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High free fatty acid coconut oil as a potential feedstock for biodiesel production in Thailand

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ABSTRACT

Coconut oil having 12.8% free fatty acid (FFA) was used as a feedstock to produce biodiesel by a two-step process. In the first step, FFA level of the coconut oil was reduced to 0.6% by acid-catalyzed esterification. In the second step, triglycerides in product from the first step were transesterified with methanol by using an alkaline catalyst to produce methyl esters and glycerol. Effect of parameters related to these processes was studied and optimized, including methanol-to-oil ratio, catalyst concentration, reaction temperature, and reaction time. Methyl ester content of the coconut biodiesel was determined by GC to be 98.4% under the optimum condition. The viscosity of coconut biodiesel product was very close to that of Thai petroleum diesel and other measured properties met the Thai biodiesel (B100) specification.

1. Introduction

Nowadays, petroleum products derived from crude oil and natural gas are important world energy resources. These resources are limited and non-renewable. If these resources continue to be consumed at the current rate, their shortage can be expected. Moreover, the widespread use of petroleum-based fuels causes environmental problems, especially the global warming and pollution [1,2]. Consequently, there has been a considerable interest in the development of some alternative energy. Biodiesel is a viable alternative fuel for diesel engine due to its non-toxicity, biodegradability, and low emission [1–3]. Thailand has insufficient amount of crude oil (petroleum resource) for domestic consumption and so it has to import most of it from overseas. In addition, the crude oil price is variation and tended to rise rapidly at times. Therefore, the use of biodiesel, which is renewable and available locally, can decrease Thailand's dependence on foreign oil and contribute to the country's economy.

Biodiesel is monoalkyl esters of long chain fatty acids derived from vegetable oils or animal fats. It is produced through a chemically reversible reaction called transesterification or alcoholysis, which has been widely used to reduce the high viscosity of triglyceride [1]. In this reaction, vegetable oil or animal fat reacts with an alcohol such as methanol in the presence of a catalyst, usually a strong base, such as sodium or potassium hydroxide [2]. The product of the reaction is a mixture of methyl esters and a commercial value coproduct, glycerol or glycerin [4]. The properties of resulting biodiesel are quite similar to those of conventional diesel fuel. The transesterification reaction can be expressed by the following general equation.

$$\text{Triglyceride} + 3\text{ROH} \xrightarrow{\text{catalyst}} 3\text{R}'\text{CO}_2\text{R} + \text{Glycerol} \tag{1}$$

A variety of oils both edible and non-edible oils can be used to produce biodiesel but most are derived from edible oils, such as sunflower, soybean, and palm oils [3,5]. Since the prices of edible vegetable oils are high, the less expensive raw materials containing FFAs, such as non-edible crude oils, waste food oils, animal fats, and byproducts of the refining vegetable oils, are preferred [6,7]. However, the FFA content in the oil has significant effect on the transesterification of glyceride with alcohol using an alkaline catalyst [8]. These FFAs react with the alkaline catalyst to produce soaps, which inhibit the separation of the product from glycerin and wash water [9]. In addition, soap increases the viscosity of the reactants and results in the lower yield of methyl ester [10]. From this reason, the oil should not contain more than 1% FFA for alkali-catalyzed transesterification reaction [5,7,11]. Thus, the one-step process involves an alkali-catalyzed transesterification is insufficient for high FFA feedstock [12]. An alternative way of processing the high FFA oil is to use an acid-catalyzed transesterification but it requires a much longer time than alkali-catalyzed transesterification [9]. Therefore, alternative processes were investigated by several researchers to use the various oils and fats with high FFA as feedstock to produce biodiesel [5–7,13].

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In Thailand, biodiesel is mainly produced from palm oil, however, there are several possible alternative oils which can be utilized as feedstock for biodiesel production. One of them is coconut oil which has been produced on a large scale in the east and south coastal areas. At present, coconut oil with high FFA is available at a low price and does not have major applications. Thus, this oil has a high potential as the feedstock to reduce the biodiesel production cost. From these points of view, it led to the study of biodiesel production from coconut oil with high FFA content by two-step process, acid-catalyzed esterification followed by alkali-catalyzed transesterification.

