Original Article

The Continuous Process of Biodiesel Production with Water Heater Assist

Thibordin Sansawang[1], Chanjira Chimmanee[1], Trakan Butsing[1]

Received: 12 June 2015; Accepted: 13 July 2015

Abstract

The paper is to design a lab-scale biodiesel production machine with continuous process.This machine consists of a 25liter - tank of used cooking oil and a 6.5 liters - tank of methanol. The used cooking oil and methanol flow to the reactor with the designed flow rate so that the complete reaction occurs at the end of the reactor. The production rate is 1.817 liter/hour for normal operation mode. Then, this machine is modified equipped with a hot water system. The temperature of hot water is set to 40, 50 and 60°C. The production rate is increased to 3.15, 3.24 and 3.37 liter/hour respectively. The properties of biodiesel are tested and found that there are according to the ASTM D6751.

Keyword: biodiesel, biodiesel production, use cooking oil, transesterification

Introduction

Since the internal combustion diesel engine was invented in the early 20th century by Rudolf Diesel. It used vegetable oil as fuel. Then, petroleum was discovered a few years later, and replaced vegetable oil due to its higher engine efficiency[1]. Currently, diesel fuel has become an important factor in our modern life. Due to the latest oil crisis, most countries realize the importance of alternative fuel resources, especially in diesel engines.Vegetable oil contains fatty acid vary with the type of them. These fatty acid may cause the problems of combustion and emissions due to the worse physical and chemical properties than that of diesel. There are four techniques to modify the raw vegetable oil to use in diesel engine; pyrolysis, micro-emulsion, transesterification and blending[1-3]. Transesterification is wide accepted to be the best method to modify the raw vegetable oil into biodiesel to be used in a compression ignition (CI) engine without modification.

The biodiesel production is the reaction between fatty acid and alcohol such as methanol and ethanol. Generally, batch production is used in the commercial scale[4-7]. The continuous process is study to produce more biodiesel at a time. The problem of continuous process is time of reaction[8-9]. In this study, the lab-scale of biodiesel production is designed and test. The test experiment is performed at the ambient temperature and higher to compare the production yield and time of reaction.

Materials and Methods

1. Material and Transesterification

Transesterification is the reaction between fatty acid and alcohol. Fatty acid will change to ester as seen in (Figure 1).[10]

Biodiesel is a product of reaction of a triglyceride and alcohol to from ester (-O-C-O-), biodiesel and by product, glycerol as shown in (Figure 1). This reaction in reversible and the excess alcohol is used to force the equilibrium to the product side. The stoichiometric molar ratioof oil to methanol is 1:3.[10] This can be converted into mass ratio is 10:1. In this experiments, the batch production done by the authors manually showed that the 10:2 is the best ratio. So this study uses10:2 for all experiments.

Triglyceride are often found in natural fat form plants or animals[11,12]. Therefore, used cooking oil was selected to use in this experiment because of it is the waste from food production.

[1] *Department of Mechanical Engineering Faculty of Engineering and Industrial Technology Silpakorn University*

E-mail: sangsawang_t@su.ac.th

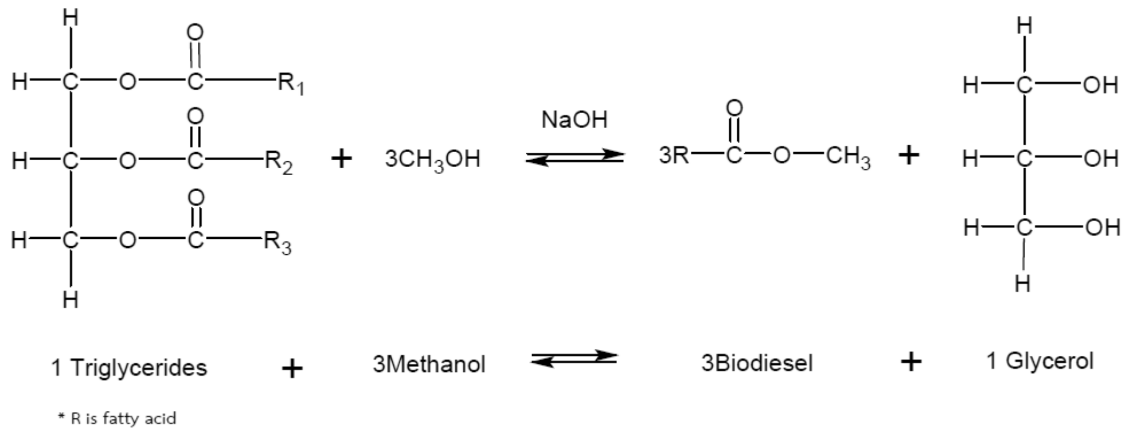

Figure 1 Transesterification[10]

2. Design and Experimental Procedure

The preliminary experiment begins with the batch production manually. Used cooking oil for 1.0 kg and 0.20 kg of methanol were mixed in the reactor tank. NaCl of 1% by mass of used cooking oil is used as catalyst. Firstly, there was no heat input to the reaction. The biodiesel from the reaction could be occurred at ambient temperature. Time of complete reaction in this case was 1 hour approximately.

