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PERFORMANCE EVALUATION OF DIESEL ENGINE WITH OXYGENATED BIO-FUEL BLENDS

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ABSTRACT

The use of oxygenated bio-fuels like bio diesel and ethanol in combination with diesel is an effective measure to substitute renewable fuels and reduce particulate matter (PM) from in-use diesel vehicles. To study the fuel performance, three oxygenated blend fuel designs containing volumes of 15% ethanol with cetane improver additive, 10% ethanol with 10% bio diesel and 15% ethanol with 20% bio diesel were formed. The physical stability of ethanol diesel blend is studied and phase separation is prevented by adding co solvents like Tetrahydrafuran and bio diesel. To meet stricter emission norms, now diesel engines are fitted with after treatment devices. This paper describes the engine and emission characteristics of the above blend fuels on a 4 cylinder, naturally aspirated light duty diesel engine fitted with diesel oxidation catalyst. The engine test results show that it is feasible to use these blends in diesel engines: the thermal efficiencies of the engine fueled by the blends are comparable with that fueled by diesel, with small increase in fuel consumption, due to the lower heating value of ethanol and bio diesel. The smoke emissions from the engine fueled by the blends are lower than that fueled by diesel owing to the increased oxygen content. The reduction is more at higher loads. The HC and CO emissions are found to be higher at lower loads due to the lower cetane number of ethanol. However, NO emissions depend on load conditions and blend contents.

Keywords: diesel engine, emission, biofuel, renewable fuel.

1. INTRODUCTION

In the context of higher crude oil price and vehicular pollution search for renewable sources of energy and cleaner technologies has become significant. The agreement to reduce CO_2 emission has a great effect on automotive sector. Diesel engines provide important transportation power sources which are receiving additional attention due to their superior fuel economy and lower green house gas emissions. However, diesel engines have the problem of emitting more amount of particulate matter (PM) due to its heterogeneous combustion. Diesel emission control is a function of combustion improvement, fuel formulation and after treatment devices [1]. Combination of fuel formulation and add on after treatment device is effective for control of emissions from in-use diesel engines.

In general, it has been recognized that the addition of oxygenated blend components to diesel fuel will result in lower particulate emissions under many operating conditions. Since ethanol (35% of oxygen content) is widely available oxygenate with long history of use in gasoline blends it has also been considered as a potential oxygenate with diesel fuel. The particulate matter reduction appeared to be related to the amount of oxygen content in the fuel blends [2, 3, 4]. Mixing up to 15% (vol) of ethanol with diesel is the easiest method to use ethanol in diesel engines. But the ethanol solubility in diesel is one of the difficulties of using ethanol in them. Solubility can be increased by adding co solvent or emulsifier to produce a homogeneous blend. Researchers identified co solvent like Tetrahydrofuran and emulsifier like bio diesel can be used for preserving diesel ethanol blends [5, 6]. Ethanol has a very low cetane number that reduces the cetane number of ethanol-diesel blend. Hence cetane improvers are required to increase the combustion behavior of diesel-ethanol blend. An octyl nitrate (2-EHN) is used as cetane improving additive for diesel fuel in petroleum refineries. The same can be used to increase cetane value of ethanol-diesel blend.

Bio diesel is an alkyl ester of fatty acids made from a wide range of vegetable oils, animal fat and used cooking oil via the transesterification process. Bio diesel can be directly used in diesel engines, or mixed with any proportion of mineral diesel [7]. Blending bio diesel and ethanol into a conventional diesel fuel dramatically improved the solubility of ethanol in diesel fuel over a wide range of operating temperature. The high viscosity of bio diesel can also compensate for the decreased viscosity caused by the presence of ethanol in the ethanol-diesel blend. The addition of ethanol and bio diesel to the diesel raises the total oxygen content in the blend fuel.