The objectives of this study were: (a) to investigate the optimum reaction conditions for the production of biodiesel from coconut oil having 12.8% FFA by a two-step process; (b) to study the effect of process parameters, including methanol-to-oil ratio, catalyst concentration, reaction temperature, and reaction time.

2. Materials and methods

2.1. Materials

The coconut oil having 12.8% FFA was obtained from Sangsook Industry Company Limited. The methyl esters such as methyl heptadecanoate, methyl esters of lauric, myristic, palmitic, and stearic acids were standard for GC. All chemicals used in the experiments such as 99.8% methanol, potassium hydroxide, 98% sulphuric acid, n-heptane, and sodium hydroxide were of analytical reagent (AR) grade.

2.2. Acid-catalyzed pretreatment

The acid-catalyzed esterification reaction was conducted in a laboratory-scale experiment. The apparatus used for the experiment consisted of flat bottom reaction flask and hotplate with magnetic stirrer. The volume of the reaction flask capacity was 250 ml and consisted of three necks, one for condenser, and the others for thermometer and inlet for the reactants. The mixture in the reaction flask was heated and stirred at the same speed for all test runs. The coconut oil feedstock, methanol, and concentrated sulphuric acid were used in amounts established for each experiment. A known amount of coconut oil feedstock was poured into the reaction flask and heated to the desired temperature. The methanol was added to the preheated coconut oil and stirred for a few minutes. Required amount of concentrated sulphuric acid was then added to the mixture and the measurement of time was started at this point. Heating and stirring were continued for different reaction times at the atmospheric pressure. After the reaction, the mixture was allowed to settle for 2 h in the separatory funnel and the methanol–water fraction at the top layer was removed. The lower layer consisted of coconut oil having lower content of FFA and impurities were purified by washing gently with hot distilled water at 60 °C until the washing water had a pH value that was similar to that of distilled water. The coconut oil layer was then dried under reduced pressure at 70 °C by rotary evaporator. Finally, the acid value of the oil product was determined by using standard test method. The averages of the results were presented in Figs. 1–3.

In this section, the effect of process parameters such as methanol-to-oil ratio, catalyst concentration, reaction temperature, and reaction time was studied. The optimum of each parameter was determined by considering the FFA content while the other parameters remained constant. After each parameter's optimum value was attained, this value was kept to be constant during the optimization of the next parameter was determined. The product having FFA content less than 1% by using the lowest amounts of methanol and acid catalyst and the lowest reaction temperature in the minimum reaction time was used as the starting material for the second step, alkali-catalyzed transesterification.

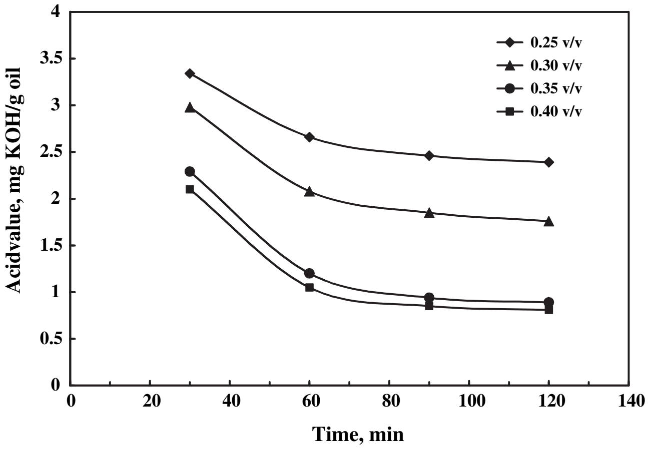

Fig. 1. Effect of methanol-to-oil ratio and the reaction time on reduction of acid value of coconut oil (catalyst concentration of 0.7% v/v of oil, reaction temperature of 60 °C).

