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The Production of Biodiesel and Bio-kerosene from Coconut Oil Using Microwave Assisted Reaction

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Abstract. Biofuels including biodiesel, an alternative fuel, is renewable, environmentally friendly, non-toxic and low emissions. The raw material used in this work was coconut oil, which contained saturated fatty acids about 90% with high percentage of medium chain (C_8 - C_{12}), especially lauric acid and myristic acid. The purpose of this research was to study the effect of power and NaOH catalyst in transesterification assisted by microwave for production of biofuels (biodiesel and bio-kerosene) derived from coconut oil. The reaction was performed with oil and methanol using mole ratio of 1:6, catalyst concentration of 0.6% with microwave power at 100W, 180W, 300W, 450W, 600W, and 850W. The reaction time was set at of 3, 5, 7, 10 and 15 min. The results showed that microwave could accelerate the transesterification process to produce biodiesel and bio-kerosene using NaOH catalyst. The highest yield of biodiesel was 97.17 %, or 99.05 % conversion at 5 min and 100W microwave power. Meanwhile, the bio-kerosene obtained was 65% after distillation.

1. Introduction

The use of petroleum still dominates the energy consumption in Malaysia. Policies were introduced to support the development of renewable energy so as to substitute a part of fossil based fuels with biofuels. Methyl (or ethyl) ester is obtained during the process of transesterification of plant oils or animal fats with the presence of methanol or ethanol and some basic catalyst. Biodiesel (most common type of methyl ester) is a nontoxic, biodegradable, clean burning fuel for diesel engines made from renewable fats and oils [1]. Aviation fuels have a number of requirements: they must stay liquid at low temperatures, and have high energy content by volume. Fuels such as diesel, biodiesel or bioethanol do not fit these requirements well. This kind of alternative jet fuel is known as bio-kerosene. Bio-kerosene is another type of methyl ester.

Coconut oils (*Cocos nucifera*) consist of various kinds of triglyceride fatty acids, which saturated fatty acid accounted 90% and are rich of medium chains (C_8 - C_{12}), especially lauric acid and myristic acid [2]. Coconut oil as a raw material has advantages compared other



vegetable oils, it contain around 65% medium chains of fatty acids. These medium chain fatty acids are good feed stock to obtain other fuels such as bio-kerosene, or jet fuel [2].

The development of biodiesel applying microwave assisted reaction to accelerate the transesterification reaction has been reviewed by many authors [3-5]. Microwave provides many advantages as follows: fast startup time, faster heating, efficient energy and the lower process cost, easy to monitor, precise, selective heating and the better quality of product [6]. The technology of bio-kerosene manufacturing is similar to the technology of biodiesel production. This fuel would have similar properties to petroleum-derived kerosene (the fuel currently used for aviation). However, application of bio-kerosene in aviation needs further detailed investigation and optimization of its production technology. This research was aimed to study the development of the process of the preparation of biodiesel and bio-kerosene from coconut oil by utilizing the microwaves as an energy source and to see the impact of the microwave exposure on the yield of the products.

2. Methods and Experimental Setup

2.1 Materials and Equipment

Food grade coconut oil was procured from a local supermarket. Anhydrous methanol, sodium hydroxide (NaOH) and other chemicals used were all of analytical reagent grade. There were from MERCK-Fluka and obtained from a local chemical supplier.

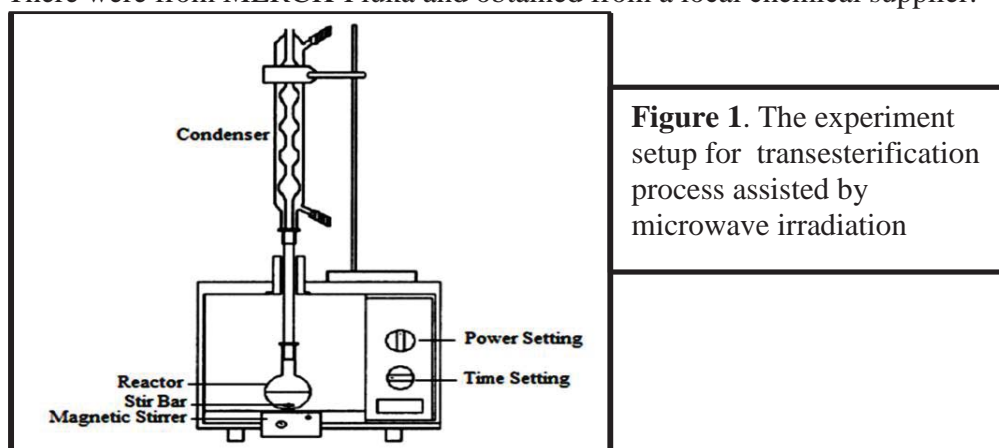


Figure 1. The experiment setup for transesterification process assisted by microwave irradiation

