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Effects of Blending Ethanol with Palm Oil Methyl Esters on low Temperature Flow Properties and Fuel Characteristics

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Abstract

In order to overcome escalating worldwide consumption of fossil fuel and global warming, an alternative fuel that is economically feasible, sustainable and environmental friendly must be developed for large-scale adoption. Alternative fuels like biodiesel, are being used as effective alternative for diesel. The feasibility of biodiesel production from palm oil was investigated with respect to its fuel properties. Though biodiesel can replace diesel satisfactorily, problems related to fuel properties persist. In this study ethanol (E) additive was blended in the ratios of 1%, 2%, 3% and 4% with palm oil biodiesel (POME) and tested for their properties improvement. These blends were tested for energy content and various fuel properties according to ASTM standards. Qualifying of the effect of additive on palm biodiesel fuel properties can serve the researchers who work on biodiesel fuels to indicate the fuel suitability for diesel engines according to fuel standards. Blends of ethanol in POME resulted in an improvement in acid value, viscosity, density and pour point with increasing content of ethanol in the blend. Further improvement in the pour point temperature of the palm oil methyl esters ethanol blends (B-E) at 5^{o}C can be achieved by adding 4% ethanol additive to POME, accompanied by less than 1% decrease in energy content of biodiesel which still within specifications contained in ASTM D6751 and EN 14214 standards, suggesting that ethanol may be the suitable prudent choice as biodiesel additive.

Keywords: *Palm oil biodiesel, Ethanol, Energy Continent, Diesel, Fuel properties*

1. Introduction

Recently, world has been confronted with an energy crisis due to fossil fuel depletion and environmental degradation. Because bioenergy renewability and considered carbon–neutral, the bioenergy utilization can contribute to the carbon dioxide emissions reduction. Therefore, biodiesel has received a great deal of attention because of the advantages associated with its biodegradability and its classification as a resource for renewable energy [1, 2]. Biodiesel is composed of fatty acid methyl esters (FAME) and is synthesized usually via vegetable oils (triacylglycerols) transesterification with low-molecular-weight alcohols [3]. The current mandates regarding the use of biodiesel around the world are mostly based on a biodiesel–diesel blend. The additive is the most visible option to introduce the biodiesel as complete alternative fuel for mineral diesel.

The availability and sustainability of biodiesel feedstocks will be the crucial determinants in the popularization of biodiesel [4]. The oil palm is a tropical perennial plant and grows

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well in lowland with humid places. Compared with other biodiesel feedstocks, oil palm is the highest oil yield crop, producing on average about 5950 litre of oil per hectare annually. Sunflower, canola, soybean, and jatropha can only produce up to 952, 1190, 446, and 1892 litre of oil per hectare annually, respectively [5]. From the literature, it has been found that feedstock alone represents 75%-80% of the overall biodiesel production cost [6–8]. Therefore, selecting the high oil yield feedstock is vital to ensure low production cost of biodiesel. Biodiesel (a mixture of mono-alkyl esters of saturated and unsaturated long-chain fatty acids) generally has a higher cloud and pour point (CP and PP), density, and kinematic viscosity as well as the acid value compared to diesel [9]. The cold flow properties (CP and PP) are used to characterize the cold flow operability of a fuel because the pour point of a fuel affects the utility of the fuel, especially in cold climate conditions [10].

Fuel injection systems measure fuel by volume, and thus, engine output power influence by changes in density due to the different injected fuel mass [11]. Thus, density is important for various diesel engine performance aspects. The use of fuel with a high kinematic viscosity can lead to undesired consequences, such as poor fuel atomization during spraying, engine deposits, wear on fuel pump elements and injectors, and additional energy required to pump the fuel [12, 13]. The fuel energy content has a direct influence on the engine power output [14, 15]. The biodiesel energy content is less than that of mineral diesel, therefore using of additive most not worsen the energy continent of the POME fuel. Because biodiesel has lower energy content compared to diesel resulting from its chemical structure, the blending of biodiesel with additive that have less energy continent usually causes the energy content of the fuel to decrease depending on the additive energy continent and portion. Currently, the energy content is one of the major technical issues in the use of biodiesel–diesel blends, as it relates to the engine power. The conducted researches on measuring the energy content very little and didn’t indicate the methods and equipment’s used for measurement. However, information concerning the energy content of palm oil biodiesel and its blending with additive remains scarce.

