Fish Oil Biodiesel as an Additive in Diesel-Ethanol Blends for a Four Stroke Single Cylinder Diesel Engine

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Abstract

The methyl esters of vegetable oils and animal fats are known as biodiesel and are becoming increasingly popular because of their low environmental impact and potential as a green alternative fuel for diesel engine and they would not require significant modification of existing engine hardware. In the same way the bioethanol-diesel fuel blends is becoming popular these days because of easy availability of bioethanol. But the bioethanol and diesel fuel are inherently immiscible because of their difference in chemical structures and characteristics, so an emulsifier or a co-solvent is needed to homogenize the diesel-bioethanol blends. The biodiesel offers an alternative application as an emulsifier for diesel and bioethanol blends. The present research is aimed to investigate experimentally the performance and exhaust emission characteristics of a diesel engine fuelled with conventional diesel fuel, fish oil biodiesel and the three blends of diesel-biodiesel-bioethanol in different percent volumes over the entire range of load.

Keywords: *Methyl Esters, Bioethanol, Emulsifier, Co-Solvent, Transesterification, Blends.*

I. INTRODUCTION

For the past few decades, a number of studies are focusing on the renewable fuels to reduce the reliance on petroleum fuels. A lot of effort has been made to reduce the dependency on petroleum fuels for power generation and transportation all over the world. Most of the developing countries like India import fossil fuels for satisfying their energy demand. The excessive usage of fossil fuels may leads to depletion of fossil fuels and environmental degradation like global warming. The present researchers have been focused on the biofuels as environment friendly energy source to reduce dependence on fossil fuels and to reduce environmental degradation.

The biofuels can play an important role towards the transition to a lower carbon economy and also combine the benefits of low green house emissions with the reduction of oil import. Bioethanol, biodiesel which may be obtained from plant or animal origin and to lesser extent pure vegetable oils are recently considered as most promising biofuels. Since 19th century, ethanol has been used as a fuel for diesel engines. Ethanol is a low cost oxygenated compound with high oxygen content (34.8%). Ethanol is an alcohol most often chosen because of the ease of production, can be obtained from various kinds of biomass such as maize, sugarcane, sugar beet, corn, cassava, red seaweed etc., relatively low-cost and low toxicity [1].

Among the proposed bio-fuels, biodiesel and diesohol have received much attention in recent years for diesel engines in transportation point of view. Moreover, the studies have shown that they are environmentally friendly because there is substantial reduction of unburned hydrocarbons, CO and particulate matter emission when it is used in conventional diesel engine. Diesel-ethanol blends are a more viable alternative and require little or no change in diesel engines. The use of diesel-ethanol blends can significantly reduce the emission of toxic gases and particulate matters when compared to pure diesel.

E. A. Ajav et al [2] studied the fuel properties of local ethanol blended with diesel with different ethanol percent by volume and the fuel properties were experimentally determined to establish their suitability for use in compression ignition engines. And some of the properties like relative density, viscosity, cloud and pour point, flash point and calorific value were determined. They found that, the blends with 5, 10, 15 and

20 percent ethanol content were found to have acceptable fuel properties for use as supplementary fuel in diesel engines.

Jincheng Huang et al [3] studied the performance and emissions of a diesel engine using ethanol-diesel blends. They showed that the thermal efficiencies of the engine fuelled by the blends were comparable with that fuelled by fossil diesel, with some increase of fuel consumption. They also found reduced smoke emissions, CO emissions above half loads.

Ozer Can et al [4] investigated the effects of ethanol addition to Diesel No. 2 on the performance and emissions of a four stroke cycle, four cylinders, turbocharged indirect injection diesel engine with different fuel injection pressures at full load. They showed that the ethanol addition reduces Carbon monoxide (CO), soot and Sulphur dioxide (SO_2) emissions, but increases Oxides of nitrogen (NOx) emissions.

However, ethanol and diesel fuel are inherently immiscible because of their difference in chemical structures and characteristics, the phase separation can be prevented in two ways. First is the addition of an emulsifier, which acts by lowering the surface tension of two or more substances and the second is the addition of a co-solvent, which acts by modifying the power of solvency for the pure solvent [5]. These two liquid fuels can be efficiently emulsified into a heterogeneous mixture of one micro-particle liquid phase dispersed into another liquid phase by mechanical blending in cooperation with suitable emulsifiers. The emulsifier would reduce the interfacial tension force and increase the affinity between the two liquid phases, leading to emulsion stability [6]. A suitable emulsifier for ethanol and diesel fuel is suggested to contain both emulsion of diesohol. Such chemical structures can be found in biodiesel, it is also reported that the presence of biodiesel or vegetable oil can improve the lubricating properties of diesel fuel [7, 8].

Biodiesels are used because of their similarity to diesel oil, which allows the use of biodiesel-diesel blends in any proportion. The biodiesel allows the addition of more ethanol-blended fuel, keeps the mixture stable and improves the tolerance of the blend to water, so that it can be stored for a long period. The large Cetane number of the biodiesel offsets the reduction of Cetane number from addition of ethanol to diesel, thus improving the engine ignition. The addition of biodiesel increases the oxygen level in the blend. Also biodiesel have lubricating properties that benefit the engine, and are obtained from renewable energy sources such as vegetable oils and animal fats. Similar to ethanol, biodiesel have a great potential for reducing emissions, especially particulate materials [9].

