Experimental investigations on the performance and emission characteristics of a biodiesel fuelled engine using nanoparticles

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Abstract: Experiment was conducted to identify the performance and emission characteristics of biodiesel with Graphene Oxide (GO) nanoparticle as an additive. The performance and emission characteristics of Rice Bran oil biodiesel (B100) with addition of graphene nanoparticle was studied and compared with diesel values by using “Enginesoft” software. Experiment was conducted in four phases by using DI engine. The engine was tested with four types of fuels i.e., Diesel, Rice Bran Oil Biodiesel (B100), Rice Bran Oil with Graphene Nanoparticle 50ppm (B100G50), Rice Bran Oil with Graphene Nanoparticle 100ppm (B100G100). The emission characteristics of the experiment resulted in decrease in NOx emissions by 7.5 %, HC Hexane emission by around 15 % and increase of CO emissions by 2.3 %. After successful validation of numerical study of the emission characteristics of the experiment, the combustion characteristics using the same fuels were verified. In the numerical study of performance characteristics, it is found that, BSFC (Brake specific fuel combustion) increases by almost 56.32% and BTE (Brake thermal efficiency) decreased by 11.78 % when pure Biodiesel (B100) was used. The combustion characteristics showed an increase in increase in peak cylinder pressure with a decrease in ignition delay period when pure RBO biodiesel (B100) and its nanoparticle blends were used (B100G50 and B100G100).

1. Introduction

The constant increase in consumption of fossil fuel resulted by an increase in population and urbanization may result in depletion of fuel resources in near future. The Greenhouse gases from fossil fuel is constantly affecting the planet and causing global warming and other pollutant emission problems [3]. So the world is searching for an alternate fuel which can overcome any fuel related crisis in the future. If the alternate fuel is clean and environment friendly it will fix all the issues. Scientists had come up with various options among which biodiesel is the most preferable fuel. Due to the fact that it is a renewable resource unlike fossil fuels and it is prepared with environment friendly methods biodiesel has gained increasing popularity in recent studies [4]. Scientists had seen the performance of biodiesel prepared from the vegetable oil which is close to the commercial diesel and it is promising to the future demand [1,2]. Biodiesel can be used as an alternative fuel as it can control the air pollution caused by burning fuel. Biodiesels are the fatty acid easter produced from vegetable oil or animal fats through a chemical process known as transesterification. The difference in composition and properties of biodiesel produce from soyabean oil, rapeseed, jatropha oil or animal fats, from pure diesel will influence the performance and emission characteristics of the engine.

Dwivedi et al. [5], Experimentally observed that an increase in the biodiesel percentage in the engine compound reduces engine power. As reported by Xue et al. [6], A decrease in engine power with biodiesel is mainly due to a decrease in the temperature of biodiesel compared to diesel. The same reason can be attributed to the increase in brakes used. On the other hand, Canak and Van Garpen [7] claim that compared to diesel fuel, biodiesel improves thermal efficiency as previously injected,
leading to early use. The short-term delay in a fuel fire is due to the higher cetane value than the effect of diesel on a previous fire[10]. Due to the difference in the amount of cetane and the reduction of the heat delay in diesel tends to increase the cylindrical pressure. The higher the oxygen content significantly improves the fire rate. Compared to diesel biodiesel promotes total heat and thus effectively reduces the emission of Carbon monoxide (CO), Nitrogen oxide (NOx), Carbon dioxide (CO2) & Particulate matter (PM). High NOx emissions are due to relatively high temperatures inside the cylinder due to biodiesel heating and high oxygen content such as fuel as defined by Mustapic [8]. From the latest additives to biodiesel, nanoparticles as an additive have a promising new addition to biodiesel to achieve significant improvements in performance and a lower level of exhaust emissions. Dreizin noted that the dispersed nanoparticle [9] oil test showed improved thermo body properties due to its excessive volume size and acts as an oxygen buffer in relation to NO emissions. Kenneth et al., Later noted that adding nanoparticles helps to improve the rate of heat transfer due to its high surface area. Many experiments have been performed using different nanoparticles indicating that cerium oxide nanoparticles can be used as fuel-carrying additives in hydrocarbon liquid fuels. Other experiments have also shown that nanoparticles can also be used in diesel emulsion oil which has shown a significant reduction in particle matter. The literature is rich in such experiments on biodiesel and nanoparticles. Numerical predictions are sometimes preferred due to difficulties in experimental works. Here the authors have attempted to compare the experimental study of emissions and performance of conventional diesel in a 4-stroke single cylinder direct ignition engine with Rice Bran Oil (RBO) biodiesel and two different concentration blends of Graphene oxide Nanoparticle with RBO. The results have been verified completely and transparently.