Another experiment was batch production, but the heat form the heating coil was used to increase the temperature of used cooking oil. Temperature was controlled to be 40, 50 and 60°C. Time of complete reaction were found to be only 30 minute approximately for all cases.

Yield of biodiesel was a very important parameter. In manual batch production, the yield of biodiesel is up to 90%. This continuous process was expected for 1.5 litre/hour and yield was not less than 50%. So that the quantity of the used cooking oil tank was 25 liters for 7 hour operation for one sample. The methanol tank was 6.5 liters and NaCl was 1% of used cooking oil. The diagram of this machine is shown in the (Figure 2).

Time of reaction were used to design the flow rate of used cooking oil and methanol. Firstly, this machine was not equipped with the hot water heater. So that the time of complete reaction would be 1 hour and then the mixture flowed to the separator tank continuously. The mixture stayed in the separate tank for 3 hours and flows continuously to the 1st cleaning tank. The hot water, 60°C, flowed from the hot water tank to wash the mixture in the 1st cleaning tank for 1 hour. The waste such as glycerin, moisture and catalyst were removed and the mixture flowed to the 2nd cleaning tank. The cleaning process was repeated so that biodiesel was purified.

Afterward, the water heater was equipped at the reactor to increase the reaction rate. The both flow rate of used cooking oil and methanol were adjust by “trial and error” with the information from the preliminary test by manual batch production. The data of time of reaction were repeated for at least 3 times and collected as the results of this investigation.

(Figure 3) shows the lab-scale biodiesel production machine. The fuel and methanol tank are placed on the top of the machine. Gravity and flow control valve are used to control the flow rate of both raw materials. The result from the preliminary test are used to control the rate of reaction. The experiment results are analyzed by the test of hypothesis.

