# Experimental Investigation on Engine Performance and Emission Characteristics using Pongamia – Orange Oil Blends

N. Sreenivasulu[1a], K. Govindarajulu[1b], K. John Samuel[2c],
Y. Rajasekhar[2d], G. Edison[2e], R. Thundil Karuppa Raj[2f]*

[1] Department of Mechanical Engineering, Jawaharlal Nehru Technological University (JNTUA), Anantapur – 515001, India
[2] School of Mechanical Engineering, VIT University, Vellore – 632014, India

([a] nandamurisreenivas@gmail.com [b] govindjntu@gmail.com [c] koppulajohn.samuel@vit.ac.in
[d] rajasekhar.y@vit.ac.in [e] edison.g@vit.ac.in [f] thundil.rajagopal@vit.ac.in)

‡ Corresponding Author: R. Thundil Karuppa Raj, School of Mechanical Engineering, VIT University, Vellore – 632014, India, Tel: +91 9444142658. thundilr@gmail.com

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**Abstract-** For the past few decades, research has scaled up in the development of environmental friendly alternative fuels such as biodiesel that can minimize the use of conventional fuel resources. The present study deals with the performance and emission characteristics of 60% crude pongamia oil with 40% diesel (DBD 1) and the results are compared with 100% conventional diesel on a single cylinder direct injection diesel engine without any modifications at full throttle condition. The study is extended further by adding 15% of orange oil to 60% crude pongamia oil and 25% diesel fuel (DBD 2). It is found that the addition of orange oil to the crude pongamia biodiesel blend have shown notable improvement in performance and reduction in emissions compared to crude pongamia diesel blend. The results indicate that the values of brake specific fuel consumption, brake thermal efficiency and mechanical efficiency obtained with the biodiesel blend (DBD 2) are very close and the emissions are less when compared to conventional diesel fuelled engine. From the study it is observed that DBD 2 can be used as an alternative fuel for conventional diesel in a direct injection diesel engine without any modifications.

**Keywords** Crude pongamia oil, orange oil, diesel engine, performance and emission characteristics, brake specific fuel consumption.

## 1. Introduction

Industrial and domestic needs of the world are being driven by energy generated from various sources including alternative energy sources. With the ever increasing trend of population and energy requirements in the developed and developing countries, the world energy demand is also growing at a faster rate [1]. So efforts are on to find alternative sources for this depleting energy source. Environmental issues concerned with exhaust gas emissions by the usage of fossil fuel also encourage the usage of biodiesel [2]. Oils derived from various bio-resources using chemical methods are eco-friendly and cost effective. However, their performance is poor when used in compression ignition engines without modification. Additives are added to improve the properties of fuel such as viscosity and volatility affecting the combustion characteristics [3, 4]. On the basis of the type of raw material used bio-oils are classified as edible or non-edible. Since, edible oils are barred from use for running engines, usually non-edible oils such as mahua oil, pongamia oil, orange oil, rubber seed oil, etc are preferred.

Many researchers have studied the potential use of vegetable oil for running diesel engines [5-7]. Karaosmanoglu et al. [8] examined the use of vegetable oil in engines and observed the insignificant change in power in long-term use. Nwafor and Rice [9] carried out combustion studies using rapeseed methyl ester on the unmodified diesel engine and observed an increase of friction power along with carbon deposits on the injector as similar to diesel. Research studies have been performed to measure the efficiency, emission and combustion characteristics of direct injection engines using vegetable oils and different forms of methyl/ethyl esters such as jatropha, jojoba oil [10] hazelnut oil [11] and orange oil [12]. Most of the studies revealed an increase in brake specific fuel consumption and NOx emissions and decrease in thermal efficiency. Researchers also found that there is a reduction in CO and HC emissions for almost all the biodiesel blends on unmodified engines.

