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Research Article

Effect of Diesel-Ethanol Blends on Performance, Combustion and Exhaust Emission of a Diesel Engine

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Abstract

In this study, the investigations were made on engine performance, combustion and exhaust emission characteristics of a single cylinder four stroke diesel engine using ethanol blended in different ratios with diesel fuel. The test was performed with five different blends of ethanol (E0-neat diesel, E10, E20, E30, E40 and E50).To satisfy homogeneity and prevent phase separation, 3% of Ethyl acetate has been added to ethanol diesel blend. The result of engine test showed that the addition of ethanol caused an increase in the performance which includes improved Brake thermal efficiency by 8% for 10% Ethanol addition and only 2% increase on further Ethanol addition with an added advantage of reduced Specific fuel consumption and the increase of ethanol, ignition\retards and combustion duration shorten, which results in rapid combustion. Ethanol heat release rate increases with increasing ethanol concentration. Considering emissions, CO, HC and Smoke are increased at lower loads but reduced at higher loads as ethanol which is an oxygenated fuel provides free oxygen to assist combustion. The NO_x is reduced by 8% with 10% of ethanol blend.

Keywords: *Fuel spray, Diesel engine, Combustion, Emission, Ethanol.*

1. Introduction

Environmental concerns, limited amount of petroleum fuels and our country's economic concern have caused the interest in the development of alternative fuels for internal combustion (IC) engines. Alcohol has been used as fuel for engines since 19th century. The low cost of ethanol production in the Indian government also market price compared to diesel 10% less so promoted the ethanol utilization through legislation that mandates the use of Ethanol as an alternative fuel, so ethanol is known as the most suited renewable, bio based and eco-friendly fuel for internal combustion engine. The most attractive properties of ethanol as an internal combustion engine fuel is that it can be produced from renewable energy sources such as sugarcane, cassava, many types of waste bio mass materials, corn and barley. In addition, ethanol has higher heat of vaporization, oxygen content and flammability temperature and therefore has a positive influence on engine performance and emission characteristics of CI engine.

Ethanol has higher miscibility in diesel than methanol(Ozer Can et al,2004). Using ethanol-diesel blend has disadvantages like lower miscibility at lower temperature, Phase separation and lower heating value, cetane number and viscosity. In addition, they reported that ethanol-containing diesel fuel exhausted greater formaldehyde, formic acid, and acetaldehyde emissions than did normal diesel(Su Han Park et al,2010). are used to enhance phase stability, improve cetane number, reduce ignition delay and cycle irregularities .Different additives perform their own unique action on its addition to the blend of fuel. The applications of ethanol fuel to direct injection gasoline engine can produces some customer merits such as full load performance improvement injector deposits suppression on the other hand HC emission remarkably increased under full load(Dattatray Bapu et al,2011). Ethanol has fossil based fuel many properties which makes it useful as a fuel for internal combustion engine it has a higher octane number. Its higher latent heat most important by the issues of low flash point and tank vapour flammability, it is a clean-burning fuel and it is also much less harmful to the environment(Eloisa Torres et al,2011). The additives of ethanol to diesel fuel simultaneously decrease cetane number, high heating value. Aromatics fractions and kinematic viscosity of ethanol blended diesel fuel change dilution temperature. The stability of two blends is dependent of the composition of diesel temperature, ethanol and water content for E30, it only keep stable for about 1 hr at the temperature about 0^{0}C (Michael D, Nobuaki Ando, Wen Dai, Jeremy et al ;2003,2007,2003,2005). The solution proposes auto ignition of the fuel via intake air heating as a means to overcome the part of load engine efficiency problem, the purpose was to determine if a continuously

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operating glow plug would encourage prompt ignition of alcohol(Joel Martinez et al,2007). When using Ethanol relatively for major component changes unascending small adjustments to injection timing and fuel volume delivery. This adjustment depends on ethanol concentration and the effects of ethanol on combustion(M. A. S. Al-Baghdadi et al,2003).

In this publication, the effect of high ethanol blends. Possibility for improving the homogeneity and prevent phase separation has been added to ethanol diesel blend, this blends were selected to be tested in a without any modification of diesel engine, and their performance, combustion and emissions were compared to those of a reference diesel fuel.