The above studies reveal that the diesel-ethanol-biodiesel blends can be used as alternative fuels for diesel engines. Recent research has shown that the use of diesel-ethanol-biodiesel blends can substantially reduce emissions of CO, total hydrocarbons (HC), and particulate matters (PM) [10]. The mixing of biodiesel and bioethanol with diesel significantly reduces the emission of particulate matter because the blended biofuel contains more oxygen [11].

Prommes Kwanchareon et al [12] studied the phase diagram of diesel–biodiesel–ethanol blends at different purities of ethanol and different temperatures. It was found that the fuel properties were close to the standard limit for diesel fuel except the flash point of blends containing ethanol was quite different from that of conventional diesel. The Cetane value, heating value of the blends containing lower than 10% ethanol was not significantly different from that of diesel. And also it was found that CO and HC emissions reduced significantly at high engine load.

Rakhi N Metha et al [13] studied the properties of petro-diesel blends with ethanol and butanol, where biodiesel as an amphiphile to stabilize the blends. They got the physical properties results such as density, kinematic viscosity, flash point, cold filter plugging point and surface tension, copper strip corrosion, oxidation stability and Cetane index, and all in accordance with the stipulated standard value with the only exception of flash points.

Hadirahimi et al [14] showed that the bioethanol and sunflower methyl ester can improve low temperature flow properties of diesel-ethanol-biodiesel blends due to very low freezing point of bioethanol and low pour point of sunflower methyl ester. The power and torque produced by the engine using diesel-ethanol-biodiesel blends and conventional fuel were found to be very comparable. The CO and HC emission concentration of diesel-ethanol-biodiesel blends decreased compared to the conventional diesel fuel and even diesel– biodiesel blends.

G. VenkataSubbaiah et al [15].investigated that the diesohol and ricebran oil methyl ester blends has highest brake thermal efficiency with 15% ethanol in diesel-biodiesel-ethanol blends. The exhaust gas temperature, carbon monoxide, smoke emissions and the sound intensity from the engine reduced with the increase of ethanol percentage in diesel-biodiesel-ethanol blends. The Hydrocarbons, Oxides of nitrogen and carbon dioxide emissions increased with the increase of ethanol percentage in diesel-biodiesel-ethanol blends but the hydrocarbon emissions were still lower than that of diesel fuel.
Xiaobing Pang et al [16] reported that the use of biodiesel-ethanol- diesel blends could slightly increase the emissions of

carbonyls and NOx but significantly reduce the emissions of PM and THC.

The above studies reveal that the diesel-biodiesel-ethanol blends reduce CO, HC, PM, smoke emissions and increase NOx emissions compared with the diesel fuel. There is a little research on the use of fish oil biodiesel in diesel-biodiesel-ethanol blends for diesel engines. In the present investigation the performance and emission characteristics of a diesel engine were studied by using 10% of fish oil biodiesel as an additive in the diesel-biodiesel-ethanol blends with 5%, 10% and 15% of ethanol and compared with that of the diesel fuel.

Fish oil is prepared from discarded parts of marine fish while manufacturing of fish products. During manufacturing process of fish products the parts of fish like viscera, fins, eyes, tails etc., are often discarded. The discarded parts of marine fish are frequently ground into fishmeal to provide food for livestock and have little economic value. However, the crude fish oil extracted from these discarded parts may provide an abundant, cheap, and stable source of raw oil to allow maritime countries to produce biodiesel and thus help to reduce fossil fuel consumption and pollutant emission [15].

II. MATERIAL AND METHODS

Crude fish oil is filtered through filter paper of 10 microns to remove suspended particles from crude fish oil. This oil was dried for removing the traces of moisture for 1 hour at 100˚C and then cooled to room temperature by closing the vessel to avoid re-attack of moisture from environment then were stored in PVC cans. By the standard titrometry method the acid number of crude fish oil was determined and it was 34 mg KOH/g oil. By the literature survey we came to know that, the presence of high FFA content (17%) in the crude fish oil, results in soap formation during the transesterification process, which decreases the final yield of the biodiesel. So three stage transesterification process which involved zero catalyzed tranesterification process followed by acid catalyzed transesterification and base catalyzed transesterification, finally water washing and moisture removing process has carried out to get pure biodiesel. The bio-ethanol of 99.5% pure was purchased and fuel properties such as density, viscosity, net heating value, acid value, flash point and fire point, of fish oil biodiesel and bioethanol were determined and as shown in the table 1.

Table 1: Properties of Fish Oil Biodiesel and Bioethanol.

Properties	Bio-Ethanol	Fish oil Methyl ester
Viscosity, mm^2/sec, at 40°C	1.35	4.5
Density at 15°C,g/cm^3	0.78	0.882
Calorific Value, KJ/kg	27000	40839
Flash Point,°C	13.5	152
Fire point, °C	22	160
Acid value, mgKOH/g	--	0.7

The experimental set up consists of a diesel engine, engine test bed, fuel and air consumption metering equipments, Exhaust gas analyzer and smoke meter. The schematic diagram of the engine test rig is shown in Figure 1.

