OPEN ACCESS
Saudi Journal of Engineering and Technology
Abbreviated Key Title: Saudi J Eng Technol
ISSN 2415-6272 (Print) |ISSN 2415-6264 (Online)
Scholars Middle East Publishers, Dubai, United Arab Emirates
Journal homepage: https://saudijournals.com

Original Research Article

Performance Characteristics of Clove Oil, Eugenol and Eugenyl Acetate as Bio-Additives in a Single Cylinder Diesel Engine

I.M. Hadi[1*], I.S. Sintali[2], H. Dandakouta[3], A. Tokan[4]

[1]Department of Automotive Engineering, Abubakar Tafawa Balewa University, Bauchi Nigeria
[2,3,4] Department of Mechanical/Production Engineering, Abubakar Tafawa Balewa University, Bauchi Nigeria

DOI: 10.36348/sjet.2021.v06i08.006 | **Received:** 03.07.2021 | **Accepted:** 05.08.2021 | **Published:** 30.08.2021

***Corresponding author:** I.M. Hadi

Abstract

The performance of the fuels blends and emission levels were investigated under various operating conditions of the engine. Performance parameters like torque, brake power, brake thermal efficiency and brake specific fuel consumption (BSFC) were studied. Also, carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbon (HC), oxides of nitrogen (NOx), oxides of sulfur (SOx) emissions and exhaust gas temperature were investigated. The tests were carried out on a horizontal single-cylinder, 4-stroke, air-cooled, 4.00 kW engine, TD115 model. The results showed that blend of diesel and eugenyl acetate (BDEA 1.0%, 0.6% and 0.2%) gave the best performance in terms of reduced exhaust emission. The test results showed that, with decreasing speed, the torque of the engine fueled with both diesel and the blends increased with the maximum torque was recorded at 1680 rpm engine speed for BDE 0.2%. Also, there was a considerable increase in exhaust temperature with the blends compared to the diesel. The exhaust gas temperature of BDC 0.2%, 0.6%, 1.0%, BDEA 0.2% and BDEA 1.0% appeared to be similar to that of the diesel at all speed conditions. The research reveals that for a constant load of 1000 g, brake power increases with the increase in engine speed, thus a maximum brake power of 1.9 kW was obtained at 1680 rpm for BDEA 0.2%, this confirmed the results reported by researchers. There was an increase in the engine's brake thermal efficiency when run on diesel and all the fuel blends at all speed conditions; however, BDEA 0.2% and BDEA 0.6% exhibited better combustion quality than diesel. The BSFC of the blends varied with the engine power and speed; therefore, for all the blends and diesel, consumption was high at low speed and vice-versa. The results also showed that the blends gave less CO compared to diesel. The minimum and maximum reduction of CO were 1.0 % and 1.5 % respectively of the blends, as compared to diesel. The emissions of NOx, SOx and CO_2 decrease with increase in clove oil, eugenol and eugenyl acetate in the blends. All the findings compared favorably with the results of other researchers.

Keywords: Clove oil, Eugenol, Eugenyl acetate, Treat rates.

1.0 INTRODUCTION

Diesel engines are one of the main sources to supply the rapid growth of energy consumption worldwide. They have been widely used in the public and commercial transport sector due to their greater durability and efficiency. The current study in diesel engines is focused on emissions from exhaust gases, as they are causing problems in human health and the ecosystem, because they contain dangerous substances, such as organic carbon, elemental carbon and inorganic ions, etc. The emissions generated by diesel engines, which can be regulated or not regulated, have been studied extensively by several authors (Lloyd & Cackette, 2001). The emissions regulated by law are carbon monoxide (CO), unburned hydrocarbons (UHC), nitrogen oxides (NOx) and for diesel engines, particulate matter (PM) (Egebackm *et al*, 2015). There are several additional unregulated contaminants that have been found in engine exhaust gases, which may have potential health effects and, therefore, should be monitored and reduced in emissions. Ghadikolaei (2016) reviewed the classification of these pollutants, among which are: alcohols, alkenes, alkyl nitrites, monoaromatics, particle emissions, nitrogen dioxide, among others. However, many of the pollutants from unregulated emissions are found in very low concentrations. The percentage of emissions depends on the type of emission control technology and the age of this technology, the operating conditions, the fuel formulations, the ambient temperature and the operation of the catalyst. Karavalakis *et al*. (2012) have suggested in recent studies that biodiesel, alcohols, natural gas and dimethyl ether (DME), could be used as alternative fuels to reduce harmful pollutants and greenhouse gases released from diesel engines. Biodiesel is produced from renewable energy materials such as vegetable seeds and wheat, corn and sugar beet (Rajan & Senthilkumar, 2009).

1.1 Mechanisms for the Formation of Emissions in Diesel Engines.

In an internal combustion engine, some pollutants are generated and emitted by the exhaust pipe, regardless of whether they are compression ignition or spark ignition because the combustion process is not completely carried out in any of the operating conditions of the engine. The emissions from the exhaust pipe of the vehicles are the products of the combustion process that occurs inside the engine and comprises a series of pollutants such as CO, CO_2, HC, NOx, SO_2, and PM. Also, certain contaminants present in the fuel, such as sulfur, are released to the environment as a product of the combustion process. Vehicles with more powerful engines tend to generate higher pollutant emissions and these emissions not only depend on the temperature at which the combustion takes place, the pressure, the homogeneity of the mixture, the constructive characteristics of the engines and its emission control system, but also the maintenance status of the vehicle and operating factors such as speed, load and the frequency and intensity of accelerations and decelerations (Giakoumis *et al*. 2012).

1.2 Aim and Objectives of the Research

The aim of this work is to produce bio additives from cloves and study their effects on the performance of a single cylinder compression-ignition engine. The following are the specific objectives to be achieved.

(i) To conduct tests on engine's performance on a single cylinder diesel engine test bed using the blends. The tests would include the torque, exhaust gas temperature, engine brake power, brake specific fuel consumption, and brake thermal efficiency;

(ii) To determine the exhaust emissions level of the various gases emitted (e.g. CO, CO_2, O_2, NOx, SO_2 and HC).

1.3 Scope of the Study

In this research work, the fuel blends are intended to be used for transportation, hence the extracted oil, the blends formed and characterized would be tested on a diesel engine test bed to determine its performance and emission characteristics.

II. MATERIALS AND METHOD

2.1 Materials

The materials used in conducting the experiments in this research work are listed below.

(i). Clove oil.

(ii). Eugenol.

(iii). Eugenyl Acetate.

(iv). Diesel.

(v). Blends of diesel and clove oil (BDC):

BDC (0.2%), BDC (0.4%), BDC (0.6%), BDC (0.8%) and BDC (1.0%) as shown in plate I.

(vi). Blends of diesel and Eugenol (BDE):

BDE (0.2%), BDE (0.4%), BDE (0.6%), BDE (0.8%) and BDE (1.0%) as shown in plate II.

(vii). Blends of diesel and Eugenyl Acetate (BDEA):

BDEA (0.2%), BDEA (0.4%), BDEA (0.6%), BDEA (0.8%) and BDEA (1.0%) as shown in plate III.

