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Effect of butanol addition on Performance and Emission Characteristics of a DI diesel engine fueled with Pongamia-Ethanol blend.

R.Senthil, E.Sivakumar, R.Silambarasan*

Department of Mechanical Engineering, University College of Engineering, Villupuram, Tamilnadu, India.

Abstract: The aim of the present study is to analyze the effect of butanol on engine performance and emissions of a diesel engine fuelled Pongamia-Ethanol blend (50-50).Testing was performed with diesel (D100),Pongamia-Ethanol blend (50-50) and various concentrations of butanol addition into Pongamia-Ethanol blend (50-50) at different engine loads. The butanol is mixed in various percentages such as10% and 20% in volume basis with Pongamia-Ethanol blend (PE45-45Bu10 and PE40-40Bu20). Result shows that (PE40-40Bu20) mixture is effective in control of **Oxides of Nitrogen(NO_X)**while exhibiting high **Carbon monoxide(CO)&Hydro Carbon(HC)** emissionthan diesel. Further, Brake Specific Fuel Consumption is increased with butanol addition Pongamia -Ethanol blend than diesel.
Keywords: Pongamia-Ethanol blend,Transterification,butanol, emissions, Diesel engine.

1. Introduction

Diesel engines are commonly used as prime movers in the transportation, industrial and agricultural sectors because of their high brake thermal efficiency and reliability. The increasing industrialization and motorization of the world has led to a steep rise in the demand of petroleum based fuels. Petroleum based fuels are obtained from limited reserves. These finite reserves are highly concentrated in certain regions of the world. Therefore, those countries not having these resources are facing energy/foreign exchange crisis, mainly due to the import of crude petroleum. Hence, it is necessary to look for alternative fuels which can be produced from resources available locally within the country such as alcohol, biodiesel, vegetable oils etc. The concept of using biodiesel in diesel engines was originated by the inventor " Rudolf Diesel" using peanut oil as a fuel at the World Exhibition in Paris in 1900[1].

In this work reported that Pongamia-Ethanol blend (50-50) is considered as a better fuel compared to other fuel blends [2].

