

Studies on the effect of ethanol addition to biodiesel: Performance and emissions of a diesel engine

M. Pugazhvadivu

Department of Mechanical Engineering, Pondicherry Engineering College, Puducherry-605 014, India
pv_pec@yahoo.com

Abstract: The interest on alternative fuels is continuously increasing to meet the growing energy needs and protect the environment. Ethanol and biodiesel are two potential and promising alternative fuels for internal combustion engines. Ethanol can be used with biodiesel fuel to extent the availability of diesel. In this work, experimental investigations were carried on a single cylinder diesel engine using B25, B50, B75 and B100 biodiesel diesel blends with 5% and 10% ethanol addition. The engine performance and emission characteristics were investigated. The thermal efficiency, NO_x and smoke emissions were found experimentally. The addition of ethanol to biodiesel diesel blends did not alter the engine performance significantly. The engine produced lower NO_x and smoke emission with ethanol addition.

Keywords: Biodiesel, ethanol, emission, alternate fuel.

Introduction

Biodiesel has properties similar to diesel and therefore can be used in diesel engines with less or no engine modifications. Biodiesel is non-toxic, biodegradable and contains no aromatics and sulfur. It can be blended with diesel at any proportion. Engine efficiency with biodiesel is proved to be comparable with diesel (Kalligeros *et al.*, 2003). Biodiesel also provides considerable emission benefits such as reduced smoke, carbon-monoxide (CO) and unburnt hydrocarbon (HC). Wang *et al.* (2000) tested nine heavy duty trucks fuelled with B35 and noted reduction in particulate matter (PM) and HC. Venteswararao *et al.* (2008) tested different blends of biodiesel produced from pongamia, jatropha and neem oil.

The biodiesel diesel blends have been reported to produce lower smoke, CO and HC and higher oxides of nitrogen (NO_x). Serdari *et al.* (2000) conducted emission tests using sunflower, corn, olive and used frying oil biodiesel and its blends with diesel. The test results indicated increase in NO_x emission and significant decrease in PM. Nabi *et al.*, (2006) investigated the exhaust emissions of a diesel engine using neem biodiesel and its blends with diesel. They found lower CO and smoke emissions but higher NO_x emission.

Ethanol is a renewable fuel which offers excellent performance and reduced air pollution compared to conventional petroleum fuels. The use of ethanol diesel blends is one of the strategies to extend the availability of diesel. However, ethanol and diesel are immiscible and the

addition of ethanol to diesel fuel affects blend stability, viscosity, lubricity, energy content, cetane number and flash point (Hansen *et al.*, 2005). In order to form a stable blend of ethanol and diesel, biodiesel is used as an additive. Kwanchareon *et al.*, (2007) used biodiesel as an additive to homogenize ethanol-diesel blends containing 5%, 10% and 15% ethanol and 80%, 85% and 90% diesel. Among the blends, a blend containing 80% diesel, 15% biodiesel and 5% ethanol was found to be optimum.

In India, non-edible vegetable oils are suggested for the production of biodiesel as the country imports edible oil to meet its requirements and the prices of edible oils are higher than that of petroleum diesel. India has the potential to produce non-edible oils from plant species like Neem (*Azadirachta Indica*), Karanja (*Pongamia Pinatta*), Mahua (*Madhuca Indica*), Sal (*Shorea robusta*), Jatropha (*Jatropha curcus*) as they can be grown in waste lands (Barnwal & Sharma, 2005). India also has the potential to produce ethanol as it is one of the largest producers of sugarcane in the world. Gasohol a mixture of 5% ethanol and 95% is a commercial fuel in some states of India. Biodiesel and ethanol production can generate local employment opportunities in the rural areas. The most promising alternative fuel for both developing and developed countries will be a fuel containing biodiesel and ethanol. Hence in this study, B100 and B50 fuels containing 5% and 10% (v/v) ethanol were used in a single cylinder diesel engine and the performance and emission characteristics of the engine were determined.