Plate-I: Blends of diesel and Clove oil

Plate-II: Blends of diesel and Eugenol

Plate-III: Blends of diesel and Eugenyl Acetate

3.1.2 Equipment

(i) Automotive Emission Analyzer.
(ii) TD 110 – TD 115 Diesel Engine Test Bed.
(iii) Standby Generator set.
(iv) Laboratory scale thermometer.

Table-1: Test Engine Characteristics/Specifications

Parameters	Specifications
Engine type	Horizontal single cylinder 4-stroke diesel
Number of cylinders	1
Overall dimension, mm	545 x 325 x 446 (L x W x H)
Bore stroke, mm	85 x 85
Compression ratio	20.5:1 to 22:1
Cooling method	Air cooling by blowing
Method of lubrication	Centrifugal lubrication, combined oil mist and splash
Valve configuration	OHC 2 valves
Oil sump capacity	1.0 liters
Fuel tank capacity	4.0 liters
Maximum speed, kW	4000rpm/min
Rated speed, rpm	2800
Advance angle injection	$20^0 – 25^0$ before TDC.

Source: (TQ Education and Training: TD110 – TD 115, 2010)

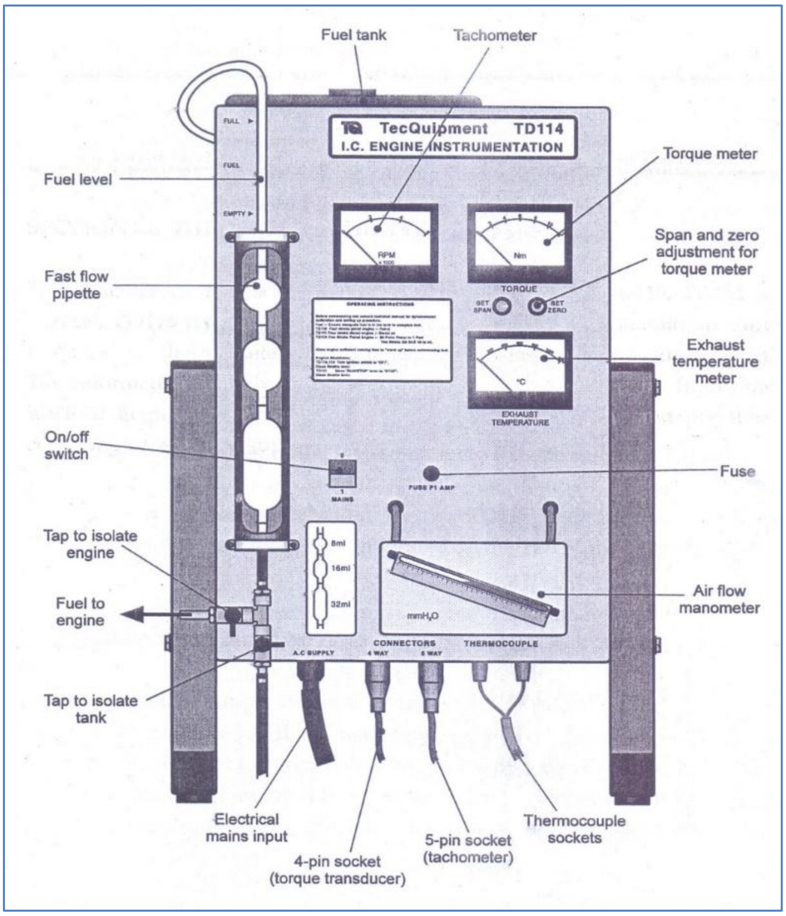

Fig-1: TD 114 Instrumentation Units

Plate-IV: TD 114 Instrumentation Unit

Plate-V: Automotive emission analyzer

Plate-VI: Complete diesel engine test bed

Plate-VII: Engine tests for the performance of blends

3.2 METHODS

3.2.1 Blending of Samples

As explained in seminar II, each treat rates samples were formed in 100ml container. 2ml, 4ml, 6ml, 8ml and 10ml of the bio additives (Clove oil, Eugenol and Eugenyl acetate) were added to 98ml, 96ml, 94ml, 92ml and 90ml of diesel fuel respectively. The 100ml blend was poured into a container mounted on a removable drum and fixed to a tumbler mixer. The timer was set to 10 minutes and the blender switched on. The same procedure was repeated for all the samples. The blends were observed after 48 hours and no phase separation was noticed, which implied there is no need to use a binder, a homogenous mixture was formed.

For the purpose of this research work, a total of fifteen blends/samples were prepared as shown in plates I, II and III. The samples were; BDC(0.2%), BDC(0.4%), BDC(0.6%), BDC(0.8%), BDC(0.8%), BDC(1.0%), BDE (0.2%), BDE (0.4%), BDE (0.6%), BDE (0.8%), BDE (1.0%), BDEA(0.2%), BDEA(0.4%), BDEA(0.6%), BDEA(0.8%), and BDEA(1.0%) respectively. Where, BDC = Blend of diesel and clove oil, BDE = Blend of diesel and eugenol and BDEA = Blend of diesel and eugenyl acetate. The percentages in parentheses represents the amount (in mills) of the bio additive added to the diesel fuel to form a blend.

3.2.2 Engine tests for the performance of blends

3.2.2.1 Brake power

An internal combustion engine is used to produce mechanical power by combustion of fuel. Power is referred to as the rate at which work is done. Power is expressed as the product of force and linear velocity or product of torque and angular velocity. In order to measure power, one needs to measure torque or force and speed. The force or torque is measured by Dynamometer and speed by Tachometer. The power developed by an engine and measured at the output shaft is called the brake power (P_b). The flywheel power is commonly referred to as brake power, P_b. The brake power was calculated using the following relation (Goering, 2003):

$$P_b = \frac{2\pi T_b N_e}{60{,}000} \quad \ldots (1)$$

Where: T_b = engine brake torque, N.m
N_e = engine speed, rpm
P_b = brake power, kW

3.2.2.2 Brake thermal efficiency

The brake thermal efficiency is the product of the indicated thermal efficiency and the mechanical efficiency. The indicated thermal efficiency is a measure of the combustion efficiency of the engine, while the mechanical efficiency indicates the efficiency in converting the indicated power to brake power. The indicated thermal and the mechanical efficiencies are defined respectively as follows (Goering, 2003):

$$\eta_{it} = \frac{P_i}{P_{fe}} \quad \dots (2)$$

$$\eta_m = \frac{P_b}{P_i} \quad \dots (3)$$

Therefore, the brake thermal efficiency is given as:

$$\eta_{bt} = \frac{P_b}{P_{fe}} \quad \dots (4)$$

Where: P_i = indicated power, kW

P_{fe} = fuel equivalent power, kW = $\frac{\dot{m}_f H_g}{3600}$ … (5)

m_f = fuel consumption rate, kg/h

H_g = gross (higher) heating value of the fuel, kJ/kg

P_b = brake (flywheel) power, kW

T_b = engine brake torque, N.m

N_e = engine speed, rpm

P_i = indicated power, kW

3.2.2.3 Brake specific fuel consumption

It is defined as the amount of fuel consumed for each unit of brake power per hour; it indicates the efficiency with which the engine develops the power from fuel. It is used to compare performance of different engines (Charles, 2009).

