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Comparison Of The Effect Of Different Alcohol Additives With Blended Fuel On Cyclic Variation In Diesel Engine

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Abstract

Blended biodiesel-diesel fuel approved as a commercial fuel for unmodified diesel engine in many countries up to 20% (B20). Biodiesel fuel properties have limited their application in diesel engines at high blending ratio therefore, chemical additives introduced as a vaible option to improve these properties. Hence, in the present study, the effect of alcohol additived with biodiesel-diesel blended fuel B30 on diesel engine cyclic variations was investigated with 6% of two alcohol additives (ethanol and butanol). The in-cylinder pressure analyses results reveal that the lowest coefficient of variation indicated for the blended fuel B30 without additives. Furthermore, the engine cyclic variability increases above that of diesel fuel when using alcohol additives with blended fuel B30 with higher engine cyclic variation for the blended fuel B30 with ethanol compared to butanol. The results of wavelet power spectra analysis reveal that the in-cylinder pressure variations exhibit different types of behavior varying from intermittent fluctuations for B30 without additive to strongly periodic oscillations for B30 with alcohol additives compare to that of diesel fuel. Furthermore, the global wavelet spectra show that the overall spectral power increases when using alcohol additives with the blended fuel B30, which is in agreement with the coefficient of variation results.

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Blended fuel; butanol; cyclic variation; diesel engine; ethanol; wavelet analysis

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1. Introduction

Biodiesel has been gaining more attention as a promising renewable and clean energy source that can use as a fuel for diesel engine with no or little modification [1]. It is a mixture of mono-alkyl esters of saturated and unsaturated long-chain fatty acids. Biodiesel-diesel blended fuel utilization limited to 20% blending ratio mainly due to higher viscosity and lower energy content of biodiesel in addition to it is higher pour point and cloud point [2]. The use of fuel additives is one of the most visible methods that make the blended biodiesel-diesel fuel available in high blending ratio as an alternative fuel for mineral diesel [3]. Typically, biodiesel energy content is less than that of mineral diesel which has direct influence on the engine power [4]; therefore the selected additive most not worsen the energy content of the fuel. Alcohol additives like ethanol (E) and butanol (BU) can be used to improve the properties of biodiesel fuel [5]. However, these additives have a relatively low flash point and auto-ignition temperature compare to diesel and biodiesel fuel [6], and it may lead to noticeable increase in engine cycle-to-cycle variations when exceeds a certain limit. These variations might lead to both a reduction of engine output power and higher emissions; so it is necessary to develop effective strategies to control the optimum additive ratio through gaining a better understanding of the different parameters that influence the overall combustion process.

Several studies were conducted using the coefficient of variation (COV) for analyzing the in internal combustion engines cycle to cycle variation (CCV). It is a practical statistic to compare the degree of variation between two time series even if their mean values are entirely different [7]. It provides a single numerical measure for a given time series characterizing the temporal variability in the data [8]. Furthermore, to consider the time series spectral characteristics, a wavelet based spectral temporal approach is used in this study to investigate the IMEP time series CCV, and estimates the influence of additives with blended fuel B30 on the engine cyclic variations. The techniques of wavelet-based are being used increasingly for analysis of time series in a various applications [9]. The detail description of the wavelet analysis methodology using CWT is found in [10]. Continuous wavelet transforms (CWT) has gotten more attention in recent research to understand the climate fluctuations for many years. In the field of internal combustion engine, earlier studies mainly focused on spark ignition engines (SI). However some recent studies have conducted on diesel engines for studying the effect of different engine speeds [11] and different alternative fuel for a diesel engine compared to mineral diesel [12].

This study aimed to investigate the diesel engine cycle to cycle variation operate with blended palm biodiesel-diesel fuel B30 with 6% of two different alcohol additive. Wavelet analysis of the indicated mean effective pressure (IMEP) time series is conducted to study the diesel engine cyclic variations. Furthermore, the IMEP coefficient of variation (COVimep) is calculated and compared with that of blended fuel B30 and mineral diesel to indicate the trend of engine cycle-to-cycle variation with chemical additives.