2. Experimental Setup and Procedure:

2.1. Preparation of test fuels
In this work commercially available Rice Bran oil biodiesel (B100) and diesel fuel is employed. The properties of the fuels are verified before they are subjected into engine experimental investigations. Graphene oxide Nanoparticles were also purchased from a reputed nanoparticle research lab in Bangalore. All its properties were also verified before subjecting into the experiment. In this experiment four types of fuels were used where two of them were readily available commercially but the other two had to be prepared by adding the Graphene nanoparticle to Biodiesel through the process of ultra sonification.

One blend was prepared by adding 50 gms of nanoparticle to 650 ml of Biodiesel so that the concentration of graphene would be 50 ppm (B100G50). The ultra-sonic vibrations from the ultrasonifier was used to mix the two into a homogenous mixture. The other blend (B100G100) which contained 100 gm of nanoparticle was also prepared by the same method. The prepared fuels were subjected to stability investigation by keeping them in a glass jar in static condition. The fuels were found to be stable and homogenous. Finally, the fuels were tested in a single cylinder 4 stroke DI engine. The properties of graphene nanoparticle use is given in the Table 1

| Specifications of Graphene oxide               |
|-----------------------------------------------|
| Purity                | 98-99%            |
| Average number of layers | 2-6               |
| Diameter             | 1-5 microns       |
| Thickness            | 0.5-2nm           |
| Colour               | Amber             |
| Bulk Density         | 0.241g/cc         |

2.2. Experimental Setup and Operating Conditions
The test is performed on a single-cylinder, four-dimensional, DI-engine heat connected to a current-type dynamometer for loading and output of gas temperature measured using a K thermocouple type.
Engine details are given in Table 1. This test was conducted at the SRI Venkateshwara Engineering Consultancy in Kancheepuram. It is provided with the necessary fire pressure tools and crank-angle measurements. The set consists of a stand-alone panel box containing an air box, fuel tank, manometer, fuel gauge unit, air and fuel gauge transmitters, process indicator and engine indicator. Rotameters are provided with a measurement of water flow and calorimeter flow as shown in Figure 1. The setting enables you to study engine performance with brake power, indicated power, frictional power, BMEP, IMEP, brake thermal performance, demonstrates efficiency thermal, Mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio and temperature balance. The software package for LabVIEW based Engine Performance Analysis “Enginesoft” is provided for online performance testing. The emission rate such as carbon monoxide (CO), unburned hydrocarbon (UBHC) and nitric oxide (NO) is measured using spec gas analyzer 444N and smoke opacity is measured using AVL 437 C Smoke. The test is performed on a single diesel diesel engine operating at a constant speed of 1500 rpm. The planned view of the test setup is shown in Table 2. The engine is started under loading mode; allowed to heat at an average speed of 1500 rpm and all readings are taken under stable state conditions. Engine operating parameters such as thermal collapse and emission parameters such as NO, EGT, CO, UBHC and light emissions are measured.

The test is done & with a single cylinder, four-sided, Direct ignition (DI) engine connected to the current eddy type dynamometer loading. At first the engine was running on diesel like gasoline load and performance and output rates recorded. After that the engine load was gradually increased from 0% to 100% and prices were recorded. After that the engine operated with a load-free Rice Bran Oil Biodiesel and gradually increased the load from 0% to 100%. After that 50ppm Graphene Nanoparticle was added to Rice Bran Oil Biodiesel (B100G50) using ultra sonification. Graphene Nanoparticles successfully mixed were found to be stable after the procedure. After that the same process is done like that of gasoline. Then the final test was performed with Rice Bran Oil Biodiesel B100 and 100ppm Graphene Nanoparticle (B100G100) and the same process was performed with the other petrol and performance and recordings. After testing all prices are calculated from the "Enginesoft" software. Emissions values are recorded in the gas analysis. After getting all the performance results and output graphs drawn. Performance and emission characteristics of Rice Bran Oil Biodiesel and Rice Bran Oil Biodiesel with Nanoparticle as an additive compared to the performance of Diesel Oil and emission markers.