With an increase of ethanol in diesel fuel, there is a reduction in smoke and particulate matter, an increase in total hydrocarbon, CO and NOx could increase or decrease depending on the engine type and operating conditions [8]. Diesel oxidation catalysts installed on a vehicle’s exhaust system oxidizes CO, HCs, and the soluble organic fraction of particulate matter in to carbon dioxide and water. The advancements made in the developments of diesel oxidation catalyst that can operate with high-sulfur fuel without significant SO_2 formation and low light off temperature provides cost effective, low maintenance and emission control with regular diesel fuel (high sulfur content) in developing countries [9,10].Based on this background, main purpose of this research is to compare the engine performance and emission characteristics when diesel engine fitted with diesel oxidation catalyst is fueled with oxygenated bio fuel blends.

2. ETHANOL RESOURCES IN INDIA

India is the second largest producer of sugarcane in the world and ethanol is mainly derived from sugarcane molasses which is by-product in the conversion of sugarcane into sugar. Therefore, ethanol does not compromise on the food security front in India. On the total sugar cane production in India, 60% is utilized for sugar production by sugar mills. At present conditions also, 25-30% of sugar cane produced is processed for production of unrefined sugar [11]. On an average basis one ton of sugar cane yields 100 kg of sugar and 45 kg of molasses. This molasses can produce 11 Liters of ethanol on fermentation. While producing unrefined sugar in cottage industries appreciable amount of molasses are produced as by-product and mostly dumped as waste. These molasses can be utilized for bio ethanol production.

3. EXPERIMENTAL PROGRAM

The experimental part is carried out in two phases. In the first phase, phase stability of bio fuel blends is tested. And then the fuel blends are used to run a diesel engine to test its performance and emissions characteristics with diesel oxidation catalyst as after treatment device.

3.1 Studies on blend stability

The phase stability of various blends is shown in Figure-1. At warm ambient temperatures (~30ºC) until anhydrous ethanol content reaches 10% volume, readily blends with diesel. When ethanol content exceeds 10% volume, the blend starts separation. In this study, addition of co-solvent Tetrahydrofuran of volume 1-2% result in single phase, homogeneous clear liquid with 15-20% volume ethanol content in the diesel. The addition of bio diesel of 5% volume in the diesel ethanol blend also produces single phase, homogeneous liquid. From this, it have been concluded that the homogeneity requirement of diesel fuels can be met with use of co-solvent or bio diesel.

3.2 Test engine and fuels

The engine under study is a four cylinder, natural aspirated diesel engine whose major specifications are shown in Table-1. A commercially available diesel oxidation catalyst is retrofitted to the engine exhaust system. The engine was coupled to an eddy current dynamo meter through which load was applied. The AVL Di gas 444 emission analyzer was used to measure the concentration of NO, HC, CO and the smoke opacity was measured using AVL Smoke meter. The exhaust temperature was measured with thermo couple.

Figure-1. Phase stability.

The regular diesel fuel and analysis grade anhydrous ethanol (99.5% purity) were used in this test. Considering the resource availability, the non-edible and underutilized vegetable oil from honge tree (whose Botanical name is *Pungamia pinnata*) in India is selected for biodiesel conversion [11]. The Table-2 shows the important properties of diesel, ethanol and bio diesel. In current study, three kinds of bio fuel blends containing volumes of 15% ethanol with 0.75% 2-EHN as cetane improver (denoted as E15+CI), 10% ethanol with 10% biodiesel (denoted as E10B10) and 15% ethanol with 20% bio diesel (denoted as E15B20) were formed. The viscosity of diesel-ethanol blend is less in comparison with diesel. Increasing ethanol and bio diesel percentage in blended fuels also increases the oxygen content of the fuel and decreases the heating value of the fuel. Without any modification on engine parameters, the brake specific fuel consumption, exhaust emissions including smoke opacity, CO, NO and HC are measured at different load conditions with engine speed of 2000 rpm when diesel engine is fueled with oxygenated diesel blend fuels and compared to the baseline diesel fuel.

