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Investigation of influences of secondary butyl-alcohol blends on performance and cycle-to-cycle variations in a spark ignition engines

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Abstract

Depletion of fossilised fuels coupled with stringent energy security has directed automotive researches to continuously investigate the use of alternative fuels in internal combustion engines. Within this subject, the research presented in this work is focused on using butanol as gasoline fuels substitution in a spark ignition engines. The present study reveals the combustion analysis specifically on cycle-to-cycle variations in spark ignition engines and performance characteristics of secondary butyl alcohol (sec-butanol) – gasoline blends at 5%, 10% and 15% by volume of sec-butanol in gasoline fuels. The engine performance characteristics was evaluated at 1000 to 4000 RPM with 50% of wide open throttle positions, while the in-cylinder pressure data were collected over 200 consecutive engine cycles for engine test at 3500 RPM. The indicated mean effective pressure time series is analyzed using the coefficient of variations and the wavelet analysis method. Comparative analysis of the performance characteristics showed that 2-butanol–gasoline blended fuel produced less brake power and brake mean effective pressure by 12.3%, 9.2% and 4.3%, for GBu5, GBu10 and GBu15, respectively, with regard to G100. From the wavelet power spectrum, it is observed that the long-term periodicities appear in gasoline fuels, while the short period oscillations become intermittently visible in blended fuels. Reduction of coefficient of variations occur as the additive of sec-butanol ratios increased, which agrees with the wavelet analysis results. Furthermore, the spectral power reduced with an increase in the additive ratio, indicating that the additive has a noticeable influence on reducing the cycle-to-cycle variations.

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1. Introduction

The search for sustainable alternative fuel for gasoline engines has recently become important due to the growing concerns with regards to rapid degradation of petroleum resources [1, 2]. Gasoline engines are widely used in private and commercial transportations [3]. Realised that petroleum reserves are non-renewable resources which means it cannot be directly replaced [4], the drive towards sustainable fuel economy for gasoline fuels is important [5]. Alcohol fuels provide an opportunity to replace a certain percentage of petroleum gasoline usage in spark ignition (SI) engines in order to significantly reduced dependency on petroleum usage [6].

Generally, butanol is a four chain of carbon with chemical structure formula $C_4H_{10}O$. Butanol is derived mainly from the fermentation of the sugars in organic feedstocks from various crops such as corn wheat, sugarcane and potato [7]. There are four types of butanol isomers: n-butanol, sec-butanol, tert-butanol and iso-butanol. Each type of butanol has different physical and chemical properties as it differs from their isomers chemical structure. Up to now, many research studies for various butanol isomers have been conducted due to its properties that closely resemble those of gasoline. Among the properties advantages include air-fuel ratio close to gasoline fuels allowing for greater ratio of butanol to be mixed; higher energy content that is 30% more than ethanol; and butanol can be transported through existing fuel pipelines due to its nature of lower tendency to separate from the petroleum fuels.

In the aspect of butanol application used as the fuel substitutes, a series of investigations have been carried out by several research groups. Feng et al. [8] is one of many researches who have studied the combustion characteristics of a four stroke single cylinder, air cooling type using 30% (Bu30) and 35% (Bu35) volume of butanol in gasoline fuels. There are three variables considered in their study such as ignition timing, butanol blend ratio and engine load. Following the mixtures, it was noted that blended fuels showed more stable rate of heat release (ROHR) indicating a more stable combustion. Bu30 and Bu35 showed a lower in-cylinder pressure than that gasoline fuels, however as the advanced ignition timing was introduced, both blended fuels indicate much higher in-cylinder pressure than that gasoline fuels. Sharper ROHR Engine load near the peak position has been found as the engine load increased. Szwaja and Naber [9] evaluated the effects of using 100% of n-butanol at two different compression ratio: 8:1 and 10:1 on a four stroke single cylinder engines. They found that rise of in-cylinder combustion temperature as the compression ratio increase, which resulted to shorten ignition delay. Despite of improved engine efficiency due to the increased of in-cylinder combustion temperature, the engine will probably suffers the bad effect of combustion knocking phenomenon. To further understand the combustion mechanisms of butanol-gasoline blends, Dernotte, Mounaim-Rousselle [10] analysed the coefficient of variation (COV) of indicated mean effective pressure (IMEP) using 20%, 40%, 60% and 80% of butanol in gasoline fuels. There was a serious evidence that with addition of butanol improved the combustion stability of the fuel blends as it reduces the COV of IMEP. From the engine performance point of view, the adaptation of butanol-gasoline blends requires efforts on development to achieve satisfactory durability of the engine due to the most of the current fuel injection system are based on gasoline fuel properties. More effort are needed to design a fuel injection system to resist alcohol corrosive nature as well as other particular components in order to simultaneously run the engine under the best possible conditions.

