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# Performance and Emissions Analysis of 4-Stroke Biodiesel Engine at Different Injection Pressure

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***Abstract: Alternative fuels for diesel engines have become increasingly important due to several socioeconomic aspects, imminent depletion of fossil fuel and growing environmental concerns. Global warming concerns due to the production of greenhouse gases (GHGs) such as carbon dioxide (CO2) as results from internal combustion engine have seen as one of major factor the promotion of the use of biofuels. Therefore, the use of biodiesel fuel (BDF) as an alternative for fossil diesel (DSL) is among the effective way to reduce the CO2 emission. In this experimental study, the effects on engine performance and fuel-induced emission characteristics were studied using fuel blends and under different fuel injection pressure. Even though the brake thermal efficiency was obtained maximum for the conventional diesel at standard operating condition, the same can also be achieved with biodiesel blends by increasing the injection pressure higher than that of the level used for conventional diesel. This experimental test was done using a small 4-stroke single cylinder diesel engine with electric dynamometer loads integrated with emission gas analyser that attached to the exhaust pipeline. As results of experimental investigations, decreasing in NOX Emission, SOX Emission, CO Emission and also brake specific fuel consumption compare to pure diesel.***
***Keyword: 1. Engine Performance, Combustion Process, Emission characteristics, Alternative Fuels (Biodiesel), Piston Design.***

## I. INTRODUCTION

Alternative fuels for diesel engines have become increasingly important due to several socioeconomic aspects and increased environmental concerns. Global warming concerns due to the production of greenhouse gases (GHGs) have seen as one of major factor the promotion of the use of bio fuels. Carbon dioxide (CO2) from fuel combustion is a major contributor to GHGs and caused a shift in the climate system. Yet the use of biodiesel as an alternative fuel for petroleum-diesel fuel operates in compression ignition (CI) diesel engines is very effective for the reduction of CO2 emission since it is classified as green and renewable energy derived from renewable biomass resources such as vegetable oils and animal fats. Nowadays, the ease of resources and use crude palm oil (CPO) makes it possible for research and development to be conducted. CPO is obtained from the seeds of the oil palm tree (Elaeisguineensis). CPO is considered a prospective to biodiesel source in Malaysia and other parts of South East Asia owing to its large scale cultivation. Furthermore, crude palm biodiesel oil can be used in diesel engine directly without major modification. From the previous studies state that crude palm biodiesel has been proven to be a good solution to help address the problem of global warming biodiesel source in Malaysia and other parts of South East Asia owing to its large scale cultivation. Furthermore, crude palm biodiesel oil can be used in diesel engine directly without major modification. From the previous studies state that crude palm biodiesel has been proven to be a good solution to help address the problem of global warming. It has been reported that the CO and HC emissions were reduced for LHR engine with Honge oil methyl ester compared with Honge oil. Heat release rate was better for HOME when compared with Honge oil operation, which resulted in improved brake thermal efficiency. It has been reported that the power of the engine is increased about 8.4% for diesel and 3.5% for biodiesel and the SFC decreases about 5% for diesel and 8% for alternative fuels. The CO and smoke emissions decreased about 24% and 8.2%brespectively, while the NOx emissions were increased about 7.3% for alternative fuels. The exhaust gas temperature increased about 11.4% for diesel and 5.4% for alternative fuels compared with the uncoated engine.

## II. EXPERIMENTAL WORK

*A.* Preparation of biodiesel fuels (BDF) from crude palm oil (CPO) based, Jatropha oil (JCO) based and waste cooking oil (WCO) based as well as their mixtures with diesel fuel.
*B.* Performing the engine operations by using the various types and blending proportions of biodiesels as fuels as well as standard diesel fuel (DSL).
*C.* Quantifying the engine performance with respect to the common engine performance parameter such as torque, brake power, exhaust gas temperature (EGT), brake mean effective pressure (BMEP), brake thermal efficiency (BTE) and brake specific fuel consumption (BSFC).
*D.* Measuring the exhaust gas emissions released from the combustion of biofuels in compression ignition (CI) diesel engine such as CO, CO2, HC and NOx.

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Figure no :-1 Injector

Figure no :– 2 Four Stroke Diesel Engine

Figure no :- 3 Exhaust Pipe, Dynomometer

1) *Biodiesel Fuels Preparation:* The study use biodiesel which derived from three kinds of sources or feedstocks i.e. oil palm, Jatropha and waste cooking oil. These biodiesel fuels were provided by UniversitiTun Hussein Onn Malaysia (UTHM) through specific production process in a biodiesel pilot-plant which has an ability of production capacity at 1 MT in a single batch. Figure 3.2 shows the view of biodiesel pilot-plant in UTHM which has been built in year of 2007. The biodiesel In general, the preparation of biodiesel fuels to be used for the operational of diesel engine in this study comprises of three main stages:

*a)* Procedure and production process of biodiesel.
*b)* Procedure and blending process of biodiesel with diesel fuel.
*c)* Measuring procedure of blended biodiesel fuel properties.