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Table-1. Engine specifications.

Cylinder bore	83 mm
Stroke	90 mm
Displacement	1948 cc
Maximum power	45 kW at 4500 rpm
Maximum torque	105 N-m at 2500rpm
Compression ratio	22.5: 1

Table-2. Fuel properties.

Properties	Diesel	E15+CI	E10B10	E15B20
Diesel (% vol)	100	83	80	65
Ethanol (% vol)	0	15	10	15
Biodiesel (% vol)	0	0	10	20
Density (kg/m^3)	840	833	839	841
Viscosity (mm^2/s, 40°C)	3.18	2.64	3.03	3.14
Lower heat value (MJ/kg)	42.5	40.1	40.6	39.0
Oxygen content (Wt %)	-	5.18	4.55	7.38
Cetane Index	48	47.5	46.6	45.8

4. RESULTS AND DISCUSSIONS

4.1 Fuel consumption and thermal efficiency

Figures 2 and 3 show the brake specific fuel consumption (BSFC) and brake specific energy consumption (BSEC) versus engine load for ethanol-diesel blend with cetane improver, ethanol-biodiesel-diesel blends and pure diesel fuel. The comparison of brake specific energy consumption is representative of brake thermal efficiency. It is clear from the Figure that as the load increases, the BSFC decreases and brake thermal efficiency increases for all fuels. At the same time, it can be seen that the BSFC for E15+CI, E10B10 and E15B20 blend fuels are slightly higher, but the brake specific energy consumption is closely similar to that of diesel. These behaviors are reasonable because the oxygenated blends have low calorific value compared to that of diesel fuel. The improvement in energy consumption is due to better combustion on account of oxygen enrichment.

4.2 Exhaust gas temperature

Figure-4 shows the exhaust gas temperature for the pure diesel fuel, ethanol-diesel blend fuel and ethanol-biodiesel-diesel blend fuels for various loads. It is observed that for all bio fuel blends, the temperature is very slightly lower than for pure diesel operation. This due the higher latent heat of evaporation of the ethanol blends compared with that for the diesel fuel. This will have some effect on the conversion efficiency of diesel oxidation catalyst at low load operating conditions.

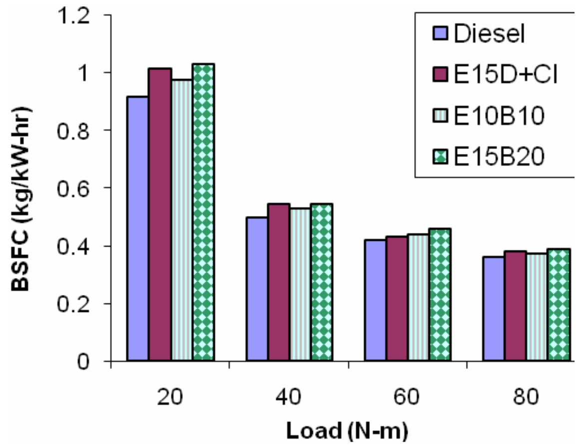

Figure-2. Brake specific fuel consumption.

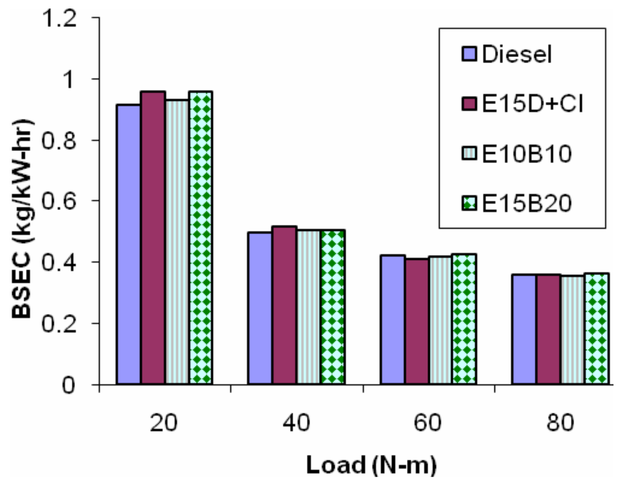

Figure-3. Brake specific energy consumption.

