Iranica Journal of Energy & Environment
Journal Homepage: www.ijee.net
IJEE an official peer review journal of Babol Noshirvani University of Technology, ISSN:2079-2115

Research note

Evaluation of Operative Factors on Conversion Efficiency of Biodiesel Production from Waste Cooking Oil

A. Hasheminezhad[1*], S. J. Hashemi[2] and R. Tabatabaie[2]

[1] *Mechanical Engineering in Agricultural Machinery*, *Agricultural Sciences and Natural Resources University of Sari*, *Iran*
[2] *Department of Bio systems Engineering*, *Agricultural Sciences and Natural Resources University of Sari*, *Iran*

P A P E R I N F O

Paper history:
Received 11 May 2018
Accepted in revised form 15 June 2018

Keywords:
Biofuels
Biodiesel
Trans-esterification
Potassium hydroxide
Methanol

A B S T R A C T

Today, the production of biodiesel from waste cooking oil due to its renewability, low cost of production and also low pollution become more popular. In this research, the factors affecting the production of biodiesel by trans-esterification method from waste cooking oil were evaluated. For this purpose, a batch reactor which equipped with a mechanical stirrer, was designed and fabricated. Waste cooking oil as feedstock and methanol were used with molar ratio of 1:6 in the presence of potassium hydroxide as a catalyst (1wt%). In order to optimize the production process, these three parameters including rate of stirring at 3 levels (450, 550 and 650 rpm), at four temperatures 40, 50, 60 and 70°C, reaction time at 6 levels (10, 20, 30, 40, 50, 60 min) were considered. The results indicated, more than 90% of ester conversion occurred in the first 30 minutes and biodiesel production increased and reached to its maximum amount at stirring speed of 650 rpm and also the highest rate of esters conversion occurred at 60 °C. Thus, 60°C for reaction temperature and 650 rpm for stirring speed at 30 min were optimum production condition in order to reach to the most amount of biodiesel from waste cooking oil using a batch stirred tank reactor.

***doi**: 10.5829/ijee.2018.09.02.04*

INTRODUCTION

In general, renewable and nonrenewable energy resources can be divided into two categories. Renewable energy known as a sustainable fuel sources and often include solar, wind, biomass, biofuels, tidal, etc [1]. Renewable-energy development has become as important part of the global energy policy to reduce the greenhouse effect caused by fossil fuels [2]. Due to the geographical extent of the scattering centers and remote energy consumption, use of renewable energy such as hydropower, wind, solar, geothermal, biomass, bio-fuels, biogas, is more economical.

Biodiesel known as an environmental friendly fuel to produce energy approximately equal to the diesel fuel. Hence it can be considered as the most efficient alternative to diesel fuel. Biodiesel considered as an approximately free of sulfur fuel (sulfur-free <10 ppm) and a total reduction of pollutants such as carbon dioxide, unburned hydrocarbons and smoke is visible in comparison with diesel fuel [3].

Biodiesel known as an alternative fuel with a high flash point, with low emissions and high security that can be used in existing diesel engines and equipment used atomization without any reduction in engine performance [4].

In the most recent researches on biodiesel production from vegetable oils in batch reactors with mechanical stirring, temperatures near the boiling point of the alcohol was used [5,6,7]. The reactor tank is filled with waste oil and subsequent alcohol and a catalyst for the reaction of trans-esterification processes can be added. After stirring completed, the contents of the reactor transmitted to water washing tank in order to wash [8].

The catalyst used for the production of biodiesel may be alkaline, acid or enzymes. Potassium hydroxide, sodium hydroxide and sodium methoxide are the alkaline catalyst used for the process [9]. Based on research conducted using homogeneous catalysts such as potassium hydroxide and sodium hydroxide; the process is speed up reaction time in comparison to sulfuric acid and phosphoric acid which are acid catalysts. It is noted that the acid esterification reaction used as a pretreatment for raw materials with high water content and fatty acid [10,11,12].

Various stirrer has been used to improve reaction and reduce biodiesel production time [13], including mechanical stirrer, magnetic stirrer [14] turbines [15], anchor stirrer [16], Helical stirrer [17], etc. Most researchers in the field of mechanical stirring focused on

* Corresponding author: Amir Hasheminezhad
E-mail: a.hasheminezhad@stu.sanru.ac.ir

type of stirrer. Their report suggests that the mechanical agitator capable of producing a product with a purity of more than 97% [18].