End of these stages, the blended biodiesel fuels are then placed in specific containers with labelled and will be mobilised to laboratory in Department Of Marine Engineering, PoliteknikUngku Omar (PUO), Ipoh for further research works.

Figure no:- 4 Electric Panel

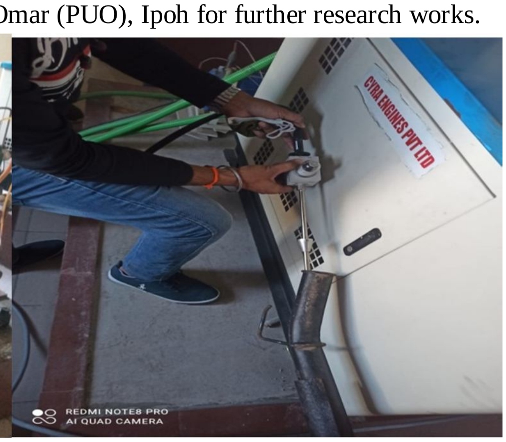


Figure no :- 5 Exhaust Emission

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Figure no- 6

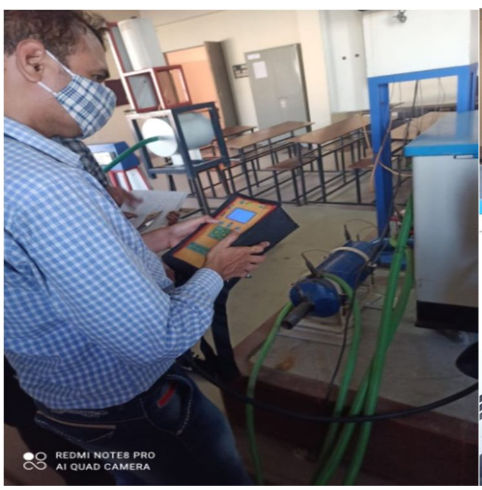



Figure no:- 7 Emission

Figure no:-8 Manometer


Figure no: - 9 Four stroke diesel engine

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Table no. 1 (pure diesel)

| Sr. No. | N (RPM) | Manometer reading | | Load on the engine | Burette reading for fuel flow rate | | Engine cooling water inlet temperature T1 (°C) | Engine cooling water outlet temperature T1 (°C) | Temperature at different points on calorimeter | | | | Engine cooling water flow meter reading | | Calorimeter water flow meter reading | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | h1 (cm) | h2 (cm) | W (kW) | X (ml) | t (sec) | | | T3 (°C) | T4 (°C) | T5 (°C) | T6 (°C) | Ve (ltrs) | Te (sec) | Vc (ltrs) | Tc (sec) |
| 1 | 1545 | 21.5 | 7 | 1 | 5 | 33.39 | 35 | 38 | 162 | 80 | 35 | 37 | 5 | 64 | 2 | 16 |
| 2 | 1542 | 21.5 | 7 | 2 | 5 | 30.26 | 35 | 39 | 196 | 94 | 35 | 38 | 5 | 64 | 2 | 16 |
| 3 | 1535 | 21.3 | 7.2 | 3 | 5 | 26.80 | 35 | 40 | 233 | 106 | 35 | 39 | 5 | 64 | 2 | 16 |
| 4 | 1515 | 21.1 | 7.5 | 4 | 5 | 23.38 | 35 | 41 | 270 | 120 | 35 | 40 | 5 | 64 | 2 | 16 |

Table no: - 1.1(Result of pure diesel)

| Sr. No. | N (RPM) | Load (kg) | Fuel consumption rate (mf) | Air consumption rate (ma) | Brake power (kW) | Brake thermal efficiency (%) | Volumetric efficiency (%) |
|---|---|---|---|---|---|---|---|
| 1 | 1552 | 1 | 0.0001409 | 0.00071598 | 1 | 16.31 | 10.01 |
| 2 | 1542 | 2 | 0.0001608 | 0.0007015 | 2 | 28.59 | 9.88 |
| 3 | 1535 | 3 | 0.000201 | 0.0006917 | 3 | 34.31 | 9.78 |
| 4 | 1525 | 4 | 0.0002329 | 0.00068675 | 4 | 39.48 | 9.77 |

Table no.1.2 (Heat balance sheet of pure diesel)

| Sr. No. | N (RPM) | Load (kg) | Heat supplied | | Heat equivalent to BP | | Heat carried away by engine cooling water | | Heat carried away by exhaust gases | | Unaccounted loss | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (kW) | % | (kW) | % | (kW) | % | (kW) | % | (kW) | % |
| 1 | 1552 | 1 | 6.129 | 100 | 1 | 16.31 | 0.979 | 15.98 | 1.487 | 24.26 | 2.662 | 43.44 |
| 2 | 1542 | 2 | 6.994 | 100 | 2 | 28.59 | 1.306 | 18.67 | 2.586 | 36.97 | 1.102 | 15.75 |
| 3 | 1535 | 3 | 8.743 | 100 | 3 | 34.31 | 1.632 | 18.67 | 3.384 | 38.70 | 0.726 | 8.31 |
| 4 | 1525 | 4 | 10.13 | 100 | 4 | 39.48 | 1.959 | 19.34 | 4.113 | 40.59 | 0.059 | 0.58 |