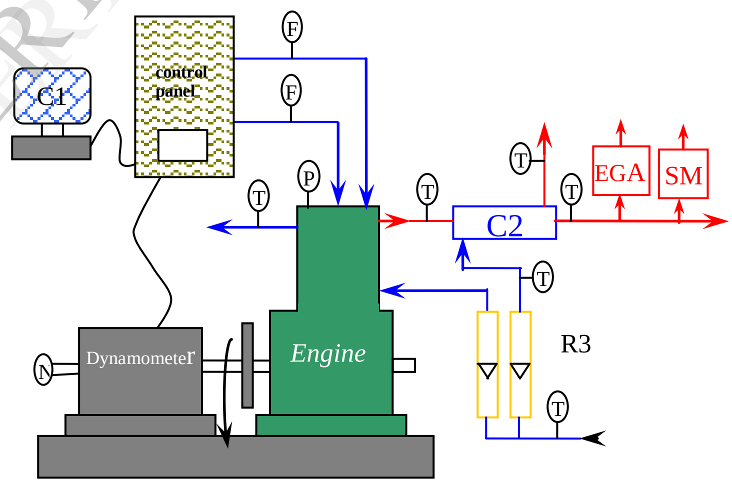

Fig 1: Diesel Engine Test Rig

Where,C1= Computer, C2= Calorimeter, R3= Rotometer, T1,T3= Inlet Water Temperature,T2= Outlet Engine Jacket Water Temperature, T4= Outlet Calorimeter Water Temperature, T5= Exhaust Gas Temperature Before Calorimeter, T6= Exhaust Gas Temperature After Calorimeter, F1= Fuel Flow DP(Differential Pressure) Unit, F2= Air Intake DP Unit, PT= Pressure Transducer, Wt= Load, N= RPM Decoder, EGA= Exhaust Gas Analyzer (5 Gas), SM=Smoke Meter.

Table 2: The specifications of the diesel engine used

SL NO	PARAMETERS	SPECIFICATION
1	Type	TV 1 (Kirloskar made)
2	Nozzle opening pressure	200 to 225 bar
3	Governor type	Mechanical centrifugal type
4	Number of cylinders	Single cylinder
5	Number of strokes	Four stroke
6	Fuel	Diesel
7	Compression ratio	16.5:1
8	Cylinder diameter (Bore)	80mm
9	Stroke length	110mm
Electrical dynamometer		
10	Type	Foot mounted, continuous rating
11	Alternator rating	3KVA
12	Speed	2800-3000RPM
13	Voltage	220 V AC

III. EXPERIMENTAL WORK

The engine was first operated on diesel fuel with no load for few minutes at rated speed of 1500 rpm until the cooling water and lubricating oil temperatures reaches to 85^0 C. The same temperatures were maintained throughout the experiment with all the fuel modes. The required readings pertaining to diesel fuel were taken down for different load conditions. The diesel fuel was replaced with the fish oil biodiesel (B100) and test was conducted by varying the loads in the same manner. After the fish oil biodiesel, three diesel- biodiesel-ethanol blends were prepared consisting of 85% diesel, 10% biodiesel and 5% bioethanol (DE5B10), 80% diesel, 10% biodiesel and 10% bioethanol (DE10B10), and 75% diesel, 10% biodiesel and 15% bioethanol (DE15B10). Here direct blending method was used in this test. The tests were conducted with these three blends by varying the load on the engine.

The brake power was measured by using an electrical dynamometer. The fuel consumption was measured by using a fuel tank fitted with a burette and a stop watch. The performance parameters such as brake thermal efficiency, brake specific fuel consumption and brake specific energy consumption were calculated from the observed values. The exhaust gas temperature was measured by using an iron-constantan thermocouple. The exhaust emissions such as carbon monoxide, Carbon dioxide, Nitrogen oxides, hydrocarbons and unused Oxygen were measured by QROTECH-QRO 401 exhaust gas analyzer and the smoke opacity by AVL smoke meter 437C for diesel fuel, biodiesel and three diesel-biodiesel-ethanol blends separately under all load conditions. The results from the engine with fish oil biodiesel and three diesel-biodiesel-ethanol blends were compared with diesel fuel at rated speed of 1500 rpm.

IV. RESULTS AND DISCUSSION

A. Performance Characteristics

The results obtained pertaining to the performance of the engine is demonstrated with the help of graphs.

Brake Thermal Efficiency

The variation of brake thermal efficiency with load for diesel fuel, biodiesel and diesel-biodiesel-ethanol blends (DE5B10, DE10B10 and DE15B10) is as shown in the Fig 2