Figure 1: Schematic diagram of the Whole setup
### Table 2. Diesel Engine Specifications

| Product               | Engine test setup 1 cylinder, 4 stroke, Diesel (Computerized) |
|-----------------------|---------------------------------------------------------------|
| Product code          | 224                                                           |
| Engine                | Make Kirloskar, Model TV1, Type 1 cylinder, 4 stroke Diesel, water cooled, power 5.2 kW at 1500 rpm, stroke 110 mm, bore 87.5 mm. 661 cc, CR 17.5 |
| Dynamometer           | Type eddy current, water cooled                               |
| Propeller shaft       | With universal joints                                        |
| Air box               | M S fabricated with orifice meter and manometer              |
| Fuel tank             | Capacity 15 lit with glass fuel metering column              |
| Calorimeter           | Type Pipe in pipe                                            |
| Piezo sensor          | Range 5000 PSI, with low noise cable                         |
| Crank angle sensor    | Resolution 1 Deg, Speed 5500 RPM with TDC pulse.             |
| Data acquisition device| NI USB-6210, 16-bit, 250kS/s.                               |
| Piezo powering unit   | Model AX-409.                                                |
| Temperature sensor    | Type RTD, PT100 and Thermocouple, Type K                    |
| Temperature transmitter| Type two wire, Input RTD PT100, Range 0-100 DegC, 1/P Thermocouple, Range 0-1200 DegC, O/P 4-20mA |
| Load indicator        | Digital, Range 0-50 Kg, Supply 230VAC                        |
| Load sensor           | Load cell, type strain gauge, range 0-50 Kg                  |
| Fuel flow transmitter | DP transmitter, Range 0-500 mm WC                           |
| Air flow transmitter  | Pressure transmitter, Range (-) 250 mm WC                    |
| Software              | “Enginesoft” Engine performance analysis software             |
| Rotameter             | Engine cooling 40-400 LPH; Calorimeter 25-250 LPH            |
| Pump                  | Type Monoblock                                               |
| Overall dimensions    | W 2000 x D 2500 x H 1500 mm                                 |
| Optional              | Computerized Diesel injection pressure measurement            |

### 3. Properties of fuels used:

The operating characteristics and emissions of a biodiesel-fired engine depend entirely on biodiesel thermo structures. Basically, biodiesels are derived from vegetable oils through a popular process known as transesterification in which there is a catalyst and alcohol as a reactant. Due to the availability and cost of methyl alcohol it is widely used and the biodiesel obtained is also known as fatty acid methyl esters. The purpose of the transesterification process is to reduce the viscosity of the oil. Ideally, transesterification may be the least expensive way to convert a large, bio-oil cellular structure into smaller, more specific molecules needed for conventional diesel fire engines. It contains very small amounts of phosphorus and sulphur so the release of sulphur oxides (SOx) is almost ignored. Rice Bran oil (RBO) biodiesel has a very high concentration and amount of cetane compared to mineral diesel. The high temperature and automatic temperature of RBO biodiesel makes it easier to store and move and safer than mineral Diesel. The amount of carbon dioxide from the hot rot of high-molecular-weight vegetable compounds is greater than that of commercial oil. The thermo-physical features of RBO biodiesel and standard diesel fuel are presented in the form of a table for easy comparison between them. Required features of some compounds are calculated in the form of a weighted average.
### Table 3: Fuel Properties

| Fuel properties        | Diesel       | Rice Bran Oil |
|------------------------|--------------|---------------|
| Cetane number          | 51           | 41            |
| Density                | 826 Kg/m³    | 875 Kg/m³     |
| Flash point            | 70°C         | 152°C         |
| Kinematic Viscosity @40°C | 5.5-8      | 36.4          |
| Calorific Value        | 45,550 KJ/kg | 39600 KJ/kg   |

#### 4. Results and Discussion

Some of the fuel used in engines is regularly tested on the basis of engine performance and its environmental impact. Thus the parameters that describe the performance and characteristics of the diesel engine emissions are assessed experimentally and clearly in this work and discussed and analysed in this section. As such the parameters defining the performance and characteristics of the diesel engine emissions have been evaluated both experimentally and graphically in this work and have been discussed and analysed in this section.