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Table no: - 2 (25 % Biodiesel at 110 bar injection pressure)

| SR NO. | N (RPM) | Manometer reading | | Load on the engine | Burette reading for fuel flow rate | | Engine cooling water inlet temperature T1 (ºC) | Engine cooling water outlet temperature T1 (ºC) | Temperature at different points on calorimeter | | | | Engine cooling water flow meter reading | | Calorimeter water flow meter reading | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | h1 (cm) | h2 (cm) | W (kW) | x (ml) | t (sec) | | | T3 (ºC) | T4 (ºC) | T5 (ºC) | T6 (ºC) | Ve (ltrs) | Te (sec) | Vc (ltrs) | Tc (sec) |
| 1 | 1552 | 21.9 | 6.9 | 1 | 5 | 28.52 | 35 | 38 | 116 | 59 | 35 | 37 | 5 | 64 | 2 | 16 |
| 2 | 1542 | 21.4 | 7.0 | 2 | 5 | 25 | 35 | 39 | 180 | 92 | 35 | 38 | 5 | 64 | 2 | 16 |
| 3 | 1535 | 21.2 | 7.2 | 3 | 5 | 20 | 35 | 40 | 208 | 101 | 35 | 39 | 5 | 64 | 2 | 16 |
| 4 | 1525 | 21.4 | 7.6 | 4 | 5 | 17.26 | 35 | 41 | 252 | 114 | 35 | 40 | 5 | 64 | 2 | 16 |

Table no. 2.1 (Result of 25% Biodiesel at 110 bar injection pressure)

| Sr. No. | N (RPM) | Load (kg) | Fuel consumption rate (mf) | Air consumption rate (ma) | Brake power (kW) | Brake thermal efficiency (%) | Volumetric efficiency (%) |
|---|---|---|---|---|---|---|---|
| 1 | 1545 | 1 | 0.000120 | 0.00070 | 1 | 19.15 | 9.84 |
| 2 | 1542 | 2 | 0.000132 | 0.00070 | 2 | 34.83 | 9.85 |
| 3 | 1535 | 3 | 0.00015 | 0.000691 | 3 | 45.97 | 9.77 |
| 4 | 1525 | 4 | 0.000171 | 0.000678 | 4 | 53.77 | 9.71 |

Table no.2.2 (Heat balance sheet of 25% Biodiesel at 110 bar injection pressure)

| Sr. No. | N (RPM) | Load (kg) | Heat supplied | | Heat equivalent to BP | | Heat carried away by engine cooling water | | Heat carried away by exhaust gases | | Unaccounted loss | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (kW) | % | (kW) | % | (kW) | % | (kW) | % | (kW) | % |
| 1 | 1545 | 1 | 5.22 | 100 | 1 | 19.15 | 0.979 | 18.75 | 1.620 | 31.03 | 1.619 | 31.01 |
| 2 | 1542 | 2 | 5.742 | 100 | 2 | 34.83 | 1.306 | 22.74 | 2.477 | 43.13 | -0.04 | -0.696 |
| 3 | 1535 | 3 | 6.525 | 100 | 3 | 45.97 | 1.632 | 25.01 | 3.263 | 50.00 | -1.37 | -20.99 |
| 4 | 1525 | 4 | 7.438 | 100 | 4 | 53.77 | 1.959 | 26.33 | 4.099 | 55.10 | -2.61 | -35.09 |

Table no.3 (50% Biodiesel at 110 bar injection pressure)

| Sr. No. | N (RPM) | Manometer reading | | Load on the engine | Burette reading for fuel flow rate | | Engine cooling water inlet temperature | Engine cooling water outlet temperature | Temperature at different points on calorimeter | | | | Engine cooling water flow meter reading | | Calorimeter water flow meter reading | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | h1 (cm) | h2 (cm) | W (kW) | X (ml) | t(sec) | T1 (ºC) | T1 (ºC) | T3 (ºC) | T4 (ºC) | T5 (ºC) | T6 (ºC) | Ve (ltrs) | Te (sec) | Vc (ltrs) | Tc (sec) |
| 1 | 1585 | 21.7 | 7.4 | 1 | 5 | 39.03 | 36 | 37 | 178 | 90 | 35 | 37 | 5 | 46.78 | 2 | 18.72 |
| 2 | 1576 | 21.7 | 7.1 | 2 | 5 | 39.03 | 37 | 38 | 171 | 90 | 35 | 38 | 5 | 46.78 | 2 | 18.72 |
| 3 | 1592 | 21.9 | 6.7 | 3 | 5 | 32.35 | 36 | 39 | 161 | 88 | 35 | 39 | 5 | 46.78 | 2 | 18.72 |
| 4 | 1578 | 22.0 | 6.7 | 4 | 5 | 29.05 | 36 | 40 | 157 | 86 | 35 | 40 | 5 | 46.78 | 2 | 18.72 |

Table no. 3.1 (Result of 50% Biodiesel at 110 bar injection pressure)

| Sr. No. | N (RPM) | Load (kg) | Fuel consumption rate(mf) | Air consumption rate (ma) | Brake power (kW) | Brake thermal efficiency (%) | Volumetric efficiency (%) |
|---|---|---|---|---|---|---|---|
| 1 | 1585 | 1 | 0.000102 | 0.000696 | 1 | 22.53 | 9.53 |
| 2 | 1576 | 2 | 0.000102 | 0.000703 | 2 | 45.07 | 9.68 |
| 3 | 1592 | 3 | 0.000124 | 0.000717 | 3 | 55.61 | 9.78 |
| 4 | 1578 | 4 | 0.000138 | 0.000719 | 4 | 66.63 | 9.88 |

Table no. 3.2 (Heat balance sheet of 50% Biodiesel at 110 bar injection pressure)

| Sr. No. | N (RPM) | Load (kg) | Heat supplied | | Heat equivalent to BP | | Heat carried away by engine cooling water | | Heat carried away by exhaust gases | | Unaccounted loss | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (kW) | % | (kW) | % | (kW) | % | (kW) | % | (kW) | % |
| 1 | 1585 | 1 | 4.437 | 100 | 1 | 22.53 | 0.4437 | 10 | 1.4420 | 32.49 | 1.5904 | 35.84 |
| 2 | 1576 | 2 | 4.437 | 100 | 2 | 45.07 | 0.4437 | 10 | 2.2350 | 50.37 | -0.2417 | -5.44 |
| 3 | 1592 | 3 | 5.394 | 100 | 3 | 55.61 | 1.331 | 24.67 | 3.063 | 56.78 | -2 | -37.07 |
| 4 | 1578 | 4 | 6.003 | 100 | 4 | 66.63 | 1.774 | 29.55 | 3.812 | 63.50 | -3.583 | -59.68 |

Calculation: Of the 25 % biodiesel

1) *Break power Developed by Engine*

$$BP = W\ (KW)$$

BP = W = 1 KW

2) *Fuel Consumption*

mf = (5/33.39) ×( 804/10^6) = 1.20 × 10^4 kg/sec

$$mf = \frac{\dot{x}}{t} \times \frac{\rho f}{10^6}\ (kg/sec)$$

3) *Brake Specific Fuel Consumption*

BSFC = (1.20 × 10^-4) / 1 = 1.20 ×10^-4

$$BSFC = \frac{mf}{BP}$$

4) *Heat Supplied by Fuel*

Qs =( 1.20 × 10^-4) × 43500 = 5.22 KW

Qs = mf × C.V(kW)

5) *Brake Thermal Efficiency*

$\eta_{bt}$= 1 / 5.22 = 19.15 %

$$\eta_{bt} = \frac{BP}{Q_s} \times 100\,\%$$

6) *Mass flow Rate of Water through Engine Cooling Jacket*

$$m_{ew} = \frac{Ve}{te} \times \frac{\rho w}{10^3}\ (Kg/sec)$$

$m_{ew}$ = (5 / 64) × (1000 / 10^3) = 0.078 kg /sec

7) *Heat Carried Away by Water*

$Q_{ecw}$ = 0.078 × 4.186 × (38-36) = 0.9795 kW

$$Q_{ecw} = m_{ew} \times Cp \times (T2 - T1)\ (kW)$$

8) *Mass flow Rate of Water Through Calorimeter*

$m_{cw}$ = (2/16) × (1000/10^3) = 0.125 Kg / sec

$$m_{cw} = \frac{Vc}{tc} \times \frac{\rho w}{10^3}\ (Kg/sec)$$

9) *Heat Carried Away by Water in Calorimeter*

$Q_{ccw}$ = 0.125 × 4.186 × ( 37-35 ) = 1.0465 kW

$$Q_{ccw} = m_{cw} \times Cp \times (T6 - T5)\ (kW)$$

10) *Heat Carried Away by Exhaust Gas*

$$Qexh = \frac{Q_{ccw}}{(T3-T4)} \times (T3 - Ta)$$

$Qexh$ = ( 1.0465 / ( 162 – 80 ) ) × ( 162 – 35 ) = 1.620

11) *Uncounted Heat Loss*

$$Qun = Qs - (BP + Q_{ecw} + Qexh)$$

$Qun$ = 5.22 – ( 1 + 0.9795 + 1.620 ) = 1.619

12) *Area of Orifice*

$$a_0 = \frac{\pi}{4} \times {d_0}^2\ (m^2)$$

$a_0 = \frac{\pi}{4} \times (0.017)^2 = 2.26 \times 10^\wedge - 4(m^2)$

13) *Head Obtained by Orifice*

$H = \frac{(21.5-7.0)\times 10^\wedge-2}{100}\left(\frac{1000}{1.21} - 1\right) = 1.1968\ (m)$

$$H = \frac{h1-h2}{100}\left(\frac{\rho w}{\rho a} - 1\right)\ (m)$$

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14) *Air Consumption*

$$Qa = Cd \times a_0 \times \sqrt{2 \times g \times H}$$

$$Qa = 0.64 \times (2.26 \times 10^{-4}) \times \sqrt{2} \times \sqrt{9.81} \times \sqrt{1.1968} = 0.0007$$

15) *Swept Volume*

$$Vs = \frac{\pi \times D^2 \times L \times N \times Nc}{4 \times 60 \times n} \ (m^3/sec)$$

$$Vs = \frac{\pi \times (0.08)^2 \times 0.11 \times 1545 \times 1}{4 \times 60 \times 2} = 0.007118 \ (m^3/sec)$$

16) *Volumetric Efficiency*

$$\eta_{vol} = \frac{Qa}{Vs} \times 100 \ \%$$

$$\eta_{vol} = \frac{0.0007}{0.007118} \times 100 \ \% = 9.84 \ \%$$

## III. RESULTS & DISCUSSION

*A.* In order to accomplish the objective of the study, all data that has been collected will be analysed and discussed in this chapter. The analysis and discussion will be divided into three main categories i.e. engine performance characteristics, fuel combustion characteristics and exhaust gas emission characteristics and yet followed by the comprehensive analysis and discussion of the entire blended biodiesel fuels with comparing to the standard diesel fuel.

*B.* Parameters that has been measured on engine performance consists of engine torque, brake power (BP), brake specific fuel consumption (BSFC), brake mean effective pressure (BMEP), brake thermal efficiency (BTE), exhaust gas temperature (EGT) and fuel mass flow rate (ṁf). While the combustion analysis parameters consists of cylinder pressure data to produce pressure-volume (P-V) diagram as well as pressure-crank angle (P-CA) diagram, heat release (HR) and cumulative heat release (CHR) from fuel combusted inside the combustion chamber of the engine. Those data are measured by the supervisory control and data acquisition system (SCADA) and transferred to computer using DYNO-MAX 2010 application for engine performance data and DEWESOFTv7.0 application for fuel combustions data. Meanwhile, the four type of exhaust gas emissions parameters that has been obtained from the experiments are consists of carbon dioxide (CO2), carbon monoxide (CO), oxides of nitrogen (NOx) and hydrocarbon (HC) using exhaust gas analyser.

Table no. 4.1 (Emission on pure diesel)

| Sr. No | CO (%) | Sox (ppm) | NOx (ppm) | Methane (%) | Co2 (%) | Excess Air Ratio (%) | H L (%) | Heat Loss (%) | Efficiency (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.078 | 444 | 184 | 0.05 | 1.5 | -66.36 | 58.34 | 64.54 | 35.46 |
| 2 | 0.084 | 565 | 197 | 0.09 | 2.1 | -65.56 | 57.65 | 63.89 | 36.11 |
| 3 | 0.088 | 769 | 182 | 0..07 | 2.7 | -64.29 | 57.10 | 63.10 | 36.55 |
| 4 | 0.099 | 941 | 259 | 0..05 | 3.1 | -63.95 | 56.21 | 62.46 | 37.54 |

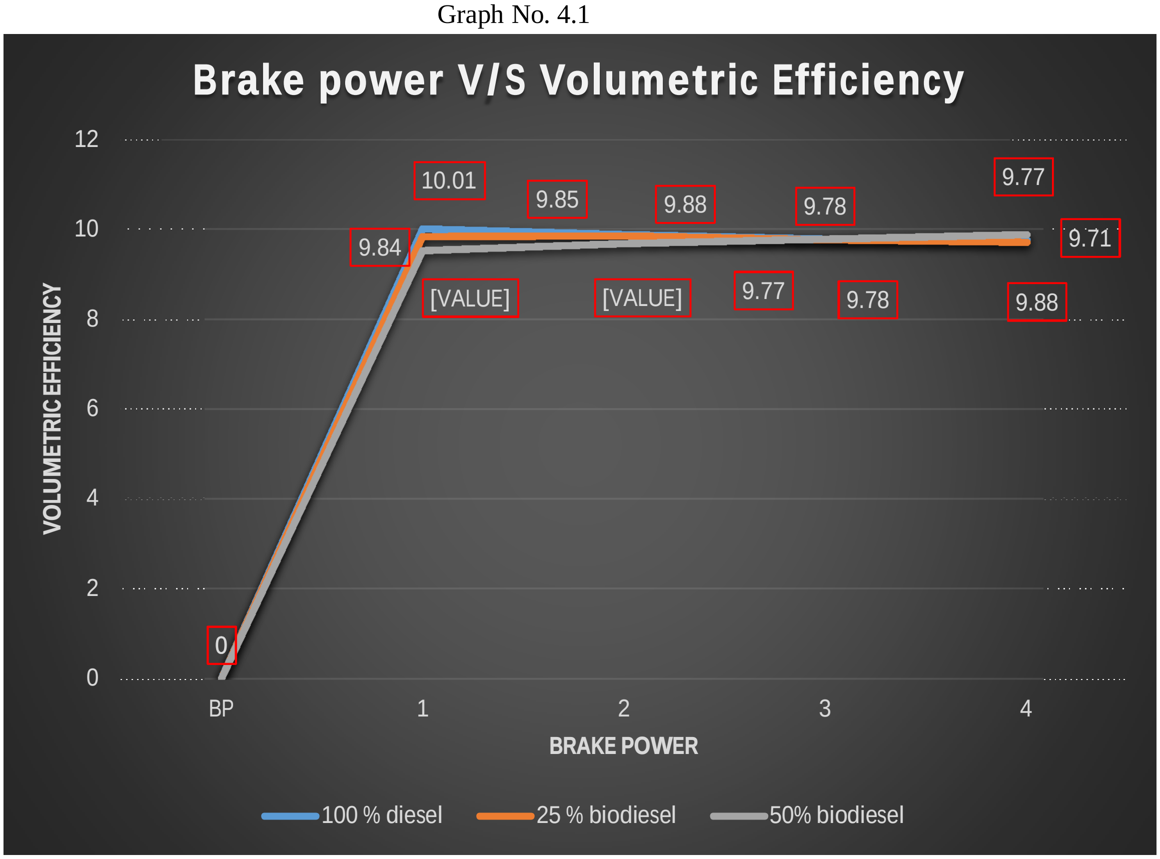
Table no. 4.2 (Emission on 25% Biodiesel at 110 bar injection pressure)

