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Effect of engine parameters on NOx emissions with Jatropha biodiesel as fuel

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Abstract
Depleting petroleum reserves on the earth and increasing concerns about the environment leads to the quest for fuels which are eco-friendly and safe for human beings. It is now well established that lower blends of biodiesel and diesel works well in the existing engines without any modifications. Use of the higher blends is restricted due to loss of efficiency and long term problems in the engine. For using higher blends of biodiesel, the engine operating parameters must be changed for recovery of power and efficiency. But these changes may affect the emissions. This study targets on investigating the effects of the engine operating parameters viz. compression ratio, fuel injection pressure, injection timing and engine speed on emissions of NO_x with pure biodiesel as fuel in a small diesel engine commonly used in agricultural applications. It is found that the combined increase of compression ratio and injection pressure and retarding injection results in lower emissions of NO_x as compared to the diesel fuel.

Keywords: Biodiesel, Compression ratio, Injection pressure, Injection timing, RPM, NOx.

1. Introduction
For diesel engines, a significant research effort has been directed towards using vegetable oils and their derivatives as fuels [1-5]. Besides having comparable energy density, cetane number, heat of vaporization, and stoichiometric air/fuel ratio with mineral diesel, the vegetable oils are biodegradable, non-toxic, and have a potential to reduce pollution significantly. Substantial reductions in emissions of sulfur oxides, carbon monoxide, poly aromatic hydrocarbons, smoke, particulate matter and noise are observed while using vegetable oils and their derivatives in diesel engines as fuel [6], [7]. Since carbon dioxide emitted during combustion is recycled in the photosynthesis process in the plants, the contribution of bio-fuels to greenhouse effect is insignificant.
Biodiesel is considered a promising alternative fuel for the diesel engines as its fuel characteristics are approximately the same as those of fossil diesel fuel and thus may be directly used as a fuel for diesel engines without any prior modification of the design or equipment [8], [9]. Many varieties of vegetable oils have been identified and found suitable for transesterification into biodiesel [10]-[13]. Although biodiesel has many advantages, its use is restricted in an unmodified engine to a maximum of 20% blend because of engine life problems [14], [15]. Further, it is observed that with biodiesel as fuel in existing engines, there is a slight power loss, lower thermal efficiency with higher specific fuel consumption and comparatively higher emission of nitrogen oxides [16]-[20]. For recovery of power and thermal efficiency, various modifications in the engine operating parameters have been suggested. Modifications in compression ratio [21]-[22], injection process and parameters [23]-[25], use of multiple injections, oil

preheating, etc. have been found to affect the engine power and efficiency while using higher blends of biodiesel [26]-[28]. These changes have some impact also on the emissions from the engine.
The aim of this study is to investigate the effects of varying engine operating parameters with *Jatropha Methyl Ester* (JME) as fuel on the emissions of NOx. The operating parameters studied are compression ratio, fuel injection pressure, injection timing and engine speed.

2. Materials and methods

The study was done with an objective of studying the effects of the engine operating parameters viz. compression ratio, injection pressure, injection timing and engine speed which are the controllable variables, on the emissions of NOx, when the engine is run with pure biodiesel. The aim was to establish the modifications required in small, constant speed, direct injection diesel engines used extensively for agricultural applications so that these can be made to run on pure biodiesel without loss in performance and at the same time improve the emissions. In the study, a small engine was run first on rated parameter values with standard diesel fuel available commercially and emissions of NOx at different loads were recorded. Then the engine was run on B100 fuel under different sets of compression ratio, injection pressures, injection timing and engine speeds, and emission was recorded.

2.1 Fuels used and their properties

Standard Diesel fuel was acquired from nationalised distribution network from a local outlet where as the biodiesel fuel was prepared in laboratory from the common Jatropha Curacas (local name: *ratanjyot*) vegetable oil, which is gaining popularity due to its good properties and has been accepted & recommended by National Biodiesel Board of India as a source of alternative fuel for blending in the commercial diesel. The vegetable oil extracted from fresh seeds was sourced from local oil mill and was trans-esterified using methanol with KOH as catalyst by standard procedure. The properties of so prepared biodiesel were tested in the lab using standard test procedures and are listed in Table 1.