Biodiesel blends are added with additives to improve the combustion performance. Sajith et al. [13] experimentally investigated the performance and emissions of a diesel engine by adding cerium oxide nanoparticles to the biodiesel. They compared their results for blends with and without the addition of additives and reported that there is an increase in flash point and viscosity whereas the emissions like HC and NOx decreased when additives are added to the biodiesel blends. Qi [14] conducted experimental investigations on direct injection diesel engine to study the effect of diethyl ether and ethanol as additives to biodiesel. With the addition of diethyl ether and ethanol to the biodiesel, it is observed that there is a drastic reduction in smoke at higher loads. Patil and Taji [15] experimentally investigated the effect of various oxygenated fuel additives on single cylinder 4-stroke diesel engine. The addition of these oxygenated fuels resulted in the reduction of CO and HC emissions with a slight increase in NOx emissions. Ramu and Saravan [16] also investigated the effect of oxygenated fuel additives with thermal barrier coating. Thermal barrier coating is used in their work for improving the efficiency by reducing the energy losses. With the combined effect of oxygenated fuel additives with thermal barrier coating, they observed a reduction in NOx emissions. Jaichandar and Annamalai [17] investigated the performance of a diesel engine with different combustion geometries. The studies revealed that brake thermal efficiency is higher for the toroidal combustion chamber and with this combustion chamber they observed a reduction in CO, particulates, and unsaturated hydrocarbons. Srithar et al. [18] investigated the performance using a combination of biodiesel, pongamia and mustard oil, as an alternative to diesel. The results revealed that the blend having diesel 90%, 5% pongamia and 5% mustard mixture performance is very close to diesel.

Pongamia oil, derived from pongamia pinnata seeds, has its physical and chemical properties similar to that of diesel [19]. The performance of the engine run by raw pongamia oil is found to be very much close to that of conventional diesel with slight reduction in power output and marginal increase in emission levels are observed [20]. However, crude pongamia oil due to its high viscosity cannot be used directly in diesel engines [21]. Hence, different processes include dilution; micro emulsions, pyrolysis, catalytic cracking, and trans-esterification are adopted to reduce viscosity [22]. However, the major problem encountered during processing of raw oil is a separation of the mixture components and choking.

From the various literatures surveyed it is found that the usage of crude pongamia oil along with diesel fuel up to 60% is missing and the performance, combustion and emission characteristics are not reported. Hence the objective of the current study is to investigate the effect of addition of crude pongamia oil to base diesel up to 60% on a conventional single cylinder four stroke compression ignition diesel engine without any modification. An attempt is also made by introducing 15% orange oil to 60% crude pongamia oil with 25% conventional diesel. This trial has been attempted to investigate any performance improvement could be achieved with reduction in emissions.

## 2. Materials and methods

### *2.1. Biodiesel properties*

In India, a lot of barren lands are available where the biodiesel crop pongamia pinnata, a shrub that does not require much maintenance, can be ideally grown. The seeds of pongamia pinnata will be used to extract about 40% raw oil contained in it. In the present study, the raw oil is bought from University of Agricultural Sciences, Bengaluru and Karnataka. Generally transesterification process is used to convert the crude vegetable oil into their corresponding biodiesel blends as reported by Suresh and Vela raj [23]. But in this present study, transesterification process is not carried out and only crude form of the pongamia oil (CPO) is used and the effects are studied. The physical and chemical properties of crude pongamia oil, DBD 1, DBD 2 with conventional diesel are shown in Table 1 and measured as per IS 15607 standards. The fatty acid chemical composition of crude pongamia oil is presented in Table 2. In the present study CPO (60%) quantity is fixed for DBD1 and DBD 2. Further, fuel properties with addition of Orange oil (OO) to biodiesel blend is determined. The addition of 15% orange oil to 60% crude pongamia oil and 25% conventional diesel has shown improvement of 4% in calorific value. Also, considerable reduction in viscosity and density are observed with addition of orange oil to crude pongamia oil diesel blends.