2.3. Alkali-catalyzed transesterification

The alkali-catalyzed transesterification reaction was carried out by using the same experiment setup of acid-catalyzed pretreatment step. The oil product from the pretreatment step was preheated to the desired temperature in the reaction flask. The solution of potassium hydroxide in methanol was prepared freshly in order to avoid the moisture absorbance and maintain the catalytic activity [1,10]. The methanolic solution was then added to the heated oil in the reaction flask. The measurement of time was started at this point. Heating and stirring were continued for different reaction times at atmospheric pressure. After the reaction, the mixture was allowed to separate into two layers by settling overnight in the separatory funnel. The upper layer consisted of methyl esters, whereas the lower layer contained a mixture of glycerol and impurities. The methyl ester layer was purified by washing gently with hot distilled water at 60 °C until the washing water had a pH value that was similar to that of distilled water. The methyl ester layer was then dried under reduced pressure at 70 °C by rotary evaporator.

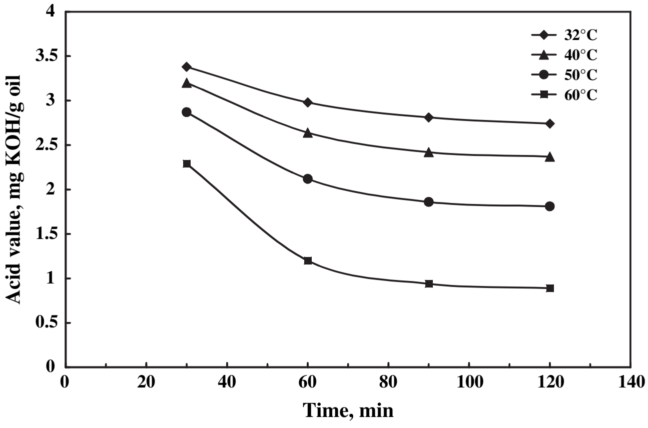

Fig. 2. Effect of reaction temperature and reaction time on the reduction of acid value of coconut oil (methanol-to-oil ratio of 0.35 v/v, catalyst concentration of 0.7% v/v of oil).

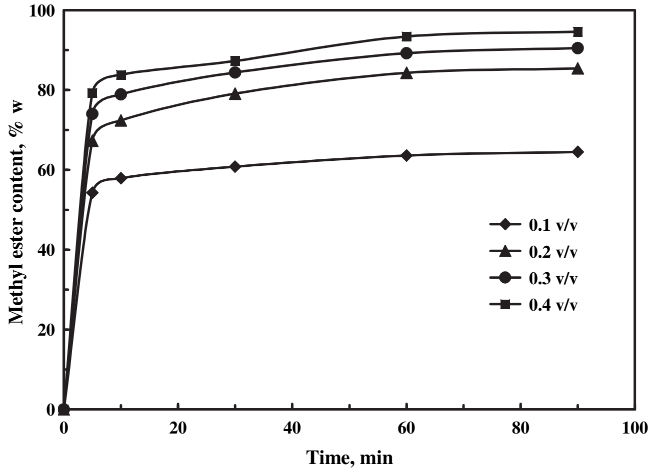

Fig. 3. Effect of methanol-to-oil ratio and reaction time on methyl ester formation (catalyst concentration of 1% w/v of oil, reaction temperature of 60 °C).

The methyl ester content in the product was determined by GC. In this section, the parameters, such as methanol-to-oil ratio, catalyst concentration, reaction temperature, and reaction time, were studied for their effect on alkali-catalyzed transesterification. The optimum value of each parameter was determined by considering the methyl ester content based on the Thai specification limit, while the other parameters remained constant. After each optimum was attained, this value was kept constant during the optimum of next parameter was determined. The condition provided methyl ester content within the acceptable level of Thai Biodiesel (B100) specification (min 96.5% w) by using the lowest amounts of methanol and alkaline catalyst at the lowest reaction temperature in the minimum reaction time was considered to be the optimum condition for this step. Finally, the coconut biodiesel properties were determined by using standard test methods.

