IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

The effect of electric field on glycerine sedimentation and reaction acceleration using multiple high voltage electrodes designed for biodiesel production

To cite this article: Tharin Ratanabuntha *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **257** 012023

The effect of electric field on glycerine sedimentation and reaction acceleration using multiple high voltage electrodes designed for biodiesel production

Tharin Ratanabuntha[1], Tanakorn Wongwuttanasatian[2] and Amnart Suksri[2]

1 Department of Electrical Engineering, Khon Kaen University, Khon Kaen, Thailand
2 Center of Alternative Energy Research and Development, Khon Kaen University, Khon Kaen, Thailand
E-mail: tharin_rat@kkumail.com, samnar@kku.ac.th

Abstract. Biodiesel is produced from fatty acids, using palm oil that is widely used in food industry as a raw material. This research aims to introduce an innovative method of acceleration in biodiesel production process. The biodiesel production was prepared by 1 liter substrate and conducted in the reactor chamber. The chamber was designed and built with coaxial cylindrical electrode consisted of multiple inner rod electrode and outer electrode. Supply high voltage level was at 10 kV and exposure time was 30 minutes. It is found that strong electric field can accelerate the rate of reaction on biodiesel production. The rate of glycerine sedimentation resulting from electric field process using single rod, double rod, triple rod and quadruple rod calculated from the results are 3.6, 4.2, 5.9 and 9.1 mL/min respectively. Electric field enhancement can be obtained by utilizing multiple rod electrodes so that the biodiesel reaction is confined within controlled environment. The fastest reaction process is by utilizing quadruple rod inner electrode. Glycerine yield separation was obtained at 100 milliliter within 11 minutes. This is 2.5 times faster than single rod configuration.

1. Introduction

Biodiesel is derived from vegetable oil or animal fats through chemical processes. The final product of the process is fuel which is consisted of Mono-alkyl esters of fatty acids (biodiesel). Presently, biodiesel production utilizes chemical reaction process called trans-esterification. Vegetable oil or animal fat reacts with methyl alcohol and using catalyst to develop reaction with conventional procedure. Methanol is commonly used as a substitute for alcohol in biodiesel production due to its low cost and can react with fats easily. It is also a good solvent for base catalysts such as sodium hydroxide or potassium hydroxide, etc. The trans-esterification process can be accelerated further by introduce heating effect during reaction time. Reheating of reaction is generally heated by boiling. The reaction time is roughly 2 hours. Then the oil is transferred to the glycerine separation process later. In normal glycerine separation process, sedimentation has been done by gravity that will take more than 2 hours for 1 liter substrate [1, 2]. Another method may be the use of centrifugation process by decanter centrifuge [3,4] which is expensive and consumes lots of energy. Nevertheless, chemical are used for reducing the reaction time in biodiesel process such as deep eutectic solvent (DES) [5] or activated charcoal [6]. Chemical contamination will still be in the water after washing process.

In order to shorten the production time of biodiesel and reducing environmental problems, there are many technologies to assist in the process of production [7, 8, 9]. It has been found that using high voltage electrical field helps accelerate the reaction time of biodiesel production from used vegetable oil [10]. By using 100 milliliter of vegetable oil substrate and expose them to the supply voltage using ring and cylinder electrode at 10 kV. It was reported that, the process under an applied electric field was lasted for 2 minutes, there is 99.8 per cent yield of biodiesel. The glycerin and ester layer is clearly separated.

A 2-pole square electrode [11] was used with 100 milliliter of soy bean oil using an applied voltage of 14 kV. It was found that with spacing of the 5 cm electrode could cause sedimentation of glycerine. This is the fastest time that was achieved with 53 seconds. But when electrodes were spaced apart, it will takes more time to precipitate. The study of trans-esterification by electrostatic field electrodes have been studied recently [12]. Each electrode consisted of double rod, point-to-point, double plate and wiring of 100 milliliters of vegetable oil, using 13 kV. It was found that double plate electrode configuration with a spacing of 5 cm apart was able to deliver the lowest possible separation time about 20 seconds. Biodiesel reaction can also be accelerated by using high-voltage electric fields utilizing various vegetable oils and electrodes [2, 13, 14]. However, it is necessary to investigate the effectiveness of high voltage electric field and electrodes design that can be applied to the Biodiesel production. Soy oil and Palm oil will be used as the substrate and characteristics of electrodes will be explored.