4.1. Parameters in consideration:

In this section, the experimental results of the characteristics of two types of fuel are validated at the same operating conditions. The validation is done with two extreme fuels, namely Rice Bran Oil Biodiesel (RBO) (B100) and mineral Diesel (B0). Also, Graphene nanoparticles were blended in the ratio of 50 ppm and 100 ppm separately with RBO and tested. Mainly four parameters were considered for validation and the parameters are Brake thermal efficiency, Brake Specific fuel consumption, NOx emissions and HC Hexane emissions.

4.1.1. Brake Thermal Efficiency:

Brake thermal efficiency is one of the most important engine performance parameters which indicates the percentage of fuel energy converted into output work. Figure 2 represents the variation of brake thermal efficiency of diesel with Rice Bran oil biodiesel. From the figure, it can be observed that Diesel (B0) has higher efficiency than Rice bran biodiesel (B100) and nanoparticle blended biodiesel at all loading conditions. However, at low load (around 4 kg), efficiency values are found to be 18.48% experimentally for pure diesel (B0). At the same operating conditions, the corresponding value came to be around 16.43% for RBO biodiesel (B100). Also, the efficiency values were around 16.33% and 16.35% for RBO with 50 ppm nanoparticle blend and 100 ppm blend respectively. At higher load conditions (around 18 kg) however the difference of efficiency between diesel and biodiesel become more prominent being 32.19% for diesel and 28.13% for RBO biodiesel (B100). But in this case the nanoparticle blends of RBO had more efficiency being 29.40% and 30.08% for 50 ppm & 100 ppm blends respectively. This difference in the efficiency of diesel being higher than the biodiesel might have been created because of higher Calorific Value of Diesel (45.5 MJ/kg) than that of RBO biodiesel (39.4 MJ/kg).

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**Figure 2:** Variation of BTE Vs Engine load
4.1.2. Brake Specific fuel consumption:

Brake specific fuel consumption (BSFC) is also another vital factor for evaluating the performances of an engine fuelled with an alternative fuel or supplementary fuels. Figure 3 graphically represents the variation of brake specific fuel consumption of the engine with gradual loading for diesel, biodiesel and nanoparticle blended biodiesel. From the graph it can be noted that the BSFC value of pure biodiesel and all its blends are higher than that of pure diesel. This can be the result of the lower heating value of RBO biodiesel which is much lower than mineral diesel. At low loading conditions, the experimental BSFC value is 0.468 kg/kWh for diesel and at the same loading conditions the value came to be 0.562 kg/kWh for RBO biodiesel (B100). The BSFC value for RBO with Nanoparticle blends were around 0.557 kg/kWh and 0.566 kg/kWh for 50 ppm blend and 100 ppm respectively. At higher load conditions, the values of all the fuels came to be very close to each other being 0.269 kg/kWh for diesel, 0.316 kg/kWh for Biodiesel (B100), 0.304 kg/kWh for RBO with 50 ppm blend and 0.311 kg/kWh for RBO with 100 ppm blend of nanoparticle.

![Figure 3: Variation of BSFC Vs Engine load](image)

4.1.3. Crank angle vs cylinder pressure:

This graph (figure 4) is drawn between Crank angle and cylinder pressure at full load. RBO B100 have the highest pressure of 68.9 bar. RBO (B100G100) have the lowest pressure value of 68.4 bar. RBO (B100G50) and Diesel have 68.5bar and 68.8 bar respectively. For nanoparticle additive fuel low cylindrical pressure and heat rate is observed because they dispersed with biodiesel with earlier combustion and improve ignition properties with catalytic combustion and shorter ignition delay. If the graph is closely observed, the graph of RBO blend with 50 ppm nanoparticle slightly shifted towards the left which signifies that the combustion started earlier in that blend and it showed reduced ignition delay. As a result of which higher in cylinder peak pressure and higher temperature was observed inside the cylinder chamber for RBO blend B100G50 fuel.

