THE COMBUSTION OF N-BUTANOL-DIESEL FUEL BLENDS AND ITS CYCLE TO CYCLE VARIABILITY IN A MODERN COMMON-RAIL DIESEL ENGINE

I. M. Yusri, R. Mamat, O. M. Ali, A. Aziz[1], M. Akasyah, M. K. Kamarulzaman, C. K. Ihsan, and H. M. Mahmadul
Faculty of Mechanical Engineering, Automotive Engineering Centre, University Malaysia Pahang, Pekan, Pahang, Malaysia
E-Mail: m.yusri890@gmail.com

ABSTRACT

The depletion of fossil fuel combine with implications of exhaust emissions is regarded as one of the future challenges towards automotive researches. The used of alcohol fuel blends with conventional diesel fuel has attracted wide attention due to their liquid nature, high oxygen contents and high octane number. In this study the used of 10% butanol blends (Bu10) in a modern common rail diesel engine were investigated by means of their cyclic variations and peak in-cylinder pressure. The experimental test results showed that Bu10 endure inconsistency in term of the combustion stability as the calculated standard deviation (SD) of peak to peak in-cylinder pressure is greater than the diesel fuel at both BMEP = 1.2 Bar and BMEP = 3.5 Bar. Based on the statistical analysis Bu10 experience less than 2.17% of peak in-cylinder pressure at minimum, median and maximum conditions. For frequency distribution most of Bu10 fall in the range of 61-62 by 42 at BMEP = 1.2 bar, meanwhile at BMEP=3.5 bar 72-73 by 58.

Keywords: cyclic variations, modern common rail diesel engine, diesel fuel, n-butanol.

INTRODUCTION

Vehicle powered by diesel engine typically used for haul goods over long distances. The engine has been using diesel fuel burned in compression-ignition engines. Despite the strong attributes of diesel engine, it consumed of diesel fuel which is considered as non renewable fuel and emit high levels of two harmful air pollutants which is particulate matter, (PM) and oxides of nitrogen, (NO_x). In term of noise pollution, the engine yield considerably higher sound levels at all engine speeds compared to typical vehicle. Extensive use of non renewable fuel will be directed to the climatic changes which resulted to global warming.

One of the potential effective method to overcome the depletion of fossilized fuel and global warming is utilizing biofuel resources as an alternative fuel. Butanol is a category of biofuel that has received renewed concern recently as a potential alternative to petroleum fuels. Butanol can be produced by fermentation of biomass; algae, corn and plant materials that contain cellulose. There are four types of butanol isomers; 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). Butanol family types is relying on the hydroxyl group (-OH) and its carbon chain [1]. Each structure of butanol has the equivalent formula and amount of heat of energy. Despite their similarity, they have dissimilar solubility properties [2, 3].

On the basis of the literature survey butanol is much less evaporative and releases higher energy per unit mass than methanol and ethanol. Butanol has also a greater cetane number than methanol and ethanol making it a more appropriate blended fuel for conventional diesel fuel. Butanol is less corrosive than methanol and ethanol and it can be blended with diesel fuel without phase separation.

Cyclic variations developed from the combustion process in both conventional compression-ignition and spark-ignition engines. The conditions of cyclic variations is when the engine operating conditions achieve the fundamental limits include lean flamability [4]. Wide variations on the pressure-crank angle development reduces the efficiency and reliability of the engine, increases its noise and exhaust-gas emissions, and is one of the major causes of the power fluctuations. There were many studies focused on the cyclic variations operating with different fuel types; methanol, ethanol and butanol [5-7].

In this experimental study, butanol-diesel blends with 10% volume in ratios were tested in modern common rail diesel engine at constant engine speed of 2500 rpm at two different brake mean effective pressure (BMEP) level 1.2 and 3.5 Bar. The combustion cycles for the test fuels were set at 100 consecutive cycles for the cyclic variations analysis. The findings from the Bu10 fuels will be compared to the baseline diesel fuel.