2. Experimental setup and procedure

The stability of ethanol-diesel-Ethyl Acetate additive blends of different proportions are investigated. The fuel blends are prepared and monitored carefully for the stability of 10 minutes interval. It is observed that the stability of the blend is achieved without phase separation for a period of more than six months. Experiments are conducted in the laboratory to determine the fuel properties of the diesel ethanol blends. The stable fuel blends E10 contains 87 % Diesel + 10% Ethanol +3 % Ethyl acetate(Volume ratio); E20 contains 77% Diesel + 20% Ethanol, 3 % Ethyl Acetate; E30 contains 67% Diesel + 30% Ethanol + 3% Ethyl Acetate; E40 includes 57% Diesel + 40% Ethanol + 3% Ethyl Acetate; E50 contains 47% Diesel + 50% Ethanol + 3% Ethyl Acetate and neat diesel are used to conduct the experiments. The experimental setup of diesel engine is shown in figure1

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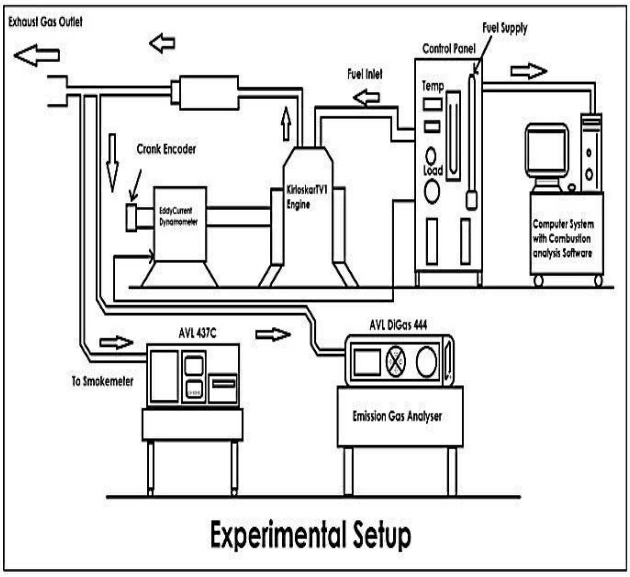

Figure1 schematic of the experimental setup

Specifications of the engine are given in the Table 2 and the properties of test instruments and their values of accuracy are shown in the Table 3. A water cooled eddy current dynamometer is coupled with the engine for precise loading and load applied on the engine is measured using load cell. A data acquisition system is used to gather and analyze the data from various sensors. A PCB, a piezo-electric pressure transducer is used to measure in cylinder gas pressure; a crank angle encoder gives crank angle pulses at every degree of crank angle. The fuel flow rate is obtained using fuel flow DP transmitter and the air-flow rate is obtained on a volumetric basis. Thermocouple is used to measure the temperature of the inlet of engine water, outlet of engine water and exhaust gas. The setup has a stand–alone panel box consisting of air box, fuel tank, manometer, fuel measurements unit, speed indicator, load indicator, temperature indicator, Rota meters (provided for cooling water) and calorimeter (water flow measurements). All the signals collected from the sensors are given as input to the data acquisition system through a signal conditioning unit. The cylinder pressure data, net heat release rate, cumulative heat release data of more than 20 consecutive cycles were collected and averaged using "Engine Soft", which is further provided for online performance and combustion evaluation. An AVL 437C smoke meter is used to measure the smoke capacity. An AVL DiGas 444-five Gas analyzer is used to measure the CO, HC, $NO_{X,}$ CO_2 and O_2 emissions.

Table 1Engine and Set up details

Engine and set up details	
Engine power	5.2 Kw
Engine max speed	1500 RPM
Cylinder bore	87.5mm
Stroke length	110mm
Connecting rod length	234mm
Compression ratio	17.5mm
No of Strokes	4
No of Cylinder	1
Cooling type	Water
Dynamometer type	Eddy current
Indicator used type	Cylinder pressure
Data acquisition device	USB-6210
Calorimeter used	Pipe in pipe
Sensor range	
Exhaust gas temp. trans. (Engine)	0-1200c
Exhaust gas temp. trans. (Engine)	:(-)250 - 0 mm WC
Fuel flow DP transmitter	0-500 mm WC
Load cell	0-50 kg
Sensor signal range (input for interface	1-5 V
Cylinder pressure transducer	0-345.5 bar