**Table 1.** Physical and chemical properties of diesel, CPO, orange oil and biodiesel blends.

| **Property** | **Pure Diesel** | **CPO** | **DBD1** | **Orange oil** | **DBD2** | IS 15607 Standard |
|---|---|---|---|---|---|---|
| Kinematic viscosity (cSt) | 2.6 | 42.83 | 15.642 | 3.52 | 4.7 | 2.5-6.0 |
| Specific density (g/cm3) | 0.831 | 0.956 | 0.911 | 0.8169 | 0.845 | 0.86 – 0.90 |
| Calorific value (kJ/kg) | 43000 | 34879 | 37663 | 40328 | 39200 | - |
| Flash point (°C) | 68 | 235 | 93 | 61 | 80 | 120 min |
| Fire point (°C) | 72 | 240 | 96 | 58 | 84 | - |

**Table 2.** Chemical fatty acid composition of crude pongamia oil

| Fatty Acid % pongamia crude oil | Molecular Formula | Percentage | Structure | Saturated/Unsaturated |
|---|---|---|---|---|
| Palmitic Acid | $C_{16}H_{32}O_2$ | 11.65 | $CH_3(CH_2)$14COOH | Saturated |
| Stearic Acid | $C_{18}H_{36}O_2$ | 7.50 | $CH_3(CH_2)$16COOH | Saturated |
| Oleic Acid | $C_{18}H_{34}O_2$ | 51.59 | $CH_3(CH_2)$14(CH=CH)COOH | Unsaturated |
| Linoleic Acid | $C_{18}H_{32}O_2$ | 16.64 | $CH_3(CH_2)$12(CH=CH)2COOH | Unsaturated |
| Eicosanoic Acid | $C_{20}H_{40}O_2$ | 21.35 | $CH_3(CH_2)$18COOH | Saturated |
| Dosocasnoic Acid | $C_{22}H_{44}O_2$ | 24.45 | $CH_3(CH_2)$20COOH | Saturated |
| Tetracosanoic Acid | $C_{24}H_{48}O_2$ | 21.09 | $CH_3(CH_2)$22COOH | Saturated |

### *2.2. Experimental setup*

In the present study, experiments **are** conducted on single cylinder four-stroke KV-5 model engine manufactured by M/s. Kissan iron works, India. The experimental setup consists of the engine, an alternator, top brake power system, fuel tank along with immersion heater, exhaust gas measuring digital device and manometer. The immersion heater **is** provided to maintain the temperature of the fuel at a required specific temperature monitored by a digital thermometer. The schematic diagram shown in Fig.1 elucidates the arrangement of different components in the experimental set-up. The specifications of the engine used for the experimental study are shown in Table. 3

The engine was coupled to an alternator providing a maximum power of 3.7 kW. The full load characteristics of the engine are measured with pure diesel, crude pongamia and other blends at maximum speed. The experiments are carried out at constant speed under various loading conditions for all the tested fuels. The pressure of the cylinder is measured by PA2045E V2 AVL pressure sensor mounted on the cylinder head. The temperature of engine oil, coolant, exhausts gas and inlet air is measured with a K-type thermocouple. The diesel fuel consumption for each reading is recorded by using alternative fuel tank of 250 $cm^3$ cylindrical vessels and a standard burette system. The emissions like HC, $O_2$, $NO_X$, $CO_2$ and CO are measured using QRO tech five gas exhaust analyser. The analyser is also used to measure the equivalence ratio and excess oxygen present in the exhaust gases. The accuracy and sensitivity of the five gas analyser is presented in Table. 4.

