Performance Analysis of Single Cylinder Diesel Engine using Diethyl Ether Biodiesel

Milind A Ekbote [1], Nikul K Patel [2]

1,2 Mechanical Engineering Department, Faculty of Technology and Engineering, The Maharaja Sayajirao University of Baroda

Abstract: *The world is presently confronted with the twin crisis of fossil fuel depletion and environmental degradation. India is the sixth largest consumer of diesel in the world. It is expected to double its consumption and become the third largest consumer of diesel by 2030. India needs around 2900 crore liters of petrol and 9000 crores of diesel per year currently. The government spends almost 6 lakh crores in its import bill on account of crude oil. These crude oils contribute immensely to green house gas emissions and have adversely effects on an environment. This study focuses on Performance Analysis of biodiesel which is di ethyl ether using a single cylinder 4 stroke water cooled diesel engine. The performance tests of an engine were carried on different load conditions for each blend of biodiesel B20, B40, B60 and then data obtained from the experiments were used to evaluate the performance parameters like BTE, BP, BSFC and exhaust gas temperature. Results have indicated that and engine run at 40% blend of DEE with diesel showed a better performance than pure diesel. The study has revealed that the DEE at 40% blend with diesel can be used as a diesel substitute. Further, DEE at 20% blend satisfies all important parameter of engine as it led to an improvement in engine performance without bringing any modifications in an engine.*

Keywords: **Biodiesel, Diethyl ether, Engine, Performance**

1. Introduction

Despite the widespread use of petroleum derived diesel fuels, interest in vegetable oils as fuels for internal combustion engines was repeated in several countries during the 1920s and 1930s and later during World War 2. Some operational problems were reported due to the high viscosity of vegetable oils compared to petroleum diesel fuel, which results in poor atomization of the fuel in the fuel spray and often leads to deposits and chocking of the injectors, combustion chambers and valves. Biodiesel is an alternative fuel similar to conventional diesel. It can be produced from straight vegetable oil, animal oil, fats, tallow and waste cooking oil. The largest possible source of suitable oil comes from oil crops such as rapeseed, palm, jatropha, Karanja etc. Biodiesel is typically used as an additive to conventional diesel fuel, ranging in content from 2% to 50% or more. For example, B20 is a common blend with 20% volume of biodiesel with 80% volume of diesel. Biodiesel is typically used as an additive to conventional diesel fuel, ranging in content from 2% to 50% or more. Biodiesel is defined as the monoalkyl esters of vegetable oils or animal fats. The higher heating values (HHV) of biodiesel are relatively low as compared to diesel. The HHV of biodiesel is 39-41 MJ/kg lower than that of gasoline 46 MJ/kg, diesel 43 MJ/kg but higher than coal 32-27 MJ/kg. The major economic factor to consider for input cost of biodiesel production is the feedstock which is about 80% of the total operating cost. The higher price of biodiesel is the large part due to the high price of the feedstock. Economic benefits of a biodiesel industry would include value add to the feedstock, an increased number of rural manufacturing jobs, an increased income taxes and investments in plant and equipment. The production and utilization of biodiesel is facilitated firstly through the agricultural policy of subsidizing the cultivation of non-food crops. Secondly biodiesel is exempt from the oil tax. The European Union accounted for nearly 89% of all biodiesel production world wide in 2005. The United States has become the world largest single biodiesel market by 2020 accounting for roughly 18% of world biodiesel consumption followed by Germany. Most commercial biodieel is made by a chemical process called transesterification. This involves mixing the feedstock oil with an alcohol – typically methanol or ethanol in the presence of catalyst. The reaction produces methyl esters (if methanol is used) or ethyl exters (if ethanol is usd) which comprises the biodiesel fuel and glycerin. Among the oxygenated alternatives which could work as ignition improvers are dimethyl ether (DME) and diethyl ether (DEE) with advantages of high cetane number and oxygen content. Di ethyl ester is a liquid an ambient condition is produced from ethanol by dehydration process which makes it attractive for fuel storage and handling. It can also assist to improve engine performance and reduce the cold starting problem and emissions when using as a pure or an additive in diesel fuel. The performance and emission characteristics of a diesel engine using fuels like DME and DEE offered promising alternatives. Many researchers have confirmed through their investigations that B20 could be better option for the countries which are in the early stage of adoption of biodiesel program both looking at the availability and benefits of biodiesel.

2. Literature Review

A comprehensive review of the open research literature available on the development of compression ignition engine using diesel as well as biodiesel. The combustion of fossil fuel in IC engine results in results in pollutant emissions that have adverse effects on the environment and human health. In an attempt to address this challenge, there has been an enormous amount of research in recent years in the area of alternative fuels. In addition, the price of fossil fuel is constantly increasing due to world wide demand and as a result biofuels have been considered an attractive due to their socio-economic advantages. The focus of most of the research work has been reduction in exhaust emissions while maintain high performance of the engine. V Edwin et al, 2010 evaluated the performance of vegetable oils can be improved by injecting a small quantity of DEE along with air. The DEE injection was at different flow rates of 100, 150, and 200 g/h. Results indicate that the BTE of an engine improves from 26.5% to 28.5% with DEE injection rate of 200 g/h. D H Qi et. Al, 2010 conducted an experimental investigation to evaluate the effects of using diethyl ether and ethanol as additives to biodiesel and diesel blends on the performance, emission and combustion characteristics of a diesel engine. Drastic reduction in smoke is observed; NOx and HC emissions are found slightly higher but CO are slightly lower as compare to diesel. DD Nagdeote and MM Deshmukh, 2012 conducted an experimental investigation to evaluate the effects of using diethyl ether and ethanol as additives to biodiesel and diesel blends. Diethyl blend has lower BSFC and reduction in smoke at higher load conditions. Diethyl blend shows better stability and can be used in engine without any modification. S Sivalakshmi and T Balusamy, 2012 carried out experimental investigation using diethyl ether additive to biodiesel. The results indicate that peak cylinder pressure and heat release rate is higher for diethyl ether blended biodiesel then that of neat biodiesel. The CO emission and smoke decrease whereas NOx and HC emission increased for all load conditions. The addition of diethyl ether in biodiesel also improved the physio chemical properties. Obed M Ali et.al, 2013 studied an oxygeneated additive diethyl ether (DEE) blended with palm oil biodiesel in the ratios of 2%, 4%, 6% and 8% and tested for their properties improvement. Blends of DEE in palm oil resulted in improvement in acid value, viscosity, density and pour point with increasing content of DEE accompanied by a slight decrease in energy content of biodiesel. A R Manickam et al., 2014 investigates the use of di-ethyl ether (DEE) as an oxygenated additive with 20% karanja methyl ester diesel blend with 5%, 10% and 15%. The results showed that the brake thermal efficiency improved and exhaust emissions are significantly detroirated with DEE blend with biodiesel at full load conditions. The BSFC slightly decreased as compared with neat biodiesel at full laod. K R Patil and SS Thipse, 2014 evaluate an experimental investigation on the effects of oxygenated cetane improver diethyl ether blends with kerosene and diesel on compustion, performance and emission characterisitics of a direct injection diesel engine. The blends were 2%, 5%, 8%, 10%, 15%, 20% and 25% DEE by volume into diesel. Similarly 5%, 10% and 15% kerosene by volume were blended into diesel to investigate the adulteration effect. The experimental test results showed that the DEE-kerosene-deisel blend have low brake thermal effeicency, high BSFC, high smoke at full load, low smoke at part load, overall low NOx, alomost similar CO, high HC at full load and low HC at part load as compared to diesel. Mura Karabektas et.al., 2014 proposed using natural gas in a diesel engine as a dual fuel and investigates the effects of employing DEE as an additive for eliminating some drawbacks of natural gas. When compared with diesel fuel the use of dual fuel yields higher CO and HC emissions at all loads along with lower NOx emission. Further more the use of DEE as an additive leads to an improvement in brake thermal efficiency and BSFC while causing lower CO and NOx emission in comparison to the use of standard dual fuel. The higher the DEE content the better the engine peroformance and exhaust emissions. S Imtenan, 2014 evaluate the comparative improvement of palm bidoeisel-diesel blend with the help of ethanol, n-butanol and diethyly ether as additives regarding emission and performance characterisitics. Use of additives prominently improved brake power, decresed BSFC and increased BTE. Diethyl ether showed highest 6.25% increment of BP, 3.28% decrement of BSFC and about 4% improvement of BTE then B20 palm biodiesel-diesel blend when used with additive. Among the additives diethyl ether showed highest improvement through its less density and viscosity profile with quite a high calorific value. N-butanol showed quite similar development to diethyl ether but ethanol showed less developmet because of its lower calorific value. Sandip Jawre and S Lawankar, 2014 studied effects of diethyl ether as additive to biodiesel of kusum methyl ester on the performance and emission of diesel engine at different load and constant speed with two different injection pressure 170 bar and 190 bar. It was observed that the performance of engine increases at high injection pressure. Drastic reduction in smoke is observed with all blends at higher engine loads. DEE addition to biodiesel reflects better engine performance compared to neat biodiesel. Smoke emission has decreased with addition of 5%, 10% additive but decreased substantially with 15% DEE addition due to high oxygen contents of DEE. The overall literature reveals that the use of additive to biodiesel is advantageous and improves the performance characterisitic of an engine.

3. Methodology

3.1 Material

Ethanol is promising alternative fuel due to its renewable bio-based resource. The inability to use ethanol in CI engines are its very low cetane number, poor ignition characterisitics and limited solubility in diesel fuel. Phase separation and water tolerance in ethanol-diesel blend fuels are crucial problems. The dynamic viscosity of ethanol is much lower than diesel fuel leading to a potential concern of lubricity. To overcome these problems, ethanol can be coverted easily to DEE through dehydration process. DEE has serveral favourable properties for CI engines such as high cetane number, low ignition temperature, high oxygen content, reasonable energy density for onboard storage, broad flammability limits, high miscibility with diesel fuel and renewable biofuel. The simplest way of putting it in chemical formula is CH_3 CH_2 –O-CH_2 CH_3 consisting of two ethyl groups bonded to a central oxygen atom. It can be produced from ethanol at an acceptable cost which is renewable. Most diethyl ether is produced as a byproduct of the vapour phase hydration of ethylene to make ethanol. This process uses solid-supported phosphoric acid catalyst and can be adjusted to make more ether if the need arises. Vapour phase dehydration of ethanol over some alumina catalysts can give diethyl ether yields up to 95%. Diethyl ether can be prepared both in laboratories and on an industrial scale by the acid ether synthesis. Ethanol is mixed with a strong acid, typically sulphuric acid. The acid dissociates in the aqueous environment producing hydronium ions. A hydrogen ion protonates the electro negative oxygen atom of the ethanol giving the ethanol molecule a positive charge. Anucleophilic oxygen atom of unprotonated ethanol displaces a water molecule from the protonated ethanol molecule, producing water, a hydrogen ion and diethyl ether. This reaction must be carried out at temperatures lower than 150 degrees centigrade in order to ensure that an elimination product (ethylene) is not a product of this reaction. At higher temperatures ethanol will dehydrate to form ethylene. The reaction to make diethyl ether is reversible so eventually an equilibrium between reactants and products is achieved. Getting a good yield of ether requires that ether be distilled out of the reaction mixture before it reverts to ethanol taking advantage of Le Chatelier's principle.