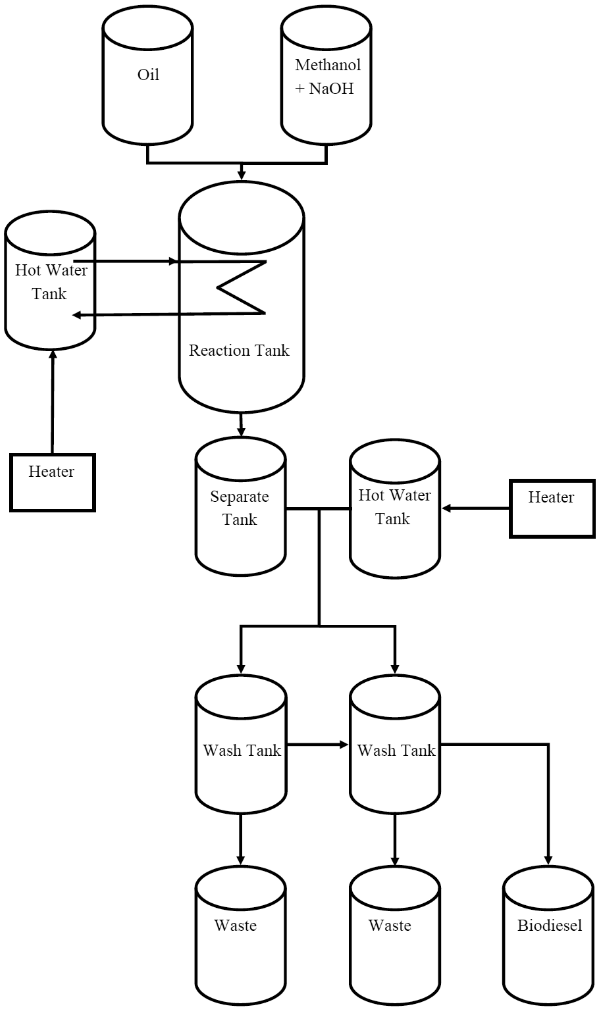

Figure 2 Diagram of Biodiesel Production Process

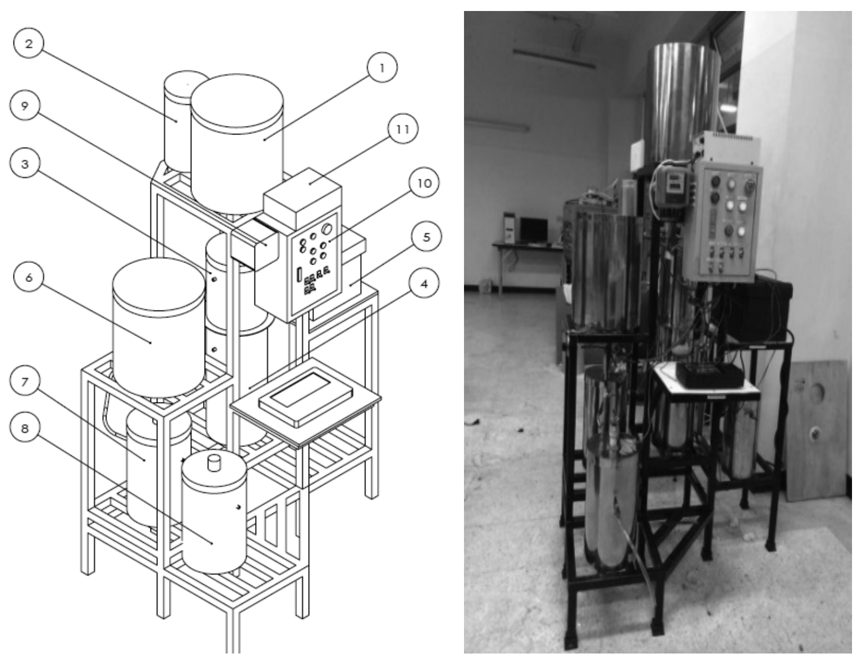

Figure 3 Biodiesel production machine 1. Oil tank, 2. Methanol tank, 3. Reactor, 4. Separator, 5. Hot water tank, 6. 1st cleaning tank, 7. 2nd cleaning tank, 8. Biodiesel reservoir, 9. kW-hr meter, 10. Control box, 11. Invertor

Results and Discussion

(Table 1) shows the time in each station of the biodiesel production machine. The ambient temperature mode uses the time to complete the reaction within 54 minutes. The higher temperature presents the shorter reaction time. The experiments shows that the temperature of 40°C to 60°C reduces the reaction time to 30 minute approximately

Table 1 Experiments result

time	temperature				unit
	Ambient temp.	**40°C**	**50°C**	**60°C**	
Reaction tank	54	32	32	31	minute
Separation tank	293	227	221	212	minute
1st cleaning tank	54	53	53	51	minute
2nd cleaning tank	59	58	57	55	minute
Total time of production	642	462	452	428	minute
Production rate	1.817	3.15	3.24	3.37	liter/hour
% yield	73.18	82.4	86	88.8	%

The separation time is shorter for the higher temperature mode due to the lower viscosity of oil. The lower viscosity leads to the higher rate to reaction with methanol. The separation times are reduced from 293 minute to about 220 minute.The time of cleaning process are not significantly different. The total production time of the water heater mode is reduced for 30% approximately. The shortest production time is 428 minutes for the temperature of 60°C of hot water.

Table 2 Statistical Analysis by Test of Hypothesis

Temperature	Production rate			% yield		
	t	**v**	**P-value**	**t**	**v**	**P-value**
40°C	20.00	2.87	0.0017	4.69	2.23	0.023
50°C	22.13	2.58	0.001	6.66	2.06	0.012
60°C	21.25	3.56	0.0005	7.15	3.12	0.0038

The hypothesis of this experiments in (Table 2) is set as follows; H_0 the temperature effect to the production rate and yield. H_1; the temperature does not effect to the production rate and yield. According to the table of Navidi[13], the t and v value in the Table 2 shows that P-value is under 0.05. At least 3 sample in each experiment were collected. It is found that H_0 is accepted. That means the higher temperature contributes the higher production rate and yield.

Table 3 Biodiesel specification

No.	Item	unit	Standard	Production temperature				Method
				Ambient	40°C	50°C	60°C	
1	Density at15°C	kg/m^3	0.86 - 0.90	0.885	0.881	0.881	0.881	ASTM D 4052-11
2	Viscosity at 40°C	cSt	3.5 – 5.0	5.612	5.0	4.8	4.7	ASTM D 445-12
3	Flash Point	°C	> 120	> 120	> 120	> 120	> 120	ASTM D 93-11
4	Cu Corrosion	-	No.1	1a	1a	1a	1a	ASTM D 130-10
5	Acid	mg KOH/g	< 0.50	0.36	0.177	0.168	0.147	ASTM D 664-09
6	Heating Value	kJ/kg	-	39,444	39,634	39,687	39,701	ASTM D 240-02

(Table 3) present the properties of biodiesel from the biodiesel production machine. All item are agreed with the ASTM standard. However, the viscosity of biodiesel from the ambient mode is out of range for 10%.