2. Effect of electric field to reaction

Improvement of biodiesel production process for faster production requires a catalytic reaction between natural oils and alcohols. The process can be done by providing input energy to the substrate during the reaction. In the biodiesel production process, the feedstock is typically heated with conventional heating method. Oil is nonpolar molecule that contained balance positive and negative charges. Under electric field, oil molecule will be emitted by moving electron and can be separated into free charges. The positive charges will move in the same path of e-field and collide with negative charge that moves in an opposite direction, which directly affects the convection coefficient as shown in Figure 1. [6, 15]

Likewise, alcohol was used as a solvent in the reaction, it is also polar molecules. Under the electric field, molecules of alcohol move and rearrange themself according to the direction of the electric field. If electric fields were present, these charges will try to move in the direction of the polarity in electric field. The dipole rotation causes the molecules to rotate as shown in Figure 2.

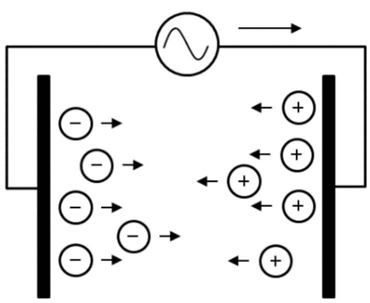

Figure 1. Effect of electric field to charges movement

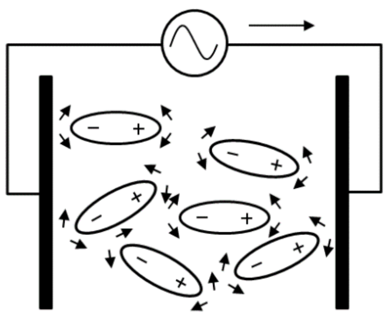

Figure 2. Effect of electric field to polar molecules movement

The rate of reaction depends on the frequency and direction of the collision in the reaction. So if there is more collisions, the more likely it is to accelerate the reaction. Based on the theory of the electric field, the electric field causes particles to move, it will increases the chance of collisions. So, the electric field can pass on energy to the molecular level. These effects can shorten the biodiesel reaction time.

3. Design of reactor chamber

The configuration of electrodes electric field design is based on a coaxial electrode, which is an electrode that has the ability to widely distribute an electric field as shown in Figure 3 [16]. The chamber consisted of a cylindrical internal electrode, which is exposed to the substrate. The insulation is a container for the substrate. There is also an outside electrode surrounded serving as a return electrode. The design and modification of internal electrodes will be optimized and investigated for biodiesel production.

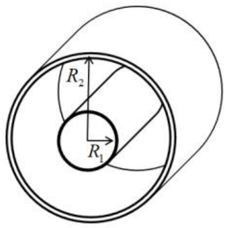

Figure 3. Coaxial cylinder electrode.

The electric field strength between the cylindrical electrodes and internal electrode can be calculated by (1).

$$E = \frac{V}{R \ln \frac{R_2}{R_1}} \tag{1}$$

E	=	maximum electric field strength (V/m)
V	=	supply voltage (V)
R	=	distance from center to notice point (m)
R_1	=	radius of internal electrode (m)
R_2	=	radius of external electrode (m)

For constant supply voltage, there are 2 ways to increase the electric field in the chamber. First, external electrode radius must be decreased and second, inner electrode can be increased. The decreasing of external radius will also decrease the volume of chamber. On the other hand, increasing of internal radius will increases the weight of electrode. Bigger electrode will result to higher cost and difficult to build. To reduce the cost of electrode, authors were able to increase the area of reaction by using bundled electrode design as shown the figure 4. Electric field contour derived from using different number of rod electrode are shown in Figure 5. The electric field was calculated by COMSOL Multiphysics software.

