Converting Waste Cooking Oil into Biodiesel using Microwaves and High Voltage Technology

RA Nurul Moulita¹, Rusdianasari², and Leila Kalsum²

¹Applied Master of Renewable Energy Engineering, Politeknik Negeri Sriwijaya, Jalan Srijaya Negara, Palembang, 30139, Indonesia
email: ranurulmoulita@gmail.com
²Chemical Engineering Department, Politeknik Negeri Sriwijaya, Jalan Srijaya Negara, Palembang, 30139, Indonesia

Corresponding authors: rusdianasari@polsri.ac.id

Abstract. Increasing fuel demand has an impact on decreasing fossil energy reserves. One of the solution to solve this problem is by increasing the production of biomass fuels, for example, biodiesel. Biodiesel can be produced from waste cooking oil through transesterification stage that reacts oil molecules with alcohol and catalyst to produce methyl esters. Heating method that can be used is combined of microwaves and high voltage technology. Microwaves technology utilizes wave emission which is absorbed and reflected by the sample’s temperature being higher than surface’s temperature of reactor’s wall. In the process of producing biodiesel, reaction temperature is one of the several factors that is affected for heating process. From this research, we had optimum reaction temperature to get good quality product is at 60°C with 88.88% yield, 0.88 gr/ml for density, 2.52 cSt for viscosity, 102.5°C for flash point, 0.27% for water content, and 0.33 mg-KOH/gr-sample.

Keyword: Biodiesel, microwaves, high voltage, transesterification, waste cooking oil, quality

1. Introduction

Increasing fuel oil can reduce fossil energy reserves. For solving this problem, the government utilizes domestic energy by increasing biomass fuel production. Utilization of biomass material as diesel fuel (biodiesel) is one of the solutions that can be applied. Biodiesel is one of an alternative fuels that can be obtained from plant and animal fats [1]. Biodiesel is a monoalkyl ester from fatty acids that is contained in vegetable oils or animal fats for using as diesel engine fuel. Biomass resources in Indonesia is amount to 32,654 MW while installed capacity currently is only around 92,726 MW [2].

One of biodiesel raw materials that often used is waste cooking oil. Total amount of waste cooking oil from various sectors in Indonesia is 3.88 million tons per year [3]. Waste cooking oil can be converted into biodiesel through transesterification that reacts oil with alcohol and catalyst. For converting it into biodiesel, we need a method that can convert into high yield and has accordance with Indonesian National Standards (SNI). The main factors that can affect the number of conversions in transesterification are ratio between triglycerides and alcohol, type of catalyst, reaction temperature, water and free fatty acids content, and speed of stirring [4]. Alcohol must be in excess condition from its stoichiometric needed in order to get a reaction that shifts towards the product. Activation energy
can be reduced using catalyst that we used so the reaction will run easily. The temperature during trans esterification can be carried out in temperature range of 30-65°C. Temperature will make molecule’s movement be faster. The amount of water content in raw material can make saponification that allows to reduce catalyst efficiency level while higher value of free fatty acid will require a lot of base catalysts. High stirring speed makes increasing the number of molecule collisions and reaction speed.

Method that commonly used to convert oil into biodiesel is conventional method. Heating process with this method is very slow because energy transfer to the material depend on convection current and thermal conductivity of reaction mixture [5]. Various alternative methods have been developed to produce biodiesel with high yield in a short time. Hartono, et al. in 2013 develop biodiesel synthesis using an interesterification method to optimize the formation of biodiesel yield [6]. However, this method is not efficient because the time to process biodiesel is quite long, which is 60 minutes for 87.63% yield. In 2015, Kalsum et al. using a reactor membrane to produce biodiesel from waste cooking oil [7]. However, this study is not efficient because it takes 2.5 hours to produce biodiesel of 94.81% yield. Moeksin, et al. (2017) has done research on biodiesel production process using electrolysis method. However, the highest yield produced using this method is only 38.3% at 12 V electricity voltage [8]. Another method that has been applied is using the Continuous Microwave Biodiesel Reactor (CMBR) [9]. This method can produce biodiesel in a shorter time. However, the highest yield of triglycerides is still relatively low, which is 65.5%. So, the authors done a research of producing biodiesel using a combination of microwaves and high voltage.