The addition of n-butanol in vegetable oil-diesel blends improves the engine performance and reduced the engine emissions such as HC, CO and $NO_x$are lower than those of diesel [3].In this paper reported that the isobutanol-diesel blends reduces exhaust gas temperature, brake thermal efficiency (BTE), CO, and NOx emissions while increasing HC emissions compared to neat diesel. It was observed that the exhaust emissions changed as a strong function of isobutanol concentration [4]. The investigation showed that exhaust gas temperature, smoke density, NOx, and CO emissions were reduced as n-butanol concentration increased, while unburned HC emissions, BSFC, and BTE increased as compared to diesel[5].The above result supported by using n-butanol /diesel fuel blends with 5%, 10%, 15%, and 20% n-butanol concentrations [6].The same trend was obtained by using medium duty DI engine[7].The result shows that n-butanol addition decreased CO and soot emissions but there is no effect on BSFC[8].The result showed that a combination of high n-butanol–diesel blends with EGR has the potential to decrease NOx and soot with high Indicated thermal efficiency [9].In this work reported that overall butanol-diesel blends in passenger car applications showed an advantage of increased thermal efficiency for 40% butanol concentrations [10]. In this work reported that butanol-diesel blend was tested by using conventional and optical techniques.Result showed that reduction in smoke while slight increase in NOx and BSFC [11].In this work, a turbocharged DI engine equipped with common rail injection system and EGR was tested in cold and warm conditions. Result shows that higher NOx, HC and CO emissions for ethanol-diesel blends and butanol-diesel blends[12].In this paper reported that addition of butanol to diesel blends reduces PM and carbon emissions[13].In this work shows that addition of butanol to biodiesel reduces NOx and Exhaust gas temperature while increasing HC,CO emissions[14].The engine was operated with DBE blends having 5, 10, 15 and 20% ethanol with fixed 10% biodiesel on a volume basis, to solve the phase separation problem, as well as on diesel fuel alone at constant load and at engine speed ranges from 800 to 1600 rpm for each run. The experimental results of the phase stability revealed that the DE blends is not stable and separated after 2, 5, 24 and 80 hours, for 20%, 15%, 10% and 5% ethanol concentration, respectively. Whereas for DBE blends the separation time is longer than of the first system and reached 1, 3 and 9 days for 20%, 15%, 10% ethanol concentration, respectively. The brake thermal efficiency was increased with fuel blends of 5 and 10% ethanol concentration and decreases with a higher ethanol proportion in the blends. In conclusion, among the different fuel blends, the blends containing 5 and 10% ethanol concentration are the most suited for CI engines due to its acceptable engine performance and to the fuels solubility [15].Methyl ester of Pongamia (PME), Jatropha (JME) and Neem (NME) are derived through transesterification process. Experimental investigations have been carried out to examine properties, performance and emissions of different blends (B10, B20, and B40) of PME, JME and NME in comparison to diesel. Results indicated that B20 have closer performance to diesel and B100 had lower brake thermal efficiency mainly due to its high viscosity compared to diesel. However, its diesel blends showed reasonable efficiencies, lower smoke, CO and HC. Pongamia methyl ester gives better performance compared to Jatropha and Neem methyl esters [16].Ethanol as an additive to research the possible use of higher percentages of biodiesel in an unmodified diesel engine. Commercial diesel fuel, 20% biodiesel and 80% diesel fuel, called here as B20, and 80% biodiesel and 20% ethanol, called here as BE20, were used in a single cylinder, four strokes direct injection diesel engine. The effect of test fuels on engine torque, power, and brake specific fuel consumption, brake thermal efficiency, exhaust gas temperature, and CO, CO2, NOx and SO2 emissions was investigated[17].The effects of biodiesel type's biodiesel fraction and physical properties on combustion and performance characteristics of a CI engine. They have conducted an experiments on 4 cylinder 4 stroke DI and turbo charged diesel engine using biodiesel of waste oil and rapeseed oil and corn oil with normal diesel. It has been satisfied the bio diesel types didn't result in any significant difference is take cylinder pressure and BSFC. They have concluded that the peak cylinder pressure of the engine running with bio diesel was slightly higher than that of diesel. This is due to advance combustion process initiated by higher lubrication effects of bio diesel [18].Experiments on diesel engine using 100% jatropha biodiesel and diesel. It has been found that the efficiency for pure diesel is 29.6% and for pure jatropha is 21.2%. It has also found the smoke, HC, CO emission decrease and NOx, CO_2 increases for jatropha fuel when compared to the neat diesel fuel [19].The experiments on DI diesel engine with 10%, 20%, 30% and 40% blending of koroch seed oil their methyl ester with the neat diesel fuel. They have reported the BTE of the engine was power for koroch seed oil. They also reported that Heat Release Rate (HRR) occurred earlier for the koroch seed oil and it confirm the shorter ignition delay periods with respect to the blends. They conducted that koroch seed oil blending up to 30% with the diesel fuel as a fuel in the diesel engine without any significant draw in the performance [20]. The effects of bio diesel types and bio diesel fraction and the emission characteristics of CI engine. They have conducted experimental work 4 cylinder by using bio diesel made from corn oil and comparing it with diesel fuel. They have found that NOx emissions was higher biodiesel and its blends. They also found that B100 bio diesel reduced 15%, 40%, and 30% CO, CO2 and HC emissions respectively as compared to diesel fuel at various operating conditions [21].

In this study, Pongamia-Ethanol blend (50-50) with the addition of butanol is used as a test fuel. The effect of butanol addition on performance and emissionsalong with Pongamia-Ethanol blend (50-50) operated direct injection diesel engine was studied.

2. Materials and methods

2.1. Test Fuels

Ethanol as fuel

Ethanol is ethyl alcohol (C_2H_5OH) is nowadays used as an alternative fuel for diesel. Unlike diesel, ethanol is a form of renewable energy that can be produced from agricultural feed stocks. It can be made from very common crops such as sugar cane, potato, manioc and corn.

Physical properties of ethanol

Ethanol is a volatile, colorless liquid that has a strong characteristic odor. It burns with a smokeless blue flame that is not always visible in normal light.

The physical properties of ethanol stem primarily from the presence of its hydroxylgroup and the shortness of its carbon chain. Ethanol's hydroxyl group is able to participate in hydrogen bonding, rendering it more viscous and less volatile than less polar organic compounds of similar molecular weight.

Combustion of ethanol

During combustion ethanol reacts with oxygen to produce carbon dioxide, water, and heat:

$C_2H_5OH + 3\ O_2 \rightarrow 2\ CO_2 + 3\ H_2O + \text{heat}$

After doubling the combustion reaction because two molecules of ethanol are produced for each glucose molecule, and adding all three reactions together, there are equal numbers of each type of molecule on each side of the equation, and the net reaction for the overall production and consumption of ethanol is just light into heat.