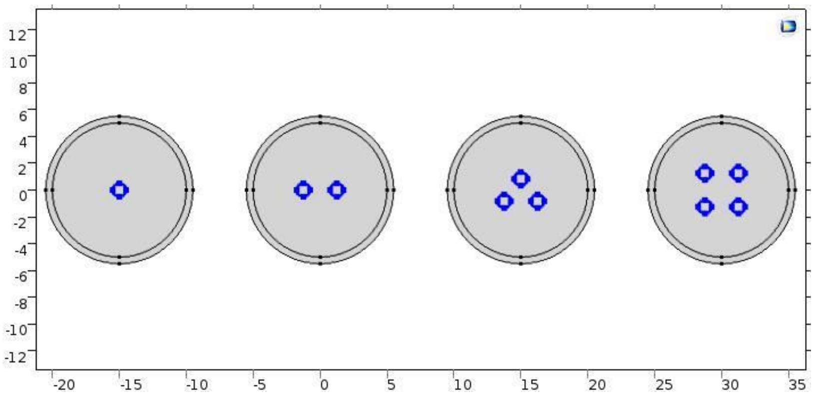

Figure 4. Bundled electrode rod.

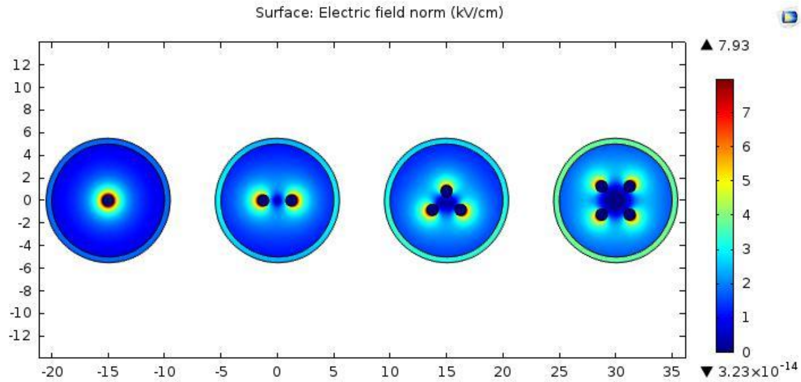

Figure 5. Coaxial cylinder electrode.

The average electric field strength in reaction area was calculated by integration method in the software was shown in table 1.

Table 1. Number of rod and average electric field strength.

Number of rod	Average electric field strength (kV/cm)
1	1.4376
2	1.8627
3	2.0121
4	2.2110

The electric field stresses at some sharp edge on electrode surface are main causes for partial discharge and resulting to a power loss. To reduce this loss, author design a 1 liter chamber with top electrode cover and external toroid shape serve as a return electrode as shown in Figure 6.

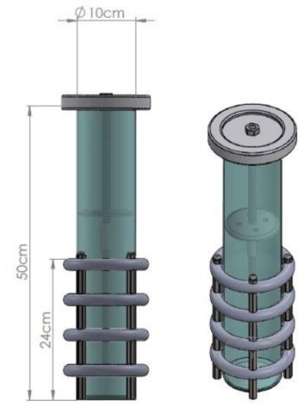

Figure 6. Designed reactor chamber.

4. Experiment

The main raw material for biodiesel production was palm oil. Methyl alcohol is used as a solvent with a molar ratio of 1:6. Also, using potassium hydroxide (KOH) as the catalyst at 1 wt. %[17]. For substrate preparation, palm oil 1 liter was warmed up with temperature of 60 ℃. At the same time the methanol was mixed with KOH until a homogeneous liquid phase in the glass bottle is achieved. When the oil was warmed, it was mixed by methanol with catalyst. Stirred for 1 min and filled in reactor chamber as shown in Figure 7.