Microwaves utilizes heating process that occurs directly without contact to the reactor’s wall so the reaction can be mixed homogenly. This makes time needed to carry out the process significantly reduced [10]. Microwave utilization can make reaction be more efficient with reaction time and separated process in a shorter time, reduce the number of side product, and energy consumption [11]. The separated process of biodiesel with glycerol can be carried out using high voltage. High voltage utilization can make the saturation of glycerine being faster [12]. Previous research shows that 9 kV has a percentage 98% in 25 seconds [13]. In this research, six experiments were done by reaction temperature variation to get a high yield and quality that is in accordance with SNI.

2. Methods and Materials
The procedure for producing biodiesel from waste cooking oil using microwaves and high voltage utilization is presented in Figure 1.
Raw material that used is waste cooking oil from crackers factory in Kenten, Palembang, Indonesia. Catalyst as a support material in this process is sodium methoxide from reaction of 1% sodium hydroxide and methanol from weight basis of oil. Emulsifier tank has function as a place to pre-heat materials that we used. The tank is also equipped with a propeller so the result will be a homogeneous mixture between oil, methanol, and catalyst. In this process, transesterification occurs in a microwave reactor. The power used is 700 watts with reaction time of 10 minutes. In this section, the mixture will absorb and reflect wave radiation that emitted by microwave. Separator as a place of separation utilizes high voltage from cathode and anode plate that is located on the right and left sides of the tank. The number of each electrode is 3 pieces with 1 cm of distance between anode - cathode and voltage used is 10 kV. Instrumentation that used in producing biodiesel with microwaves and high voltage utilization is shown in Figure 2.

**Figure 1. Biodiesel Production Process Diagram**
2.1 Product Quality Analysis

2.1.1 Density Determination
Density is one of the important parameters that must be known from an oil fuel product. The density that allowed for biodiesel according to SNI is 850-890 kg/m$^3$ at 40°C. According to Hadrah, et al. (2018), the value of density that in accordance with SNI can produce a perfect combustion reaction on engine while density value that exceeds the standard will cause the combustion reaction to be imperfect so it will increase emissions and wear on the engine [14]. In 2018, Mustariani, et al. has done research in biodiesel production from waste cooking oil using conventional methods. Heating process that carried out at 55°C will produce biodiesel with density value that still in permitted range, which is 880 kg/cm$^3$.

2.1.2 Viscosity Determination
Viscosity determines thickness level of an oil fuel. Viscosity can be determined using falling ball method. Based on SNI, range that allowed for biodiesel viscosity value is 2.3-6.0 cSt at 40°C. High viscosity value will make it difficult to flow, pumping process, and fuel ignition while if it is too runny, fuel will be difficult to burn and can cause leaks in the injection pipe [15]. According to research that done by Kartika and Widyaningsih in 2012 that using 60°C as reaction temperature, the value of viscosity was 3.06 cSt and still in the range of values that is permitted by SNI [16].

2.1.3 Flashpoint Determination
Biodiesel flash point was determined by using Pensky-Martens closed cup instrument. Flash point need to be known because it will affect storage process of biodiesel fuel. Flash point that is lowest will make storage process of biodiesel fuel being more difficult because it will be flammable while highest flash point will complicate fuel during the ignition process. In SNI, flash point value has been set with minimum value 100°C. Research by Zulhardi, et al. shows that in the temperature range of 60-70°C, flashpoint of biodiesel will be at 227°C [17].

2.1.4 Water Content Determination
Water content in biodiesel will affect the formation of soap as an unwanted product in process of biodiesel production. High water content will allow hydrolysis of triglycerides become free fatty acids and glycerol [17]. Water content that is permitted by SNI is not more than 0.05%. Based on the journal Chhetri, et al., by using 60°C as reaction temperature will produce biodiesel with 0% water content so it is still in permissible range [18].
2.1.5 Acid Number Determination

Low acid number indicates content of free fatty acids that contained in biodiesel fuel has decreased. High acid number can complicate the process of separation between biodiesel and glycerol so net result obtained will decrease [14]. The number of acids that permitted by SNI is not more than 0.5 mgKOH/gr. Meng, et al., research in 2008 showed that the reaction using temperature 50°C for 90 minutes produced biodiesel with an acid number of 0.48 mg KOH/gr [19].

