaust emissions of a conventional diesel engine with tobacco seed biodiesel 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 tobacco seed biodiesel. Comparative studies on exhaust emissions were made with diesel working on similar conditions. Particulate emissions decreased, while  $NO_x$  levels increased with biodiesel operation. Exhaust emissions improved with increase of injector opening pressure and advanced injection timing.*

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

## 1. 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. 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]. The drawbacks associated with crude vegetable oil for use in diesel engine of high viscosity and low volatility were reduced to some extent, if crude vegetable oils are chemical converted into biodiesel. Experiments were conducted with biodiesel in conventional engine. [McCarthy *et al*, 2011; Xue *et al*, 2011; Anirudh Gautam *et al*, 2013; Durga Prasada Rao *et al*, 2014]. They reported that marginal

improvement of performance and reduction of particulate emissions and increase of nitrogen oxide levels with biodiesel operation in comparison with diesel operation on conventional engine.

Experiments were conducted on preheated vegetable oils [temperature at which viscosity of the vegetable oils were matched to that of diesel fuel]. [S. Bari *et al*, 2002; Nwafor *et al*, 2003; M. Senthil Kumar *et al*, 2005; D. Agarwal *et al*, 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

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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° 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 tobacco seed oil with diesel engine. Hence an attempt was made here to determine exhaust emissions with crude tobacco seed oil at different operating conditions with varied injection timing and injector opening pressure.

## 2. Materials and Methods

### Preparation of Biodiesel

The chemical conversion of esterification reduced viscosity four fold. Crude jatropha oil contains up to 15 % (wt.) free fatty acids. The flow chart of extraction of biodiesel was shown in Fig.1.

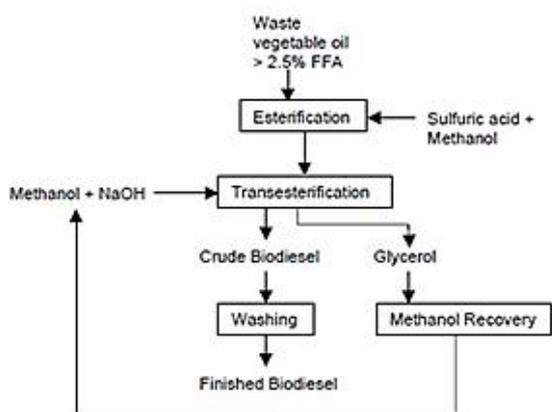


Fig.1 Flow chart of preparation of biodiesel

The methyl ester was produced by chemically reacting the crude pongamia oil with methanol in the presence of a catalyst (KOH). A two-stage process was used for the esterification of the crude vegetable oil. [Anirudh Gautam, 2013]. The first stage (acid-catalyzed) of the process is to reduce the free fatty acids (FFA) content in pongamia oil by esterification with methanol (99% pure) and acid catalyst (sulfuric acid-98% pure) in one hour time of reaction at 55°C. In the second stage (alkali-catalyzed), the triglyceride portion of the pongamia oil reacts with methanol and base catalyst (sodium hydroxide-99% pure), in one hour time of reaction at 65°C, to form methyl ester and glycerol.

The physical-chemical properties of the biodiesel in comparison to ASTM standards are presented in Table-1. Molar ratio of tobacco seed oil to methanol

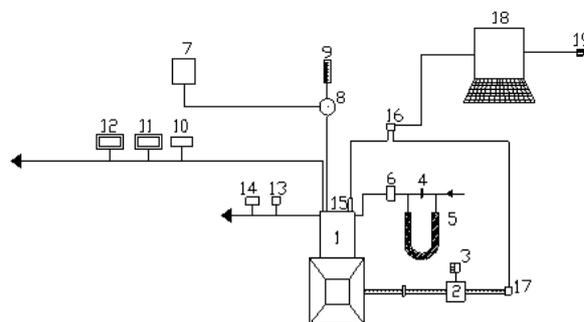
was 9:1 and 0.75% catalyst (w/w). To remove unreacted methoxide present in raw methyl ester, it is purified by the process of water washing with air-bubbling.