EXPERIMENTAL SETUP

Engine Setup

The experimental test was performed on a 4-cylinder, 4-stroke modern common rail diesel engine. The engine was a water-cooled, fitted with a high pressure direct fuel injection system from common rail and equipped with turbochargers and exhaust gas recirculutaion (EGR). Table-1 described the details of the engine. Figure-1 shows the engine test bed used in this study. One of the four engine cylinders was attached with a Kistler water cooled piezoelectric transducer (Type

ARPN Journal of Engineering and Applied Sciences

6041A) to measure the in-cylinder pressure readings of the engine. The data was captured for 100 consecutive combustion cycles. The pressure transducers were synchronized with kistler cam crank angle encoder type 2713B1 attached to the end crank shaft and the reading is measured by Dewe-5000. 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 are measured by KANE gas analyzer. Figure-2 shows the schematic diagram of the experimental setup.

Table-1. Engine specifications.

Engine Parameters	Details
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

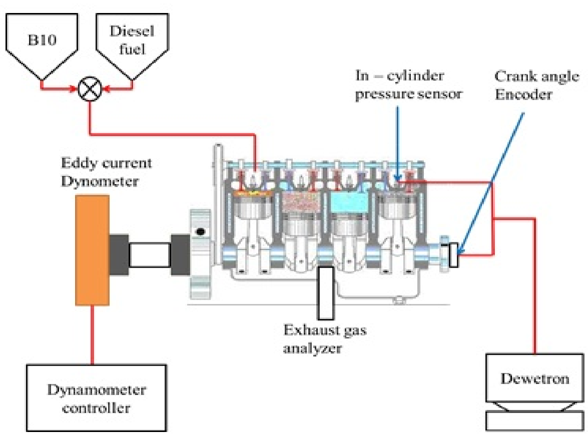

Figure-1. Experimental test diagram.

The engine testing was carried out initialy using diesel fuel in order to generate the baseline data and it was denoted as "Diesel" in each figure. Afterward n-butanol/diesel fuel blends "Bu10" (contains 10% n-butanol and 90% diesel fuel in volume) were prepared and tested under the same conditions for the purposed of comparison. In this study the engine was operated at constant engine speed = 2500 rpm with BMEP = 1.2 Bar and 3.5 Bar. The in-cylinder pressure was recorded for 100 consecutive combustion cycles. The captured combustion cycles is used for the purpose of investigating (1) cyclic combustion variations analysis (2) in-cylinder peak to peak variations (3) statistical peak to peak in-cylinder pressure and (4) frequency distribution between diesel and Bu10 fuel.

Fuel Properties

The fuel-related properties of diesel fuel, and butanol are presented in Table-1. The commercial diesel fuel produced by Caltex was used as the based fuel. Butanol certified to a purity of 99.5% (analytical grade), was chosen as the oxygenated alternative fuel addition to the base fuel. Mixtures of diesel and 10% by volume fraction of butanol with the base fuel were tested in the study, expressed as Bu10. The properties of diesel and butanol used in the study are summarized in Table-1. One can observe that butanol has smaller density, lower cetane number and lower energy content, as compared to the base diesel fuel.

Table-2. Physicochemical properties of butanol and diesel fuels.

Property	Diesel Fuel	Butanol
Research octane number (RON)	40 – 55	96
Cetane No.	46	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

RESULTS AND DISCUSSIONS

The modern common rail diesel engine was used to test the fuels; diesel (baseline fuel) and Bu10 with measuring the in-cylinder pressure corresponding to the crank angle degree (CAD) at 100 consecutive cycles. The experimental study for the test fuels was performed at a constant engine speed 2500 rpm with BMEP level 1.2 and 3.5 Bar. Diesel fuel was first to be tested followed by Bu10. The same procedure has been repeated for each test with the same engine operating conditions.

Figure-2 and 3 shows the engine cyclic variations with different fuels; namely diesel and Bu10 for 100 consecutive combustion cycles at different BMEP level 1.2 Bar amd 3.5 Bar with the constant engine speed of 2500 rpm. Red line represented as mean value at the center of 100 consecutive combustion cycles. The engine combustion system is based on the pilot and main injection strategy of modern common rail diesel engine. During first stage, the peak in-cylinder pressure decreased as the torque increased to a high load conditions. Less fuel combusted during pilot injection stage, hence reflected to lower heat release during the first peak. On the other hand, further fuel will escaped from the first stage of combustion, which causes to increase second peak of in-cylinder pressure [8]. Lower cetane number of n-butanol fuel blend for Bu10 causes more inconsistency compared to diesel fuel especially at BMEP=1.2 Bar.