In view of all that has been mentioned so far, these studies provide important insights into the combustion and performance characteristics of butanol-gasoline blends in a spark ignition engines. Based on the authors' opinion, adding butanol to gasoline do not significantly modify the engine performance characteristics, however interestingly it signifies a better combustion characteristics as butanol additions improved the combustion stability of the mixture. Therefore, in this investigation, the authors intentions is to apply a novel difference analysis of proving the combustion stability of the blends using continuous wavelet transform (CWT) method. To the authors' knowledge, this is the first time CWT method was used to study the combustion stability of sec-butanol-gasoline blends in a SI engines. Along with the CWT analysis, performance characteristics of sec-butanol-gasoline blends was included in order to provide a more explicit views of the fuels.

2. Methodology

2.1. Fuel selection

In this research paper, engine testing was performed with gasoline fuels as a reference fuels denoted as (G100) and blends of 5%, 10% and 15% by volume of 2-butanol in a gasoline fuels denoted as GBu5, GBu10 and GBu15 respectively. Gasoline was supplied from local Malaysia petrol station and stored in the lab inside the proper container. The sec-butanol with purity of 99.5% were procured from Merck distributor in Malaysia. The fuel properties of G100 and sec-butanol are given in Table 1.

Table 1 Properties of gasoline and 2-butanol [11-13]

Property	Gasoline	2-butanol
Molar C/H ratio	0.44 – 0.50	-
Density (kg/m^3)	736	806.3
Latent heating value (kJ/kg)	44, 300	33, 000
Stoichiometric air/fuel ratio	14.6	11.1
RON/MON	95/85	101/92~97
Auto – ignition temperature (°C)	228 – 470	406.1
Boiling point (°C)	27 – 225	99.5
Heat of vaporization (kJ/kg)	349	551
Flammable limits (%volume)	1.4 – 7.6	1.7 – 9.8
Laminar flame speeds	~33	~48

2.2. Description of experimental setup

The engine tests of the fuel selections were performed on a four stroke four cylinder, Mitsubishi 4G93 port fuel injection naturally aspirated type with a water cooling system. Figure 1 shows the actual engine setup. Table 2 indicates the engine specifications. The engine was coupled with an eddy current dynamometer with a capacity of 100 kW. A Dynalec controller was used, which control and measures the effective torque and engine speeds. The tests was carried out from 1000–4000 RPM at 50% of wide open throttle (WOT). A total of seven thermocouple was attached to the engine setup in order to monitor the engine temperatures and surrounding conditions. One of the four engine cylinders was attached with the in-cylinder pressure sensor to measure instantaneously in-cylinder pressure of the engine using. Kistler piezoelectric in-cylinder pressure transducer 6125B spark plug type.

Table 2 Engine specifications

Engine Descriptions	
Bore x Stroke	81.0mm x 89.0mm
Piston Displacement	1834cc
Compression Ratio	9.5:1
Fuel injection type	ECI-Multi (Electronically Controlled Multi-point Fuel Injection
Max Power	86kW @ 5500rpm
Max Torque	161Nm @ 4500rpm