The amount of fuel which an engine consumes is rated by its brake specific fuel consumption (BSFC) (Yahuza *et al.*, 2016). For most internal combustion engines, the BSFC will be in the range of 0.5 to 0.6 and the fuel efficiency will tend to peak at higher engine speeds. At near wide-open throttle the BSFC will be closer to a value of 0.5. The BSFC tends to be the same for similar engines. Really for huge diesel engines, it has been reported that BSFC values are in order of 0.35. The estimate of brake specific fuel consumption for two-stroke engines ranges from 0.55 to as high as 0.8 (Charles, 2009).

The brake specific fuel consumption was calculated by dividing the fuel mass flow rate, m_f, by brake power. Mathematically,

$$BSFC = \frac{m_f}{P_b} \quad \dots (6)$$

Where: m_f = fuel consumption rate, kg/h

P_b = brake (flywheel) power, kW

IV. RESULTS AND DISCUSSIONS

4.1 Engine's performance analysis

The samples of the bioadditive blends BDC (0.2%), BDC (0.6%), BDC (1.0%), BDE (0.2%), BDE (0.6%), BDE (1.0%), BDEA (0.2%), BDEA (0.6%), and BDEA (1.0%) were tested in the diesel engine test bed at varying speeds with a constant load of 1000 g to know the performance of the blends. Various values of torque, time taken to consume 8 ml of fuel, exhaust temperature and air flow manometer readings were taken and tabulated as shown in Tables 2 – 11.

The test results show that, with decreasing speed, the torque developed by the engine run on diesel and the blends increased, and the higher torque was recorded as 10.50 Nm at 1680 rpm of engine speed. This is the trend for the all samples. It signifies that as the speed decreases, the engine requires more torque to overcome the frictional forces. Also, from the results, the time required to consume the 8 ml of the fuel decreases with decrease in speed. This is an evidence that for all the fuels (diesel and its blends) consumption was high at low speed and vice-versa.

There was a considerable increase in exhaust temperature of the blends compared to the diesel at varying speed, but the exhaust temperatures of the blend were higher than that of the diesel fuel in the study. The maximum value of exhaust temperature was obtained with the BDEA 0.2% (190 ^{0}C) followed by the BDEA 0.4% (189 ^{0}C), both at engine speed of 1680 rpm. However, there was a steady rise of this temperature as the power of the engine was increased. The BDC 0.8% and BDC 1.0% have the same amount of exhaust heat (142 ^{0}C) under the same operating condition of the test engine, same thing with BDEA 0.8% and BDEA 1.0% having 182 ^{0}C at 1680 rpm. The percent difference for BDC 0.8%, BDC 1.0%, BDEA 0.8% and BDEA 1.0% at 1680 rpm compared to that of diesel was just 1%, and 1.8% respectively. This agrees with the study carried out by (Giakoumis *et al.*, 2012) on exhaust temperature released by diesel engine.

Table-2: Engine Performance for Diesel Fuel

Load (g)	Speed (rpm)	Time taken (s)	Torque (Nm)	Exhaust Temp. (^{0}C)	Air pressure (mmH_2O)
1000	2000	82	2.00	100	18.00
1000	1920	68	2.30	115	18.50
1000	1840	60	4.00	125	19.00
1000	1760	50	6.00	130	19.50
1000	1680	40	8.00	150	20.00

Table-3: Engine Performance for BDC 0.2%

Load (g)	Speed (rpm)	Time taken (s)	Torque (Nm)	Exhaust Temp. (^0C)	Air pressure (mmH_2O)
1000	2000	105	1.95	110	17.50
1000	1920	78	4.00	121	18.30
1000	1840	65	5.95	130	19.00
1000	1760	55	7.50	139	19.00
1000	1680	45	8.90	151	20.40

Table-4: Engine Performance for BDC 0.6%

Load (g)	Speed (rpm)	Time taken (s)	Torque (Nm)	Exhaust Temp. (^0C)	Air pressure (mmH_2O)
1000	2000	102	1.85	106	17.50
1000	1920	73	3.93	115	17.80
1000	1840	61	5.70	125	18.00
1000	1760	53	7.30	135	18.30
1000	1680	43	8.69	145	19.20

Table-5: Engine Performance for BDC 1.0%

Load (g)	Speed (rpm)	Time taken (s)	Torque (Nm)	Exhaust Temp. (^0C)	Air pressure (mmH_2O)
1000	2000	100	1.80	101	17.30
1000	1920	70	3.90	111	17.50
1000	1840	59	5.40	122	18.20
1000	1760	50	7.00	130	18.95
1000	1680	40	8.40	142	19.50

Table-6: Engine Performance for BDE 0.2%

Load (g)	Speed (rpm)	Time taken (s)	Torque (Nm)	Exhaust Temp. (^0C)	Air pressure (mmH_2O)
1000	2000	80	2.00	100	17.50
1000	1920	68	4.00	105	18.50
1000	1840	50	6.00	125	19.50
1000	1760	51	8.10	140	20.50
1000	1680	43	10.00	175	21.50

Table-7: Engine Performance for BDE 0.6%

Load (g)	Speed (rpm)	Time taken (s)	Torque (Nm)	Exhaust Temp. (^0C)	Air pressure (mmH_2O)
1000	2000	75	1.80	97	17.00
1000	1920	64	3.50	100	18.00
1000	1840	44	5.20	120	19.30
1000	1760	47	7.00	134	20.10
1000	1680	38	9.20	170	20.00

Table-8: Engine Performance for BDE 1.0%

Load (g)	Speed (rpm)	Time taken (s)	Torque (Nm)	Exhaust Temp. (^0C)	Air pressure (mmH_2O)
1000	2000	75	1.80	97	17.10
1000	1920	65	3.48	100	18.00
1000	1840	45	5.20	121	19.35
1000	1760	45	6.80	133	19.90
1000	1680	38	9.15	169	19.90

Table-9: Engine Performance for BDEA 0.2%

Load (g)	Speed (rpm)	Time taken (s)	Torque (Nm)	Exhaust Temp. (^{0}C)	Air pressure (mmH_2O)
1000	2000	120	2.60	114	18.00
1000	1920	101	6.10	120	19.50
1000	1840	98	7.00	150	20.00
1000	1760	76	9.00	170	20.70
1000	1680	51	10.50	190	21.50

Table-10: Engine Performance for BDEA 0.6%

Load (g)	Speed (rpm)	Time taken (s)	Torque (Nm)	Exhaust Temp. (^{0}C)	Air pressure (mmH_2O)
1000	2000	118	2.50	113	17.95
1000	1920	100	6.00	119	19.00
1000	1840	97	6.90	148	19.85
1000	1760	75	8.95	168	20.50
1000	1680	50	10.00	188	21.00