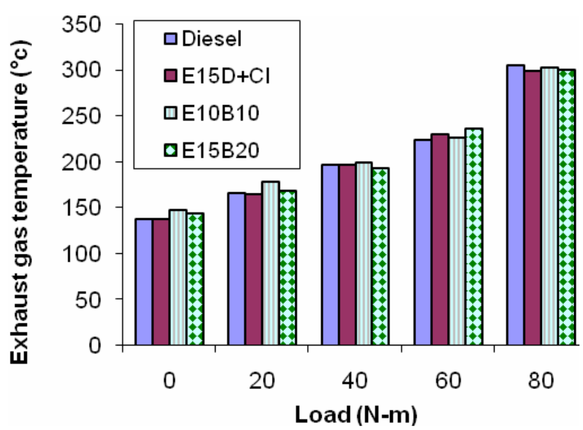

Figure-4. Exhaust gas temperature**.**

4.3 Emission characteristics

Figure-5 shows the smoke emission at various load of the engine with diesel oxidation catalyst in the exhaust system. It is seen that the smoke emission increases with increasing of load. The smoke emission

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significantly lowered for oxygenated blend fuels compared to diesel fuel, with the reduction being higher for the E15B20 blend fuel. The reduction is due to the increase of oxygen content to 7.38% for E15B20. As it is important to control smoke emission at higher loads from diesel engines, oxygenated bio fuel blends are effective in this regard. This is because of the availability of fuel-bound oxygen in the ethanol and biodiesel even in locally rich zones of combustion. Addition of after treatment device diesel oxidation catalyst is also responsible for reduction of smoke emission. This is due to oxidation of carbon soot particle by the oxidation catalyst.

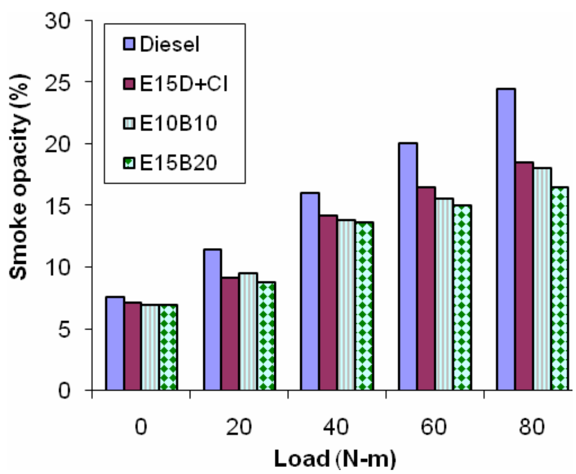

Figure-5. Smoke emission.

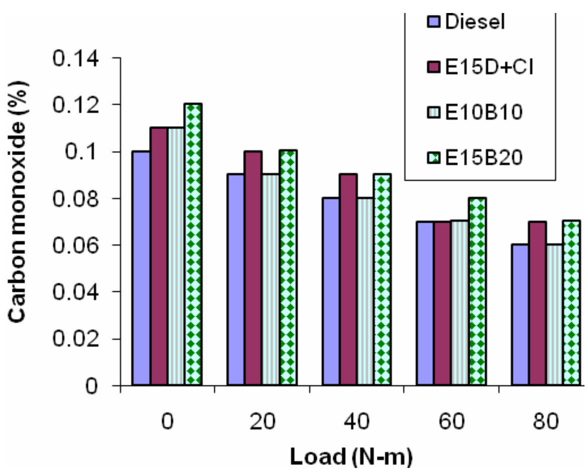

Figure-6. Carbon monoxide emission.

