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# Experimental Study on Performance and Exhaust Emission Characteristics of a C.I. Engine Fuelled with Tri Compound Oxygenated Diesel Fuel Blends

**P. Navaneethakrishnan[1*] and D.Vasudevan[2]**

[1]Department of Mechanical Engineering, University College of Engineering, BIT Campus, Tiruchirappalli, India; navaneethak@gmail.com
[2]PSNA College of Engineering and Technology, Dindigul, India

## Abstract

Transport vehicles greatly pollute the environment through emissions such as CO, $CO_2$, $NO_X$, $SO_X$, unburnt or partially burnt HC and particulate emissions. Fossil fuels are the chief contributors to urban air pollution and major source of Green House Gases (GHGs) and considered to be the prime cause behind the global climate change. Though diesel fuelled compression ignition engine can operate at high thermal efficiency creates more emission of HC and CO, the high level of $NO_x$ poses problems. The high combustion temperature and lean mixtures used are the reasons. This paper presents the results of performance and emission analyses carried out in an unmodified diesel engine fuelled with Tamanu Methyl Ester (TME), DiEthyl Ether (DEE) its blends with diesel. Engine tests have been conducted to get the comparative measures of Brake Specific Fuel Consumption (BSFC), Brake Thermal Efficiency (BTE) and emissions such as HC, CO, $NO_x$ and Exhaust gas temperature to evaluate the behaviour of TME, DEE and diesel in varying proportions. The results reveal that blends of TME, DEE with diesel up to 20% and 20% by volume provide better engine performance (BSFC and BTE) increased up to 3-4% and the exhaust emission gets decreased dramatically.

**Keywords:** C.I. Engine, Diethyl Ether, Exhaust Emission, Performance

## 1. Introduction

The world is presently confronted with the twin crises of fossil fuel depletion and environmental degradation. Indiscriminate extraction and lavish consumption of fossil fuels have led to reduction in underground-based carbon resources. The search for alternative fuels, which promise a harmonious correlation with sustainable development, energy conservation, efficiency and environmental preservation, has become highly pronounced in the present context. The fuels of bio-origin can provide a feasible solution to this worldwide petroleum crisis. Gasoline and diesel driven automobiles are the major sources of Green House Gases (GHG) emission which was reported by Agarwal A.K. Reduction of exhaust emissions is extremely important for diesel engine development in view of increasing concern regarding environmental protection and stringent exhaust gas regulations. Diesel engines are the major contributors of various types of air polluting exhaust gases such as particulate matter, carbon monoxide, oxides of nitrogen and other harmful compounds. Baskar P et al. concludes in his article that increasingly Stringent regulations governing particulate emissions, nitric oxides from diesel engines have prompted research directed toward methods for reducing the in-cylinder formation of pollutants by modifying fuels or controlling particles by after

*Author for correspondence*

treatment technologies. Among the various deployments to reduce emissions, the use of oxygenated fuels like alcohols, biodiesels and vegetable oils etc., in diesel engines as an effective way to reduce vehicular pollution. Biodiesel and ethanol can be produced from feed stocks that are generally considered to be renewable. Raheman H. makes the statement in his paper, Since the carbon in biodiesel originates mostly from $CO_2$ in the air, the full cycle $CO_2$ emissions for biodiesel contribute much less to global warming than fossil fuels.

Tri compound oxygenated diesel fuel blends, due to the high latent heat of evaporation of ethanol as well as methanol, the combustion temperature was reduced which resulted in lower $NO_X$ emissions. Blending of biodiesel and ethanol with fossil diesel dramatically improve the solubility of ethanol in diesel fuel over a wide range of temperature was reported by Rajasekar E. et al. Alcohols and ethers are also explored as other alternatives as oxygenated fuels or Diesel fuel additives for Compression Ignition (CI) engines. Alcohols are produced from fossil or renewable resources such as methanol, ethanol, etc., are generally added to diesel fuel to reduce emissions especially smoke or particulate emissions. DiMethyl Ether (DME) and DiEthyl Ether (DEE) were tried out as alternatives to petro-diesel. DEE is liquid at the ambient conditions, which makes it attractive for fuel storage and handling. DEE can be a renewable fuel as it is produced from ethanol by dehydration process. It has several favourable properties, including exceptional cetane number, reasonable energy density, high oxygen content, low auto-ignition temperature, and high volatility. Therefore, it can assist in improving engine performance and reducing the cold starting problem and emissions when using as a pure or an additive in diesel fuel Sezer. I also reported in the same problem in his research article.

