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Biodiesel Production from Palm Oil Using an Oscillatory Baffled Reactor

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***Abstract*—**Biofuel production especially that of biodiesel has gained tremendous attention during the last decade due to environmental concerns and shortage in petroleum oil reservoir. This research aims to investigate the influences of operating parameters, such as the alcohol-to-oil molar ratio (4:1, 6:1, and 9:1) and the amount of catalyst (1, 1.5, and 2 wt.%) on the trans esterification of refined palm oil (RPO) in a medium-scale oscillatory baffle reactor. It has been shown that an increase in the methanol-to-oil ratio resulted in an increase in fatty acid methyl esters (FAMEs) content. The amount of catalyst has an insignificant effect on the FAMEs content. Engine testing was performed on B0 (100 v/v% diesel) and blended fuel or B50 (50 v/v% diesel). Combustion of B50 was found to give lower torque compared to pure diesel. Exhaust gas from B50 was found to contain lower concentration of CO and CO_2.

***Keywords*—**Biodiesel, oscillatory baffled reactor, palm oil, transesterification, fatty acid methyl esters.

I. Introduction

NOWADAYS, researches were conducted to develop technology for production of alternative transportation fuel from the relatively abundant and inexpensive resources. Conversion of triglyceride content in vegetable oil to FAMEs and glycerol through reaction with alcohol and a catalyst in the transesterication reaction is an interesting option for energy sustainability. Currently, FAMEs, or also referred to as biodiesel, have been employed as liquid transportation fuel. On the other hand, glycerol can be converted to hydrogen gas via the plasma technology, which can then be supplied to power fuel cell vehicle [1]-[4]. In order to meet the 96.5% FAMEs specification according to EN 14214 standard while maintaining a low production cost, many types of intensification techniques have been studied including microwave-assisted trans esterification, ultrasonic cavitation and hydrodynamic cavitation [5], [6]. Recently a new model to intensified transesterification by improving mixing intensity through oscillation and baffled placement has demonstrated high potential for biodiesel production.

Oscillatory baffled reactor (OBR) is a tubular type of reactor with baffles along the length of the tube and equipped with a motor-pistol device to generated oscillatory motion. Higher mixing intensity is observed inside the tube reactor due to the oscillatory motion of liquid material that is moving against the baffles. As the liquid is pushed against the baffle in one direction, small vortices are created on the opposite side, which help increase the degree of mixing inside the reactor [7]. Flow behavior inside an OBR is also considered as plug flow, which is an ideal type of flow where the velocity profile of liquid material is uniformed along the axial length of the reactor [8]. Apart from transesterification, examples are the uses of OBR to intensify biological processing [9], [10], polymerization [11], [12], and enzymatic saccharification [13].

Transesterification is a process where high-viscosity triglyceride content is transformed to lower viscosity FAMEs, which is suitable for combustion in a diesel engine. This reaction was found to be influenced by operating parameters such as reaction temperature, amount of catalyst, residence time and alcohol-to-oil ratio [14]. In addition to these operating parameters, another important criterion for a high-yield transesterification reaction is the mixing intensity between alcohol, catalyst and the reactant. Phan et al. reported transesterification of rapeseed oil in an OBR reactor using KOH-methanol solution. In their research, production of biodiesel with FAMEs content as high as 97% was achieved at reaction temperature of 333 K, methanol-to-oil ratio of 6:1, 2 wt.% KOH catalyst and residence time of 5 minutes. It was also found in this research that a residence time of higher than 5 minutes had a negative effect on the transesterication reaction [15]. So far, most experiments were conducted in a small-scale OBR with effective reactor volume of lower than 60 cm^3.

The main aim of this research is to investigate the effect of operation conditions such as amount of catalysts and methanol-to-oil ratio, on the FAMEs content of biodiesel produced from RPO. The obtained biodiesels were blended with pure diesel (B50; 50 v/v% biodiesel) then tested in a 1-cylinder Kubota diesel engine. The exhausted gas was analyzed in order to measure and compared the concentration of hazardous and greenhouse gases such as CO, CO_2, and NO_x.