Figure 7. Reactor chamber.

High voltage electric field generator includes autotransformer for controlling the voltage supplied to the main transformer. The voltage from the main transformer that supply to the test chamber reactor, is measured by a voltage divider that is connected to the voltmeter. The supply voltage to chamber was fixed at 10 kV for 25 minutes and recording the glycerine sedimentation. Also, the control set of biodiesel oil (without supplied voltage) was prepared to compare the result. The configuration of the test rig is shown in Figure 8.

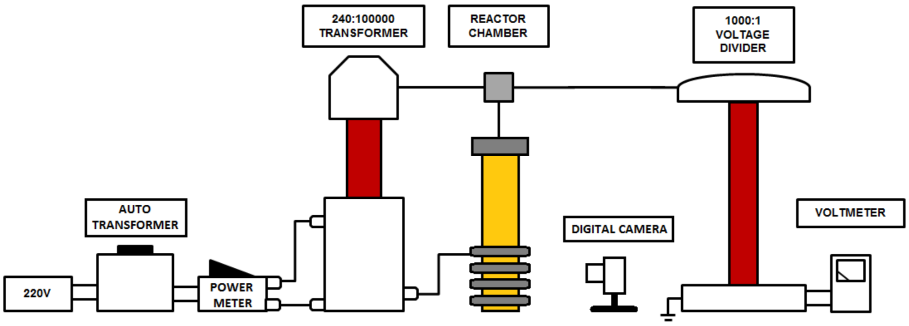

Figure 8. Equipment configuration.

In order to compare the rate of reaction in each period, researchers have measured and compared the volume of glycerine by-products from the reaction. In some cases, the reaction is not completed and the substrate was not formed as biodiesel but the experiment will have to terminate at 30 minutes time.

5. Results

The reactor was energized with 10 kV at the top cover electrode of chamber for 30 minutes. During the process, sedimentation of glycerine was recorded by digital camera. Power consumption throughout the experiment was recorded by energy meter. The timer for process duration counting start when circuit breaker was on and stop when the volume of glycerine is reached to 100 milliliter which is the saturation point of reaction. The results from each of electrode cases are shown in table 2.

Table 2. Number of rod, process time and energy consumption.

Number of rod	Process Duration (min)	Energy Consumption (W.hr)
1	28	4.8
2	24	4.8
3	17	3.1
4	11	2.3

Results from table 1 and table 2 showed that, the number of electrodes used has affected the process time duration. The increasing number of rod electrode will result to higher average electric field strength. The energy consumption is depending on process duration. The fastest process is quadruple rod that complete the glycerine sedimentation within 11 minutes and consume energy of 2.3 W.hr. The slowest one is using single rod processes that complete the sedimentation of 28 minutes using 4.8 W.hr. Moreover, the ester layer from the quadruple rod process is more transparency than others as shown in Figure 9.

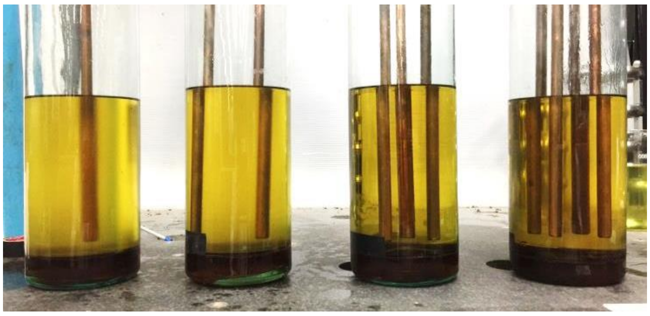

Figure 9. Glycerine sedimentation after process.

