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Analysis of blended fuel properties and engine performance with palm biodiesel–diesel blended fuel

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ABSTRACT

Depleting fossil fuel sources accompanied by continuously growing energy demands lead to increased interest in alternative energy sources. Blended biodiesel–diesel fuel has been approved as a commercial fuel at a low blending ratio. However, problems related to fuel properties are persistent at high blending ratios. Hence, in this study, the feasibility of biodiesel produced from palm oil was investigated. Characterization of blended fuel properties with increasing palm biodiesel ratio is conducted to evaluate engine performance test results. The qualifying of blended fuel properties was used to indicate the maximum blending ratio suitable for use in unmodified diesel engines according to the blended fuel standard ASTM D7467. The property test results revealed that blended fuel properties meet blended fuel standard requirements at up to 30% palm oil biodiesel. Furthermore, blending is efficient for reduction of the pour point from 14 °C for unblended biodiesel to less than 0 °C at a 30% biodiesel blending ratio. However, the energy content reduces by about 1.42% for each 10% increment of biodiesel. Engine test results demonstrated that there was no statistically significant difference for engine brake thermal efficiency among tested blended fuels compared to mineral diesel, and the lowest engine cyclic variation was achieved with blended fuel B30.

1. Introduction

Biodiesel is a renewable energy, which is considered the most viable alternative for replacement of mineral diesel fuel in compression ignition engines [1,2]. It is a biodegradable fuel comprised of fatty acid methyl ester and synthesised from the transesterification of vegetable oil or animal fats [3]. The world currently mandates biodiesel usage based mostly on blending with diesel fuel. These blends are designated according to the biodiesel blending volumetric percentage, where B100 represents 100% biodiesel, B20 indicates 20% biodiesel and B30 indicates 30% biodiesel, depending on the volumetric percentage after the letter “B” [4].

Biodiesel feedstock availability and sustainability are the most important determining factors in the popularisation of biodiesel [5]. Palm oil is derived from a plant that is perennial and grows in tropical regions, especially humid lowlands. In general, palm oil has the highest oil yield compared to other common biodiesel feed stock; as a comparison, production is about thirteen times higher than that of soybean [6]. The previous studies have shown that biodiesel production cost mainly depends on feedstock cost, which represents about 75%–80% of the total production cost [7]. Hence, the choice of biodiesel feedstock with high oil yield is a crucial determinant to produce biodiesel with low cost.

Biodiesel is a mixture of mono alkyl esters of saturated and unsaturated long-chain fatty acids with high viscosity and density and poor cold-flow properties compared to mineral diesel fuel. The blending of biodiesel with mineral diesel is the most common method for overcoming low temperature flow problems in biodiesel and improving their properties due to their similar characteristics.

Currently, fuel energy content is one of the more important technical issues that indicates the use of blended biodiesel–diesel fuel at a high blending ratio, as the engine power output is influenced directly by fuel energy content [8]. Typically, the energy content of biodiesel fuel is less than that of mineral diesel due to different chemical compositions, which affect the blended fuel energy content with increasing biodiesel fuel ratio in the blend with mineral diesel. The previous research work conducted to

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measure blended fuel energy content was limited and did not detail the measuring methods and equipment used. Moreover, research concerning the energy content of palm oil biodiesel remains scarce.

The wavelet analysis is becoming a common tool for analysing localised variations of power within a time series. By decomposing a time series into the time-frequency space, both the dominant modes of variability and how those modes vary in time can be determined. Therefore, it is extremely useful for many applications in which a signal may potentially singularities and/or on stationary power over a wide range of frequencies. These applications include environmental changes [9] and engine cyclic variation [10]. Earlier work focused mainly on spark ignition engines, but more recent studies have directed their attention on diesel engines also [11,12]. Many descriptions of the theory and applicability of the wavelet analysis exist in various references. Therefore, the treatment in this section is based on those most cited by Torrence and Compo [13].

Blending of biodiesel with mineral diesel is the most common method for enhancing the biodiesel property and overcoming the fuel cold flow problems. Biodiesel from different feedstock's can blend with mineral diesel and used as a fuel for diesel engine. This blend is approved as a fuel for the existing diesel engines at low blending ratio up to 20% biodiesel (B20) according to the ASTM D7467 fuel standard specification. Accordingly, it is used as a commercial fuel in many countries. However, at high blending ratios problems related to fuel properties are worsening. The measurement and evaluation of blended fuel property is an important indicator for the maximum blending ratio of biodiesel from different sources that can meet the fuel specification requirements. Furthermore, it will be easier to analyse the engine performance results with increasing biodiesel ratio in the blend when the key properties of the used fuel are known. Biodiesel fuels properties differ from those of mineral diesel fuel, which means different combustion characteristics. Therefore, investigations of engine cyclic variation with increasing biodiesel ratio in the blend are needed before using in a diesel engine.

