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Study of diesel-biodiesel fuel properties and wavelet analysis on cyclic variations in a diesel engine

Mohd Hafizil Mat Yasin[a,*], Rizalman Mamat[a], Obed Majeed Ali[b], Ahmad Fitri Yusop[a], Mohd Adnin Hamidi[a], Muhammad Yusri Ismail[a], Muhammad Rasul[b]

[a]*Faculty of Mechanical Engineering, Universiti Malaysia Pahang, Address, City and Postcode, Malaysia*
[a] *Technical Institute of Haweeja, Northern Technical University, Iraq*
[a]*School of Engineering & Technology, Central Queensland University, Australia*

Abstract

Continuous searching in new energy sources has been a crucial issue for sustaining the increasing energy demand. Due to the present economic and social modernization as well as petroleum oil depletion crisis, makes promising alternatives such as renewable energy sources an important choice for the next power generation. Petroleum fuel includes diesel currently used in power generation, transportation, and industrial sectors. The introduction of biodiesel as a secondary fuel for diesel engines has revolutionized the use of different fuels with fuel blending in current diesel. Though biodiesel-diesel fuel can substitute diesel fuel at an acceptable blending ratio rate up to 20%, fuel properties could be affected with beyond the limit from the engine manufacturer's standard when blending at high volume ratio. Thus, in the present study, the use of the diesel-biodiesel fuel (B20) was investigated corresponding to the fuel properties and engine cyclic variations. Also, the tested fuels include mineral diesel were tested experimentally in a diesel engine with the in-cylinder pressure data measurement for 1000 cycles. These data were analyzed using the coefficient of variation (COV) and wavelet power spectrum (WPS). Fuel properties test results showed significant differences in density and acid value with a significant reduction in viscosity when diesel is blended with biodiesel at 20%. Despite that, the low heating value was significantly affected for B20 compared to pure biodiesel. While as for the wavelet analysis results, the short period oscillations appear periodically in pure biodiesel and mineral diesel, but in contrast, the long and intermediate-term periodicities has are found in B20. Moreover, the spectral power has increased with B20, which attributed significantly to the engine cyclic variations. This characteristic validated the coefficient of variation (COV) for the indicated mean effective pressure (IMEP) time series that B20 produces the lowest fluctuation in cyclic variations compared to other fuels.

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Keywords: diesel-biodiesel; fuel properties; wavelet analysis; cyclic variations; diesel engine

* Corresponding author. Tel. +6-013-711-4669.
E-mail address: mohdhafizil80@gmail.com

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1. Introduction

The current situation of fossil fuel is very critical, and it is become urgent to look for a suitable alternative due to the continuous increasing demand for these fuels and depleting of their sources. The transportation sector is the primary consumer of these fuels because of the huge number of vehicles that uses in different walks of life [1]. Diesel fuel occupies the larger share of fuel trade in 2010 resulting from the extensive usage of a diesel engine in the different a applications [2]. Furthermore, the usage of fossil fuel can be considered as the main contributor to air pollution and global warming. Diesel engine designed and developed to operate using mineral diesel fuel, therefore, it is important to look for a suitable alternative with similar characteristics to suit the existing diesel engines. Though many alternative fuels have been suggested to replace mineral diesel in a diesel engine, it is still facing the challenge of high engine modification cost. Therefore, the implemented alternative fuel should be suit the current engine design. Biodiesel fuel has been considered as the unique alternative fuel that can be used directly for a diesel engine with no or little modification. The different sources of biodiesel are available in mostly all the regions of the world and can be considered as a domestic product. Furthermore, these fuels can be adopted to mitigate the environmental pollution from diesel engine due to the high CO_2 saving and fewer engine emissions [3]. In general, the properties of biodiesel from different sources are slightly different depending on the biodiesel feedstock according to the ASTM biodiesel fuel standard. The blending of biodiesel with mineral diesel is one of the common methods to introduce biodiesel as a fuel for direct usage in diesel engine under the ASTM blended fuel standard [4,5]. Accordingly, selection of the maximum percentage of biodiesel for blending with diesel according to the blended fuel standard depends on the biodiesel feedstock property. Therefore, evaluating the blended fuel properties is the most important criteria to choose the suitable blend ratio.

