



IJRASET

International Journal For Research in
Applied Science and Engineering Technology



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 Issue: V Month of publication: May 2021

DOI: <https://doi.org/10.22214/ijraset.2021.34817>

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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 NO_x Emission, SO_x 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% respectively, while the NO_x 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 NO_x.



Figure no :-1 Injector



Figure no :- 2 Four Stroke Diesel Engine



Figure no :- 3 Exhaust Pipe, Dynamometer

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 Universiti Tun 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, Politeknik Ungku Omar (PUO), Ipoh for further research works.



Figure no:- 4 Electric Panel



Figure no :- 5 Exhaust Emission



Figure no- 6

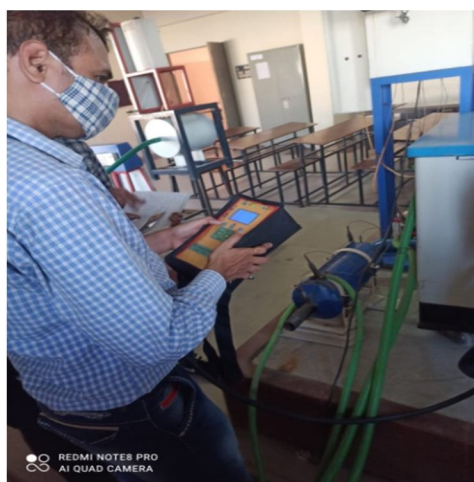


Figure no:- 7 Emission



Figure no:-8 Manometer



Figure no: - 9 Four stroke diesel engine

Table no. 1 (pure diesel)

Sr. No.	N (RPM)	Manometer reading		Load on the engine W (kW)	Burette reading for fuel flow rate X (ml) t (sec)		Engine cooling water inlet temperature T1 (°C)	Engine cooling water outlet temperature T1 (°C)	Temperature at different points on calorimeter T3 (°C) T4 (°C) T5 (°C) T6 (°C)				Engine cooling water flow meter reading Ve (ltrs) Te (sec)		Calorimeter water flow meter reading Vc (ltrs) Tc (sec)	
		h1 (cm)	h2 (cm)													
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

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

SR NO	N (RPM)	Manometer reading		Load on the engine (kW)	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)		x (ml)	t (sec)			T3 (°C)	T4 (°C)	T5 (°C)	T6 (°C)	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 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	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

$$BP = W \text{ (KW)}$$

$$BP = W = 1 \text{ KW}$$

2) Fuel Consumption

$$mf = (5/33.39) \times (804/10^6) = 1.20 \times 10^{-4} \text{ kg/sec}$$

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

3) Brake Specific Fuel Consumption

$$BSFC = (1.20 \times 10^{-4}) / 1 = 1.20 \times 10^{-4}$$

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

4) Heat Supplied by Fuel

$$Q_s = (1.20 \times 10^{-4}) \times 43500 = 5.22 \text{ KW}$$

$$Q_s = mf \times C.V(\text{kW})$$

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

$$m_{ew} = \frac{V_e}{t_e} \times \frac{\rho_w}{10^3} \text{ (Kg/sec)}$$

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

7) Heat Carried Away by Water

$$Q_{ecw} = 0.078 \times 4.186 \times (38-36) = 0.9795 \text{ kW}$$

$$Q_{ecw} = m_{ew} \times C_p \times (T_2 - T_1) \text{ (kW)}$$

8) Mass flow Rate of Water Through Calorimeter

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

$$m_{cw} = \frac{V_c}{t_c} \times \frac{\rho_w}{10^3} \text{ (Kg/sec)}$$

9) Heat Carried Away by Water in Calorimeter

$$Q_{ccw} = 0.125 \times 4.186 \times (37-35) = 1.0465 \text{ kW}$$

$$Q_{ccw} = m_{cw} \times C_p \times (T_6 - T_5) \text{ (kW)}$$

10) Heat Carried Away by Exhaust Gas

$$Q_{exh} = \frac{Q_{ccw}}{(T_3 - T_4)} \times (T_3 - T_a)$$

$$Q_{exh} = (1.0465 / (162 - 80)) \times (162 - 35) = 1.620$$

11) Uncounted Heat Loss

$$Q_{un} = Q_s - (BP + Q_{ecw} + Q_{exh})$$

$$Q_{un} = 5.22 - (1 + 0.9795 + 1.620) = 1.619$$

12) Area of Orifice

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

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

13) Head Obtained by Orifice

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

$$H = \frac{h_1 - h_2}{100} \left(\frac{\rho_w}{\rho_a} - 1 \right) \text{ (m)}$$

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

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

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

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 (mf). 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 (NO_x) 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

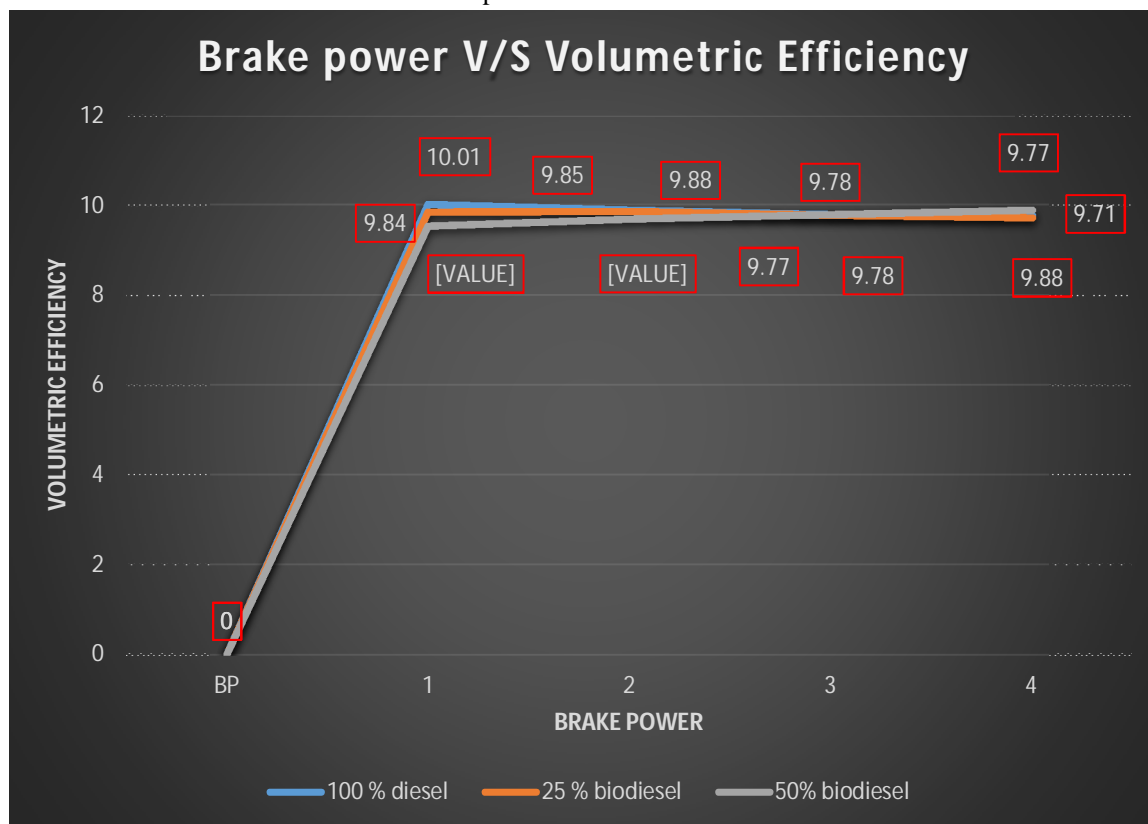
Table no. 4.2 (Emission on 25% Biodiesel at 110 bar injection pressure)

Sr.No	CO (%)	Sox (ppm)	NOx (ppm)	Methane (%)	Co2 (%)	Excess Air Ratio (%)	HL (%)	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

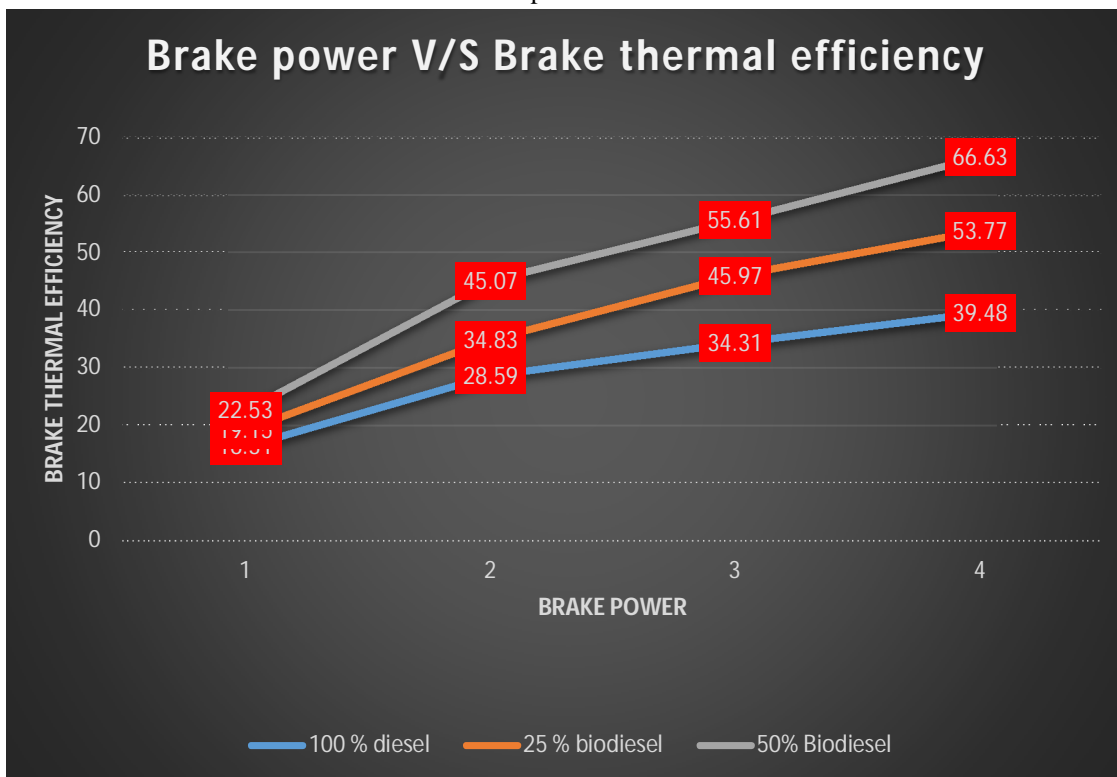
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Sr.No	CO (%)	Sox (ppm)	NOx (ppm)	Methane (%)	Co2 (%)	Excess Air Ratio (%)	HL (%)	Heat Loss (%)	Efficiency (%)
1	0.076	383	138	-0.01	1.3	-63.66	58.59	64.70	35.30
2	0.078	480	159	-0.04	2.0	-65.61	57.68	63.88	36.12
3	0.081	617	170	-0.22	2.5	-64.94	57.09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

