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Experimental investigation to reduce emissions of direct injection diesel engine fuelled with methyl ester of jatropha oil using antioxidant

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***Abstract* - Biodiesel fuels have some advantages over diesel fuels which comprise reduced particulate matter, CO and unburned hydrocarbon emissions. But latest studies show that there is a slight increase in NO_x with biodiesel (about 10 to 20 %) compared to diesel fuel which may become a barrier to the expansion of biodiesel as a diesel engine fuel. Recent studies have shown that the increased formation of prompt NO_x is responsible for biodiesel NO_x effect. Since the treatment of biodiesel with antioxidants reduces the formation of hydrocarbon free radicals, which are responsible for prompt NO_x production in the combustion process, it is a promising approach for reduction of NO_x emissions. This experimental study is an investigation of the effect of antioxidant additives on the emission characteristics of biodiesel fuelled diesel engine with an emphasis on the reduction of NO_x emissions.**

***Index Terms* - Biodiesel, jatropha methyl ester, p-phenylenediamine, antioxidants, fuel additives, engine emissions**

I. INTRODUCTION

In recent years biodiesel has been found as an alternative fuel resource to the diesel fuel which is one of the most well-known fossil fuels used for transportation [1]. It has advantages such as higher cetane number, lack of aromatics or sulphur content, less engine modifications while in use etc. Though it has many advantages, it shows disadvantages such as higher viscosity, higher pour point and cloud points, lower oxidative stability, shortening storage life and higher NO_x emissions [1, 2-9].

Though studies have shown significant decrease in other emissions while using biodiesel as a fuel, significant increase in NO_x emissions for biodiesel fuel compared with conventional diesel fuel have also been observed [2,3-7]. This is known as the *biodiesel NO_x effect*. Researchers in past so many years have developed numerous techniques to reduce the NO_x from biodiesel emissions.

Reduction of the NO_x emissions

NOx reduction techniques can broadly be classified into two groups as: pre combustion treatment techniques and post combustion treatment techniques [10] as shown in table 1. Numerous researches have been done to develop all the techniques in order to reduce NOx emissions occurring with the use of biodiesel as a diesel engine fuel. All the techniques have been found to be effective in reducing the NOx emissions with acceptable increase in other emission.

This paper represents the results of an investigation on the effect of an antioxidant additive on emission characteristics of a jatropha biodiesel-fuelled direct injection diesel engine. An attempt also has been made to evaluate the various performance and emission characteristics in order to effectively utilize antioxidants for the NOx reduction in biodiesel fuelled diesel engine.

Table.1: NO_x reduction techniques [10]

Sr. No.	Pre combustion Techniques	Post combustion techniques
1	Use of different additives	NO_x adsorber catalyst (NAC)
2	Exhaust gas recirculation (EGR) method	Selective catalytic reduction (SCR)
3	Water injection method (WI)	Selective non-catalytic reduction (SNCR)
4	Water—fuel emulsion method (WFE)	$DeNO_x$ (Lean NO_x) catalysts
5	Retardation of injection timing (RIT)	

II. EXPERIMENT SET-UP

The layout of experimental setup is shown in **Fig.1**. The experiments were carried out in a computerized single cylinder, water cooled, naturally aspirated direct injection diesel engine with rated power 5 H.P., coupled with an eddy current dynamometer. The specifications of the diesel engine are given in Table 2.