Table-11: Engine Performance for BDEA 1.0%

Load (g)	Speed (rpm)	Time taken (s)	Torque (Nm)	Exhaust Temp. (^{0}C)	Air pressure (mmH_2O)
1000	2000	115	2.20	110	17.90
1000	1920	93	5.85	115	18.20
1000	1840	92	6.70	140	19.65
1000	1760	72	8.90	162	19.85
1000	1680	48	9.85	182	20.00

4.2 Brake power

The brake power, brake thermal efficiency and the brake specific fuel consumption of the diesel and the blends were computed using SpiLab Version 6.1.0. Figure 2 shows the variations of torque and brake power for the diesel and the various blends with the speed. At constant load of 1000 g, the brake power increased with increase in engine speed as shown. The maximum brake power was found to be 1.9 kW at 1680 rpm for BDEA 0.2%, this confirms the results reported by Agarwal and Das (2001). Furthermore, Agarwal and Das (2001) stated that engine produces its higher power at high engine speed provided that the frequency of cycles is completely balanced with the increase in torque. This hypothesis was confirmed by the results presented here as shown in Figure 2 which shows the variations of torque and brake power for the diesel, as a control, and the BDEA 0.2% (being the best blend) with the speed. The power range was same, but fuel consumption varies at different rates; this also agrees with the findings reported by Hansen *et al.* (2011), Roskilly *et al.* (2008) and (Reeser *et al.*, 1995).

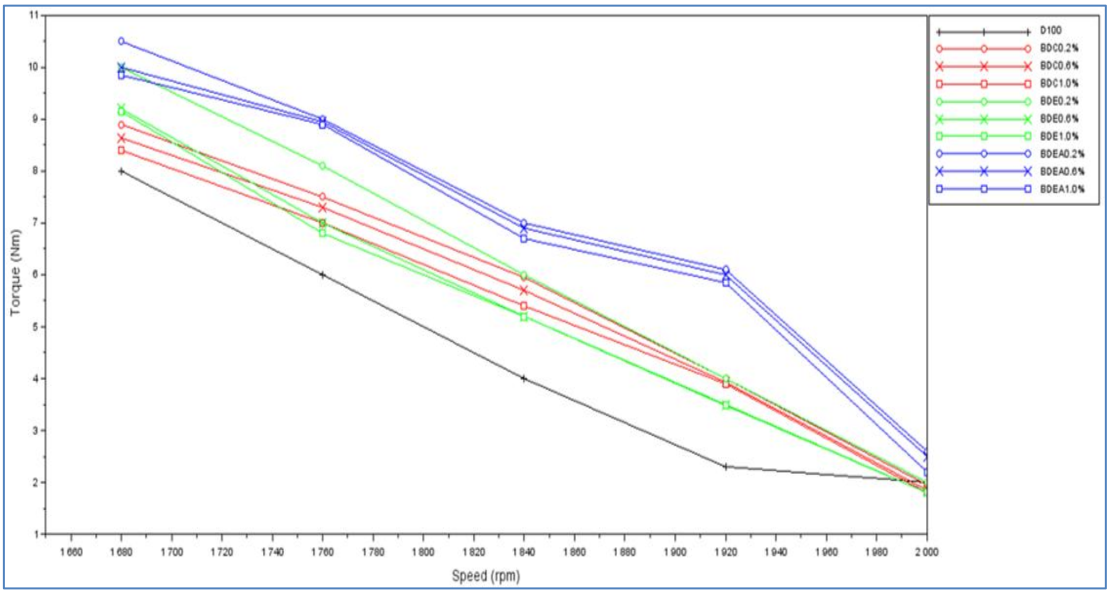

Fig-2: Variation of torque and brake power for the Blends with the speed at a load of 1000 g

4.3 Brake thermal efficiency

Figure 3 shows the brake thermal efficiency of the test engine when run on the diesel fuel blend samples under varying speed conditions. The efficiency was measured with diesel as a base fuel at various speeds. There was an increase in the engine's brake thermal efficiency when run on diesel and all the fuel blends at all speed conditions. Of all the fuel blends used, BDEA 0.6% gave higher brake thermal efficiency at high-speed conditions (1840 rpm to 2000 rpm) as indicated in Figure 3. From 1760 rpm to 2000 rpm, the brake thermal efficiencies for BDC 0.2%, BDC 0.6%, BDC 1.0%, BDE 0.2%, BDE 1.0%, BDEA 0.2% and BDEA 1.0% are higher than that of standard diesel. However, BDEA 0.6% gave the lowest brake thermal efficiency of 0.2% at 1985rpm to 2000 rpm. The brake thermal efficiency depends upon the combustion quality of the fuel; hence, BDEA 0.6% blend exhibited better combustion quality than diesel. This result agrees with the findings of (Basinger *et al*, 2010) whom also reported that the brake thermal efficiency of an engine depends on the heating value and specific gravity, meanwhile, the combination of heating value and mass flow rate indicate energy input to the engine.

Hansen *et al.* (2004), also reported that the thermal efficiency of the engine is found to improve by increasing the concentration of eugenol in the blend, the reason given was the possibility of more complete combustion due the presence of more oxygen in the blends.

