ISSN 2319 – 7757 EISSN 2319 –7765

Indian Journal of

Engineering

# Effect of nozzle opening pressures on diesel engine fuelled with Madhuca Indica biodiesel and its blend with diesel fuel

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**Publication History**
Received: 23 October 2013
Accepted: 17 December 2013
Published: 1 January 2014

**Citation**
Solaimuthu C, Vetrivel P, Subbarayan MR, Channankaiah. Effect of nozzle opening pressures on diesel engine fuelled with Madhuca Indica biodiesel and its blend with diesel fuel. *Indian Journal of Engineering*, 2014, 7(17), 14-22

## ABSTRACT

The engine performance, combustion and emission characteristics of Mahua (Madhuca Indica) biodiesel (Methyl Ester of Mahua Oil) and its blends with diesel is presented. The thermo-physical properties of all the fuel blends have been measured and presented. The engine tests are conducted on a 4-Stroke Tangentially Vertical (TV) single cylinder kirloskar 1500 rpm water cooled direct injection diesel engine with eddy current dynamometer at different nozzle opening pressures of 210, 220 (standard), 230, 240 and 250 bar with standard static injection timing of 23° bTDC maintained as constant throughout the experiment under steady state conditions at full load condition. From the test results, it could be observed that the higher nozzle opening pressure of 250 bar and standard static injection timing of 23° bTDC gives better performance like higher brake thermal efficiency lower specific fuel consumption, higher heat release rate, higher $CO_2$ and lower exhaust gas temperature, HC, CO, Smoke density and $NO_x$ as compared to standard nozzle opening pressure of 220 bar for B0 fuel and B25. The Optimum nozzle opening pressure of 250 bar, the percentage reduction in CO, smoke density and $NO_x$ is 41.03%, 34.79%and 7.92% respectively. Day by day cost of the petroleum hikes due to unavailability in the world market. The research findings show that B100 gives lowest emissions which make it a good alternative fuel to operate diesel locomotives without any modification in existing diesel engine.

**Keywords:** Mahua Oil; Biodiesel; Nozzle Opening Pressure; Static Injection Timing; Performance; Emissions

**Nomenclature:**

| | | |
|---|---|---|
| bTDC | - | before Top Dead Center |
| NOP | - | Nozzle Opening Pressure |

SIT - Static Injection Timing

## 1. INTRODUCTION

In recent years, a growing interest is evinced concerning renewable and alternative fuels. These fuels are bio-degradable and oxygenated and the examples include vegetable oils, their derivatives and their mixtures with diesel. Research on vegetable oils in diesel engine is in progress at least for over 100 years. However, due to availability of fossil diesel, in the last century the research on vegetable oil based engine fuels lost importance with time. In the present time due to the price hike of petroleum diesel, the research on biodiesel has again gained importance. Biodiesel is derived from vegetable oils such as Corn, Sunflower, Karanja, Cotton Seed, Jatropha, Neem and Madhuca Indica (Mahua), by a process called transesterification. Out of these vegetable oils, non-edible vegetable oils are preferred for engine applications in India. This study is focussed on Mahua biodiesel. Mahua biodiesel and its blend in different volumetric proportions with fossil diesel are used to study the performance, combustion and emission characteristics. From table 1 it can be seen that Madhuca Indica has a lower calorific value but higher density. This means that the calorific value of Madhuca Indica oil on a volumetric basis approaches the volumetric calorific value of diesel fuel. However, it is essential to compare the economy of the two fuel using brake thermal efficiency and not as specific fuel consumption. The combustion characteristics of vegetable oil can be improved by transesterification. In the case of Madhuca Indica oil, the cetane number increases along with flash and fire point (refer table 2) compared to neat diesel. A brief literature review of research work carried out by various researchers is presented below.

