Glycerin Separation from Biodiesel Transesterification Process by Pulsed Electric Field with Specific Pulse Forming Network

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Abstract. Biodiesel production process can be rapidly done if the glycerin separation can be removed faster. With the palm oil crisis, biodiesel is needed for faster production to add more value and to solve the oversupply problem. Pulse forming network circuit can generate pulsed electric field (PEF) to speedily separate glycerin from biodiesel production. While the substance is reacting, the electrical impedance value of glycerin is changed, the pulse forming network will keep waveform to be a square wave. Transesterification process using palm oil mixed with methanol with a molar ratio of 1:6 by using 1 wt.% of KOH as a catalyst. The reaction chamber electrode was coaxial cylindrical electrodes with diameter 6 cm and 1 cm. The maximum voltage across the reaction chamber is 500 V with 1.5 and 10 kHz frequency. Glycerin separation was best achieved when using 5 kHz frequency. The glycerin was obtained at 155 ml in 20 minutes.

1. Introduction
Presently, Palm plantation have been planted around South East Asia. The raw material of palm oil has oversupply and the price has fallen recently. To make full use of the palm oil product and to overcome the palm oil crisis situation, biodiesel is most preferred product that can help increase the value of palm and palm oil industry. It is also by means of a replacement of the usage of fossil fuel that cause the environment problem.

Most common method used in producing biodiesel is a transesterification process. Palm oil reacts with alcohol and a base-catalyzed at 40-60\textdegree C[1]. The product obtained from process is biodiesel, glycerin and water as a byproduct. The yield of biodiesel depends on the molar ratio of the substrate. While the process is reacting, the substances will separate from each other by gravity acceleration. After the process, the biodiesel is then washed by water to remove the alcohol and glycerin[2].

To separate the biodiesel and glycerin, the gravity method takes more than 2-4 hours[3] to separate the substances. The chemical process can reduce the separation time but the chemical such as the deep eutectic solvent (DES)[4] makes the biodiesel contaminated. The centrifuge machine is most used method to separate glycerin in oil industry but it is difficult for a small industry due to the expensive
price of the machine and high energy consumption. The method that using heat generated such as boiling and ultrasonic[5-6] at temperature of more than 60° C reduce the yield of biodiesel because of alcohol evaporation[7].

Electric field method with low current can shorten the separation time that depends on electric field stress, type of electrode[8] and the frequency of electric field. The goal achievement is to sediment the glycerin in fluid form and to reduce the viscosity faster[9-10].

2. Electric field and glycerin molecule

Electric field affects the polar molecule according to the field direction and waveform length. For alternating current (AC) electric field, polar molecule as glycerin will arrange in the direction of electric field that polarized between positive and negative voltage. The rotation of molecule will create a chance of collisions and pass on energy between molecule[11].

The direct current (DC) electric field will trapped glycerin molecule in the direction of the electric field. Glycerin molecule will then be aligned to the crystalline chain and created dipole bond between molecule[12], the dipole bond will result to larger particle size. However, molecule that moves in perpendicular direction to electric field has decreased the velocity while travelling into DC electric field[13].

As for a pulse electric field (PEF), glycerin molecule will align according to the same direction as for DC electric field. But when an electric field is not energized, the glycerin molecule will sediment to the bottom faster because of the larger size of glycerin molecule. The time that glycerin coagulates and sediment depends on the on/off states of electric field duration. All of electric field applying methods and molecule alignment are shown in Figure 1.

![Figure 1. Glycerin molecule in (A) no E-field, (B) AC E-field, (C) DC E-field, (D) PEF.](image)

3. Material and method

In transesterification process, palm oil was prepared by heating at 55° C as substrate. Palm oil and alcohol with a molar ratio of 1:6 was mixed with 1 wt. % potassium hydroxide (KOH) as catalyst, it was reacted until became Homogeneous liquid. Mixed the all substance and stirred for 1 minute, it will change to biodiesel and glycerin. After the transesterification reaction occurred, apply the PEF to the reaction chamber. The chamber made of glass that attached with valve. The valve situated at the bottom of chamber used to export glycerin that slit to the bottom of the chamber. The diameter of designed ground electrode was 6 cm. High voltage electrode diameter was 1 cm and both electrodes had a length of 50 cm. The electrode is sectionalized by 5 cm apart for 5 sections to avoid the trapped molecule and to observe the glycerin particle.

To produce the square pulse waveform, PEF is generated from pulse forming network circuit as shown in Figure 2. Pulse forming network will charge the capacitor while switch has closed. After switch on via switching mosfet, the charges from capacitor will be discharged through the inductor
sections. The length and shape of waveform depends on the impedance of pulse forming circuit [14-15] and load. The capacitor 0.47 μF and inductor for 5 mH for each section has an impedance of 110 Ω. The maximum voltage applied was at 500 V across the chamber. Using higher voltage can generate the breakdown through the glycerin particle and may lead to ignition because glycerin molecules become more conductive.

The waveform that measured from R0 has shown the characteristic impedance of the substance and the current that flow through it. The magnitude of voltage has changed while PEF was applying. At first, the waveform showed the voltage at start applying and after 5 minutes in Figure 4. The voltage across the chamber is increased due to an increasing of the substance impedance.
4. Results
Pulse electric field can cause the combination process of glycerin. After applying PEF, larger particle size of glycerin molecule is formed, and sedimeted to the bottom of the chamber rapidly as shown in Figure 5. The 150 ml glycerin is obtained from transesterification process using 1000 mL of palm oil.