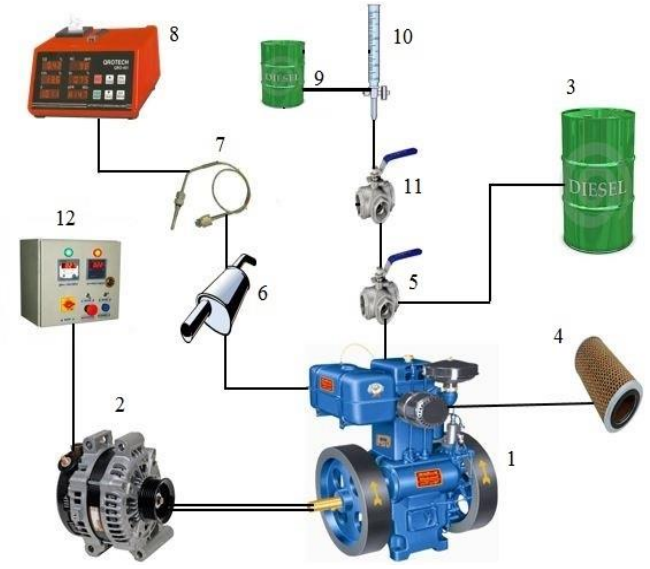

**Fig. 1.** Schematic diagram representing the experimental setup

**Table 3.** Engine specifications

| S. No | Engine parameters | Description |
|---|---|---|
| 1 | Engine | KISSAN Engine, 4-stroke stationary |
| 2 | Type | water-cooled |
| 3 | Injection | Direct injection |
| 4 | Maximum speed | 1500 rpm |
| 5 | Number of cylinders | One |
| 6 | Rated power | 3.7 kW at 1500 rpm |
| 7 | Bore | 85 mm |
| 8 | Stroke | 110 mm |
| 9 | Compression ratio | 16.5:1 |
| 10 | SFC at full load | 240 gms/kW/hr |

| | | |
|---|---|---|
| 11 | Injection timing | $25^0$ before TDC |
| 12 | Injection pressure | 200 bar |

**Table 4. Range and resolution of QRO tech five gas analyser**

| Measuring Item | Measuring Range | Resolution | Display |
|---|---|---|---|
| CO | 0.00-9.99% | 0.01% | 4 digit 7 segment LED |
| $CO_2$ | 0.00-20% | 0.10% | 4 digit 7 segment LED |
| Air surplus rate | 0.00-2.00 | 0.00% | 4 digit 7 segment LED |
| HC | 0-9999 ppm | 1 ppm | 4 digit 7 segment LED |
| $O_2$ | 0.00-25.00 % | 0.01% | 4 digit 7 segment LED |
| AFR | 0.00-99.0 | 0.1 | 3 digit 7 segment LED |

### *2.3. Test method*

The components and the instrumentation of the experimental setup are connected as per the schematic diagram shown in Fig. 1. Three types of fuels are tested in the experimental studies: diesel, crude pongamia diesel blend (DBD 1) and orange oil biodiesel blend (DBD 2). Table 1 shows the description of different fuel blends used in the experimental analysis. The experimental study is carried out to analyse the performance and emission characteristics of DBD 1 and DBD 2 in comparison with conventional diesel.

Initially, the engine is started with the help of conventional diesel. Once the engine gets warmed up the required biodiesel blend is introduced. Before starting the engine, the lubricating oil level in the engine is checked, and it is also ensured that all moving and rotating parts are properly lubricated. The injection pressure is measured using a pressure sensor mounted on the cylinder head, and the required injector pressure (200 bar) is achieved by adjusting the screw provided at the top of the injector. The tests on the engine are carried out at various loads at constant speed for an injection pressure of 200 bar with pure diesel as fuel and performance and emission characteristics are determined. The results are compared by repeating the experiments with crude pongamia diesel blends.

## 3. Results and Discussions

### *3.1. Performance Characteristics*

The performance and emission characteristics of an unmodified diesel engine with crude pongamia oil and its biodiesel blends are studied. The engine performance characteristics include variation of brake specific fuel consumption, brake thermal efficiency and emission characteristics (NOx, CO, HC, $CO_2$) for different brake power are analysed and studied. The performance curves for unmodified diesel engine with conventional diesel, DBD 1 and DBD 2 are shown in Figs. 2 & 3. It is observed that the trend of these curves matches with the previous results reported in the literature for biodiesel blends [17, 24].

Brake thermal efficiency of samples DBD 1 and DBD 2 are lower compared to that of diesel at all loads because of their lower calorific values. The brake thermal efficiency of DBD 2 is higher than DBD 1 because of its lower viscosity and higher calorific value due to the introduction of orange oil [12]. The lower viscous nature of DBD 2 helps in better mixture formation with air, which leads to better combustion characteristics and thus increases BTE.

