Jurnal
Teknologi

Full Paper

COMBUSTION AND EMISSIONS CHARACTERISTICS OF A COMPRESSION IGNITION ENGINE FUELLED WITH N-BUTANOL BLENDS

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Article history
Received
22 July 2015
Received in revised form
27 August 2015
Accepted
15 October 2015

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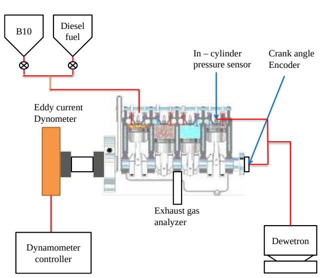
Graphical abstract



Abstract

The use of biomass based renewable fuel, n-butanol blends for compression ignition (CI) engine has attracted wide attention due to its superior properties such as better miscibility, higher energy content, and cetane number as compared to other alternatives fuel. In this present study the use of n-butanol 10% blends (Bu10) with diesel fuel has been tested using multi-cylinder, 4-stroke engine with common rail direct injection system to investigate the combustion and emissions of the blended fuels. Based on the tested engine at BMEP=3.5Bar. Based on the results Bu10 fuel indicates lower first and second peak pressure by 5.4% and 2.4% for engine speed 1000rpm and 4.4% and 2.1% for engine speed 2500rpm compared to diesel fuel respectively. Percentage reduction relative to diesel fuel at engine speeds 1000rpm and 2500rpm for Bu10: Exhaust temperature was 7.5% and 5.2% respectively; Nitrogen oxides (NOx) 73.4% and 11.3% respectively.

Keywords: Compression ignition engine, n-butanol, diesel fuel, combustion, emissions

1.0 INTRODUCTION

Compression Ignition (CI) engine is a well-known internal combustion engine available in the present day. Generally CI engine produces higher thermal efficiency compared to spark ignition (SI) engine because of higher compression ratio of the engine and the carbon content of the fuel itself [1]. Unfortunately, the pollution emitted by CI engines usually includes higher nitrogen oxides (NO_x) and soot. In order to meet the stringent emissions regulations, increasing energy demand and depletion of non-renewable fuels the present worldwide research is directed to search for alternative fuels; alcohol and biodiesel for CI engine.

Alcohol fuels such as methanol (CH_3OH), ethanol (C_2H_5OH), and butanol (C_4H_9OH) can be used with diesel fuels in various percentage blends for CI engine as a clean alternative fuel source. Low percentages of alcohol; 5%, 10% and 15% in diesel fuel blends does not require any modifications to the engine [2]. Other studies on alcohol fuels blended with standard diesel fuels has been studied extensively on CI engines to observe the engine performance and emissions. However, the use of n-butanol fuel is still not widely explored by researchers.

Butanol is produce by fermentation of biomass; algae, corn and plant materials that contain cellulose. There are four groups of butanol isomers namely normal butanol, $CH_3CH_2CH_2CH_2OH$ (n-butanol), secondary butanol $CH_3CH_2CHOHCH_3$ (2-butanol), isobutanol $(CH_3)_2CH_2CHOH$ (i-butanol), and ter-butanol $(CH_3)_3COH$ (t-butanol). Each structure of butanol has the same formula and amount of heat energy. Despite their similarity, they have different solubility properties [3].

Using butanol diesel fuel blends in diesel engines and its effects on engine performance and exhaust emissions have been investigated in several literatures. Yao et al. [4] investigated the effects of butanol ratios (5%, 10% and 15%) by volume in diesel blends on a sixcylinder diesel engine equipped with common rail injection system. The results show that increasing butanol in the blends led to reduction of CO and soot emissions with little increase in brake specific fuel consumption (BSFC). Rakopoulos et al. [5-7] performed experimental tests on a single-cylinder, compression–ignition, direct injection, naturally aspirated diesel engine. They showed that the addition of n-butanol (8, 16 and 24%, by vol.) to diesel fuel increased the BSFC, brake thermal efficiency (BTE) and unburned hydrocarbon (HC) emissions while significantly decreased CO, NO_x and soot.

