Experimental investigation on performance of Bioethanol-Diesel-Biodiesel blends for Particulate Matter effect on CI engine.

1Bhavik F. Chaudhary
1PG Student
1L.D. College of Engineering, Ahmedabad

Abstract - **The fossil fuel energy requirement and the ever-growing energy demand of the world, require an alternative to this fossil fuel energy. In this quest, the diesel–ethanol blend might be a good option for alternate fuel researches. The emission of particulate matters (PM)is the primary concern of diesel engines. This research aims to reduce NOx and PM by the addition of ethanol in the blend of diesel-biodiesel and be an alternative fuel option. This is investigated in this study by finding D70B20E10 as impactful performance blend for this purpose. Performance and exhaust characteristics were performed and measured on CI engine of this D70B20E10 blend as well as for diesel fuel to compare and analyze them. PM emission characteristics were measured by setting up PM measurement setup which consist of PM filters in connection to the engine exhaust system for both diesel and D70B20E10. Emissions of NOx and PM were main parameters in focus to reduce them. Result of emission showed there's significant reduction in NOx in D70B20E10 about 44% at high load compare to diesel fuel. While PM measurement shows there's quite reduction in PM2.5 of 87%-88% at high load and 90%-92% for PM10 at high load for D70B20E10 compare to diesel fuel. From the experiment data, it is observed that blending ethanol to diesel-biodiesel blend tends to reduce in the emission of NOx and PM compare to conventional diesel fuel.**

keywords - **Alternate fuel, Biodiesel, Ethanol, PM, NOx**

1. Introduction

The fossil fuel energy requirement and the ever-growing energy demand of the world, require an alternative to this fossil fuel energy. Day by day depleting fossil fuel is not sufficient for the population. World has to be depended upon the limited sources which is available to them and have to utilize them fully in order to fulfil their requirement. Many researches been going on to reduce conventional fuel by blending them in a conventional fuel rather than completely replacing it. Electric vehicles now adays very popular to get rid of the day by day increasing price of conventional petroleum products. But they are not giving the best result at high employed temperature condition. So many focus on this alternate fuel researches to develop sustainable fuel. In this quest, the diesel–ethanol blend might be a good option for alternate fuel researches. Among all the proposed alternative fuels for CI engines, the biodiesel and diesel–ethanol/bioethanol blend has gained so much attention in recent years. This attention is due to the fact that it's renewable energy and it can be produced domestically rather than other conventional fuels. Ethanol is already being in blend with petrol at so many places. By using Bio-diesel, It brings so many advantages such as: It is non-toxic, Biodiesel degrades four times faster than diesel fuel, The higher flash point makes its storage safer. Biodiesel can be used directly in CI engines with no substantial modifications of the engine, It Provides a domestic, renewable energy supply.

Density of biodiesel is higher than that of diesel in cold weather. But some of its properties, such as density and viscosity, are higher than those of diesel fuel. These properties can be enhanced by adding bioethanol, which allows the biofuel's level-increase in the whole blend. Diesel engines have better thermal efficiency and higher engine torque than petrol engines. Furthermore, the emission of particulate matters (PM) and NOx is the primary concern for the diesel engines. Diesel PM is a complex mixture of elemental carbon, Sulphur compounds, a variety of HCs, and other species. It is a mixture of solid and liquid and mainly consists of carbon acetous material also known as-soot, sulphates and some absorbed organic compound. PM emission from IC engines might be caused by fuel or lubricant, but fuel has got the greater effect on PM emission rather than those lubricants. As PM2.5 having the size of <2.5 microns which are so much less than even a human hair, need to be reduced otherwise it may lead to hazardous effect to the mankind.

As per Air Quality Index 2021, India having 10 cities out of 15 most polluted cities all over the world, Particulate Matter needs to be reduced immediately. They are of in both the forms of solid as well as liquidous. Emission of the PM mainly from the vehicle emission & thermal powerplant which produces energy by burning out the coal. PM possess very hazardous effect such as Difficulty in breathing for children as well as aged persons, Burning out of eyes, Pain in the chest, Asthma, Heart disease. So, for the better health for the future of human kind it's a must thing to reduce PM for the environment by any process of fuel or blending. To reduce these PM within safe limits in diesel or biodiesel operated engine required complex and costlier aftertreatment devices, which increase complexity and cost in engine. Addition of ethanol reduce simultaneously PM and NOx due to its chemical properties e.g., higher latent heat of vaporization, low carbon content and higher oxygen content.