Nomenclature

WPS	wavelet power spectrum
GWS	global wavelet spectrum
IMEP	indicated mean effective pressure
COV	coefficient of variation
E	Ethanol
BU	Butanol
B30	blended fuel (70% diesel+30% biodiesel)

2. Methodology

2.1. Materials and fuel preparation

Palm oil biodiesel (POME) was supplied by local commercial company in Selangor, Malaysia. Diesel fuel was provided by a commercial fuel manufacturer. The fuel samples of palm oil methyl ester and mineral diesel were prepared as a blended fuel B30 through blending 30% POME + 70% mineral diesel, by volume, and mixing using an electric magnetic stirrer. The mixtures were continuously stirred for about 20 minutes. Then, butanol and ethanol were added at low stirring rate into the blended fuel. Further stirring of the mixtures were conducted continuously for additional 20 minutes after that left for 30 minutes at room temperature to reach equilibrium before subjected to any test. The use of chemical additives has also some limitations, such as lower lubricity, reduced ignitability and cetane number, higher volatility and lower miscibility [2] which may lead to increased unburned hydrocarbons emissions. Therefore, butanol and ethanol additives were added to the blended fuel at small proportions of 6% by volume, which corresponded to B30BU6 and B30E6 fuels, respectively.

2.2. Diesel engine test

The fuels engine tests were conducted with natural aspirate type four cylinder Mitsubishi4D68 diesel engine water cooled. The engine specifications are; 22.4:1 compression ratio with total displacement of 1.998 dm^3 and 0.89 bore/stroke ratio. The tested fuels include blended fuel B30, B30E6, B30BU6 and mineral diesel. The engine is coupled to eddy current dynamometer with a capacity of 150 kW controlled by a Dynalec controller; measuring and controlling the effective torque and engine speed. The tests were conducted at 2500 rpm engine speed, with a 50% open throttle. A Kistler 6041A water cooled ThermoComp transducer with a measuring rate 0 to 250 bar and a sensitivity of -20 pC/bar was used to measure the in-cylinder pressure. The crank angle signal was acquired with a Kistler 2613B1 crank angle encoder, and the pressure and crank angle information were recorded by a DEWECA data acquisition system. The in-cylinder pressure data were collected for 200 consecutive engine cycles. The engine is equipped with an exhaust gas recirculation system, however in this experiment the EGR mode is set to OFF.

2.3. Engine cyclic variation

The cycle to cycle variations (CCV) of the IMEP time series are assessed using (a) the coefficient of variation (COV), and (b) wavelet analysis. The COVimep is widely used to evaluate the cycle by cycle variations in the engine studies. It is defined as the ratio of its standard deviation (SD) to its mean value $\overline{IMEP}$, and is usually expressed in percent form:

$$\text{COV}=(\text{SD(IMEP)})/\overline{IMEP}\times 100 \tag{2}$$

where (IMEP) represents the indicated mean effective pressure of a specific combustion cycle.

The continuous wavelet transform of IMEP time series for N number of consecutive engine cycles with respect to a wavelet ψ(t) is defined by [10]:

$$W_n(s) = \sum_{n'=0}^{N=1} (\frac{\delta t}{s})^{1/2} x_n \psi^* \left[\left[\frac{(n'-n)\delta t}{s}\right]\right] \tag{3}$$

where: n is the time index, s is the wavelet scale, δt is the sampling interval and ψ* Is the complex conjugate.