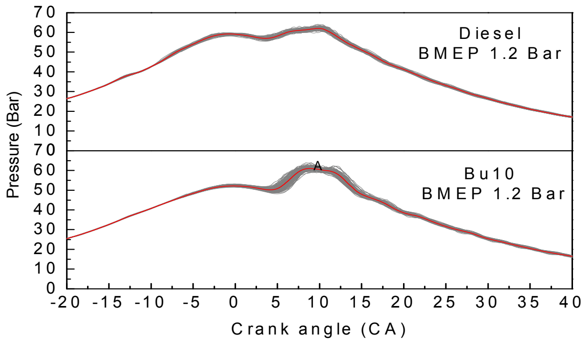

Figure-2. Engince cyclic variations at engine speed 2500rpm with BMEP = 1.2Bar.

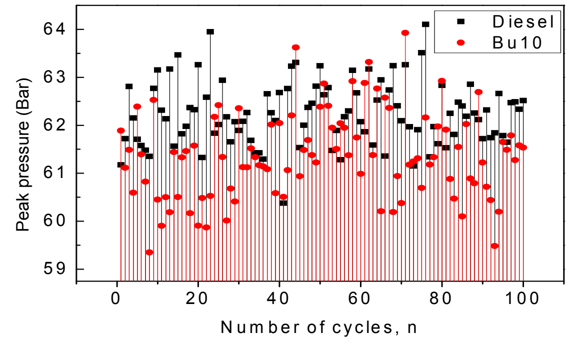

Figure-4. Engine peak cylinder at engine speed 2500rpm with BMEP = 1.2Bar.

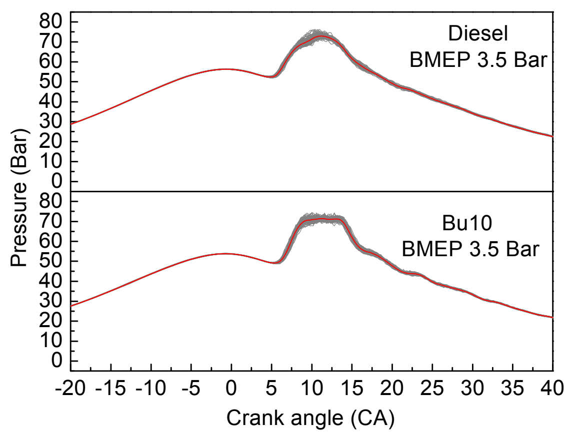

Figure-3. Engince cyclic variations at engine speed 2500rpm with BMEP = 3.5Bar.

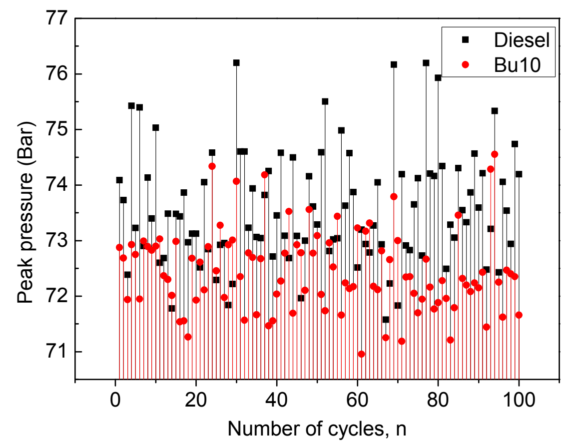

Figure-5. Engine peak cylinder at engine speed2500rpm with BMEP = 3.5Bar

Figure-4 and 5 shows the engine peak cylinder with different fuels; namely diesel and Bu10 for 100 consecutive combustion cycles at different BMEP level 1.2 Bar amd 3.5 Bar with the constant engine speed of 2500 rpm. Based on the figure it shows that the diesel fuel has dominated the overall peak cylinder pressure for both engine load conditions. From the value of peak pressure for every engine cycles, the standard deviation (SD) of the data is calculated as in Table-3. Based on the calculated SD, BMEP = 1.2 Bar indicates Bu10 SD = 0.9 is greater than diesel SD = 0.67 meanwhile at BMEP = 3.5 Bar, Bu10 SD = 1.01 is greater than Diesel SD = 0.73. This value prove that the spread of data for Bu10 is higher than diesel fuel hence resulted to inconsistency combustion stability of the Bu10 cyclic variations.