| Sr.No | CO (%) | Sox (ppm) | NOx (ppm) | Methane (%) | Co2 (%) | Excess Air Ratio (%) | H L (%) | Heat Loss (%) | Efficiency (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.076 | 383 | 138 | -0.01 | 1.3 | -63.66 | 58.59 | 64.70 | 35.30 |
| 2 | 0.078 | 480 | 159 | -0.04 | 2.0 | -65.61 | 57.68 | 63.88 | 36.12 |
| 3 | 0.081 | 617 | 170 | -0.22 | 2.5 | -64.94 | 57.09 | 63.31 | 36.69 |
| 4 | 0.086 | 790 | 198 | -17.50 | 3.1 | -63.96 | 56.22 | 62.53 | 37.47 |

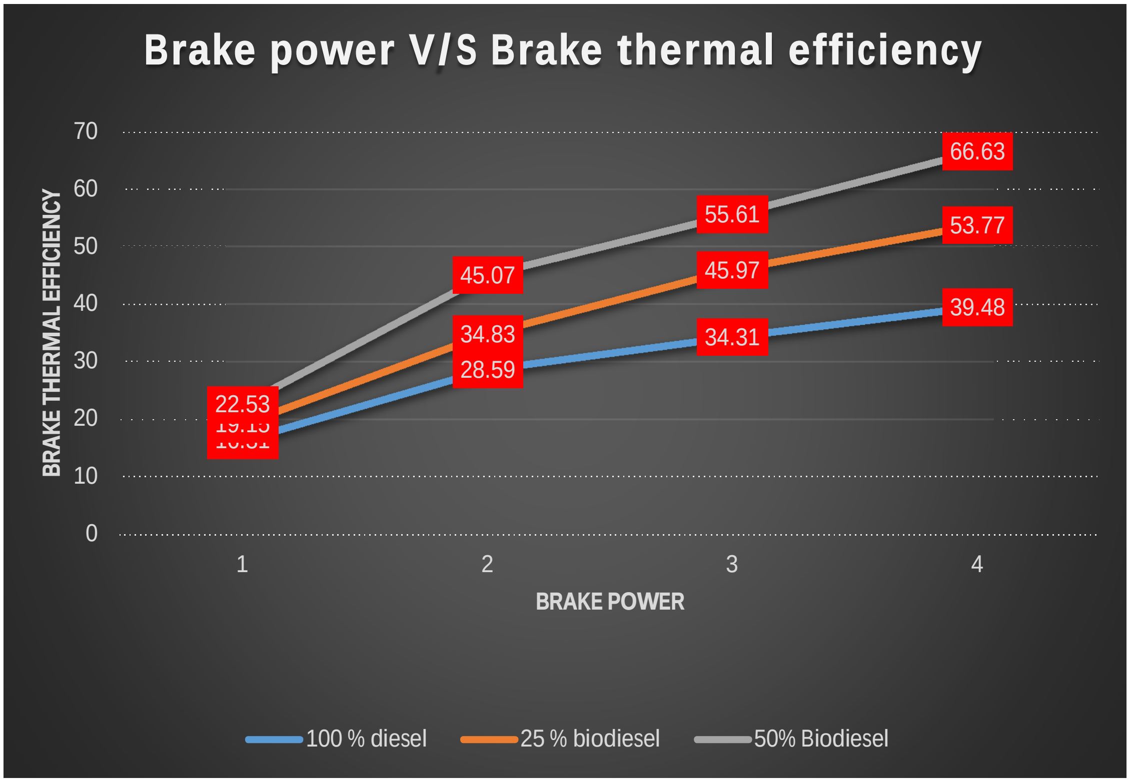
Table no. 4.2 (Emission on 25% Biodiesel at 110 bar injection pressure)

| Sr.No | CO (%) | Sox (ppm) | NOx (ppm) | Methane (%) | Co2 (%) | Excess Air Ratio (%) | H L (%) | Heat Loss (%) | Efficiency (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.076 | 383 | 138 | -0.01 | 1.3 | -63.66 | 58.59 | 64.70 | 35.30 |
| 2 | 0.078 | 480 | 159 | -0.04 | 2.0 | -65.61 | 57.68 | 63.88 | 36.12 |
| 3 | 0.081 | 617 | 170 | -0.22 | 2.5 | -64.94 | 57.09 | 63.31 | 36.69 |
| 4 | 0.086 | 790 | 198 | -17.50 | 3.1 | -63.96 | 56.22 | 62.53 | 37.47 |

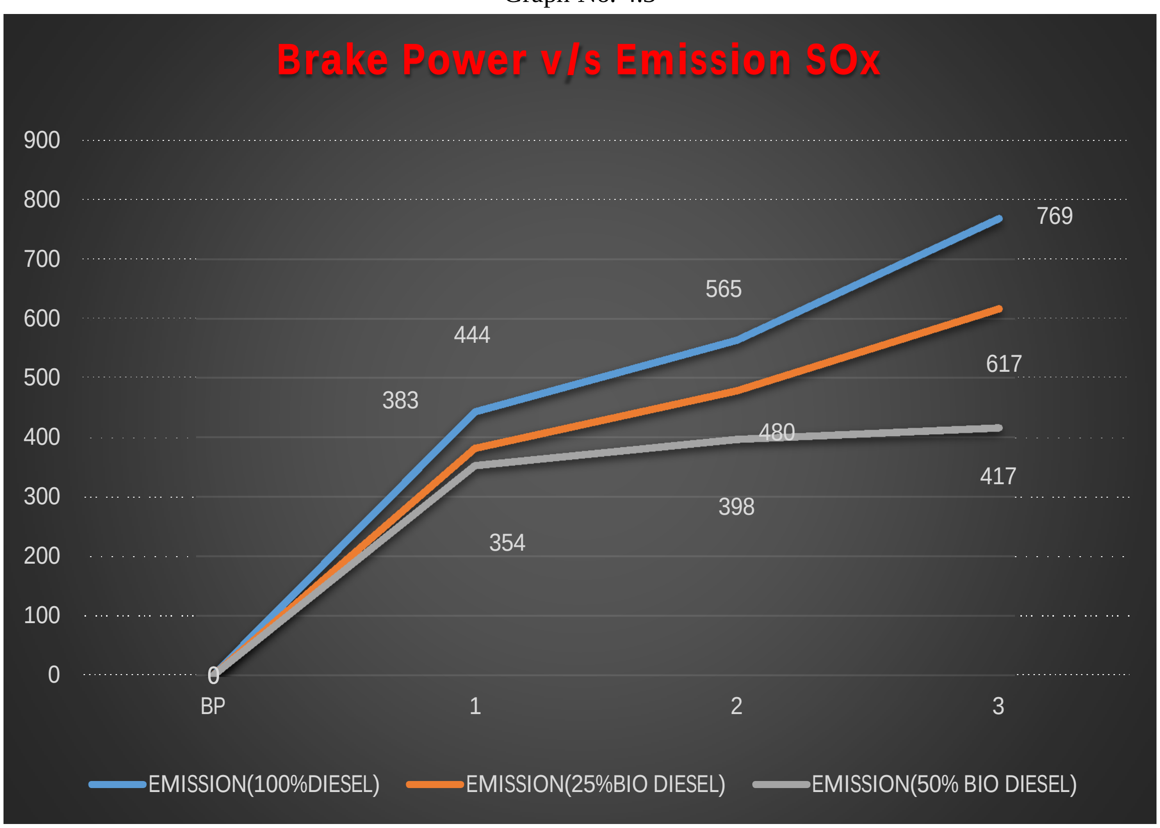
Graph No. 4.1



Graph No. 4.2




Graph No. 4.3



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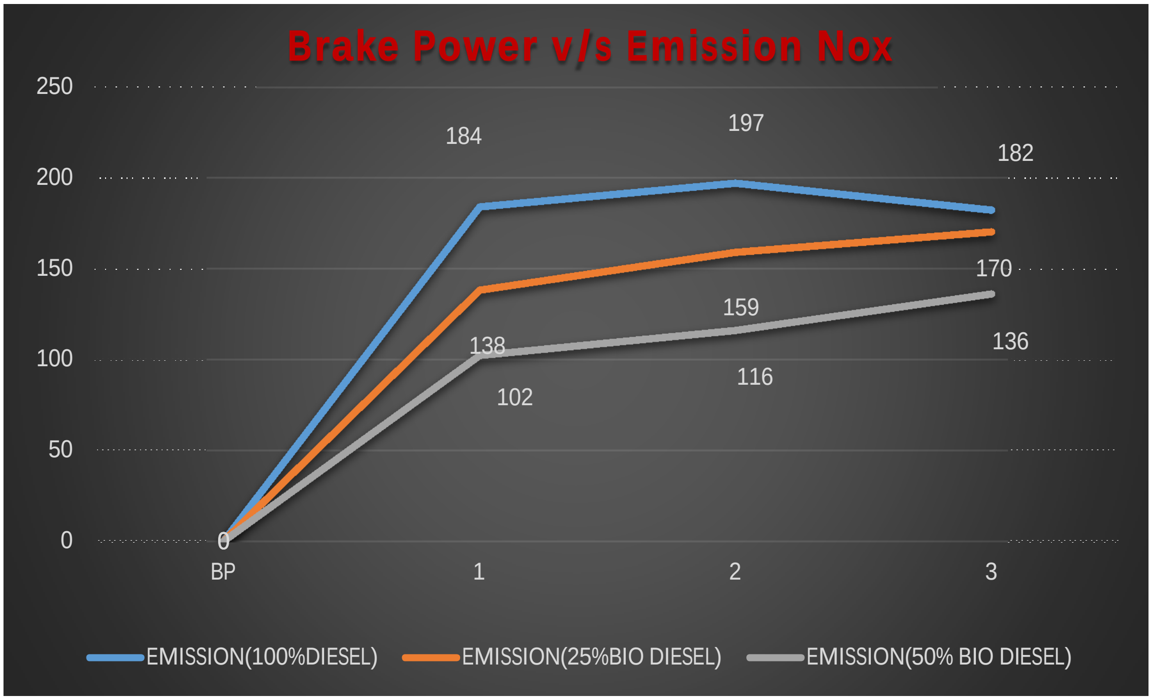