II. Details Experimental

A. Trans Esterification Setup

The trans esterification setup for continuous biodiesel production from RPO over homogenous KOH catalyst solution was carried out in an OBR. The reactor is made up of glass with a total volume of 300 cm^3, diameter of 13 mm and placed in a water bath equipped with a heater (Mermerth,

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WMB 14). Oscillation of medium inside the reactor was generated by a motor attached to a disc, a 20-cm rod, and a piston. Movement of the piston can be adjusted by the amplitude and the frequency of the oscillatory motion which is controlled by the length of the linkage and the rotational speed of the motor. During transesterification reaction, RPO which is supplied by Research and Technology Institute Petroleum Authority of Thailand (RTI PTT) is delivered into the piston holder by a peristatic pump (Watson, 603s). Additionally, KOH solution in methanol was delivered by another peristaltic pump (Watson, 505s) into the OBR reactor as shown in Fig. 1.

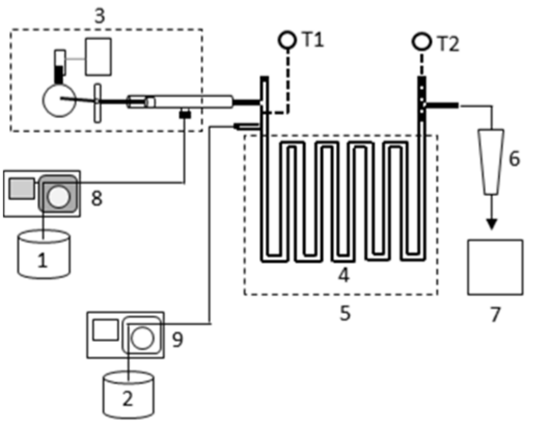

Fig. 1 Transesterification setup using OBR: (1) RPO feedstock, (2) KOH in methanol, (3) Oscillatory motion creator, (4) Baffled reactor, (5) Conventional heating, (6) Separating funnel, (7) Gas chromatography, (8, 9) peristaltic pump and (T1, T2) thermocouple probes

Flow rate of individual peristatic pump is based on the alcohol-to-oil molar ratio. The total flow rate was set at 550 mL/min, which is equaled to a residence time (τ) of roughly 33 seconds. The temperature of the water bath was set at 333 K. At this temperature, the viscosity and density of palm oil is 16.93 mPa and 0.870 g/cm^3, while the viscosity and density of methanol is 0.3630 mPa and 0.754 g/cm^3. Through the viscosity blending index method, viscosity of the methanol-oil mixture was found to be 6.8 mPa [16]. Before entering the system, palm oil in the reservoir is pre-heated to 333 K.

B. Product Analysis

Products were collected 2, 4, and 5 minutes after operation. These products are separated into two phases in a funnel; the top phase is biodiesel, and the bottom phase is methanol and glycerol. The standard EN14103 was adopted in order to analyze FAMEs content of the collected product [17]. Approximately, 50 mg of the top phase is taken to be mixed with 1 mL of stock solution containing 10 mg of methyl-heptadecanoate in 1mL of heptane. The sample solution is injected into a gas chromatography equipped with a Stabilwax column (30 m × 0.25 µm × 0.25 µm) and an FID detector. The area of designated peak is then put into the equation suggested in standard EN14103. Biodiesel yield was calculated by the follow equation:

$$Biodiesel\ \ yield(\%) = \frac{Biodiesel\ \ produce}{Amount\ \ of\ \ RPO\ \ fed} \times 100 \quad (1)$$

C. Engine Performance Testing

Product from the OBR was collected for a period of time to attain approximately 10 liters. After the product was separated from glycerol, washed with warm water and evaporated, the produced biodiesel was blended with pure diesel and tested with a 1-cylinder Kubota diesel engine (Specification: direct Injection diesel engine 4 stroke, bore x stroke equaled to 97 mm x 96 mm, displacement of 709 cm^3 and compression ratio of 18:1.) The system for engine performance testing consisted of an automated solenoid type flow meter (Tokyo Kokukeiki, TK1) used to measure fuel consumption, an eddy current dynamometer (Tokyokoki-Schenck, TS1) and a control panel to adjust the engine speed and torque. The exhaust gas was analyzed using a portable gas analyzer (Emission System, 5003).