The diesel engine was operated fuelled with Mahua oil and LPG by changing the injection pressure for the entire operations. The Mahua biodiesel can be used as an alternative fuel in dual fuel engine with pilot fuel of 5 mg per cycle and injection pressure of 200 bar (Kapilan and Reddy 2008). The diesel engine operation was carried out with 1,4 dioxine-ethanol-diesel blends on diesel engines with and without thermal barrier coating. The blend ratio of 70% diesel, 20% ethanol and 10% dioxane blend gives better performance and lower emissions (Sundarraj et al. 2010). The Diesel engine operation was investigated fuelled with 1,4 dioxine-ethanol-diesel blends. The blend ratio of 60% diesel, 30% ethanol and 10% dioxane by volume gives better performance and lower emissions without any engine modification (Sundarraj et al. 2009). The performance of the diesel engine was carried out with Mahua biodiesel as an alternative. The Mahua biodiesel gives lower emissions than that of petro-diesel (Kapilan and Reddy 2008). The effect of injection time on the performance and emission on diesel engine was carried out fuelled with Mahua biodiesel. The B100 can be used as substitute fuel for diesel with advanced injection timing for better performance and lower emissions (Kapilan et al. 2009). The biodiesel was prepared and discussed its percentage of acid catalyst and esterified and transesterified oils for constant methanol and oil ratio of the fuel (Padhi and Singh 2010). The Mahua biodiesel and fossil diesel study was done and discussed extensively the engine performance obtained by blend with different volumetric ratios. The biodiesel 20% by volume with 80% diesel formed an optimum mixture for their engine parameters (Raheman and Ghadge 2007). The investigation was carried out to produce biodiesel from Mahua oil (Madhuca Indica) having high free fatty acids (FFA) (Raheman and Ghadge 2005). The operation was carried out on a DI diesel engine fuelled with pure Mahua oil methyl ester (B100) and neat diesel (B0). The B100 gives the lower emissions as compared with B0 (Saravanan et al. 2010). A study of biodiesel (Mahua Oil Methyl and Ethyl Ester) production was carried out by transesterification process and investigated the combustion and emission parameters of the DI engine. The Mahua Oil Methyl Ester dominates ethyl ester of Mahua oil and diesel fuel in terms of performance and emission of naturally aspirated DI diesel engine (Sukumar Puhan and Nagarajan 2007). The operation was investigated on diesel engine for calibrating the performance and emission of DI engine fuelled with Mahua Oil Methyl Ester, Mahua Oil Ethyl Ester, Mahua Oil Butyl Ester and diesel fuel (Sukumar Puhan and Nagarajan 2005). The performance of the diesel engine test was investigated fuelled with Mahua biodiesel in naturally aspirated diesel engines. The neat diesel and neat biodiesel. Emissions are measured and reported that the impact of biodiesel (B100) is lower than that of diesel (B0) (Puhan et al. 2005). The report of the biodiesel preparation was done and discussed its performance and emission characteristics of diesel engine with B0 and B100 fuel. The Mahua Oil Methyl Ester (B100) burn more efficiently than diesel (B0) and the emissions of B100 is lower than that of B0 (Puhan et al. 2005). The observation has been made on DI diesel engine. The significant improvement in engine performance and emission parameters with Mahua Oil Methyl Ester and its blends with diesel. The B20 blend gives better performance and lower emissions and thus could be used as an alternative fuel for heavy-duty engines (Sharanappa Godiganur et al. 2009). The report has been prepared for the calibration of the performance and emission parameters fuelled with Mahua Oil Methyl Ester and its different blends on diesel engine. Among the blends, the B20 gives the maximum brake thermal efficiency and lower brake specific fuel consumption of their engine set up (Sharanappa Godiganur et al. 2009). The performance of the DI diesel engine was tested with Mahua oil in different volumetric proportions to

**Table 1**

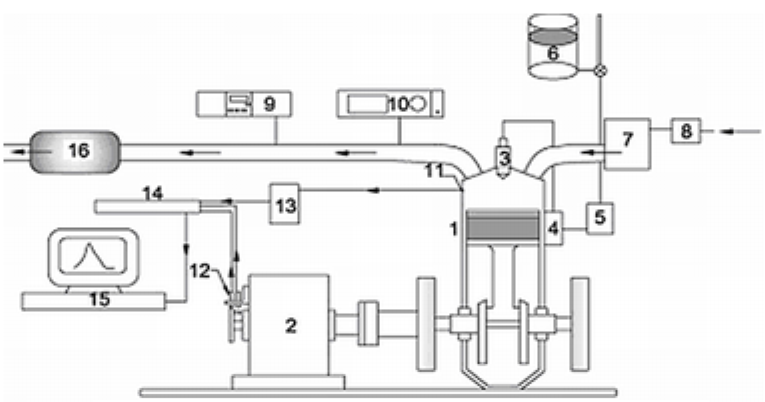
Specification Details of the Engine

| Name of the Description | Details / Value |
|---|---|
| Make | Kirloskar TV – I |
| Type | Single Cylinder, DI Diesel engine |
| Bore × Stroke | 87.5 mm x110 mm |
| Compression ratio | 17.5:1 |
| Speed | 1500 rpm |
| Rated brake power | 5.2 kW |
| Cooling system | Water Cooled |
| Nozzle Opening Pressures | 210, 220, 230, 240 and 250 bar (modified) |
| Static Injection Timing | 23° bTDC (rated) at full load |

