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Sustainable Biodiesel Production from Waste Cooking Oil and Crude Palm Oil Using a Custom Mini Pilot Plant

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Abstract

The widespread practice of reusing Waste Cooking Oil (WCO) in hawker food stalls, often for multiple frying cycles, presents a significant public health concern due to the degradation of the oil, which can lead to the formation of toxic compounds. These practices not only pose health risks, such as increasing the potential for cardiovascular diseases and cancer, but also contribute to environmental pollution when the oil is improperly disposed of. This study seeks to address these issues by converting WCO, along with crude palm oil (CPO), into biodiesel using a custom-designed mini pilot plant. The biodiesel production process involved a two-step reaction. The first step, esterification, was conducted using a 55:100 alcohol-to-oil volume ratio with 1% by volume sulfuric acid (H_2SO_4) as the acid catalyst, at 60°C, with a reaction time of 30 minutes and a stirring speed of 800 rpm. The second step, transesterification, utilized a 6:1 alcohol-to-oil molar ratio, with 1 wt.% sodium hydroxide (NaOH) as the alkaline catalyst, carried out at 70°C over the course of one hour. These conditions were carefully selected to optimize the conversion efficiency and to minimize the free fatty acid content, which is crucial for achieving a high yield of biodiesel. The results demonstrated that the mini pilot plant is highly effective in producing biodiesel from both WCO and CPO. The study also led to the development of a standard operating procedure (SOP) for the biodiesel production process, ensuring reproducibility and efficiency.

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1. Introduction

In the past decade, the production of biodiesel from Waste Cooking Oil (WCO) has seen significant development and application. Biodiesel, an alternative fuel, is produced through the chemical processes of transesterification and esterification, which involve vegetable oils or animal fats, such as lard and tallow. Among various feedstocks, WCO is considered the most economical and renewable raw material for biodiesel production. WCO is generated predominantly from cooking, particularly during the preparation of deep-fried foods. Unfortunately, WCO is often disposed of irresponsibly, either by pouring it down household drains or onto the soil, leading to environmental and infrastructural issues [1]. Disposal of WCO into drains can cause blockages in drainage systems, increasing maintenance costs for businesses and potentially leading to flooding during the rainy season [2]. These concerns have prompted extensive research into biodiesel production from WCO as a means of mitigating environmental impact.

Several companies, such as Living Fuels in the UK and Tri-State Biodiesel (TSB) in New York, have demonstrated their commitment to environmental conservation by collecting WCO and processing it into biodiesel. The Environmental Protection Department in Hong Kong has highlighted the detrimental effects of improper WCO disposal, noting that direct release into rivers can severely reduce oxygen levels, impede sunlight penetration, and render aquatic environments uninhabitable [3].

In Africa, particularly in Nigeria, the production of biodiesel from WCO has gained serious attention as a strategy to reduce health risks among local populations [4]. Reusing WCO for cooking, especially after multiple uses, deteriorates the oil's quality, potentially leading to health issues such

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as hypertension, diabetes, and vascular inflammation [5]. In Malaysia, deep-fried hawker foods are ubiquitous, contributing to the widespread generation of WCO. A preliminary survey conducted by Universiti Sains Malaysia (USM) revealed that local citizens have limited awareness of proper WCO management. Many individuals reuse WCO more than three times before disposal or continue using it until it is completely depleted [1].

WCO is readily available from a wide range of sources, including households and food manufacturers. As the global population continues to grow, the production of WCO is expected to increase in parallel with the rising demand for food. To facilitate biodiesel production under low temperature and pressure conditions, it is essential to use oil with a free fatty acid (FFA) content of less than 1% [6]. Therefore, WCO with low FFA is preferred; otherwise, pretreatment is necessary to reduce the FFA content before proceeding with conventional transesterification [7].

The research interest in biodiesel production remains strong, driven by the pursuit of processes that are simple, efficient, and environmentally friendly. In this study, a custom-built mini plant was fabricated to evaluate the properties of biodiesel produced from WCO and crude palm oil (CPO). Understanding the biodiesel production process is crucial before commencing production. Thus, a thorough review of the literature was conducted, focusing on the suitability of various feedstocks for biodiesel production and the impact of process conditions on the properties of the resulting biodiesel. This review included studies from journals, articles, and relevant books.

To ensure the validity of the results, it is important to reference established standards. In the field of biodiesel, the ASTM (American Society for Testing and Materials) and EN (European Norm) standards are commonly used as benchmarks by researchers. These standards are critical for ensuring safety, quality, performance, accuracy, and other essential aspects of biodiesel production.