The aim of this study is to characterise the properties of palm oil biodiesel–diesel blended fuel compared to the blended fuel standard ASTM D7467. Investigation of engine; performance, emissions, and cyclic variations have been conducted with the blended fuel that meet the fuel standard specification. The engine test results with blended fuel are evaluated compared to the results of diesel fuel engine test as a standard fuel for comparison.

2. Methodology

2.1. Materials and method of blend preparation

A local industrial company in Selangor, Malaysia supplied the Palm oil biodiesel (POME). A commercial fuel supplier provided diesel fuel that is available in public fuel stations. Samples of palm oil biodiesel and mineral diesel were prepared using an electrical magnetic stirrer. Briefly, palm oil biodiesel was added to petroleum diesel at a low stirring rate. The mixture was stirred continuously for 20 min and left for 30 min at room temperature to reach equilibrium before subjected to any tests. In addition to Palm oil biodiesel (B100) and mineral diesel (D) five biodiesel–diesel blends were prepared through blending palm oil biodiesel at 10%, 20%, 30%, 40%, and 50% by volume with mineral diesel, which corresponded to B10, B20, B30, B40, and B50 fuels, respectively.

2.2. Palm biodiesel fatty acid composition

The fatty acid (FA) composition of unblended palm oil biodiesel was indicated through the gas chromatography (GC) analysis. In this test, the used GC was an Agilent type from Agilent Technologies, model 6890 equipped with FID detector. The GC column was Agilent 19091S-433 (0.25 mm diameter × 0.25 μm film thickness × 30.0 m length) with 1.1 mL/min initial flow, 17.63 psi head pressure and 31 cm/s average velocity. Helium gas was used as a carrier at 1.1 mL/min gas flow rate. The FID detector temperature and the injector temperature were 250 °C and 240 °C, respectively. The initial oven temperature was held at 140 °C for 2 min and then increased to 220 °C at a rate of 8 °C per minute.

2.3. Fuel property measurements

The fuel properties tests were conducted in a chemical laboratory under controlled temperatures and humidity to ensure accurate results. The test apparatus manufactured by the Koehler instrument company K46195 (USA) was used for the cloud and pour point measurements according to ASTM D-2500 and ASTM D-97 standard methods, respectively. The acid value was determined using the test apparatus manufactured by Metrohm 785 (USA) according to the ASTM D-664 standard method. Kinematic viscosity measurements were made with a digital constant temperature kinematic viscosity bath according to the standard ASTM D-445 method, while the density was measured using a portable density/gravity meter according to the ASTM D1298 standard method. The heating value of blended fuel that was not specified in the biodiesel standards ASTM D6751 had a minimum value of 35 MJ/kg in EN 14214, which was determined by an oxygen bomb calorimeter model 6772 (Parr instrument company, USA).

2.4. Engine test

The fuels engine tests were conducted with a natural aspirated-type water-cooled four-cylinder Mitsubishi 4D68 diesel engine with a compression ratio of 22.4:1, a total displacement of 1.998 dm^3, and a bore to stroke ratio of 0.89. A schematic diagram of the experimental engine setup is illustrated in Fig. 1. The engine was coupled to an eddy current dynamometer with a capacity of 150 kW controlled by a Dynalec controller, which measured and controlled the effective torque and engine speed.

The in-cylinder pressure trace was instantaneously measured using a Kistler 6041A ThermoComp water-cooled piezoelectric transducer for pressure measurement. A crank angle encoder was used to specify the crankshaft position during the combustion process, with comparisons drawn to the differential cylinder pressures. The DEWECa software, provided by DEWETRON, was used to collect the pressure data and analyse combustion characteristics. The tests were conducted at a constant engine speed of 2500 rpm with 50% open throttle. The engine was equipped with an exhaust gas recirculation (EGR) system; however, in this experiment the EGR mode was set to off.

A statistical analysis technique called “Tukey Grouping” is performed on the engine test data. In Tukey Grouping, if the variables have the same letter this means that there is no statistically significant difference between those variables [14]. This technique provides specific information on the interaction between engine performance parameters and the tested fuels.

2.5. Cyclic variation analysis

The *COV* is defined as the ratio between the standard deviation in the indicated mean effective pressure (*IMEP*) over many consecutive cycles divided by its mean value, and is usually expressed in a percentage as follows [15,16]: