Research Journal of Applied Sciences, Engineering and Technology 7(11): 2394-2399, 2014
DOI:10.19026/rjaset.7.542
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: September 14, 2013 Accepted: September 21, 2013 Published: March 20, 2014

Research Article

Experimental Investigation on DI Diesel Engine Fueled with Diesel-Ethanol Emulsions

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Abstract: In this study, Four different ratio of emulsified fuels are used as alternative fuels for four stroke, single cylinder, water cooled, naturally aspirated direct injection diesel engine to analyze the performance, emission and combustion characteristics, namely Specific Fuel Consumption (SFC), Brake Thermal Efficiency (BTE), Hydrocarbon (HC), Nitrogen Oxides (NO_x), smoke, cylinder pressure and heat release rate and compared with diesel fuel under different load conditions with constant engine speed of 1500 rpm. The blends prepared were D80E10 (80% Diesel and 10% Ethanol), D70E20, D60E30 and D50E40 with the addition of 10% surfactant in each blend on volume basis. At full load, compared to diesel fuel, the experimental results of D50E40 blend showed 3.06% reduction in SFC, 21.3% improvement in BTE, 37.08% increase in HC, 31.1% increase in NO_x and 42.3% reduction in smoke. The cylinder pressure and heat release rate of D50E40 blends is higher with increasing ethanol percentage in the blend.

Keywords: Combustion, diesel engine, emission, ethanol, performance

INTRODUCTION

Diesel engine are widely used in different fields including engineering machinery, automobile, shipping power requirement, electricity production and agricultural activities due to high combustion efficiency, reliability, adaptability, excellent drivability and cost effectiveness. It is a Major contributor of various types of air pollutants such as Carbon monoxide (CO), Oxides of Nitrogen (NO_x) and Particulate Matter (PM) than gasoline engine (Jamil and Damon, 2005; Mohammadi *et al*., 2005; Ajav *et al*., 1999).

In the last two decades of the 20^{th} century major advances in engine technology have occurred; it has led to greater fuel economy in vehicles and the reduction of emission is in a desirable route as approved by environmental protection agency. More money is being spent on import of crude and other petroleum products. This expenditure is unavoidable because petrol and diesel are essential and imperative for power generation. Hence elite scientists are confronted with the following new challenges. They are related to environmental hazards, fuel scarcity, energy demand and stringent emission norms. The above difficulties can easily be overcome by discovering more environmental friendly substance like ethanol (Bang-Quan *et al*., 2006; Hansen *et al*., 2005).

Ethanol can be manufactured from simple agricultural materials like sugarcane, cassava, molasses, waste biomass materials, sorghum, corn, barley and sugar beets. It can be derived chemically from ethane or ethylene. It is a volatile, colorless liquid with a slight odor and high octane number when compared to other fuels like methanol, gasoline, natural gas and diesel (He *et al*., 2003; Kremer and Fachetti, 2000).

Ethanol is immiscible with diesel fuel because of the presence of wax content, hydro carbon composition of diesel fuel, water content and wide range temperature of the blend. The addition of ethanol to diesel affects properties such as viscosity, lubricity, energy content, volatility, cetane number and stability (Bilgin *et al*., 2002; Lin and Wang, 2003). The problem of this occurrence can be solved by using an emulsifier (or) a co-solvent (Letcher, 1983). The emulsifier would reduce the interfacial tension between the two liquid phases leading to emulsion stability (Lapuerta *et al*., 2007).