![Figure 5](image)

Figure 5. Glycerin (A) before applying PEF and (B) during applying PEF.

The observe time was selected for 5, 10, 15 and 20 minutes for 1 kHz, 5 kHz, 10 kHz and observe heating method with temperature of 60° C. The amount of glycerin obtained is shown in Table1.

| Observe time (min) | 60 °C Volume of glycerin (mL) | 1 kHz | 5 kHz | 10 kHz |
|-------------------|-------------------------------|-------|-------|--------|
| 5                 | 15                            | 120   | 130   | 100    |
| 10                | 23                            | 135   | 145   | 125    |
| 15                | 30                            | 145   | 150   | 133    |
| 20                | 37                            | 148   | 155   | 138    |

Glycerin is rapidly sedimeted from 5 to 10 minutes and slow down afterward. This is due to the amount of glycerin that mixed with biodiesel has been decreased, the remaining glycerin particle are spread-out and has less opportunity for a recombination process.

| Observe time (min) | 1 kHz Impedance of substance [Ω] | 5 kHz | 10 kHz |
|-------------------|---------------------------------|-------|--------|
| 5                 | 666.67                          | 571.43| 416.67 |
| 10                | 1666.67                         | 4375  | 1666.67|
| 15                | 2500                            | 4375  | 2222.22|
| 20                | 3333.33                         | 4375  | 2500   |

The electrical impedance of substance has increased during process because the glycerin that already sedimeted to the bottom of the chamber. The remaining substance contained most of the biodiesel product that have poor conductivity. The impedance of substance that changes during process of applying PEF is shown in Table2.

5. Conclusion
Glycerin separation from biodiesel transesterification process by Pulsed Electric Field with specific pulse forming network have been investigated. The pulse forming network will generate pulsed electric field and keep waveshape to the square wave even if the impedance of substance has changed. The PEF can increase the rate of glycerin separation at an initial of the process until 10 minutes. Using
pulse forming network with the frequency of 5 kHz process, most glycerin volume were obtained. PEF with 10 kHz process has sedimented slowly because of high frequency waveform switching behaves as DC electric field. It can be concluded that, while the electrical impedance of the substance was increasing slowly, the voltage across the substance has also been increased. Hence, Glycerin separation using pulse electric field and pulse forming network can be a promising technique for a biodiesel industry in the near future.

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References
[1] A. A. Mayvan et al., “Current Biodiesel Production Technologies : a Comparative Review,” Most, vol. 63, pp. 4–7, 2011.
[2] S. B. G. Č and D. U. Skala, “DESIGN AND OPTIMISATION OF PURIFICATION PROCEDURE FOR BIODIESEL WASHING *,” vol. 15, no. 3, pp. 159–168, 2009.
[3] G. Anastopoulos, Y. Zannikou, S. Stournas, and S. Kalligeros, “Transesterification of vegetable oils with ethanol and characterization of the key fuel properties of ethyl esters,” Energies, vol. 2, no. 2, pp. 362–376, 2009.
[4] M. Hayyan, F. S. Mjalli, M. A. Hashim, and I. M. AlNashef, “A novel technique for separating glycerine from palm oil-based biodiesel using ionic liquids,” Fuel Process. Technol., vol. 91, no. 1, pp. 116–120, 2010.
[5] I. Istadi, A. D. Yudhistira, D. D. Anggoro, and L. Buchori, “Electro-catalysis system for biodiesel synthesis from palm oil over Dielectric-Barrier Discharge plasma reactor,” Bull. Chem. React. Eng. Catal., vol. 9, no. 2, pp. 111–120, 2014.
[6] A. B. Koc and E. H. McKenzie, “Effects of ultrasonication on glycerin separation during transesterification of soybean oil,” Fuel Process. Technol., vol. 91, no. 7, pp. 743–748, 2010.
[7] N. Sirirat, Biodiesel Production From Transesterification Process Using Electric Field. Chiang Mai: Graduate School , Chiang Mai University, 2011.
[8] A. Abbaszadeh, B. Ghobadian, and G. Najafi, “Electrostatic coagulation for separation of crude glycerin from biodiesel,” Adv. Environ. Biol., vol. 8, no. 1, pp. 321–324, 2014.
[9] Y. Hemar, “The effect of pulsed electric field processing on particle size and viscosity of milk and milk concentrates,” no. May 2014, 2011.
[10] R. Tao et al., "Reducing the Viscosity of Crude Oil by Pulsed Electric or Magnetic Field," no. 7, pp. 2046–2051, 2006.
[11] T. Ratanabuntha, K. Tommitr, and A. Suksri, “Acceleration in biodiesel production from palm oil process by high voltage electric field,” pp. 225–230, 2018.
[12] E. Abedi, M. A. Safari, M. Barzegar, and M. H. Azizi, “Designing of high voltage electric field for soybean and sunflower oil bleaching,” Innov. Food Sci. Emerg. Technol., vol. 36, pp. 173–180, 2016.
[13] H. L. Bethlem, F. M. H. Crompvoets, R. T. Jongma, S. Y. T. van de Meerakker, and G. Meijer, Deceleration and trapping of ammonia using time-varying electric fields, vol. 65, no. 5, 2002.
[14] J. Saisut, “Design and Low Power Test of Pulse Forming Network for Klystron Modulator at Chiang Mai University,” Energy Procedia, vol. 89, pp. 104–109, 2016.
[15] M. Wofford, M. C. Baker, and M. Day, “Design, Simulation, And Testing Of A Pulse Forming Network- Transformer Power Supply For The Texas Tech Railgun,” pp. 138–140, 2005.