**Table 2**

Properties of Mahua biodiesel and its Diesel blends

| S. No | Name of the Properties | ASTM Code | B0 | B25 | B50 | B75 | B100 |
|---|---|---|---|---|---|---|---|
| 1 | Kinematic Viscosity at 40ºC in cSt | D2217 | 2.6 | 3.49 | 4.17 | 4.98 | 6.04 |
| 2 | Gross Calorific Value in kJ/kg | D4809 | 45596 | 43976 | 43268 | 42523 | 41819 |
| 3 | Flash Point in ºC | - | 65 | 71 | 78 | 112 | 170 |
| 4 | Fire Point in ºC | - | 70 | 79 | 88 | 123 | 183 |
| 5 | Cloud Point in ºC | - | -15 | 4 | 8 | 11 | 13 |
| 6 | Specific Gravity | D445 | 0.82 | 0.83 | 0.85 | 0.87 | 0.88 |
| 7 | Acidity | - | 0.065 | 0.067 | 0.070 | 0.083 | 0.26 |
| 8 | Cetane Number | - | 46 | 51.6 | 51.7 | 51.8 | 52.4 |



1. Kirloskar TV1 Engine
2. Eddy Current dynamometer
3. Injector
4. Fuel pump
5. Fuel filter
6. Fuel tank
7. Air stabilizing tank
8. Air filter
9. AVL smoke meter
10. AVL Di-gas analyzer
11. Pressure transducer
12. TDC Encoder
13. Charge amplifier
14. Indimeter
15. Monitor
16. Exhaust silencer

**Figure 1**

Schematic of the Diesel Engine Setup

evaluate performance and emission parameters. There is an increase in thermal efficiency of the engine with preheated Mahua straight vegetable oil mixed with flow improvers (Kale et al. 2009). From the previous studies, it could be observed that most of the studies were mainly related to the performance, combustion and emission characteristics of diesel engine using biodiesel as fuel at standard nozzle opening pressure. In this paper an analysis of 4S TV single cylinder DI with different nozzle opening pressures of 210, 220, 230, 240 and 250 bar and with a constant static injection timing of 23° bTDC at full load condition of the diesel engine with eddy current dynamometer using B0, B25, B50, B75 and B100 as fuel is presented.

## 2. EXPERIMENTAL SETUP AND PROCEDURE

Experiments have been conducted on a 4 stroke, kirloskar, TV 1 direct injection diesel engine developing power output of 5.2 kW at 1500 rpm connected with water cooled eddy current dynamometer. The schematic of the engine setup is shown in Figure 1. Specifications of the engine are presented in Table 1. The standard static injection timing of 23°bTDC and nozzle opening pressures of 210, 220, 230, 240 and 250barareused for the entire experiments at full load condition of the engine. AVL 444 di-gas analyzer is used for the measurement of exhaust emission of HC, CO, $CO_2$, $O_2$ and $NO_x$. Smoke level is measured using