Sezer et al. has investigated performance and emission characteristics of a diesel engine with DME and DEE and felt that the two fuels hold promising alternatives. Qi et al. has been studied experimentally the effect of diethyl ether and ethanol additives and concluded that the additives could be a promising technique for using biodiesel/diesel blend efficiently in diesel engines without any modifications in the engine. Effect of oxygenates on the stability and low temperature storage Hoshino T. et al. reported the same. De Menezes et al. experimentally observed that the presence of ethanol and Ethyl Tert-Butyl Ether (ETBE) significantly alters the volatility and reduces cetane number. As an oxygenated additive, DiMethyl Carbonate (DMC) is usually blended with diesel fuel to improve combustion and reduce emissions of diesel engines in conventional combustion conditions, emissions such as CO, UHC and soot can be reduced by blending ethanol with diesel, which is mainly attributed to the higher oxygen content of ethanol (35%) was reported by Likos B. et al., Di J.G. et al. mentioned in his research on PM emissions from diesel and diesel-ethanol indicates that particulate mass, total particulate number concentration and soot decrease with increased ethanol percentage in diesel from 0% (diesel) to 24% by volume under conventional diesel combustion mode.

When blending ethanol into biodiesel, a simultaneous reduction in particulate matter and $NO_X$ emission is achieved for a naturally aspirated diesel engine with conventional combustion mode was reported by Zhu L. et al. A 4.75 liters engine under different steady modes using 5%, 10%, 20%, 35% blends and pure rapeseed-oil biodiesel. Magin L. et al. has achieved the thermal efficiency appeared to reach a maximum for 5-10% blends. At the same injection timing, methyl ester promoted a rise in $NO_X$ emissions and decrease of HC and CO together with a strong reduction of smoke was reported by Ramadhas A.S. et al. founds that at high loads using single injection, particle and CO emission were decreased. A slight increase in $NO_X$ was observed as the biodiesel concentration is increased. But in the case of multiple injection, decrease in particulate emission was observed with little or no effect on $NO_X$. Choi C. et al. stated that at low loads, addition of biodiesel and multiple injection schemes were found to be detrimental to particulate matter and CO emission.

Incorporation of bioethanol in the tri-component mixture increases its oxygen content, thus ensuring higher combustion efficiency. It is known from the experimentation work of Crumbling D.M., that the gasoline oxygenates Methyl Tertiary-Butyl Ether (MTBE) reduces pollutant concentration of engine emissions. Therefore, the assumption could reasonably be made that, when fuelling with diesel fuel containing increased oxygen content, the levels of exhaust emissions should be lower compared with conventional diesel fuel. The oxygen content of biodiesel is an important factor in the $NO_X$ formation, because it causes to high local temperatures due to excess hydrocarbon oxidation. The increased oxygen levels increases the maximum temperature during the combustion, and increases $NO_X$ formation as reported by Qi D.H. Vegetable oils are widely used as biodiesel for the improvement of engine efficiency in diesel engines and reducing the exhaust emissions was reported by several researches Zejewski M. et al., Pryde E.H., Vellgruth G. and Ziejewski M. et al. The objective of this study is to investigate the performance, emissions characteristics of a single cylinder four stroke direct injection diesel engine operating on biodiesel Tamanu Methyl Ester (TME) Diesel-Diethyl Ether (DEE) (tri compound blends) blends, composed of diesel fuel with diethyl ether as additive in volume basis (5%, 10%, 20%), Tamanu biodiesel as blend in volume basis of 20% and to compare these results with those operating on diesel fuel.

## 2. Experimental Work

### 2.1 Bio Diesel Preparation

Tamanu oil is a non-edible species capable of growing in coastal area. The yield from a single tree varies from 50 to 100 kg of seed containing approximately 50 – 63% of oil. The characteristic of Tamanu oil fall within a fairly narrow band and are quite close to those of diesel. The tamanu oil has less calorific value than that of diesel due to the oxygen content in their molecules. The tamanu oil has less calorific value than that of diesel due to the oxygen content in their molecules. Previous research works show that high viscosity, density, iodine value and poor non volatility are the problems associated with the use of vegetable oils in diesel engines leading to problems in pumping, atomization and gumming, injector fouling, piston and ring sticking and contamination of lubricating oils in the long run operation. Hence, it is essential to reduce the viscosity of the vegetable oils by methods such as preheating, thermal cracking and transesterification. Transesterification is the best way to convert the vegetable oils to suit for the use in diesel engines.

Transesterification of tamanu oil was carried out by heating of oil, addition of NaOH [3g] and methyl alcohol [200 ml], stirring of mixture, separation of glycerol, washing with distilled water and heating for removal of water. Certain impurities like sodium hydroxide (NaOH) etc., are still dissolved in the coarse biodiesel. This cleaned biodiesel is taken up for the study. The TME so produced was mixed with diesel 20% by volume in varying proportions of DEE (Di Ethyl Ether) with 5% to 20% by volume with the help of a magnetic stirrer. The blends were stirred continuously to achieve stable property values.

### 2.2 Evaluation of Fuel Properties

Several important fuel properties were evaluated using the appropriate ASTM test methods and are given in Table 1. Testing procedures were conducted according to the relevant ASTM test methods. The densities of blended fuels were measured as a function of temperature and these correlations were later used to calculate the brake specific fuel consumption (BSFC).

### 2.3 Experimental Procedure

The experimental set up (Figure 1) consists of a single cylinder four-stroke, water-cooled and constant speed (1800 rpm) compression ignition engine. The detailed specification of the engine is given in Table 2. A series of experiments were carried out using diesel, biodiesel and the various blends. All the blends were tested under varying load conditions at the rated speed. During each trial, the engine was started and after it attains stable condition,

**Table 1.** Properties of fuel samples

| Property | Diesel | TME 20% & DEE 5% (Sample 1) | TME 20% & DEE 10% (Sample 2) | TME 20% & DEE 20% (Sample 3) |
|---|---|---|---|---|
| Calorific Value (MJ/Kg) | 43.0 | 41.6 | 41.3 | 41.2 |
| Flash Point ($^0$C) | 52 | 64.1 | 63.2 | 61.4 |
| Cetane Number | 48 | 52 | 58 | 65 |
| Specific Gravity (@ 15 $^0$C) | 0.82 | 0.83 | 0.83 | 0.83 |
| Kinematic Viscosity (@ 40 $^0$C) (CST) | 3.9 | 4.3 | 4.1 | 4.0 |
| Density (Kg/m$^3$) | 840 | 850 | 831 | 818 |

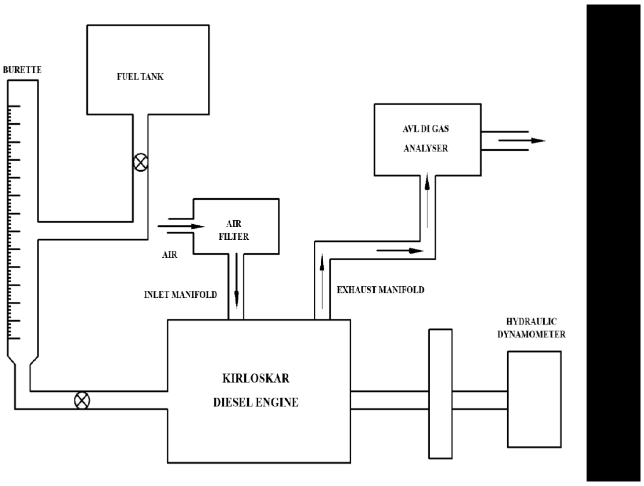


**Figure 1.** Engine Set up.

important parameters related to thermal performance of the engine such as the time taken for 50 CC of fuel consumption. Also, the engine emission parameters like CO, $CO_2$, HC, $NO_X$ and the exhaust gas temperature were noted and recorded by AVL Di Gas 444 exhaust gas analyser. The specification for exhaust gas analyser is given in Table 3.

# 3. Results and Discussion

## 3.1 Characteristics of Diesel and Various and Fuel Blends

It is seen from Table 1 that the specific gravity and calorific values of TME with DEE fuel blends are in closer agreement with the diesel and the kinematic viscosity and flash point are comparatively higher. In comparison with diesel, the flash point and fire point were found more, facilitating safe transport and storage. The calorific value of TME blends was measured to be around 41 MJ/kg, which is less than that of diesel (43 MJ/kg) and greater than that of raw tamanu oil. The kinematic viscosity of the TME was measured to be greater that of diesel at 40°C. It is observed that increasing concentration of TME in the diesel resulted in the remarkable increase in the kinematic viscosity and the concentration of DEE in the diesel resulted in the corresponding remarkable decrease in the kinematic viscosity. Increasing concentration of TME in the diesel resulted in the increase in specific gravity and DEE concentration shows no variance. The flash point of the various blends with TME concentration is found to increase due to the higher value of flash point for TME than diesel and DEE concentration is found to decrease due to the lower value of flash point for DEE. Conversely, a decreasing trend is observed for the calorific value in the fuels with TME and DEE concentration.

**Table 2.** Specification of diesel engine

| **Make:** | **Kirloskar** |
|---|---|
| Description: | Single cylinder, four stroke, CI engine |
| Rated Speed: | 1800 rpm |
| Brake power: | 5.9 KW |
| Bore and Stroke: | 87.5 and 110 mm |
| Cubic Capacity: | 661 $cm^3$ |
| Fuel Injection Pressure: | 210 bar |
| Cooling System: | Water cooling |
| Lube Oil: | SAE 30/SAE 40 |

**Table 3.** Specifications of AVL DiGas analyser

| Parameter | Range | Principle of Detection |
|---|---|---|
| CO | 0–10 % vol | NDIR |
| $O_2$ | 0–22 % vol | Electro Chemical |
| $CO_2$ | 0–20 % vol | NDIR |
| $NO_X$ | 0–5000 ppm | Electro Chemical |
| HC | 0 - 20000 ppm | NDIR |

## 3.2 Brake Specific Fuel Consumption

The variation of BSFC with load for different blends and diesel is presented in Figure 2. It is observed from Figure 2 that the BSFC for all the fuel blends and diesel tested decrease with increase in load. This is due to higher percentage increase in brake power with load as compared to increase in the fuel consumption. For the blends sample 1, 2 and 3, the BSFC is equal to that of diesel at all loads. Though the blended compounds have the lower calorific value when compare with diesel, the BSFC is slightly reduced when compare with diesel fuel. This could be due to the presence of dissolved oxygen in the TME and DEE that enables complete combustion and the negative effect of increased viscosity would not have been initiated. However, as the DEE concentration in the blend increases further, the BSFC decreases slightly at all loads.

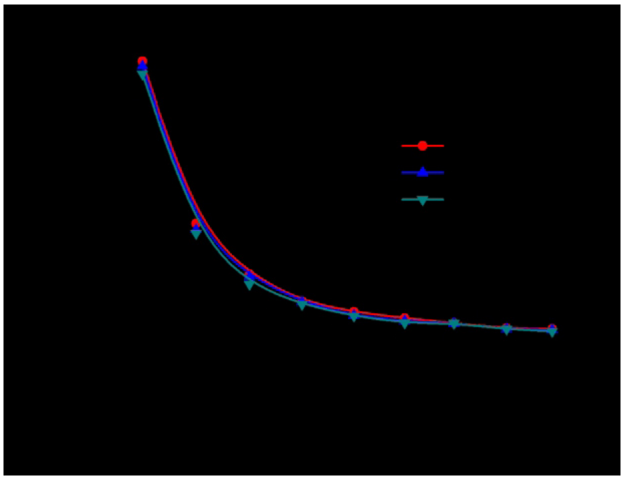

**Figure 2.** Variation of BSFC with load.

## 3.3 Brake Thermal Efficiency

The variation of BTE with load for different blends and diesel is presented in Figure 3. Whereas the BTE for all the fuels tested slightly increases initially at low loads and at higher load conditions, there is a significant increase than that of diesel for all the blends. If the concentration of DEE present in the fuel increases the BTE increases due to the blended fuels have more oxygen rate than diesel fuel, the combustion becomes better and so the thermal efficiency increases. This could be due to the higher cetane number of DEE though the calorific values of the blended fuels are low when comparing with diesel fuel. Moreover, the vaporization of the fuel also continues in the compression stroke when the latent heat of vaporization increases. Since the fuel absorbs heat from the cylinder during the vaporization in, the necessity work for compressing the air fuel mixture decreases and this situation increases the brake thermal efficiency. In addition, the specific fuel consumption for blends are low when compared with the diesel fuel and high viscosity of the blends is more or less equal to the diesel fuel, so there is no change in atomization of the fuel, which in turn affects the combustion process. Brake thermal efficiency of blended fuel increases with respect to the concentration of DEE up to 3-4% of conventional diesel fuel while the engine is operating at high loads. At low loads the brake thermal increase for the blended fuel is low when compare to the brake thermal efficiency of the diesel fuel.