Presently there are limited number of studies on combustion and emission characteristics of n-butanol as alternative fuel. This paper investigates the effects of n-butanol in a water cooled CDI engine equipped with high pressure common rail fuel injectors, fitted with turbochargers with exhaust gas recirculation (EGR). The engine was tested at speeds 1000rpm and 2500rpm with single brake mean effective pressure (BMEP) level of 3.5Bar.

2.0 EXPERIMENTAL SETUP

2.1 Fuel Properties

Compared to the other alcohol kinds, n-butanol has more advantages than methanol and ethanol as fuel substitutions for CI engine. Butanol has a lesser auto-ignition temperature than methanol and ethanol. Thus, butanol can be ignited easier when combusted in the combustion chamber. Moreover Butanol has also a higher cetane number, therefore more suitable fuel blends than ethanol and methanol for diesel fuel. Energy content of the butanol is the highest among the alcohol family thus it released more energy per unit mass. The physical and chemical properties of butanol indicate that it is capable to overcome the limitations of low carbon alcohols which are methanol and ethanol [8].

Table 1 Physicochemical properties of butanol and diesel fuels [8]

Property	Diesel Fuel	Butanol
Research octane number (RON)	15-25	96
Cetane No.	40-55	25
Energy content (Lower heating value) (MJ/Kg)	42.8	33.1
Heat of vaporization (MJ/Kg)	44.8	36.6
Density at 20 °C (g/ml)	0.829	0.8098
Flash Point (°C)	74	35
Auto ignition temperature (°C)	235	397

2.2 Engine Setup

The experimental test setup was conducted on a 4-cylinder, 4-stroke CI engine. The engine is water-cooled, fitted with a high pressure direct fuel injection system from common rail and equipped with turbochargers and EGR. Commercial Diesel fuel produced by Petronas was used as the base fuel and will be referred to as "Diesel". Apart of the base fuel, 10% of n-butanol blended with diesel fuel were tested, and hereto referred as "Bu10". The engine was operated at engine speeds 1000rpm and 2500rpm at constant BMEP level of 3.5Bar. One of the four engine cylinders was attached with a Kistler water cooled piezoelectric transducer (Type 6041A) to measure the in-cylinder pressure of the engine. The pressure transducers were synchronized with the Kistler cam-crank angle encoder Type 2713B1, attached to the end of the crank shaft, and the reading was recorded by Dewe-5000 data acquisition system. The brake torque of the engine was measured with an eddy-current dynamometer model ECB-200F SR No.617 from Dynalec Controls. The emissions of the engine were measured by KANE gas analyzer. Figure 1 shows the schematic diagram of the experimental setup. The specifications of the engine are as in Table 2.

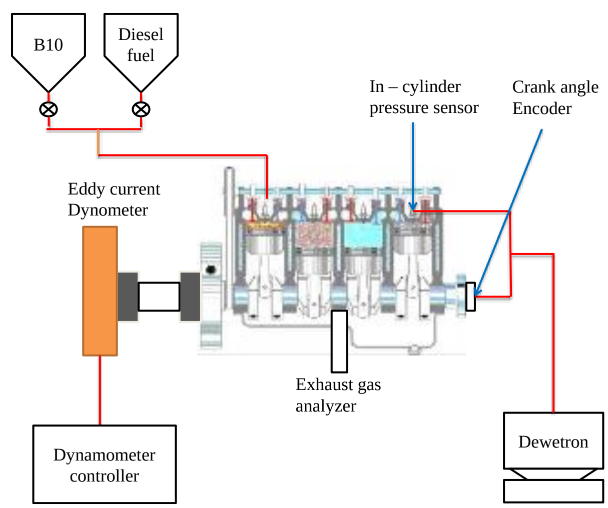


Figure 1 Experimental diagram

Table 2 Engine specifications (ISUZU model 4JJ1)