The microwave irradiation was used to carry out the reaction to produce biodiesel. The batch reactor equipment used in this study is shown in Figure 1. The reactor was a flat bottom flask made from Pyrex glass equipped with magnetic stirrer. The microwave irradiation was carried out using a domestic microwave oven (Samsung, CE2877N, S. Korea) with an operating frequency of 2450 MHz. The microwave oven provided microwave radiation at variable power levels of 100 W, 180 W, 300 W, 450 W, 600 W and 850 W and time setting from 0-30 min. The separation of the biofuels into biodiesel and bio-kerosene was carried out by employing a vacuum distillation using a rotary evaporator (Yamato, Japan-YMT255116).

2.2 Transesterification Reaction Using Microwave Heating

Coconut oil was introduced into the reactor and mixture of methanol and sodium hydroxide (NaOH) were added. The molar ratio oil to the methanol was 1:6 (Note: 1 mol oil is estimated as 950 g/mol and 1 mol methanol is 40 mL) and alkaline catalyst used for reaction was 0.6%.wt of the oil. Two hundred grams of coconut oil (0.21 mol) was fed to the

reactor and mixed with 50.4 mL methanol (1.26 mol) per run. The solution was reacted in a 500 ml reaction flask attached to a reflux set apparatus. The power was set at 100 W and 3 min. The reaction mixture was stirred at 200 rpm. The process was repeated for different time setting (5, 7, 10 and 15 min) while keeping the power at 100W. Further experiments were carried out at 5 min but with different power setting. After completion, the product was left at room temperature for separation. Separation took only 2 min. The upper layer was methyl ester and the bottom layer was glycerol. The methyl ester was washed using warm water for three times and the product was dried at 100°C for 1 h in conventional oven to get rid of the water. The methyl ester obtained was followed by vacuum distillation using a rotary evaporator to separate bio-kerosene from biodiesel at 185°C and 70 mmHg.

3. Results and Discussion

3.1 *Effect of Reaction Time on Product Viscosity and Yield*

Coconut oil and palm kernel oil are two important tropical plant oils that can be mass produced and satisfy medium chain requirement and have dominant fatty acid as lauric acid, which is the important point for production of bio-kerosene. If the feedstock is proper, then no cracking step is necessary, results in using the simple production technology, reducing investment and production costs for aviation biofuel. The composition of fatty acid of coconut oil shows that the highest contents were 51.02 % of lauric acid and 18.94 % of myristic acid, which were reported in previous studies [2, 6, 7].

Experiment was carried out with 0.6wt % NaOH for various microwave powers, in which input power influenced to the amplitude of wave. If the electric field rises, (greater power) the amplitude of the microwave increases. The rotational speed of the polar molecules has a linear relationship to the amplitude of the microwave.

Results show (figure not shown) that there is an effect of the microwave irradiation time on the viscosity of methyl ester (biofuel) produced. It was found that the viscosity decreased drastically from 28.3 at the initial time of the reaction (taken as control) to 3.05 mm²/s at 3 min and was relatively constant for the rest of the time until 15 min. It was indicative that the reaction had completed in 3 min. It was interesting to note that the viscosities of products were relatively similar for all the other powers used.

The results (figure not shown) for the yield of product obtained with respect to reaction time conducted at 100W is as follows: The yields of product increased to 91.20% at 3 min and then to 97.17% at 5 min. After 5 min, the yields slightly decreased and then were relatively constant. This indicated that the longer time did not significantly influence the yield of methyl ester (mixture of biodiesel and bio-kerosene). It was characteristic of microwave assisted reaction in biodiesel preparation, that less time is needed for the reaction to achieve high yields of around 97% [3, 8].