Materials and methods

Diesel fuel and ethanol were obtained from local commercial markets. Biodiesel was prepared from raw Pongamia oil by following a two step acid-base catalyst transesterification reaction (Patil & Shuguang Deng, 2009). The fuels used in this study were: i) 100% biodiesel (B100), ii) a blend of 50% biodiesel with diesel (B50), iii) 5% ethanol added to B100 (B100E5) and iv) B50 (B50E5) and v) 10% ethanol added to B100 (B100E10) and vi) B50 (B50E10). The density, viscosity and flash point of the fuels were determined by following standard test methods. It is seen from Table 1 that the density and viscosity of B100 and B50 are higher than

Table 1. Properties of fuels

Property	B50	B50E5	B50E10	B100	B100E5	B100E10	Diesel
Density (kg/m^3)	860	850	835	880	865	855	835
Viscosity @40°C (cSt)	3.56	3.45	3.23	5.82	5.00	4.82	3.0
Flash point °C	84	53	41	160	81	75	70

that of diesel. In addition, the viscosity of B100 and B50 reduced with ethanol addition, due to the fact that ethanol has lower density and viscosity compared to B100 and B50. The flash point of B100 and B50 fuels are higher than diesel. The flash point of B100 and B50 fuels reduce drastically with ethanol addition due to the very low flash point of ethanol (13°C).

The experiments were carried out in a stationary diesel engine (Kirloskar make) coupled to an alternator and a loading rheostat. The fuel consumption and emission measurements were taken at different engine loads. The experimental setup is shown in Fig 1. The engine specification is presented in Table 2. The NO_x

Table 2. Engine specification

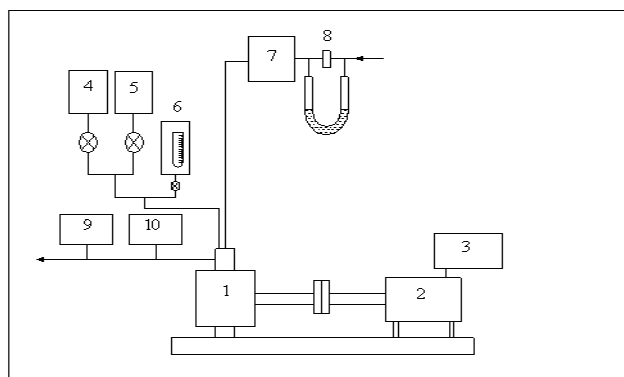
Engine type	Single cylinder, four stroke, direct injection, water cooled
Speed	1500 rpm
Bore x stroke	80 x 110 mm
Compression ratio	18.5:1
Rated power output	3.8 kW @ 1500 rpm

brake thermal efficiency for both B100 and B50 is found to decrease marginally with ethanol addition due to the presence of oxygen and low heat content of ethanol.

NO_x emission

The variation of NO_x emission at various power outputs for B50 and B100 fuels is shown in Fig 2a. Compared to

Fig. 1 Experimental setup



1. Diesel engine; 2. Electrical generator;
3. Electrical load box; 4. Diesel fuel tank;
5. Biodiesel fuel tank; 6. Burette; 7. Surge tank;
8. Orifice plate; 9. NO_x analyzer;
10. Smoke analyzer

concentration in the exhaust gas was measured using NO_x analyzer with chemical sensor (Technovation make). The smoke density was measured using AVL smoke meter.

Results and discussion

Based on experimental data, the graphs were drawn for the variations in brake thermal efficiency, NO_x and smoke emission with respect to brake power. The variation of brake thermal efficiency at various power outputs of the engine is compared between diesel, B100 and B50 in Fig.1a. The brake thermal efficiency has a tendency to increase with increase in load for all the fuels. This is due to the reduction in heat loss and increase in power developed with increase in load. It is seen that the brake thermal efficiency of the engine with B100 and B50 is lower than diesel at all loads. The lower heat content and higher density of biodiesel fuels resulted in lower thermal efficiency. Fig.1b and Fig.1c shows the variation of brake thermal efficiency with respect to brake power with ethanol addition to B100 and B50 respectively. The