Thus, the objective of this study to investigate application of ethanol in the blend of diesel- biodiesel for reduction of NOx and PM in CI engine.

2. DIESEL-BIODIESEL-ETHANOL TERNERY BLEND

From literature [2] it's found 70%Diesel-20%Biodiesel-10%Ethanol (D70B20E10) to be most impactful blend among others. So, in this chapter discussion is related to blend preparation, process used for the blending, fuel properties of different blends & solubility test of D70B20E10 blended fuel. Blending of Ethanol with Diesel fuel was done by stirring and ultrasonication process. Below Table 1 shows blend preparation of D70B20E10 & D90E10.

Table-1: Blend preparation of D70B20E10 & D90E10

Fuel	*Stirring time (Hour)*	*Ultrasonication (Minutes)*	*Percentage (%v/v)*
Diesel+ Biodiesel + Ethanol	2	15	D70B20E10
Diesel + Ethanol	1.5	15	D90E10

- Fuel Properties

Biodiesel which was made with the use of mustard oil's been tested in lab. Properties of biodiesel made of mustard oil found to be good enough in terms of Gross Calorific Value which is higher than diesel, so later on it's been used for blending with diesel. Fuel properties of pure diesel (D100), biodiesel (B100), 90%Diesel-10%Ethanol(D90E10) & D70B20E10 were tested in lab to check and compare various properties of blends. Fuel properties are shown in below Table 2

Table-2: Different fuel properties

PROPERTIES	*DIESEL*	*BIODIESEL (Mustard oil)*	*D90E10*	*D70B20E10*	*METHOD*
DENSITY(g/ml)	0.830	0.880	0.832	0.850	IS:1448(P: 16)
FLASH POINT(˚C)	57	47.6	37.2	45.2	IS:1448(P: 69)
KINEMATIC VISOCITY @40(˚C) cst	2.734	6.69	2.30	3.09	IS:1448(P: 25)
CETANE INDEX	47	48.13	44.84	47.57	ASTMD 976- 06
GROSS CALORIFIC VALUE (Cal/gm)	10000	11712	11937	11872	IS:1448(P: 6)

Characteristics of Biodiesel & D70B20E10 is as per below discussed, which include properties comparison of density, flash point, Kinematic viscosity, cetane index & gross calorific value

- Characteristics of Biodiesel & D70B20E10

A] Density(g/ml)

Density is an important property of a blend or pure fuel. Too low or too high density of fueloil is not desirable, because lower density leads to higher fuel consumption which is not a desirable property for any fuel, whereas higher density leads to less fuel consumption than required. Density of Biodiesel & D70B20E10 were more than Diesel fuel but not that significantly high as per IS:1448(P:16) standards so both can be used in engine without anymajor modification to engine.

B] Flash Point(˚C)

Flash point is the lowest temperature at which it can vaporize to form an ignitable mixture.Flash point is used to characterize the fire hazards of fuels. The flash point of Biodiesel & D70B20E10 was measured according to IS:1448(P:69) method. Measured flash point of biodiesel was 47.6 & for D70B20E10 was 45.2. Both were low compare to diesel fuel. Adding ethanol (D90E10) shows there's significance of low temperature in flash point compare to diesel fuel. Low flash point shows the presence of highly volatile materials in the fuel that is a serious safety concern in handling and transporting. By adding some additives can increase the flash point of fuel without any treatment.

C] Kinematic Viscosity @ 40(˚C) cst

The kinematic viscosity of fuel can directly influence atomization quality of the fuel as well as the size of the fuel droplet in the spray. Low kinematic viscosity flow very easily which may cause leakage in the system while high viscosity can disturb fuel flow rate during intake. It was measured according to IS:1448(P:25). Biodiesel having 6.69 cst value which is quiet high compare to diesel kinematic viscosity which is 2.734. So biodiesel cannot be directly used in to the engine without any blending. While D70B20E10 kinematic viscosity was 3.09 which is near to the diesel kinematic viscosity so which is ok. D90E10 shows quite low kinematic viscosity which suggests adding ethanol to biodiesel can lower the kinematic viscosity and would make it to within permissible range.

D] Cetane index

Cetane index is the value which denotes the quality of a diesel fuel, which is based upon it's density and volatility. Cetane index is roughly approximate to its cetane number. Cetane index is measured based on the ASTMD 976-06. Biodiesel having 48.13 and D70B20E10 having value of 47.57 which were nearly of diesel which is 47. So, they are ready to go further for the experiment work.

