Effects of incompletely converted palm oil on biodiesel quality and engine performance

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Abstract

This study investigates how an incomplete conversion of methyl ester influences the parameters of quality standards and engine performance. The parameters evaluated include viscosity, cloud point, acid number and heating value. Biodiesel oil produced from palm oil is examined. In terms of engine performance, the 3-liter engine with a 4 cylinders 4 strokes, are used. The proportion of methyl ester in biodiesel is varied by adding an appropriate amount of triglyceride. Properties of biodiesel with the methyl ester between 75% and 96.8% by mass are tested against the standard diesel. The engine performance and efficiency with biodiesel of different qualities are determined under the operating engine speed. It was found that incomplete conversion of triglyceride to methyl ester, which led to lower methyl ester content, considerably affected the quality of biodiesel. The biodiesel of all methyl ester content generally gave lower engine performance than that given by the standard diesel. Among the biodiesel fuels, biodiesel with higher methyl ester content provided better engine performance.

***Keywords**:* Biodiesel; Palm oil; Methyl ester; Triglycerides; Transesterification; Engine performance

1. Introduction

Biodiesel has become the focus of a large number of studies since it has been proved to be technically sufficient alternative diesel. In addition to its great renewability, biodiesel has many advantages of good lubricity, reduced emissions [1-2]. Biodiesel consists of alkyl monoesters derived from animal fats or vegetable oils or waste cooking oils. A number of previous works investigated vegetable based biodiesel such as sunflower, palm, rapeseed, soybean, jatropha [3-5]. Biodiesel produced from vegetable oils is a potential alternative to diesel since their physical and chemical properties are similar to those of standard diesel [6]. Transesterification reaction of triglycerides with methanol has proved to be the most promising process to produce biodiesel [7-9]. In this process, fats or oils known as triglycerides are converted into biodiesel in a chemical form of mono-alkyl esters. During the process, fatty acids within triglycerides are reacted with alcohol in the present of catalyst to form the mono-alkyl esters and glycerol. To determine biodiesel quality, the ASTM task force identified the following as critical items: Complete reaction to the mono alkyl esters, the removal of reactant alcohol and the absence of free fatty acid [10]. While the main component of biodiesel that gives biodiesel similar properties to diesel is esters, the unfavorable components are impurities such as mono-glyceride and triglyceride. The total ester content can be a measure of the completeness of the transesterification reaction. The unconverted triglycerides in biodiesel have been found to strongly affect the mechanical and chemical properties of biodiesel [11-12]. It was reported for instance, the glycerol content is substantially raised with the increased proportion of the raw soybean oil leading to failure to pass the ASTM (American Society for Testing and Materials) D 6751 standard [11]. It was found that incomplete conversion of triglyceride to methyl ester led to the presence of triglyceride in biodiesel, which considerably affected the quality of biodiesel. In real productions, the cause of incomplete reaction may stem from various problems including inhomogeneous mixing, too low temperature, reaction time too short, or too low amount of methanol used. In the present study, biodiesel from palm oil is produced to investigate effects of the presence of triglycerides not only on the fuel properties but also on engine performance.

2. Experimental Procedure

In this study we produced biodiesel from palm oil kindly supplied by Prathum Vegetable Oil Co., Ltd. (Thailand). The biodiesel production was based on the transesterification reaction through our pilot plant (Fig. 1). The transesterification of fresh palm oil was carried out by using the ratio of methanol: oil = 7: 1 by mole. The amount of KOH catalyst added was 0.49 wt% of the oil using the reaction temperature of about 55 to 60 $^{\circ}$C and the reaction time of 2 hours. The reaction mixture was then settled to remove the lower glycerol layer. The biodiesel produced was then neutralized, washed, and dried at slightly above 100 $^{\circ}$C to remove excess methanol and water. One way to determine the completeness of the transesterification reaction is to measure the ester content in the produced biodiesel. In the present work, our biodiesel produced from palm oil with different proportions of methyl ester are investigated. Methyl ester contents reflect quality level of biodiesel. Biodiesel with different methyl ester contents are prepared by adding the designated amounts of triglyceride. Properties of all types of biodiesel as well as standard diesel are measured according to EN 14103 standards.