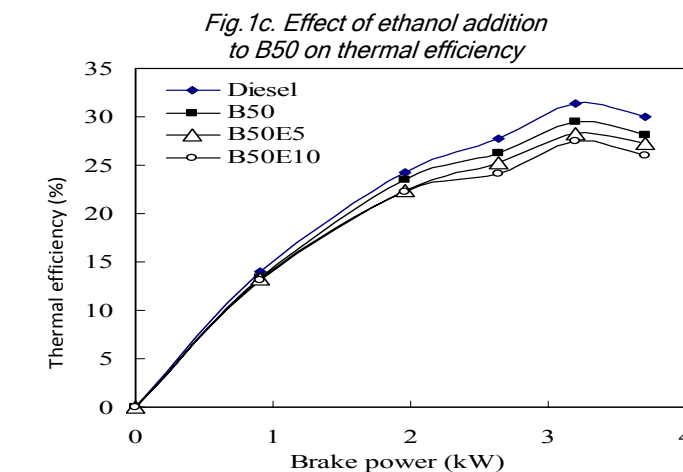
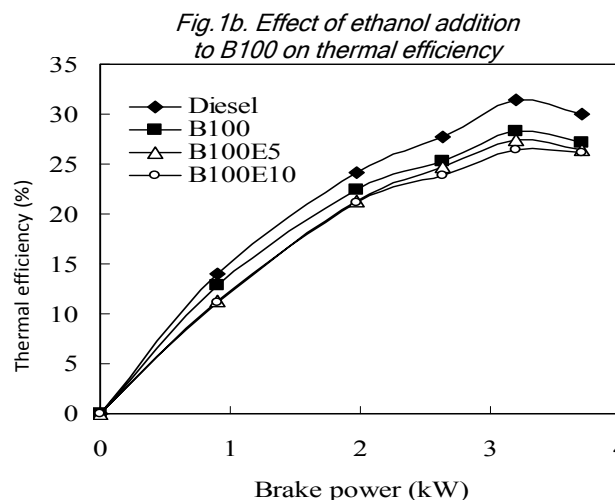
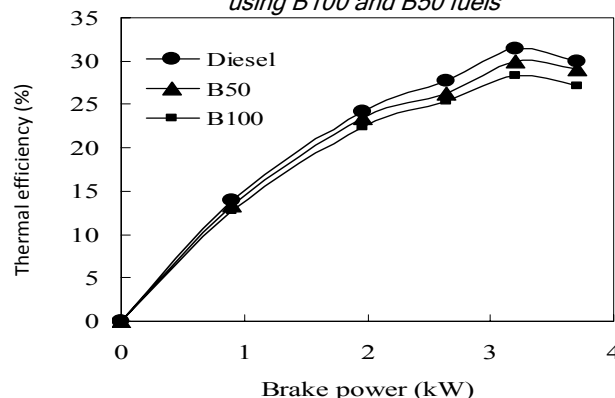


Fig. 2a. NO_x emission using B100 and B50 fuels

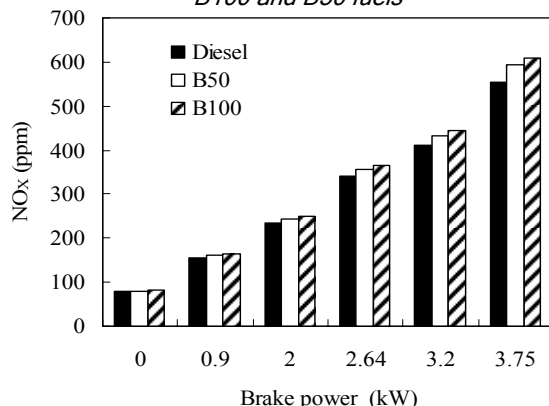


Fig.2b. Effect of ethanol addition to B100 on NO_x emission

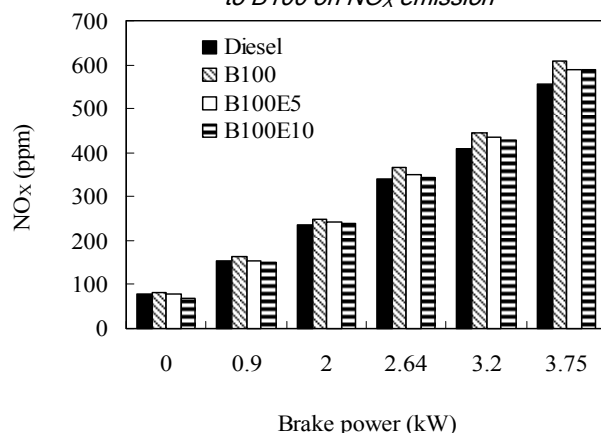
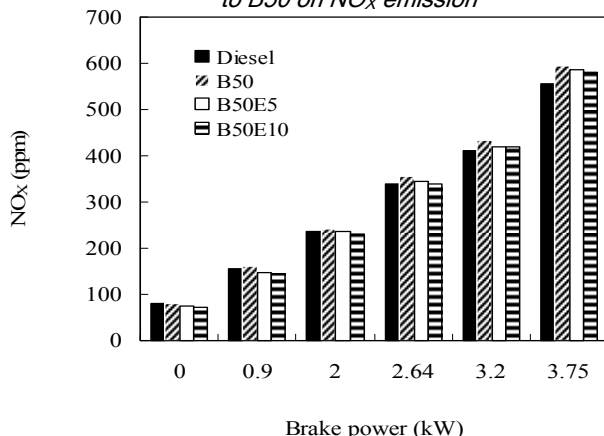


Fig.2c. Effect of ethanol addition to B50 on NO_x emission



diesel, the NO_x emission using B50 and B100 fuels are higher. The increase in NO_x emission may be due to the oxygen present in biodiesel, which is added to fuel rich zones, resulting in the oxidation of nitrogen (Serdari *et al.*, 2000, Nabi *et al.*, 2006). Szybist *et al.* (2005) showed that the higher bulk modulus for biodiesel fuels produce an advance in injection timing compared to diesel fuel which causes an increase in NO_x emissions. At maximum

power output, the NO_x emission increased by 10% and 7% with B100 and B50 respectively.

Fig. 2b and Fig. 2c show the variation of NO_x emission at various power outputs with 5% and 10% ethanol added to B100 and B50 respectively. The NO_x emission is found to decrease with ethanol addition. As ethanol contains oxygen it can be thought of adding oxygen in the same way as biodiesel. However, for ethanol other factors such as heat of evaporation and flame temperature also dominate. Ethanol has a higher heat of evaporation and reduces the combustion temperature. Ren *et al.* (2008) showed that the temperature drop due to the high heat of evaporation of ethanol reduce NO_x emission. The flame temperature of ethanol is 1930°C whereas it is 2054°C for diesel fuel (Wyman, 1996). The lower flame temperature of ethanol may be another reason for the reduction in NO_x emission. At lower power outputs, the decrease in NO_x emission is higher. This is due to the fact that the large heat of evaporation of ethanol results in high temperature reduction at lower load and the in-cylinder temperature at the end of compression stroke is very low compared to high loads. There is only a marginal decrease in NO_x emission at higher power outputs.

Smoke emission

The smoke emission with B100 and B50 is shown in Fig.3a. The smoke emission was higher at high loads since the air-fuel ratio decreases with increase in load (Ramadhas, 2005). It is seen that B100 and B50 emit lower smoke compared to diesel due to the presence of oxygen in these fuels. The smoke emission with B100 was lower compared to B50 as B100 contains more oxygen than B50. Compared to diesel, the maximum smoke density with B100 and B50 are 25% and 16% lower respectively. Fig.3a and Fig. 3b show the effect of ethanol addition to B100 and B50 on smoke density. The results clearly show that the exhaust smoke could be decreased markedly on the addition of ethanol to diesel fuel. The addition of ethanol decreases the engine smoke by providing more oxygen and making it burn completely.