Higher concentration of oxygen in biodiesel improves lubricity, combustion and reduces emissions while it slightly increases NOx. Low-level blends of ethanol can further reduce the emissions and can decrease viscosity [16]. However, drawbacks of E-diesel include reduced energy content [17], cetane number [18], flash point [18], lubricity [19] and immiscibility of ethanol in diesel [18, 20]. A recent study [19] explored the utility of ethanol-biodiesel-diesel blends (EB-diesel) as a means to mitigate the miscibility issues of E-diesel. The disadvantages of E-diesel were substantially reduced or eliminated in the case of EB-diesel prepared from 5% ethanol and 20% biodiesel (soybean oil methyl esters) in ultralow sulfur diesel (LSD) fuel [19]. A later study [21] revealed that 3% ethanol, 2% biodiesel (sunflower oil methyl esters), and 95% low sulfur diesel improved the pour point (PP) of the resultant blend. In general, EB-diesel blends resulted in reduced CO and HC exhaust emissions versus neat LSD. Also elucidated were the effects of blending ethanol with biodiesel (E-biodiesel) in a 6:4 ratio on PP, kinematic viscosity, and flash point (FP). Specifically, the PP of biodiesel was reduced from 3 oC to 9 oC, kinematic viscosity (40 oC) was reduced from 4.22 to 1.65 mm2/s, and FP was reduced from 187 to 14 oC after blending with ethanol [21].

Analogously, [22, 23] a blend of ethanol and biodiesel prepared from Madhuca indica oil (MME) and poultry fat (PFME) exhibited better fuel properties versus unblended biodiesel. Where the reduction in cloud point and pour point was 4 oC and 3 oC for MME and 6 oC and 4 oC for PFME respectively, when blended with 20% of ethanol, with reduction in CO, lower NOx emissions and decrease in smoke emissions on an average without affecting the thermal efficiency.

Other experimental investigations [24, 25] were conducted to evaluate the effects of using ethanol as additives to soybean biodiesel/diesel blends on the performance, emissions and combustion characteristics of a direct injection diesel engine. The tested fuels denoted as B20E5 (20% biodiesel and 80% diesel in vol.) with 5% ethanol and (B30E5) 30% biodiesel and 70% diesel in vol.) with 5% ethanol. The results indicate that, compared with blended fuel, there is slightly lower brake specific fuel consumption (BSFC). Drastic reduction in smoke is observed with ethanol at higher engine loads. Nitrogen oxide (NOx) emissions and hydrocarbon (HC) emissions are slightly higher for blended fuel with ethanol, but carbon monoxide (CO) is slightly lower. However, the blended fuels with ethanol could lead to reduction of both NOx and HC emissions of a diesel engine [26], where biodiesel was blended with 5%, 10% and 15% by volume of ethanol and tested in a 4-cylinder direct-injection diesel engine.

Therefore, the first objective of the current study was to characterize the properties of the palm oil methyl esters (POME), including the energy content and low temperature operability. The second objective was to improve the low temperature operability of palm oil methyl esters (POME) through addition of small portion of ethanol additive. Of additional interest was a comparison of POME-E fuel properties to ASTM D6751 [27] and EN 14214 [28], the American and European biodiesel standards, respectively. The low temperature operability of the resultant POME-E blends was ascertained through measurement of cloud point (CP) and pour point PP. Also of interest was the influence of ethanol addition on the kinematic viscosity (40 C), density (15 C), acid value (AV), and energy content of POME.

2. Methodology

Palm oil biodiesel (POME) was supplied by local commercial company in Selangor, Malaysia. Samples of palm oil methyl ester and ethanol (E) were prepared through mixed and blended using electrical magnetic stirrer shown in Figure 1(a). Briefly, E was added in to palm oil methyl ester at low stirring rate. The mixtures were stirred continuously for 20 minutes and left for 30 minutes to reach equilibrium at room temperature before they were subjected to any test. The use of E has also some limitations, such as lower lubricity, reduced ignitability and cetane number, higher volatility and lower miscibility [29] which may lead to increased unburned hydrocarbons emissions. Therefore, E was add at small proportions of 1%, 2%, 3% and 4% by volume to POME, which corresponded to B-E1, B-E2, B-E3 and B-E4 fuels, respectively.