Fig. 1 Pilot plant for biodiesel production

Next, different types of fuel are tested with the direct-injection diesel engine. The engine specifications are shown in Table. 1. The performance of the diesel engine was measured by the eddy current dynamometer. The engine was then test under variable loads there by variable speeds. The experiment was repeated three times. The collected data were averaged before being analyzed.

Table. 1 Engine specifications

Make	Nissan
Model	BD-30
Number of Cylinders	4
Bore x Stroke	96 mm x 102 mm
Displacement	2,953 cc.
Compression Ratio	18.5 :1
Maximum Power	67.1 kW (90 HP)

The engine performance is analyzed based on a number of parameters [13]. In terms of Torque, *T*, power (*P*) is computed using

$$P \text{ (kW)} = 2 \times \pi \times N \times T \quad (1)$$

where *N* is the engine speed. To determine how efficiently the engine consumes fuel brake specific fuel consumption (*bsfc*) is examined as is given by

$$bsfc\ (\text{g/kW} \cdot \text{hr}) = \frac{\dot{m}_f}{P} \quad (2)$$

where $\dot{m}_f$ is a fuel consumption rate. One useful relative engine performance that does not depend on an engine size is the brake mean effective pressure, *bmep*, defined as

$$bmep = P \times 2 / V_d \times N \text{ (kPa)} \quad (3)$$

Furthermore, engine efficiency is considered based on the fuel conversion efficiency (η_f) given by

$$\eta_f = \frac{P}{\dot{m}_f Q_{HV}} \quad (4)$$

where Q_{HV} is the heating value of fuel.

3. Results and Discussion

Results for the measured properties of different types of fuel are graphically shown in Figs. 2 – 6. Petroleum base diesel used as a reference was acquired from PTT Public Company Ltd. (Thailand). It is found in Fig. 2 that diesel has lower density than that of biodiesel of every type. The density increases with an increase in triglyceride content since triglyceride has higher density than methyl ester. Comparison among the fuels in term of the difference in heating value is shown in Fig. 3. As seen in this figure, heating value of regular diesel is substantially higher than that of biodiesel. However, the heating values measured from biodiesel of all types are nearly equal. This indicates that methyl ester and glycerides have comparable heating values.

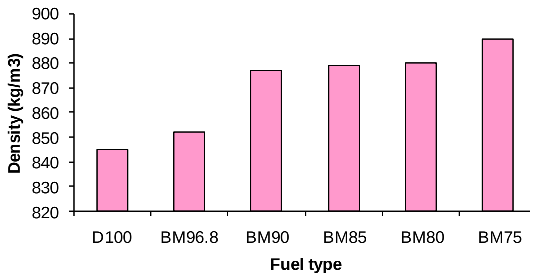

Fig. 2 Comparison of density

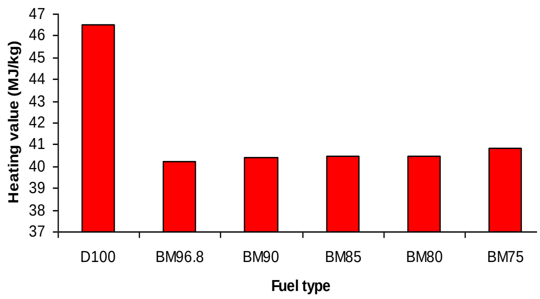

Fig. 3 Comparison of heating value

In terms of viscosity, it is evident in Fig. 4 that viscosity is proportional to glyceride content. Fig. 5 presents measuring results for cloud point. The value of cloud point by diesel is substantially lower than biodiesel. Higher methyl ester content causes higher cloud point value which is not favorable. Therefore unlike the other properties, biodiesel is degraded with larger methyl ester contents in regard to cloud point.