One another major reason for the brake thermal efficiency of biodiesel blends are lower than diesel is that the engine operation takes place under constant injection timing and biodiesel blends have smaller ignition delay. This smaller ignition delay triggers the combustion earlier well before the piston reaches the top dead centre. This causes an increase in additional compression work and much heat loss and thus resulting in the reduction of BTE. From Fig. 2 it can be observed that the trend in the variation of brake thermal efficiency with brake power for all the tested fuels is similar to that of diesel.

It is pertinent to recall that, at full brake power of 2.608 kW, the brake thermal efficiency of the engine for diesel, DBD 1 and DBD 2 are 31.41%, 27.92% and 29.42% respectively. The reduced brake thermal efficiency of biodiesel blends is due to higher viscosity and lower warming characteristics which lead to poor atomization and fuel vaporization.

From Fig. 3 it can be observed that the trend in the variation of BSFC with brake power for all blends is little higher than that of diesel. Further observation, it may be noted that at all loading conditions and for all blends the BSFC is higher when compared to diesel and this can be attributed to lower calorific value of blends. The higher specific fuel consumption of biodiesel blends is attributed due to poor air fuel mixing resulting from higher viscosity and leads to poor combustion. It is evident from the Fig. 3 that, at full brake power of 2.608 kW, the BSFC of the engine for diesel, DBD 1 and DBD 2 blends are 0.266 kg/kW-h, 0.349 kg/kW-h and 0.313 kg/kW-h respectively.

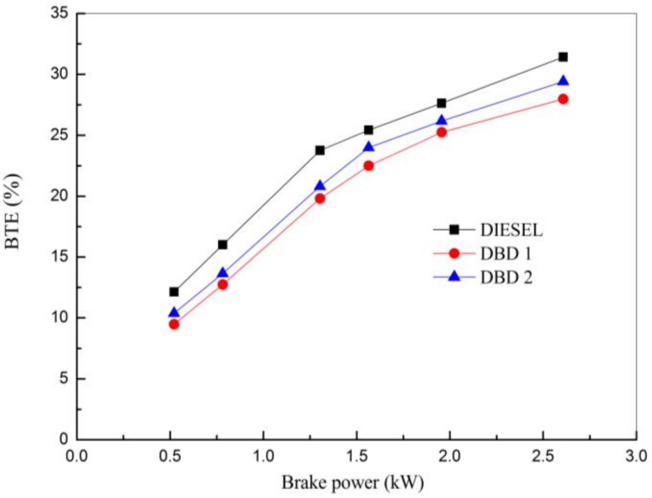

**Fig. 2.** Variation of brake thermal efficiency with brake power

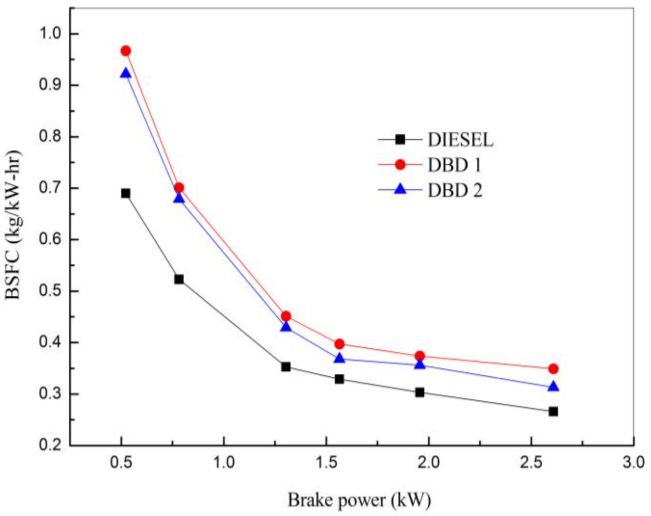

**Fig. 3.** Variation of brake specific fuel consumption with brake power

### *3.2. Emission Characteristics*

The emission characteristics curves of an unmodified diesel engine are shown in Figs. 4-8. It is observed that the trend of the curves matches almost same with the previous results reported in literature for the biodiesel blends [17, 24].