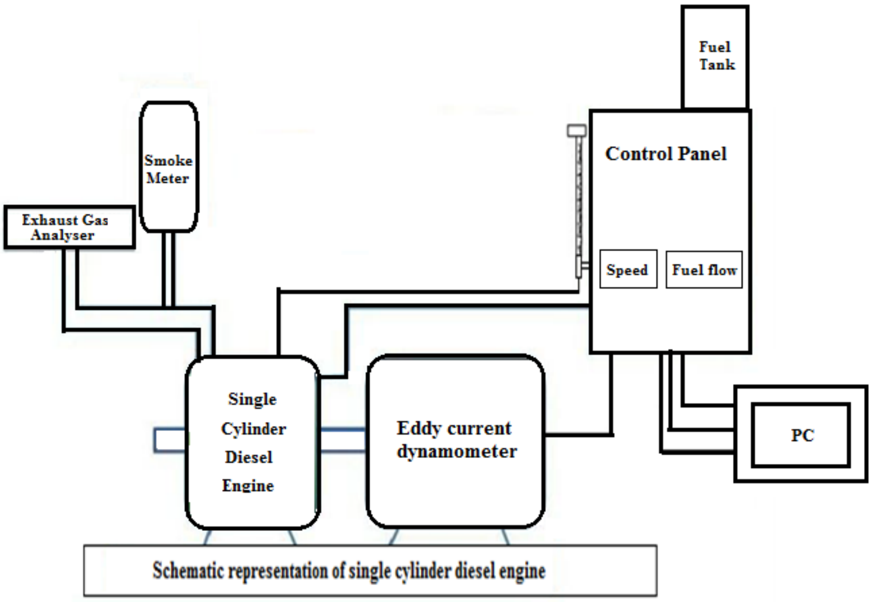


Fig 1 Engine and data acquisition system

The exhaust emissions were measured with an AVL DiGas 444 analyser. Before taking the emission test, a leak check has to be conducted in the digital gas analyser.

Table 3 Exhaust gas analyser specifications

Measured quality	Measuring range	Resolution	Accuracy
CO	0…10% vol	0.01%vol	< 0.6%vol: ± 0.03% vol > 0.6 % vol ± 5% of ind. value
HC	0….20000 ppm Vol	< 2000: 1ppm vol > 2000: 0ppm vol	< 200 ppm vol : ± 10ppm vol > 200 ppm vol: ± 5% of ind. value
CO_2	0…..20%vol	0.1% vol	< 10% vol ±0.5% vol > 10% vol ± 5% vol
O_2	0…..22% vol	0.01% vol	< 2% vol ±0.1% vol > 2% vol ± 5% vol
NO_x	0……5000ppm Vol	1 ppm vol	< 500 ppm vol : ± 50ppm vol > 500ppm vol : ± 10% of ind value

The leak check is conducted by closing the probes nozzle manually. The purpose of the leak check is to discharge the residual gases through the gas analyser's exhaust tube.

Table 2 Specifications of a diesel engine

Parameters	**Specifications**
Make	Rocket engineering model VRC1
Bore	80 mm
Stroke	110 mm
Swept Volume	553 cc
R.P.M.	1500
Rated Power	5 H.P.
Compression ratio	17.5:1
Fuel Oil	High Speed Diesel
Density of Fuel	0.8275
Calorific Value	43500 KJ/Kg
Co-efficient of Discharge	0.65
Water Flow Transmitter	0 to 10 lpm
Air Flow Transmitter	0-250 wc
Temperature Transmitter	0-800^{o}C
Weighing Balance for fuel	0-2 kg
Piezo Sensor	0 to 5000 psi with low noise cable
Software	Labview

The measuring range and resolution are given in the Table 3. A Hartridge smoke meter is attached to exhaust pipe to measure smoke levels. The specifications of the smoke meter are presented in Table 4.

Table 4 Specifications of Smoke meter

Parameter	Specifications
Model & Type	ED-1950 (with a stand), ST-100N
Measuring Form	Paper Filter Reflection Form
Object of Measurement	Diesel Engine Exhaust Smoke
Measuring Range	0 ~ 100 % (Pollution Rate)
Measuring Accuracy	± 3 % over full scale
Suction Duration	1.4 ± 0.2 Seconds
Suction Capacity	330 ± 15 cc
Calibration	By Standard Colored Paper
Power	AC, Single Phase
Outside Dimensions	W 460 X D 300 X H 400 mm
Weight	Approximately 13 kg
Dimension of Stand	W 533 X D 430 X H 680 (With Castors)

p-phenylenediamine is accurately weighed using a high precision electronic weighing balance and added to measured quantity of jatropha biodiesel blend (B20- Diesel 80%, Jatropha biodiesel 20%) which is chosen according to concerns of engine modifications. To make 0.010%-m of antioxidant mixture, 100 mg of the antioxidant is added to 1 kg of the biodiesel. A 4000 rpm mechanical homogenizer is used to prepare a homogeneous mixture of the antioxidant and B20. The cooling water flow rate and temperature at the inlet are maintained at 0.083 kg/s and 29°C. Experiments are carried out after thorough inspection of the engine and calibration of measuring instruments. The same test procedure and practice are followed for all the test fuel mixtures.

The emissions from the engines are studied at different antioxidant mixtures 0.05, 0.10, 0.15, 0.20 %-m. The effects of antioxidants addition on NO_x, HC, CO and smoke emissions in a jatropha methyl ester-fuelled DI (direct injection) diesel engine at different loads have been studied in this investigation.