Table 4 Cost of Production

Item	Production Temperature				Unit
	Ambient	40°C	50°C	60°C	
Used Cooking Oil	25	25	25	25	Liter
Methanol	6.41	6	6.03	6.08	Liter
NaCl	208.2	110	110	110	gram
Electricity Consumption	1.33	3.33	3.43	3.37	Unit
Total Cost	466.33	566.45	567.47	568.51	Bath
Product	18.87	20.6	21.5	22.2	liter
Production Cost	30.74	27.49	26.39	25.61	Bath/liter

(Table 4) shows the details of biodiesel production. The higher temperature increases the production rate and lower energy consumption. The lowest cost is 25.61 Baht/liter at 60°C of reaction tank. The highest cost is 30.74 Baht/liter for ambient temperature of the reaction. The table shows that the highest cost is from the raw materials. In this experiments, electric oil is used to heat up the water in the reactor tank. Cost of electricity are about 25% of total cost. The electricity of production could be reduced from another method which are not mentioned here.

Conclusion

The transesterification of used cooking oil yield biodiesel is an effective way to reduce the waste from food production and pollution. The major drawback is the production cost. The one way to reduce process cost is change from batch production to continuous production. This study is to built the continuous process of biodiesel production machine in lab-scale. The water heater is equipped to increase the production rate. The experiments show that the production rate is increased for 73.36,78.32 and 85.47% for the hot water temperature of 40, 50 and 60°C respectively. The production cost is reduced up to 16.69%. The properties of biodiesel are meet the requirement of ASTM 6751.

The next step of this investigation is to reduce the production cost by using a solar water heater. This could lower the energy usage and reduce the production cost.

Acknowledgement

The authors would like to thank the Department of Mechanical Engineering, Faculty of Engineering and Industrial Technology, Silpakorn University for their financial support.

References

[1] Agarwal, A.K., Biofuels (Alchohols and Biodiesel) Applications as fuels for Internal Combustion Engines, Progress in Energy and Combustion Science, 2007; 33, 233 – 271.

[2] Ma, F. and Hanna,M., Biodiesel Production: a Review,Bioresource Technology, 1999; 70: 1-15.

[3] Fukuda, H., Kondo A. and Noda,H., Biodiesel Fuel Production by Transesterification of Oils, Journal of Bioscience and Bioengineering, 2001; 92(5): 405-416.

[4] Jantaban, N. and Supapu, N., Design and Built Biodiesel Production Equipment from Used Cooking Oil. Bachelor Project, Department of Mechanical Engineering, Faculty ofEngineering, Khonkan University. 2549.

[5] Sukharom,S., Study and Design of Lab-Scale Biodiesel Production, Department of Engine, Lampang Technical College,2556.

[6] SurampaiS., Biodiesel Production with Combine Energy, Clinic Technology, Ubolrachathani Technical College, 2554.

[7] Buaphumi, W.,Tepa, S. and SudprasertK., Biodiesel Production with Solar Assist, Energy Technology Division, School of Energy, Environment and Material. King Mongkut's University of Technology Thonburi, 2550.

[8] Vedalou, M.F. and Mekbutr, S., Design and Build the Continuous Biodiesel Production Process, Department of Mechanical Engineering, Faculty of Engineering and Industrial Technology, Silpakon University,2554.

[9] Sorndee, J. and Skulpram, P., Design and Build the Continuous Biodiesel Production Process, Department of Mechanical Engineering, Faculty of Engineering and Industrial Technology,Silpakon University, 2555.

[10] Peng, B.X., Shu, Q., Wang, J.F. and Wang, G.R., BiodieselProduction from Waste Oil Feedstock by Solid Acid Catalysis, Process Safety and Environment Protection, 2008; 86: 441-447

[11] Hernandez, D.,Astudillo, L.,Gutierreza, M.,Tenreiro, C.,Retamal, C. and Rojas, C. Biodiesel Production from an Industrial Residue: Alperujo, Industrial Crops and Products, 2013; 52: 495-598.

[12] Costa,J.F.,Almeida,M.F.,Alvim-Ferraz,M.C.M. and Dias, J.M., Biodiesel Production using Oil from Fish Canning Industry Wastes, Energy Conversion and Management, 2013; 74: 17-23.

[13] Navidi, W. Tables. Statistics for Engineers and Scientists, 3rd ed. New York: McGraw-Hill, 809,2010.