The acid value, cloud point, pour point, density, and kinematic viscosity were determined according to ASTM D-664, ASTM D-2500, ASTM D-97, ASTM D1298 and ASTM D-445, respectively. In addition, the heating value of blended fuel which not specified in the biodiesel standards ASTM D6751 and have a minimum value of 35 MJ/kg in EN 14214 was determined by Oxygen Bomb Calorimeter model 6772 (Parr instrument company, USA). In these calorimeter systems shown in Figure 1(e), the heat leak is precisely measured during the calorimetric pre-period. This evaluation results in an estimate of the effective, average temperature of the calorimeter surroundings. This temperature value is then used throughout the test interval to provide the calorimeter heat leak correction. It harnesses the computing power of the controller, with no additional hardware costs, to provide heat leak correction capability that is almost identical to the approach used when non-electronic thermometry and manual calorimetric techniques are employed.

Cloud point is defined as the temperature at which a cloud of wax crystals first appears in a liquid form when the liquid is cooled under certain conditions. PP is defined as the lowest temperature at which a liquid can flow; the PP apparatus and procedure adopted were according to the ASTM D97 standard method. The test apparatus shown in Figure 1(f) manufactured by Koehler instrument company K46195 (USA) was used for the cloud and pour point measurements.

Acid number or neutralization number is a measure of free fatty acids contained in a fresh fuel sample. Free fatty acids (FFAs) are the saturated or unsaturated monocarboxylic acids that occur naturally in fats, oils or greases but are not attached to glycerol backbones [30]. Fatty acids vary in carbon chain length and in the number of unsaturated bonds (double bonds). Higher amount of free fatty acids leads to higher acid value [31]. Acid value is expressed as mg KOH required for neutralizing 1 g of FAME. Higher acid content can cause severe corrosion in the fuel supply system of an engine. The acid value is determined using the ASTM D664 and EN 14104. The test apparatus manufactured Metrohm 785 (USA) shown in fig. 1(d) was used to measure the acid value.

Kinematic viscosity measurements were made with a Digital Constant Temperature kinematic viscosity bath shown in Figure 1(c), while the density is measured by using Portable Density/Gravity Meter shown in Figure 1(b). High viscosity leads to problem in pumping and spray characteristics (atomization and penetration, etc.). The inefficient mixing of oil with air contributes to incomplete combustion. It was observed that the kinematic viscosity of POME was found to be about 1.2 times of diesel at 40oC.

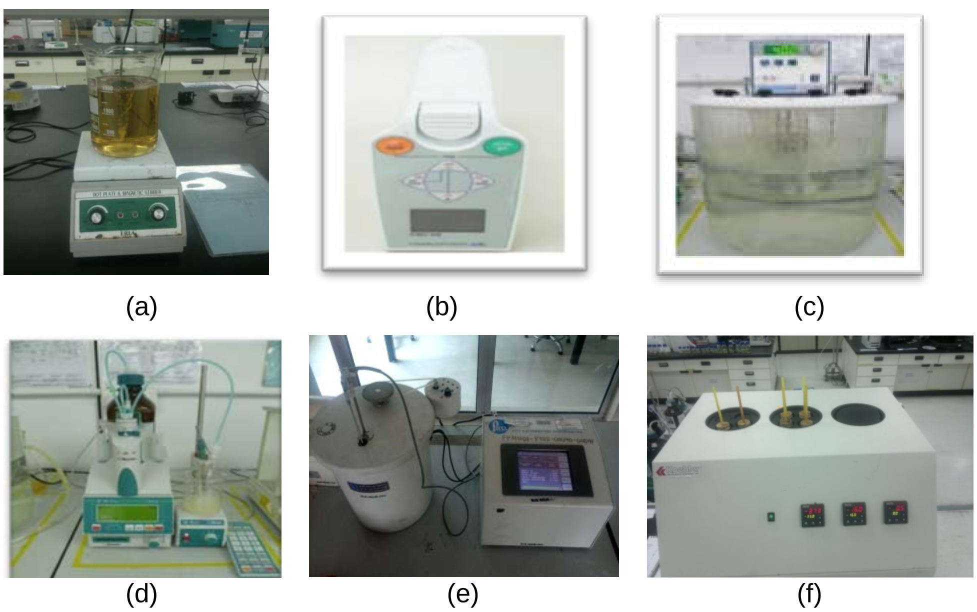

Figure 1. Analytical Instruments used to Measure Fuel Properties; (a) Magnetic Stirrer, (b) Density Meter, (c) Viscosity Bath, (d) Acid Value & Acidity Tester, (e) Oxygen Bomb Calorimeter, (f) Cloud and Pour Point Measuring Equipment