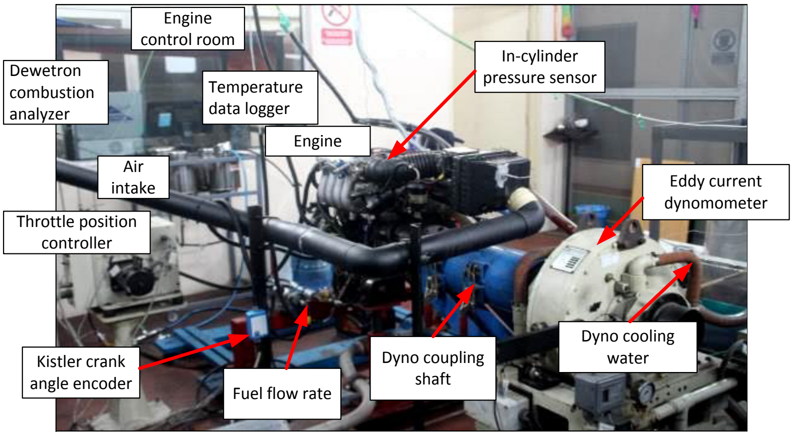


Fig. 1. Engine setup

3. Results and discussions

The coefficient of variation (COV) of IMEP for 500 cycles was intended to verify the combustion stability of the tested fuels as in Fig. 2. As the butanol percentage increases, the COV decreases, indicating that 2-butanol has better combustion stability towards the engine. The results revealed that the COVs are 4.4 bar, 4.0 bar, 3.8 bar and 3.6 bar for G100, GBu5, GBu10 and GBu15, respectively. Further calculations showed that GBu5, GBu10 and GBu15 produced better combustion stability by 9.1%, 13.6% and 18.2%, respectively. These results indicated that the existence of 2-butanol in the gasoline fuels produced an improvement in terms of its combustion stability.

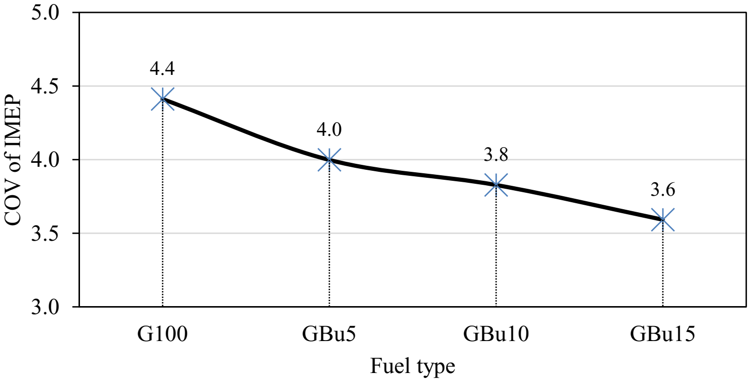
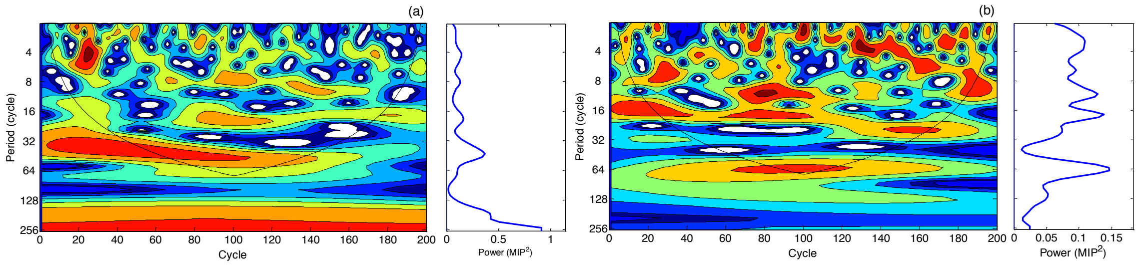


Fig. 2. COV of IMEP for different tested fuels at 3500 RPM

Using the wavelet power spectrum (WPS) and the global wavelet spectrum (GWS), the time series of IMEP for the tested 2-butanol–gasoline blends at 3500 RPM are analysed. In the WPS, the confidence level greater than 95% can be represented by red region spectrum contour lines. The 95% confidence level is equivalent to a significant at 5% level which implies that 5% of the wavelet power could lies above this level [14]. Figure 3 presents the wavelet analysis of IMEP time series for (a) G100, (b) GBu5, (c) GBu10 and (d) GBu15. Among all of the fuels it can be seen that the power in the wavelet power are distinctly higher and persists over the brief interval between 0 to 200 cycles at the periods of 200 to 256 for G100. However, as the 5%, 10% and 15% of 2-butanol introduces in the mixture of the G100 fuels the WPS started to occur at multiple time scales. On the other hand, by comparing the GWS plots for all tested fuels, GBu15 indicated lowest spectral power by less than 0.2. Accordingly, the decrease in the overall spectral power of the blended fuel with increasing concentration of 2-butanol further support results obtained from the COV of the indicated mean effective pressure time series.



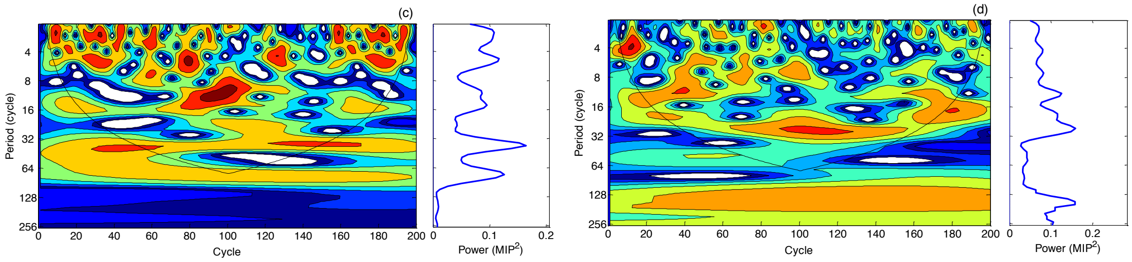


Fig. 3. Wavelet power spectrum (WPS) and global wavelet spectrum (GWS) of the IMEP time series (a) G100 (b) GBu5 (c) GBu10 and (d) GBu15

Figure 4 show the experimental data on engine (a) brake power and brake mean effective pressure (BMEP) for the tested 2-butanol–gasoline blends at engine speed of 1000–4000 RPM. When the 2-butanol content in the 2-butanol–gasoline blended fuel is increased, the engine power and BMEP slightly increased for all engine speeds. The 2-butanol–gasoline fuel blends produced an average (overall the speed ranges) of 12.3%, 9.2% and 4.3% less brake power and BMEP than that of the G100, respectively. The increase of butanol content in-creases the brake power and BMEP of the engine. Added butanol produces lean mixtures that increase the relative air–fuel ratio to a higher value and makes the burning more efficient [15].

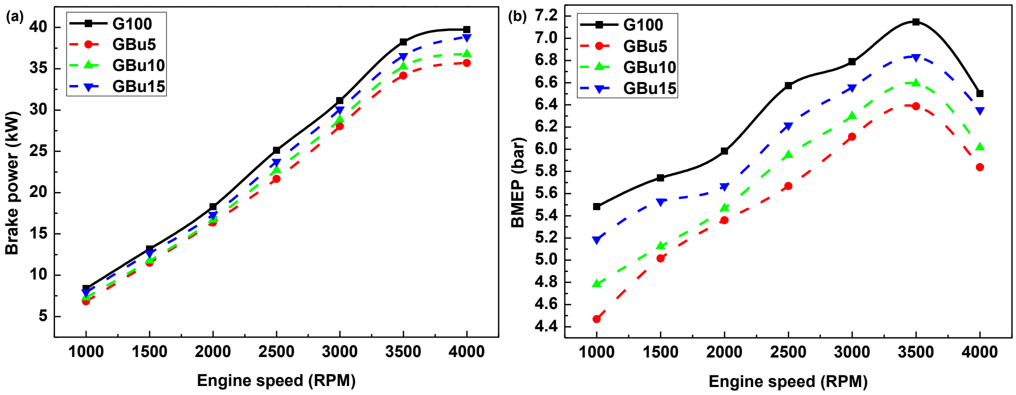


Fig. 4. Engine performance characteristics (a) brake power and (b) brake mean effective pressure (BMEP)

4. Conclusions

Experimental studies were carried out to investigate the influences of 2-butanol additions on gasoline engine operating at 50% of throttle position. The main conclusions of this study can be summarised as follows:

a. The COV of IMEP is reduced, which signifies the addition of 2-butanol stabilising the combustion process.
b. Based on the GWS plot, GBu15 indicates lowest spectral power by less than 0.2.
c. Despite better combustion process achieved by the 2-butanol–gasoline blended fuels, GBu5, GBu10 and GBu15 experienced lower brake power and BMEP.

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