Effect of stability and phase separation

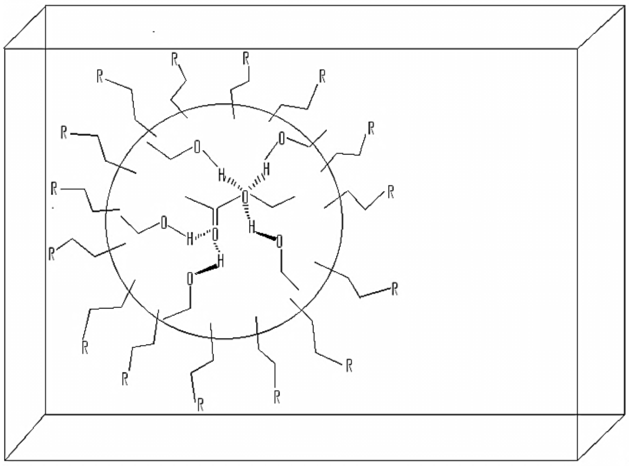

Figure 2 Representation of a micelle between the diesel, ethanol and ethyl acetate

It is apparent that ethyl acetate acts as a template for the formation of hydrophilic core and hydrophobic surface. The consequence is the polar moiety of the ethanol interacts with the complementary part of the ethyl acetate. It gives polar core which stabilizes both ethanol and ethyl acetate and thereby avoids phase separation between ethyl acetate and ethanol. The hydrocarbon surface makes a hydrophobic environment. The resultant structure allows the assembly of hydrocarbons of the diesel components in a three dimensional fashion. Such ternary complex interaction prevents the formation of individual components so that there exists a homogenous solution indefinitely.

Table.2 Specifications of AVL DiGas 444 and AVL 437C

	Measurement Range	**Accuracy**
AVL DiGas 444		
CO(% vol)	0-10	0.01
CO2(% vol)	0-20	0.1
HC(ppm)	0-20000	1
O2(% vol)	0-22	0.01
NO(ppm)	0-5000	1
Oil Temperature(C)	-30 to 125	1
Lambda	0-9.999	0.001
AVL 437C		
Opacity (%)	0-100	0.1
Absorption (k) (m-1)	0-99.99	0.01

3. Result and discussion

Brake Specific Fuel Consumption (BSFC)

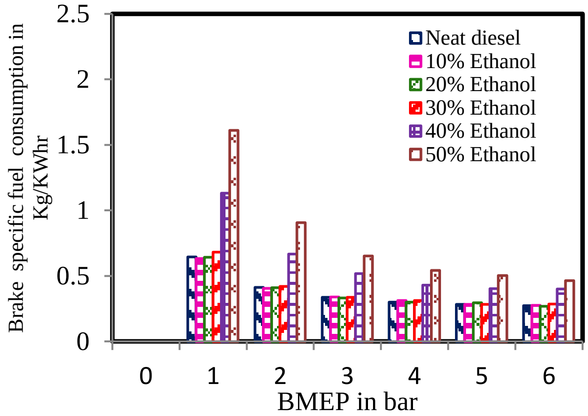

Figure 3 Variation of break specific fuel consumption with BMEP for different blend percentage.

The figure 3 shows the effect of ethanol on Brake Specific Fuel Consumption. It can be seen that BSFC of E10, E20 & E30 decreased slightly due to improvement of performance at full load, which is contributed to combustion improvement. It is caused by ethanol with in fuel-rich regions. However, for E40 & E50 results show worse engine behaviour due to the partial combustion.

Brake Thermal Efficiency (BTE)

As the percentage of ethanol in the mixture is increased, increment trend can be observed in the brake efficiency compared to Neat diesel fuel. This is may be due to cooling effect of the ethanol, as well as more efficient combustion compared to diesel, since the exhaust gas temperature is low in the case of ethanol-diesel fuel blend operation, lesser heat loss through exhaust channel happen and higher brake thermal efficiency can be obtained[7]. Also by reducing combustion duration with increasing ethanol percentage in the mixture, combustion efficiency could be enhanced. It enhances the thermal efficiency by 8% for E10 and it increases by 2% for every 10% of ethanol up to E30. However, E40 and E50 blends, show the opposite trend.

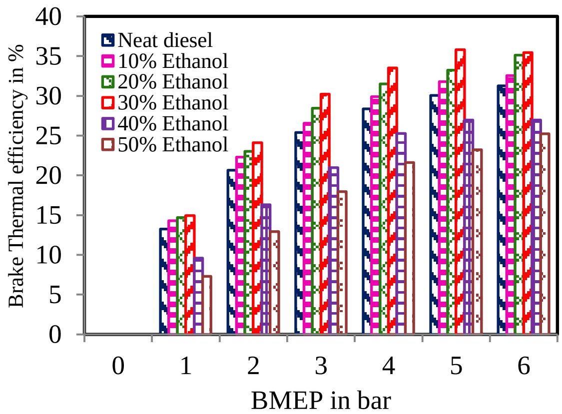

Figure 4 Variation of brake thermal efficiency with BMEP for different blend percentage.