The methyl ester (or biodiesel) produced from crude tobacco seed oil was known as tobacco seed biodiesel. The properties of the Test Fuels used in the experiment were presented in Table-1. Fuels with flash point above 52° C are considered as safe. Thus biodiesel is extremely safe fuel to handle, as its flash point is 165° C. The lower heat of combustion of biodiesel was 6% lower, while its density is 5% higher than neat diesel giving rise to heat input marginally equal to mineral diesel.

Table.1 Properties of Test Fuels

Property	Units	Diesel(DF)	Tobacco seed biodiesel	ASTM Standard
Carbon chain	--	C8-C28	C16-C24	
Cetane Number		55	52	ASTM D 613
Density	gm/cc	0.84	0.86	ASTM D 4809
Bulk modulus @ 20Mpa	Mpa	1475	1800	ASTM D 6793
Kinematic viscosity @ 40°C	cSt	2.25	3.5	ASTM D 445
Sulfur	%	0.25	0.0	
Oxygen	%	0.3	11	
Lower calorific value	kJ/kg	42 000	38500	ASTM D 7314

Schematic diagram of experimental setup used for the investigations on compression ignition diesel engine with tobacco seed biodiesel is shown in Fig.2



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 indicator, 14. Outlet-jacket water flow meter, 15.Piezoelectric pressure transducer, 16.Console, 17.TDC encoder, 18.Pentium Personal Computer and 19. Printer

Fig.2 Schematic diagram of experimental set-up

The test fuels used in the experimentation were neat diesel and tobacco seed biodiesel. The specifications of the experimental engine are shown in Table-2. 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°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

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<sub>x</sub> were recorded by AVL (A company trade name) smoke meter and Netel Chromatograph (A company trade name) NO<sub>x</sub> 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 NO <sub>x</sub> analyzer	0-5000 ppm	5 ppm	1 ppm

Various test fuels used in experimentation were neat diesel and tobacco seed biodiesel oil. Different operating conditions of the crude tobacco seed oil were normal temperature and preheated temperature. Different injector opening injector opening pressures attempted in this experiment 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 Discussions

3.1 Performance

Fig.3 indicates that variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) with conventional engine (CE) at various injection timing with biodiesel at an injector opening pressure of 190 bar. From Fig.3 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 biodiesel. 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. Low calorific value of biodiesel might have produced low BTE in comparison with diesel operation at recommended injection timing. BTE increased with the advancing of the injection timing in engine with the biodiesel at all loads, when compared with engine at the recommended injection timing and pressure.

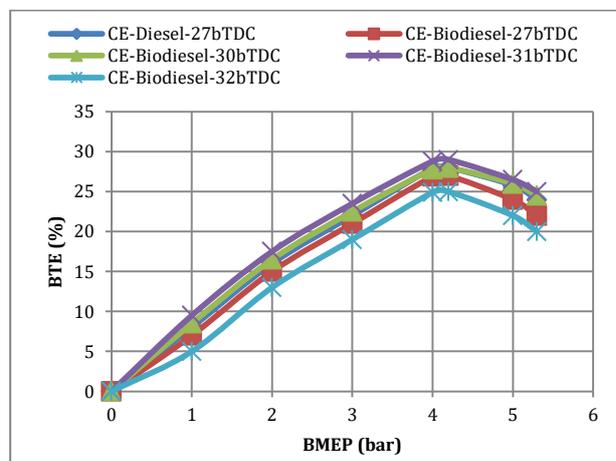


Fig.3 Variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) in conventional engine (CE) at different injection timings with tobacco seed biodiesel operation

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 31°bTDC in the CE at the normal temperature of biodieesl.