3. Result and Discussion

3.1 Effect of Reaction Temperature for Biodiesel Yield

Reaction temperature will affect transesterification that is occured. Reaction temperature that used in this study are 35, 40, 45, 50, 55, and 60°C. Relationship between reaction temperature and percent of biodiesel yield can be seen in Figure 3.

![Figure 3. Effect of Reaction Temperature for Biodiesel Yield](image)

Based on Figure 3, increasing reaction temperature will cause increasing in percent yield of biodiesel. High percentage of yield is due to faster movement of reactant molecules. This is in accordance with Wahyuni et al. (2015) that higher temperature causes faster molecular movement or kinetic energy by reacting molecules increased, so collisions between reacting molecules also being increased [20]. The collision between these reacting molecules will produce heat which is used to convert oil into biodiesel. Increasing temperature will increase the rate of reaction that occurs due to an increasing in kinetic energy system [21]. The lowest yield percentage at 50°C is due to imperfect transesterification which results in low conversion due to a shift in reaction towards saponification which produces more soap than biodiesel.

3.2 Effect of Reaction Temperature for Biodiesel Density

Density analysis has a function to find out how combustion reaction that occurs in diesel engine combustion chamber. High density value will cause combustion reaction to be imperfect so it can increase engine emissions and wear [14]. Higher conversion was gained when biodiesel density decreased into lower value [22]. Effect of reaction temperature on biodiesel density is shown in Figure 4.
Figure 4. Effect of Reaction Temperature for Biodiesel Density

Figure 4 shows higher reaction temperature will decrease biodiesel product density. Decreasing biodiesel density is caused by faster movement of molecular substances due to an increasing temperature which causes the molecules to collide with each other [23]. This movement makes molecules of the substance stretch and decreases density of the substance. Lowest density is in biodiesel with a reaction temperature of 60°C.

3.3 Effect of Reaction Temperature for Biodiesel Viscosity

Viscosity will affect fuel injection process on the engine. High viscosity will hamper vehicle pump system and make engine hard to turn on [12]. Based on analysis of product characteristics, reaction temperature affects viscosity of biodiesel. Effect of reaction temperature on biodiesel viscosity can be seen in Figure 5.

![Figure 5. Effect of Reaction Temperature for Biodiesel Viscosity](image)

Figure 5 shows that higher reaction temperature will get lower viscosity of biodiesel product. Decreasing viscosity value is caused by faster movement of substance molecules due to an increasing temperature. This faster movement will increase pressure so the molecules will expand and wide the distance between molecules [24].

3.4 Effect of Reaction Temperature for Biodiesel Flash Point

Flash point will affect the treatment of biodiesel product storage. Lowest flash point will complicate storage process because of its flammability, but when its too high, it will make difficulty for engine to ignite the fuel [13].
Based on the result of product characteristics analysis, it is known that reaction temperature affects biodiesel flash point. Analysis result shows that higher reaction temperature was used, flash point will be lower. High reaction temperature will make converted triglyceride molecules into methyl esters being higher in shorter time [25].

In Figure 6, biodiesel products with reaction temperature 55 and 60°C are in accordance with SNI standards. Biodiesel products with reaction temperatures 55 and 60°C have higher flash point due to the process of converting triglycerides and methanol to methyl esters being perfect enough, so methanol which does not react with triglycerides, residual catalysts, and pollutants being less. However, flash point of biodiesel products with a reaction temperature of 35, 40, 45, and 50°C are not in accordance with SNI. This value shows that impurity compounds contained in biodiesel products such as methanol which does not react is still quite large at these temperatures. This is because reaction is not perfect, so the conversion of triglycerides to methyl esters being low.

3.5 Effect of Reaction Temperature for Biodiesel Water Content
Based on Figure 7, it is known that reaction temperature affects water content in biodiesel. Higher reaction temperature was used, lower water content will be get. Water content that is contained in biodiesel products is caused by presence of side product from production of sodium methoxide catalyst. This water content will affect and inhibit the reaction because water will hydrolyze methyl esters that were produced [14]. If water content is lower, possibility of a saponification that forms soap due to reaction with catalyst, waste cooking oil, and residual water contained has been minimal [26]. The highest water content is found in biodiesel with reaction temperature 50°C which is 0.4335 while the lowest is found in 60°C which is 0.265%. High water content is caused by shift of the reaction towards saponification so some of the reaction turns into soap and will reduce percentage of biodiesel yield [4].
Based on Figure 7 above, biodiesel products does not including SNI. All of the products still have water content that exceeds permitted limit. High water content of the product is caused by amount of water remaining in product. Existence of water can be caused by the presence of remaining water produced by purifying biodiesel. The remaining water will make machine being difficult to ignite because it will inhibit delivery of fuel to the piston.