Conclusion

The addition of ethanol to B100 and B50, fuels produced from pongamia oil resulted in a marginal decrease in engine thermal efficiency. Compared to B100 and B50, the NO_x emission decreased at low and medium power outputs significantly. At rated power output, the NO_x emission decreased marginally. The smoke emission was lower for B100 and B50 fuels. The addition of ethanol to B100 and B50 resulted in significant decrease in smoke emission compared to diesel. It is thus possible to achieve simultaneous reduction of NO_x and smoke emission by adding ethanol to B100 and B50. It is concluded that the addition of 5% to 10% ethanol with

biodiesel fuels can extend the availability of diesel and reduce the NO_x and smoke emissions simultaneously.

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Fig. 3a. Smoke emission using B100 and B50

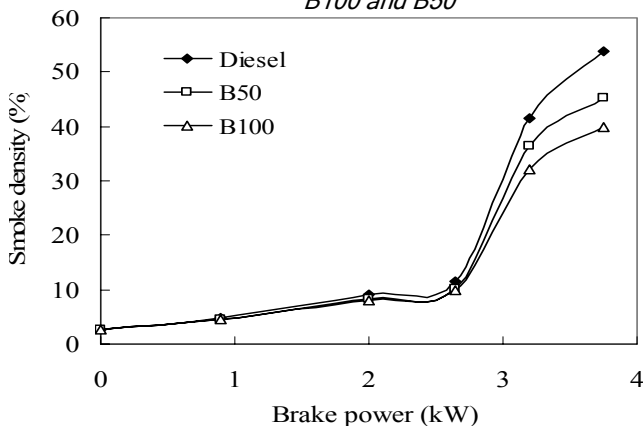


Fig.3b. Effect of adding ethanol to B100 on smoke density

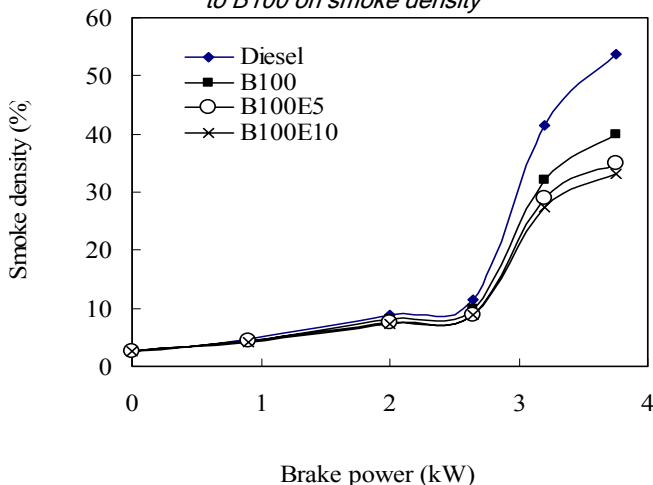
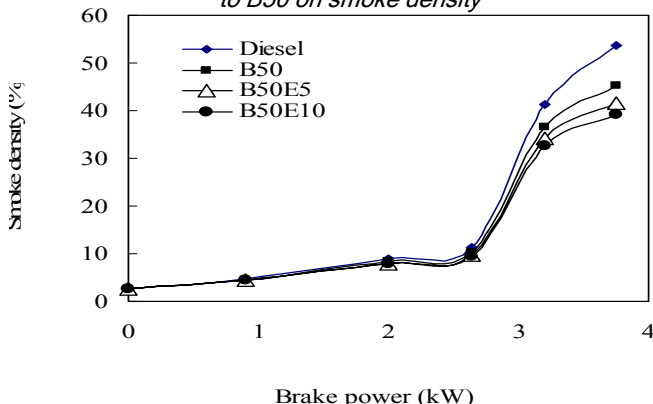


Fig.3c. Effect of adding ethanol to B50 on smoke density



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