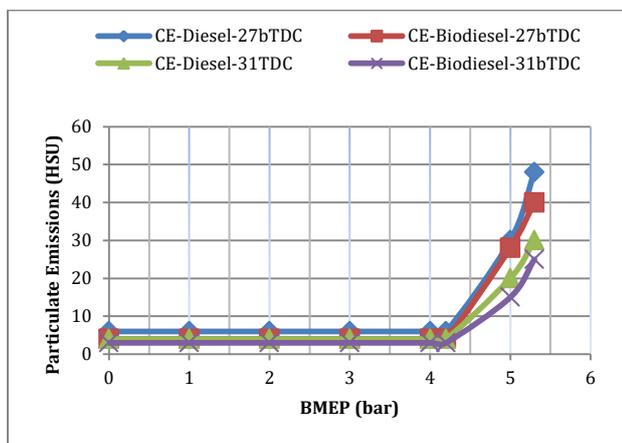
Part load variations were very small and minute for the performance parameters and exhaust emissions. The effect of varied injection timing (advanced injection timing) on the performance with test fuels was discussed with the help of bar charts, while the effect of increase of injector opening pressure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

### 3.2 Exhaust Emissions

Particulate emissions and NO<sub>x</sub> 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.

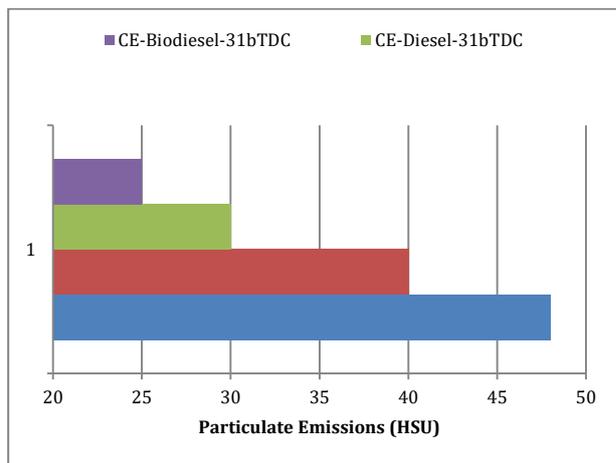
Fig.4 shows variation of particulate emissions with brake mean effective pressure (BMEP) at recommended injection timing and optimum injection timing with CE with biodiesel oil operation. In the same graph, trends of diesel fuel were also given for the purpose of comparison.

From Fig.3, it is observed that reduction of particulate emissions at full load operation with biodiesel operation was observed when compared with neat diesel operation. Presence of oxygen in fuel composition improved combustion, causing 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** Variation of particulate emissions with brake mean effective pressure with test fuels in conventional engine (CE) with biodiesel and diesel at recommended and optimum injection timing

Fig.5 presents bar charts showing the variation of particulate emissions at full load with biodiesel and diesel at recommended injection timing and optimum injection timing with conventional engine.



**Fig. 5** 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 decreased by 6% at recommended injection timing and 17% at optimum injection timing with biodiesel 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 biodiesel.

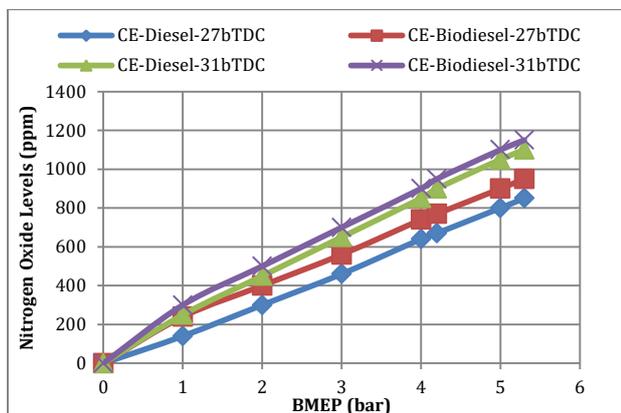
**Table.4** Data of exhaust emissions at full load operation

Injection Timing (° bTDC)	Test Fuel	Particulate emissions (Hartridge Smoke Unit)			NO <sub>x</sub> Levels (ppm)		
		Injector Opening Pressure (Bar)			Injector Opening Pressure (Bar)		
		190	230	270	190	230	270
27	DF	48	38	34	850	900	950
	Biodiesel	40	30	25	950	1050	1100
31	DF	30	35	40	1100	1150	1200
	Biodiesel	25	20	20	1150	1250	1300

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

Temperature and availability of oxygen are two favorable conditions to form NO<sub>x</sub> levels. Fig.5 shows variation of NO<sub>x</sub> levels with brake mean effective pressure (BMEP) with biodiesel operation with CE at recommended injection timing and optimum injection timing. At full load, NO<sub>x</sub> 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 NO<sub>x</sub> levels were higher with biodiesel operation at the full load when compared with diesel operation.