There is a reduction in calorific value by adding the ethanol along with diesel fuel is compensated by varying the supply of fuel (the fuel supply system was modified during the lower & higher load operation) during the part and full load engine operation. At full load operation, the combustion chamber temperature is high and minimum fuel will be supplied. At low load operations, the fuel supply will be maximum due to biodiesel have low calorific value and more oxygen content.

The heat of the combustion of ethanol is used to drive the piston in the engine by expanding heated gases.

Selection of lubricating oil for ethanol

Pongamia oil

Pongamiapinnata (L.) Pierre has also been called *Derris indica* (Lam.) Bennet and *Pongamiaglabra*Vent, all of these three names are still commonly found in literature. According to Lewis (1988), this species may eventually be transferred to genus *Millettia. Pongamiapinnata* is one of the few nitrogen fixing trees (NFTS) to produce seeds containing 30-40% oil. It is often planted as an ornamental and shade tree. This species is commonly called Pongamia, Karanja, or a derivation of these names.

2.2. Transesterification

Transesterification is the process of using an alcohol (e.g. methanol or ethanol) in the presence of catalyst such as sodium hydroxide (NaOH). Which chemically breaks the molecule of the raw oil into methyl or ethyl esters with glycerol as a by-product, which reduces the high viscosity of oils. This method also reduces the molecular weight of the oil to 1/3 of its original value, reduces the viscosity and increase the volatility and cetane number to levels comparable to diesel fuel.

2.3. Experimental setup

Experiments are carried out in a single-cylinder, water-cooled, naturally aspirated direct injection diesel engine coupled with an eddy current dynamometer. An eddy current dynamometer coupled to the engine is used as a loading device as shown in Fig.1.

The fuel flow rate, speed, loads, exhausts gas temperature and gas flow rate are measured through data acquisition system. AVL 444Di-gas Analyzer is used to measure the CO, HC and NO_xemissions.

The performance and emissions from the engines were studied at different concentrations such as 10% and 20% with a constant engine speed of 1800 rpm. The butanol addition effect on performance and emissionswith Pongamia-Ethanol (50-50) fuelledwith DI diesel engine at different loads have been studied in this investigation.The properties of diesel, butanol and Pongamia-Ethanol (50-50) are shown in Table 1.

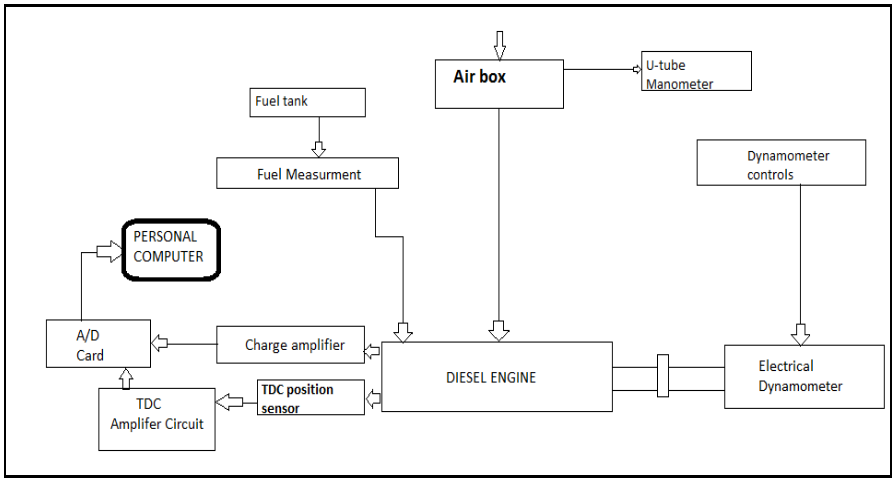

Fig.1. Schematic diagram of experimental set-up

Table 1: Properties of diesel, butanol and P-E (50-50).

Fuels	Diesel	Butanol	P-E(50-50)
Heating Value(MJ/kg)	44.4	33.1	38.7
Density @ 20^0C(kg/m^3)	815	808	846.5
Viscosity@40^0C(m Pa s)	2.95	2.63	3.85
Flash Point(^{0}C)	70	35	112
Cetane number	52	25	52

Heating values

To study the calorific it was used biodiesel from Annona oil blends calorimeter using the combustion IKA200, with 99.7% oxygen pressurized at 30 bar. Analyses were performed in triplicate.