4.1.4. Crank angle vs heat release

As shown in figure 5 the graph is drawn between crank angle and heat release rate at full load. Net Heat release rate is high for the diesel with 43.5kJ. Then followed by RBO B100, B100G50 and B100G100. Diesel has the higher heat release rate as compare to other fuel because it has higher calorific value and shorter ignition delay as compare to biodiesel which has low calorific value.

4.1.5. NOx emissions:

The environmental parameter validated in this work is the NOx emission. Figure 4 represents the variation of NOx emissions of pure diesel, RBO biodiesel and its nanoparticle blends. A close look at the graph reveals that the maximum values of the experimental result for NOx emissions are 583 ppm for diesel (B0) and 531 ppm for RBO biodiesel at the same operating conditions. At higher loading
conditions it is noted that the difference in the concentration of NOx emissions between the fuels decrease significantly which are 1502 ppm for Diesel and 1488 ppm for RBO Biodiesel (B100). The values with nanoparticle blends in RBO are very close to that of pure biodiesel being 1473 ppm for 50 ppm blend and 1420 ppm for 100 ppm blends.

Figure 4: Crank angle Vs Cylinder pressure

Figure 5: Crank angle Vs Heat release

So, it is very clear from the graph of figure 6 that there is a total reduction of NOx emissions of **7.11 %** in pure Rice Bran Oil (RBO), **7.7 %** in RBO with 50 ppm Graphene nanoparticles & **6.4 %** in RBO with 100 ppm graphene nanoparticles respectively. It was also observed that there was more reduction of NOx emissions at low load being up to 10.12 % when pure biodiesel with 50 ppm nanoparticle was used. At high load only 5.7 % reduction was observed & this also with 50 ppm nanoparticle. Hence it is observed that pure biodiesel with 50 ppm of graphene nanoparticle is more suitable that adding 100 ppm. At higher concentration of nanoparticles, the blend becomes unstable even if properly mixed with the help of ultrasonifier.

Figure 6: Variation of NOx Vs Engine load
4.1.6. HC Hexane emissions:

One more pollutant that is discussed in this section is Hydro Carbon (HC) Hexane emissions. Figure 5 represents the variation of HC Hexane emissions of diesel with RBO biodiesel and its nanoparticle blends. It is noted from the graph that the maximum value of experimental result of HC Hexane emissions are 32 ppm for pure diesel and 30 ppm for pure biodiesel at the same operating conditions having low loads. Also, the values of nanoparticle blends were not that far from the previous two being 25 ppm for 50 ppm blend and 33 ppm for 100 ppm blend of graphene nanoparticle with RBO. So, at low loading conditions there is very little decrease (around 6.4 % to 8.25%) of HC hexane emissions when fuelled by alternate biodiesel (B100) and its nanoparticle blends. At higher load conditions, the emissions increase dramatically for diesel which are at 86 ppm but the values for RBO and Its 50-ppm blend had the same value of 71 ppm which is about 17.44 % reduction of Hydrocarbon emissions. But at the same operating conditions the value for the 100-ppm blend of RBO increased to 88 ppm which is even more than the pure diesel (B0). Therefore, it is clear from the experiment that adding up to 50 ppm of graphene nanoparticle to RBO biodiesel is suitable in decreasing HC emissions thus decreasing soot or unburnt particulate matters. This is also due to the fact that pure biodiesel already contains low elemental carbon to hydrogen ratio because of which there is less formation of harmful Hydrocarbons and unburnt particles.

4.1.7. CO and CO2 emissions:

One of the major pollutants of the air that is discussed in this section is CO (Carbon monoxide) emission. Figure 6 represents the variation of CO emissions of diesel with RBO biodiesel and its nanoparticle blends. The graph makes it clear that the maximum value of the experimental results of CO emission are 0.09 & 0.13 for pure diesel and RBO biodiesel respectively. Also, the values of nanoparticle blends of 50 and 100 ppm with RBO are 0.14 and 0.16 respectively. Therefore, at low load conditions (around 0.25 kg) a 30.7 % increase in Pure biodiesel (B100) and around 40 % increase in nanoparticle blend oil was observed. At higher load conditions (around 18 kg) however, a 6 % decrease of CO emissions in B100 was observed while emissions being still high in 50 ppm blend by 5.8 % and highest in 100 ppm nanoparticle blend by 24.3 % than diesel was observed. This suggests that RBO biodiesel alone can decrease the CO emissions by a little but both 50 ppm and 100 ppm nanoparticle blend RBO biodiesel are not suitable in decreasing CO emissions at any load.