3. Results and Discussions

3.1. Analysis of Biodiesel Properties

The measured fuel properties of the POME are listed in Table 1 and compare to the biodiesel specifications, including ASTM D6751 in the United States and EN 14214 in Europe. The PP, CP, kinematic viscosity, density and acid value of the POME were significantly higher than those of the mineral diesel, while the heating value was lower than that of mineral diesel. The POME presented satisfactory fuel properties that satisfied most biodiesel specifications. The PP value of the POME was about 14oC, a property that limited the beneficial use of the POME in cold climates [32, 33].

Table 1. Properties of POME Compared to the Biodiesel Specifications

Property	Unit	POME	ASTM D6751	EN 14213
Acid Value	mg KOH/g	0.49	0.5 max	0.5 max
Viscosity at 40 ^oC	mm^2/s	4.6116	1.9-6.0	3.5-5
Density	kg/m^3	880.8	900	860-900
CP	^oC	14	---	---
PP	^oC	14	---	---
Heating Value	MJ/kg	38.5745	----	35 min

The selection of additives for oxygenating the fuel depends on economic feasibility, toxicity, fuel blending property, additive solubility, flash point of the blend, viscosity of the blend, solubility of water in the resultant blend, and water partitioning of the additive [29]. Based on the fuel blending properties, toxicity and economic feasibility ethanol was selected. There are a number of fuel properties that are essential to the proper operation of a diesel engine. Ethanol was further added to POME at different volumetric ratios (varied from 0% to 4% in steps of 1%) to study the variations in the CP, PP, density, heating value, acid value and kinematic viscosity of the POME-E blends.

3.2. Cloud Point and Pour Point Results

POME-E blends improved low temperature operability compared to unblended POME since the freezing points of E (-114^{o}C) are substantially below the temperature at which biodiesel typically undergoes solidification. Addition of ethanol to POME does not affected CP, while increasing ethanol content from 2 to 4% resulted in a dramatic decline in PP. Figure 2 shows the variations of the PP for POME with the volumetric percentage of the ethanol. The maximum reduction of PP for POME was 5 ^{o}C when adding 4% ethanol. The low-temperature properties of biodiesels not indicated in ASTM and EN standards as it related to climatic conditions.

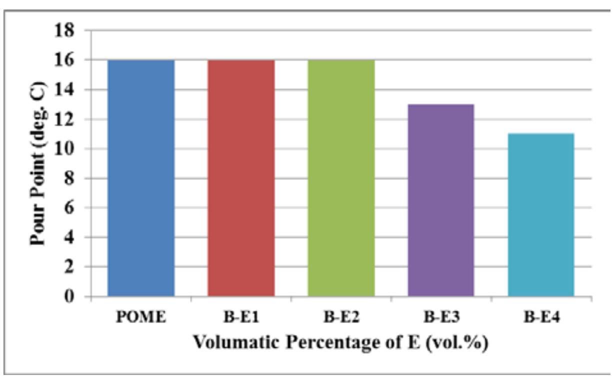

Figure 2. Variation in PP with the Volumatric Percentage of E (vol.%) for POME

3.3. Density Results

The densities of POME-E blended fuel produced in this study are very close to each other and in the range of 878–880.8 kg/m3 for B-E4 and POME respectively. They are suitable for the ASTM D6751 and EN 14214 standards and slightly higher than those of the diesel fuel. Figure 3 presents the density values of the POME. It is clear that the density of the fuel decreases with rising of ethanol portion in the mixture. The density of the POME-E blend decreased linearly with a higher volumetric percentage of the ethanol, indicating that the additivity for the volume.