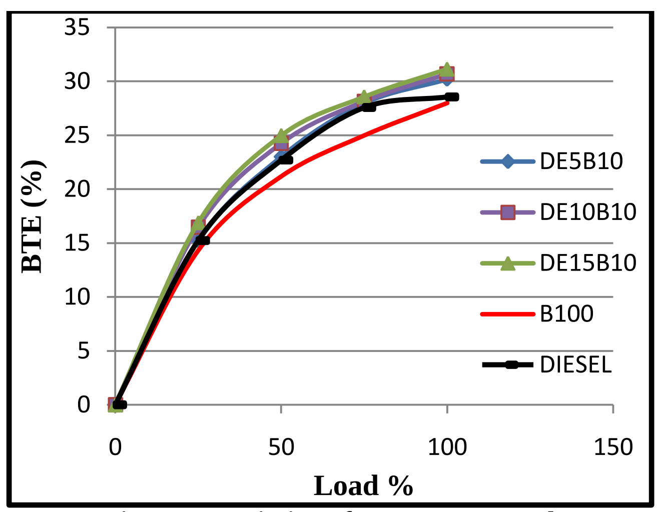

Figure 2. Variation of BTE % vs Load

The brake thermal efficiency increased with load for all fuel modes. The brake thermal efficiency of fish oil biodiesel (B100), diesel and blends of 10% biodiesel with different % volume of ethanol (5%, 10% and 15%) is as shown in the graph. The brake thermal efficiencies of all diesel-biodiesel-ethanol blends were higher than that of the conventional diesel fuel over the entire range of the load. The reason may be the extended ignition delay and the leaner combustion of biodiesel, resulting in a larger amount of fuel burned in the premixed mode of the ethanol blends. The brake thermal efficiency was increased by 7.22%, 8.76% and 10.11% respectively with 5%, 10% and 15% of ethanol in diesel-biodiesel-ethanol blends compared with the blend B100 at the maximum load. The brake thermal efficiencies of DE5B10, DE10B10, and DE15B10 are 10.53%, 12.02% and 13.32% are higher than the diesel at maximum load. The maximum brake thermal efficiency was observed with DE15B10 at all the loading conditions of the diesel engine and it was 13.32% and 10.11% higher than that of diesel fuel and B100 respectively at full load of the engine. It may be due to the reduction in the density and viscosity of the fuel by the addition of ethanol [15].

Brake Specific Fuel Consumption

The variation of brake specific fuel consumption with load for diesel fuel, biodiesel and diesel-biodiesel-ethanol blends (DE5B10, DE10B10 and DE15B10) is as shown in the Fig 3.

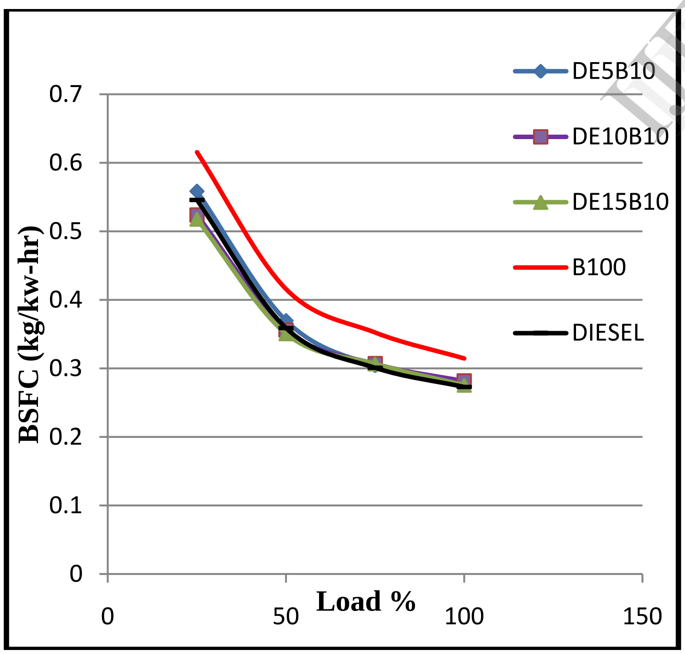

Figure 3. Variation of BSFC vs Load

The BSFC reduced with load for all the fuel modes. The BSFC of B100 is 14% higher than that of the diesel fuel at full load of the engine. The BSFC increased by 4.28%, 7.58% and 10.66% respectively with the blends DE5B10, DE10B10 and DE15B10 compared with diesel. The BSFC increased with the increase of ethanol percentage in the diesel-biodiesel-ethanol blends at all loading conditions of the engine. It is due to the lower heating values of biodiesel and ethanol compared with diesel fuel. The highly oxygenated ethanol blending into the blends leads to leaner combustion resulting in higher BSFC [3].

Brake Specific Energy Consumption

The variation of brake specific energy consumption with load for diesel fuel, biodiesel and diesel-biodiesel-ethanol blends (DE5B10, DE10B10 and DE15B10) is as shown in the Fig 4.