Bhattacharya *et al*. (2004) have studied the performance of a constant speed CI engine on alcohol-diesel micro emulsion. They found that the CO emissions were decreased but UBHC and NO_X emissions were higher, compared to diesel fuel. Yanuandri *et al*. (2013) conducted the experiment with

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E2.5, E5, E7.5 and E10%, respectively ethanol-diesel and EGT decrease, meanwhile the emission of CO, HC and smoke decrease. No abnormal maintenance or fuel injection system was identified with diesel-ethanol blend in diesel engine (Hansen *et al*., 2001; Meiring *et al*., 1983). Rakopoulos *et al*. (2008) found reduced NOx, CO and smoke density and increased unburned hydro carbon emissions with the use of ethanol-diesel fuel blends. De-gang *et al*. (2005), studied the effect of diesel-ethanol blended fuels. The results indicated that BSFC, BTE and THC increased significantly with decreased smoke emission. Cheng-Yuan and Wang (2004) reported increased efficiency with 5, 10 and 20% ethanol-diesel blend in diesel engine. Ajav *et al.* (1999), investigated the emulsified fuels with 5, 10 and 15% of ethanol by volume. The results showed that BSFC increased by up to 9% and CO, NOx were lower with diesel-ethanol blends. Moses *et al*. (1980) reported that improve in the SEC and BTE with ethanol-diesel blends.

Hansen *et al*. (2005) reported that brake thermal efficiency increased by about 2-3 with 10% ethanol. Donahue and Fostor (2000) found that the improvement in emissions based on the oxygen enhancement. Jae *et al*. (2000) investigated the combustion characteristics of emulsified fuel in an RCEM water-oil emulsion. They showed the best performance and better combustion characteristics. Ashok and Saravanan (2007) studied that increase in BTE with decrease in SFC, PM, NOx and smoke when compared to diesel fuel. Fayyad *et al*. (2010) noticed that the best performance of the engine was obtained when 15% of ethanol was used in the gasoline blend. Recent research blends in a diesel engine and reported that the BSFC has reported that the use of diesel-ethanol blends can reduce the emissions of Carbon monoxide (CO) and smoke but increases Oxides of Nitrogen (NOx) and hydrocarbon (Ozer *et al*., 2004; Jincheng *et al*., 2004).

In this test, carboxymethyl cellulose (Surfactant) is added as an emulsifier to the diesel-ethanol blend to prevent layer formation and to make it a homogeneous blend. The performance, emission and combustion characteristics of four different ratios of emulsified fuels were tested in a single cylinder, four stroke naturally aspirated, water cooled DI diesel engine and compared with diesel fuel.

MATERIALS AND METHODS

Experimental setup and test procedure: Experiments were conducted on a four stroke single cylinder direct injection diesel engine as shown in Fig. 1 and its specifications are given in Table 1. The engine was loaded by an eddy current dynamometer. A burette and stop clock was used to find out the fuel flow rate. The engine exhaust gas temperature was measured by using chromel-alumel (K-type) thermocouple. An AVL digas 444 analyzer was used to measure the amount of unburned Hydrocarbon (HC), Oxides of Nitrogen (NOx), Carbon monoxide (CO) and Carbon dioxide (CO_2). The combustion chamber pressure was measured by a water cooled piezoelectric pressure transducer with a sensitivity of 16.11 Pc/bar, mounted on the engine cylinder head.

The engine is first run with diesel fuel at different load conditions such as 20, 40, 60, 80 and 100%. respectively. Further the test was repeated under above load conditions with different ratio of emulsified fuels