III. Results and Discussion

A. Influence of Methanol-To-Oil Molar Ratio

According to Le Chatelier's principle, having excess methanol in the transesterification reaction will drive the reaction forward meaning that more FAMEs will be generated. Fig. 2 illustrated an increase in FAMEs content as the methanol-to-oil molar ratio increased from 4:1 to 8:1. This finding correlated well with the theory and results from other works [18]-[20]. The methanol-to-oil ratio was not increased beyond 8:1 because it was also reported that adding too much methanol will cause glycerol solubility to increase which led to emulsification of biodiesel and reduction in FAMEs content [21], [22]. It is observed that an increase in methanol-to-oil molar ratio from 4:1 to 8:1 caused FAMEs content to increase from 92.9 wt.% to 96.2 wt.%.

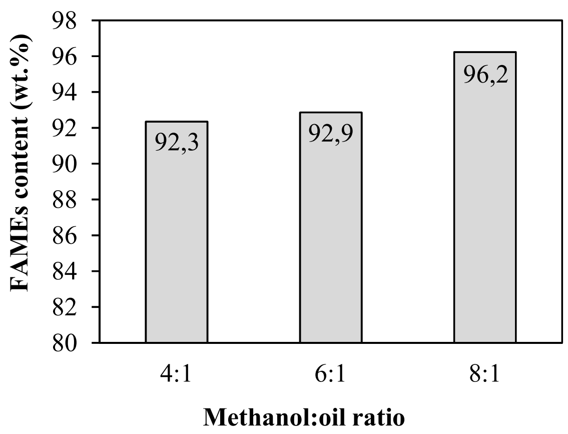

Fig. 2 Influence of methanol-to-oil molar ratio on FAMEs content (operating conditions: 333 K, 2 wt.% KOH catalyst, τ = 33 seconds. oscillation conditions: amplitude = 10 mm and frequency = 3.75 Hz)

In order to produce high FAMEs biodiesel, the amount of catalyst need to be set at an appropriate level. If the amount of catalyst is too low, then there might not be enough hydroxide ion to react with triglyceride molecule. On the other hand, if too much catalyst is added, then the excess hydroxyl ion may react with methyl ester to form soap through the saponification reaction [15]. This is because the saponified products create a steric barrier which prevent the lone pair of oxygen atom in the alcohol molecule from being exposed to the carbonyl group of the triglyceride molecule during the transesterification reaction [23].

In this research, KOH was chosen as a catalyst because it dissolves well in methanol [24]. The amount of KOH catalyst in methanol was found to have insignificant effect on the formation of FAMEs.

B. Influence of Amount of Catalyst

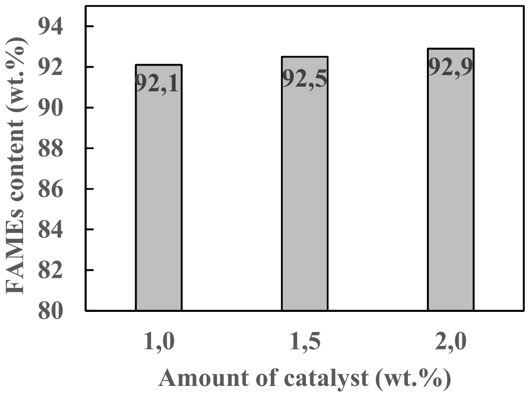

Fig. 3 Influence of the amount of catalyst on FAMEs content. (operating conditions: 333 K, methanol-to-oil ratio = 6:1, τ = 33 s. oscillation conditions: amplitude = 10 mm and frequency = 3.75 Hz)

C. Engine Performance Testing

B0 (100 v/v% Diesel) and B50 (50 v/v% biodiesel) were tested using a 1-cylinder Kubota diesel engine. Fig. 4 demonstrates the torque of the engine at different engine speed. The blended fuel was found to give lower torque compared with the combustion of pure diesel. This mean that the brake power at each engine speed generated by blended fuel is lower than pure diesel. Pure diesel gave higher brake power because diesel has significantly lower viscosity and higher heating value compared to biodiesel.