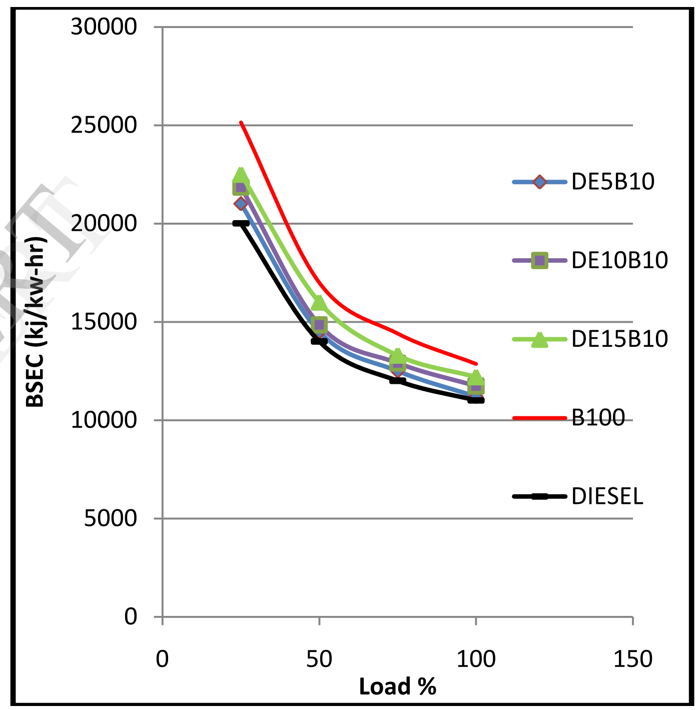

Figure 4 Variation of BSEC vs Load

Brake specific energy consumption (BSEC) is an ideal variable because it is independent of the fuel. Hence, it is easy to compare energy consumption rather than fuel consumption. In all cases, it decreased sharply with increase in percentage of load for all fuels. The main reason for this could be that the percent increase in fuel required to operate the engine is less than the percent increase in brake power, because relatively less portion of the heat is lost at higher loads. The BSEC for all blends was higher than that of diesel. This trend was observed due to lower calorific value, with increase in biodiesel and ethanol percentage in blends. Same decreasing trend of BSEC with increasing load in different biodiesel blends were also reported by some researchers [17] while testing biodiesel obtained from karanja oil. The BSEC of DE5B10, DE10B10 and DE15B10 are 1.78%, 6.23% and 9.83% more respectively, when compared with diesel. And the BSEC of B100 is14.4% more than diesel at maximum loads.

Exhaust Gas Temperature

The variation of exhaust gas temperature with load for diesel fuel, biodiesel and diesel-biodiesel-ethanol blends (DE5B10, DE10B10 and DE15B10) is as shown in the Fig 5.

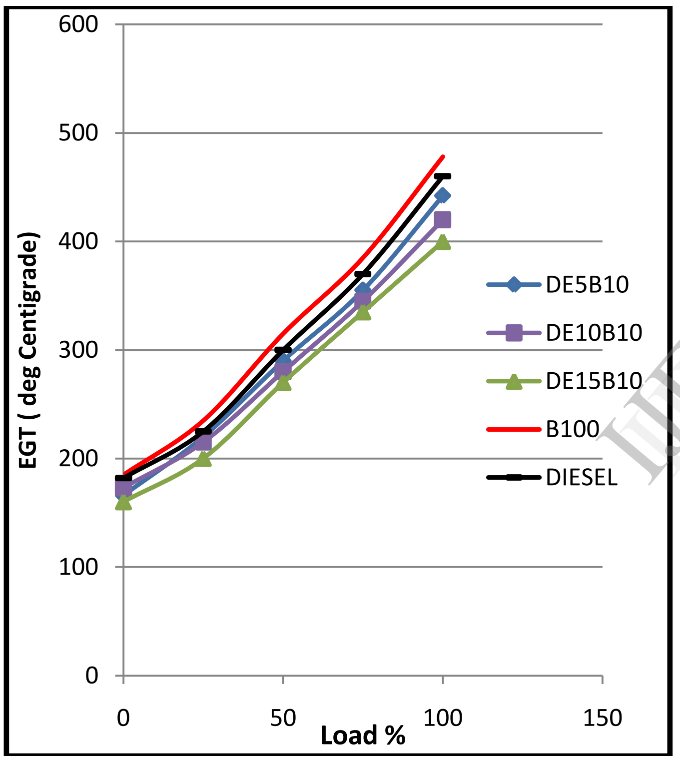

Figure 5. Variation of EGT vs Load

The exhaust gas temperature increased with the load for all the fuels. The exhaust gas temperature of the blend B100 was 3.76% higher than that of diesel fuel. The increase of the ethanol percentage in the diesel-biodiesel-ethanol blends reduced the exhaust gas temperature. And it was 3.91%, 8.69% and 13.04% lesser than that of the diesel respectively with the blends DE5B10, DE10B10 and DE15B10; it is due to the advanced fuel injection. The decrease in exhaust temperatures with increased ethanol concentration is due to the high evaporative heat and low heating values of ethanol, which takes off the heat from combustion space.

B. Emission Characteristics

Carbon-dioxide emission

The variation of carbon dioxide emission with load for diesel fuel, biodiesel and diesel-biodiesel-ethanol blends (DE5B10, DE10B10 and DE15B10) is as shown in the Fig 6.