The unburned hydrocarbon discharge patterns for all biodiesel blends and diesel are presented in Fig. 4. From Fig. 4 it is evident that the hydro carbon emissions that are obtained by using different biodiesel blends are higher than the emissions obtained by using diesel at all loads. It is also observed that the hydro carbon emissions for all the tested fuels increase with increase in brake power. The values of hydro carbon emissions in the exhaust are observed to be lower for DBD 1when compared to DBD 2. Poor injection characteristics and improper mixing of blended fuels with air during the first phase of combustion must be the reason for this behavior. At full brake power of 2.608 kW, the HC emissions of the engine for diesel, DBD 1 and DBD 2 are 25 ppm, 31 ppm and 33 ppm respectively.

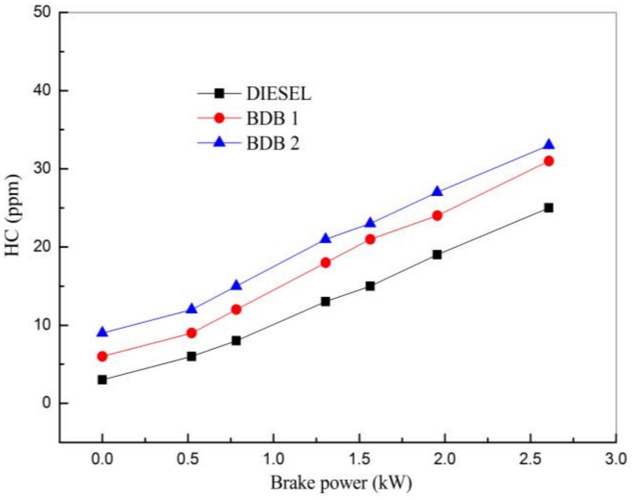

**Fig. 4.** Variation of hydrocarbons with brake power

From the Fig. 5 it can be observed that the trend in the variation of CO2 emissions with brake power for all the blends is lower than that of diesel. Further, it is observed that all the biodiesel blends have CO2 emissions lower than the diesel at all loading conditions. The reason for lower values for biodiesel blends is presence of higher oxygen content which leads to better burning of fuel at higher temperature in the engine cylinder. The CO2 emissions for all the tested fuels increase with increase in brake power and this is because at lower load the oxygen concentration is lesser when compared with engine operated at higher loads. At full brake power of 2.608 kW the CO2 emissions of the engine for diesel, DBD 1 and DBD 2 are 5.2% vol, 4.4% vol and 4.8 % vol respectively.