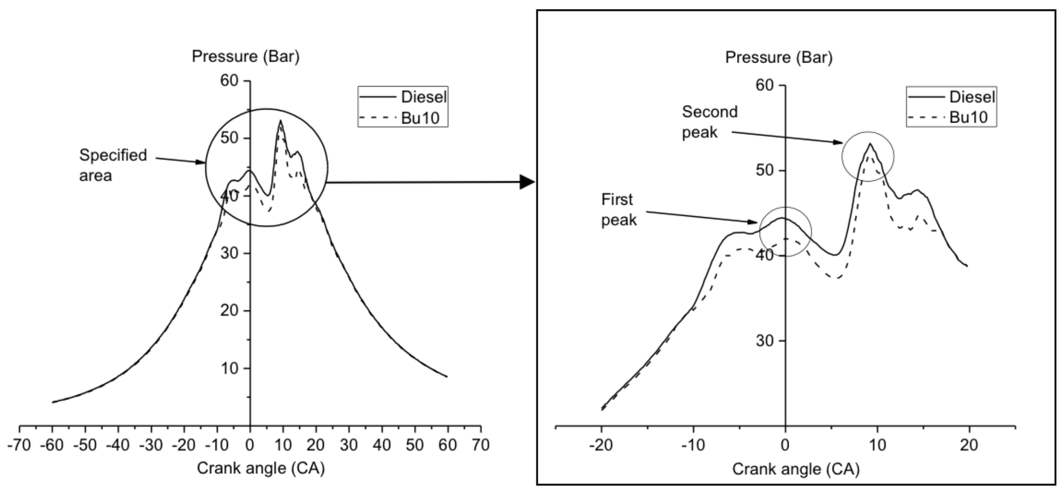
Engine model	ISUZU 4JJ1
Type	Inline 4 – cylinder
Injection system	Common rail direct injection
Bore x stroke	95.4mm x 104.9mm
Displacement	3.0L
Compression ratio	17.5 to 1
Max power at 2500 rpm	61kW
Max torque at 1800 rpm	280Nm

3.0 RESULTS AND DISCUSSION

3.1 Combustion Characteristics

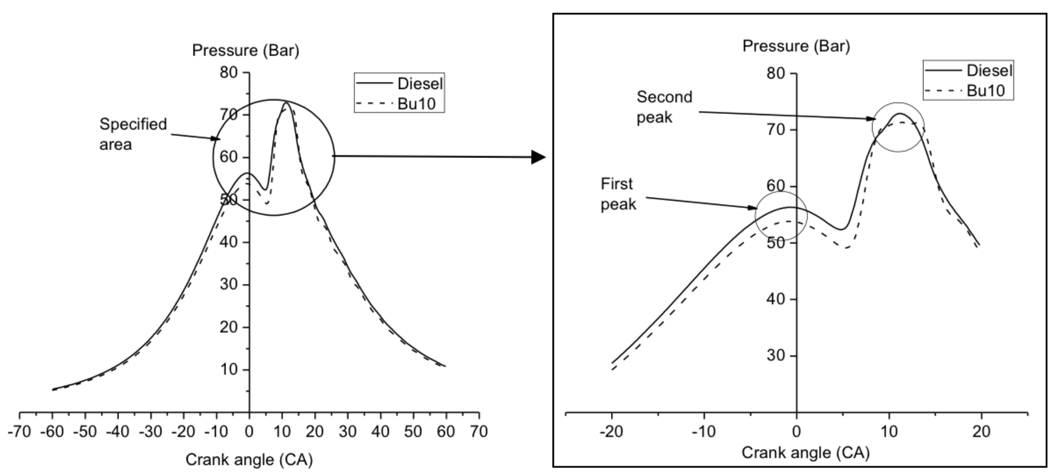
The in-cylinder pressure profile of the 4-cylinder, 4-stroke common rail direct injection CI engine using diesel and Bu10 fuels at 1000 rpm with constant BMEP of 3.5 bar is presented in Figures 2. Figure 2(a) shows the pressure profile for crank angles -60 to 60 degrees. The graph shows clearly the double peaks characteristics due to the pilot and main combustions. Figure 2(b) shows the peaks in more detail from CA -20 to 20 degrees. This figure shows a reduction of 5.4% and 2.4% of pressures for pilot and main combustion respectively from diesel to Bu10. This phenomenon is due to the lower auto ignition and Cetane number of Bu10 cpmpared to diesel [2]. Thus, less fuel was combusted at the first and second stage of combustion with more n-butanol in the blend, hence lower heat released.

Figure 3(a) shows the in-cylinder pressure at 2500 rpm with constant BMEP=3.5 bar for CA -60 to 60 degrees, while figure 3(b) shows the peaks in more detail for CA -20 to 20 degrees. The main combustion peak pressures were increased from 54 bar to 72 bar for diesel and from 53 bar to 71 bar for Bu10, for 1000 rpm to 2500 rpm respectively. But the peak pressures for Bu10 were reduced by 4.4% and 2.1% for the pilot and main pressure peaks respectively, compared to diesel.