Selecting an appropriate feedstock is vital to avoid unnecessary waste of chemicals, labor, and time during biodiesel production. Key factors to consider include the water content and FFA level of the feedstock, as these can significantly affect the efficiency of the chemical reactions involved.

Various sources can be utilized for biodiesel production, with raw materials typically derived from plants or animals. These can be classified into three main categories: oil-yielding plants, animal fats, and used cooking oil. WCO, which uses cooking oil that has been heated at least once or has expired, often exhibits degraded quality. The production of WCO typically involves high oil concentrations, as deep-frying requires full immersion and cooking at high temperatures. WCO is characterized by a dark color, an unpleasant odor, and high acidity, necessitating pretreatment before it can be used in the final biodiesel production process.

The pretreatment of Waste Cooking Oil (WCO) is primarily undertaken to ensure its suitability for storage and subsequent biodiesel production. WCO often contains food residues, which can lead to various issues, such as microbial growth, increased acidity, and rancidity. Therefore, the pretreatment of WCO typically involves three main processes: filtration, drying, and de-acidification.

Filtration is performed to remove solid impurities from the oil. While WCO is usually filtered before being collected from food manufacturers, an additional filtration process is recommended in biodiesel production. This process should be carried out at temperatures above 60°C, where carbonaceous residues from burnt food can be effectively removed [8]. Additionally, solid fats with lower melting points are also eliminated during this stage. The filtration mesh should be as fine as possible; however, finer meshes may require higher pressure to expedite the filtration process.

The drying process is essential for removing water content from WCO. Water molecules in WCO can react with triglycerides to form free fatty acids (FFA), which can negatively impact the efficiency of the transesterification process during the conversion of triglycerides to biodiesel. Moreover, in base-catalyzed transesterification, FFAs can cause saponification with the alkaline catalyst, resulting in the formation of fatty acid salts (soap) [9]. Additionally, removing water molecules helps to inhibit the growth of microorganisms during storage [10]. The drying process is straightforward: the WCO is heated to temperatures exceeding 100°C for approximately 1.5 hours. This temperature is sufficient to evaporate water, as well as other substances with lower boiling points [10].

De-acidification, or esterification, is carried out to reduce the FFA content in the feedstock, as high FFA levels can hinder the efficiency of biodiesel conversion and negatively affect the yield percentage. According to [11], the optimal conditions for esterification involve an alcohol-to-oil volume ratio of 55:100, 1% by volume of sulfuric acid relative to the oil, a reaction temperature of 60°C, a reaction time of 30 minutes, and a stirring speed of 800 rpm. Under these conditions, FFA content is minimized, thereby significantly enhancing the biodiesel yield.

CPO is used as feedstock for biodiesel production in common. Inside CPO does consist of a few unwanted components that must be removed before proceeding to transesterification. The general component of CPO is shown in Table 1.

Table 1. Common components in CPO [10]

Group	Components
Oil	Triglyceride, Diglyceride, Monoglyceride, FFA
Oxidized Products	Peroxide
Non-oil but oil soluble	Carotene, Tocopherol, Phospholipids
Impurities	Metal particle
Water soluble	Water (Moisture)
	Glycerol, Chlorophyl pigments

In the category of oil, triglyceride is the major component whereas diglyceride and monoglyceride are the minor components. FFA is formed due to hydrolysis process with triglyceride molecules when exposed to moisture. Rancidity is caused by the component of peroxide, an oxidation product when reacts with oxygen particles [10]. The natural color of reddish brown in CPO is caused by the components of tocopherol and carotene that also been treated as natural antioxidant. Phospholipids are usually referred to as gums and must be removed. This component has unwanted flavor and pigment. Also, phospholipid has its strong emulsifying action that will cause low efficiency during separation process and affect the oxidative stability of the CPO. Next, the presence of metal components (pro-oxidant) in the CPO lowers the quality of the oil as they will cause mechanical wear at the mills and refineries. Again, the presence of water molecules causes the hydrolysis process and affects the efficiency of biodiesel production. Glycerol brings opposite effect in the oil quality. Thus, in order to remove those unwanted components, pretreatment for CPO is required. Those common pretreatments for CPO are degumming, bleaching process, and esterification.

Phospholipids bring a lot of problems during storage and processing of CPO [12]. Thus, it has to be removed during refining by degumming process. Phospholipids can be separated into two types; they are hydratable (HPL) and nonhydratable (NHPL). Both are removed in this process as well. HPL can be removed easily by water degumming whereas NHPL requires a more critical process in order to eliminate it. There are three types of degumming process: water degumming, acid degumming and Totaal Ontslijmings Process (TOP) degumming [13]. Water degumming is to remove HPL phospholipids from the oil by warm water only. Acidic degumming can be carried out by either citric acid or phosphoric acid with parameter. TOP degumming is the combination of water degumming and acidic degumming with specified conditions.