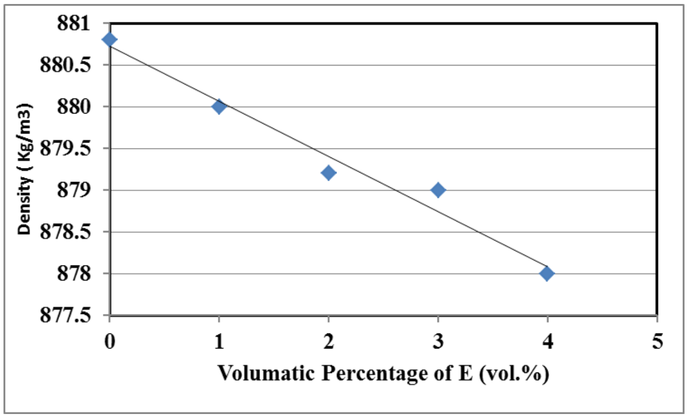

Figure 3. Variation in Density with the Volumatric Percentage of E (vol.%) for POME

Excellent agreement between the measured and estimated values of the density of the POME-E blends at 15 °C is given by:

$$\text{Density (kg/m3)} = -0.515x + 878.69 \qquad R^2 = 0.9883 \qquad (1)$$

Where x is the volumetric percentage of the ethanol (vol.%).
These results are in agreement with a previous study [34] that determined blends of microalgae oil biodiesel and its blends with petroleum diesel.

3.4. Viscosity Results

The viscosities of methyl esters vary in the range of 4.17, 4.23, 4.37, 4.45 and 4.611 mm2/s for B-E4, B-E3, B-E2, B-E1 and POME respectively. All blends, as well as neat POME, satisfied the kinematic viscosity specification contained in ASTM D6751 and EN 14214 standards. The viscosity of the blend decreases as the ethanol portion increases in the fuel mixture as observed from Figure 4. Similar to density, the kinematic viscosity of the POME-E blend decreased linearly with a higher volumetric percentage of the ethanol. The kinematic viscosity at 40 oC can be described by Eq. (2) for the POME-E blends, with a linear relationship:

$$\text{Kinematic Viscosity (mm2/s)} = -0.061x + 4.6123 \qquad R^2 = 0.9885 \qquad (2)$$

Where x is the volumetric percentage of the ethanol (vol.%).
Likewise, the kinematic viscosity of the POME-E blends are in agreement with a previous study [34] that determined blends of microalgae oil biodiesel and its blends with petroleum diesel.

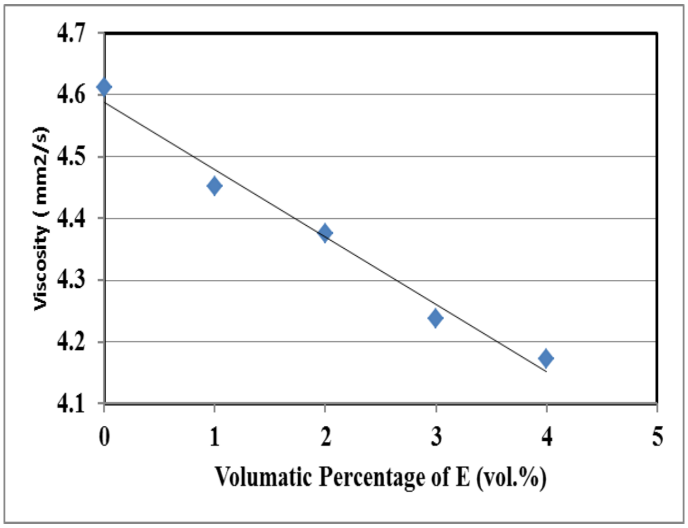

Figure 4. Variation in Viscosity with the Volumatric Percentage of E (vol.%) for POME

3.5. Acid Value

Addition of ethanol to POME improved the AV, and a slight reduction in AV was achieved by increasing ethanol portion. The acid value is determined using the ASTM D664 and EN 14104. Both standards approved a maximum acid value for biodiesel of 0.50 mg KOH/g [35], [36]. Figure 5 shows acid value profile of POME–E blends. The acid value decrease by approximately 1% for each 1% of E added, by volume with a linear relationship, a minimum acid value was 0.46 mg KOH/g for POME-E4. This was expected, as ethanol will dilute the free fatty acids present in POME, resulting in a reduction in AV. The acid value of the POME-E blend satisfies the requirement of ASTM D6751-06 and EN 14104 Standard for all blending range.