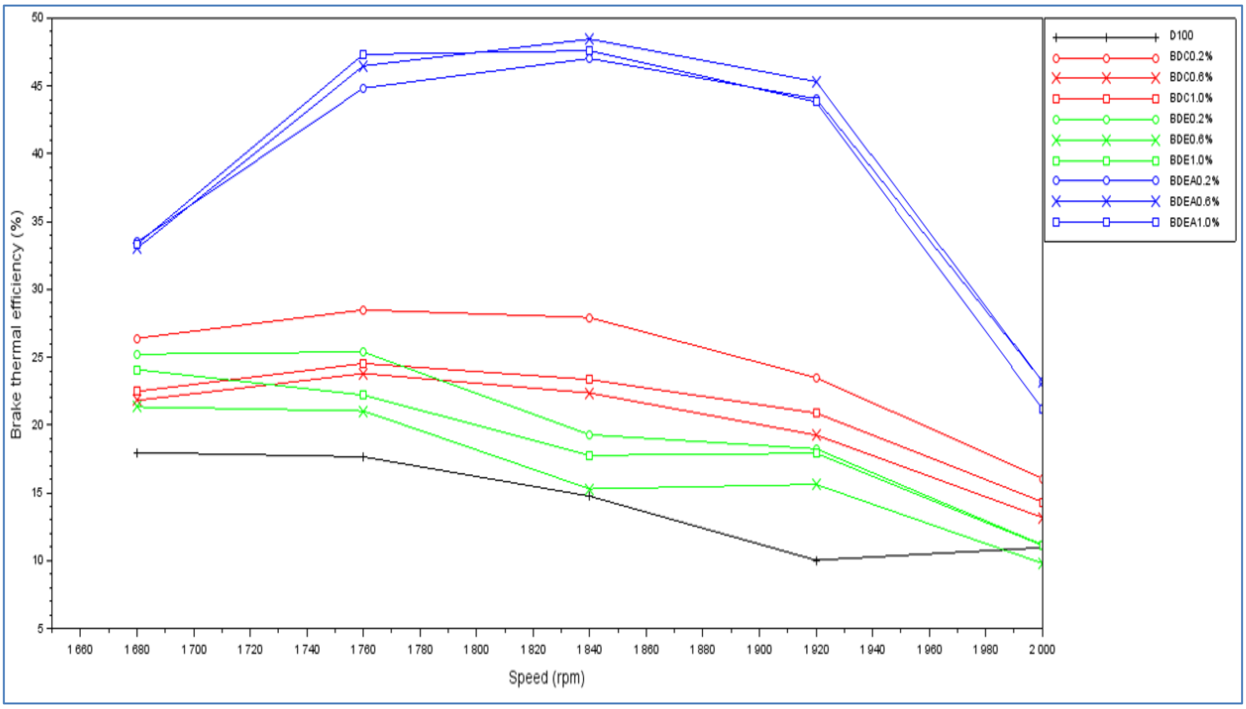

Fig-3: Variation of brake thermal efficiency for the blends at different speeds

4.4 Brake specific fuel consumption

The specific fuel consumption depends upon the mass flow rate, and the results for the specific fuel consumption of the diesel and the various blends were presented in Figure 4. The brake specific fuel consumption for BDEA 0.2%, BDEA 0.6%, BDEA 1.0% and BDE 0.2% are lower than that of diesel at all speed conditions, whereas for BDE 0.6%, it is slightly high compared with that for diesel. It is also observed that specific fuel consumption increases with increase in speed. Brake specific fuel consumption means the fuel consumption has been normalized by dividing by the engine's power. Thus, BSFC is equal to the fuel flow rate divided by the engines power. The brake specific fuel consumption (BSFC) of the blends varies depending on the engine power and speed. For all the blends and diesel, consumption was high at low speed, with increasing speed it decreases.

Figure 4 shows the behaviour of the fuels at different speeds. At 2000 rpm and 1.2 kW power, the brake specific fuel consumption of BDC 0.2%, BDC 0.6%, BDC 1.0%, BDE 0.2%, BDE 0.6%, BDE 1.0%, BDEA 0.2%, BDEA 0.6%, BDEA 1.0%, are 605.8, 779.7, 809.8, 920.5, 1079.7, 1077.7, 469.4, 484.4, and 565.3 kg/kW.hr respectively. It can be seen that there was an increase of 24.8%, 30.5%, 33.8%, 41.7%, 68.0% and 69.8% respectively over that of diesel.

The results show that the difference at any particular speed increases up to a maximum value of 69.8%. This result agrees with the one reported by Puhan *et al.* (2005).

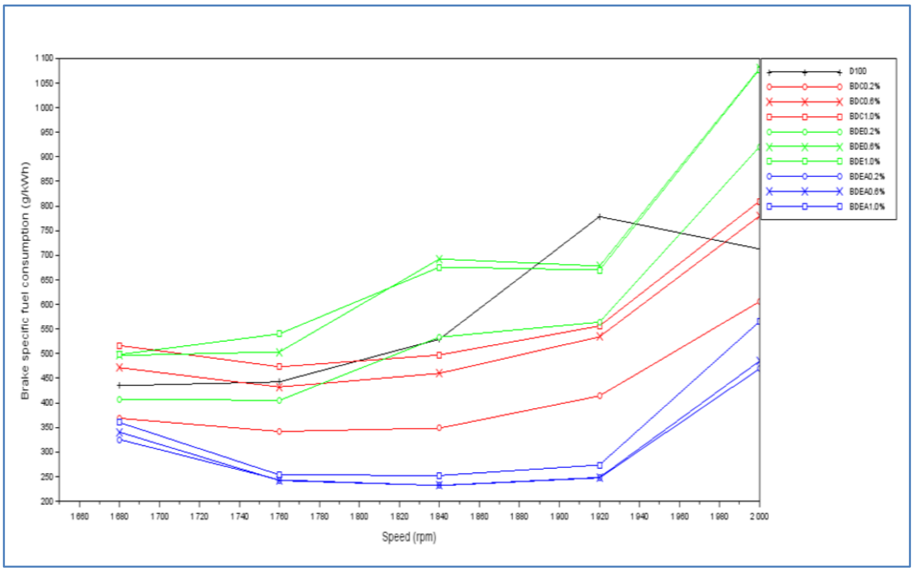

Fig-4: Variation of brake specific fuel consumption for the diesel and the blends at different speed conditions

4.5 Exhaust Emission Analysis

4.5.1 Exhaust gas temperature

The exhaust gas temperatures from the test engine are higher with all the fuel blends than with diesel fuel due to the higher heating value of the blends. The exhaust gas temperature of BDC 0.6% appeared to be similar to that of the diesel at speed conditions 1840 rpm to 1920 rpm, except at 1680 rpm, where it is a bit higher (150^{0}C for the diesel and 152^{0}C for the BDC 0.6%). The BDE 1.0% appeared to be the best among the blends due to the lower heating value at all speed conditions. The variation of the exhaust temperature with engine speed tends to be linear for the blends BDC 0.2%, BDC 0.6% and BDC 1.0% respectively, while the trend is similar for BDE 0.2%, BDE 0.6%, BDE 1.0% BDEA 0.2%, BDEA 0.6% and BDEA 1.0%, and the highest value was below 190 ^{0}C at all the speed conditions as shown in Figure 5, this confirmed with the study carried out by Yahuza *et al.* (2016). The higher exhaust temperature with the diesel is due to containing lower amount of oxygen molecules which is indicative of lower thermal efficiency, less of the energy input in the fuel was converted to useful work, the remaining heat is given out as exhaust temperature. This agrees with the findings reported by Yahuza *et al.* (2016) and Pramanik (2003). However, Hansen *et al.* (2011) stated that higher efficiency may be an indicator of better combustion behavior of the bioadditive-diesel blends, resulting in higher temperature and consequently higher exhaust temperature. Hansen *et al.* (2011) explained, for the high exhaust gas temperature is the fact that higher ignition delays result in a delayed combustion and higher exhaust temperature. Agarwal (2007) reported that when oxygen concentration is increased the exhaust gas temperature increases.