Bleaching process is optional in CPO pretreatment as the purpose of the process is to remove the pigment from the oil only by using bleaching earth.

2. Methods

Figure 1 shows the flow chart of biodiesel production. The beginning was the pretreatment for WCO and CPO and FFA value analysis. The second part was the core process for biodiesel production. The last part was the washing and drying process and properties analysis.

2.1. Feedstock and chemical

Regarding the source of the WCO and CPO, WCO was collected from hawker food stalls in Parit Raja area. Food stalls that sell deep fried food such as deep-fried banana, Keropok Lekor, fried chicken and so on. The WCO collected in this project was from Keropok Lekor food stalls. CPO was acquired from Biodiesel Laboratory, UTHM.

Throughout the biodiesel production, there were utilized seven types of chemicals. They were methanol (CH_3OH), sulfuric acid (H_2SO_4), isopropanol (C3H8O), bleaching earth, phosphoric acid (H_3PO_4), phenolphthalein, and sodium hydroxide (NaOH).

2.2. Pretreatment

In this project, there were two cycles of biodiesel production. For WCO biodiesel production, the pretreatment involved is filtration. There were six stages of filtration with six different types of nylon mesh. The verity of the nylon mesh was 200, 100, 75, 48, 40, and 25 microns. At the end of the filtration process, fairly clean oil was obtained.

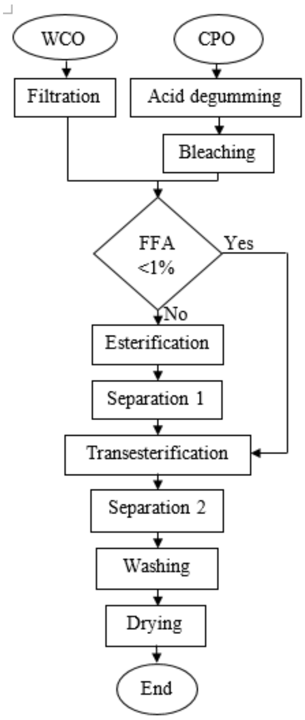

Figure 1. Flowchart for WCO and CPO Biodiesel Production

For CPO biodiesel, the pretreatment involved degumming and bleaching process. In the degumming process, the parameter was 0.1 % vol. of H_3PO_4 measured according to the volume of oil and 400 rpm stirring speed. The oil was pre-heated to temperature 90 to 110 ˚C before the mixing process is started. The reaction was held for 15 to 20 minutes. After that, 1 % vol. of water was added to the mixture and stirred. The mixture was left for 60 minutes' separation. Water was drained out. For bleaching process, the parameter applied on this project was also referring to the parameter used on biodiesel pilot plant, UTHM. It was mixing the bleaching earth measured 1 wt.% with the weight of oil and operating at temperature 90 to 110 ˚C for 30 minutes.

2.3. FFA value analysis

Titration solution was prepared by mixing 1 gram of NaOH and 1 liter of distilled water together. Mixture to be titrated was prepared by mixing 1 ml of oil and 10 ml of C_3H_8O together with few drops of phenolphthalein. The titration process was completed by adding the titration solution drop by drop into the mixture. The mixture was gently shaken every time the titration solution was dropped with around 30 seconds interval until the mixture turned into pink color for more than 30 seconds.

The volume of titration solution used was recorded and FFA % was calculated according to the formula stated on (1) and (2).

$$V_t = V_o - V_f \tag{1}$$

$$FFA\% = \frac{V_t}{1.3} \tag{2}$$

Where, V_t is total volume titrated (ml), V_o is initial volume (ml), and V_f is final volume (ml).

2.4. Esterification

Both WCO and CPO excess the required value to skip this process. The parameter utilized in this process was alcohol-to-oil volume ratio 55:100, and 1% vol. of H2SO4. Operated at temperature 60 ˚C, 30 minutes' reaction time, and 800 rpm stirring speed.

After the esterification process, the catalyst was removed before proceeding to transesterification. Chemical equation (3) shows the product formed between H2SO4 and NaOH. The equation clearly displayed that the comparison among the moles of chemical was 1 mole of H2SO4 to 2 moles of NaOH. From MSDS, the mass per mole for H2SO4 is 98.08 g/mole whereas for NaOH is 40 g/mole. By following the formula (4) to (6), amount required to neutralize the added H2SO4 was calculated.

$$H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O \tag{3}$$

$$mole\ H2SO4 = \frac{massH\,2SO4}{98.08} \tag{4}$$

$$mole\ NaOH = 2 * mole\ H2SO4 \tag{5}$$

$$mass\ NaOH = mole\ NaOH * 40 \tag{6}$$

2.5. Transesterification

For basic concept of transesterification, the process is to transform triglyceride into methyl ester. However, there is a side product produced if FFA is present during the process. The side effect of FFA in this process is saponification. The mechanism of how triglyceride turns into methyl ester is shown in Figure 1. The functional groups, represented by R1, R2, and R3 are long chain fatty acids consisting of the carbon-hydrogen bonds.

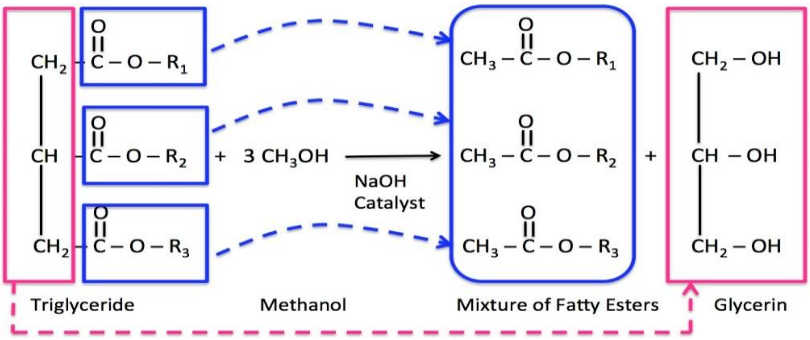

Figure 2. Transesterification Process of Triglyceride

As studied, the best parameter and condition was alcohol-to-oil molar ratio 6:1, 1 wt.% NaOH referring the feedstock, and operate at temperature 70 ˚C for more than 1 hour with moderate stirring speed. From the referenced molar ratio, the molecular mass of CPO was required to calculate the volume of methanol to be used in this process. Thus, from the study of [10], the average molecular mass of CPO was 848.24 g/mole. According to MSDS, the molecular mass for methanol is 32.04 g/mole. The weight of methanol is calculated based on the formula (7) to (9).

$$mole\ CPO = \frac{weight\ CPO}{848.24} \tag{7}$$

$$Mole\ methanol = mole\ CPO * 6 \tag{8}$$

$$Weight\ methanol = mole\ methanol * 32.04 \tag{9}$$

Due to the presence of alcohol which has lower boiling point, the evaporation may occur easily. Thus, the built-in condensing chamber on the mini plant was utilized as shown in Figure 3. The condenser was utilized to recycle the evaporated alcohol from the mini plant.

Figure 3. Location of Condensing Chamber

2.6. Alcohol

There are two types of promoted alcohol that could be used in transesterification. They are methanol and ethanol. When ethanol is used, it created difficulty during recovery process into pure ethanol because of the present of azeotrope situation in ethanol and water mixture. Furthermore, the comparison among ethanol and methanol, methanol has the higher conversion of methyl ester. In addition, with the ability to handle emulsification, methanol probably is easier and faster in dissolving the emulsified oil molecules and effectively separating the glycerol and methyl ester during separation process. On the other hand, there is another issue that ethanol has higher viscosity than methanol. High viscosity level in biodiesel will gives effect on smoothness in the injection system of the vehicles engine performance [8], [14].

Employing ethanol in biodiesel production will bring more complex procedures and require more energy to manage and handle. Thus, choosing methanol is the best way to produce biodiesel. Methanol in biodiesel production leads to higher conversion, less time require, and low cost [8].

From the study of [8], concluded that molar ratio alcohol to oil 6:1 was the best to get highest conversion of biodiesel. Transesterification with lower molar ratio was probably not going to perform the reaction completely. The molar ratio of 9:1 and 12:1 gave a good result also. However, molar ratio higher than 15:1 will have difficulty during separation process.

2.7. Catalyst

In general, the function of catalyst is to speed up the rate of reaction. In biodiesel production, homogeneous, heterogeneous or enzymes are applied. Homogeneous catalyst, it can be acidic or alkaline.

From the study of [8], [15] the most effective transesterification was using acid-catalyst. However, the time taken for the process was very long and it must be operated at a temperature higher than 100˚C. Acid catalyzed, the transesterification would take around 50 hours for complete reaction. On the other hand, the conversion of biodiesel using base-catalyst was lower than using acid-catalyst. But, in terms of rate of reaction, base-catalyst efficiently boosted the transesterification process. In common, for alkaline catalyst, sodium hydroxide (NaOH) is used with the condition of 1% vol. and temperature at 60˚C. There is another alkaline catalyst used, potassium hydroxide (KOH). But it gave lower yield of biodiesel compared to NaOH with same operating condition. Thus, NaOH is commonly chosen as catalyst in transesterification with the condition.

Furthermore, the increase in amount of catalyst does not increase the rate of reaction but increases the formation of emulsion and increase the viscosity. In addition, the operating temperature must not be higher than the boiling point of the alcohol as the cause of vaporization brings to the loss of alcohol and then lower the efficiency of the production process.

2.8. Washing and drying process

After the reaction of transesterification is done, it is important to remove all the impurities, remaining alcohol and catalyst, water and side product [9]. By doing so, warm water (40˚C to 60˚C) is used. Water is able to neutralize the remaining alkaline catalyst because water has acidic properties that will form salt particles with alkaline elements.

Washing process was done by adding warm water at a temperature around 40˚C to 60˚C with the amount approximately 25% of the oil volume and stir gently for about 30 seconds. Then, the water was allowed to settle down for 10 minutes. The washing process was performed in about three cycles. After that, the product was dried through drying process that increase the temperature to 100˚C for about 2 to 4 hours to remove any excessing water molecule and alcohol from the biodiesel. After the washing process is done, the biodiesel must be rich with water molecules. Therefore, drying process is needed. This is the final stage for the whole biodiesel production. The drying process is simple as it heads the biodiesel to the boiling point of water (100˚C). Throughout the process of washing and drying, gentle stirring is needed for better mass transfer process [10].

2.9. Separation process

For the whole biodiesel production process, there are three times the separation process involved. They are located after esterification, after transesterification, and after washing process. First separation process after esterification is to separate out the remaining alcohol and water produced from neutralization. Second separation is after transesterification, that is to separate methyl ester and glycerol. Time for separation of more than 8 hours if required due to different density among them [8] and longer separation time will result better separation phase. Finally, after washing process, this separation process is to drain out the washed water for better purity of biodiesel.

3. Results and Discussion

WCO biodiesel production was first conducted followed by CPO biodiesel production. Both productions were similar except for pretreatment process only.

3.1. Pretreatment for both of the biodiesel production

For the first cycle of production, WCO was filtered using vary levels of filtering mesh from 200micron to 25micron before production is started. Figure 4. shows the appearance of filtered WCO. After the WCO was filtered, the sample was taken to FFA analysis at biodiesel laboratory, UTHM. The result shown was 1.616% FFA value that higher than 1% and esterification was conducted.

For the second cycle, CPO went through acid degumming and bleaching process. For acid degumming process, CPO was preheated to 100^0 C and 20ml of H_2SO_4 was added into it. The process was held for 20 minutes and operated at 400rpm. After that, 200ml of water was added to the mixture and stirred for 5 minutes and left for settlement for 1 hour. Water was drained out after the settlement was done. Figure 5. shows the appearance of two layers when separation is done. For bleaching process, CPO was preheated to 100°C and 198g of bleaching earth was added into it. The whole process was held for 30 minutes and moderate stirring speed. After that, the mixture was filtered using 75micron filtering mesh. Figure 6 shows the product after the bleaching process. The pretreated CPO was brought to FFA analysis, the result showed that the FFA% was 8.9% and esterification process was conducted.

Figure 4. Appearance of filtered WCO

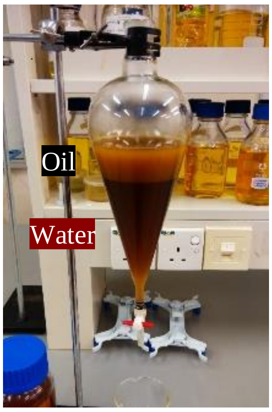

Figure 5. Appearance of two layers when separation is done after acid degumming

Figure 6. Appearance of the CPO after Bleaching Process

3.2. Esterification

Both of the productions were utilizing the same parameter for esterification. The parameter was 55:100 alcohol-to-oil volume ratios in the presence of 1% vol. H_2SO_4 as an acid catalyst in 30mins reaction at 60°C and 800 rpm stirring speed. For neutralization, NaOH was calculated and mixed with the oil to neutralize the H_2SO_4. After that, the mixture was settled down for one hour and the lower layer (oil) was drained out and brought to FFA analysis. As the result, FFA value for WCO was reduced to 0.41% whereas CPO was reduced to 1.21%.

3.3. Transesterification

Both of the productions were utilizing the same parameter for transesterification. The parameter was 6:1 alcohol-to-oil molar ratio in the presence of 1 wt.% NaOH as an alkaline catalyst in 1h reaction at 70°C. The mixture was then left for one day for separation process. When the separation process is done, the bottom layer is glycerin, and the top layer is biodiesel. Glycerin was drained out and the remaining biodiesel was processed to washing process.

3.4. Washing and drying process

Both of the productions were utilizing the same parameter for washing and drying process. The biodiesel was mixed with warm water at temperature around 40 to 60°C and 25% volume of the biodiesel. The mixture was stirred gently for about 30 seconds and settled down for 10 minutes. Water waste was drained out and the process was repeated for 3 cycles. After that, the washed biodiesel was heated to 100°C to evaporate all the water molecules for 2 hours. Figure 7 and Figure 8 show the appearance of both of the biodiesel for every washing cycle and the final product.

3.5. Product analysis

Both biodiesel was brought to Fuel Analysis Laboratory in Faculty of Mechanical Engineering (FKMP), UTHM for analysis. Properties tested were kinematic viscosity, flash point, water & sediment, acid number and moisture content.

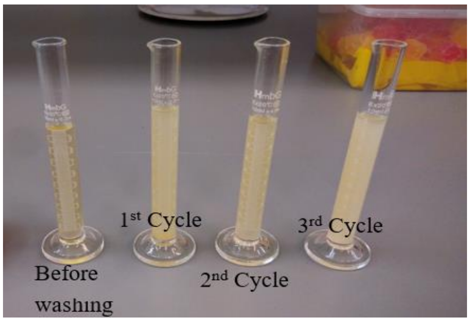

Figure 7. Appearance of Biodiesel for Every Washing cycle for WCO

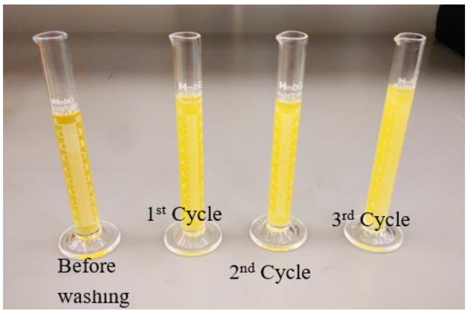

Figure 8. Appearance of Biodiesel for Every Washing Cycle for CPO

For kinematic viscosity analysis, viscometer was used to test the samples as stated in ASTM D445. As a result, both of the biodiesel produced from WCO and CPO were 5.1 mm2/sec. The values were within the limit stated in ASTM D445 that is between 1.9 to 6.0 mm2/sec. Figure 9 shows the setup for kinematic viscosity analysis.

Figure 9. Setup for kinematic viscosity analysis

For flash point, closed cup analysis, method ASTM D93 was referred. Biodiesel produced from WCO; the flash point was 170°C whereas biodiesel produced from CPO was 172°C. Both samples met the ASTM D93 that the minimum value is 93°C. Figure 9 shows the Pensky-Martens (PMA 4) Machine that analyzes flash point (closed cup).

To determine the purity of the biodiesel, Mettler Toledo moisture analyzer was used, the result for biodiesel produced from WCO was 0.05 % mc whereas biodiesel produced from CPO gave 0.18 % mc. The purity for WCO's biodiesel and CPO's biodiesel are 99.95% and 99.82% respectively. Refer to European Committee for Standardization, EN14214, the ester content is stated as 96.5% as minimum. Figure 11 shows the moisture analysis was in process.

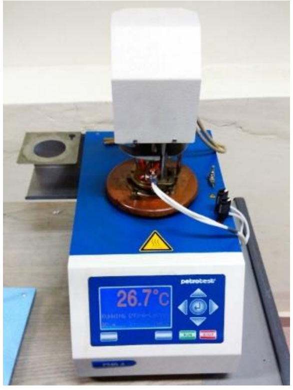

Figure 10. Pensky-Martens (PMA 4) Machine

Figure 11. Mettler Toledo Moisture Analyzer in Process

For acid number analysis, method ASTM D664 was referred. In this analysis did not involve any machine. After the titration process, the result for the biodiesel produced from WCO was 0.7314 mg KOH/g whereas result from biodiesel produced from CPO was 0.284 mg KOH/g. In this section acid value for CPO's biodiesel did not excess 0.5 mg KOH/g whereas WCO's biodiesel excessed the maximum value stated in ASTM standard. Figure 12 shows the acid value analysis process that titrating process must be stopped when the color sample changed.