2.4. Analytical methods

2.4.1. GC method

The coconut biodiesel product was analyzed by GC of Agilent 6890N that was equipped with a flame ionization detector and a capillary column of crosslinked polyethylene glycol (HP-INNO-WAX, 25 m × 0.20 mm × 0.2 μm). The GC oven was kept at 200 °C for 5 min. The carrier gas was helium (0.5 ml/min). The analysis was carried out by injecting 1 μl of sample solution into GC. In this experiment, the n-heptane was used as solvent for preparing sample solution. The produced methyl esters were identified by comparing their retention times to those of standard methyl ester of fatty acids, and the methyl ester content was determined by using methyl heptadecanoate as the internal standard.

2.4.2. Properties of coconut oil, pretreated coconut oil, and coconut biodiesel

The properties of coconut oil, pretreated coconut oil, and coconut biodiesel were determined by standard test methods as follows:

(i) Fatty acid composition AOAC (2000), 963.22, 969.33; (ii) Density ASTM D 4052-96; (iii) Kinematic viscosity ASTM D 445-06; (iv) Acid value (FFA content) AOAC (2000), 940.28; (v) Water content AOAC (1990) 984.20 (for coconut oil and pretreated coconut oil) and EN 12937(for coconut biodiesel); (vi) Copper strip corrosion ASTM D 130-94; (vii) Total acid number ASTM D 664-01; (viii) Carbon residue ASTM D 4530-00; (ix) Iodine value EN 14111; (x) Gross heat of combustion ASTM D 240; (xi) Oxidation stability EN 14112; (xii) Quantities of monoglyceride, diglyceride, and triglyceride EN 14105.

3. Results and discussion

3.1. Characterization of coconut oil

The coconut oil had an initial FFA content of 12.8% (as lauric acid), which corresponded to an acid value of 25.5 mg KOH/g oil, and it was clear and brown in color. The fatty acid composition and some important properties of this oil were shown in Table 1. It consisted of 74.7% saturation comprising mainly of lauric and myristic acids and 17.2% unsaturation comprising of oleic and linoleic acids. Like other vegetable oils, coconut oil has high viscosity and low volatility. These disadvantages lead to difficulty in atomizing the fuel and in mixing it with air when the coconut oil is directly used in diesel engine. To improve its performance in diesel engine, the coconut oil has to be converted to biodiesel. After this conversion, the viscosity of coconut oil is reduced to a level close to diesel.

3.2. Acid-catalyzed pretreatment

To reduce FFA content of coconut oil feedstock from 12.8 to less than 1% (acid value of 2 mg KOH/g oil), the coconut oil was esterified with methanol by using concentrated sulphuric acid as the catalyst. The FFAs reacted with methanol to form methyl esters as shown in the following general equation.

$$\mathrm{RCOOH} + \mathrm{CH_3OH} \overset{\mathrm{H_2SO_4}}{\rightarrow} \mathrm{RCOOCH_3} + \mathrm{H_2O} \qquad (2)$$

This reaction is reversible and a large excess of methanol is required to shift the equilibrium towards the formation of esters.

3.2.1. Effect of methanol-to-oil ratio and reaction time

One main parameter affecting the reduction of FFA content in the oil is the amount of methanol. In this study, different methanol-to-oil ratios (0.25, 0.30, 0.35 and 0.40 v/v) and reaction times (30, 60, 90, and 120 min) were used to investigate their effect on the reduction of FFA content of coconut oil. The reaction was carried out with the catalyst concentration of 0.7% v/v of oil and at the reaction temperature of 60 °C. The acid values of oil versus time at different methanol-to-oil ratios were shown in Fig. 1. It was found that the rate of acid-catalyzed esterification increased with increasing methanol amount. It was in accordance with the results obtained by several researchers [5,6,14]. The acid value reduced rapidly

Table 1
Properties of coconut oil feedstock.