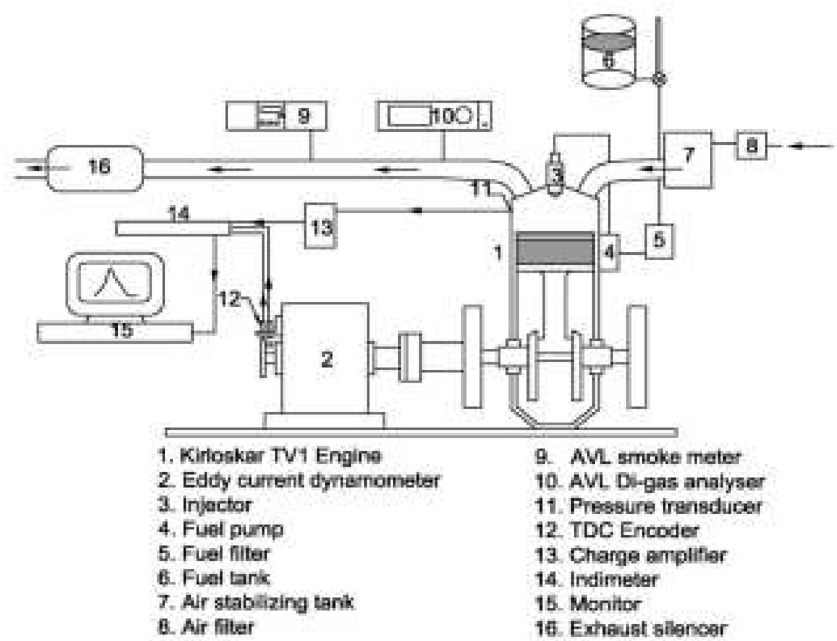

Fig. 1: Schematic diagram of experimental setup

Table 1: Specifications of the diesel engine

Make	Kirloskar Tv-1 engine
Type	Single cylinder, water cooled, 4 stroke diesel engine
Bore×stroke	87.5×110 mm
Compression ratio	17.5:1
Rated brake power	5.2 kw
Speed	1500 rpm
Ignition system	Compression ignition
Ignition timing	23° bTDC
Injection pressure	220 kgf/cm²

Table 2: Physico-chemical properties of diesel, ethanol and best emulsified fuel

Properties	Diesel	Ethanol	D50 E40
Density @ 15°C in g/cc	0.8289	0.789	0.8194
Specific gravity at 15°C	0.8100	0.796	0.8290
Kinematic viscosity @40°C in cst	3-4	1.2	2.8900
Flash point °C	74	13	14
Cetane number	50	5-8	46
Calorific value kj/kg	42800	26,600	37940

at constant speed of 1500 rpm. Steady state performance, emission and combustion readings were taken for three times and finally the average value of the three readings was observed for further calculation. The Physical-chemical properties of diesel, ethanol and best emulsified fuels are summarized in Table 2.

RESULTS AND DISCUSSION

Specific fuel consumption: The variation of Specific Fuel Consumption (SFC) with brake power of the engine is shown in Fig. 2. It is observed that the SFC is found to decrease with increase in load and increase in the percentage of ethanol in diesel fuel. The specific fuel consumption is lower for the diesel-ethanol emulsion (D50E40) than for the diesel fuel. Among the blends, the minimum SFC is observed to be 0.253 kg/kw-h for D50E40 blend whereas for diesel fuel it was 0.261 kg/kw-h at maximum brake power of the engine. The SFC were 24.5, 6.5, 18.3 and 3.06% lower than the diesel fuel with D80E10, D70E20, D60E30 and D50E40 blends. It may be due to the reduction of energy content, heating value and longer ignition delay of emulsified fuel (Bhattacharya and Mishra, 2006; Naveenkumar *et al.*, 2002).

Brake thermal efficiency: The variation of Brake Thermal Efficiency (BTE) with brake power for different fuels is presented in Fig. 3. The brake thermal efficiency increased for all emulsified fuels than diesel fuel at all operating conditions of the load. The results showed that the BTE increased with increase of ethanol percentage in diesel fuel. The maximum BTE is obtained as 36.4% for D50E40 blend whereas it is 30% for diesel fuel. Compared with diesel fuel, the BTE increased by 2.6, 9.6, 6.3 and 21.3%, respectively with D80E10, D70E20, D60E30 and D50E40 blends at maximum brake power of the engine. This is due to the addition of ethanol in the diesel fuel reduces its viscosity thereby improving the fuel spray atomization which supports better combustion (Rakopoulos *et al.*, 2007; Lu *et al.*, 2004).