Test fuel

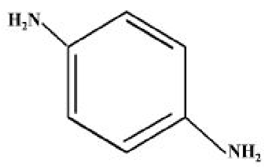
Jatropha methyl esters of non-commercial biodiesel fuels along with a diesel base fuel was used as a test fuel. Jatropha biodiesel was obtained from the South Central Railway.

Table 5 The fuel properties of biodiesel fuels used in the study.

Parameter	Jatropha Methyl Ester
Density @37°C in kg/m^3	856
Kinematic viscosity @40°C, mm^2/s	5.172
Flash point (°C)	166
Pour point, °C	2
Calorific value, kJ /kg	39230
Sulphur content, %	0.012
Moisture	0.025
Iodine Value	103.62
Cetane number	49

In this study, antioxidant p-phenylenediamine (PPD) was used which was selected as per cost, availability and effectiveness, which was procured from Unique Traders, Hyderabad. The chemical structure and specifications of antioxidant additive are as follows in table 6.

Table 6. The chemical structure and specifications of antioxidants used in the study

Antioxidant	Chemical structure	Specifications	
p-phenylenediamine (PPD)		IMDG Code	6.1/III
		Minimum assay	98%
		Molecular Weight	108.14
		Melting point	139 – 143°C
		Sulphated ash	0.05%
		Chemical formula	$C_6H_4(NH_2)_2$

The performance parameters such as brake thermal efficiency and brake-specific fuel consumption and emission parameters such as NO_x, HC, CO and smoke emissions are measured for diesel fuel, B20 and B20 - p-phenylenediamine mixtures.

III. RESULTS AND DISCUSSION

The effect of antioxidant additives on NO_x, HC, CO and smoke intensity with jatropha biodiesel is investigated in this experimental study. The emission and performance measurements are taken repeatedly for three times with a separate engine run. The analysis is done for the average of the readings.

Comparison of NO_x emissions

Figure 2 shows the variation of NO_x with engine load. The results show that NO_x emission increases with the increase in engine load. The addition of antioxidant decreases NO_x emission compared with B20. The NO_x concentration decreases with the increase in antioxidant fraction, up to 0.15% m-concentration, then it increases. It is found that B20 with 0.15% m-concentration reduces NO_x by 6.86% compared with B20 at full load without antioxidant. The decrease in NO_x emission is due to the reduction in the formation of free radicals by antioxidant addition.

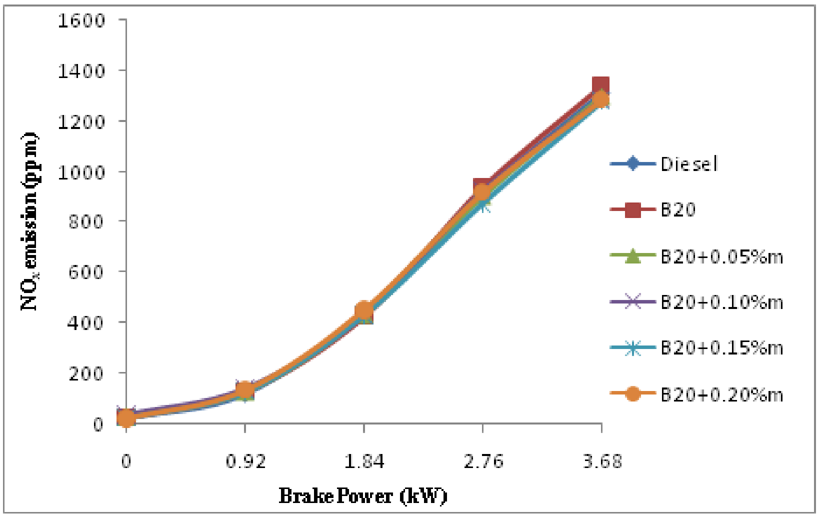


Fig. 2. Variation of NO_x with brake power

Comparison of HC emissions

Hydrocarbon (HC) emissions result from the presence of unburned fuel in the engine exhaust. **Figure 3** shows the variation of HC with engine load. HC emissions increase with increase in engine load.