3.6 Effect of Reaction Temperature for Biodiesel Acid Number
Based on the analysis of biodiesel characteristics, reaction temperature affects acid number of biodiesel. Acid number is an indication of the number of fatty acids that is contained in biodiesel products [27]. Acid number indicates that biodiesel product is not corrosive so it will not cause damage to the engine injector [28]. The higher reaction temperature was used, the lower acid number will be get. The highest acid number is in biodiesel with reaction temperature 35°C which is 0.981 mg-KOH/gr-sample while the lowest acid number is in 60°C which is 0.330 mg-KOH/gr-sample.

Figure 8 shows that biodiesel products with reaction temperatures 55 and 60°C are in accordance with SNI. These results indicate that the product is not corrosive to the engine injector. Meanwhile, other biodiesel products have not been in accordance with SNI. This is possible due to incompleteness of the process for converting triglyceride molecules into methyl esters so acid numbers are still quite high that is contained in product.
4. Conclusions
Utilization of biomass material as diesel fuel is one of the solutions that has potential to be applied in order to keep energy needed. Microwaves and high voltages can be combined to produce biodiesel from waste cooking oil in a short time and get high yield. Heating process using microwave method utilizes wave radiation absorbed and reflected by the mixture so contact does not occur with reactor wall. The optimum reaction temperature for getting good quality product is 60°C with 0.88 gr/ml density, 2.52 cSt viscosity, 102.5°C flash point, 0.27% water content, and 0.33 mg-KOH/gr-sample acid number. Water content has not accordance with SNI, but this can be handled by adding a refining process by heating biodiesel products so the water that contained in the product can be reduced.

Reference
[1] H B Perkasa Riviani and Zahidah 2011 Biodiesel Marine Fish Oil from Side Catching Result’s Fish (Bogor: Institut Pertanian Bogor)
[2] A Sugiyono, Anindhita, L M A Wahid and Adriarso 2016 Outlook Energi Indonesia 2016 (Jakarta: Pusat Teknologi Sumber Daya Energi dan Industri Kimia dan Badan Pengkajian dan Penerapan Teknologi)
[3] Saraswati Purbo Kayun 2007 Study of Biodiesel Industry Development Strategy Based on Waste Cooking Oil in Indonesia (Bogor: Institut Pertanian Bogor)
[4] A A Susilo 2010 Pre Design of Biodiesel Plant from CPO (Crude Palm Oil) and Methanol With Capacity of 500,000 Tons/Year (Surakarta: Jurusan Teknik Kimia Fakultas Teknik Universitas Muhammadiyah Surakarta)
[5] A A Refaat and El Sheltawy S T 2008 Time Factor in Microwave-Enhanced Biodiesel Production (Kairo: Jurusan Teknik Kimia Fakultas Teknik Universitas Kairo)
[6] R Hartono, A P Listiadi and I M Bayupramana P 2013 Biodiesel Intensification from Waste Cooking Oil using Interesterification and Dry Washing Purification Method (Cilegon: Jurusan Teknik Kimia Fakultas Teknik Universitas Sultan Ageng Tirtayasa)
[7] Ummi Kalsum, Syarfi and Syamsu Herman 2015 Biodiesel Production from Waste Cooking Oil using Membrane Reactor (Variation of Feed and Catalyst Concentration Molar Ratio) Jom FTEKNIK Vol 2 No 2
[8] Moeksin, Rosdiana, M Zaki Shofihaudy and Dyah Pratiwi Warsito 2017 Methanol and Electrolysis Current Voltage Ratio Influence for Biodiesel Yield from Waste Cooking Oil (Indralaya: Jurusan Teknik Kimia Fakultas Teknik Universitas Sriwijaya)
[9] Galih P and Yudi A 2017 Biodiesel Production from Waste Cooking Oil using Continuous Microwave Biodiesel Reactor Simultaneously (Seminar Nasional Cendekiawan 3)
[10] A Santoso 2008 Utilization of Microwaves to Improve The Efficiency of Biodiesel Synthesis as Renewable Energy (Malang: Universitas Muhammadiyah)
[11] Hernando, J Leton P, Matia M P, Novella J L and Alvarez-Builla J 2007 Biodiesel and FAME Synthesis Assisted Microwave: Homogenous Batch and Flow Processes Fuel 86 p 1641-1644
[12] Jaya Utama P, Leila K and Yohandri B 2018 Effect of DC Voltage on Prototype of Biodiesel Electrostatic Separator with Glycerin from Waste Cooking Oil Indonesian Journal of Fundamental and Applied Chemistry 3 p 89-93
[13] Andi Mulya A, Syaiful B and Zuchra H 2016 Hydrodeoxygenation of Pyrolysis of Ketapang Wood (Terminalia catappa L) Becoming Bio-Oil Using Mo/Clay Catalyst Jom Fteknik Vol 3 [3] No 1
[14] Hadrah, Monik K and Fitria Mayang S 2018 Analylist of Waste Cooking Oil as Biodiesel Fuel Using Transesterification Process Jurnal Daur Lingkungan Vol 1 [1] p 16-21
[15] Evy S and Fatmir E 2012 Technology Processing of Biodiesel from Used Cooking Oil by Microfiltration and Transesterification Techniques as an Alternative Fuel of Diesel Engine. Jurnal Riset Industri Vol 6 No 2 p 117-127
[16] Dwi K and Widyaningsih S 2012 Catalyst Concentration and Optimum Temperature of Esterification using Activated Natural Zeolite (ZAH) for Biodiesel Production from Waste Cooking Oil Jurnal Natur Indonesia 14 [3] p 219-226