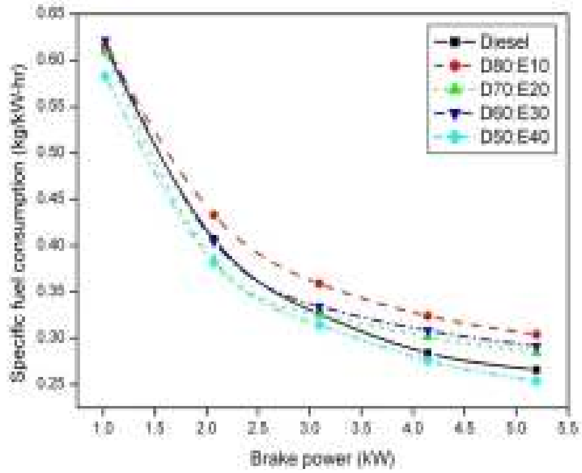

Fig. 2: Specific fuel consumption with brake power

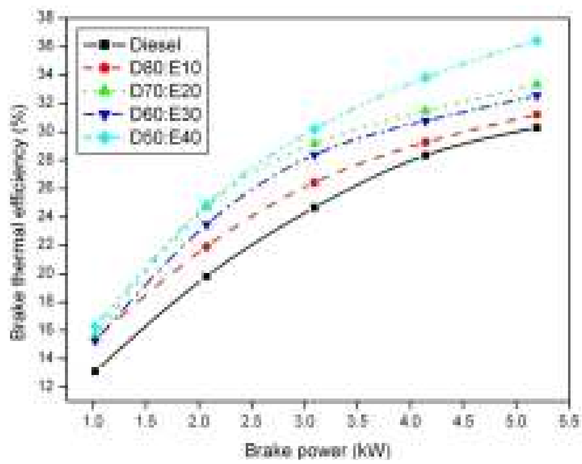

Fig. 3: Brake thermal efficiency with brake power

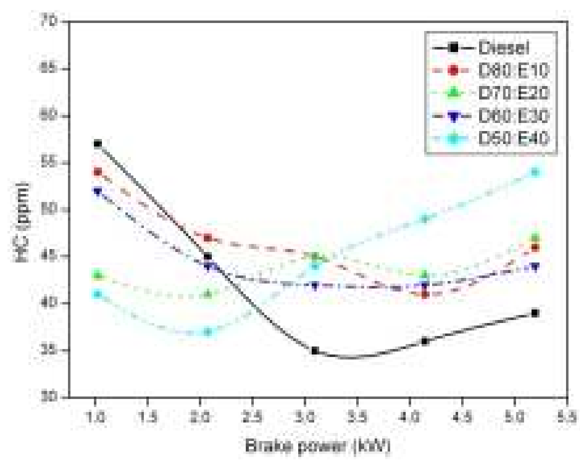

Fig. 4: Hydrocarbon with brake power

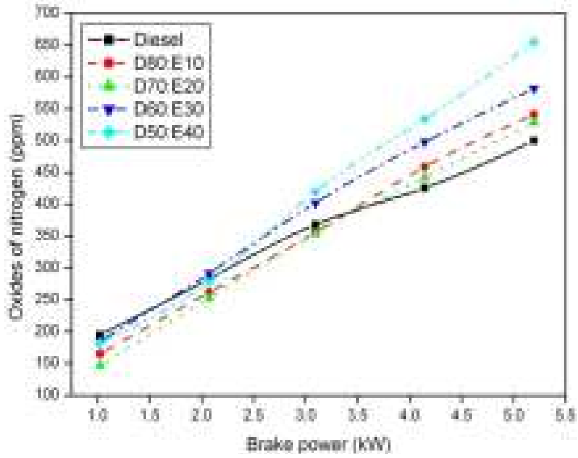

Fig. 5: Oxides of nitrogen with brake power

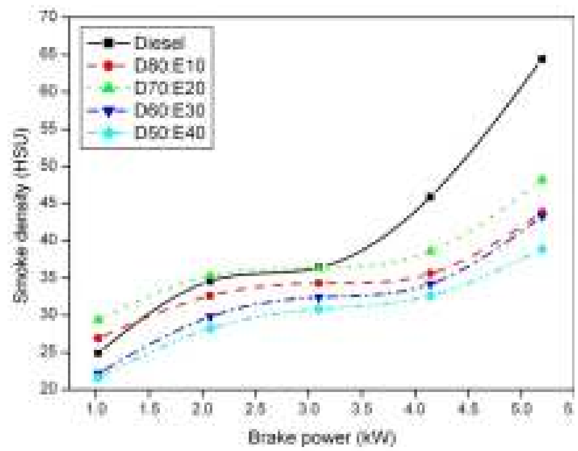

Fig. 6: Smoke density with brake power

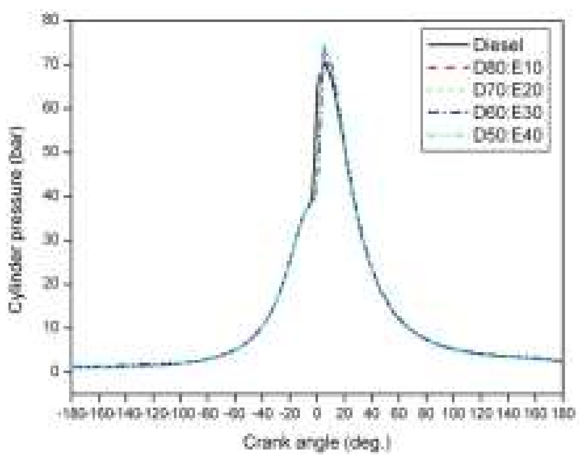

Fig. 7: Cylinder pressure with crank angle

Hydrocarbon: Figure 4 shows the increase in Hydrocarbon (HC) with brake power is due to fuel-rich mixture at higher loads, reduces in-cylinder temperature, poor oxidation reaction rate and incomplete combustion of blended fuels (Sahih, 2003). The HC emission increases with increase in load for all the tested fuels. At maximum load, the HC emission for D50E40 blend is higher, compared to diesel fuel. The HC emission is 53.6 ppm for D50E40 blend whereas 39 ppm for diesel fuel. The HC emission of D80E10, D70E20, D60E30, D50E40 blends were 15.3, 16.1, 10.2 and 37.08%, respectively higher than that of diesel fuel.

Oxides of nitrogen: The variation of Oxides of Nitrogen (NO_X) with brake power for different ratio of emulsified fuels and diesel fuel is shown in Fig. 5. The NO_X emission for the fuel was found to minimum at lower load and again it increases at higher loads. At maximum brake power of the engine, the NO_X emissions of all diesel-ethanol blends are