Variation of cylinder pressure

The combustion parameters such as the variation of cylinder gas pressure, heat release rate are discussed with reference to the crank angle. The experiments are conducted for various ethanol blends. It is at low loads and stable operation is observed. It is may be due to early combustion. Peak cylinder pressure occurs earlier in the crank angle for diesel than for the ethanol blends at low engine load. The peak cylinder pressure occurs at nearly the same crank angle for all ethanol blends. Increase in engine load cause an increase in the maximum combustion pressure due to the increase in injection quantity.

Variation of Diesel-Ethanol Blend Effects: The figure 5 shows the peak pressure for diesel ethanol blends. It is higher than that of the neat diesel. From the pressure angle diagram of engine with ethanol diesel blend as fuel, there is a M shaped curve that show. A drastic variation in auto-ignition temperature. The first peak pressure is obtained due to combustion of diesel with lower self-ignition temperature. Then a depression is formed as the heat is continuously absorbed by ethanol for vaporization. When temperature and pressure of the combustion chamber reaches the auto ignition condition of ethanol, combustion takes place in it and so sudden rise of temperature and pressure expressed. This ignition and combustion duration can be seen with the increase of ethanol, ignition\retards and combustion duration shorten, which contributes to rapid combustion ethanol.

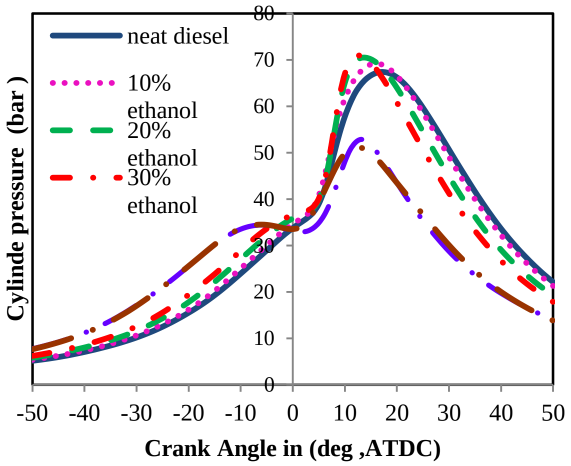

Figure 5 Variation of cylinder pressure with crank angle for different blend percentage.

Net heat-release rate

The peak heat release rate shifts occur closer to TDC for ethanol blends. This shows that the attainment of peak heat release rate is faster with ethanol concentration. The maximum heat release rate increases with an increase in load and with an increase in ethanol concentration up to 30% ethanol and diesel (Figure 6). The use of oxygenated fuel enhances the combustion for all the stable fuel blends and has faster laminar flame speed than that of diesel and is the cause for the increase in sudden heat release rate. The heat release profile has slightly negative depression during the ignition delay period which is seen in figure 3. The effect is mainly due to heat loss from the cylinder during the fuel vaporizing phase. Heat released during the premixed combustion is higher for ethanol diesel blend than diesel due to higher ignition delay, which is due to lower cetane number and higher latent heat of vaporization of ethanol in the diesel blend.

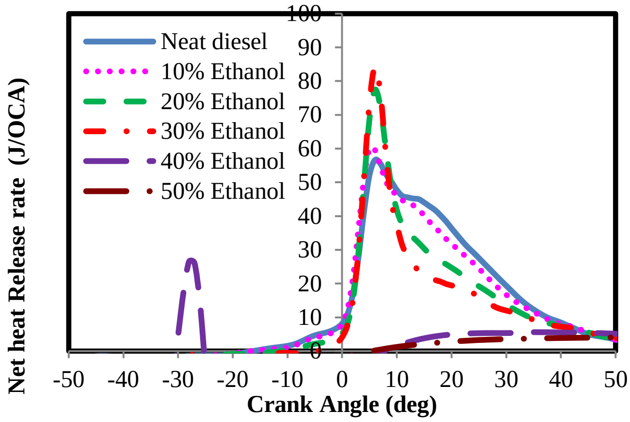

Figure 6 Variation of Net heat release rate with crank angle for different blend percentage.