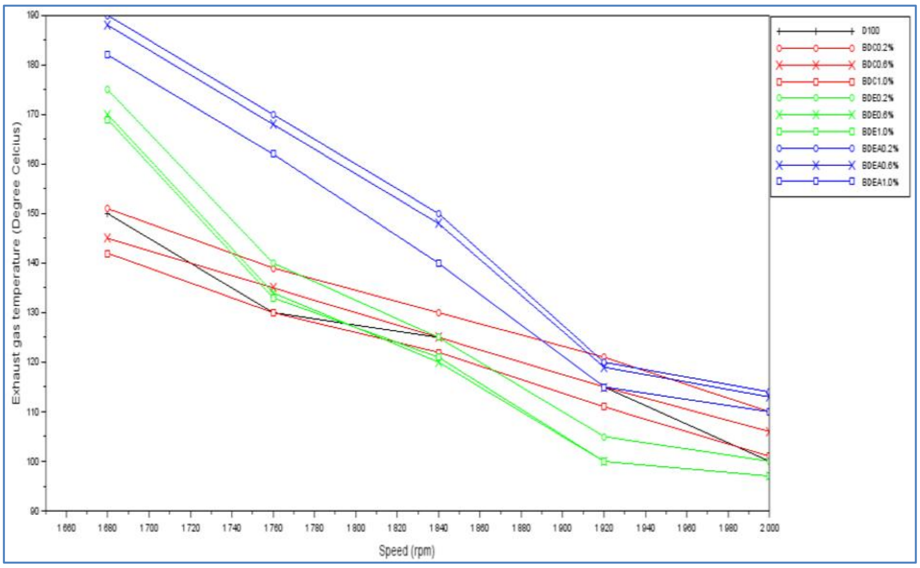

Fig-5: Exhaust gas temperature for the blends and diesel at different speeds

4.5.2 Carbon dioxide (CO_2) emission at different speed conditions

The carbon dioxide (CO_2) emission depends upon the complete combustion of the fuel. Since all the blends have more oxygen molecules content, this results in complete combustion. Due to the complete combustion of the fuel blends, carbon dioxide emission also increases. It can be seen from Figure 6 that the carbon dioxide (CO_2) emission using diesel fuel is lower because of the incomplete combustion as compared to the blends. At all speed conditions, BDEA 0.2% and BDEA 0.6% exhibited the highest values of CO_2 emission, because of the complete combustion, they are best among the fuel blends as indicated in Figure 6. The increase in CO_2 is directly propositional to the increase in the amount of oxygen molecules as shown in Figure 6, this is because eugenyl acetate contained more oxygen molecules.

Carbon dioxide (CO_2) has great effect on the greenhouse gases, in that it has the tendency to form a blanket effect on the atmosphere which aids the global warming. The CO_2 generally increases with increase in engine speed. At 1680 rpm, D100, BDC 1.0% and BDE 1.0% has the lowest CO_2 emissions, while at 2000 rpm, CO_2 emission is high for almost all the blends. Agarwal (2007) found that the CO_2 emissions from a diesel engine was higher. At the highest speed of 2000 rpm, the CO_2 emitted for BDEA 0.2% and BDEA 0.6% is 5.8% as compared to 2.0% at 1680 rpm. CO_2 emission indicates how efficiently the fuel burns inside the combustion chamber.

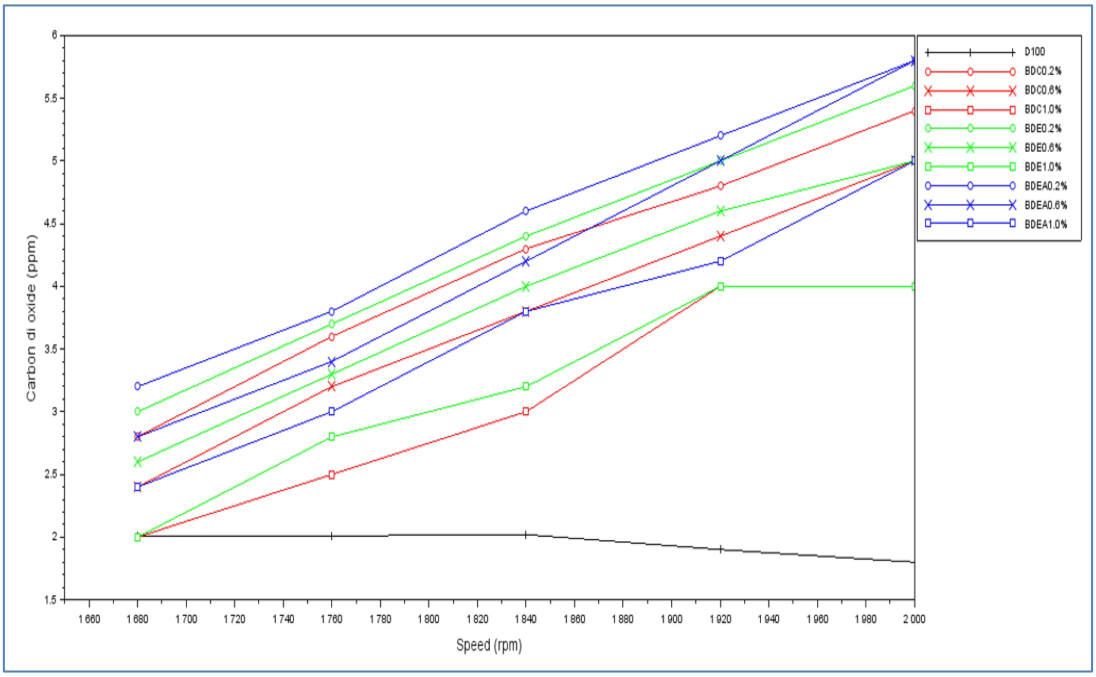

Fig-6: Carbon dioxide (CO_2) emission for the blends and diesel at different speeds

4.5.3 Carbon monoxide (CO) emission at different speed conditions

The results for the carbon monoxide emission of the blends and diesel at different speed conditions are shown in Figure 7. The carbon monoxide emission depends upon the oxygen content and cetane number of the fuel. The blends have more oxygen content than the diesel fuel; so, the blends having more oxygen content are involved in complete combustion process. The maximum carbon monoxide emission was observed at 1760 rpm of the engine speed for BDC 0.2% blend when run on diesel fuel.

Figure 7 illustrates the variation of CO emission with engine speed. It can be seen that at 1680 rpm the BDEA 0.6% has the least CO emission followed by the BDEA 1.0% and BDE 1.0% respectively. The CO emission is lower at 2000 rpm for all the blends. This shows that with more speed, the engine requires additional oxygen for its combustion which was not readily available with the additional injection of fuel. This tends to increase the emission of CO. This result is in line with the findings of studies conducted by Hansen *et al.* (2011), Kalligeros, *et al.* (2003) and Marshall *et al.* (1995). The most noticeable reduction appeared at speed of 1920 rpm. At low-speed condition, cylinder temperature was too low, that increased with loading due to more fuel injected inside the cylinder. Findings of Kalligeros *et al.* (2003) indicated that for low speed, CO reduction was practically unaffected by the addition of any fuel to diesel. The study, further stated that at elevated temperature, performance of the engine improved with relatively better burning of the fuel resulting in decreased CO.