Table 1. Evaluated properties of Jatropha oil and its methyl ester

Property	Unit	Biodiesel BIS Std	Diesel	Jatropha	
				Oil	Methyl ester
Relative density	gm/cm^3	0.87-0.90	0.8394	0.9187	0.8838
Calorific value	MJ/kg	-	44.13	40.65	39.40
Kinematic Viscosity					
at 32^{o}C	cSt	3.5-5.0	3.93	46.8	10.8
at 60^{o}C	cSt		2.77	23	5.82
Cloud Point	^{o}C	-	<3	4	0
Pour Point	^{o}C	-	<-5	1	-3
Flash Point	^{o}C	>100	56	210	118
FFA	%	<0.8	-	5.01	0.28
Iodine value		<115	-	98.91	100.01

2.2 Experimental set-up

The study was carried out in the laboratory on an advanced fully computerised experimental engine test rig comprising of a single cylinder, water cooled, four stroke, VCR (Variable Compression Ratio) Diesel engine connected to eddy current type dynamometer for loading. Setup (Figure 1) is provided with necessary instruments for online measurement of cylinder pressure, injection pressure and crank-angle. The specifications of the engine used for study are given in Table 2.

2.3 Measurement of NOx emission

The exhaust gases are sampled from exhaust line through a specially designed arrangement for diverting the exhaust to sampling line without increasing the back pressure and is then anlysed using a portable multi-gas analyser of make- MRU Airfare, Germany; Model- DELTA 1600 S. Oxides of Nitrogen (NOx) are measured with the help of electrochemical cell. The instrument calibrates itself every time it is started and displays the quantity of gases in ppm.