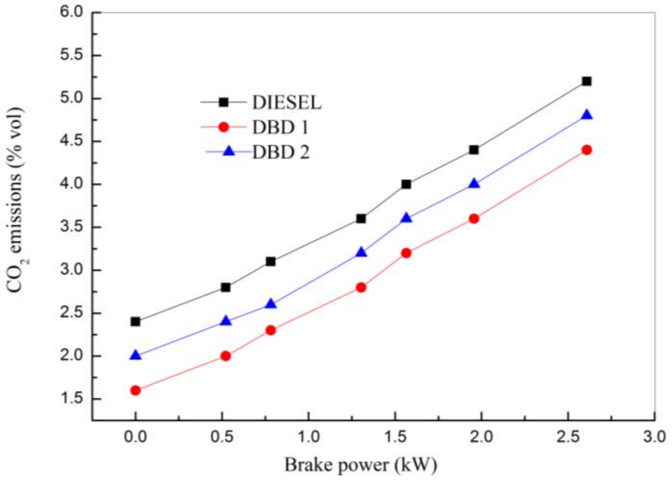

**Fig. 5.** Variation of carbon dioxide with brake power

The variation of CO emissions from no load to full load for conventional diesel and biodiesel blends is shown in Fig. 6. During combustion process, incomplete combustion of fuel results in CO emissions and also due to unavailability of chemically correct proportion of oxygen-fuel mixture. CO2 is produced from CO when complete combustion of fuel takes place under the presence of suitable amount of oxygen. The emission of CO happens at very low flame temperature or if the fuel air mixture is rich. It is observed that CO emissions are relatively low for sample DBD 2 when compared to pure diesel and DBD 1 at all loading conditions. Also, the CO emissions are found to be varying exponentially for pure diesel and DBD. More amounts of CO emissions at higher loads are obtained for all tested fuels due to more amount of fuel consumption. Hence, 2-10 times decrease in CO emissions are observed at no load as compared to full load conditions of engine operation. The CO emissions of biodiesel blends are lesser than that of conventional diesel at all loads and this is because the oxygen content of the biodiesel blends are higher than that of conventional diesel. At full brake power of 2.608 kW the CO emissions of the engine for diesel, DBD 1 and DBD 2 are 0.064% vol, 0.057 % vol and 0.048 % vol respectively.

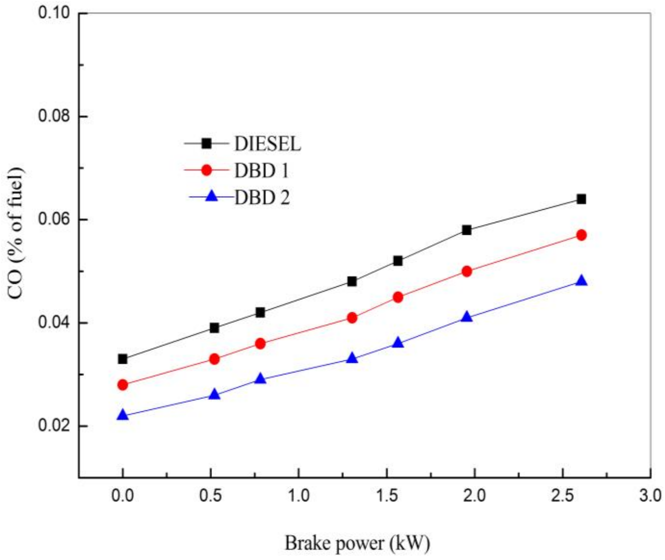

**Fig. 6.** Variation of carbon monoxide with brake power

NOx is formed due to presence of nitrogen in the air reacting with the combustion products at higher temperatures inside the cylinder. From Fig. 7 it can be observed that the NOx emissions obtained at all loading conditions for the biodiesel blends are lesser than the NOx emissions obtained while using conventional diesel as the fuel. The NOx emission of all the tested fuels increases with increase in brake power. The variation in NOx emissions of biodiesel blends with conventional diesel is very marginal at low brake power of 0.522 kW and it is found that the NOx emissions obtained for all the biodiesel blends are nearer to that of diesel. However, at higher loads the NOx emissions of biodiesel blends are lesser than that of conventional diesel fuelled engine. This is due to the fact that higher combustion temperature is obtained for conventional diesel at higher loads when compared to the biodiesel blends. At higher brake power of 2.608 kW the NOx emissions for diesel, DBD 1 and DBD 2 are 11 ppm, 9.3 ppm and 8 ppm respectively.