Emissions

Ethanol is an oxygenated fuel. If generally oxygenated fuels are used the lower emission levels are observed. In Ethanol, the oxygen atom is connected to carbon atom with a very strong bond and it is difficult to break that bond at low load condition. Thus it restrains the formation of black carbon at higher loads. In the fuel rich region the oxygen content of the ethanol inhibits the formation of smoke, CO and HC especially at heavy load. At higher loads the excess oxygen is need for better combustion which is being provided by C-C-O bond that is in ethanol. HC and CO emission is higher at low loads and remains almost the same as that of the base fuel at higher loads showing very negligible change due to the free oxygen molecules provided by Ethanol. Thus ethanol blending shows reduced smoke and maintains the HC and CO emission at higher loads.

Carbon monoxide

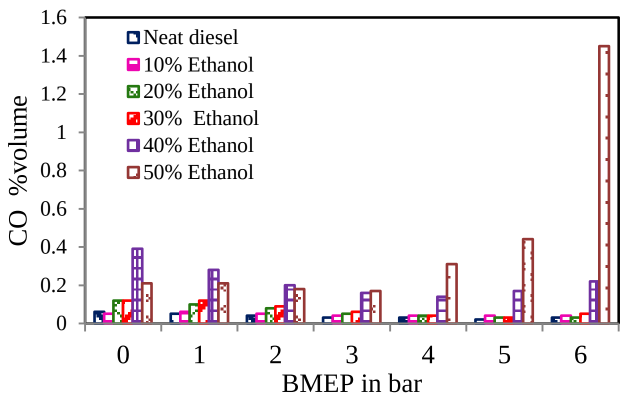

Figure 7 Variation of CO emission with BMEP for different blend percentage.

The figure 7 shows the variation of CO in difference percentage of ethanol blends. It is formed when the used fuel undergoes partial combustion. The CO emission is high at low loads and then decreases with increase in load. This decrease at higher loads is due to speed decrease and hence increased time provided for combustion to occur, thus resulting in complete combustion, however CO emission are higher at lower loads. This resemblance is due to oxygen molecules which get separate by breaking of bond with carbon in ethanol molecule. Oxygen molecules help for the combustion to be completed and thus preventing the formation of partially burnt CO. Carbon readily combines with oxygen than with any other molecule and further formed CO gets converted to CO_2 during complete combustion in the presence of oxygen. These effects are observed only up to E30 blend. A thickened quenching layer created by the cooling effect of vaporising ethanol could play a major role in increased CO emissions. For E40 and E50, CO is much higher and this is due to the increased ignition delay period and lower cetane number.

Hydrocarbons

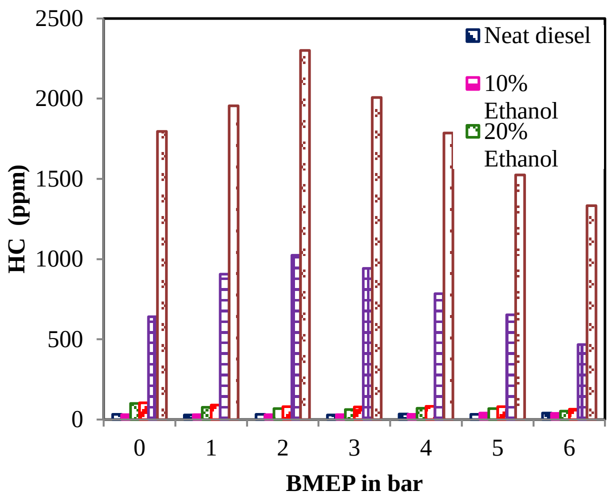

Figure 8 Variation of HC emission with BMEP for different blend percentage..

HC is an unburned and partial burned fuel emission. This HC emission is formed when fuel remains unburned due to flame front collision that results in knocking. About 40% of HC emissions are unburned components of fuel, and other 60% consist of partially reacted components that were not present in the original fuel but formed during combustion. These partially reacted components consist of small non equilibrium molecules, which are formed when large fuel molecules break up during the combustion reaction. During the experiments of E40 and E50, the authors found that the pressure oscillation at TDC is very audible, combustion noise increased substantially and metal noise radiated from inner cylinder can be heard, on the other hand, engine operation was unstable when a misfire or partial combustion occurred. This leads to much higher HC emissions (Z.Sahin et al,2009).