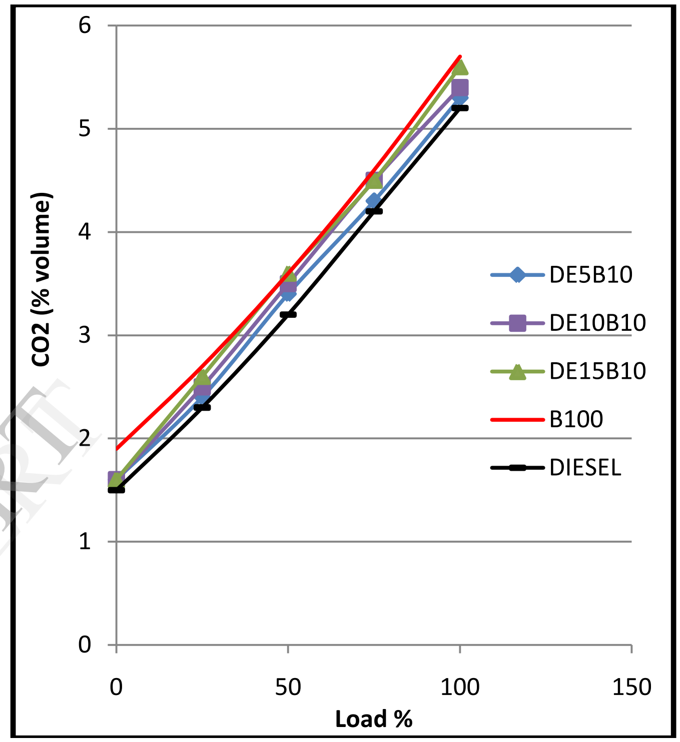

Figure 6. Variation of CO_2 vs Load

The CO_2 emissions increased with load for all the fuel modes. The CO_2 emissions of B100, DE5B10, DE10B10 and DE15B10 were slightly higher than those of diesel fuel. The CO_2 emissions increased by 1.88%, 3.7% and 7.14% respectively with 5%, 10% and 15% of ethanol in diesel-biodiesel-ethanol blends compared to diesel at maximum load condition. And also the carbon dioxide emission of B100 increases a value of 8.7 % when compared to diesel at maximum load condition.

Hydro-Carbon emissions

The variation of hydro-carbon emissions with load for diesel fuel, biodiesel and diesel-biodiesel-ethanol blends (DE5B10, DE10B10 and DE15B10) is as shown in the Fig 7.

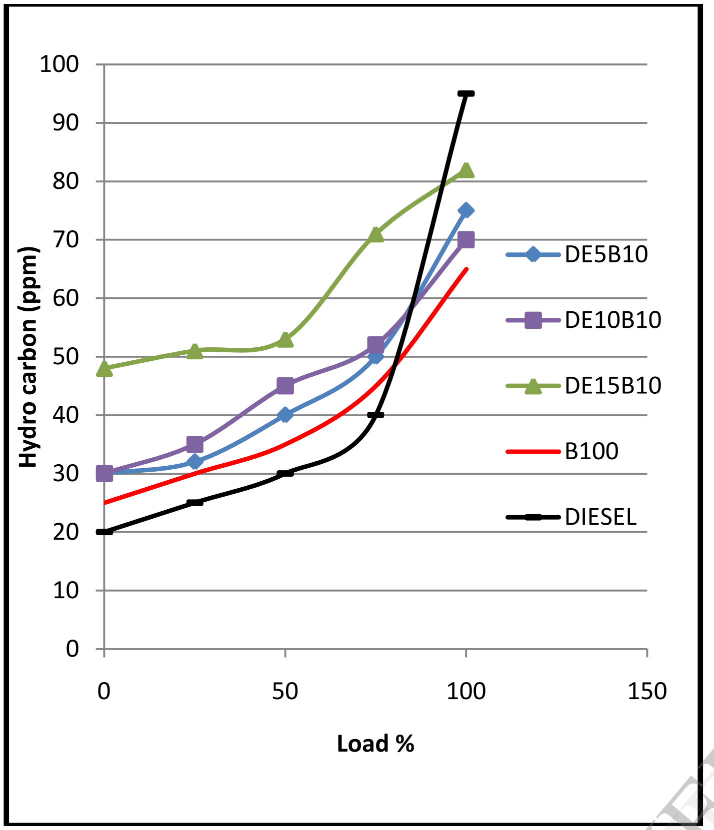

Figure 7. Variation of HC vs Load

The HC emissions were minimum at medium load and maximum at full load of the engine for all the fuel modes. The HC emissions of the pure biodiesel and diesel-biodiesel-ethanol blends were higher at low and medium loads and significantly lower at higher loads than those of diesel fuel. It is due to the better combustion achieved at a medium speed and with a medium sized load. The HC emissions increased with increase of ethanol percentage in the diesel-biodiesel-ethanol blends. Higher HC emission means that there is some unburned ethanol emitted in the exhaust due to the larger ethanol dispersion region in the combustion chamber. The HC emissions were 21%, 26.31% and 13.68% lower than those of diesel fuel with 5%, 10% and 15% of ethanol addition at full load of the engine. Among these blends, the blend of 85% diesel, 10% biodiesel and 5% ethanol had the lowest HC emissions at the full load of the engine. The pure biodiesel produced lowest HC emissions among all fuels and were 31.57% lower than those of diesel fuel.