Table-3. Calculated value of the standard deviation from peak cylinder pressure.

Engine conditions		Fuel type	Standard Deviation
BMEP	1.2 Bar	Diesel	0.67
		Bu10	0.9
	3.5 Bar	Diesel	0.73
		Bu10	1.01

Figure-6 and 7 shows the peak in-cylinder pressure statistical analysis with different fuels; namely diesel and Bu10 for 100 consecutive combustion cycles at different BMEP level 1.2 Bar and 3.5 Bar with the constant engine speed of 2500 rpm. Diesel fuel is producing higher in-cylinder pressure at minimum, median and maximum for both engine BMEP conditions. Based on the statistical analysis Bu10 experienced reduction of peak pressure by 1.71%, 1.42% and 0.27% at minimum, median and maximum respectively for BMEP=1.2 bar as compared to the diesel fuel. Meanwhile Bu10 undergo reductions of peak pressure by 1.4%, 1.46% and 2.17% at minimum, median and maximum respectively for BMEP =

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3.5 bar as compared to the diesel fuel. From the calculated value, Bu10 is not yielding major difference. Only a slight decrease of peak pressure less than 2.17% at minimum, median and maximum conditions. This indicates that a small proportions of butanol is acceptable for diesel fuel blend although there are not sharing similar fuel properties. [9, 10].

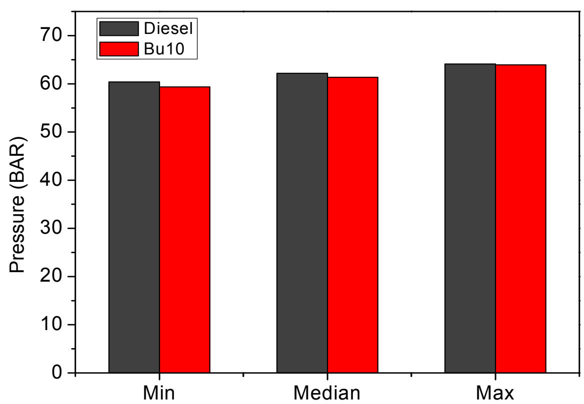

Figure-6. Peak in-cylinder pressure statistical analysis for Diesel and Bu10 at engine speed 2500rpm with BMEP = 1.2Bar.

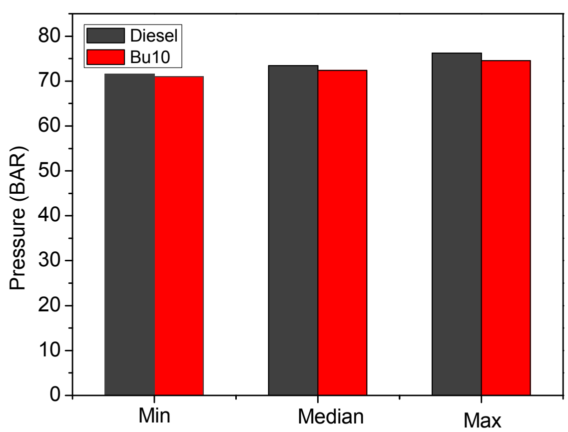

Figure-7. Peak in-cylinder pressure statistical analysis for Diesel and Bu10 at engine speed 2500rpm with BMEP = 3.5Bar.