Engine cyclic variation has been investigated recently by many researchers as it is related to the output power and fuel consumption [6,7]. The earlier studies mainly focused on spark ignition engine. However, recent studies were conducted to analyze diesel engine cyclic variations with different alternative fuels [8]. These fuels have different chemical combustion and therefore, different combustion behavior is expected. Accordingly, the engine stability for long-term operation should be considered and evaluated using diesel fuel as the threshold.
The aim of this paper is to characterize the blended fuel, B20 properties compared to the palm biodiesel and mineral diesel as well as according to the biodiesel blended fuel standard ASTM D7467. Moreover, this study also evaluates the engine cyclic variations at 2500 rpm with engine load of 60%, operating with the test fuels at 1000 cycles each using the coefficient of variation of the indicated mean effective pressure (COVimep) and wavelet spectrum analysis approach.

Nomenclature

COV	coefficient of variation
WPS	wavelet power spectrum
IMEP	indicated mean effective pressure
COVimep	coefficient of variation of the indicated mean effective pressure

2. Methodology

Palm biodiesel is also known as palm oil methyl ester (POME) which purchased from a local biodiesel production company in Pahang, Malaysia. While as for mineral diesel fuel to be a reference fuel was provided by a commercial fuel supplier. Samples of palm biodiesel and mineral diesel were prepared using an electric, magnetic stirrer for mixing and blending into B20 fuel (80% vol. mineral diesel + 20% vol. palm biodiesel). These blend fuels were stirred continuously for an hour to achieve well blending and left for an hour to reach the stability before being tested. The use of biodiesel in different blending could provide some limitations such as higher lubricity, reduction in ignitability, shorter ignition delay, lower volatility and higher cetane number. Test fuel samples were analyzed for the density measurement at the temperature of 15 °C using the Portable Density/Specific Gravity Meter (model DA-130N). Also, the viscosity analysis was conducted on the test fuels using a digital constant temperature kinematic viscosity bath model K23376-KV1000 at a steady temperature of 40 °C ±0.01. While as for the acid value content, the test fuels were measured by a Metrohm test instrument model 785 with referring to the method procedure proposed by American

Oil Chemists Society. The energy content is among other fuel properties that been considered, which influence the engine power performance when operating with diesel-biodiesel blends. Thus, limited studies on the energy content analyses have been conducted which do not reveal much on the instrumentation and equipment as well detailed procedure used for analysis. The experimental study of cyclic variations was conducted using a four-stroke, four cylinder diesel engine with water-cooled and EGR system. The engine was coupled to a 150 kW eddy current dynamometer which controlled by a Dynalec controller. The controller is used to measure and control the torque, load, and engine speed. Engine specifications, and test conditions are listed in Table 1 and Table 2 respectively.

Table 1 Specifications of the test engine

Description	Specification
Number of cylinders	4 in-line
Combustion chamber	Swirl chamber
Total displacement cm	1.998 cc (121.925 cu in)
Cylinder bore mm x Piston stroke mm	82.7 x 93
Bore/stroke ratio	0.89
Compression ratio	22.4:1

Table 2 Test condition

Parameters	Test condition
Type of Fuel	Diesel, B20, B100
Speed (rpm)	2400
Load	60%
Fuel temperature	27 ± 1 °C
Air temperature	30 ± 1 °C

Since the engine cyclic variation focuses on the peak by peak cylinder changes, the in-cylinder pressure was determined using a water-cooled Kistler 6041A ThermoComp pressure transducer with a measurement range from 0 to 250 bar using sensitivity at -20 pC/bar. A Kistler crank angle encoder (type 2613B1) was used to obtain the crank angle signal. These pressure and crank angle signal measurement were recorded and analyzed with DEWECA data acquisition system. Those in-cylinder pressure data were set and collected at 1000 following cycles. Since the study is not included the EGR mode, the mode was set OFF during the engine testing. In this study, evaluation of cyclic variations of the IMEP time series is accomplished using the coefficient of variation in the IMEP (COVimep) and wavelet spectrum analysis approaches. The details of this study are available in the previous literature [9,10].