Property	Coconut oil
Fatty acid composition (%)[a]	
(i) Caprylic acid (C8:0)	3.35
(ii) Capric acid (C10:0)	3.21
(iii) Lauric acid (C12:0)	32.72
(iv) Myristic acid (C14:0)	18.38
(v) Palmitic acid (C16:0)	13.13
(vi) Stearic acid (C18:0)	3.60
(vii) Oleic acid (C18:1)	12.88
(viii) Linoleic acid (C18:2)	4.35
Density at 15 °C, kg/m^3	920.6
Free fatty acid content (as lauric acid), % w	12.8
Kinematic viscosity at 40 °C, mm^2/s	28.05
Water content, % w	0.22

[a] Other fatty acids (arachidic and lignoceric acids) were present in amounts of <1%.

during the first 60 min and after that it reduced gradually. This might be owing to the effect of water formation during the esterification of FFAs, which prevented further reaction [5]. Further increase of the methanol-to-oil ratio up to 0.40 v/v should be avoided because the reduction of acid value was insignificant while the cost is higher. Therefore, 0.35 v/v was the lowest ratio which provided acid value of oil less than 2 mg KOH/g oil in the minimum time, so it was selected as the optimum methanol-to-oil ratio.

In a commercial application, the methanol in the methanol–water fraction which is separated from the top after esterification step can be removed by fractional distillation and returned to the process. Thus, the methanol consumption is reduced and results in the reduction of biodiesel production cost [5].

3.2.2. *Effect of catalyst concentration and reaction time*

Another important parameter that affects the acid value of oil in the acid-catalyzed esterification is the catalyst concentration. The reaction was carried out at different catalyst concentrations (0.5, 0.6, 0.7, and 0.8% v/v of oil) and reaction times (30, 60, 90, and 120 min) for investigating their effect on the reduction of the acid value of oil. The methanol-to-oil ratio and reaction temperature were 0.35 v/v and 60 °C, respectively. The results indicated that ester formation rate increased with increasing catalyst concentration. The results of other researchers confirmed these results [6,13,14]. However, at lower catalyst concentration of 0.5% v/v of oil, acid value could not be reduced below 2 mg KOH/g oil even after 120 min. In this section, 0.7% v/v of oil was selected as the optimum catalyst concentration because it was the lowest catalyst concentration which provided the acid value less than 2 mg KOH/g oil in the minimum time. The catalyst concentration beyond 0.7% v/v of oil would make the removal of residual acid from pretreated oil more difficult which resulting in an additional cost.

3.2.3. *Effect of reaction temperature and reaction time*

Study was carried out at different reaction temperatures (32, 40, 50, and 60 °C) and reaction times (30, 60, 90, and 120 min) while the methanol-to-oil ratio and catalyst concentration were 0.35 v/v and 0.7% v/v of oil, respectively. The acid values of oil versus time were plotted at different reaction temperatures as shown in Fig. 2. The results showed that the reaction temperature had an important role in the acid-catalyzed esterification. As can be seen that the rate of reaction increased by increasing the reaction temperature. This was in accordance with the results obtained in previous reports [4,14]. However, it was observed that the acid-catalyzed esterification could occur at room temperature (32 °C) but the acid value of oil could not be reduced to less than 2 mg KOH/g oil even after 120 min. The highest reaction rate was obtained at 60 °C and the acid value reduced from 25.5 to 1.2 mg KOH/g oil within 60 min. Hence, the reaction temperature of 60 °C was considered to be the optimum temperature for this reaction.

Therefore, the optimum condition for acid-catalyzed pretreatment step was methanol-to-oil ratio of 0.35 v/v, catalyst concentration of 0.7% v/v of oil, reaction temperature of 60 °C, and reaction time of 60 min. At this condition, the FFA content in coconut oil was reduced to 0.6% and the water content of pretreated oil was 0.0146% w. The pretreated coconut oil product was clear and yellow in color.

3.3. *Alkali-catalyzed transesterification*

To carry the alkali-catalyzed transesterification to completion, the oil having FFA content less than 1% is required. In addition, all materials used for this reaction must be substantially anhydrous because water causes the production of soap [1,15]. At this study, the pretreated coconut oil met these requirements and it was transesterified with methanol by using potassium hydroxide as the catalyst to convert the triglycerides to methyl esters.