Nitrogen oxides

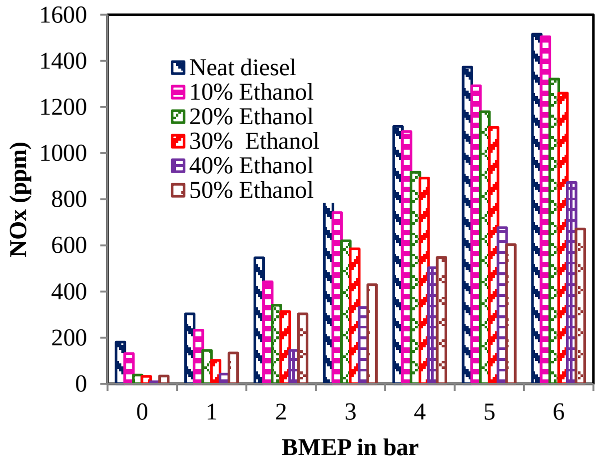

Figure 9 Variation of NO_x emissions with BMEP for different blend percentage.

NO_x formation is a major function of temperature and then comes the oxygen availability. Oxygen is always available in combustion chamber and so the only factor to be considered is temperature of combustion chamber. It is based on calorific value of fuel used; mean effective pressure during combustion and also on heat of vaporization of fuel used. The NO_x emission is higher at increased loads, which is due to the high temperature produced during combustion using large fuel quantity. With ethanol usage the combustion temperature is low due to low calorific value and the high latent heat of vaporization of ethanol. This is lowered the flame temperature and lower NO_x emissions[4], which provides less heat energy after combustion. Compared to E0, the emission of NO_X for E10, E20 & E30 is 8%, 17.5% and 25% respectively. For E40 and E50 it acts increased to 45% and 58% respectively.

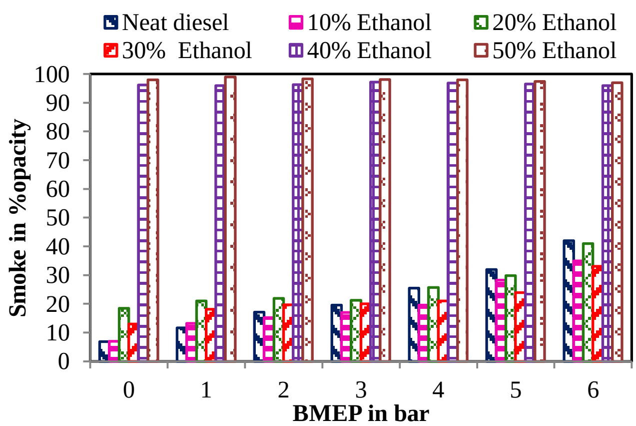

Figure 10 Variation of Smoke emissions with BMEP for different blend percentage.

Smoke is a visible emission caused in the engine and it contains un-burnt carbon particles (soot) in it. It also contains unburned lubricating oil, ash forming fuel components and also oil additives. Smoke is an indication of incomplete combustion in the engine. Smoke emission increases with incomplete combustion which may be due to short combustion cycle at high speed (low load), long delay period, improper mixing of air and fuel and insufficient oxygen which may be due to improper mixing or usage of rich fuel[2]. While using ethanol blends the smoke emission is higher than diesel at lower loads and less than the base fuel at higher loads. Compared to E0, the smoke reduction for E10, E20 and E30 is 10.5%, 6.5% and 8% respectively. For E40 and E50, the smoke opacity reaches its peak. This is due to very high ignition delay which leads to improper mixing of fuel-air.

Conclusion

In this study, the effects of ethanol blends on the performance, combustion and exhaust emission characteristics of a diesel engine were experimentally investigated. Based on the experimental results of this study, the following conclusions were drawn.

- When the different percentage of ethanol blends the BSFC is increased at low and medium engine load but there is no significant change at high engine load.
- Higher brake thermal efficiency is achieved by increasing of ethanol blend, BTE increases from 32% to 36% (up to E30).
- When increase ethanol blend there is higher peak in cylinder pressure and higher heat release occurs closer to TDC for ethanol blend.
- It can be seen that CO and HC emission is closer than those with base fuel up to E30. When using E40 and E50 Engine operation was unstable when a misfire or partial combustion occurred. This leads to much higher CO and HC emission
- There decrease in NO_x emission arising from cooling effect of ethanol and low combustion temperature caused by higher latent heat of vaporization of ethanol.

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