CO2 which is also one of the major greenhouse gas emissions is responsible for majority of pollutions. Figure 7 shows a graph between CO2 in Y axis and Engine load in X axis. CO2 emissions increases on increasing the engine load due to higher fuel consumption on increasing the load. CO2 emissions was increased by 4.5 % for pure biodiesel and 4 % on an average for both its nanoparticle blends as compared
to diesel in low load conditions (0.25 kg). In the figure the maximum emission reached for pure diesel is 11.3 and for pure biodiesel is 11.6 for maximum load (around 18 kg). So there is an increase of 2.6% in CO2 emissions of pure biodiesel and also a very similar increase in both 50 and 100 ppm blends of biodiesel. Though the increase of CO2 emission is less in maximum load, it does not change the fact that neither pure RBO biodiesel nor its nanoparticle blends were able to decrease the CO2 emissions.

**Figure 8:** Variation of CO vs Engine load

**Figure 9:** Variation of CO2 Vs Engine load
4.1.8. Smoke Opacity:
This is another fuel property that was tested in the experiment i.e., the smoke opacity of RBO and its blends compared to diesel at different loads. Figure 8 shows a graph that indicates variation of smoke with respect to Engine load. It can be observed that RBO B100G100 has the highest smoke opacity than other fuel and diesel has the lowest smoke opacity. Smoke opacity often corresponds to O2 content of the fuels. The smoke is less opaque in diesel than RBO and its other blends owing to its higher O2 content that RBO biodiesel. As a result, the Smoke opacity is more in the biodiesel at all loading conditions constantly.

![Figure 10: Variation of Smoke Vs load](image)

5. Conclusion
In this study, experiments were performed on the DI engine in which performance and emission characteristics were tested. In this experiment four types of fuels were used and they were mineral diesel and Biodiesel and two blends of nanoparticles with Biodiesel. The biodiesel used was Rice Bran Oil (RBO) and the nanoparticle used was Graphene Oxide (GO). The engine was tested with these biodiesel blends as fuel and the performance and emission characteristics were found out and then were compared to that of diesel. The results are as followed:

- It was found that the emission of NOx was less when Biodiesel was used as fuel when compared to that when mineral diesel was used at higher loading.
- The trend was found similar for the emission of HC for the same loading conditions because of the more oxygen content of the biodiesel.
- The CO & CO2 emissions were found to be higher when biodiesel and its two nanoparticle blends were used as compared to diesel.
- It was found that the emission of smoke was similar for low and high load but at medium loads the emission of smoke was higher when mineral diesel was used as fuel.
- When SFC was compared to the brake power it was found that they were inversely proportional to each other and the SFC was found lowest at every load for the diesel when compared to the biodiesels.
- As the brake power increased the brake thermal efficiency also increased and the efficiency was greater for the Diesel than Biodiesel at the same loading condition.
- Cylinder pressure and heat release rate were better for biodiesels and its nanoparticle blends during the combustion process.
Nomenclature

BTE : Brake Thermal Efficiency

BSFC : Brake Specific Fuel Consumption

BMEP : Brake Mean Effective Pressure

IMEP : Indicative Mean Effective Pressure

DI : Direct Ignition

EGT : Exhaust Gas Temperature

UBHC : Unburned Hydro Carbon

NO : Nitrogen Oxide

B100G50 : 100% Rice Bran oil Biodiesel + 50ppm Graphene Nanoparticle.

B100G100 : 100% Rice Bran oil Biodiesel + 100 ppm Graphene Nanoparticle.

RBO : Rice Bran Oil Biodiesel

B100 : 100% Biodiesel

Ppm : Parts per million

CO : Carbon monoxide

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