E] Gross Calorific Value

Gross Calorific Value is one of the important properties of a fuel based on which its efficiency is measured. The calorific value is defined as the energy given out when unit mass of fuel is burned completely in sufficient air. The calorific value of biodiesel & D70B20E10 was measured according to IS:1448(P:6) method. The calorific value of biodiesel was 11712 cal/gm & for D70B20E10 was 11872 cal/gm, which were more than diesel fuel which was 10000 cal/gm. So, both were ready to go for the experiment purpose in the engine.

- **Solubility test**

It is done to observe the effect of miscibility of fuel for the period of time. The blend used for the test was D70B20E10. It's being magnetic stirred for 2 hours and ultrasonicated for 15 minutes. It's being observed for a week and It's found to be a thin layer of low miscible content at the top layer of the fuel on 7th day and which is same as on 1st day of inspection. So, this blend is miscible.

3. EXPERIMENTAL SETUP

Figure 1 Photograph of experimental setup

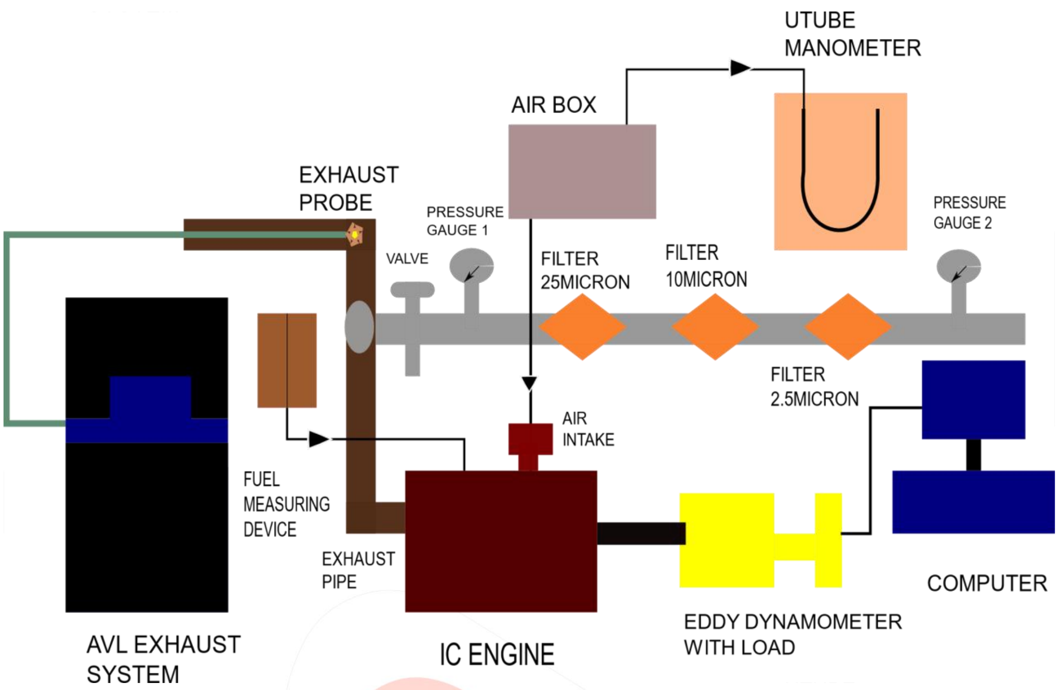

Figure 2 Line diagram of experimental setup

Table-3: Technical specification of 4 stroke diesel engine

Parameters	***Specifications***
Engine manufacturer	Kirloskar AVI
Software	Engine soft Engine performance analysis software
Engine type	Single cylinder 4 stroke engine
Type of cooling	Water cooled
Rated power	3.7 kW@1500 rpm
Cylinder diameter	80 mm
Stroke length	110 mm
Lubrication	Wet sump lubrication
Dynamometer	Eddy current, Water cooled with loading unit

Experimental work was carried out on the Kirloskar single cylinder 4 stroke water cooled engine having rated power of 3.7 kW shown in Figure 1 & Figure 2. Fuel performance and emissions were measured with this setup.Performance parameters such as Break Power(kW) and engine speed (RPM) were directly observed and calculated from the computer connected to engine as well as to eddy current dynamometer. While Specific Fuel Consumption(kg/kWh) of the engine measured with help of the burette providedat the fuel tank. Brake Specific Fuel Consumption (%) & Brake Thermal Efficiency (%) were obtained from these parameters. Volumetric Efficiency (%) of the engine & Air-Fuel Ratio are measured with thehelp of air box and U-tube manometer provided at the back side of the setup. Emission parameters such as CO, CO2, O2, HC & NOx were directly measured from the AVL exhaust system where data collected from the probe which was inserted into the engine exhaust line. HC & NOx were measured in ppm unit whereas rest of the emission parameters were measured in %vol. One of the emission parameter- Particulate Matters (PM) were measured by the PM measurement setup connected to engine exhaust pipe. They were measured in the size of 25µm, 10 µm & 2.5 µm.

Engine performance and emissions were done for Diesel fuel & D70B20E10 (70%Diesel, 20%Biodiesel, 10%Ethanol). Observations and results were obtained at different loading condition for both the fuel. Optimum performances for both the fuels were determined and later PM were measured on that data with the help of PM filter attached to PM measurement setup. Result of performances and emissions of both the fuels were observed and compared to each other to determine which fuel observed better performance and having lesser emission.

- Particulate Matter (PM) Measurement Setup

Figure 3 PM measurement Setup

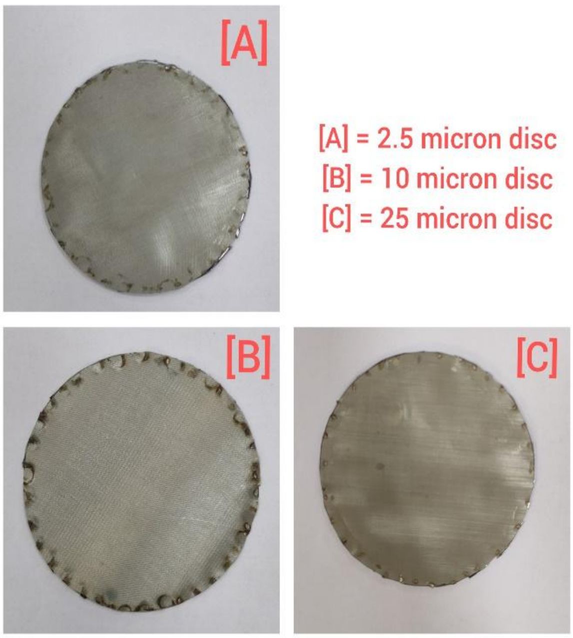

Figure 4 PM filter disc

Figure 3 shows PM measurement setup which consist of 2 pressure gauges & 3 filter discs of 25µm, 10 µm & 2.5 µm. Same of PM discs are shown in Fig. 4. Particulate Matters were measured in unit of milligrams/m^3. Weight of filter discs were measured in grams by placing them onto the weighing machine. Weight of the filter discs were noted down individually for different microns of filter discs before the samplecollection. Then readings of weight of filter discs were taken after the sample collection, where PM is trapped in the disc filters. Readings of PM weight measurements were calculated by taking difference of initial mass & final mass of filter discs. Average flow rate of air is calculated by height difference observed in u-tube manometer during experimental work at various loads.

4. Result and Discussion

This section shows comparative analysis of various result data gained from result table under various test load condition from the observations.

4.1 Engine Performance Parameters for Various Blends

In this part comparison of various performance parameters like Brake Specific Fuel Consumption (BSFC), Brake Thermal Efficiency (BTHE), Volumetric Efficiency, Air-Fuel Ratio are investigated for different blends of fuel at different loading condition.