TABLE I
ANALYSIS OF EXHAUST GAS FROM COMBUSTION OF B0 ANS B50 IN THE 1-CYLINDER DIESEL ENGINE

Emission (ppm)	Fuel: B0	Fuel: B50
Carbon monoxide; CO	1.310	0.930
Carbon dioxide; CO_2	678.0	667.0
Nitrogen oxide; NOx	12.00	12.22

The exhaust gas from combustion of B0 and B50 in diesel engine was found to contain carbon monoxide (CO), nitric oxide (NO_x) and carbon dioxide (CO_2). As shown in Table I, exhaust gas from BO or pure diesel was found to contain more CO and CO_2 compared to exhaust gas from the blend fuel (B50). This is because, in addition to the increase in viscosity, biodiesel also have oxygen in the molecule. The results regarding engine performance and exhaust emission corresponded well with other researches [25], [26].

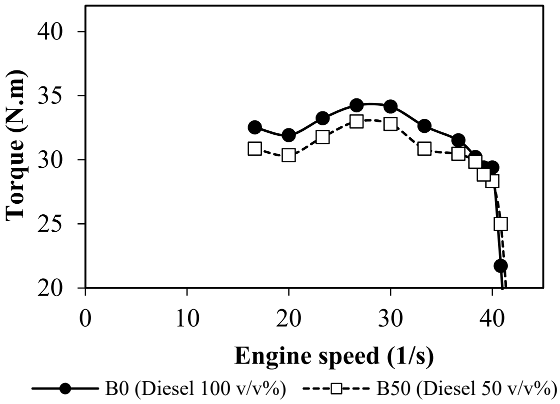

Fig. 4 Torque at increasing engine speed from B0 (Diesel 100 v/v%) and B50 (Diesel 50 v/v%) fuels

IV. CONCLUSION

An OBR was operated for transesterification of RPO using a KOH catalyst in methanol at 333 K, oscillatory frequency of 3.75 Hz, and amplitude of 10 mm. It was found that an increase methanol-to-oil molar ratio had a positive effect on the FAMEs content, and the amount of catalyst had very little effect on FAMEs content. Engine performance testing suggested that blend fuel (B50) gave lower torque compared to pure diesel. However, analysis of the exhaust gas suggested that blend fuel contained lower concentration of CO and CO_2 compared to pure diesel.

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REFERENCES

[1] F. Chen, X. Huang, and D.-g. Cheng, X. Zhan, “Hydrogen production from alcohols and ethers via cold plasma: A review,” International Journal of Hydrogen Energy. vol. 39 pp. 9036-9046, June 2014.
[2] D.H. Choi, S.M. Chun, S.H. Ma, and Y.C. Hong, “Production of hydrogen-rich syngas from methane reforming by steam microwave plasma,” Journal of Industrial and Engineering Chemistry, vol. 34, pp. 286-291, Feburary 2016.
[3] D. Czylkowski, B. Hrycak, R. Miotk, M. Jasiński, M. Dors, and J. Mizeraczyk, “Hydrogen production by conversion of ethanol using atmospheric pressure microwave plasmas,” International Journal of Hydrogen Energy, vol. 40, pp. 14039-14044, October 2015.
[4] X.Z. Liu, C.J. Liu, and B. Eliasson, “Hydrogen production from methanol using corona discharges Energy,” Chinese Chemical Letters, vol. 14, pp.631-633, June 2003.
[5] I. Choedkiatsakul, K. Ngaosuwan, S. Assabumrungrat, S. Mantegna, G. Cravotto, “Biodiesel production in a novel continuous flow microwave reactor,” Renewable Energy, vol. 83, pp. 25-29, November 2015.
[6] L. F. Chuah, J. J. Klemeš, S. Yusup, A. Bokhari, M. M. Akbar, A review of cleaner intensification technologies in biodiesel production, Journal of Cleaner Production.
[7] G. G. Stephens and M. R. Mackley, “Heat transfer performance for batch oscillatory flow mixing,” Experimental Thermal and Fluid Science, vol.25, pp. 583-594, February 2002.

[8] X. Ni, J. A. Cosgrove, A. D. Arnott, C. A. Greated, and R. H. Cumming, "On the measurement of strain rate in an oscillatory baffled column using particle image velocimetry," Chemical Engineering Science, vol. 55, pp. 3195-3208, August 2000.

[9] M. S. R. Abbott, A. P. Harvey, G. V. Perez, and M. K. Theodorou, "Biological processing in oscillatory baffled reactors: operation, advantages and potential," Interface Focus, vol. 3, pp.1-12, December 2013.