(a) Diesel (b) B100 (c) DEE

Figure 1. Diesel, Biodiesel B100 and DEE used during experimentation

Figure 1 shows (a) diesel (b) B100 that is biodiesel and (c) DEE that is diethyl ether used to improve the combustion characteristics of fuel used in engine. Important properties of DEE biodiesel blends used in the study is shown in table 1 along with diesel.

Table 1. Properties of different blend

Blend (%)	Density (kg/m^3)	Calorific Value (MJ/kg)
Diesel	830	44.20
B20	806	42.14
B40	783	40.08
B60	759	38.02
B100	713	33.90

3.2 Experimental Set Up

A four stroke single cylinder Swaraj make diesel engine is used to conduct the test. The engine is coupled with electrical generator of 5 kW and operated at constant speed of 1500 rpm. The fuel used during normal engine operation were diesel, DEE and various blend of DEE biodiesel which are 20%, 40% and 60%. The detailed specification of engine is given in table 2. As shown in Figure 2 an engine is connected with an electric generator of 5 kW rating. The various measuring instrument is mounted on the engine like burette, which measures fuel consumption. There is a separate load panel consisting of 100 W two number of bulb, 200 W one number of bulb, 500 W two number of halogen and 1000 W four number of halogen to vary load on the engine. Battery is used to start an engine and also self-cranking mechanism is provided. Thermocouple are used to measure temperatures at radiator inlet and outlet, exhaust inlet and outlet. The details of experiments conducted in different modes of operation are explained. All tests were conducted at the rated speed of 1500 rpm. All readings were taken only after the engine attained stable operation. All measuring equipment are calibrated. Firstly, the blend of biodiesel like diesel, B20, B40, B60 and B100 were prepared. After the engine is started and set to no load condition the observations were taken only after the temperature become constant. The observations made during the experiment are time taken for 10 ml fuel consumption from burette, all temperatures shown by thermocouple, load on an engine, current and voltage from electric dynamometer. Once the readings are taken the load on the engine is changed by switching on bulb from the load panel and again measuring all parameters at this load condition. The different load at which observations were recorded are 300 W, 500 W, 1000 W, 2000 W, 3000 W and 4000 W respectively.

Table 2. Specification of Engine

Particular	Details
Make	Swaraj
Model	PV-4
Type	Four stroke, Water cooled
Fuel	HS Diesel
Cylinders	1
Displacement Volume	780 cm^3
Bore	95 mm
Stroke	110 mm
Compression ratio	15.5:1
Rated output (kW)	5.9 kW / 8 BHP
Specific fuel consumption	251 g/kWh
Rated speed	1600 rpm
Lubricant Oil Grade	SAE 30/40/Multigrade

Figure 2. Experimental Test Facility

4. Results and Discussion

The experiments were conducted using diesel and biodiesel blend of B20, B40 and B60. The performance of the engine was evaluated using several parameters such as Brake Thermal Efficiency (BTE), Brake Specific Fuel Consumption (BSFC), Brake Power (BP), Exhaust Gas Temperature (EGT), NOx and CO. Parameters were evaluated in two different ways in first part parameters were evaluated for different blends without addition of DEE and in second part it diesel and different blends were having 10% addition of DEE. Figure 3 indicates the variation of BTE with load where load on the engine is varied from no load to full load condition. It is observed that as compared to diesel the blend of B40 is showing better performance at full load conditions. All other blends have BTE less as compared to diesel. The blend of B40 gives better combustion of fuel resulting into more power to be generated at piston.