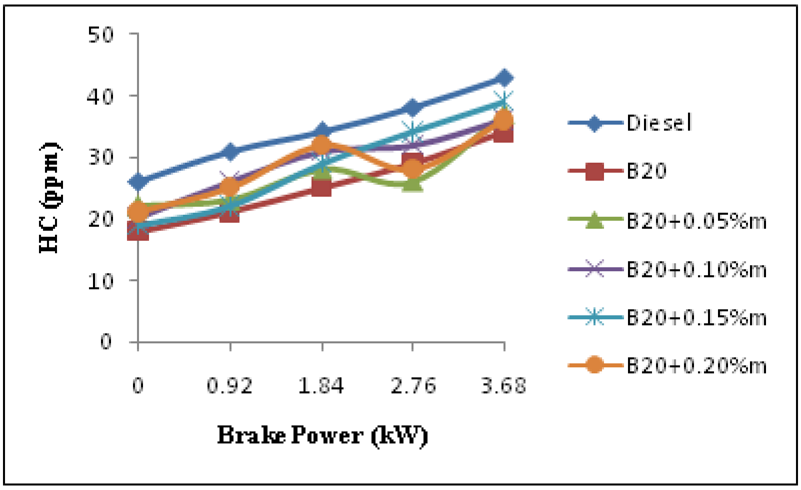


Fig. 3 Variation of HC emission with brake power

B20 showed the decrease in HC emissions compared to diesel with mean reduction of 25.92%. Addition of PPD showed increase in HC compared to B20 with average increment of 25.62% though no specific trends were observed according to amount of antioxidant and the values of HC emissions were below the level of pure diesel.

Comparison of CO emissions

Figure 4 shows the variation of CO with engine load. A low flame temperature and too rich fuel air ratio are the major causes of CO emissions from engines. Higher CO emissions results in loss of power in engines. Diesel engines usually produce significantly lower levels of carbon monoxide and biodiesel can produce even lower CO emissions. Biodiesel contains 11% of oxygen by mass which promotes complete combustion, and thus leads to the reduction in CO emissions.

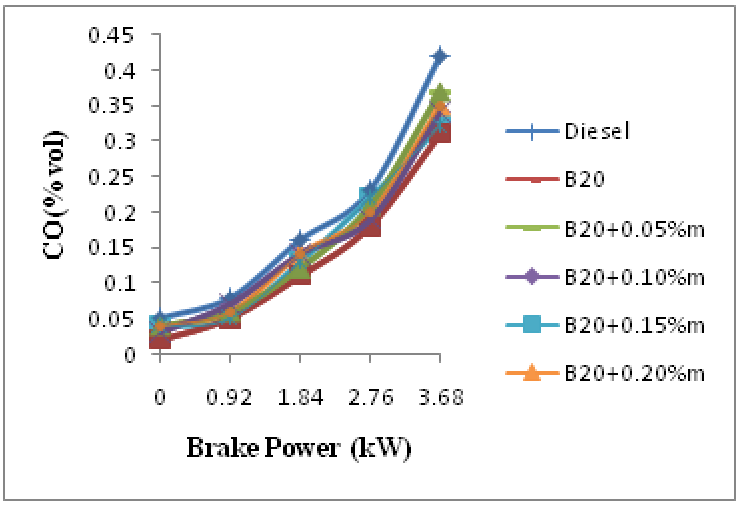


Fig 4. Variation of CO with brake power

The addition of the antioxidants PPD produced mean increase in CO emission of 28.81% compared to B20. This can be explained by the fact that the antioxidants hindered the conversion of CO. Treating biodiesel with antioxidants reduced the concentration of peroxyl and hydrogen peroxide radicals, which affected the CO conversion process greatly. It is found that B20 with 0.15% m-concentration reduces CO by 23.81% compared with diesel at full load though it was slightly higher as compared to that of B20 without antioxidant.

Comparison of smoke opacity

A high concentration of particulate matter or soot is manifested as visible smoke in the exhaust gases. Soot particulates in diesel engines are carcinogenic and otherwise harmful to the environment. All the diesel engine design and operating variables that affect soot formation and oxidation also influence black smoke intensity.