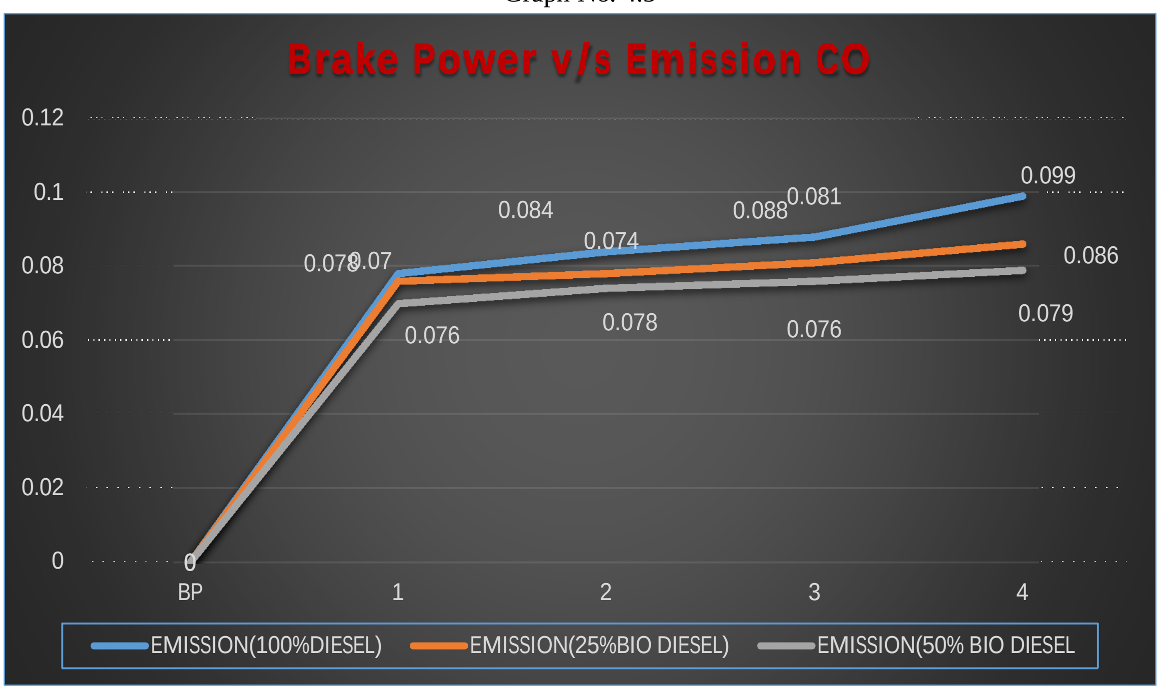
Graph No. 4.4




Graph No. 4.5




## IV. CONCLUSIONS

*A.* At full load condition, emission of $SO_X$ at pure diesel is about 769 while at 25% Biodiesel is 617 and at 50% Biodiesel is 417.

*B.* At full load condition, emission of $NO_X$ at pure diesel is about 182 while at 25% Biodiesel is 170 and at 50% Biodiesel is 136.

*C.* At full load condition, emission of CO at pure diesel is about 0.099 while at 25% Biodiesel is 0.086 and at 50% Biodiesel is 0.079.

*D.* Hence the overall emission using Biodiesel decreases.

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