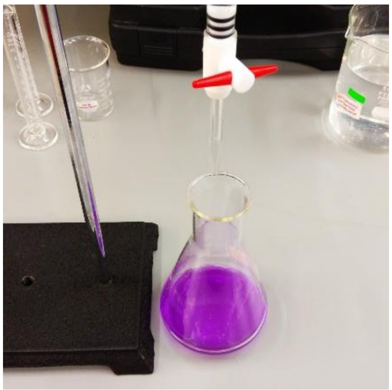

Figure 12. Sample Color Changed During Titration

For water content analysis, Karl Fischer Compact Titrators was used. This method referred to method ASTM D2709. Before the analysis was started, the machine was calibrated. The reading for WCO's biodiesel was 356.9 ppm (0.036%) whereas CPO's biodiesel was 553.0 ppm (0.055%). The specification stated in EN14214 and ASTM D6751 was 500 ppm (0.05%) maximum. Thus, biodiesel produced from WCO successes to meet the specification whereas CPO's biodiesel does not. Figure 13 shows the setup of Karl Fischer Compact Titrators.

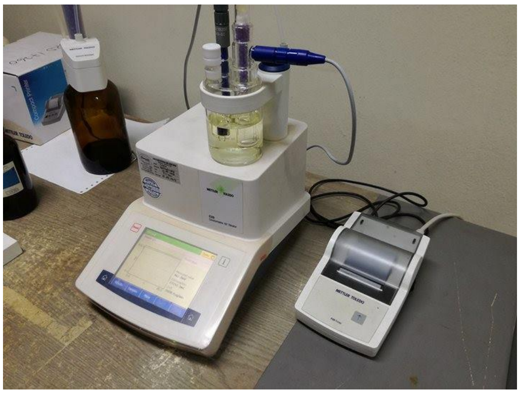

Figure 13. Karl Fischer Compact Titrator

To determine the calorific value, a bomb calorimeter was used. The method referred was ASTM D240. It is an important parameter to be determined in order to know the potential of heat transferred inside the engine during combustion and indicate the available energy in a fuel. The reading for WCO's biodiesel and CPO's biodiesel were 39.90 MJ/kg and 39.80 MJ/kg respectively. The values were good that the optimum reading range was from 39 to 41 MJ/kg for biodiesel. Figure 14 shows the setup for bomb calorimeter and the status of the nichrome fuse wire after the test was done.

Figure 14. Setup of Bomb Calorimeter

Table 2. Comparison of B100 Between Previous Researcher and This Research

Parameter	Specification	Ngo (2016)	B100 from WCO	B100 from CPO
Kinematic viscosity, mm2/sec	1.9-6.0	5.40	5.10	5.10
Water and sedimentation, %	0.05 max.	0.008	0.036	**0.055**
Acid value, mg KOH/g	0.5 max.	**3.383**	**0.7314**	0.284
Flash point, °C	130 min.	164	170	172
Calorific Value, MJ/kg	39-41	39-20	39.90	39.80
Purity, %	96.5 min.	97.69	99.95	99.82

The kinematic viscosity is probably affected by the molar ratio of alcohol-to-oil [16]. In this study, the final kinematic viscosity value of the B100 has to be within the specified range. Figure 15 shows a graph to figure out the trend of the kinematic viscosity value from previous researcher to this study. From the result, the kinematic viscosity values in this study from both of the B100 were lower than the B100 from previous researcher. It was a good condition that higher kinematic viscosity in B100 created higher resistance the fluid flow in the engine [16].

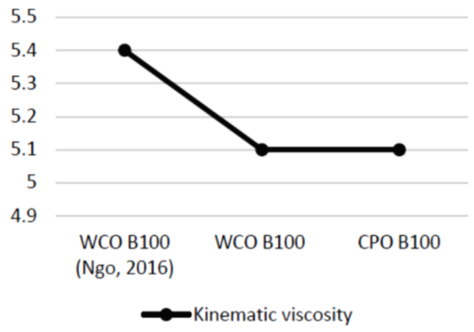

Figure 15. Graph of kinematic viscosity (mm²/sec)

During washing and drying process, it involved water mixing in the biodiesel. Thus, water had to be removed completely from the biodiesel to ensure the quality of the final product. Figure 16 illustrates the trend of the water and sediment value in this study with the one from the previous researcher. From the result, CPO B100 failed to meet the ASTM standard, and it showed that longer drying process was required to remove more water molecules from the B100.

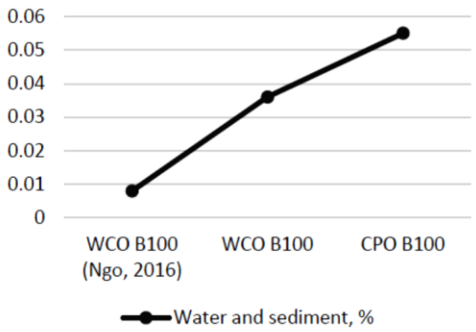

Figure 16. Graph of Water and Sediment (%)

Researchers are very concern about the acid value in the biodiesel as it will affect the storage period and the growth of micro-organism [10]. Figure 17 shows the trend of the acid value in the graph for this study with the previous researcher. From the result, there was a large decrement in acid value in this study with previous researcher. However, WCO B100 in this study failed to meet the ASTM standard. In this case, detail in chemical study or repeated production is required. For the reason of the second FFA analysis during WCO B100 production was below the required limit and no other acidic chemical was added after the process.