Oxides of nitrogen emission

The variation of oxide of nitrogen with load for diesel fuel, biodiesel and diesel-biodiesel-ethanol blends (DE5B10, DE10B10 and DE15B10) is as shown in the Fig 8

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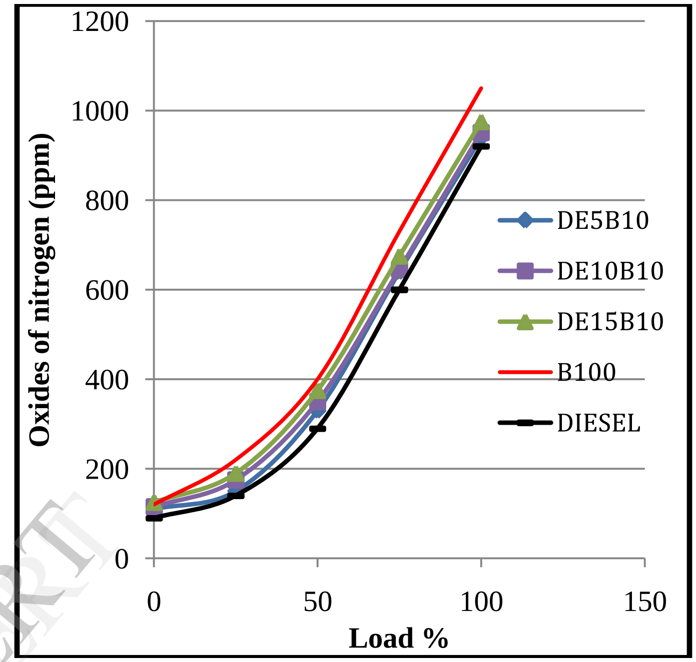

Figure 8. Variation of NO_X vs Load

The NOx emissions of biodiesel, and diesel-biodiesel-ethanol blends goes on increasing and it is more at medium and high loads than those of diesel fuel. It is due to the higher oxygen content and combustion temperature of the biodiesel and the ethanol at medium and high loads. The NOx emissions increased with the increase of ethanol percentage in diesel-biodiesel-ethanol blends. The NOx emissions of DE5B10, DE10B10 and DE15B10 were 2.12%, 3.25% and 5.64% higher than diesel at full load of the engine. The oxide of nitrogen emission of B100 goes on increasing and it is 12.38% higher than the diesel.

Carbon-monoxide emission

The variation of carbon monoxide with load for diesel fuel, biodiesel and diesel-biodiesel-ethanol blends (DE5B10, DE10B10 and DE15B10) is as shown in the Fig 9.

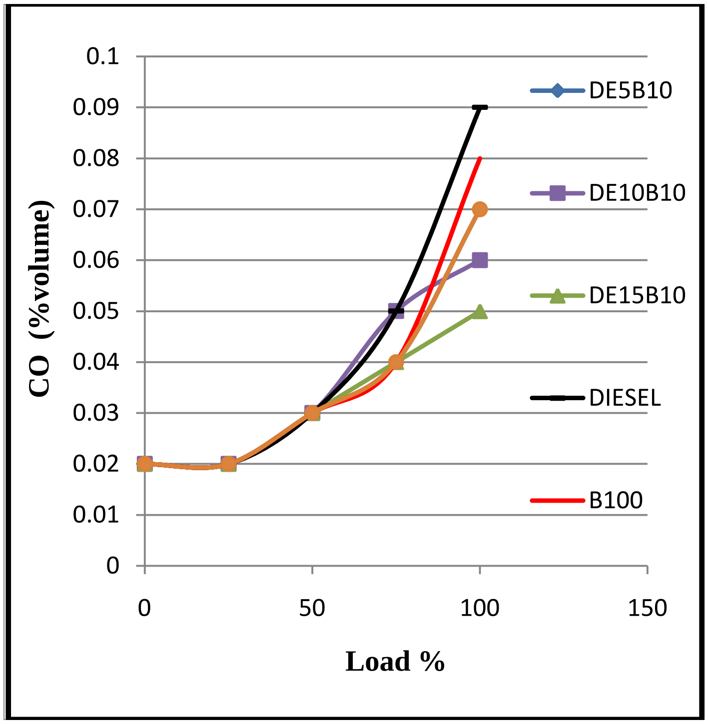

Figure 9. Variation of CO vs Load

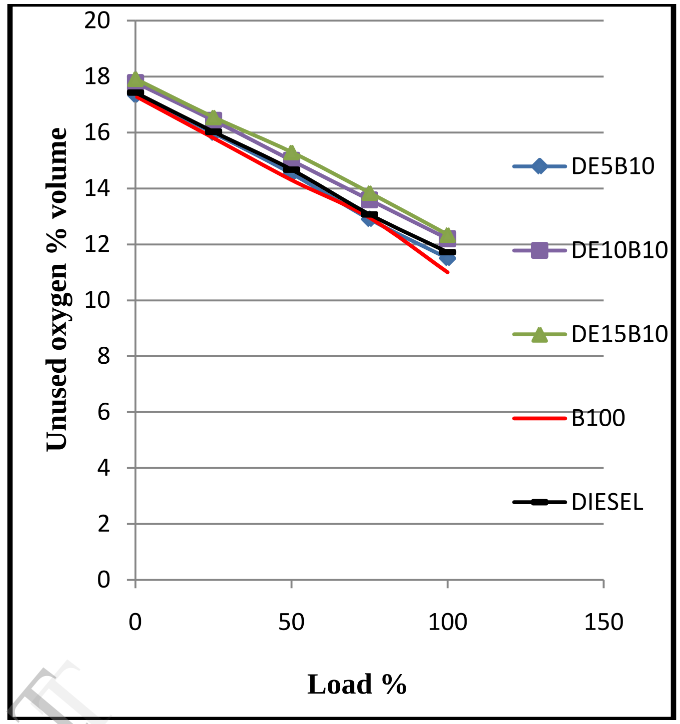

Figure 10. Variation of O_2 vs Load

The CO emissions slightly increased at low and medium loads and increased significantly at higher loads with all the fuel modes. The CO emissions of the diesel-biodiesel-ethanol blends were not much different from that of conventional diesel at low and medium loads as shown in the figure. However, the CO emissions of these blends decreased significantly, when compared with those of conventional diesel at full load of the engine. This is due to the higher amount of oxygen with the ethanol and biodiesel addition, which will promote the further oxidation of CO during the engine exhaust process. The results showed that the CO emissions reduced with increase of ethanol percentage in the diesel-biodiesel-ethanol blend. The CO emissions reduced by 25%, 37.5% and 50% than the conventional diesel with the addition of 5%, 10% and 15% of ethanol in diesel-biodiesel-ethanol blends at maximum load condition.