increased when compared with diesel fuel. It is due to combustion temperature, fuel-air residence time and availability of oxygen during combustion (Prommes *et al*., 2007). The results indicated that the NO_X emissions increased with increases of ethanol percentage in diesel fuel. At full load, the NO_X emission for diesel-ethanol blends D80E10, D70E20, D60E30 and D50E40 is 535, 525, 575 and 655 ppm, respectively, whereas it is 500 ppm for diesel fuel. Compared to diesel fuel, the NO_X emissions increased by 6.8, 5, 15 and 31.1%, respectively with 10, 20, 30 and 40% ethanol in the blends.

Smoke: The variation of smoke density with brake for different ratio of emulsified fuels and diesel fuel is depicted in Fig. 6. It was observed that smoke density decreases as the load increases. This is due to low C/H ratio, aromatic fractions, low viscosity of fuel and the presence of oxygen in the blend. At higher load the smoke emission for D50E40 blend is lower when compared to other concentrations of emulsified fuels and diesel fuel. The smoke density in the engine exhaust is found to be 37.1 HSU for D50E40 blend, whereas for diesel, it is 64.4 HSU. Compared to diesel fuel, there is a 42.3% decrease in smoke density for D50E40 blend, also found that the ethanol in the bend reduces the cetane number which causes much ignition delay allowing more time for fuel air mixing. All these factors contribute the reduction in smoke density (Choi and Reitz, 1999; He *et al*., 2003).