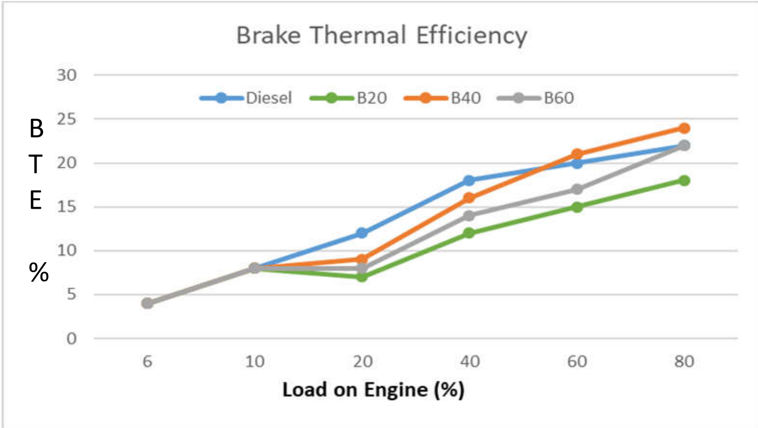

Figure 3. Variation of BTE with Load

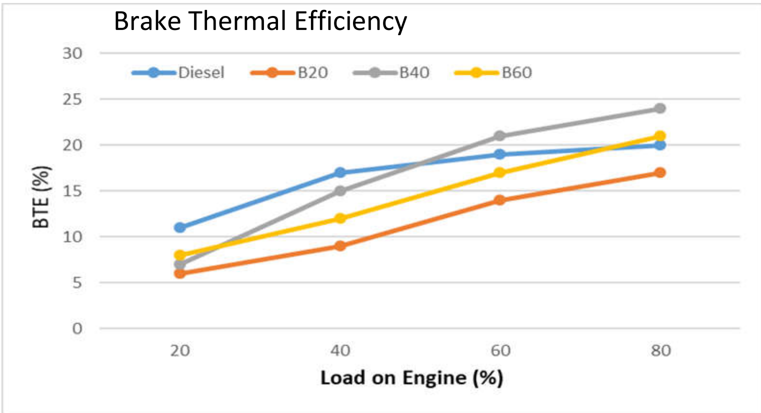

Figure 4. Variation of BTE with 10% DEE blend

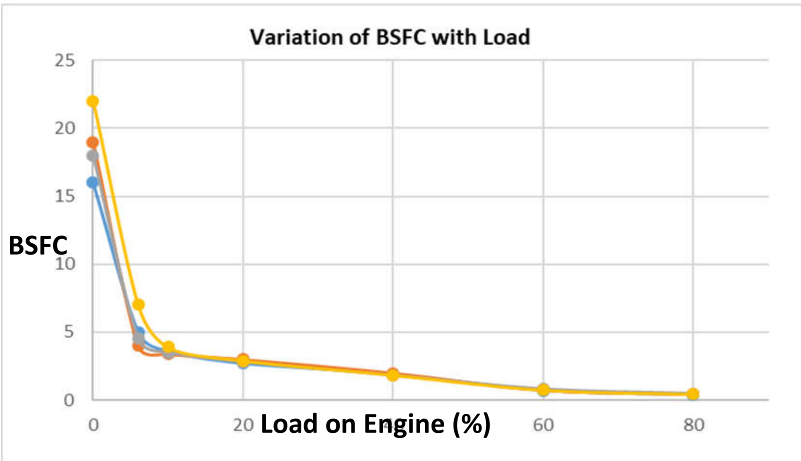

Figure 5. Variation of BSFC with 10% DEE Blend

Figure 4 shows the variation of the brake thermal efficiency with respect to load for diesel fuel and DEE-diesel fuel blends. It can be observed from the figure 4 that DEE B40 shows higher brake thermal efficiency at 80% load conditions compared to that of diesel fuel. Except full load condition diesel give better BTE than other blend but at higher load B40 give BTE 23.86% which is highest among all. The initial increase in BTE may be attributed to the complete and high combustion of fuel but once the load reached the full load level; the time taken for complete combustion of fuel decreased, hence a slight drop in BTE was observed. Specific gravity of the DEE perhaps also played an important role in affecting the performance of engine at full load levels. One other cause for lower efficiency for biodiesel blends is the poor atomization which is attributed to lower density and kinematic viscosity of biodiesel blends. Figure 5 shows the variation of BSFC with load. When two different fuels of different heating values are blended together, the fuel consumption may not be reliable, since the heating value and density of the two fuels are different. It can be observed from the figure 5 that BSFC for DEE diesel is lower compared to that of DEE biodiesel. The availability of the oxygen in the DEE biodiesel blend fuel may be the reason for the BSFC. The lowest BSFC is 15.90 for DEE diesel and highest is 21.83 is for B40.

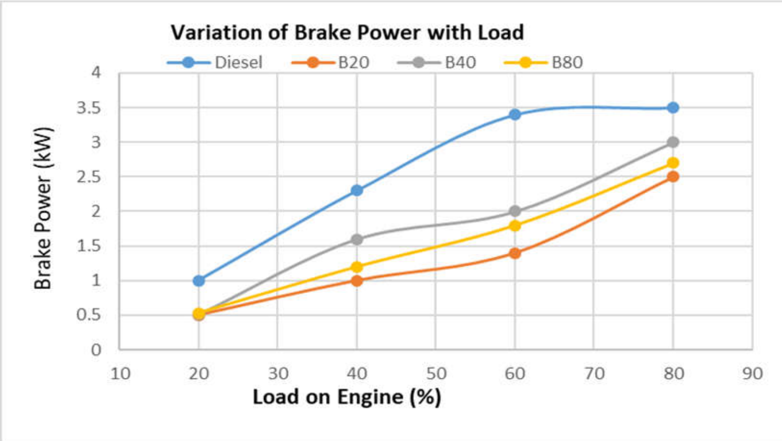

Figure 6. Variation of Brake Power with 10% DEE Blend

Figure 6 shows the variation of BP with load for different blend of diesel fuel and DEE. It can be observed that at higher load diesel give more BP than any other blend. However, for all loading condition as load increase BP is improve marginally. However, B40 at various load condition BP increases rapidly than all other blend. Highest BP for full load condition is 3.43 kW for diesel blend and lowest BP is for B20 blend which is 2.48 kW.

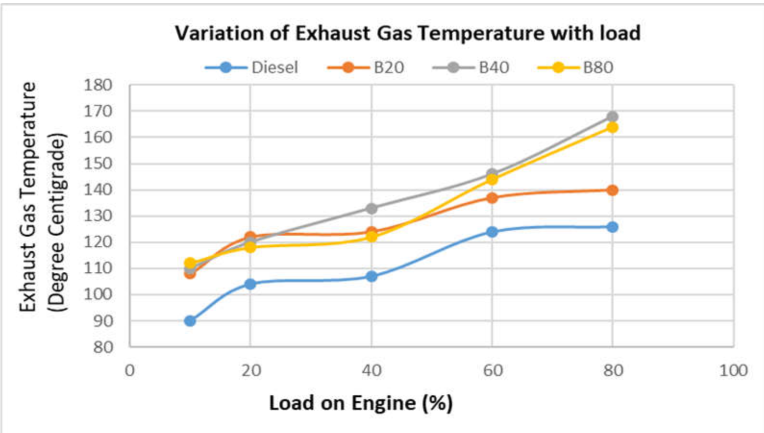

Figure 7. Variation of Exhaust Gas Temperature with 10% DEE Blend

Figure 7 depicts about variation of EGT with load for different blends. The EGT of an engine is an indication of the conversion of heat into work. The EGT increases with increase of load. With the increase in load more fuel is burned inside the cylinder and more temperature is generated and so the EGT increases. The EGT also increases with the increase in biofuel blends. From the curve it is observed that all other biodiesel blends have higher EGT than diesel fuel. At starting condition, higher EGT but low power output for biodiesel blends indicate late burning to the high proportion of biodiesel. This would increase the heat loss, making the combustion a less efficient.