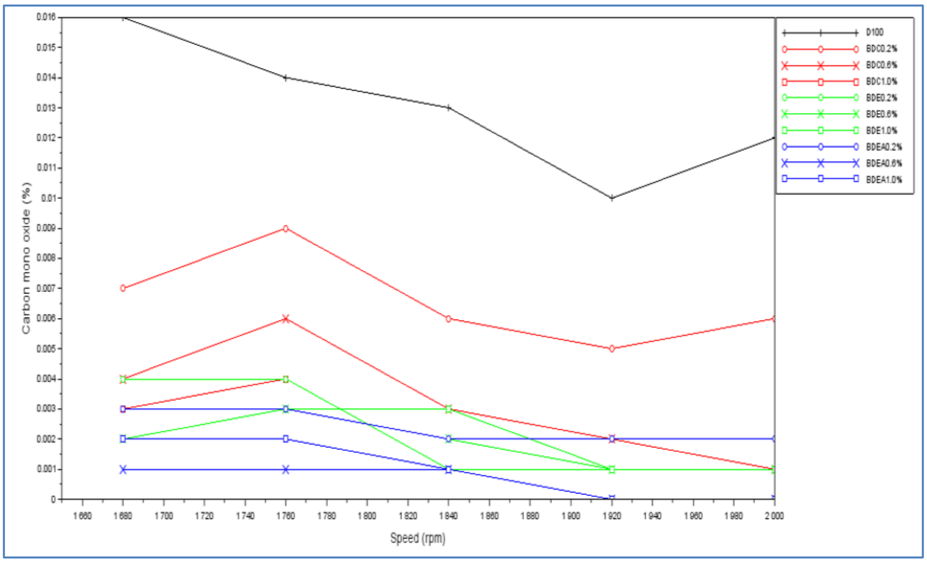

Fig-7: Carbon mono (CO) emission for the blends and diesel at different speeds

4.5.5 Oxides of nitrogen (NO_X) emission at different speed conditions

NO_X emissions depend on the oxygen concentration and the combustion time. At all speeds conditions, NO_X emission of the blends is always higher than that of standard diesel due to the oxygen concentration and combustion timing. Since clove oil, eugenol and eugenyl acetate has very low cetane number, the cetane numbers of the blends are lower than that of standard diesel (as previously presented in Seminar II). This causes increase in the NO_X emission of the blends. The shorter ignition delay could be a reason of increased NO_X emission. D100 and BDC 1.0% show similar values at 1920 rpm speed conditions. Similarly, BDEA 0.6% and BDEA 1.0% show the same trend. All the fuel blends have values of NO_X which is above 100ppm at high speed (1920 rpm - 2000 rpm), while that of diesel was below this value at the rate of the same speeds.

At 2000 rpm, BDEA 0.2% has more NOx emission than all the blends, with BDC 1.0% having least. As speed is increased, so does all NOx emission in all the blends. However, the diesel gave the least NOx emission at speed of 1680 rpm. At low speeds, engine block and cylinder temperature were not very hot therefore little amount of NOx was produced. But studies by Puhan *et al.* (2005) show reduction in NOx consistently for some tests done. They stated that the emission of NOx is determined by oxygen concentration, peak pressure, combustion temperature and time. From this, it can be concluded that any change in combustion temperature and stoichiometry will affect the production of NOx. In summary, it can be seen that there was a gradual increase of NOx. Emission in all the fuels as the speed is increased.

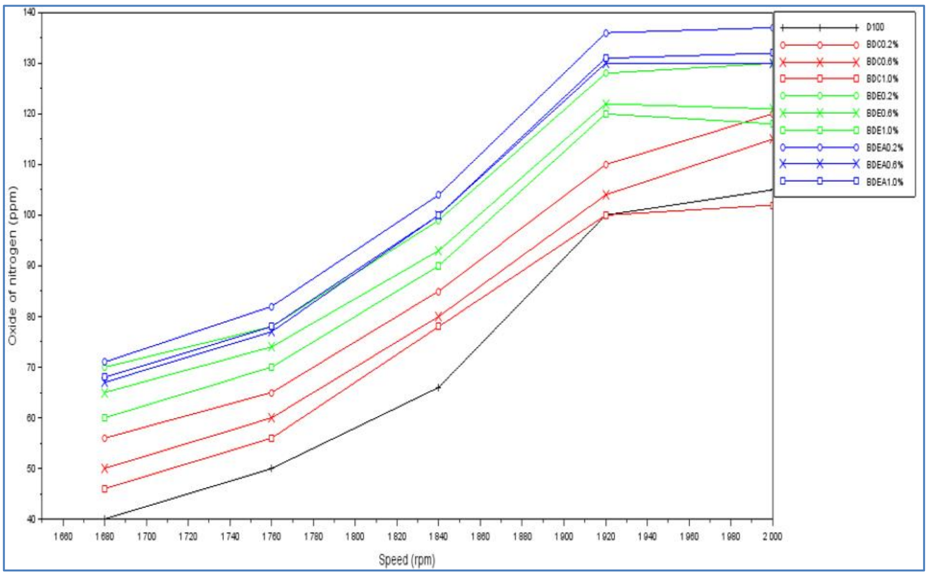

Fig-8: Oxide of Nitrogen (NO_X) emission for the blends and diesel at different speeds

4.5.6 Oxides of sulfur (SO_X) emission at different speed conditions

Figure 9 shows the results for the oxide of sulfur emission of the blends and diesel at different speed conditions. When fuel is burnt in an engine, any sulfur will be converted into sulfur dioxide (SO_2) gas. This readily dissolves in water to produce an acid, which accounts for the irritation to respiratory tract if inhaled and it also affects the ecology (IEA 2014).

Sulfur dioxide (SO_2) is generated from the sulfur present in diesel fuel. The concentration of SO_2 in the exhaust gas depends on the sulfur content of the fuel. Low sulfur fuels of less than 0.05% sulfur are being recommended for most diesel engine applications (IEA, 2014). SO_2 is a colorless toxic gas with a characteristic, irritating odor. Oxidation of sulfur dioxide produces sulfur trioxide which is the precursor of sulfuric acid which, in turn, is responsible for the sulfate particulate matter emissions. Sulfur oxides have a profound impact on environment being the major cause of acid rains. It can be seen, from Figure 9, that the SO_2 decreases with increase in the speed of the engine and BDEA 1.0%3, BDE 1.0% followed by BDC 1.0% appeared to be the best candidates with lowest SO_2 emission when compared with diesel and the blends. The decrease of the SO_2 emission as the speed increases indicated that the fuel consumption is low at high speed, and this agrees with the findings reported by Hansen *et al.* (2011). The SO_2 content of the diesel and the blends is below 13 ppm which indicated a better sulfur content. The sulfur limit for highway diesel fuel is 0.015% (15 ppm) (Mittelbach & Remschmidt, 2006).