3. Results and Discussion

Fuel properties are the most important indicator to approve the suitability of individual fuel usage for diesel engine within the fuel standard [5,11]. Therefore, evaluation of fuel properties is very necessary when considering different alternative fuels before operating the engine and analyze the fuel combustion. The fuel property test results for diesel, pure biodiesel (B100) and blended fuel (B20) are shown in Table 3 together with the standard test method for each property. In general, biodiesel fuel density is higher than that of diesel fuel which increases the specific fuel consumption for the same engine power [12]. The fuel injection systems measure the fuel flow by volume while the calculation of fuel consumption based on mass which reveals the effect of density on engine operation. Fig. 1(a) shows the effect of blending 20% biodiesel with 80% diesel on fuel density. It is clearly obvious that biodiesel fuel density is higher than diesel by about 5%. However, this value is reduced to about 1% for B20 compared to diesel fuel due to the blending effects. From Table 3, it is evident that biodiesel fuel density is much more than that of diesel fuel which affects the fuel droplet formation and sprays penetration [13]. Fig. 1(b) shows the effect of blending 20% biodiesel with 80% diesel on fuel viscosity. It is clearly obvious that biodiesel fuel density is higher than diesel by about 34%. However, this value is reduced to about 6.5% for B20 compared to diesel fuel due to the blending effects.

Fuel energy content can be defined as the amount of heating energy liberated by the combustion of a unit value of the fuel. Biodiesel fuel energy content is less than that of diesel fuel which reduces the output power from the engine for the same specific fuel consumption [14]. Fig. 1(c) shows the effect of blending 20% biodiesel with 80% diesel on fuel energy content. It is clearly obvious that biodiesel fuel energy content is lower than diesel by about 20%. However, this value is reduced to about 8.5% for B20 compared to diesel fuel due to the blending effects. From Table 3, it is evident that biodiesel fuel flash point is much more than that of diesel fuel which ensures safe handling and storage of fuel. Fig. 2(a) shows the effect of blending 20% biodiesel with 80% diesel fuel. It is clearly obvious that biodiesel fuel has the higher flash point which is 180ºC. This value is reduced to 110ºC for B20 which is greater than that of diesel fuel (70ºC) due to the blending effects.

Table 3 Tested fuel properties results

Properties	Testing method	Diesel	B20	B100
Density (kg/m^3)	ASTM D287	837	845	878
Viscosity (mm^2/s)	ASTM D445	4.237	4.514	5.680
Energy content(MJ/kg)	ASTM D240.	49.96	45.71	39.92
Flash point (°C)	ASTM D93	70	110	180
Acid value	ASTM D3339	0.24	0.02	0.03
Moisture content (%)	ASTM D6304	0.42	1.16	1.24