Meng et al. [19] concluded that the use of batch reactor for the production of biodiesel from jatropha oil, 93% of triglycerides were converted into methyl esters. Batch stirred tank reactor was operated with morality of alcohol to triglyceride ratio ranging from 4: 1 to 20: 1 and the operating temperature range is reported 25-85℃ and at temperatures above the boiling point of alcohol, reactor should equipped with a condenser [20].

The objectives of this research are to find the suitable time, temperature and optimized condition to produce biodiesel from waste cooking oil using a batch reactor equipped with mechanical stirrer.

MATERIALS AND METHODS

Specification

Figure 1 shows reactor system which designed (Solidworks 2012) and fabricated, different parts of reactor are demonstrated in Figure 1. The device is designed for a capacity of 30 liters of liquid in the tank.

To facilitate phase separation during discharge and also ensure a uniform mixing bottom part of the tank was built in the shape of a cone. Reaction and leaching tanks were built separately; heating system parts includes (1000-watt heater, temperature sensors and digital display of temperature) for heating the liquid and keep the temperature at a constant value. The signal from the sensor turn on or off the power to the heater.

Power Transmission system (electric motor (1.5 KW), inverter (hi run model N100 for measuring the rotational speed of the stirrer), Electric pump (0.37 KW) were used for mixing and transport raw materials (reactants) and move products between the tanks. The reactor frameworks was made with a 3 × 5 cm profile. The bearings were used for each axis to prevent horizontal and vertical vibrations [21].

Test method

To perform the test, molarity of 6: 1 oil to alcohol and KOH catalyst was 1% of oil by weight selected. Tests based on three levels of the factor variable stirrer speed (650, 550, 450 rpm), and the reaction temperature at four levels (40, 50, 60, 70℃) and a reaction time of 6 levels (10, 20, 30, 40, 50, 60 min) was performed. The waste cooking oil at a rate of 8 liters per test batch was chosen.

Two factors, free fatty acids and water, affected the reaction procedure to saponification, and thus reduce the quality and quantity of product. As a result of oil with a high content of free fatty acid (more than 0.05%) requires pre-treatment stage (stage esterification).

After the reaction is finished, liquid divided in two parts, the upper layer is biodiesel and bottom layer is glycerin. In accordance with ASTM, biodiesel glycerin content should be less than 0.24% of produced glycerin. Separation of the products also depends on the quality of oil and the soap made in reaction, witch time needed to settle down will vary.

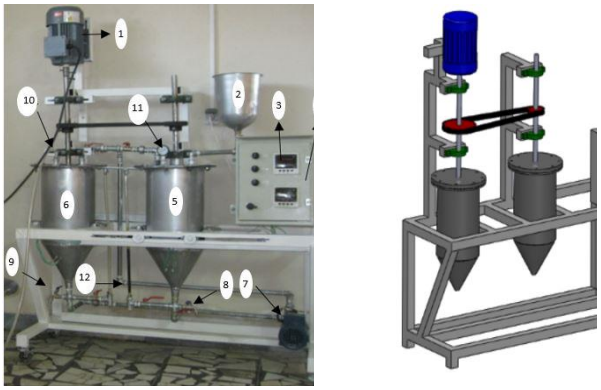

Figure 1. Actual experimental rig with designed and fabricated reactor (1: Electrical motor , 2: Input of reaction tank, 3: Digital display of temperature, 4: electrical panel, 5: reaction tank, 6:water washing tank, 7: electrical pump, 8: Output of reaction tank, 9: Output of water washing tank, 10: input of water washing tank, 11: pressure gauge, 12: flush hose)

RESULTS AND DISCUSSION

Biodiesel fuel properties according to ASTM standard and measured values are provided in Table (1). According to the results, the characteristics of biodiesel match within the standard ASTM D6751.

TABLE 1. Characteristics of Biodiesel Standards and Measurement

Characteristics	Unit	ASTM Standard	Measurement
Flash point	C°	Min 93	172
Water content	% volume	Max 0.050	0.026
Viscosity(at 40 C°)	mm^2/s	1.9-6	3.4
Cloud point	C°	-	-2
Carbon residue	% mass	Max 0.050	0.042
Acid number	$mg\ KOH/gr$	Max 0.5	0.321
Free glycerine	% mass	Max 0.024	0.007

Analysis of main variance and interaction affected on temperature, time and stirring, which is provided in Table (2). The results showed that stirring has significant effect on efficiency of conversion of free fatty acids at 1wt% level. The effect of time on biodiesel conversion efficiency is significant at 1% level. Effect of transestirification reaction temperature on the biodiesel conversion efficiency is significant at 1% level.