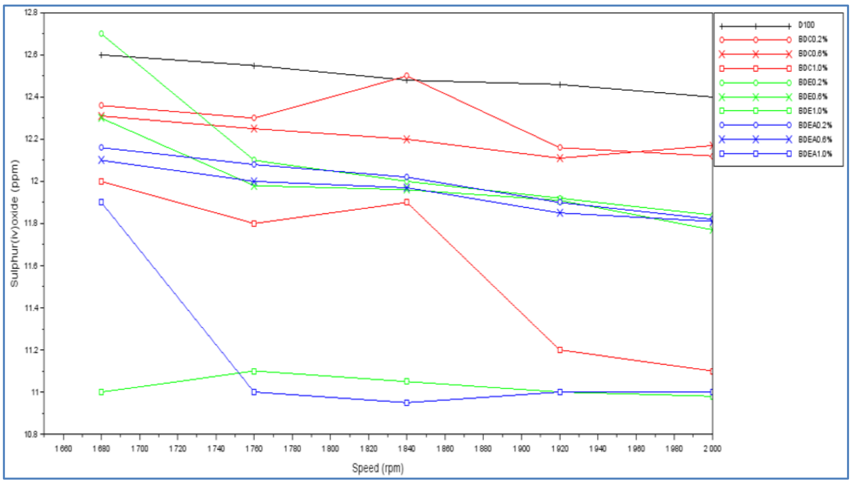

Fig-9: Oxide of sulfur (SO_2) emission for the blends and diesel at different speeds

4.5.7. Hydrocarbon (HC) emission at different speed conditions

The results for the hydrocarbon (HC) emission of the blends and diesel at different speed conditions are shown in Figure 10. The variation of HC emission with engine speed was shown in figure 10. Hydrocarbon concentration decreases with increase in engine speed. D100 has the highest concentration of HC (70 ppm at 1680 rpm). The least value was recorded at 5 ppm for BDEA 0.6% at 200 rpm followed by BDEA 1.0% (6 ppm at 2000 rpm). This result agrees with the one reported by Kadarohman *et al.* (2010).

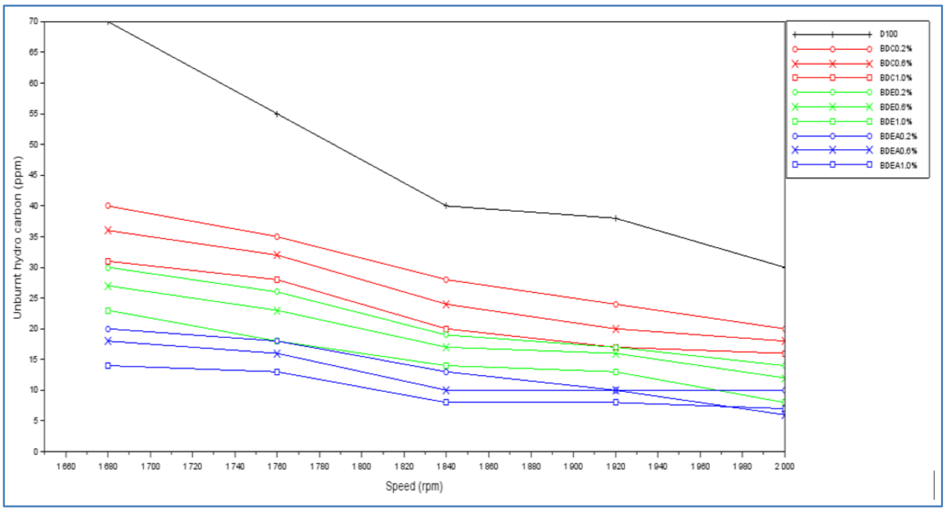

Fig-10: Unburnt hydrocarbon (UH) emission for the blends and diesel at different speeds

5.0 REFERENCES

- Agarwal, A. (2007). Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines. *Prog Energy Combustion Science*, *33*; 233–271.
- Basinger, M., Reding, T., Williams, C., Lackner, K., & Modi, V. (2010). CI engine modifications for straight plant oil fueling in remote contexts: modification design and short-run testing. *Fuel*, 89:2925–38.
- Charles, F. (2009). The Internal Combustion Engine, The google books. *Books.google.co.in. 1985-01-01. ISBN 9780262700276.*, Retrieved 2017-03-22.
- Egeback, K., Henke, M., Rehnlund, B., Wallin, M., & Westerholm, R. (2015). Blending of Ethanol In Gasoline for Spark Ignition Engines-Problem Inventory and Evaporative Measurements. *Renewable and Sustainable Energy Review.*, 78 - 87.
- Ghadikolaei, M. A. (2016). Effect of alcohol blend and fumigation on regulated and unregulated emissions of IC engines. *A review: Renewable and Sustainable Energy*, 57, 1440–1495.
- Giakoumis, E., Rakopoulos, C. D., Dimaratos, A. M., & Rakopoulos, D. C. (2012, 05 02). *Exhaust emissions of diesel engines operating under transient conditions with biodiesel fuel blends.* Retrieved from https://doi.org/10.1016/j.pecs.
- Goering, C. E. (2003). Engine Performance Measures. Chapter 2 in Off-Road Vehicle Engine Principles . *American Society of Agric Engineers.*, 19-36.
- Hansen, A. C., Hornbaker, R. H., Zhang, Q., & Lyne, P. W. (2011). Evaluaton of Diesel fuel oxygenated with ethanol . *ASEA Paper*, N0 3-5620.
- Hansen, A. C., Hornbaker, R., Zhang, Q., & Lyne, P. (2004). Interest of Combining an additive with Diesel Ethanol Blends for Use in Diesel Engines; . *Fuels*, *80*(4) 565–574.
- Kalligeros, S., Zannikos, F., Stournas, S., Lois, E., Anastopoulos, G., Teas, C., & Sakellaropoulos, F. (2003). An investigation of using biodiesel/marine diesel blends on the performance of a stationary diesel engine. *Biomass and Bioenergy*, *24*(2), 141-149.
- Karavalakis, G., Poulopoulos, S., & Zervas, E. (2012, 05 30). *Impact of diesel fuels on the emissions of non-regulated pollutants*. Retrieved from https://doi.org/10.1016/j.
- Lloyd, A. C., & Cackette, T. A. (2001). Diesel Engines: Environmental Impact and Control. *Journal of Air Waste Management.*, 6, 809–847.
- Marshall, W., Schumacher, L. G., & Howell, S. (1995). Engine Exhaust Emissions Evaluation of a Cummis L10e when fueled with a biodiesel blend. *NIPER-BDM, Oklahoma, University of Missouri MARK IV*.
- Mittelbach, M., & Remschmidt, C. (2006). *Biodiesel: The comprehensive handbook. Austria:*
- Pramanik, K. (2003). Properties and use of jatropha curcas oil and diesel fuel blends in compression ignition engine. *Journal of Renewable Energy*, 28; 239–48.
- Puhan, S., Vedaraman, N., Ram, B. V., Sankarnarayanan, G., & Jeychandran, K. (2005). 'Mahua oil (Madhuca Indica seed oil) methyl ester as biodiesel-preparation and emission characteristics,. *Biomass and Bioenergy*, *28*(1), 87-93.
- Rajan, K., & Senthilkumar, K. R. (2009). Effect of Exhaust Gas Recirculation (EGR) on the performance and emission characteristics of diesel engine with sunflower oil methyl ester. *Jordan Journal of Mechanical and Industrial Engineering*, 3; 4-10.
- Yahuza I., D. H. (2016). Performance Evaluation of Ethanol-Diesel Blend in Compression Ignition Engine. *Journal of Bioprocess Biotechology*, 6; 281. doi:10.4172/2155 9821.1000281.
- Yahuza, I., Dandakouta, H., & Hadi, I. M. (2016). Performance Evaluation of Ethanol-Diesel blend in Compression-Ignition Engine. *Journal of Bioprocess Biotech.*, 6; 281. doi:10.4172/2155.