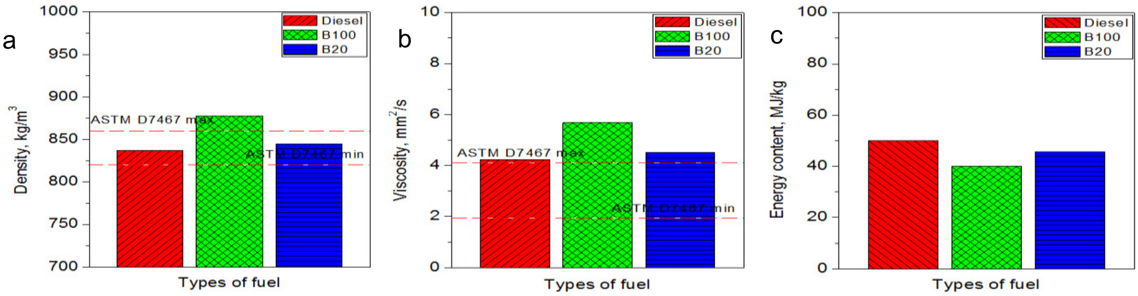

Fig. 1. (a) Density b) Viscosity c) Energy content

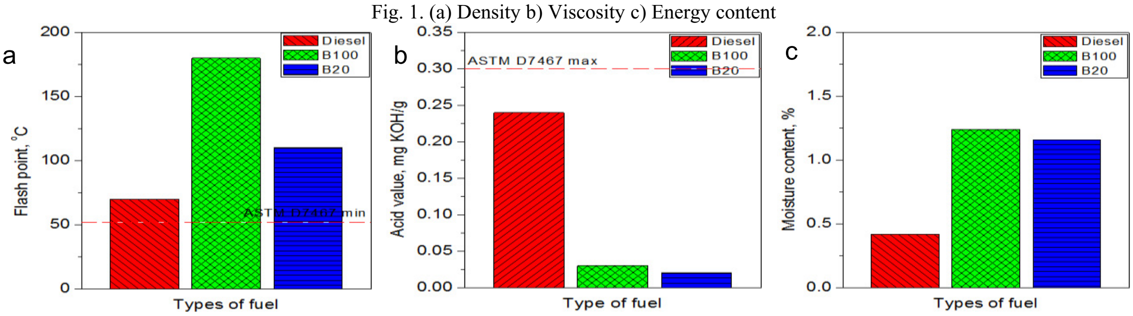

Fig. 2. (a) Flashpoint b) Acid value c) Moisture content

Fuel acid value is defined as the amount of mg KOH required to neutralizing 1g of FAME. An increase in the fuel acid value content may lead to enhance the corrosion of the engine fuel supply system [15]. Fig. 2(b) shows that all the tested fuel samples are within the maximum value limit of the blended fuel standard (ASTM D7467). From Table 3, it is evident that biodiesel fuel moisture content is relatively higher than that of diesel fuel due to the high water content of the biodiesel feedstocks. Fig. 2(c) shows the effect of blending 20% biodiesel with 80% diesel fuel. It is clearly obvious that biodiesel fuel has the higher moisture content which is 1.24%. This value is reduced to 1.16% for B20 which is greater than that of diesel fuel (42%) due to the blending effects.

3.2. Engine Cyclic Variations

Fig. 3 describes the engine cyclic variation with the different tested fuels using the calculated coefficient of variation (COV) of indicated mean effective pressure (IMEP). A consecutive 1000 engine cycles were collected for each test at the same engine conditions for more accurate results. In this study, the engine cyclic variation has been considered as the threshold for comparison to evaluate the other tested fuels. The Fig. shows a decrease in the COV when using B20 to operate the engine compared to diesel. This trend may attribute to the effect of high cetane number of palm biodiesel compared to diesel fuel which enhances the combustion of the fuel [16]. However, the COV increases when using B100 compared to B20 which can be attributed mainly to the relatively high viscosity of biodiesel compared to diesel fuel. The high fuel viscosity affects the fuel spray quality and leads to atomization and penetration problems [17].

The wavelet analysis results have been described through the wavelet power spectrum (WPS) in which the contour lines enclose regions with greater than 95% confidence represented by red noise background spectrum. The region under the U-shaped curve represents the cone of influence (COI) in which the results inside may be unreliable and should be used with caution due to the edge effects [9]. Based on the calculated IMEP time series of the 1000 collected cycles, the considerations has been confined to the periodicities up to 256-cycle. Fig. 4 illustrates the WPS and global wavelet spectra (GWS) for diesel fuel; it is evident that the IMEP cycle to cycle variations occur at multiple time scales. The strong, persistent oscillation for diesel appears around the 64-cycle period lasting over almost 100 engine cycles and 128-cycle period lasting over almost 280 engine cycles. On the other hand, the engine cyclic variations with blended fuel B20 exhibits lower frequency compared to diesel fuel with intermittent fluctuations as illustrated in Fig. 5. The high, persistent oscillation for B20 appears around the 64-cycle period lasting over almost 200 engine cycles and 128-cycle period lasting over almost 180 engine cycles. Persistent low-frequency oscillations tend to develop in the engine cycle to cycle variations with pure biodiesel as shown in Fig. 6. The high, persistent oscillation for B100 appears around the 128-cycle period lasting over almost 340 engine cycles.