Figure-6 illustrates the carbon monoxide (CO) emissions versus engine load for pure diesel, E15+CI, E10B10 and E15B20 fuels. For blend fuels, CO emission slightly increases with that of diesel. The factors causing combustion deterioration such as high latent heat of evaporation of ethanol could be responsible for the increased CO emissions.

It is found that the HC emissions have increased for ethanol blended fuels compared with base diesel fuel at lower load conditions as shown in Figure-7. But at higher load conditions HC emission is same for ethanol-biodiesel-diesel blend fuels. It is also noted that increase in ethanol content in blend fuel increases HC emission. This is due to lower cetane number of ethanol compared with diesel.

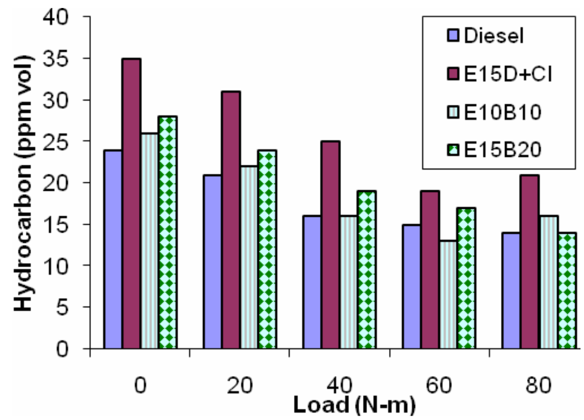

Figure-7. Hydrocarbon emission.

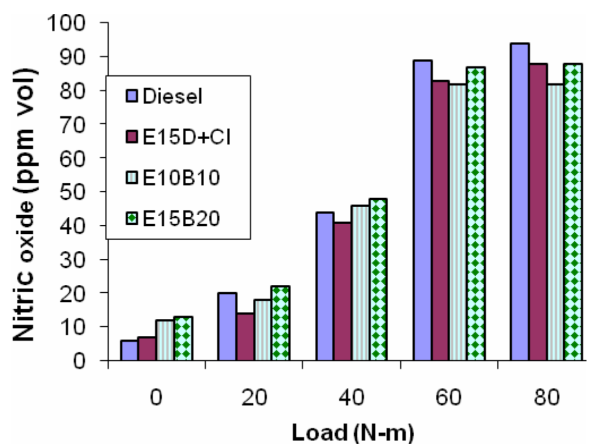

Figure-8. Nitric oxide emission.

The NO emissions of diesel engine fueled with ethanol-diesel blend and ethanol-biodiesel-diesel blend fuels for various loading conditions are given in Figure-8. The NO emission increases with increase in engine load and tend to reduce when ethanol is added to diesel fuel. The NO emission depends on peak combustion temperature, high temperature duration and oxygen concentration in the air-fuel mixture. The combined effect of this factors influence the NO emissions of diesel engine fueled with oxygenated blends. The addition of ethanol in to diesel helps in simultaneous control of both nitric oxide and smoke emission from diesel engines.

5. CONCLUSIONS

The effects of addition of bio ethanol and biodiesel in to diesel fuel on the engine performance and emission characteristics of the four cylinder light duty diesel engine have been investigated and compared to the baseline diesel fuel. The main results can be obtained as follows:

a) Ethanol-biodiesel-diesel blends have similar viscosity as diesel and good phase stability than ethanol-diesel blend;
b) The BSFC slightly increased due to the lower energy content of ethanol and the brake thermal efficiency improved with respect to base diesel;
c) The smoke and NO emission decreased simultaneously when oxygenated diesel blends are used in diesel engines;
d) CO emission and HC emission is slightly increased at lower loads compared with diesel;
e) Diesel fuel formulation with oxygenated bio fuels can reduce particulate emission from diesel engines of in-use vehicles; and
f) Blending of renewable fuels with diesel fuel helps to achieve low carbon emissions from diesel engines.

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