Unused oxygen emission

The variation of Unused Oxygen (O_2) emissions with load for diesel fuel, biodiesel and diesel-biodiesel-ethanol blends (DE5B10, DE10B10 and DE15B10) is as shown in the Fig 10.

The unused oxygen emissions reduced with load for all the fuel modes. The unused O_2emissions of biodiesel is 6.14% lower than those of diesel fuel. The O_2 emissions reduced with 5% addition of ethanol and increased with 10% and15% of ethanol in diesel-biodiesel-ethanol blends. The O_2 emissions reduced by 1.87% with the blend DE5B10 and increased by 3.93% and 5.10% respectively with the blends DE10B10 and DE15B10 at the maximum load of the engine.

Smoke opacity

Smoke opacity was determined with AVL Smoke analyzer as per ASTM Standards. The AVL Smoke analyzer is a filter-type smoke meter for measuring the soot content in the exhaust of diesel engines. The variable sampling volume and thermal exhaust conditioning assures wide applications. The variation of smoke opacity with load for diesel fuel, biodiesel and diesel-biodiesel-ethanol blends (DE5B10, DE10B10 and DE15B10) is as shown in the Fig 11.

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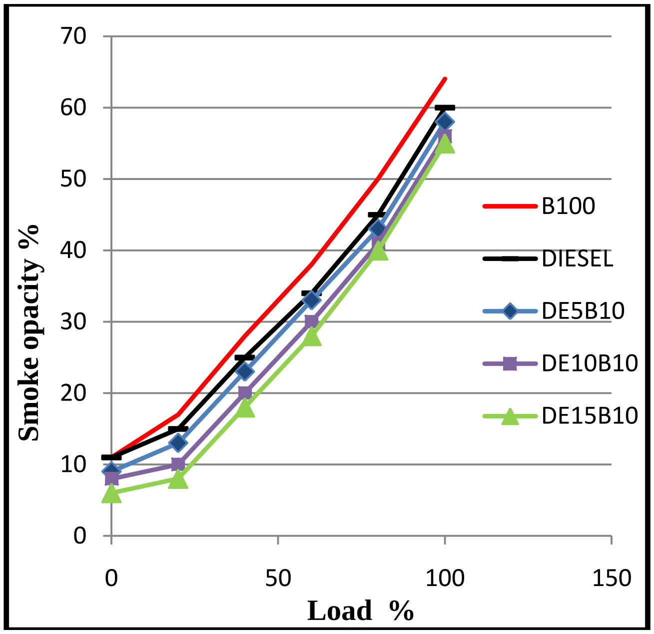

Figure 11. Variation of Smoke opacity vs Load

The smoke opacity increased with the load for diesel fuel, biodiesel and diesel-biodiesel-ethanol blends. The smoke opacity of the pure biodiesel was higher than those of all the other fuels used in this test. The smoke opacity of biodiesel was 13.88% higher than that of diesel fuel at full load of the engine. The smoke Opacity reduced with increase of ethanol percentage in diesel-biodiesel-ethanol blends. The smoke opacity of the blend DE5B10 higher with the blends DE10B10 and DE15B10 respectively 6.98% and 11.29% lower than that of the diesel fuel at the full load of the engine.

V. CONCLUSIONS

The performance and emission characteristics of conventional diesel, fish oil biodiesel, and diesel-biodiesel-ethanol blends were investigated on a single cylinder diesel engine. The conclusions of this investigation are as follows:

- The maximum brake thermal efficiency of 13.32% higher than diesel fuel and 10.11% higher than fish oil biodiesel was observed with the blend DE15B10.
- The BSFC of the biodiesel and all the other fuel blends was higher than that of the diesel fuel.
- The exhaust gas temperatures of the blends were lower than that of diesel fuel throughout the range of the load on the engine. The maximum reduction of 13.04% than that of the diesel with the blend DE15B10 was observed.
- The CO emissions reduced by 50% than the conventional diesel with the blend of DE15B10 were observed at the maximum load of engine.
- The HC emissions increased with the increase of ethanol percentage in diesel-biodiesel-ethanol blends, but lower than those of the diesel at higher loads on the engine.
- The NOx emissions of the biodiesel and all the other fuel blends were low at lower loads and high at higher loads compared with the diesel fuel.
- The O_2 emissions reduced by with the blend DE5B10 and increased with the blends DE10B10 and DE15B10 at the maximum load of the engine.
- Smoke opacity is found to increase in B100 and fossil diesel, and as the percent of ethanol increases in the blends the smoke opacity decreased.

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