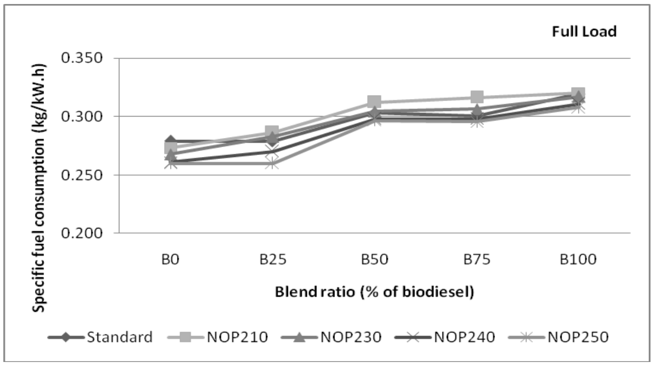



**Figure 2**
Specific Fuel Consumption vs Blend Ratio

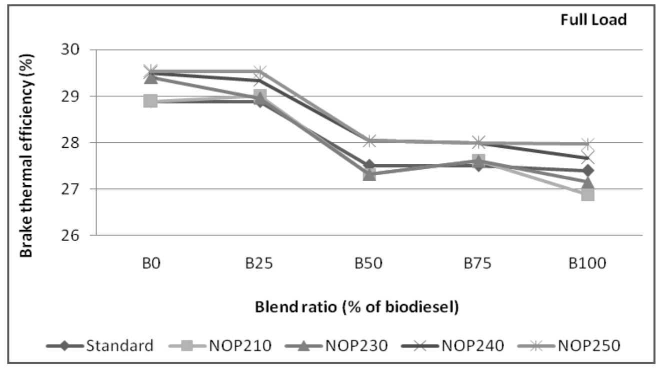



**Figure 3**
Brake Thermal Efficiency vs Blend Ratio

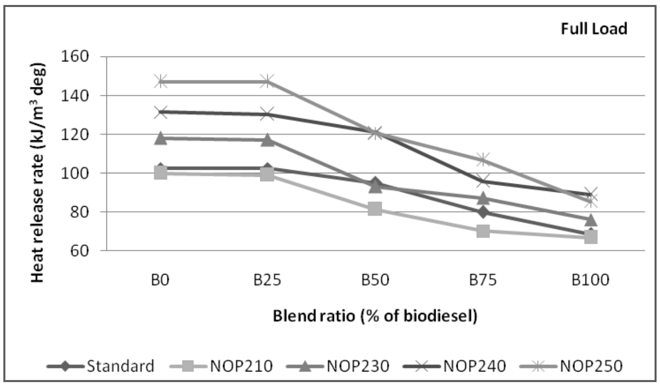



**Figure 4**
Heat Release Rate vs Blend Ratio

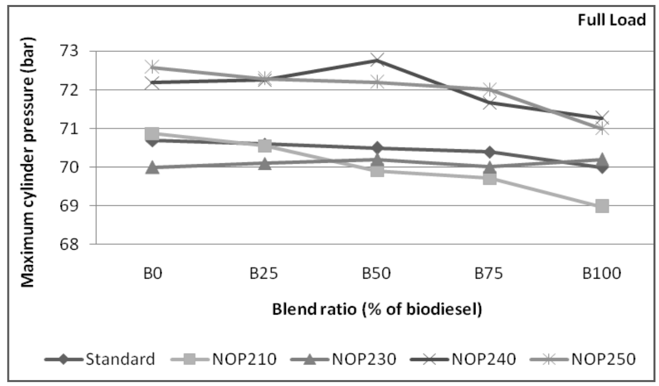



**Figure 5**
Maximum cylinder pressure vs Blend Ratio

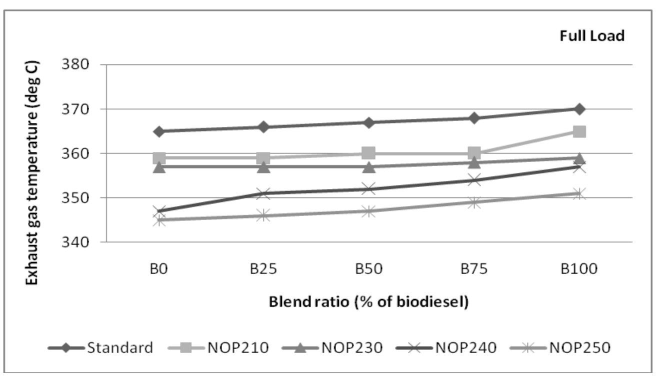



**Figure 6**
Exhaust Gas Temperature vs Blend Ratio

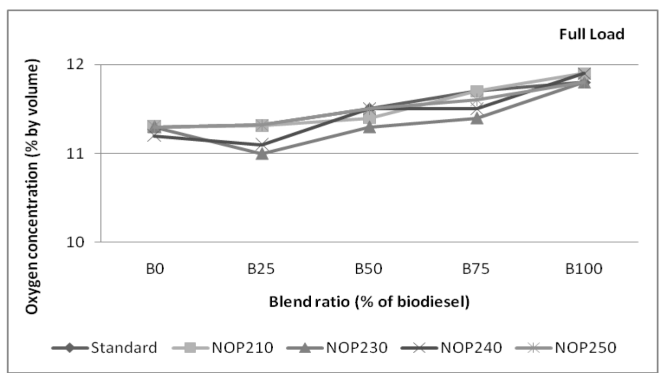



**Figure 7**
Oxygen Concentration vs Blend Ratio

standard AVL 437 smoke meter. All the experimental readings are taken at full load and steady state conditions of the engine.

## 2.1. Thermo-Physical Properties of Mahua Biodiesel and Its Diesel Blends

Using standard test facilities, the thermo-physical properties of Mahua biodiesel and its blend in various volumetric proportions with fossil diesel have been evaluated. Table 2 reports the values of pure diesel (B0), a blend of 25% Mahua biodiesel and 75% diesel by volume (B25), a blend of 50% Mahua biodiesel and 50% diesel by volume (B50), a blend of 75% Mahua biodiesel and 25% diesel by volume (B75) and pure Mahua biodiesel (B100). From Table 2, it is clear that specific gravity, acidity, kinematic viscosity, flash point, fire point and cloud point increases as the biodiesel content in the biodiesel-diesel blends increases. Especially, the significant increase in the fire point shows that the volatility of the mixture having increased biodiesel content will decrease. It is also observed that the flash point and



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fire point of biodiesel blend in various volumetric proportions increase. Therefore the blends of fuel are very easy to store and safe for transportation as compared with B0 (pure diesel). The gross calorific value decreases as the biodiesel in the mixture increases. This is due to the oxygen content in the fuel and it requires more fuel to be burnt for a given heat release. Table 3 and 4 show that specification details of gas analyser and uncertainty measurements of emissions respectively.