**Fig.6** Variation of nitrogen oxide levels (NO<sub>x</sub>) with brake mean effective pressure with test fuels in conventional engine (CE) at recommended and optimum injection timing

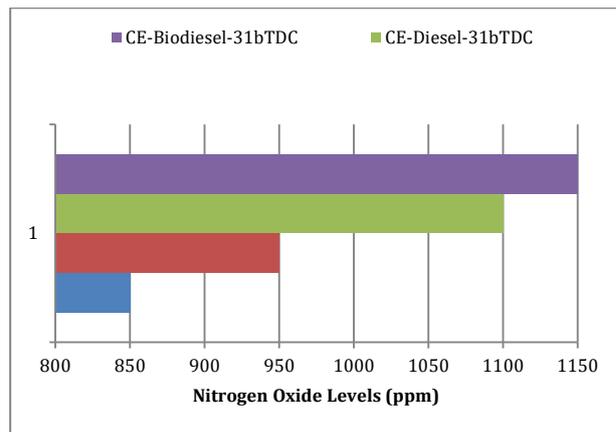
The tobacco seed oil biodiesel having long carbon chain (C<sub>20</sub>-C<sub>32</sub>) recorded more NO<sub>x</sub> than that of fossil diesel having both medium (C<sub>8</sub>-C<sub>14</sub>) as well as long chain (C<sub>16</sub>-C<sub>28</sub>). The increase in NO<sub>x</sub> emission might be an inherent characteristic of biodiesel due to the presence of 54.9% of mono-unsaturated fatty acids (MUFA) and 18% of poly-unsaturated fatty acids (PUFA). That means, the long chain unsaturated fatty acids (MUFA and FUPA) such as oleic C18:1 and linoleic C18:2 fatty acids are mainly responsible for higher levels of NO<sub>x</sub> emission. Another reason for higher NO<sub>x</sub> levels is the oxygen (10%) present in the methyl ester. The presence of oxygen in normal biodiesel leads to improvement in oxidation of the nitrogen available during combustion. This will raise the combustion bulk temperature responsible for thermal NO<sub>x</sub> formation.

The production of higher NO<sub>x</sub> with biodiesel fueling is also attributable to an inadvertent advance of fuel injection timing due to higher bulk modulus of compressibility, with the in-line fuel injection system.

Residence time and availability of oxygen had increased, when the injection timing was advanced with test fuels, which caused higher NO<sub>x</sub> levels. NO<sub>x</sub> 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 NO<sub>x</sub> levels.

Fig7 presents bar charts showing the variation of nitrogen oxide levels at full load with biodiesel and diesel at recommended injection timing and optimum injection timing with conventional engine.

From Fig.7, it is noticed that NO<sub>x</sub> levels increased by 12% at recommended injection timing and 5% at optimum injection timing with CE with biodiesel operation in comparison with neat diesel operation.



**Fig. 7** Bar charts showing the variation of nitrogen oxide levels (NO<sub>x</sub>) at full load operation with test fuels at recommended and optimum injection timings at an injector opening pressure of 190 bar

From Table 4, it is noted that NO<sub>x</sub> levels increased with increase of injector opening pressure with different operating conditions of biodiesel.

NO<sub>x</sub> 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<sub>x</sub> formation. This is an evident proof of enhanced spray characteristics, thus improving fuel air mixture preparation and evaporation process.

## Conclusions

- 1) Particulate emissions at full load decreased by 6% at recommended injection timing and 17% at optimum injection timing with biodiesel operation on CE in comparison with neat diesel operation.
- 2) NO<sub>x</sub> levels increased by 12% at recommended injection timing and 5% at optimum injection timing with CE with biodiesel operation in comparison with neat diesel operation.
- 3) With increase of injector opening pressure, particulate emissions decreased and NO<sub>x</sub> levels increased with test fuels.

## Research Findings and Suggestions

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

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

catalytic reduction technique can be employed. [N.Janardhan et al, 2012]

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