The squared modulus of the continuous wavelet transform is defined as the wavelet power spectrum (WPS) and representing the signal energy. The WPS is plotted on a time-frequency (or time-period) plane, which depicts the various time series periodicities and their temporal variations. To describe the time series of IMEP considered in this study, the WPS is plotted on a plane with the cycle number as the x-axis and period (cycle) as the y-axis. Another useful quantity called the global wavelet spectrum (GWS) can be computed from the WPS. The GWS is the average of the WPS overall time, and is analogous to a smoothed Fourier spectrum:

$$\overline{W}_s^2 = \frac{1}{N}\sum_{n=1}^{N}\left|W_n(s)\right|^2 \quad (4)$$

The time series dominant periodicities can be identified from the peak locations in the GWS. The wavelet ψ is referred to as the analyzing wavelet or mother wavelet, and an asterisk on ψ represents a complex conjugate. In this study a Morlet wavelet of order 6 was used as the mother wavelet in the analysis. The choice of order 6 provides a good balance between the time and frequency resolutions. The Morlet wavelet has been used successfully as a mother wavelet in a different of applications [10].

3. Results and discussions

Figure 1 presents the coefficient of variation of indicated mean effective pressure collected from the engine test at 2500 rpm for 200 consecutive cycles and half load conditions. The graph reveals that the blended fuel B30 has the lowest COVimep among the tested fuels due to the effect of high cetane number of POME compared to mineral diesel. Adopt alcohol additives with blended fuel B30 result in an increase in the COVimep to above that of mineral diesel fuel by about 14% and 10% for ethanol and butanol additives respectively. This means that, the cyclic variations become more noticeable with blended fuel B30 and alcohol additive. This is due to the different chemical composition and high volatility of the chemical additives which is affecting the combustion process of the fuel mixture [13]. Furthermore, The COVimep was higher with ethanol than butanol due to the low flash point of ethanol (16 ^{o}C) compared to butanol (35 ^{o}C).

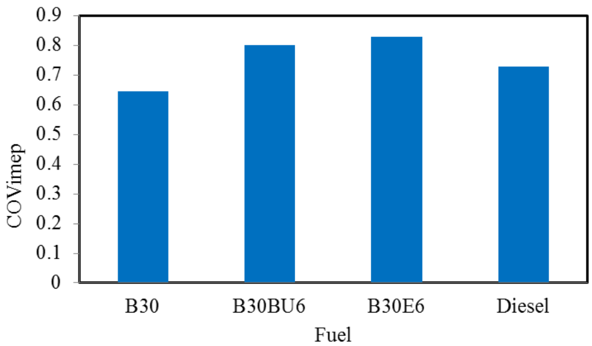

Fig.1. COVimep for different fuels

In the wavelet power spectrum (WPS), the red noise background spectrum contour lines enclose regions represent greater than 95% confidence. The region under the U-shaped curve is referred to as the cone of influence (COI). The COI is the region of the WPS in which edge effects become important and the results inside the COI may be unreliable and should be used with caution [10].

Based on the record length of 200 cycles of the IMEP time series, we confine our considerations to the periodicities of less than 64-cycle. From the WPS and global wavelet spectra (GWS) illustrated in Fig. 2 it is clearly obvious that the cycle to cycle variations of the IMEP occur at multiple time scales with diesel fuel. However, Fig. 3 reveals that the engine cycle to cycle variation (CCV) exhibit mainly low frequency intermittent fluctuations for blended fuel B30. As the additive is introduced, persistent low frequency oscillations tend to develop in the engine cycle to cycle variation as shown in Fig. 4 and Fig. 5. The persistent oscillation for blended fuel with butanol appears between the 4-cycle period and 16-cycle period lasting over almost 20 engine cycles. On the other hand, the persistent oscillation for blended fuel with ethanol appears between the 8-cycle period and 16-cycle period as well as between the 16-cycle period and 32-cycle period lasting over almost 50 engine cycles. In general, it can be seen from the GWS plots for different fuels that the spectral power increases as the additive introduce with the blend fuel B30. A comparison of the GWS for the tested fuel reveals that the blended fuel B30 has the lowest overall spectral power, while the blended fuel B30 with ethanol additive has the higher overall spectral power; indicating that alcohol additive has a pronounced effect on increasing the CCV of the IMEP time series.