## 3. RESULTS AND DISCUSSION

### 3.1. Specific fuel consumption

Figure 2 shows variation of specific fuel consumption with respect to blend ratio of the NOPs of 210, 220 (standard), 230, 240 and 250 bar at full load condition. For B0 and B25 fuel, 250 bar of NOP give almost equal and lowest specific fuel consumption of 0.2791 and 0.2789 kg/kW.h respectively as compared with all NOPs for all blends of fuel. The percentage reduction in specific fuel consumption for NOP of 250 bar for B0, B25, B50, B75 and B100 is 6.84%, 6.82%, 1.98%, 1.33%, and 3.69% respectively as compared with standard NOP of 220 bar. From table 2, it is seen that all the blends have lower calorific value compared to B0. Specific fuel consumption increase with respect to blends of fuel. However, at full load B0 and B25 have the lowest specific fuel consumption and these increases with the blend value. This is due to comparatively higher viscosity and lower calorific value.

### 4.2. Brake thermal efficiency

Figure 3 shows variation of brake thermal efficiency with respect to blend ratio of the NOPs of 210, 220 (standard), 230, 240 and 250 bar at full load condition. For B0 and B25 fuel, 250 bar of NOP give highest brake thermal efficiency (%) as compared with all NOPs. The same trend is followed for B50, B75 and B100. For B0, B25, B50, B75 and B100, the percentage of increase in brake thermal efficiency for 250 bar, is 2.27%, 2.24%, 1.93%, 1.79% and 2.09% respectively as compared with standard NOP of 220 bar. Among all the blends, the B0 and B25 give almost same and highest brake thermal efficiency of 2.2% in terms of percentage of increase in brake thermal efficiency at full load. The Brake thermal efficiency depends on heating value and specific gravity. The combination of heating value and mass flow rate indicate energy input to the engine. It is very clear that the increase in efficiency is high compared to biodiesel blends, which is due to the oxygen content in the ester, which results in better combustion. This energy input to the engine in case of B50, B75 and B100 are more compared to B0 and B25. This may be the reason to have lower brake thermal efficiency for the blends of B50, B75 and B100 as compared with B0 and B25. Similar results are reported elsewhere. This could be due to increased heat losses of the higher blends as compared to B0. Similar findings were obtained by other researchers while testing with Mahua biodiesel in different blend proportions.

### 4.3. Heat release rate

Figure 4 shows variation of heat release rate with respect to blend ratio of the NOPs of 210, 220 (standard), 230, 240 and 250 bar at full load condition. From the test results, it is observed that heat release rate decreases with respect to increase in blends of biodiesel with fossil diesel fuel. For B0 fuel, 250 bar of NOP gives highest heat release rate as compared with all other NOPs for all blends of fuel at full load. The percentage increase in heat release rate for NOP of 250 bar for B0, B25, B50, B75 and B100 is 43.65%, 43.61%, 26.95%, 33.37% and 24.18% respectively as compared with standard NOPs of 220 bar. Among all the blends, B0 gives highest heat release rate of in terms of percentage increase. However, B25 also similar to that of B0 in terms of percentage of increase in heat release rate. From the table 2, it could be seen that there is a decreasing trend of calorific value with respect to blends of fuel. Not much variation between B25 and B0 value in terms of calorific value (45596 to 43976 kJ/kg). This may be due to slightly lower calorific value of B25 as compared to B0.

### 4.4. Maximum Cylinder Pressure

The variation of maximum cylinder pressure with respect to blend ratio of the NOPs of 210, 220 (standard), 230, 240 and 250 bar is shown in figure 5. From the test results, it is observed that the 250 bar of NOP gives highest maximum cylinder pressure as compared to all other NOPs for all blends of fuel. The percentage increase in maximum cylinder pressure for NOP of 250 bar for B0, B25, B50, B75 and B100 is 2.67%, 2.39%, 2.38%, 2.27% and 1.43% respectively as compared with standard NOP of 220 bar. Among all the blends, the B0 and B25 have almost same maximum cylinder pressure and develop highest maximum cylinder pressure at full load. Therefore, B25 seems to be the best option from the point of view of combustion as compared to other blends. From table 2, it can be seen that the B25 has got higher caloric value as compared to other blends of fuel like B50, B75 and B100. But as compared to B0 it is only slightly lower. The percentage reduction calorific value for B25 is 3.6% as compared with B0. This may be the reason for the slight reduction in the cylinder pressure for B25 as compare to B0.