TABLE 2. Analysis of variance factors affecting conversion efficiency of biodiesel

	Mean square		
Variable	Degrees of freedom	Conversion efficiency	F-value
Stirring rate (V)	2	30832.7	41110.22 **
Reaction time (t)	5	13839.5	18452.62 **
(V*T)	10	110.3	147.02 **
Temperature (T)	3	7397.5	9862.33 **
(V*T)	6	0.074	0.0989 ns
(t*T)	15	0.026	0.0346 ns
(V*t*T)	30	0.019	0.0256 ns
Error	144	0.75	
The coefficient of variation (CV)		10.11	

** and ns are significant and non-significant at the 1% level, respectively.

The results suggest that the interaction between the stirring speed and reaction time (V × t) , the conversion efficiency of biodiesel at 1% level is significant. If the interaction of temperature and stirring in the study area as well as the interaction between time and temperature on the conversion efficiency of biodiesel is not meaningful. This means that in any case using the excessive heat (over ℃ 60) evaporates the alcohol (methanol) which stops the reaction and will not affect on conversion efficiency of biodiesel.

The effect of reaction temperature

The reaction temperature is an important factor in the production of biodiesel. The results in Table 3 are given the reaction temperature increased from 40 to 60 ° C, the efficiency of biodiesel production has increased from 72.14 to 95.81%. Increasing the temperature increases the reaction rate and mass transfer in the reaction tank. With further increase of the temperature to 70℃, biodiesel conversion efficiency decreased; that could be due to evaporation of alcohol (close to the boiling point of methanol). Knothe [22] reported more than 95% conversion reached at 60 ℃ and reaction time was 3 hours.

TABLE 3. Average effect of reaction temperature on the conversion efficiency of biodiesel

Temperature, ºC	Biodiesel conversion efficiency %
40	72.14 c
50	81.36 b
60	95.81 a
70	94.92 a

The optimum temperature of 80 ℃ with a performance of 80% was concluded [22]. Koria and Thangaraj [23] at the best temperature for the production of biodiesel obtained 60-65℃. According to the results obtained in this study, 95.81% efficiency at a lower temperature than the boiling point of methanol (69℃) 60℃ was obtained, which saves time and energy. As a result, the reaction temperature of 60 ℃ was the optimum reaction temperature for the production of biodiesel from waste vegetable oil in a stirred tank batch reactor. Please note that the use of a mechanical stirrer makes better heat transfer between the reactants.

The effect of reaction time

Table (4) shows the effect of conversion efficiency of biodiesel, in a reaction time in the range of 10 to 60 minutes. The results showed that biodiesel conversion efficiency gradually increased from 43.3% to95.3% in the reaction time of 10 to 30 minutes. When the stirring process starts the Trans esterification reaction begins between methanol and oil in the presence of potassium hydroxide.

The response rate was primarily due to the low dissolution of alcohol and oil, and second, by dissolving those increases and finally reduced consumption of reactants and reaches to equilibrium. In addition, the response time greater than 30 minutes, made no change in the conversion efficiency of the reactor. That was probably due to the ability of mixing stirrer reactor, which is designed to reduce the reaction time to 30 minutes.

Efficiency of 95% biodiesel production using potassium hydroxide catalyst with an alcohol such as methanol, ethanol and 1-butanol have been reported in literature [24]. The effect of reaction time on the yield of biodiesel production using the catalyst of calcium hydroxide at a temperature 60 ℃ and the speed of the stirring 300 rpm and the molar ratio of methanol to oil 15: 1 and the amount of catalyst to 6% by weight of waste vegetable oil were experimented. The results found that trans esterification reaction time is dependent on the severity of the reaction condition [25].

TABLE 4. effect Average of reaction time on the conversion efficiency of biodiesel

Reaction time (min)	Biodiesel conversion efficiency average
10	43.3 c
20	77.3 b
30	95.3 a
40	94.3 a
50	94.0 a
60	94.7 a

By changing the reaction time in the range of 0 to 120 minutes, biodiesel production efficiency significantly increased [26]. Decrease in efficiency was shown that can be caused by operation at low temperature which was caused by increasing oil viscosity due to low temperature. Reduction of two-phase separation of methanol and oil mixture. The optimum reaction time for a batch reactor was set at 30 minutes.