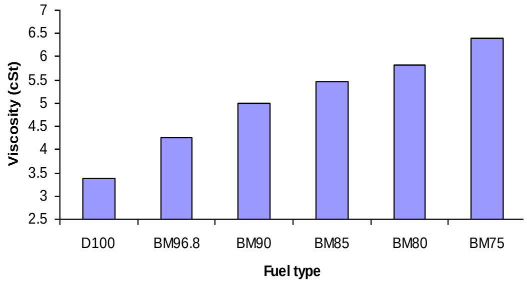

Fig. 4 Comparison of viscosity

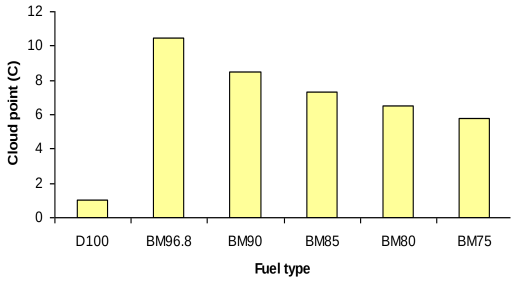

Fig. 5 Comparison of cloud point

Fig. 6 shows the data regarding the differences in acid value. The acid value represents the amount of free fatty acid. The contents of free fatty acids (FFAs) considerably affect transesterification. Conversion is complicated if oil contains large amounts of FFAs (>1% w/w) that will form soap with alkaline catalyst [14]. The acid value of biodiesel is about 0.146 which is lower than the acceptable value in accordance with ASTM standard. It should be noted the acid value of our palm oil biodiesel is relatively low compared among different biodiesel originated from different raw materials [15].

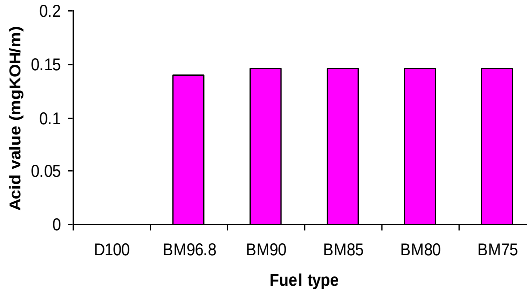

Fig. 6 Comparison of acid value

In what follow, the results of engine tests are discussed. Variations of torque and power with the engine speed ranging from 1,800 to 4,000 rpm are depicted in Figs. 7 and 8 respectively.

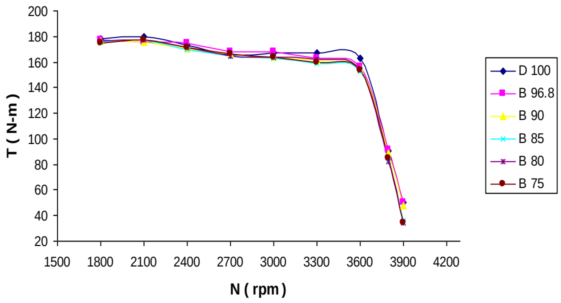

Fig. 7 Variation of torque with engine speed

For regular diesel, maximum torque of 180 Nm occurs at 2100 rpm while power has a peak value of 63 kW at 3600 rpm. In overall, regular diesel produces higher values of torque and power since regular diesel has higher heating value than that of biodiesel. Further, torque and power continually drop as proportion of ester is reduced even though the heating values of all types of biodiesel are equally low. This tendency is due mainly to an increase in viscosity with smaller proportion methyl ester that was shown previously in Fig. 4. High viscosity leads to poor atomization of the fuel spray and less accurate fuel injection rate.