Global wavelet spectra (GWS) can provide more noticeable results for the engine cyclic variations with different fuels. A comparison of the GWS for the tested fuels reveals that blended fuels B20 has the lowest overall spectral power compared to diesel and pure biodiesel fuels.

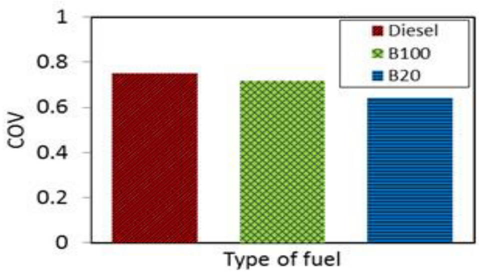

Fig. 3. COV For different fuels

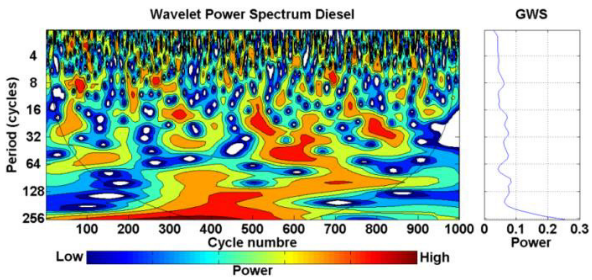

Fig. 4. WPS and GWS for mineral diesel

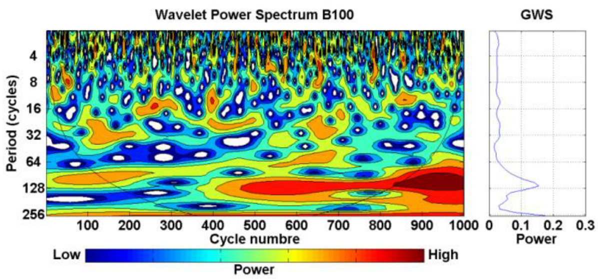

Fig. 5. WPS and GWS for palm biodiesel (B100)

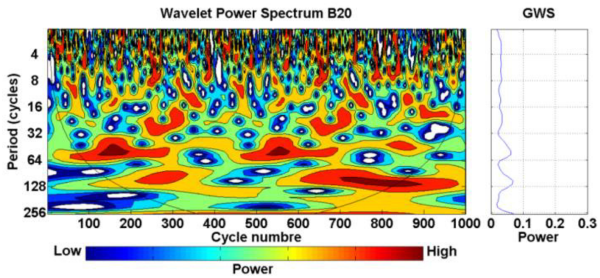

Fig. 6. WPS and GWS for palm biodiesel-diesel blends (B20)

4. Conclusion

In this study, blended fuel properties were investigated and evaluated compared to blended fuel standard ASTM D7467. Furthermore, the engine cyclic variation has been analyzed using the coefficient of variations and wavelet analysis method. Fuel property analysis results show an improvement in biodiesel fuel density and viscosity close to that of diesel fuel. However, fuel energy content value is reduced to about 8.5% for B20 compared to diesel fuel. On the other hand, blended fuel B20 flash point is much more than that of diesel fuel which ensures safe handling and storage for the fuel. The fuel's acid value for all the tested fuel samples is within the maximum value limit of the blended fuel standard ASTM D7467 with slightly higher moisture content for blended fuel and biodiesel compared to mineral diesel. The wavelet power spectrum (WPS) analysis for diesel fuel shows that the IMEP cycle to cycle variations occur at multiple time scales. On the other hand, the engine cyclic variations with blended fuel B20 exhibits lower frequency compared to diesel fuel with intermittent fluctuations. Persistent low-frequency oscillations tend to develop in the engine cycle to cycle variations with pure biodiesel. A comparison of the Global wavelet spectra (GWS) for the tested fuels reveals that blended fuels B20 has the lowest overall spectral power compared to diesel and pure biodiesel fuels.

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