A. Brake Specific Fuel Consumption & Brake Thermal Efficiency

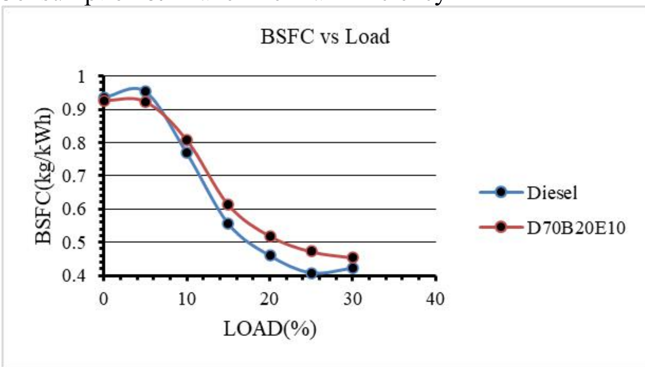

Figure 5 BSFC Vs Load

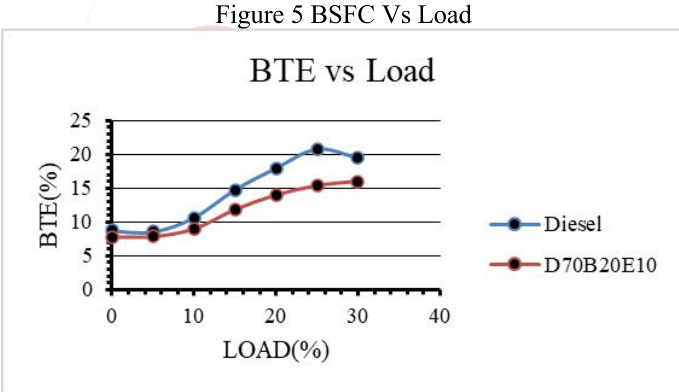

Figure 6 BTE Vs Load

Variation of brake specific fuel consumption with engine load for Diesel and D70B20E10 is shown in Fig. 5. This increase in BSFC depends upon the biofuel- here they were ethanol and biodiesel content in the blends. As the biofuel portion in the blends increases, the BSFC also increases. The specific fuel consumption shows decrease in values with increase in load for both of the fuels. At the start of the engine, Diesel fuel shows higher consumption than ternary blend. But, As the load increases, BSFC for D70B20E10 increases. It is due to the lower heating values of biodiesel. Figure 6 shows variation of brake thermal efficiency (BTE) with different load for both fuels. Figure shows that the brake thermal efficiency increases significantly with increase in the load for both the fuels. But ternary blend having lower BTE than diesel fuel. This is due to higher Calorific Value of ternary blend compare to diesel fuel.

B. Volumetric Efficiency & Air-Fuel Ratio

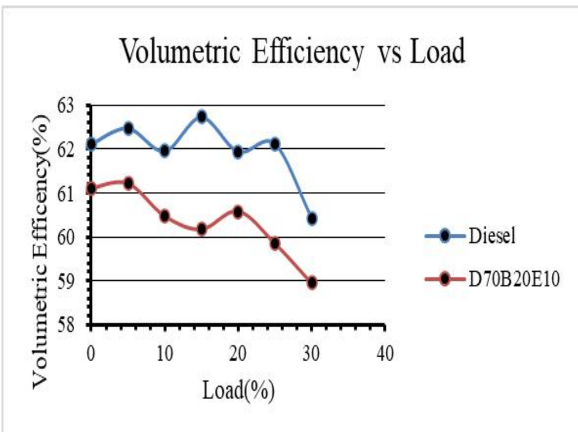

Figure 7 Volumetric Efficiency vs Load

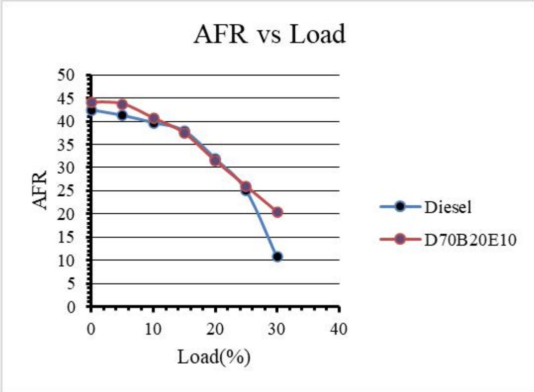

Figure 8 AFR vs Load

Volumetric Efficiency is the ability of the engine to work efficiently. Fig. 7 shows variation of Volumetric Efficiency with different load for both fuels. As it shows volumetric efficiency significantly decreases as increasing load for both the fuel. But ternary blend having lower volumetric efficiency than conventional diesel fuel, which shows engine can run more efficiently on diesel fuel. This lower volumetric efficiency due to higher density of ternary blend compare to ternary blend. Figure 8 shows AFR vs Load consisting Diesel and D70B20E10 fuel. It is strongly depending upon the engine load, As the load on the engine increases, the air–fuel ratio decreases for both of the fuels. While at medium level load between 10%-25% load it shows almost same AFR for both of the fuel. AFR for ternary blend increases compare to diesel fuel at higher level load after 25% load particularly. Where it shows at higher load biodiesel and ethanol blends having higher AFR value compare to pure diesel fuel which suggests leaner mixture of ternary blend compare to diesel.