Cylinder pressure: Figure 7 illustrates the variation of cylinder pressure with crank angle for different ratio of diesel-ethanol blended fuels and diesel fuel. It is observed that the concentration of ethanol increases in the blends provide higher cylinder pressure for all emulsified fuels, compared to that of diesel fuel. The maximum cylinder pressure of the diesel engine with D50E40 blend is 75.2 bar where it is 68.8 bar for diesel fuel. This is mainly due to lower cetane number and longer ignition delay period of emulsified fuels which causes a larger amount of fuel is accumulated in

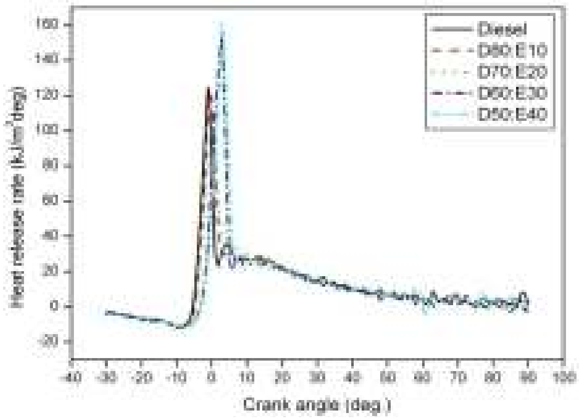

Fig. 8: Heat release rate with crank angle

combustion chamber during the premixed combustion phase leading to higher cylinder pressure and heat release rate (Jamil and Damon, 2005).

Heat release rate: The variation of heat release rate with brake power for different fuels is shown in Fig. 8. The heat release rate of all emulsified fuels were higher than that of diesel fuel at the different load conditions, moreover the heat release rate increased with increase of ethanol percentage in the blended fuels. The higher heat release rate is recorded as 162.2 kj/m^3 deg for D50E40 blend whereas it is 121.2 kj/m^3 deg for diesel fuel at full load condition. This is attributed to lower cetane number, longer ignition delay period, heat loss from the cylinder and cooling effect of emulsified fuels, resulting in high peak combustion temperature, higher cylinder pressure and higher heat release rate (Rakopoulos *et al*., 2007; Huchen *et al*., 2007).

CONCLUSION

A four stroke single cylinder naturally aspirated DI diesel engine was used to study the performance, combustion and emission characteristics of different ratio of emulsified fuels and compared with those of diesel fuel. The following conclusion can be obtained:

- The D50E40 blend gives the best performance of 21.3% increase in BTE and 3.06% decrease in BSFC.
- From the emission analysis, it is observed that 37.08% increase in HC emissions, 31.1% increase in NOx emissions and 42.3% decrease in smoke for the D50E40 blend at full load.
- The maximum cylinder pressure and heat release rate for D50E40 blends are recorded as 75.2 bar and 162.2 kj/m^3 deg at Maximum brake power of the engine.

From the experimental investigations, D50E40 emulsified fuel ratio can reduce environmental hazards with increase an engine performance and hence it can be used as an alternative fuel for DI diesel engine.

ABBREVIATIONS

SFC = Specific fuel consumption
BTE = Brake thermal efficiency
HC = Hydrocarbon
NOX = Oxides of nitrogen
BP = Brake power
CA = Crank angle
PPM = Parts per million
HSU = Hatridge smoke unit
TDC = Top dead centre
bTDC = Before top dead centre
rpm = Revolution per minute
CI = Compression ignition
DI = Direct injection
D80E10 = 80% Diesel + 10% Ethanol + 10% Surfactant by volume
D70E20 = 70% Diesel + 20% Ethanol + 10% Surfactant by volume
D60E30 = 60% Diesel + 30% Ethanol + 10% Surfactant by volume
D50E40 = 50% Diesel + 40% Ethanol + 10% Surfactant by volume

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