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**Table 3**
Specification details of the Gas analyzer and Smoke meter

| **Model of the Gas analyzer** | **AVL 444 di-gas analyser** | **Accuracy** |
|---|---|---|
| Pollutant | Range | |
| CO | 0-10 % volume | 0.01 |
| HC | 0-20000 HC | ± 10 ppm |
| $NO_x$ | 0-5000 ppm | ± 10 ppm |
| Smoke meter | AVL 437 Smoke meter | |
| Smoke intensity | 0-100 opacity in % | ± 1% full scale reading |

**Table 4**
Uncertainties of some measured and calculated parameters

| S. No | Parameter | Percentage Uncertainties |
|---|---|---|
| 1 | $NO_x$ | ± 0.1 |
| 2 | CO | ± 0.01 |
| 3 | HC | ± 0.1 |
| 4 | Kinematic viscosity | ± 1.3% |
| 5 | BTE | ± 1% |
| 6 | SFC | ± 1.5% |

### 4.5. Exhaust Gas Temperature

Figure 6 shows variation of exhaust gas temperature with respect to blend ratio of the NOPs of 210, 220 (standard), 230, 240 and 250 bar at full load. From the graph results, it is seen that the 250 bar of NOP gives lowest exhaust gas temperature as compared to all other NOPs. The percentage reduction in exhaust gas temperature for NOP of 250 bar for B0, B25, B50, B75 and B100 is 5.48%, 5.47%, 5.45%, 5.16% and 5.14% respectively as compared with standard NOP of 220 bar. Among all the blends, the B0 gives highest exhaust gas temperature in terms of percentage reduction. However, B25 also nearer to that of B0 in the case of percentage reduction at full load. From the figure 6, it is also observed that there is an increasing trend of exhaust gas temperature as increase in blend ratio of biodiesel with diesel fuel. This could be due to increased heat losses of the higher blends, which is also evident from their lower brake thermal efficiencies as compared to B0. Similar findings were obtained by other researchers while testing with Mahua biodiesel in different blend proportions.

### 4.6. Oxygen Concentration

The variation of oxygen concentration with respect to blend ratio for the NOP of 210, 220 (standard), 230, 240 and 250 bar is shown in figure 7. From the graph results, it is seen that the 250 bar of NOP gives the lowest $O_2$ as compared with all NOPs for all blends of fuel. There is not significant variation in $O_2$ for all NOPs. Among all the blends, the B0 gives highest $O_2$ in terms of percentage of reduction in $O_2$ at full load. The B25 is nearer to that of B0 value in terms of percentage reduction in $O_2$. The B100 gives lowest percentage reduction in $O_2$ as compared to B75, B50, B25 and B0. It implies that B100 trends towards incomplete combustion during the operation. This may be due to the poor utilization of air in the combustion chamber. In case of ester based fuel, as it contains oxygen, the air fuel ratio requirement is lower compared to diesel fuel for complete combustion. The similar findings were obtained by other researcher while tested with Mahua biodiesel.

### 4.7. Carbon di-oxide

Figure 8 shows variation of carbon di-oxide with respect to blend ratio of the NOPs of 210, 220 (standard), 230, 240 and 250 bar. From the test results, it is stated that 250 bar of NOP gives highest $CO_2$ as compared to all other NOPs. The percentage increase in $CO_2$ for NOP of 250 bar for B0, B25, B50, B75 and B100 is 12.86%, 12.68%, 9.46%, 7.89% and 6.33% respectively as compared with standard NOP of 220 bar. Among all the blends, the B0 and B25 give almost equal and highest percentage increase in $CO_2$ at full load. From figure 7, it is observed that the B0 and B25 give highest $O_2$ in terms of percentage reduction at full load. Therefore it is clearly stated that better combustion takes place in the case of B0 and B25 as compared with other blends of fuel. The $CO_2$ emissions from a diesel engine indicate how efficiently the fuel is burnt inside the combustion chamber. The ester-based fuel burns more efficiently than diesel. Similar findings were obtained by other researchers while the engine tested with Mahua biodiesel.