4.2 Comparison of Emission Characteristics for Various Blends

In this section analysis of various emission parameters such as oxides of nitrogen (NOx), CO2, CO, unburned hydrocarbons (HC) are done for different load condition for diesel fuel and D70B20E10 blended fuel.

C. Oxides of Nitrogen (NOx) Emission & Carbon Dioxide (CO2) Emission

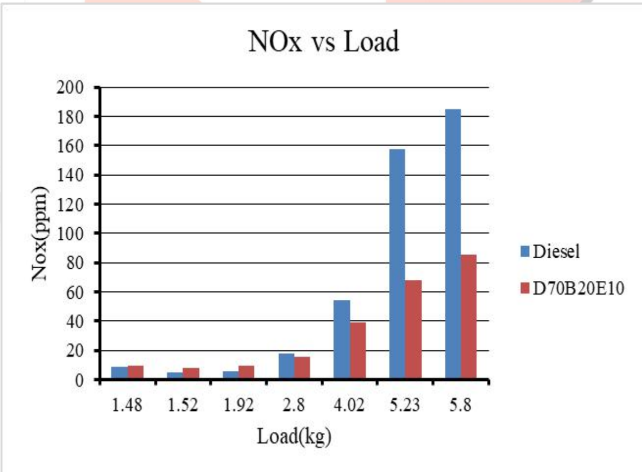

Figure 9 Variation of NOx with Engine Load

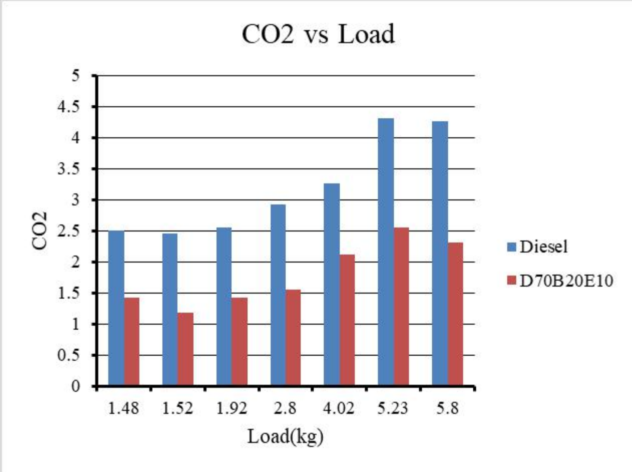

Figure 10 Variation of CO2 Emission with Engine Load

At higher temperature nitrogen separating into nitrous oxide. NOx is most harmful gaseous emission from engines and it's mainly found in CI engines. The NOx defines as parts per million for both of the fuels with function of load in Fig. 9 NOx emissions were higher than diesel at low to medium load but as load was increased, NOx emissions were decreased significantly in D70B20E10 blend around 44% at high load compare to diesel fuel because of more amount of ethanol which led to higher AFR value that showed leaner mixture, which allowed more air to blend lead to complete burn of ternary blend compare to diesel fuel. CO2 emission in CI engine indicates how efficiently the fuel is burnt inside the combustion chamber. The variation of Carbon dioxide (CO2) emission with different load for both fuels of the engine is shown in Fig. 10. CO2 emissions of diesel were higher than ternary blend. CO2 emissions were directly proportional to the percentage of diesel in the fuel blend. As the amount of ethanol is increased, CO2 emission decreases.