[17] Rizky Z, Fajar R and Yelmira Z 2018 The Addition of Methanol in Making Biodiesel from Waste Cooking Oil with Ash Catalyst Jurnal UR Vol 5 [1]

[18] Arjun B Chhetri, K Chris Watts and M Rafiqul Islam 2008 Waste Cooking Oil as an Alternate Feedstock for Biodiesel Production Energies Vol 1 p 3-18

[19] Xiangmei Meng, Guanyi Chen and Yonghong Wang 2008 Biodiesel Production from Waste Cooking Oil via Alkali Catalyst and Its Engine Test Fuel Processing Technology 89 p 851-857

[20] Silvira W, Ramli and Mahrizal 2015 Effect of Process Temperature and Deposition Time for Biodiesel from Waste Cooking Oil Quality (Padang: FMIPA Universitas Negeri Padang)

[21] Irwan Fauzi 2013 Effect of Methanol Ratio, Temperature, and Reaction Time of Biodiesel Rendement in Bintaro Seeds In Situ Transesterification. (Bogor: Departemen Kimia, Fakultas Matematika dan Ilmu Pengetahuan Alam Institut Pertanian Bogor)

[22] Susumun, Rusdianasari and Syahirman Yusi 2018 Biodiesel Production from Waste Cooking Oil using Electrostatic Method Indonesian Journal of Fundamental and Applied Chemistry 3 [3] p 71-76.

[23] Ni Luh Arpiwi 2015 Bioenergi: Biodiesel and Bioetanol (Malang: Fakultas Matematika dan Ilmu Pengetahuan Alam Universitas Udayana)

[24] Andi Sanata 2012 Optimization of Gasoline Engine Performance Using Temperature Variations of Premium Fuel and Ethanol Mixtures Jurnal Rotor Vol 5 No 2

[25] Maharani N H and Zuliyana 2010 Methyl Ester (Biodiesel) Production from Bran Oil and Methanol Using Esterification and Transesterification Process (Semarang: Jurusan Teknik Kimia Fakultas Teknik Universitas Diponegoro)

[26] Septi Puji H 2010 Biodiesel Production from Fish Oil Using Microwaves Radiation (Surakarta: Fakultas Matematika dan Ilmu Pengetahuan Alam Universitas Sebelas Maret)

[27] Arva S P, Z Helwani and E Saputra 2016 Synthesis of Impregnated Fly Ash Using Na2O as Catalyst in Transesterification Process of Off-Grade Palm Oil into Biodiesel (Riau: Jurusan Teknik Kimia Universitas Riau)

[28] Eka Sri Y and Rusdianasari 2016 Separation Process Biodiesel from Waste Cooking Oil Using Ultrafiltration Membranes Proceeding Forum in Research, Science, and Technology (FIRST)