Generally, from the results (figure not shown) for the effect of microwave power on yield of biodiesel (conducted at 0.6 wt% NaOH for 5 min. and molar ratio of oil to methanol of 1: 6), there is a decrease in biodiesel yield as the power is increased, which was similar to other works [9]. The increase of microwave power caused the damage of organic substances, such as triglycerides [3]. The energy required for the microwave method was 10 times lower than that of the conventional method. The results showed that the use of microwave in transesterification reaction with NaOH was better conducted within a low power 100 W. It was also found that preparation methyl ester (biodiesel and/or bio-kerosene) by microwave assisted reaction takes only 5 min as compared to conventional technique which takes about 1

h [8]. The highest yield of methyl ester obtained was 97.17% at 100W for molar ratio of oil to methanol 1:6 and 0.6 wt% NaOH.

The preparation of methyl ester conducted above 60°C using NaOH and conventional heating was not effective because of the rivalry between transesterification and saponification reactions as previously noted by some researchers [11]. Therefore, the process of transesterification reaction using 0.6 wt% NaOH in microwaves, carried out with shorter time (5 min) was not only rapid and economical but also gave higher yield of methyl ester. It is anticipated that at low power level of microwave irradiation non-thermal effects of microwave play a role. At low power level the reactive side of the catalyst may undergo conformational changes to favor efficient substrate-catalyst interaction which will enhance the reaction rate [11].

3.2 Separation of Biodiesel and Bio-kerosene

The methyl ester prepared was then followed with the separation process to obtain biokerosene. The separation was conducted by heating at 185°C and 70 mmHg using a rotary evaporator. The time taken was 45 min. The bio-kerosene was evaporated and condensed to be the distillate; meanwhile the portion of the methyl ester that remained which did not escaped because of higher boiling point was the biodiesel. The biodiesel product, which was not evaporate was golden yellow, and the distillate (bio-kerosene) was more transparent. The percentage of bio-kerosene obtained from the methyl ester after distillation was 65% while the remaining was biodiesel.

3.3 Biodiesel Properties of Coconut Biodiesel

The quality of the product is determined by several parameters, such as cetane number, kinematic viscosity, density, and others. Table 1 describes the comparisons of biodiesel properties obtained with those of biodiesel standard value (EN14214). It was found that the product of biodiesel met the European standard (EN) and ASTM standards for biodiesel.

Table 1. Comparison of biodiesel product properties with the biodiesel standard properties values (based on European Standard –EN 14214)

Physical Properties	EN14214	Sample from this work
Density at 15°C	860-900 kg/m ³	868 kg/m ³
Viscosity at 40°C	3.5-5.0 mm ² /s	3.91 mm ² /s
Acid number	< 0.50 mg KOH/g	0.07 mg KOH/g
Flash point	120°C (min)	130°C

Table 2. Comparison of bio-kerosene properties produced after distillation with the bio-kerosene standard properties values (based on ASTM-D1655).

Physical Properties	ASTM 1566	Sample from this work
Density at 15°C	775-840 kg/m ³	768 kg/m ³
Viscosity at -20°C	8.0 mm ² /s (max)	6.72 mm ² /s
Freezing point	Max -47.0°C	10.2°C
Flash point	38°C (min)	45°C
Lower heating value	42.8 MJ/kg (min.)	42.9 MJ/kg

For the case of bio-kerosene it must comply with the ASTM D1655 standard for some critical parameters such as freezing point, density, flash point, viscosity, lower heating value.

As can be seen in table 2, the bio-kerosene does not meet the criteria for freezing point as well as the flash point. The requirement for freezing point, which is -47°C, is perhaps the most stringent and the hardest to meet. Blending the bio-kerosene with the mineral kerosene may help to improve the parameters. The other way to improve the freezing point is by adding certain amount of aromatic compounds. Typically propylbenzene at 10-20% vol. can be

added. No attempt was made in this study to see the effect of additives on the freezing point of the biokerosene.

4. Conclusion

The biofuels, biodiesel and bio-kerosene were successfully prepared using the microwave, which decreased the reaction time. It was found that the greater the power used, the lower was the yield of biodiesel. The highest yield was 97.17 %, at power 100 W for 5 min using 0.6 wt% NaOH. The methyl ester containing mixture of biodiesel and bio-kerosene was separated applying vacuum distillation at 185°C. The distillate (bio-kerosene fraction) obtained was 65%. In general, the biodiesel met with standard quality required, however the bio-kerosene was not up the requirement for jet-fuel quality especially in terms of the freezing point. The quality could be improved by blending with petroleum based kerosene or by addition of aromatics.

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