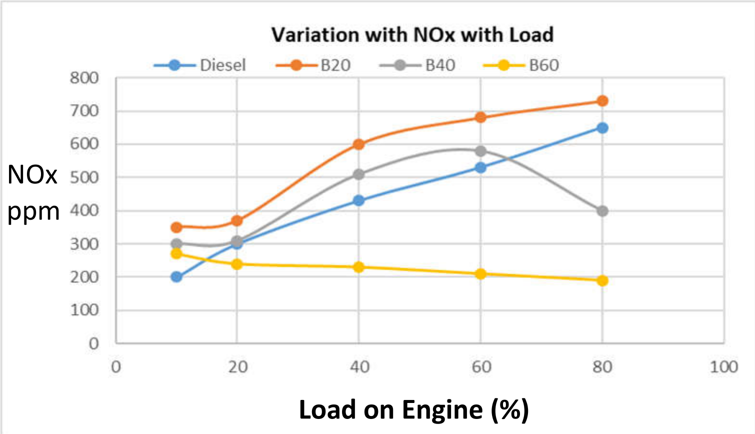

Figure 8. Variation of NOx with 10% DEE Blend

NOx emission can be calculated with the help of NO and NO_2. Figure 8 describes variation of NOx with different load. It is observed that NOx emission increases with increase in load and B20 produces more emission as compared to other blending. It is observed that B60 has lowest emission than other at full load conditions. CO emission is observed minimum for B40 than all other blends. With the increase in load CO emission increased initially and further increased as the load increased. Figure 9 shows the variation in CO emission with different blends of biodiesel at varying load.

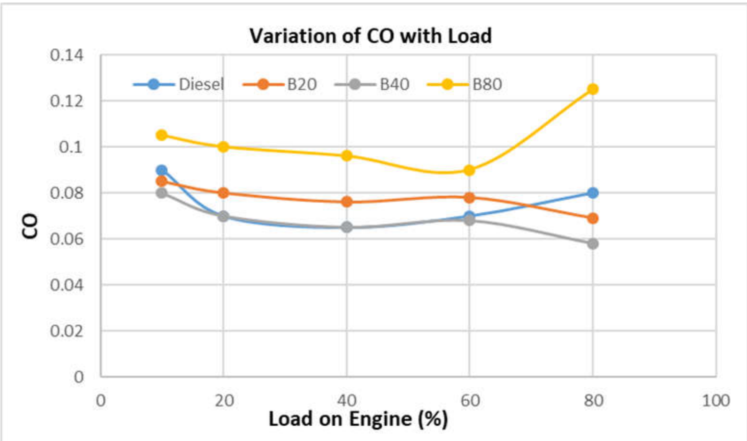

Figure 9. Variation of CO with 10% DEE Blend

5. Conclusion

The important conclusions drawn from the present investigations are (a) The BTE of DEE diesel blend B40 is higher than all other blends. However, as blend percentage increases the BTE is decreased. Highest BTE is 23.86% obtain when B40 with DEE is blend with diesel with full load. It can be seen that efficiency for B40 is 2.79% more than pure diesel for full load. (b) From the experiment it is noticed that BSFC for B40 is lowest among all blend. In case of B40 the BSFC is around 2.65% less than diesel fuel. It is also seen that as blend percentage increase the BSFC is increased than diesel at full load. For other load condition diesel has less BSFC. (c) It can be observed that at higher load diesel give more

BP than any other blend. However, for all loading condition as load increase BP is improved marginally. This happen because at higher load better mixing of fuel and air take place and it improve the BP. (d) The exhaust gas temperature increases with the increase in load. With the increase of load more fuel is burned inside the cylinder and more temperature is generated and so the exhaust temperature increases. The EGT also increases with the increase of biofuel blends. (e) In comparison of all blends, diesel and DEE B40 we can conclude that DEE B40 is most efficient at all load conditions. Thus it is evident that at full load DEE B40 can be considered as suitable blend for diesel engine. Since DEE has extremely limited use at present, its production for use in diesel engine will not only enable the country to attain self – reliance but also help mitigate the conventional fuel crisis.

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