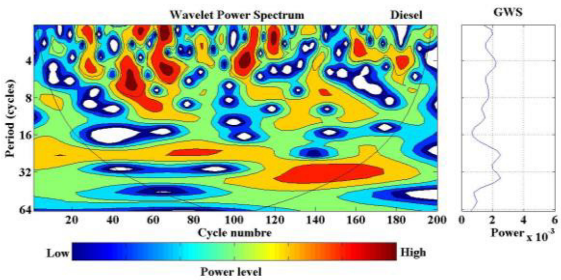

Fig. 2. WPS and GWS for diesel fuel

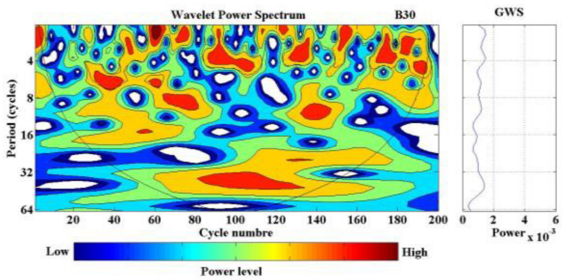

Fig. 3. WPS and GWS for blended fuel B30

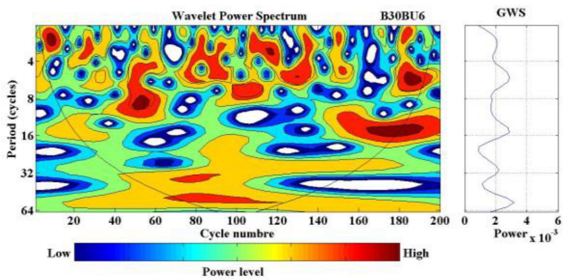

Fig. 4. WPS and GWS for blended fuel B30BU6

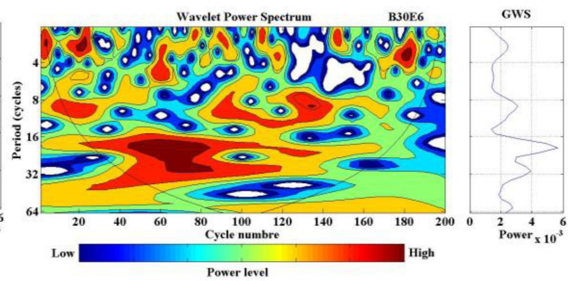

Fig. 5. WPS and GWS for blended fuel B30E6

4. Conclusions

The results of indicated mean effective pressure analysis reveal that the lowest COVimep was indicated for blended fuel B30 without additive. Furthermore, the engine cyclic variability increases by 23% and 28% when using 6% of butanol and ethanol respectively with blended fuel B30. Moreover, the engine cyclic variation with both additives rises above that with diesel fuel and the effect is more noticeable with ethanol. The results of wavelet power spectra analysis show that the in-cylinder pressure variations exhibit different types of behavior varying from intermittent fluctuations for B30 without additive to strongly periodic oscillations for B30 with alcohol additives compared to that of diesel fuel. The different periodicities and the number of cycles over which they persist are determined from a wavelet power spectrum time-period representation. The intermittency patterns are readily discerned from the wavelet spectra also. Furthermore, the global wavelet spectra show that the overall spectral power increases when using additives with the blended fuel B30, which is in agreement with the coefficient of variation of indicated mean effective pressure results. Accordingly, both additives seem to increase the cycle to cycle variations with lower engine cyclic variation for the blended fuel B30 with butanol compared to ethanol.

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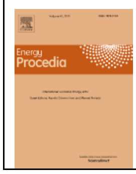

Biography

Dr. Obed M. Ali is a senior lecturer at Universiti Malaysia Pahang. He was graduated his Doctor of Philosophy at Malaysia.