Density

For measuring the density, standard procedures have been followed. A glass hydrometer with specific gravity range of 0.7 to 1.0 with an accuracy of three decimal places was used in the measurement. To collect temperature-dependent data, a 100ml graduated cylinder containing a biodiesel sample was placed in a temperature controlled bath. The water bath temperature could vary from room temperature to 95^{o}C. The test was repeated twice and the average value was taken. In addition to the hydrometer measurements, mass/volume method of density measurement was also used for comparison at 15.6^{o}C.

Viscosity measurement

The Standard Method Petroleum products: Determination of kinematic viscosity and calculation of dynamic viscosity, the European standard EN ISO 3104:1996 was used to measure the viscosity of the biodiesel samples. This method is commonly used to measure the kinematic viscosity of liquid petroleum products. Since biodiesels also have almost similar properties as the fossil fuel this method has been considered appropriate for the measurement of viscosity of the biodiesel samples. The kinematic viscosity is determined by measuring the time taken for a known volume of fuel flowing under gravity to pass through a calibrated glass capillary viscometer tube. Cannon-Fenske Viscometer tube (size B) and Select a viscosity bath were used for this purpose. The size B viscometer has approximate constants of 0.01 and kinematic viscosity range from 2 to $10 mm^2/s$. The timing device with 0.01 seconds least count was used in present tests. The water bath temperature used has a temperature range from room temperature to 85^oC. The viscosity values below the room temperature were determined from the regression correlation from the data of this study and previous reports. For the experimental data to be acceptable the EN ISO 3104:1196 standards require the tests to be done two times and the first and second measurements should be within an accuracy of $0.02 mm^2/s$. If the accuracy condition is satisfied the average of the two tests was taken. The tests were repeated two times and the average value was taken as representative value.

Flash point

The flash point was determined by the method of ASTM D93 using the Pensky-Martens closed cup tester,Flash point helps to monitor the safe handling and storage of fuel. The higher the flash point the safer the fuel and vice versa. The flash point of Biodiesel is higher than that of fossil diesel; therefore it could be said that Biodiesel is safer to handle than fossil diesel.

Cetane number

The cetane number, cetane index and distillation parameters T90 and T95 of biodiesel and diesel fuel was measured in the unit IROX DIESEL , calibrated with hexane 99% PA. The measuring principle is based on the methodology of infrared (IR) absorption measurement in the range of 2.7 to 15.4 ì, using a Fourier Transform spectrometer. The resulting spectrogram of this range is correlated with a matrix of the spectra of the substances to be analysed in variable concentrations. A measuring cell of 0.1 mm length is introduced in the beam of an adequate infrared source and the intensity of the beam with a sample in the cell is measured.

2.4. Specifications of the apparatus

The experiment was conducted in the following instruments/equipment sand the details are given below.

I. Diesel Engine

- Manufacturer : Kirloskar oil engines limited
- Type of Engine : Vertical, 4-Stroke Single cylinder
- Model : SV1
- Rated Output
  As per IS: 11170: 8 HP (5.9kW)
- Speed : 1800 rpm
- Compression Ratio : 17.5:1
- Bore and stroke : 87.5 x 110 (mm)
- Injection pressure : 200 bar

II.Exhaust gas analyzer

An AVL gas analyzer is used to measure the exhaust gas composition. The brief specification of exhaust gas analyzer is given below.

- Manufacturer : AVL private limited
- Type : AVL 444 DI gas Analyzer

2.5. Testing Procedure

Engine was started and warmed up at low idle, long enough to establish the recommended oil pressure, and was checked for any fuel and oil leaks. The engine was run on no-load condition and speed was adjusted to 1800 rpm by adjusting fuel injection pump. Engine was run to gain uniform speed, after which it was gradually loaded. Experiments were conducted at different load levels. The engine was run for 10 minutes and data's were collected during last 4 minutes. The performance and emission tests were carried out at different butanol mixture concentrations. The exhaust gas is sampled from exhaust pipe line and passed through an exhaust gas analyzer for measurement of carbon monoxide, unburnt hydrocarbon, oxides of nitrogen present in exhaust gases. The experimental uncertainties are shown in Table 2.