D. Carbon Monoxide (CO) Emission & HC Emission

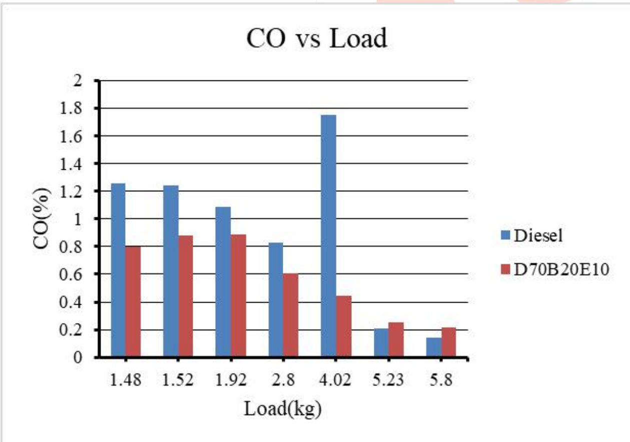

Figure 11 Variation of CO Emission with Engine Load

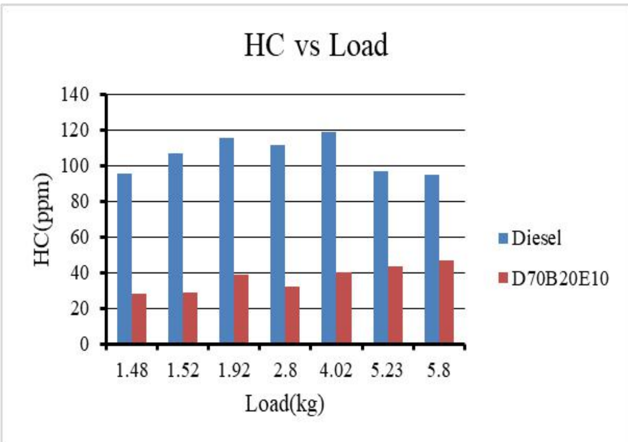

Figure 12 Variation of HC Emission with Engine Load

CO emission generally shows extent of incompleteness of combustion of fuel. The percentage variation of CO emission for the ternary blend and diesel is shown in Fig. 11. It was observed that CO emissions were decreased with increase in engine load for both fuels till 2.8 kg load. But at 4.02 at medium level load there's significance higher level of CO for diesel fuel. While it's been decreasing for ternary blend. As the proportion of ethanol increases there's lower CO emission from the engine. The variation of HC emission in parts per million for the ternary blend and diesel fuel with different loads are shown in Fig. 12. HC emission increased with increase in load on the engine for the diesel fuel. This was due to availability of less oxygen for the reaction when more fuel was injected into the engine cylinder at particular load. As there's slight level of decrement in HC emission at higher load. Unburned hydrocarbon emissions were remarkable for ternary blend at all loading conditions compare to diesel fuel because of increased gas temperature and higher cetane number of ternary blends. The higher cetane number of biodiesels resulted decrease in HC emission due to shorter ignition delay.

4.3 Comparison of PM Characteristics for Various Blends at varying loads

Particulate Matter is a complex mixture of elemental carbon, Sulphur compounds, a variety of HCs, and other species. It is a mixture of solid and liquid and mainly consists of carbon acetous material also known as-soot, sulphates and some absorbed organic compound. PM measurement was done on the engine for both of the fuel at varying load condition for all micron discs. Measurements were taken total 2 times for the better evaluation of PM characteristics which were also included in PM measurements. Variation of PM in unit of milligrams/m^3 for the size of 25µm, 10µm& 2.5µm at varying load is shown in as below

A) PM25 vs Load

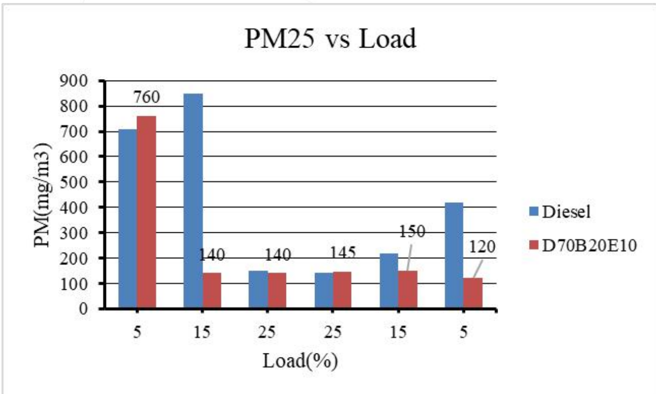

Fig 13 Variation of PM25 with Load

PM25 has the highest PM size among selected PM for fuels. Fig. 13 shows at starting condition of low load condition D70B20E10 having higher PM25 than diesel fuel. Which is due to high density of D70B20E10 than diesel fuel. Each fuel shows almost similar emission of PM25 at higher load condition. Most of the time PM25 for D70B20E10 is lower than diesel fuel at every load condition, which is a great result for D70B20E10 fuel.