[10] M. S. R. Abbott, C. M. Brain, A. P. Harvey, M. I. Morrison, and G. Valente Perez, "Liquid culture of microalgae in a photobioreactor (PBR) based on oscillatory baffled reactor (OBR) technology – A feasibility study," Chemical Engineering Science, vol. 138, pp. 315-323, December 2015.

[11] E. Lobry, T. Lasuye, C. Gourdon, C. Xuereb, Liquid–liquid dispersion in a continuous oscillatory baffled reactor – Application to suspension polymerization, Chemical Engineering Journal, vol. 259, pp. 505-518, January 2015.

[12] T. McGlone, N. E. B. Briggs, C. A. Clark, C. J. Brown, J. Sefcik, and A. J. Florence, "Oscillatory Flow Reactors (OFRs) for Continuous Manufacturing and Crystallization," Organic Process Research & Development, vol. 19, pp.1186-1202, August 2015.

[13] M. S. R. Abbott, G. Valente Perez, A. P. Harvey, and M. K. Theodorou, "Reduced power consumption compared to a traditional stirred tank reactor (STR) for enzymatic saccharification of alpha-cellulose using oscillatory baffled reactor (OBR) technology," Chemical Engineering Research and Design, 92, pp. 1969-1975, October 2014.

[14] P. Verma and M. P. Sharma, "Review of process parameters for biodiesel production from different feedstocks," Renewable and Sustainable Energy Reviews, vol. 62, pp. 1063-1071, September 2016.

[15] A. N. Phan, A. P. Harvey, and V. Eze, "Rapid Production of Biodiesel in Mesoscale Oscillatory Baffled Reactors," Chemical Engineering & Technology, vol.35, pp. 1214-1220, May 2012.

[16] B. Zhmud, Viscosity Blending Equations, Lube-Tech, vol. 93, pp.22-27, June 2014.

[17] T. C. C. T., "Fat and oil derivatives - Fatty Acid Methyl Esters (FAMEs) - Determination of ester and linolenic acid methyl ester contents," in, European Commitee for Standardization, Brussels, pp. 11, April 2003.

[18] A. N. Phan, A. P. Harvey, and M. Rawcliffe, "Continuous screening of base-catalysed biodiesel production using New designs of mesoscale oscillatory baffled reactors," Fuel Processing Technology, vol. 92, pp. 1560-1567, August 2011.

[19] I. A. Musa, "The effects of alcohol to oil molar ratios and the type of alcohol on biodiesel production using transesterification process," Egyptian Journal of Petroleum, vol.25, pp. 21-31, March 2016.

[20] S. A. El Sherbiny, A. A. Refaat, and T. El Sheltawy, "Production of biodiesel using the microwave technique," Journal of Advanced Research, vol.1, pp. 309-314, October 2010.

[21] I. K. Hong, H. Jeon, H. Kim, S. B. Lee, "Preparation of waste cooking oil based biodiesel using microwave irradiation energy," Journal of Industrial and Engineering Chemistry, vol.42, pp. 107-112, January 2016.

[22] H. Yuan, B. L. Yang, and G. L. Zhu, "Synthesis of Biodiesel Using Microwave Absorption Catalysts," Energy & Fuels, vol. 23, pp. 548-552, December 2009.

[23] X. Yin, X. Zhang, M. Wan, X. Duan, Q. You, J. Zhang, S. Li, "Intensification of biodiesel production using dual-frequency counter-current pulsed ultrasound," Ultrasonics Sonochemistry, vol. 37, pp. 136-143, December 2017.

[24] E.T. Akhihiero, K.M. Oghenejoboh, P.O. Umukoro, "Effects of process variables ontransesterification reaction of jatropha curcas seed oil for the production of biodiesel," Int J Emerg Technol Adv Eng., vol. 3, no. 6, pp. 388–393, March 2013.

[25] A.N. Ozsezen, M. Canakci, V. Turkcan, C. Sayin, "Performance and combustion characteristics of a DI diesel engine fueled with waste palm oil and canola oil methyl esters," Fuel, vol.167, pp. 629–636, March 2016.

[26] M.A. Kalam, H.H. Masjuki, M.H. Jayed, A.M Liaquat, "Emission and performance characteristics of an indirect ignition diesel engine fuel with waste cooking oil," Energy, vol. 36, pp. 397–402, August 2011.