The effect of mixing speed

Table 5 shows the effect of stirring velocity on the conversion efficiency of biodiesel, biodiesel production increases with increasing stirrer speed and reaches its maximum at the speed 650rpm. With increasing stirring rate, collisions between molecules which are insoluble in alcohol and oils happened and constitute a heterogeneous phase and more mass transfer occurs.

TABLE 5. The effect of stirring rate on biodiesel conversion efficiency

Conversion efficiency	Stirring rate (rpm)
42.3 c	450
83.5 b	550
94.5 a	650

Mean that shown with common letters are not significantly different.

High stirring rate, leads to high conversion rate and reaction time will be lower. However, excessive stirring rate may reduce the conversion rate of the reaction [28]. Hoseini [28] found that more than 90% biodiesel conversion happened in a the reactor with stirrer speed of 900 rpm, it was also stated that further increase in mixing speed does not affect on the progress of the reaction .

CONCLUSION

In this study, biodiesel was produced from waste cooking oil using a batch stirred tank reactor which designed and constructed. Results showed that the efficiency of conversion of waste cooking oil into biodiesel using stirred tank reactor at optimum temperature 60℃, the stirring speed of 650 rpm and the reaction time of 30 minutes using methanol as alcohol and potassium hydroxide as a catalyst.

REFERENCES

1. Ghobadian, B., Najafi, G., Rahimi, H., Yusaf, T.F. 2009. Future of renewable energies in Iran. Renewable and sustainable energy reviews.13:689-695.
2. Ghobadian, B. Liquid biofuel potential and outlook in Iran. 2012. Renewable and sustainable energy reviews. 16:4379-4384.
3. Specchia, S., Tillemans, F.W.A., Oosterkamp, P.F., Saracco,G. 2005. Conceptual design and selection of a biodiesel processor for a vehicle fuel cell auxiliary power unit. Journal of power sources. 145:683-690.
4. Dube, M.A., Tremblay, A.Y., Liu, J. 2007. Biodiesel production using a membrane reactor. Bioresource Technology. 98:639-647.
5. Yoosuk, B., P. Krasae, B. Puttasawat, P. Udomsap, N. Viriya-empikul, K .Faungnawakij. 2010. Biodiesel production using supper critical methanol. Chemical Engineering Journal.162, 58-66.
6. Sharma, Y. C.; B. Singh, J. Korstad. 2010. Waste lipid conversion to Biodiesel. Energy & Fuels. 24: 3223-3231.
7. Silva, C. C. C. M., N.F.P. Ribeiro, M.M.V.M. Souza, D.A.G. 2010. Biodiesel production technology. Fuel Processing Technology. 91: 205-210.
8. I. Syaichurrozi, J. Jayanudin, Effect of Tofu Wastewater Addition on The Growth and Carbohydrate-Protein-Lipid Content of Spirulina platensis, International Journal of Engineering (IJE), TRANSACTIONS B: Applications Vol. 30, No. 11, (November 2017) 1631-1638 .
9. Marchetti, J.M., Miguel, V.U., Errazu, A.F. 2007. Possible methods for biodiesel production. Renewable and sustainable energy reviews. 11: 1300-1311.
10. Shimada, Y., Watanabe, Y., Samukawa, T., Sugihara, A., Noda, H., Fukuda, H. 1999. Conversion of vegetable oil to biodiesel using immobilized candida Antarctica Lipase. J Am Oil Chem soc. 76(7):789-793.
11. Sivasamy, A., Cheah, K.Y., Fornasiero, P., Kemausuor, F., Zinoviev, S., and Miertus, S. 2009. Catalytic application in the production of biodiesel from vegetable oils. Chem Sus Chem. 2:278-300.
12. Canakci, M., Van Gerpan, J. 1999. Biodiesel production via acid catalysis. Trans ASAE.:45(5):1203-1210.
13. Freedman, B., Butterfield, R.O., Pryde, E.H. 1985. Transesterification kinetics of soybean oil. J. Am. Oil chem. Soc. 61:1638-1643.
14. Daranko, D. and Cheryan, M. 2000.Kinetics of palm oil Transestirification in a batch reactor. Fuel. 77:1263-1267.
15. Vincente, G., Martinez, M., Aracil, J., Esteban, A. 2005. Kinetics of sunflower oil methanolysis. Ind. Eng. Res. 44:5447-5454.
16. Noureddini, H., Harkey, DW., Gutsman, MR. 2004.A continuous process for the glycolysis of soybean oil. J. Am. Oil Chem. Soc. 81:1-5.
17. Komers, K., Skopal, F., Cegan, A. 2010. Continuous biodiesel production in a cascade of Flow ideally stirred reactors. Bioresource Technology. 101:3772-3775.
18. Mitteblach, M., Trathnigg, B. 1990. Kinetics of alkaline catalyzed methanolysis of sunflower oil. Fat. Sci. Technol. 92:145-148.
19. Meng, X.; G. Chen, Y. Wang. 2008. Fatty acids esterification by reactive distillation. Fuel Processing Technology. 89: 851-857.
20. Liang, X.; S. Gao, H. Wu, J. Yang. 2009. Biodiesel production technology reviews. Fuel Processing Technology. 90: 701-704.
21. Hasheminezhad, A., Hashemi, SJ., Tabatabaie, SR. Biodiesel production from waste cooking oil using transesterification method. Paper presented at 4th international conference on environmental challenges and Dendrochronology. Sari-Iran. 14-15 May 2014.
22. Knothe,G . 2001. Analytical Methods used in the production and Fuel Quality assessment of Biodiesel, American society of agricultural Engineers. 44-2:103-200.
23. Litty Koria and T. Thangaraj. 2010. Optimization of Biodiesel Production Process in Datura stramonium Seed Oil, a Non-edible Oil Source .Journal of Eco biotechnology. 2/5: 42-46.