6. Conclusion

The acceleration rate of the glycerine sedimentation on biodiesel production process by electric field is depending upon average electric field strength in the chamber area. Increasing the number of internal rod will result to an increase of electrical field strength inside chamber area. The rate of glycerine sedimentation resulting from electric field process using single rod, double rod, triple rod and quadruple rod calculated from the results from table 2 are 3.6, 4.2, 5.9 and 9.1 mL/min respectively. It can be concluded that electric field enhancement can be obtained by utilizing multiple rod electrodes so that the biodiesel reaction is confined within a tight environment. Strong electric field causes particles to move and increases the chance of collisions. Therefore electric field passes on energy to break up the molecular bond level. These effects can shorten the biodiesel reaction time as well as glycerine separation. The fastest process is using quadruple rod, glycerine yield separation was obtained at 100 mL within 11 minutes. This is faster than single rod configuration by 2.5 times.

7. References

[1] Rungthip C, Chakrit T, Kulchanat P 2013 Biodiesel production from used frying oil using sodium methoxide as catalyst in continuous process. *The 3rd International Thai Chemical Engineering and Applied Chemistry Conference* (Khon Kaen, Thailand)

[2] Shakinaz A 2010 Production of biodiesel using the microwave technique. *Journal of Advanced Research* pp 309-314

[3] Kraai GN 2009 Novel highly integrated biodiesel production technology in centrifugal contactor separator device, *Chemical Engineering Journal* pp 384-389.

[4] Pedro F 2006 Production of biodiesel from waste frying oils. *Waste Management* pp 487-494.

[5] Gu L, Huang W, Tang S, Tian S and Zhang X 2015 A Novel Deep Eutectic Solvent for Biodiesel Preparation Using a Homogeneous Base Catalyst. *Chem Eng Journal* pp 647-652.

[6] Abdelrahman BF, Mohammed MD, Abdul-Qader YA 2012 Purification of biodiesel using activated carbons produced from spent tea waste. *Journal of the Association of Arab Universities for Basic and Applied Sciences* pp 45-49.

[7] Chen KS, Lin YC, Hsu KH and Wang HK 2012 Improving biodiesel yield form waste cooking oil by using sodiummethoxide and a microwave heating system, *Energy* pp 151-156.

[8] Cubas ALV 2015 Biodiesel production using fatty acids from food industry waste using corona discharge plasma technology. *Waste Management* pp 149-154.

[9] Hamed M 2010 Ultrasonic-assisted biodiesel production process from palm oil using alkaline earth metal oxides as the heterogeneous catalysts. *Fuel* pp 1818-1825.

[10] Noppadol Sirirat 2011 Bio-diesel production from transesterification using electric field. *Master of Engineering Thesis* (Department of Energy Engineering Graduate School, Chiang Mai University, Thailand)

[11] Komol Siriwatanakul 2012 Sedimentation technique of biodiesel using oil to flow through high voltage. *Independent Study Master Degree* (Engineering Department of Energy Engineering College, Khonkaen University, Thailand)

[12] Ahmad A., Barat G and Gholamhassan N 2014 Electrostatic coagulation for separation of crude glycerine from biodiesel. *Advances in Environmental Biology* pp 321-324.

[13] Barmwal BK and Sharman MP 2005 Prospects of biodiesel production from vegetable oils in India. *Renewable and Sustainable Energy Reviews* pp 363-378.

[14] Guan G 2009 Synthesis of biodiesel fuel using an electrolysis method. *Chemical Engineer Journal* pp 159-164.

[15] Tanongkiat K 1999 The effect of electric field in increasing heat transfer in dielectric fluid, *Journal of Research and Development* (KMUTT, Thailand) pp 93-106.

[16] Samruay S 2012 High Voltage Engineering. Electric field stress and insulation durability. (Bangkok. Thailand)

[17] Luque R and Melero J 2012 Advances in biodiesel production: processes and technologies (Woodhead Pub Ltd.)

Acknowledgments
This research project is fully supported by Center for Alternative Energy Research and Development, Khon Kaen University, Thailand.