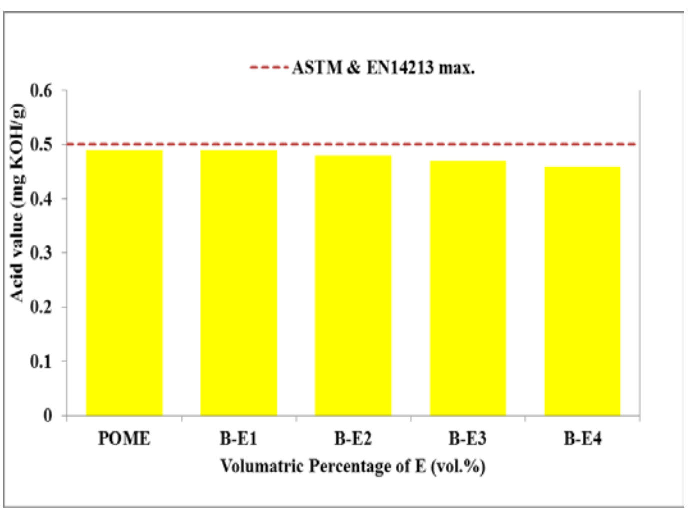

Figure 5. Variation in Acid Value with the Volumatric Percentage of E (vol.%) for POME-diesel Blends

3.6. Heating Value

Heating value, heat of combustion is the amount of heating energy released by the combustion of a unit value of fuels. One of the most important determinants of heating value is the moisture content of the feedstock oil [37]. The heating value is not specified in the biodiesel standards ASTM D6751 and EN 14214 but is prescribed in EN 14213 (biodiesel for heating purpose) with a minimum of 35 MJ/kg [30]. Figure 6 shows that the heating value of the POME-E blend decreased slightly with increasing volumetric percentage of the ethanol, a minimum heating value for B-E4 was 38.245 MJ/kg. The heating value of the POME-E blend satisfies the requirement of EN 14213 Standard for all blending range.

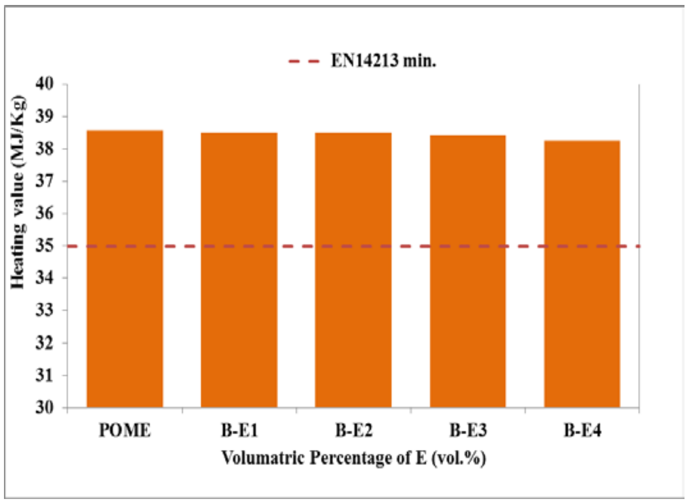

Figure 6. Variation in Heating Value with the Volumatric Percentage of E (vol.%) for POME-diesel Blends

4. Conclusions

The objective of this study was to characterize how the key fuel properties changed when ethanol were blended with palm oil methyl esters. According to the experimental results; the density of the POME-E blend decreased linearly from 880.8 kg/m^3 to 878 kg/m^3 with the increase of ethanol concentration in the blended fuel from 0% to 4% by volume, accompanied by a decreases in kinematic viscosity from $4.6mm^2/s$ to $4.17mm^2/s$ and displayed satisfactory fuel properties for all blending ranges. Similarly, the acid value of POME-E blends slightly improved with increasing ethanol content and satisfies both the ASTM D6751 and EN14213 standard in all blending ranges. Likewise, increasing ethanol content in POME resulted in a statistically significant difference in low temperature performance, with maximum decrease in pour point by 5 ^oC when adding 4% ethanol. On the other hand, there was no significant difference in the cloud point of the blends. In general, the heating value for the blend decreases with increasing ethanol portion in the blends and the maximum reduction is less than 1% for 4% ethanol additive. B-E4 has the minimum heating value of 38.24 MJ/kg which is still satisfy the limits of the EN 14213.

Finally, ethanol blended biodiesel is totally a renewable, viable alternative fuel for improved cold flow behaviour and exhibited better fuel characteristics with slight lower energy continent in comparison to POME and satisfies both ASTM and EN14213 standards specifications.

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