Table 2. Experiment Uncertainties

Parameters	Systematic Errors (±)
Speed	1 ± rpm
Load	± 0.1 N
Time	± 0.1 s
Brake power	± 0.15 kW
Temperature	± 1°
Pressure	± 1 bar
NOX	± 10 PPM
CO	± 0.03%
CO2	± 0.03%
HC	± 12 PPM
Smoke	± 1 HSU

3. Results and discussion

3.1. NO_x emission

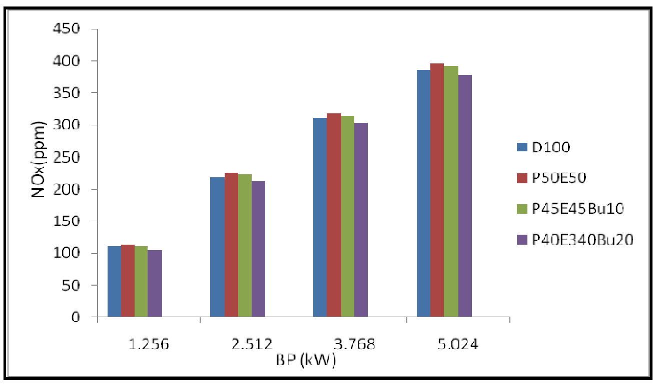

Figure 2 Oxides of Nitrogen emission (NO_x) vs Brake Power (BP)

Temperature plays a vital role in NO_x formation. It is also depends upon the compression ratio, equivalence ratio, geometry of the combustion chamber, fuel injection advance ,pressure and temperature of the inlet air. Fig 2 shows that variation of NO_x emission with brake power for diesel fuel, Pongamia-Ethanol blend (50-50),PE45-45Bu10 and PE40-40Bu20. It can be seen from Fig 2that NOx emissions increases with increase of engine load. The NO_x emission decreases with the percentage of butanol concentrations. Further it is also seen that NOx emission ofPE40-40Bu20 concentration is decreased by 20.38% when compared to neat diesel fuel respectively. This is due to the addition of butanol increases the oxygen content and this will create a cooling effect. Further, this cooling effect outweighs the benefit to the combustion process provided by the excess oxygen content from butanol which leads to reduction in NO_x emissions.The similar trends are obtained in the literature studies with diesel-butanol blends, as in introduction section.

3.2. Hydro carbon emission (HC)

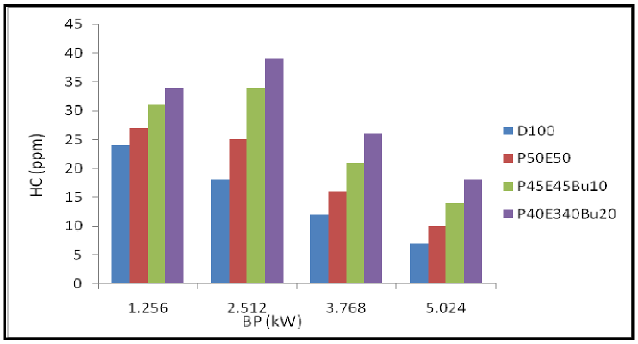

Figure Hydro Carbon emission (HC) vs 3Brake Power (BP)

Fig 3 shows that variation of HC emission with brake power for diesel fuel, Pongamia-Ethanol blend (50-50),PE45-45Bu10 and PE40-40Bu20.It can be seen thatHC emissions decrease with increase of engine load. The HC emission increases with the percentage of butanol concentrations with the Pongamia-Ethanol (50-50). This is due to incomplete combustion because butanol has lower cetane number and high heat of vaporization. Further, it takes long time to vaporize which leads to longer ignition delay and short duration of combustion Thus, incomplete combustion and HC emissions are formed. This similar trend was observed in butanol-diesel blendsas mention in the introduction part.

3.3. Carbon monoxide emission (CO)

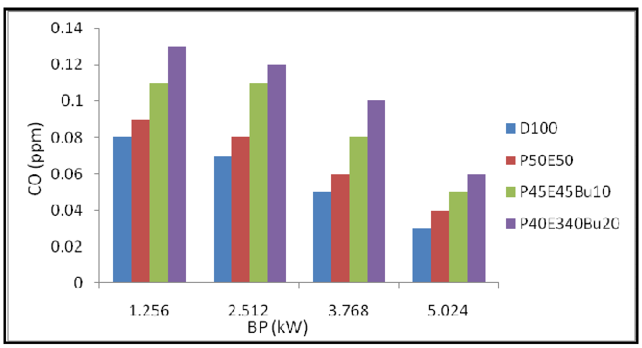

Figure 4 Carbon mono oxide emission (CO) vs Brake Power (BP)

Fig 4 shows that variation of CO emission with brake power for diesel fuel, Pongamia-Ethanol blend (50-50),PE45-45Bu10 and PE40-40Bu20.It can be seen from the Fig 4 that CO emission decreases with increase of engine for all fuel types at all load conditions. The CO emission increases with the percentage of butanol addition along with the Pongamia-Ethanol blend (50-50).At high load, there is no significant difference on CO emissions but low load CO emission increases with the percentage of butanol addition. According to literature studies with butanol –diesel blend as mention in the introduction section, there is an opposite trend was obtained.