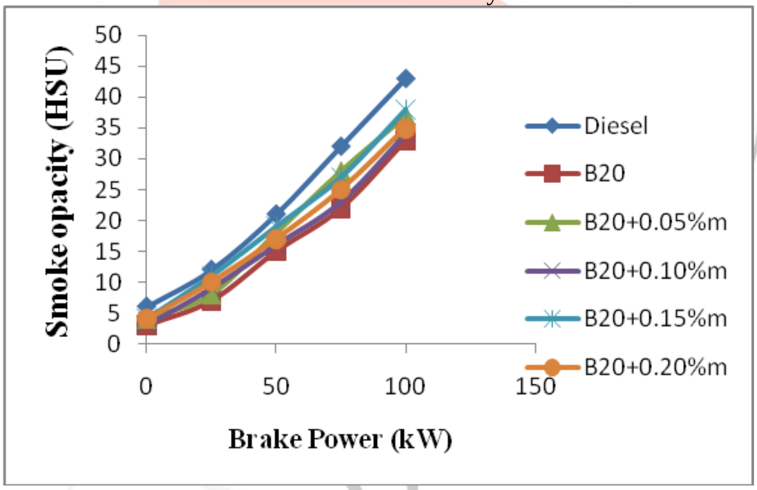


Fig. 5. Variation of smoke opacity with brake power

Smoke emissions increase with increase in engine load due to overall richer fuel-air ratios. Smoke emissions can be reduced by accelerating combustion. Higher combustion rates are obtained by increasing fuel air mixing through use of high swirl rates, by increasing injection rate and improving fuel atomization.

Figure 5 shows the variation of smoke opacity with engine load. The smoke density increases with increase in the load. As load increases, more fuel is injected and because of problem of mixing of fuel with air, leads to incomplete combustion and higher emission of smoke from the engine. B20 showed the least smoke opacity compared to pure diesel at all the loads. The mean reduction in smoke opacity value as compared to pure diesel for B20 was observed to be 28.15%. The addition antioxidants PDD though they were observed to be less than that of the diesel fuel.

Comparison of exhaust gas temperature (EGT)

Figure 6 shows the variation of exhaust gas temperature with load. To indicate the cylinder combustion temperature, engine exhaust temperature is considered one of the important parameters. It is a good parameter for analyzing the exhaust emissions, especially NO_x. Figure shows that the EGT increases with the increasing engine load which is because of the increased fuel quantity injected.

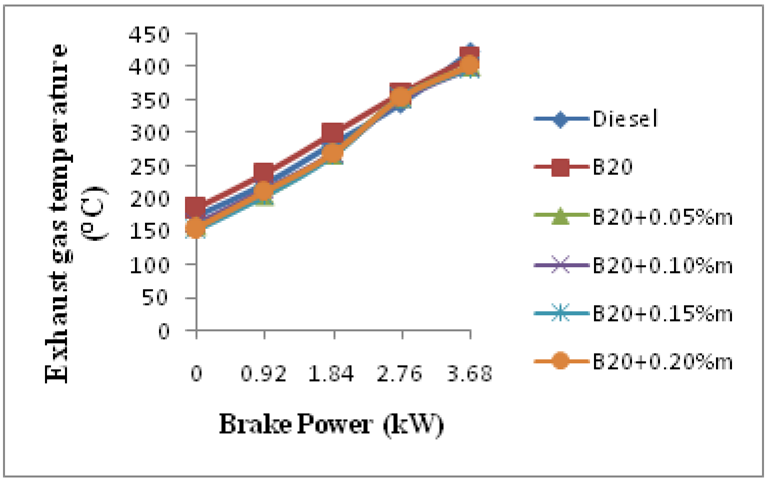


Fig. 6. Variation of exhaust gas temperature with brake power

The test results show that diesel operation results in an EGT about 1–4% lower compared to other fuels (on average over the speed range) though the maximum value of exhaust gas temperature for the diesel engine with PURE DIESEL was 425°C at 100% load. Higher ignition delay results in delayed combustion and higher EGT. Highest reduction in EGT in case of B20 with p-phenylenediamine was observed with 0.10%-m concentration at 75% load with reduction of 5% compared to B20.

Comparison of Brake Specific Fuel Consumption (BSFC)

Figure 7 shows the variation of brake specific fuel consumption with load. The BSFC of B20 with or without antioxidants increased more than that of diesel fuel.