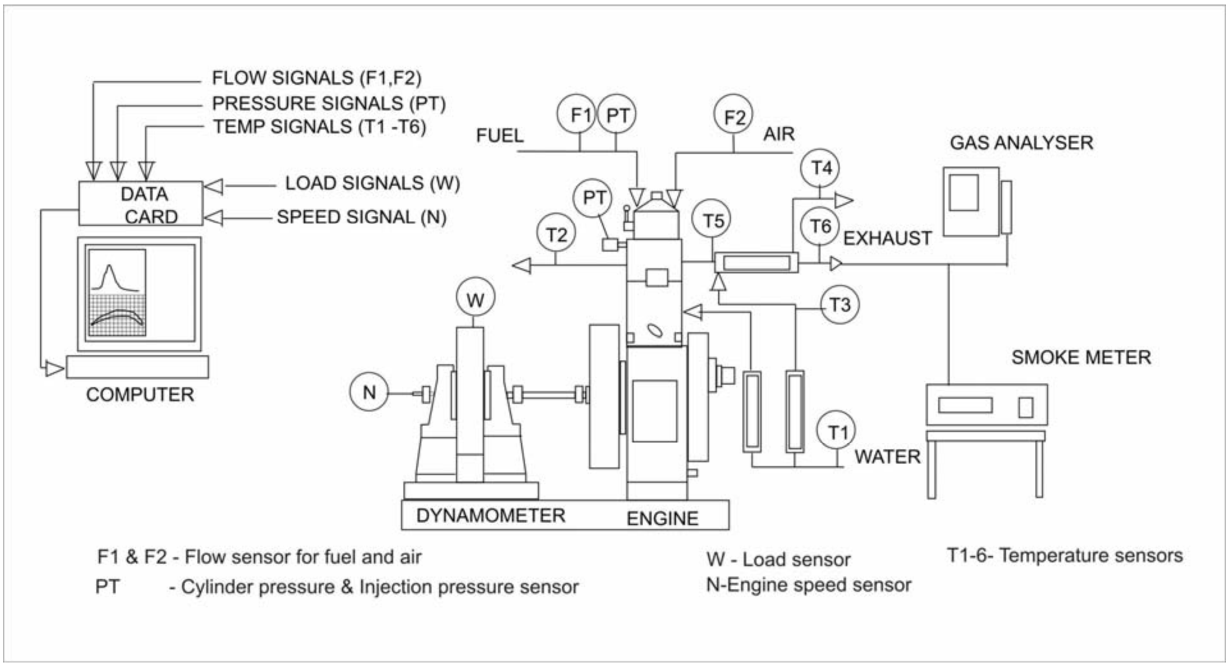

Figure 1. Experimental set up

Table 2. Test engine and instrument details

Engine specification	
Make	Kirloskar
Model	TV1
Details	Single cylinder, DI, Four stroke
Cooling	Water
Bore and stroke	87.5mm × 110 mm
Cubic capacity	0.661 liters
Compression ratio	17.5:1
Rated power	3.5 kW at 1500 rpm
Injection timing	23 ° BTDC static (diesel)
Eddy Current Dynamometer	Model AG10 of Saj Test Plant Pvt Ltd
Cylinder pressure sensor	Piezo sensor of PCB Piezotronics Inc, Model- M111A22; Resolution- 0.1 psi; sensitivity- 1 mV/psi
Fuel pressure sensor	Piezo sensor of PCB Piezotronics Inc, Model- M108A02; Resolution- 0.4 psi; sensitivity- 0.5 mV/psi
Air Flow Transmitter	Make- Wika; Model- SL1

2.4 Experimental procedure

The experiment was conducted on the aforesaid test rig. The performance test of the engine was conducted as per IS: 10000 [P: 5]:1980. For diesel the performance test were conducted at rated condition of 17.5:1 compression ratio and injection pressure of 210 kg/cm² was maintained at rated speed of 1500 rpm. For 100 percent biodiesel, in addition to the above settings, performance tests were carried out at three different compression ratios i.e.16, 17 and 18; three injection pressures (150, 200, 250 kg/cm²); five engine speeds (1400, 1425, 1450, 1475, 1500 and 1525 rpm); and, six values of the injection timing (in steps of three degree between 9 degree advance to 6 degree retard), and emissions were recorded at full load operation of the engine.

3. Results and discussion

The effects of fuel and engine operating parameters on the emission of NOx were evaluated with different settings and are presented in following section.

3.1 Effect of fuel

The measured values of NOx emissions with JME are lower than that with diesel (Figure 2). With JME the reduction is 25%. At full load JME emitted 178 ppm of NOx against 237 ppm of NOx with diesel. The decrease in NOx emissions with biodiesel has been reported by many others also. Jhala [29] reported 8.69% lower emission with JME. Graboski et al. [30] indicated a linear relationship between NOx emission and iodine number of the fuel being tested. Similar reductions (4-5%) are also witnessed by Knothe et al. [31].

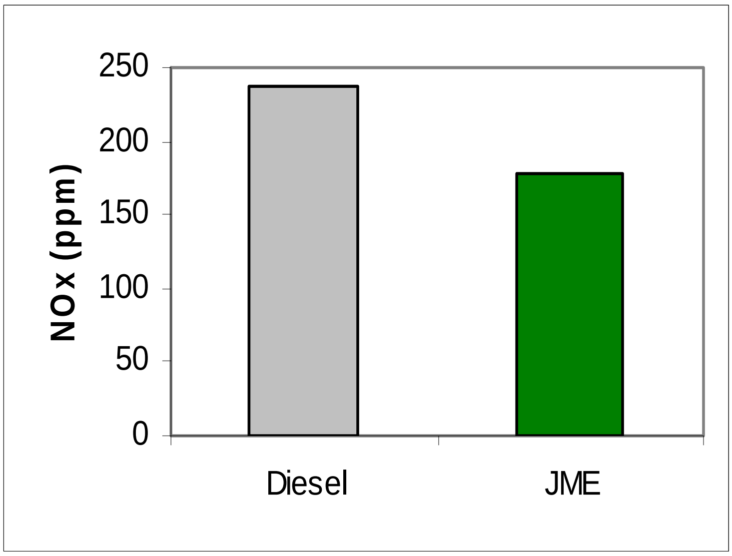

Figure 2. Comparison of NOx emissions at full load

3.2 Effect of compression ratio

Emission of NOx increases with increase in compression ratio (Figure 3). With lower compression ratio, the premixed burning is high due to longer delay resulting in lesser production of NOx in naturally aspirated engines [30]. With increase in compression ratio, ignition delay reduces and peak pressure increases resulting in high temperature which causes larger amounts of NOx formation. The measured values of NOx at the selected three compression ratios of 16, 17 and 18 for JME are 165, 182 and 215 ppm.

3.3 Effect of injection pressure

Emission of NOx decreases with increase in injection pressure (Figure 3). At lower injection pressure, the fuel entry is slightly advanced as the spring pressure on needle is low resulting in more premixed combustion which is considered as one of the major cause of NOx formation. Leung et al. [31] also proposed increased injection pressure as a measure to control NOx. The measured values of NOx at the selected three injection pressures of 150, 200 and 250 bar for JME are 216, 182 and 165 ppm.

3.4 Engine speed

Although the energy of burned gas is a nearly linear function of temperature, the same cannot be said of NOx since the chemical rates are nonlinear functions of temperature. The dependence on engine speed cannot be stated simply and one has to consider the variations in combustion duration and heat loss with engine speed. The emissions of NOx in exhaust with biodiesel (JME) are found to increase with reduction in speed with peak around 1440 rpm (175 ppm) after which it drops (Figure 4). The maximum temperature of exhaust gases is also found near this speed which is one of the major causes for NOx formation. Also higher amount of energy in mixing controlled combustion causes more generation of NOx.

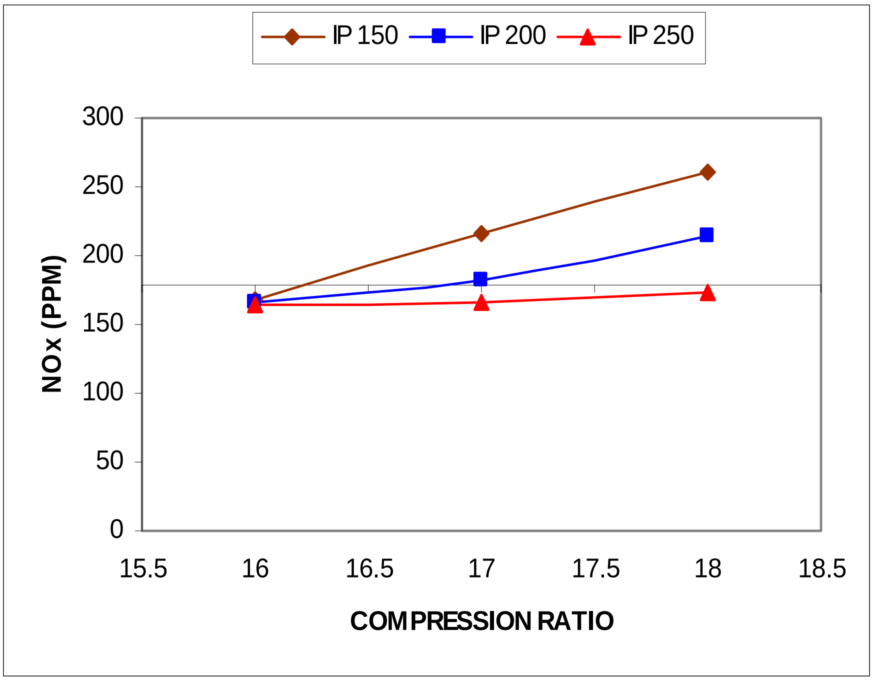

Figure 3. Effect of compression ratio and injection pressure at full load

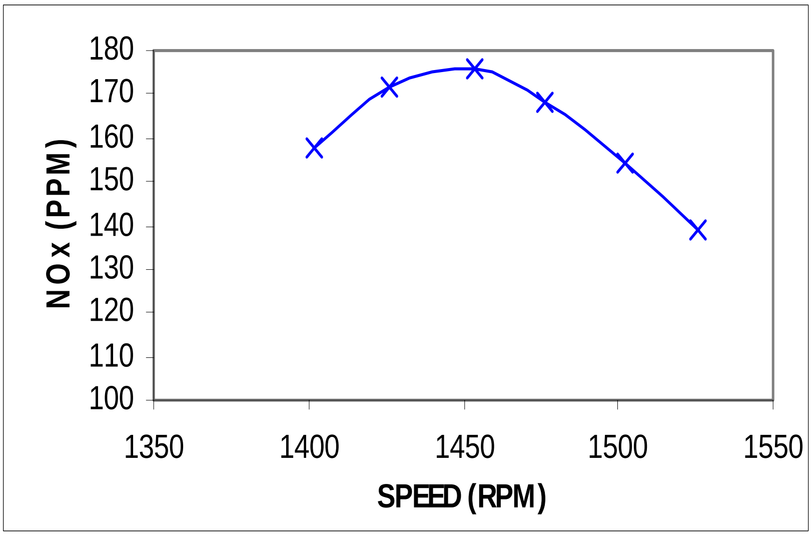

Figure 4. Effect of speed on emissions of NOx at full load

3.5 Injection timing

As reported by many studies, the NOx emission is found to vary with injection timing (Figure 5). The advancement of injection time enhances the NOx emissions whereas retarding the injection helps reduce the same. Parlak et al. [34] reported 40% reduction in NOx with 4 degree retardation of injection. The higher bulk density and viscosity transfers the pressure wave through fuel pipe lines faster and an earlier needle lift will lead to advanced injection. With additional advancing, the effect is magnified and leads to still higher flame temperature causing increase in NOx emission. Retarding the engine compensates for the bulk density effect and hence lower emissions are observed. The results are in line with that obtained by Verbiezen [35].

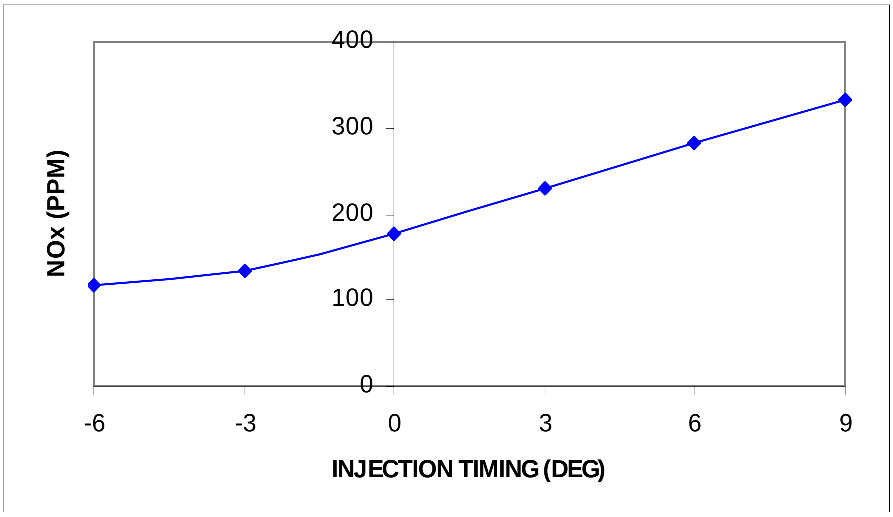

Figure 5. Effect of injection timing at full load

4. Conclusions

The emissions of oxides of nitrogen from compression ignition engines have attracted attention of scientists working in the area of development of alternative fuels. With fuels of vegetable oil origin, the findings are not uniform. Some studies reported reduction in emissions of NOx whereas many has reported increase while using biodiesel made from different feedstock. Further, the performance of engine is found to be better with biodiesel concentration upto 20% only. For improvement of performance with pure biodiesel, engine parameters needs to be reset.

The current study aimed at finding the effects of variations in engine operating parameters on the emissions of NOx while operating with pure biodiesel (Jatropha methyl ester). At standard operating parameters, the emissions of NOx are found to be lesser with JME as compared to diesel as fuel. It is observed that increase in compression ratio tends to raise the emission level of NOx whereas increase in injection pressure leads to reduction in NOx emissions. While using pure JME as fuel, high compression ratio associated with high injection pressure, results in lower NOx emissions as compared to diesel emissions. At lower speeds of engine, the emissions increases peaking at 1440 rpm. The effect of retarding the injection timing is positive as emission of NOx tends to decrease with retardation. Thus NOx emissions can be minimised by increasing compression ratio, increasing injection pressure, maintaining engine speed and retarding injection timing from standard values of these parameters.

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