24. Freedman, B., Butterfield, R.O., E.H. 1986. Transestirification kinetics of soybean oil. J Am Oil Chem Soc. 63:1375-1380.
25. H. Hadiyanto, W. Widayat, A, Duma, Ultrasound Assisted in Situ Esterification of Rubber Seeds Oil for Biodiesel Production, International Journal of Engineering (IJE), TRANSACTIONS C: Aspetcs Vol. 29, No. 12, (December 2016) 1635-1641.
26. Atadashi, I.M., Aroua, M.K., Abdulaziz, A.R., Sulaiman, N.M.N. 2012. The effects of water on biodiesel production and refining technologies: A review. Renewable and sustainable energy reviews.16:3456-3470.
27. M. Feizbahr, C. Kok Keong, F. Rostami, M. Shahrokhi, Wave Energy Dissipation Using Perforated and Non Perforated Piles, International Journal of Engineering (IJE), IJE TRANSACTIONS B: Applications Vol. 31, No. 2, (February 2018) 212-219.
28. Hoseini M. 2013 .biodiesel production in batch reactor with helical agitator. Paper presented at the 20th annual conference of mechanical engineering of Iran. Shiraz-Iran, 27-29 May 2013.

Persian Abstract

DOI: 10.5829/ijee.2018.09.02.04

چکیده

امروزه بیودیزل تولیدی از روغن پسماند به علت آلایندگی و هزینه تولید کمتر و تجدید پذیری، بیش از پیش مورد توجه قرار گرفته است. در این تحقیق عوامل موثر بر تولید بیودیزل به روش ترنس¬استیریفیکاسیون از روغن پسماند آشپزی مورد بررسی قرار گرفت. برای این منظور یک رآکتور همزن¬دار بچ، طراحی و ساخته شد. روغن پسماند آشپزی به عنوان ماده اولیه و متانول به عنوان الکل با نسبت مولی ۱:۶ در حضور پتاسیم هیدروکسید به عنوان کاتالیزور به میزان ۱٪ وزنی روغن پسماند استفاده ¬شد. بهینه سازی فرآیند تولید، در سه پارامتر دور همزنی در ۳سطح (650 rpm، 550، 450)، دما در ۴ سطح (40 C°،50،60،70) و زمان واکنش در ۶ سطح (۶۰، ۵۰، ۴۰، ۳۰، ۲۰، ۱۰دقیقه) انجام شد. نتایج نشان داد، تبدیل بیش از ۹۰٪ استر ها در ۳۰ دقیقه اول اتفاق افتاد. در دور همزنی 650 rpm میزان تولید بیودیزل افزایش یافته و به حداکثر میزان خود رسید. بیشترین میزان تبدیل استرها در دمای 60^{o} C اتفاق افتاده است. بنابراین زمان واکنش ۳۰ دقیقه و دور650 rpm و دمای واکنش 60^{o} C بهینه¬ترین حالت برای تولید بیودیزل از روغن پسماند با استفاده از رآکتور همزن¬دار بچ می¬باشد.