3.3.1. *Effect of methanol-to-oil ratio and reaction time*

One of the important parameters affecting the alkali-catalyzed transesterification reaction is the methanol amount. In this present study, the different methanol-to-oil ratios (0.1, 0.2, 0.3, and 0.4 v/v) and reaction times (5, 10, 30, 60, and 90 min) were used to investigate their effect on the methyl ester content of biodiesel product. The transesterification was carried out with the catalyst concentration of 1% w/v of oil and at the reaction temperature of 60 °C. The methyl ester contents versus time at different methanol-to-oil ratios were shown in Fig. 3. As can be observed, the reaction was incomplete at methanol-to-oil ratio of 0.1 v/v even after 90 min. The results indicated that the rate of transesterification increased with increasing methanol amount. This was in accordance with the results reported by other researchers [10,16]. However, the methyl ester content slightly improved with longer time duration. In this section, the best result was obtained at the methanol-to-oil ratio of 0.4 v/v and the methyl ester content reached 93.4% w in 60 min. With the economical reason, the excess methanol in glycerin phase was recovered by using distillation equipment and reused.

3.3.2. *Effect of catalyst concentration and reaction time*

Catalyst concentration is another important parameter affecting the methyl ester formation in the alkali-catalyzed transesterification. This is due to the presence of a catalyst which accelerates the conversion of triglycerides to fatty acid alkyl esters and glycerol. Prior report in literature indicated that the ester conversion was 0% after 120 min when the transesterification of *Cynara cardunculus* L. oil with methanol was carried out without a catalyst (0% NaOH) [16].

To investigate the effect of the catalyst concentration on the methyl ester content, the reaction was carried out at four different catalyst concentrations (0.5, 1.0, 1.5, and 2.0% w/v of oil) and in different reaction times (5, 10, 30, 60, and 90 min). The methanol-to-oil ratio and reaction temperature were 0.4 v/v and 60 °C, respectively. Fig. 4 showed the methyl ester contents versus time at different catalyst concentrations. As expected, increasing the catalyst concentration increased the transesterification rate. These results were confirmed by the results of other researchers [10,16]. For a catalyst concentration of 1.5% w/v of oil, the methyl ester content was achieved 98.4% w within 60 min, which was higher than

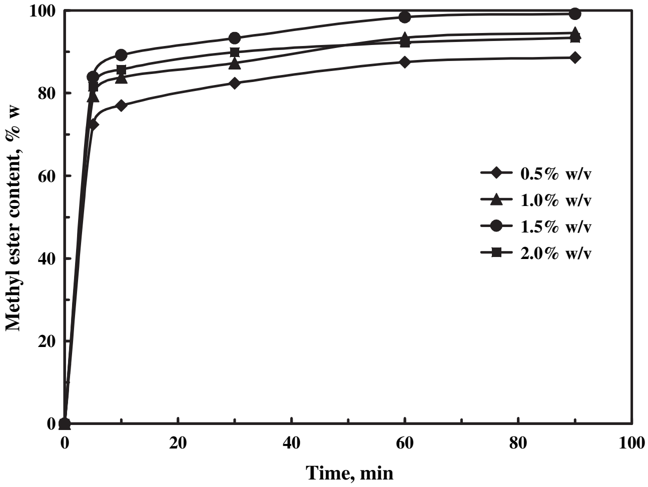

Fig. 4. Effect of catalyst concentration and reaction time on methyl ester formation (methanol-to-oil ratio of 0.4 v/v, reaction temperature of 60 °C).

the minimum limit of Thai biodiesel (B100) specification. At 2% w/v of oil, however, the methyl ester contents were lower than those of 1.5% w/v of oil. This was in accordance with the results found by other researchers [10,16]. It was due to the formation of soap during transesterification in the presence of high concentration of catalyst and resulted in the increasing of viscosity of the reactants [10]. Thus, the lower methyl ester contents were obtained. Therefore, 1.5% w/v of oil was selected as the optimum catalyst concentration.