Figure-8 shows the peak in-cylinder pressure frequency distribution with different fuels; namely diesel and Bu10 for 100 consecutive combustion cycles at different BMEP level 1.2 Bar and 3.5 Bar with the constant engine speed of 2500 rpm. The frequency distribution bar graph indicates that most of the Bu10 peak pressure fall in the range of 61 - 62 by 42 at BMEP = 1.2 bar meanwhile 72 - 73 by 58 at BMEP = 3.5 bar. Meanwhile for diesel the peak pressure fall in the range 62 - 63 by 48 at BMEP = 1.2 bar and 73 - 74 by 34 at BMEP = 3.5 Bar.

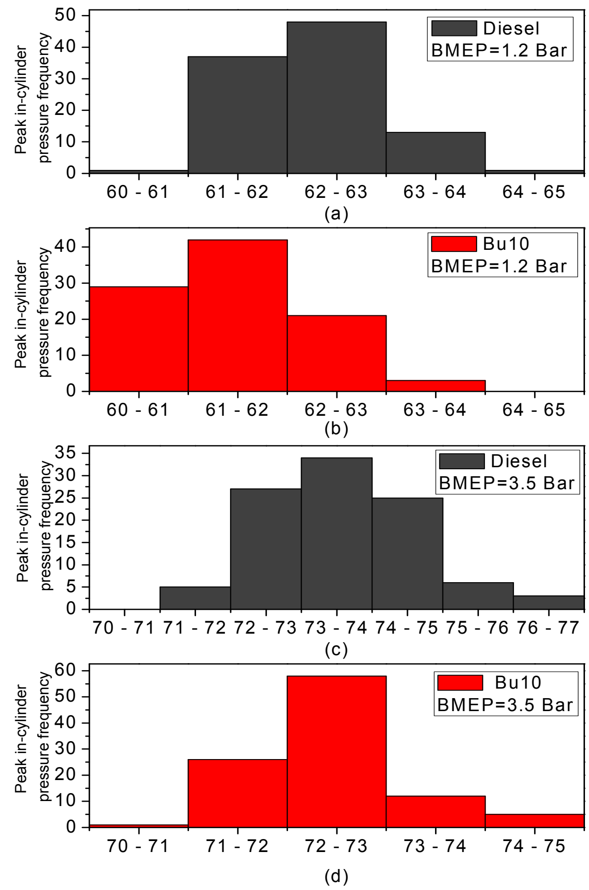

Figure-8. Peak in-cylinder pressure frequency distribution for Diesel and Bu10 at engine speed 2500 rpm (a) Diesel BMEP = 1.2 Bar (b) Bu10 BMEP = 1.2bar (c) Diesel BMEP = 3.5Bar (d) Bu10 BMEP = 3.5 Bar.

CONCLUSIONS

As for the conclusion, the influences of 10% n-butanol blends with diesel fuel on the cyclic variation characteristics were investigated under constant engine speed at BMEP = 1.2 Bar and BMEP = 3.5 Bar. The main results can be summarized as follows.[6, 11, 12]G[1, 6, 13-16], 2011 #27}Alimin, 2014 #26;Altun,

i. Based on the mean value represented by the red line at the center of the 100 consecutive combustion cycles, Bu10 shows inconsistency of cyclic combustion stability at both BMEP = 1.2 Bar and BMEP = 3.5 Bar.
ii. SD at BMEP = 1.2 Bar Bu10 SD = 0.9> Diesel SD = 0.67, meanwhile at BMEP = 3.5 Bar Bu10 SD = 1.01> diesel SD = 0.73. From the calculated value it proves that the inconsistency of combustion stability for Bu10 caused by higher spread of data in term of the peak in-cylinder pressure for each 100 consecutive combustion cycles.
iii. 10% of butanol blends is accepted as it producing lower than 2.17% of in-cylinder peak pressure reduction at minimum, median and maximum for

BMEP = 1.2 Bar and BMEP = 3.5 Bar compared to the diesel fuel.

iv. Frequency distribution indicates that most of the Bu10 peak in-cylinder pressure fall in the range of 61 - 62 by 42 at BMEP = 1.2 bar, meanwhile 72 - 73 by 58 at BMEP=3.5 bar. Meanwhile for diesel the peak pressure fall in the range 62-63 by 48 at BMEP=1.2 bar and 73 - 74 by 34 at BMEP = 3.5 Bar.

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