Retraction: Combustion and emissions characteristics of a compression ignition engine fueled with n-butanol blends (2015 IOP Conf. Ser.: Mater Sci Eng. 100 012048)

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Combustion and emissions characteristics of a compression ignition engine fueled with n-butanol blends

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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. In this present study the use of n-butanol 10% blends (Bu10) with diesel fuel has been tested in a 4-cylinder, 4-stroke common rail direct injection CI engine to investigate the combustion and emissions of the blended fuels. Based on the tested engine at BMEP=3.5 Bar 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.

1. 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 a higher compression ratio of the engine and the carbon content of the fuel itself [1]. Unfortunately the operation enabled by the CI engine usually producing higher nitrogen oxides (NOx) and so an order to meet the stringent emissions regulations, increasing energy demand and depletion of non-renewable fuel the present worldwide research is directed to search for alternatives fuel; alcohol and biodiesel for CI engine.

Alcohol fuels such as methanol (CH₃OH), ethanol (C₂H₅OH), and butanol (C₄H₉OH) 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 diesel engine [2]. Study 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 the researchers.

Butanol is produce by fermentation of biomass; algae, corn and plant materials that contain cellulose. There are four of butanol isomers namely normal butanol, CH₃CH₂CH₂CH₂OH (n-butanol), secondary butanol CH₃CH₂CHOHCH₃ (2-butanol), isobutanol (CH₃)₂CHCHOH (i-butanol), and tert-butanol (CH₃)₂COH (t-butanol). Each structure of butanol has the same formula and amount of heat of 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 six cylinders diesel engine equipped with common rail injection system. Throughout the results increasing butanol blends reflected to reduction of CO and soot emissions while little increased in BSFC. Rakopoulos et al. [5-7] perform the experimental tests on single-cylinder, compression-ignition, direct injection, naturally aspirated diesel engine. Based on the data, with addition of n-butanol (8, 16 and 24%, by vol.) to diesel fuel increased the BSFC, BTE and HC emissions while significantly decreased CO, NO\textsubscript{x} and soot.

Presently there are limited numbers of study on combustion and emission characteristics using n-butanol as an alternative fuel. Thus an effort has been done to investigate the use of n-butanol blends on the water-cooled engine fitted with a high pressure direct fuel injection system from common rail equipped with turbochargers and exhaust gas recirculation (EGR). The engine was tested at engine speed 1000rpm and 2500rpm with single brake mean effective pressure (BMEP) level 3.5Bar.

2. Experimental set up

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 seize the limitations from low carbon alcohols which are methanol and ethanol [8].

| Property                        | Diesel Fuel | Butanol |
|---------------------------------|-------------|---------|
| Research octane number (RON)    | 15-25       | 96      |
| Cetane number                   | 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 was a 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 based fuel and will be referred to as “Diesel”. Apart of the base fuel, 10% of n-butanol blended with diesel fuel were tested and referred to as “Bu10”. The engine was operated at engine speeds (1000rpm and 2500rpm) and constant BMEP level 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 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 1 shows...
the schematic diagram of the experimental setup. The specifications of the engine are based on Table 2.

![Experimental diagram](image)

**Figure 1:** Experimental diagram.

**Table 2: Engine specifications.**

| 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. Results and discussion

3.1. Combustion characteristics

The in-cylinder pressure profile of a 4-cylinder, 4-stroke common rail direct injection CI engine are presented. Figure 2 depicts the combustion profile at engine speed 1000rpm with constant BMEP=3.5Bar. The graph denoted as the scale graph of in-cylinder pressure in the range -60° to 60° CA. The circle indicates the specified area of the analysis at peak combustion.
Figure 2. In-cylinder pressure at engine speed 1000rpm.

Figure 3 shows the specified graph with smaller scale in the range of -20° to 20°CA. Based on the graph, two stages of in-cylinder peak pressure can be observed under 1000 rpm engine speed at constant BMEP=3.5Bar. The resulted peak is reflected on the plot and the injection strategy of the engine behavior. During first stage, the peak in-cylinder pressure decreased as the torque increased to a high load conditions. Bu10 indicates lower first and second peak in-cylinder pressure by 5.4% and 2.4% respectively compared to diesel fuel. This phenomenon is due to the lower auto ignition of the fuel properties [9]. The cetane number of the blended fuel decreases as 10% of n-butanol was mixed with diesel fuel. Thus, less fuel combusted at the first and second stage of combustion when more n-butanol is blended hence reflected in lower heat release for both stages.

Figure 3. Focus area of peak pressure at engine speed 1000rpm.

Figure 4 shows the in-cylinder pressure at engine speed 2500 with constant BMEP=3.5Bar. The graph indicates scale of combustion profile in the range of -60° to 60° CA. The circle indicates the
specified area of the analysis at peak combustion. The in-cylinder pressure is directly proportionally to the engine speed, thus increase of in-cylinder peak pressure can be observed.

Figure 4: In-cylinder pressure at engine speed 2500 rpm.

Figure 5 denoted as the smaller scale of peak combustion in the range of -20 to 20° CA. The combustion profile shows similar trend of injection strategy. Bu10 indicates 4.4% and 2.1% of reduction for both first and second peak in-cylinder pressure respectively.

Figure 5: Focus area of peak pressure at engine speed 2500 rpm.

3.2. Emissions characteristics

Figure 6 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 n-butanol/diesel fuel blends resulted to lower exhaust temperature than diesel fuel by 7.5% and 5.2% at engine speeds 1000rpm
and 2500rpm respectively. This is due to the lower energy content and the cetane number of n-butanol/diesel fuel blends [9, 10].

Figure 6: Exhaust temperature at engine speed 1000 and 2500rpm.

Figure 7 shows NO\textsubscript{x} emissions at engine speeds 1000rpm and 2500rpm with constant BMEP=3.5Bar. It was observed that NO\textsubscript{x} emissions decreased at engine speeds 1000rpm and 2500rpm by 73.4% and 11.3% than diesel fuel respectively. The emissions of NO\textsubscript{x} strongly related to incylinder temperature during combustion. The mixture of n-butanol/diesel fuel blends lead to lower combustion temperature due to lower heating value and oxygen content of n-butanol fuel properties [11, 12].

Figure 7: NO\textsubscript{x} emissions at engine speed 1000 and 2500rpm.

4. Conclusion

For the conclusion, the influences of 10% n-butanol blend with diesel fuel on combustion and emissions characteristics were investigated under two different engine speeds (1000rpm and 2500rpm) with constant BMEP=3.5Bar. The main results can be summarized as follows.

(i) Combustion characteristics of n-butanol/diesel fuel blends 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.

(ii) Exhaust temperature of n-butanol/diesel fuel blends are reduced significantly by 7.5% and 11.3% for both engine speeds 1000rpm and 2500rpm compared to diesel fuel respectively.
(iii) Reduction of NOx emissions using n-butanol/diesel fuel blends by 73.4% and 11.3% for both engine speeds 1000rpm and 2500rpm compared to diesel fuel respectively.

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