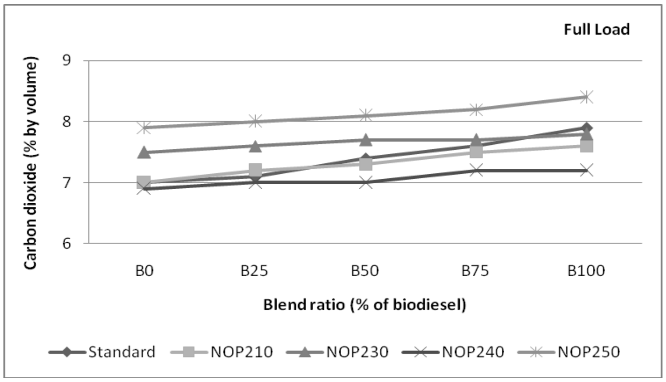


**Figure 8**

Carbon di-oxide vs Blend Ratio

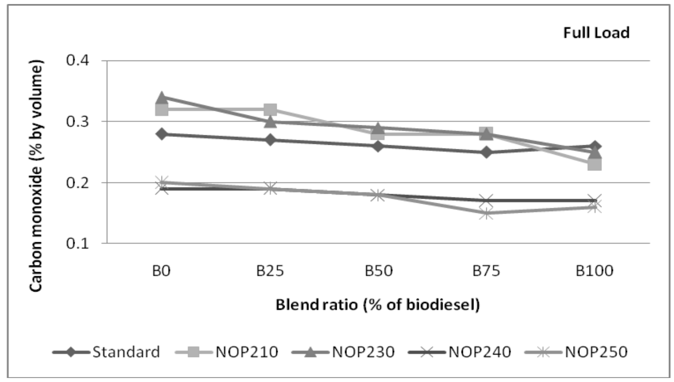


**Figure 9**

Carbon Monoxide vs Blend Ratio

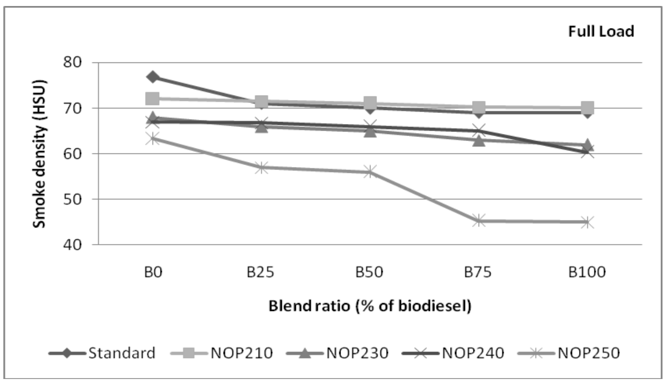


**Figure 10**

Smoke Density vs Blend Ratio

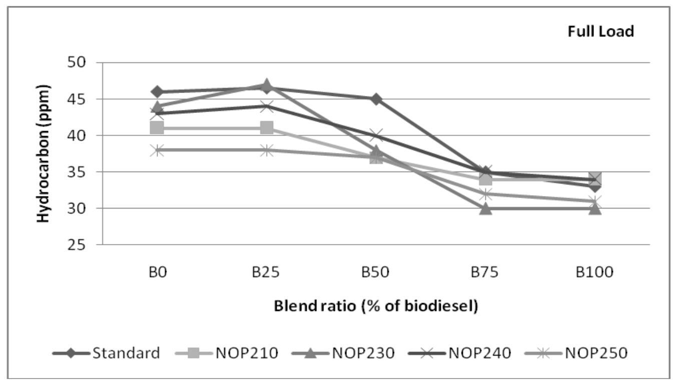


**Figure 11**

Hydrocarbon vs Blend Ratio

## 4.8. Carbon Monoxide

The variation of carbon monoxide with respect to blend ratio of the NOPs of 210, 220 (standard), 230, 240 and 250 bar is shown in figure 9. From the graph results, it is observed that the 250 bar of NOP gives lowest CO as compared to all other NOPs for all blends of fuel. The percentage reduction in CO for NOP of 250 bar for B0, B25, B50, B75 and B100 is 28.57%, 29.62%, 30.77%, 40.02% and 41.03% respectively as compared with standard NOP of 220 bar. Among all the blends, the B100 gives highest percentage reduction in CO of 41.03%at full load condition. These lower CO emissions of biodiesel blends may be due to their more complete oxidation as compared to diesel. Some of the CO produced during combustion of biodiesel might have converted into $CO_2$ by taking up extra oxygen molecule present in the biodiesel chain and thus reduced CO formation.