(a) (b)

Figure 2 In-cylinder pressure profile during the combustion stroke at engine speeds of 1000 rpm (BMEP 3.5 bar), (a) In-cylinder pressure during combustion stroke, (b) Closed-up view at peak pressure



(a) (b)

Figure 3 In-cylinder pressure profile during the combustion stroke at engine speed of 2 500 rpm (BMEP 3.5 bar), (a) In-cylinder pressure during combustion stroke, (b) Closed-up view at peak pressure

3.2 Emissions Characteristics

Figure 4 shows the effect of n-butanol/diesel fuel blends on exhaust temperature at engine speeds 1000rpm and 2500rpm with constant BMEP=3.5Bar. It was observed that Bu10 blend combustion resulted in lower exhaust temperatures compared to diesel fuel by 7.5% and 5.2% at engine speeds 1000 rpm and 2500 rpm respectively. This is due to the lower energy content and the lower Cetane number of Bu10 blend [9-10].

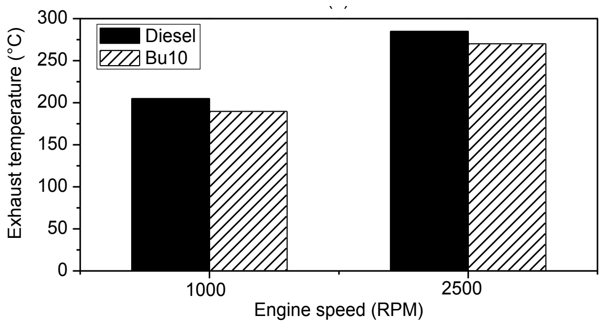


Figure 4 Exhaust temperature at engine speed 1000 and 2500rpm

Figure 5 shows NO_x emissions at engine speeds 1000rpm and 2500rpm with constant BMEP=3.5Bar. It was observed that NO_x emissions decreased by 73.4% and 11.3% when Butanol was added to the fuel at engine speeds 1000rpm and 2500rpm. The emissions of NO_x is strongly related to in-cylinder temperature during combustion. The Bu10 fuel blend led to lower combustion temperature due to lower heating value and oxygen content of Bu10 fuel properties [11-12].

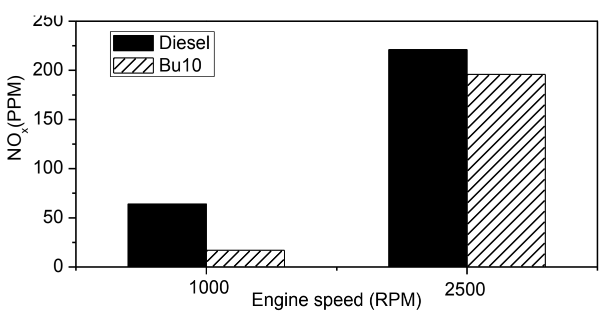


Figure 5 NO_x emissions at engine speed 1000 and 2500rpm

4.0 CONCLUSIONS

The results presented show the influences, of 10% n-butanol blend compared to diesel fuel, on combustion pressures and temperatures, and emissions characteristics in a common rail CDI engine at two different engine speeds (1000rpm and 2500rpm) with constant BMEP=3.5 bar. The main results can be summarized as follows

(i) Combustion characteristics of Bu10 fuel blend results in lower first and second peak pressure by 5.4% and 2.4% for engine speed 1000rpm and 4.4% and 2.1% for engine speed 2500rpm compared to diesel fuel respectively.

(ii) Exhaust temperature of Bu10 fuel blend are reduced significantly by 7.5% and 11.3% for both engine speeds 1000 rpm and 2500 rpm compared to diesel fuel respectively.

(iii) NO_x emissions using Bu10 fuel blend reduced by 73.4% and 11.3% engine speeds 1000 rpm and 2500 rpm compared to diesel fuel respectively.

Acknowledgements

The authors would like to acknowledge the financial support by the Malaysian Ministry of Education through My Brain 15 and Universiti Malaysia Pahang to enable this research project.

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