3.3.3. *Effect of reaction temperature and reaction time*

The alkali-catalyzed transesterification of pretreated coconut oil was carried out at four different reaction temperatures (32, 40, 50, and 60 °C) and in different reaction times (5, 10, 30, 60, and 90 min) in order to investigate the effect of reaction temperature and reaction time on the methyl ester formation. In this section, methanol-to-oil ratio of 0.4 v/v and catalyst concentration of 1.5% w/v of oil were used.

It was found that the reaction temperature influenced the reaction rate and methyl ester content. As can be observed, the alkali-catalyzed transesterification could occur at different temperatures even at room temperature (32 °C). However, at 32 °C, the reaction was slowest and the methyl ester content was 87.7% w even after 90 min. The results indicated that the reaction was faster at a higher temperature, whereas a longer reaction time was required for a lower reaction temperature to achieve the same methyl ester content. This was in agreement with results obtained by other researchers [10,16,17]. In this section, the reaction proceeded most satisfactorily at 60 °C with the methyl ester content of 98.4% w in 60 min. This methyl ester content was higher than the minimum limit of the Thai biodiesel (B100) specification. Hence, the optimum reaction temperature was 60 °C.

Therefore, the optimum condition for alkali-catalyzed transesterification was methanol-to-oil ratio of 0.4 v/v, catalyst concentration of 1.5% w/v of oil, reaction temperature of 60 °C, and reaction time of 60 min. At this condition, the methyl ester content was achieved 98.4% w and the GC chromatogram of coconut biodiesel was shown in Fig. 5.

3.4. *Properties of coconut biodiesel*

The physical and chemical properties of coconut biodiesel were determined by standard test methods and the results in comparison with those of Thai Biodiesel (B100) specification were shown in Table 2. The result showed that the viscosity of coconut oil was reduced from a value of 28.05 to 2.937 mm^2/s by the two-step process. It was lower than the acceptable level of the Thai biodiesel (B100) specification, however, it was very close to that of Thai petroleum diesel (3.068 mm^2/s). This is the advantage of coconut biodiesel over other biodiesels. The viscosity of coconut biodiesel was lower than those of other biodiesels, such as soybean (4.08 mm^2/s), rapeseed (4.5 mm^2/s), and rubber seed (5.81 mm^2/s) [4]. This was due to coconut triglyceride consisted of 57.7% short chain fatty acids comprising mainly of lauric and myristic acids containing 12 and 14 carbon atoms, respectively. On the other hand, the other kinds of triglycerides, such as soybean, rapeseed, and rubber seed, consisted mainly of long chain fatty acids containing 18 carbon atoms [4]. Thus, coconut biodiesel contained a high proportion of lower molecular weight methyl esters, especially methyl laurate and methyl myristate, while biodiesels produced from other kinds of triglycerides contained chiefly of higher molecular weight methyl esters, especially methyl oleate and methyl linoleate. This resulted in a lower viscosity of coconut biodiesel as compared with the other biodiesels. The oxidation stability of biodiesel depends on the fatty acid composition as well as on the natural antioxidants. High content of unsaturated fatty acid makes biodiesel susceptible to oxidative degradation and this lead to the engine and injection problems [18]. It was found that coconut biodiesel had high oxidation stability and this was due to its high proportion of saturated methyl esters. Hence, the coconut biodiesel could be used to blend with lower oxidation stability biodiesels to improve their oxidation stability. This improvement was confirmed by the report that when palm biodiesel (high oxidation stability) was blended with rapeseed biodiesel (lower oxidation stability), the blended biodiesel had higher oxidation stability than rapeseed biodiesel [18]. In the transesterification, monoglycerides and diglycerides are the intermediates in this reaction and can cause fuel filter plugging [1]. In this present study, only trace amount of monoglyceride was detected. This value associated with high methyl ester content, 0% diglyceride, and 0% triglyceride ensured that the alkali-catalyzed transesterification reaction was complete at the optimum condition. Thus, coconut biodiesel could be used in a diesel engine without any problem from these reaction intermediates. In addition, the other measured properties of coconut biodiesel also met Thai biodiesel (B100) specification.