## 3.4 Combustion Pressure

Figure 4 shows the variation of cylinder pressure with crank angle for the samples and pure diesel when the engine is operating at constant speed (1500 rpm) and full load conditions. The fuel starts to inject at $1^0$CA before top dead center (TDC), and ends that $9^0$ CA after TDC. The fuel injection pressure and temperature are 44 MPa and $48.4^0$C, respectively. The intake air temperature and pressure are $35.5^0$ C and 0.099 MPa respectively. A slight drop in the cylinder pressure can be observed for the blended fuels. The diesel fuel has the maximum combustion pressure when compare with Tamanu Methyl Ester and DiEthyl Ether fuel blends. More amount of oxygen in the blended fuel samples is one of the important reason for low combustion pressure. The pressure variation inside the cylinder is lies in the 365-375 CA.

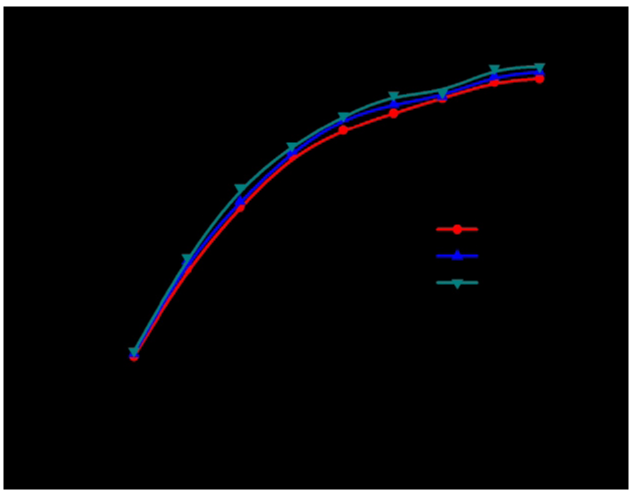

**Figure 3.** Variation of BTE with load.

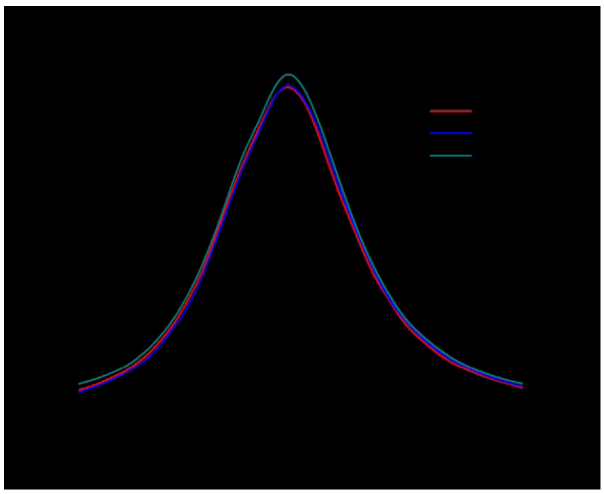

**Figure 4.** Variation of cylinder pressure with crank angle.

## 3.5 Hydrocarbon Emissions

The HC emission variation for different blends is indicated in Fig. 5. It is seen from the figure that the HC emission decreases with increase in load for diesel and other tri compound fuel blends. As the Cetane number of blended fuel is higher than diesel, it exhibits a shorter delay period and results in better combustion leading to low HC emission. Also the oxygen content in the blended fuels also responsible for the reduction in HC emission. Tamanu methyl ester and Diethyl ether lowers the carbon combustion activation temperature and thus enhances hydrocarbon oxidation, promoting complete combustion.

## 3.6 Carbon Monoxide Emissions

It is interesting to note that the engine emits more CO for diesel as compared to TME and DEE blends under all loading conditions. It is seen from Figure 6 that the CO concentration is very low for the blends of sample 2 and sample 3 for all loading conditions and as the DEE concentration in the blend increases, the reduction of CO is observed. The presence of TME is gives sufficient oxygen for the combustion process and resulting in the lower concentration of CO of the blended fuels when compare with sole diesel. At lower DEE concentration, the oxygen present in the DEE aids for complete combustion. However, as the DEE concentration increases, the negative effect due to high viscosity and small increase in specific gravity suppresses the complete combustion process which produces small amount of CO. The reason explained above is also confirmed from the effects shown in Figures 2 and 3 for BSFC and BTE.