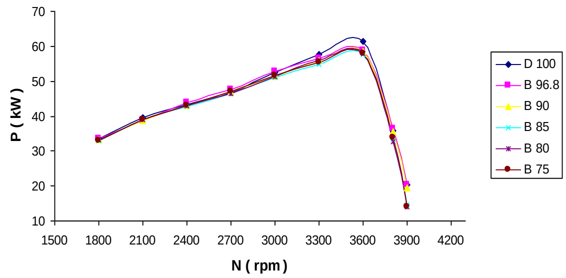

Fig. 8 Variation of power with engine speed

Fig. 9 shows how brake specific fuel consumption (sfc) changes with engine speed. Diesel has lower specific fuel consumption than the tested biodiesels. This is because diesel has greater heating value in addition to its less viscous than biodiesel. At the engine speeds below 3300 rpm, sfc from diesel is five to ten percent lower than that of biodiesel. The sfc increases with increased triglycerides. The difference is larger at higher speeds especially at 3900 rpm. Regarding the brake mean effective pressure (bmep) shown in Fig. 10, diesel has greater bmep than that of biodiesels. At differences of the bmep values are clearer at the engine speeds higher than 3000 rpm corresponding to power variations previously seen in Fig. 8.

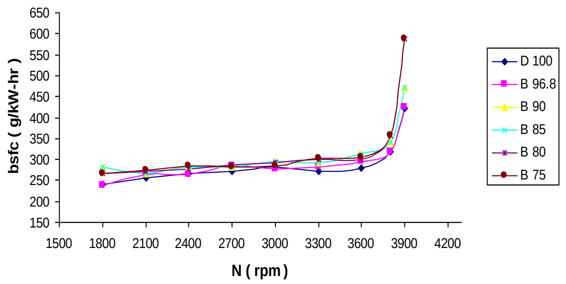

Fig. 9 Variation of brake specific fuel consumption with engine speed

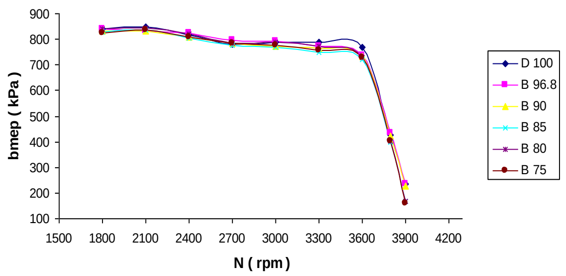

Fig. 10 Variation of brake mean effective pressure with engine speed

To gain more insight of the effects of triglycerides on engine, the fuel conversion efficiency is computed and shown in Fig. 11. It is interesting to point out from the results that biodiesel of all types has greater fuel conversion efficiency than that of regular diesel. Although biodiesel has lower heating value, it converts available chemical energy from fuel into usable work more efficiently than regular diesel does. Additionally, biodiesel with higher ester content has better conversion efficiency than biodiesel with lower ester content.

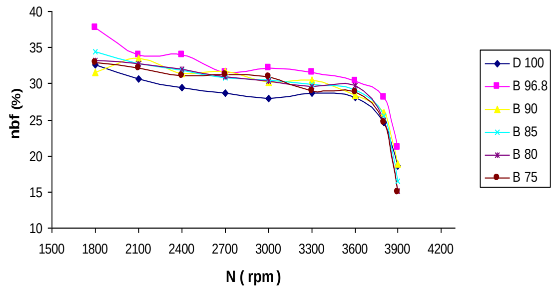

Fig. 11 Variation of brake fuel conversion efficiency with engine speed

5. Conclusion

Biodiesel originated from palm oil was systematically produced via a transesterification process. During the process, transesterification reaction converted palm oil into methyl ester. Biodiesel with higher methyl ester had better overall performance. Methyl ester content essentially reflects quality of biodiesel. On the other hand, unconverted triglycerides due to incomplete transesterification reaction considerably degraded biodiesel properties especially the viscosity, which in turn negatively affected the engine performance. The ongoing work is to carry out the exhaust gas analysis.

6. Acknowledgement

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