3.4. Brake specific fuel consumption (BSFC)

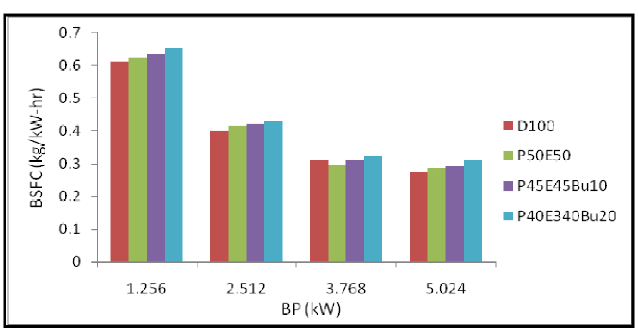

Figure 5 Brake Specific Fuel Consumption (BSFC) vs Brake Power (BP)

Fig 5 shows that variation of BSFC with brake power for diesel fuel, Pongamia-Ethanol blend (50-50),PE45-45Bu10 and PE40-40Bu20. It can be seen from Fig 6 that BSFC decreases for all fuel types at all engine loads. The BSFC increases with the percentage of butanol addition along with Pongamia-Ethanol blend (50-50).In all loads diesel has lower BSFC for all fuel types which is due to higher heating value.This similar trend was observed in butanol-diesel blends as mention in the introduction part.

3.5. Exhaust Gas Temperature (EGT)

Fig 6 shows that variation of EGT with brake power for diesel fuel, Pongamia-Ethanol blend (50-50),PE45-45Bu10 and PE40-40Bu20. It can be seen from Fig 6 that EGT increase for all fuel types at all engine loads. The EGT decreases with the percentage ofbutanol addition along with Pongamia-Ethanol (50-50). This is due to lower energy density and lower cetane number than diesel.Further, addition of butanol to fuel blends increase the oxygen content which reduces the combustion and exhaust gas temperature.This similar trend was observed in butanol-diesel blends as mention in the introduction part.

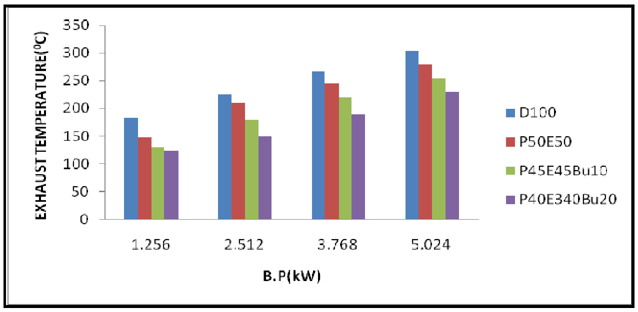

Figure 6 Exhaust Gas Temperature (EGT) vs Brake Power (BP)

4. Conclusion

The effects of butanol addition on performance and emissionalong with Pongamia-Ethanol blend (50-50) have been studied at different fuel condition in this present work. The main conclusions of the present study are given below.

1. It was observed that addition of butanol is an effective method for controlling the NO_x emissions. For the P40-E40Bu20 blend, theNO_xemission is reduced by 23.38% at full conditions than diesel but aHC, CO emissions and BSFC is increased by at all load conditions when compared to the neat diesel fuel.
2. The EGT is reduced by 9.67% for the P40-E40Bu20 blend at full load conditions when compared to the neat diesel fuel.
3. It is concluded that NOx emission and Exhaust Gas Temperature can be reduced considerably by using butanol addition along with the Pongamia-Ethanol blend (50-50).It is simple and cost effective method without change in any engine modification.
4. The main limitation of this present work is slightly increasing the BSFC and also the engine efficiency can be slightly decreasing.

Acknowledgement

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Conflicts of Interest

The authors declare no conflict of interest.

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