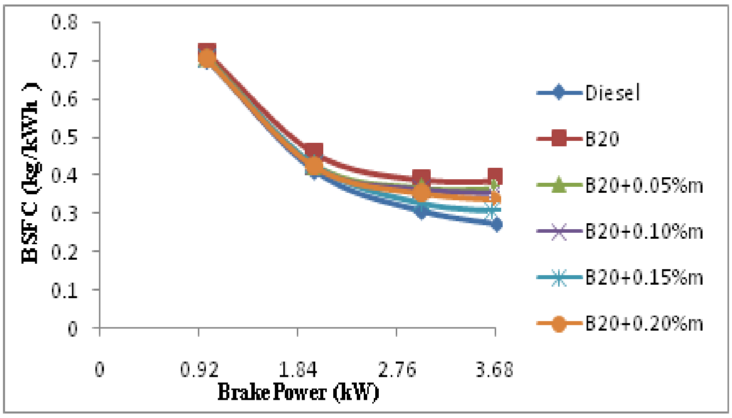


Fig.7 Variation of BSFC with brake power

The B20 with antioxidant produced average 4.71% higher BSFC compared to B20 without antioxidant. The addition of antioxidants to B20 reduces its calorific value further. However, this contributes to decreasing the BSFC.

Comparison of Brake Thermal Efficiency (BTE)

Figure 8 shows the variation of brake thermal efficiency with respect to load. The addition of antioxidants to biodiesel fuels affect the reaction rate, and hence, engine brake thermal efficiency.

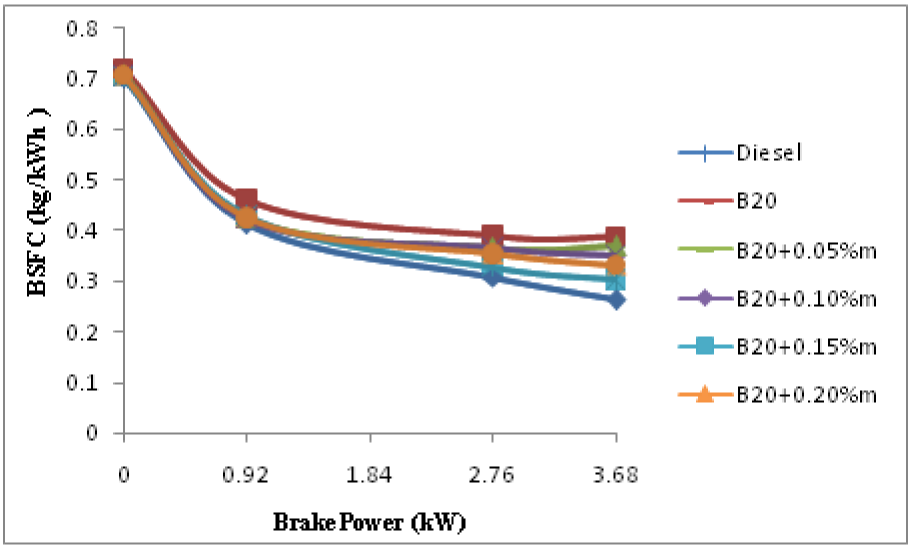


Fig. 8 Variation of BSFC with brake power

The maximum value of BTE observed for pure diesel, B20, B20+P1, B20+P2, B20+P3 was 33.54%, 23.75%, 30.69%, 26.13%, 27.67%. B20 produced average reduction in BTE 10.80% compared to pure DIESEL. The lower BTE can be attributed to the combined effect of their lower heating value and higher viscosity. The addition of antioxidant PPD showed the mean increase in BTE of about 9.29% which can be attributed to the higher power output and lower BSFC compared to B20, though it was less than that of pure diesel fuel.

IV. CONCLUSIONS

The effects of antioxidant (p-phenylenediamine) addition on NO_x, HC, CO_2, CO and smoke intensity with jatropha biodiesel fuelled DI diesel engine at different loads have been reported in this paper. The main conclusions of the study are:

1. B20 with 0.15% m-concentration reduces NO_x by 6.86% compared with B20 at full load without antioxidant. Addition of PPD showed increase in HC and CO emissions compared to B20 with average increment of 25.62% and 28.81% though no specific trends were observed according to amount of antioxidant and the values of both the emissions were below the level of pure diesel.
2. The addition of antioxidant PPD showed the mean increase in BTE of about 9.29% which can be attributed to the higher power output and lower BSFC compared to B20, though it was less than that of diesel fuel.
3. 3.Highest reduction in EGT (parameter for analyzing the exhaust emissions, especially NOx) in case of B20 with PPD was observed with 0.10%-m concentration at 75% load with reduction of 5% compared to B20.
4. The addition of antioxidant to biodiesel fuel blend was found to be effective compared to blend without antioxidant with acceptable increase in other emissions.

V. ACKNOWLEDGEMENT

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