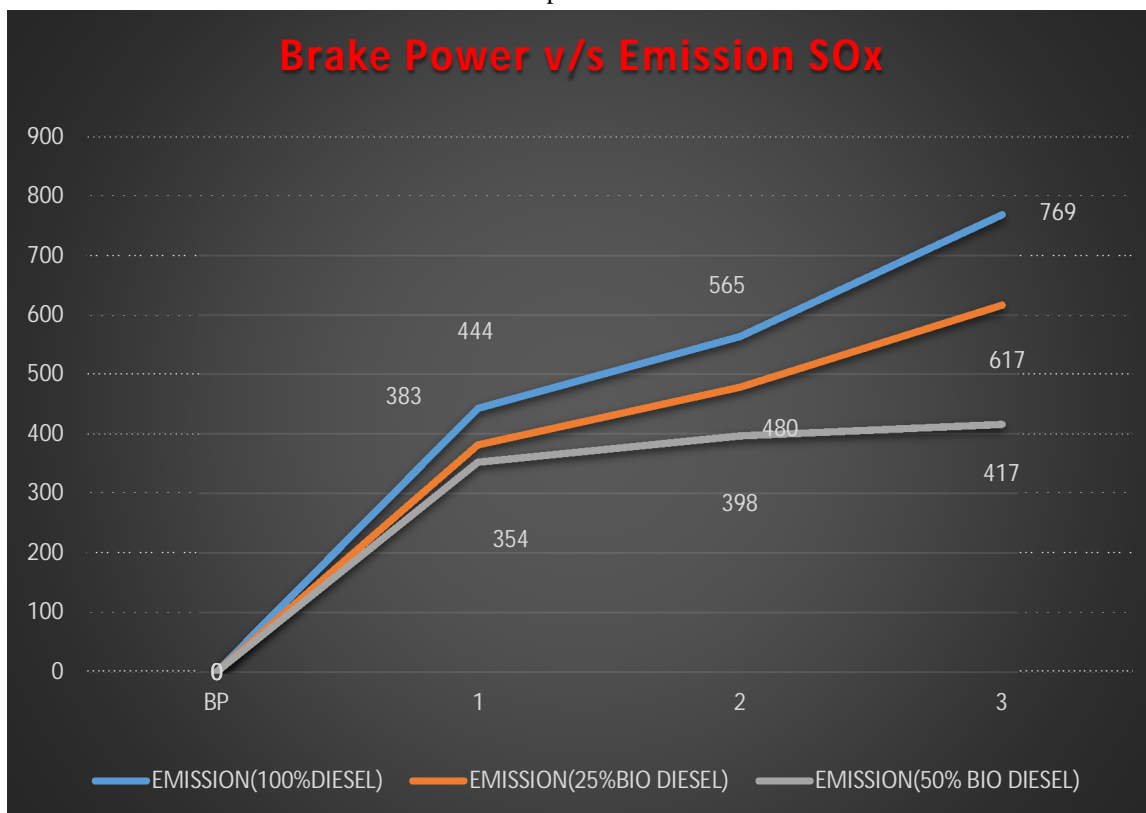
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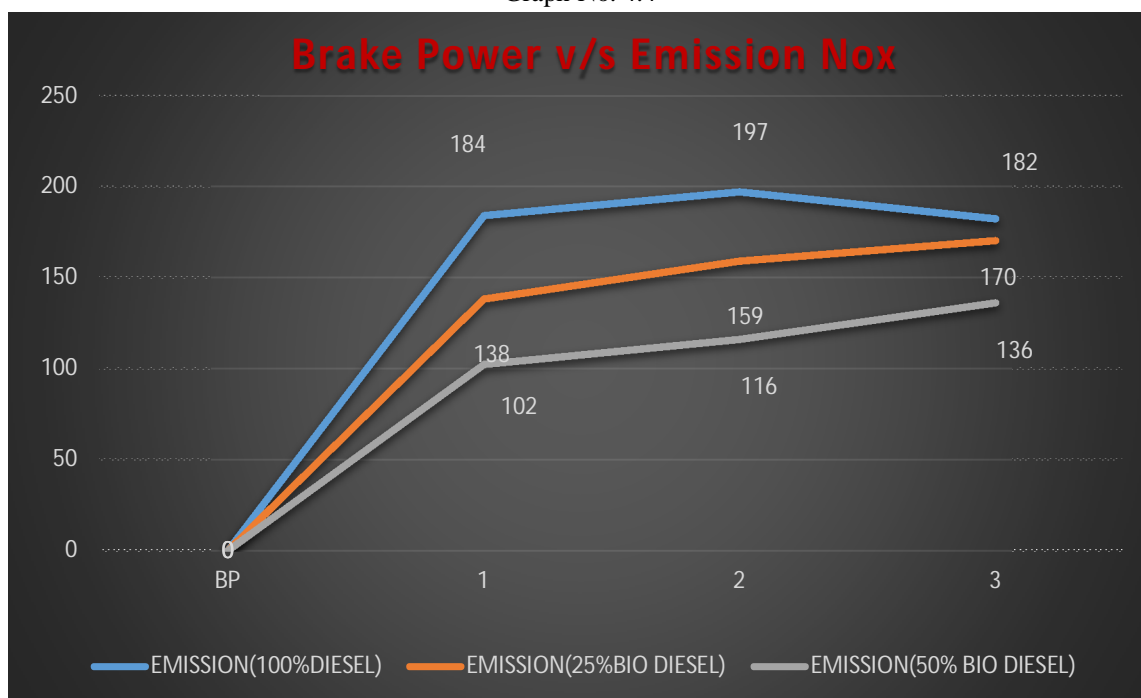
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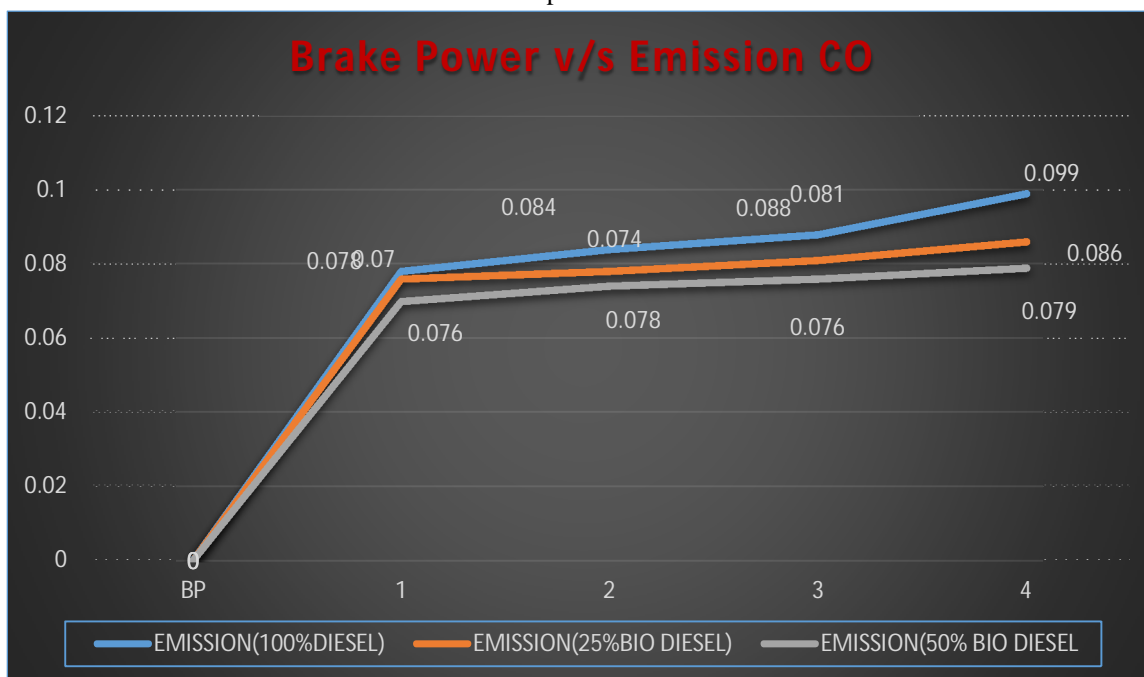
Graph No. 4.3



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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