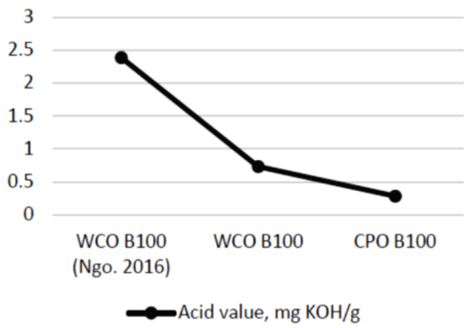

Figure 17. Graph of acid value (mg KOH/g)

Flash point indicated the minimum temperature on the surface of the flammable liquid to get ignited [17]. The ignition was due to the evaporated vapor on the surface of the volatile liquid. Figure 18 illustrates the trend of the flash point of B100 from previous researcher to this study. Flash points analyzed in this study were both higher than previous researchers that had indicated the B100 produced in this study was less flammable and safer.

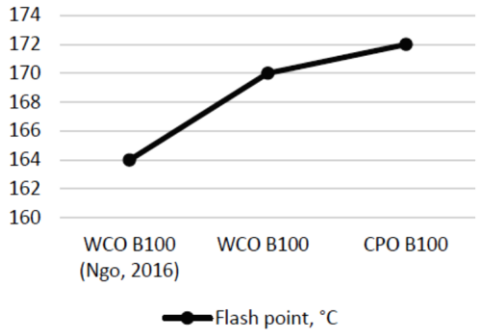

Figure 18. Graph of flash point (°C)

The calorific value indicated the total energy produced during combustion in the engine per liter of the fuel consumed [18]. Figure 19 shows the trend of the calorific value in this study with the previous researcher. The calorific values for the B100 produced in this study were higher than the previous researcher, showing the energy stored in the B100 in this study was higher.

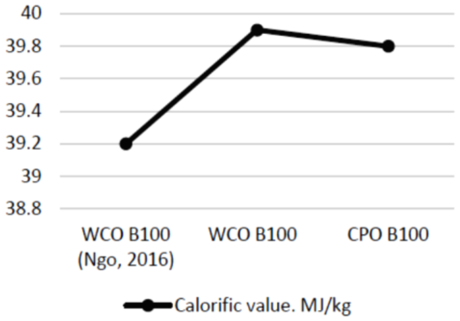

Figure 19. Graph of Calorific Value (MJ/kg)

From Figure 20, the graph indicates that the B100 produced in this study was cleaner than the B100 produced in previous researcher. Higher purity showing the quality of the B100 is higher.

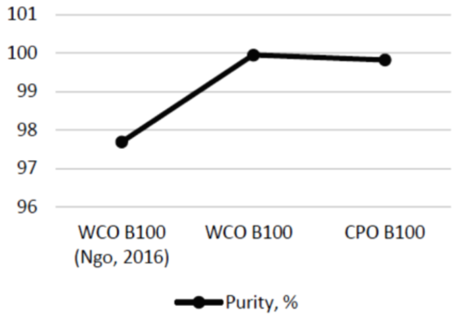

Figure 20. Graph of Purity (%)

4. Conclusions

In the end of the project, biodiesel produced from WCO and CPO as feedstock was successfully completed by using the mini plant that custom made for WCO biodiesel production. Also, both of them utilized the same parameter to produce biodiesel. Each of the biodiesel produced failed to meet the ASTM D6751 standard from five of the properties analyzed. For both of the biodiesel production, the parameter implied was 55:100 alcohol-to-oil volume ratio, 1% vol. of H2SO4, 60°C, 30 minutes and 800 rpm stirring speed for esterification process; 6:1 alcohol-to-oil molar ratio, 1 wt.% NaOH, 70°C, more than 1 hour and moderate stirring speed for transesterification process; 25% of oil volume of warm water at temperature 40 to 60°C for washing process. In addition, the mini pilot plant is able to perform CPO's biodiesel production was proven.

To the mini plant, it is recommended to install side glass for better observation during chemical reaction and separation process, further investigation for the outlet at the bottom of the mini plant is required to avoid blockage during separation process for transesterification and built in operation program make the whole production process as the parameter for the production have produced.

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