B) PM10 vs Load

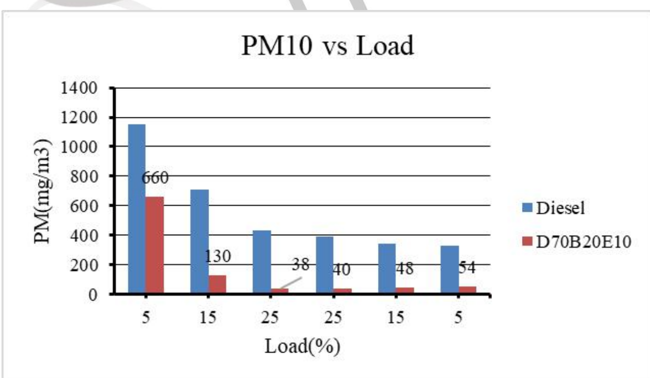

Figure 14 Variation of PM10 with Load

Fig. 14 shows PM10 variation against varying load condition. PM10 is decreasing for diesel fuel from low to high load condition. It clearly shows observation of PM10 in comparison of both the fuels. It's clearly observed that PM10 is quite low for D70B20E10 compare to diesel fuel at each and every load condition. It's been observed that at low load condition there's average reduction of 68%-70% in D70B20E10 blend. Average 83%-85% reduction at medium load while 90%-92% reduction at high load level observed in D70B20E10 blend.

C) PM2.5 vs Load

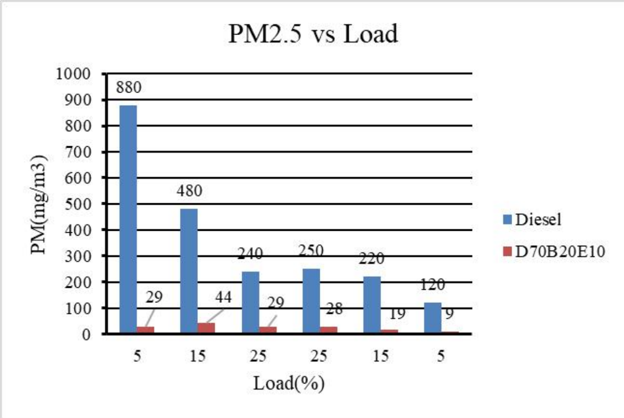

Figure 15 Variation of PM2.5 with Load

Figure 15 shows variation of PM2.5 against varying load for both the fuels. It's observed D70B20E10 had quite low emission of PM2.5 compared to diesel fuel at each and every load condition. It's observed that at low load condition PM2.5 reduced up to 93%-97% in D70B20E10 blend compare to diesel fuel. At medium load level it's reduced up to 91%- 93%, while 87%-88% reduction at high load. PM25 data analysis showed quite mix phenomenon for D70B20E10 emissions but PM2.5 and PM10 results showed that D70B20E10 blend have quite impactful emission performance to be an alternate fuel.

5.CONCLUSION

The results were obtained from calculations and graphical data from data analysis section. The conclusions may be summarized as follows:

❖ *For Performances*

- Specific Fuel Consumption for D70B20E10 was more than the diesel at all varyingloads.
- The Brake Thermal Efficiency for diesel was higher as compared to D70B20E10 atevery load condition.
- As load increased BP increased for both of test fuels. There was not any significantimprovement in BP in blend compare to diesel.
- Volumetric efficiency for D70B20E20 blend was lower than diesel fuel at all varyingload.
- At high load condition AFR for D70B20E10 is higher than diesel fuel.

❖ *For Emissions*

- NO_X emissions were higher for D70B20E10 blend till medium load compare to diesel fuel but as the load increased, NO_X emissions were found to be reduced about 44% at high load for D70B20E10 blend compare to diesel fuel.
- HC & CO_2 increased for all fuels in both conditions. But they are having lower valuein D70B20E10 blend emissions compare to diesel emissions.
- CO emissions reduced with increase in load for both of the fuels in varying load condition but D70B20E10 having lower CO emissions compare to diesel fuel.
- NO_X emission decreases at load increases, while HC emissions were reduced significantly. CO & CO_2 also decreasing for D70B20E10.

❖ *For PM*

- D70B20E10 showed very least emission of PM2.5 & PM10 compare to diesel fuel.
- While for PM25 it was mix response.
- Reduction in PM2.5 & PM10 for D70B20E10 fulfilling the objective and researchgap of this work.

6. FUTURE SCOPE

This research work has following scope for doing further research in future.

- Requirement of an aftertreatment can be investigated using proposed ternary fuelblend.
- Performance and regeneration characteristics of DPF can be investigated usingproposed fuel blend.
- Effect of PM by varying different injection pressure, injection timing, Compression Ratio can be investigated in CI engine.

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