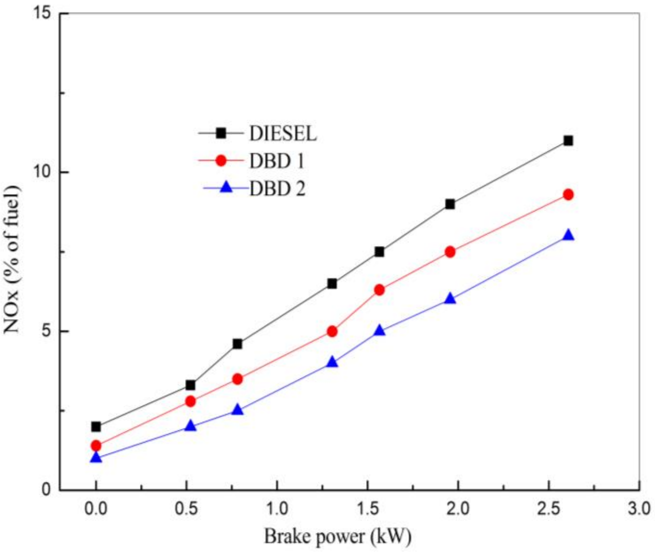

**Fig. 7.** Variation of oxides of nitrogen with brake power

Figure 8 shows the variation of exhaust gas temperature for all the tested fuels and it is observed that the exhaust gas temperatures of all the biodiesel blends are lesser than diesel at all loading conditions. The trend shows that the exhaust gas temperature increases with increase in brake power. The increase in exhaust temperature with brake power for all the tested fuels indicates that more amount of fuel is injected to produce more power. The biodiesel blends are having lesser exhaust temperatures when compared with conventional diesel due to their lower heating value and excess oxygen content. From the Fig. 8 it is evident that at higher brake power of 2.608 kW the exhaust gas temperature of the engine is observed to be lowest for DBD 2 (202°C). Similarly the values for diesel and DBD 1 are 220°C and 210°C respectively as expected.

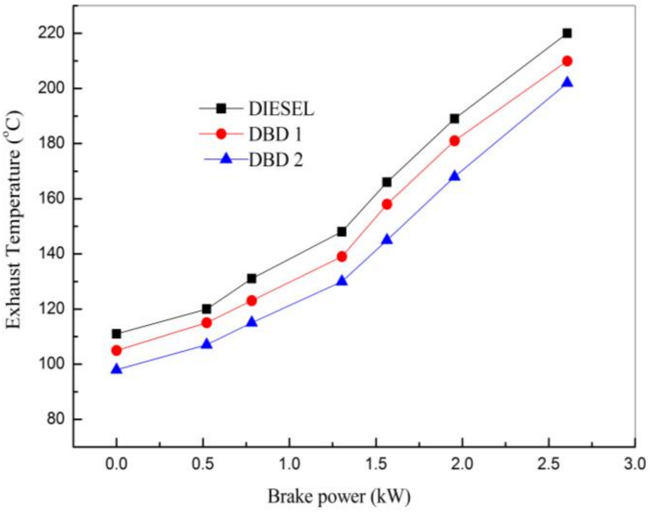

**Fig. 8.** Variation of exhaust gas temperature with brake power

## 4. Conclusions

Performance and emission characteristics of a compression ignition diesel engine with crude pongamia oil and its blends were experimentally investigated and compared with conventional diesel fuelled engine. The following are the important remarks observed:
1. Engine operation with the blend of orange oil to crude pongamia oil (DBD 2) gave better performance and improved engine efficiency than DBD 1 from no load to full load operating conditions. Also it is observed that the brake thermal efficiency of DBD 2 is almost nearer to conventional diesel at full load operating condition.
2. The brake specific fuel consumption of DBD 2 is lesser by 14% when compared to the biodiesel blend DBD 1 at full load working condition but still its value is higher when compared with conventional diesel.
3. Emissions like $CO_2$ and CO are lesser for DBD 2 when compared to DBD 1 and conventional diesel at all brake power and its being maximum for the pure baseline diesel fuelled engine.
4. $NO_x$ emissions for conventional diesel is higher than the biodiesel blends. By the introduction of orange oil to the crude pongamia biodiesel blend a significant reduction in $NO_x$ is observed.
5. Engine exhaust temperature for all the tested fuels increases with brake power and is higher for diesel compared to biodiesel blends due to its higher heating value.

From the experimental investigation, out of the two biodiesel blends investigated DBD 2 has shown better performance and lower emissions when compared with DBD 1. Hence it is evident that crude pongamia oil along with orange oil can be used as an alternative fuel for conventional diesel.

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**Nomenclature**

AFR – Air fuel ratio

bTDC – before top dead centre

BP – Brake power

BSFC – Brake specific fuel consumption

BTE, $\eta_{bth}$ – Brake thermal efficiency

CO – Carbon monoxide

$CO_2$ – Carbon dioxide

CPO – Crude pongamia oil

D – Diesel

DBD – Diesel biodiesel

DBD 1 – 60% CPO + 40% D

DBD 2 – 60% CPO + 25% D + 15% OO

EGT – Exhaust gas temperature

HC – Hydro carbons

OO – Orange oil