## 4.9. Smoke density

Figure 10 shows variation of smoke density with respect to blend ratio of the NOP of 210, 220 (standard), 230, 240 and 250 bar. From the test results, it is observed that the 250 bar of NOP gives lowest smoke density as compared to all other NOPs. The percentage reduction in smoke density for nozzle opening pressure of 250 bar for B0, B25, B50, B75 and B100 is 17.58%, 19.71%, 20.01%, 34.35% and 34.79% respectively as compared with standard NOP of 220 bar. Among all the blends, the B25 gives highest smoke density of 34.35% in terms of percentage of reduction in smoke density at full load. It is interesting to note that B100 emits lower smoke as compared to B0. This may be due to the chemistry of fuel blend which may promise conducive atmosphere for lower smoke density for B100 compared to B0. This could be due to the presence of oxygen molecule in the biodiesel chain, which enhanced its complete burning as compared to diesel. The other main reason could be attributed to the basic difference in their chemical structure and the presence of oxygen in the molecule of the biodiesel. This may be the reason for reducing smoke density at full load.

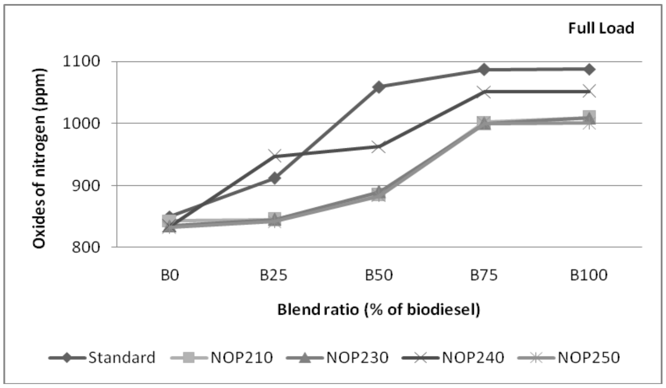


**Figure 12**

Oxides of Nitrogen Vs Blend Ratio

### 4.10. Hydrocarbon

The variation of hydrocarbon with respect to blend ratio of the NOPs 210, 220 (standard), 230, 240 and 250 bar is shown in figure 11. From the test results, it is observed that the 250 bar of NOPs gives lowest hydrocarbon as compared with standard NOP of 220 bar for all blends of fuel at full load. The percentage reduction in hydrocarbon for NOP of 250 bar for B0, B25, B50, B75 and B100 is 17.39%, 18.28%, 17.78%, 8.57% and 6.06% respectively as compared with standard NOP of 220 bar. Among all the blends, the B25 gives highest hydrocarbon of 18.28% in terms of percentage reduction of hydrocarbon at full load. This may be due to the viscosity and surface tension affects the penetration rate, maximum penetration and droplet size of the fuel, which in turn affects the mixing of fuel and air. Cetane number of the fuel also plays a vital role in ignition process. From table 2, it could be seen that the cetane number of B25 is higher than that of B0 (46 to 51.6). Therefore the B0 emits more hydrocarbon than that of B25. Here oxygen content of the fuel comes into picture as it enhances the combustion process. Therefore overall result of oxygen content and cetane number of the fuel leads to lower CO and hydrocarbon emission. Similar results found by other researchers [10] while the engine tested with Mahua Oil Methyl and Ethyl Ester.

### 4.11. Oxides of nitrogen

Figure 12 shows variation of oxides of nitrogen ($NO_x$) with respect to blend ratio for the NOP of 210, 220 (standard), 230, 240 and 250 bar. From the test results, it is seen that the 250 bar of NOP gives lowest $NO_x$ as compared to all other NOPs for all blends of fuel. The percentage reduction in $NO_x$ for NOP of 250 bar for B0, B25, B50, B75 and B100 is2.12%, 7.68%, 16.62%, 8.01% and 7.92% respectively as compared with standard NOP of 220 bar. Among all the blends, the B50 gives highest $NO_x$ of 16.62% in terms of percentage of reduction in $NO_x$ at full load. The $NO_x$ level was found to be directly related to the exhaust gas temperature while it was inversely related to the smoke and CO values. Similar reports were found by other researcher while the engine tested with Mahua biodiesel in different blend proportions.

## 5. CONCLUSIONS

From these readings, it could be concluded that the Mahua biodiesel could be used as an alternative fuel for operating four stroke tangentially vertical single cylinder kirloskar direct injection water cooled constant speed diesel engine with static injection timing of 23° bTDC and nozzle opening pressure of 250 bar at full load. As compared to all NOPs, the optimum NOP of 250 bar gives better performance, combustion and lowest emissions of diesel engine at full load. In situations of shortage of availability of fossil diesel (B0), it could be suggested that B100 could be used as alternative fuel to operate the diesel engine without any modification in the existing design of the diesel engine.

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