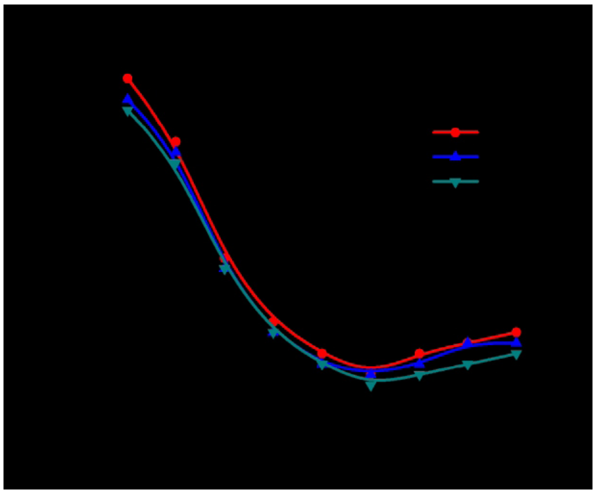

**Figure 6.** Variation of CO with load.

## 3.7 Oxides of Nitrogen

The variation of $NO_X$ emission for different blends is indicated in Figure 7. The $NO_X$ emission explains how the better combustion takes place inside the combustion chamber. The $NO_X$ emission for all the fuels tested followed an increasing trend with respect to load. The reason could be the higher average gas temperature, residence time at higher load conditions. At higher temperature only the nitrogen and oxygen reacts together and for the oxides of nitrogen. When the concentration of oxygenated fuel blends increases the $NO_X$ emission also increases when compare with sole diesel fuel. The maximum and minimum amount of $NO_X$ produced were 744 ppm and 110 ppm corresponding to sample 3.

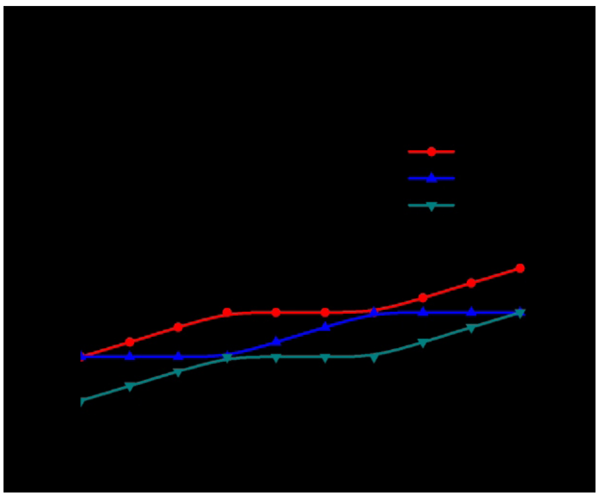

**Figure 5.** Variation HC with load.

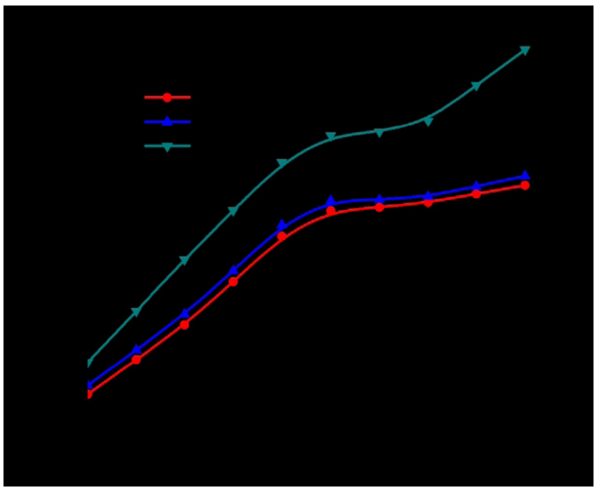

**Figure 7.** Variation of $NO_X$ with load.

## 4. Conclusion

The aim of the present investigation was to analyze the usability of TME and DEE as a replacement to diesel in an unmodified CI engine. It was found that blends of TME, DEE and diesel could be successfully used with acceptable performance and better emissions than pure diesel. From the experimental investigation, it is concluded that blends of TME and DEE with diesel could increase the brake thermal efficiency up to 3–4% and fuel consumption is more or less equal when compare with sole diesel fuel and reduced the exhaust emissions dramatically and thus why it is suggested to replace the diesel for diesel engine applications for getting less emissions and better performance and will thus help in achieving energy economy, environmental protection and rural economic development. In the near future conventional fuels will be fully replaced by biodiesel and will provide a viable solution for the much threatening environmental pollution problems.

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