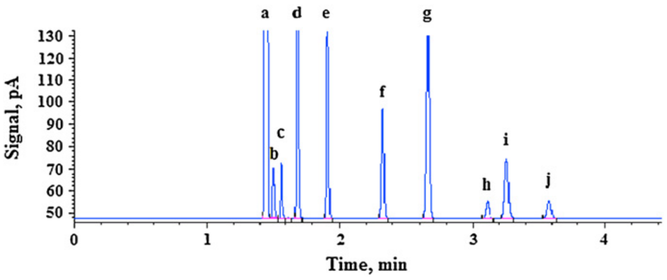

Fig. 5. Chromatogram of coconut biodiesel: (a) n-heptane, (b) methyl caprylate, (c) methyl caprate, (d) methyl laurate, (e) methyl myristate, (f) methyl palmitate, (g) methyl heptadecanoate (used as internal standard), (h) methyl stearate, (i) methyl oleate, (j) methyl linoleate.

Table 2
Properties of coconut biodiesel in comparison with Thai biodiesel (B100) specification.

Test item	Limit	Result
Density at 15 °C, kg/m^3	860–900	874.8
Kinematic viscosity at 40 °C, mm^2/s	3.5–5.0	2.937
Copper strip corrosion (3 h at 50 °C)	Max No.1	1a
Total acid number, mg KOH/g	Max 0.50	0.29
Water content, % w	Report	0.028
Carbon residue on 10% distillation Residue, % w	Max 0.30	0.24
Iodine value, g I_2/100 g	Max 120	30
Gross heat of combustion, MJ/kg	Report	38.1
Oxidation stability at 110 °C, h	Min 6	14.98
Triglyceride, % w	Max 0.2	0.000
Diglyceride, % w	Max 0.2	0.000
Monoglyceride, % w	Max 0.8	0.2049

4. Conclusions

This study revealed that the coconut biodiesel could be produced successfully from coconut oil having 12.8% FFA by two-step process, acid-catalyzed esterification followed by the alkali-catalyzed transesterification. The first step converted the FFAs in coconut oil to methyl esters and resulted in the reduction of FFA level. Triglycerides in low FFA pretreated oil were then converted to methyl esters in the second step. The viscosity of coconut biodiesel was very close to that of Thai petroleum diesel and the other measured properties met with the Thai biodiesel (B100) specification.

The specific conclusions of the present study were the following:

(a) In the first step, the FFA content in coconut oil was reduced from the initial value of 12.8 to 0.6% by acid-catalyzed esterification. The optimum condition of this step was methanol-to-oil ratio of 0.35 v/v, catalyst concentration of 0.7% v/v of oil, reaction temperature of 60 °C, and reaction time of 60 min. After that, the 0.6% FFA oil was transesterified with methanol using an alkaline catalyst. The optimum condition for this step was methanol-to-oil ratio of 0.4 v/v, catalyst concentration of 1.5% w/v of oil, reaction temperature of 60 °C, and reaction time of 60 min. The methyl ester content of the coconut biodiesel product was achieved at 98.4% w.

(b) The results showed that all process parameters had the effect on the acid-catalyzed esterification and alkali-catalyzed transesterification in the positive manner. However, in the case of the acid-catalyzed esterification, methanol-to-oil ratio and catalyst concentration beyond the optimum values showed little improvement in the reduction of FFA contents. For alkali-catalyzed transesterification, the negative effect of catalyst concentration was observed when the catalyst concentration beyond the optimum value.

From all of these results, therefore, the low cost coconut oil having 12.8% FFA has a high potential as a feedstock for biodiesel production. It can be recommended as supplementary oil feedstock for biodiesel production in Thailand if engine performance tests provide satisfactory results.

Acknowledgements

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