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BIODIESEL PRODUCTION OF WASTE COOKING OIL (WCO) AND CRUDE PALM OIL (CPO) BY USING MINI PLANT

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Abstract

Cooking deep fried foods produce huge amount of waste cooking oil (WCO) and hawker food stall likes to reuse it for several cycles just to get more profits. Reheating cooking oil cause degradation and it could become a toxic to human health. The aims of this project are to produce biodiesel from WCO and crude palm oil (CPO) by using the selected mini pilot plant. The parameter utilized on both of the production are 55:100 alcohol-to-oil volume ratio 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 esterification process and 6:1 alcohol-to-oil molar ratio in the presence of 1 wt.% NaOH as an alkaline catalyst in 1h reaction at 70°C for transesterification process. As the result, the mini pilot plant is also suitable to CPO's biodiesel production and standard operating procedure (SOP) is developed.

Keywords: Biodiesel, waste cooking oil, crude palm oil, pilot plant, alternative energy

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1 Introduction

In the recent decade, production of biodiesel from Waste Cooking Oil (WCO) has been actively applied and developed. Biodiesel is a kind of alternative fuel developed from chemical reaction of transesterification and esterification which involved vegetable oil or animal fat such as lard and tallow.

WCO is the most economic raw material for biodiesel production and it is renewable. WCO is created from food cooking especially deep fried food for human consumption. Therefore, WCO is usually been abandoned incautiously to our surrounding such as household drainage system or pour on soil [1]. Disposing WCO into the sink or drains will cause blockage of the drain system [2]. In business field, this will cause the increase in drainage maintenance cost. Furthermore, blockage in drainage system may cause flooding during rainy season. Hence, this issue has aroused many researchers to further study regarding biodiesel production from WCO in order to contribute to the environment.

Those famous companies whom take the responsibility to collect the WCO and process it into biodiesel such as Living Fuels in UK and Tri-State Biodiesel (TSB) in New York have shown themselves their enthusiasm to save the environment. According to the environmental protection department in Hong Kong, if WCO being thrown directly without treatment, it will pollute the environment. For instance, the release of WCO directly into the river will cause the oxygen level to drop sharply where the sunlight is unable irradiate the aquatic for survive and the river will no longer be suitable for any organism that live in and around the water [3].

In Africa and Nigeria, biodiesel production from WCO has been taken into consideration very seriously and it has been developed to decrease the health risk among the local citizen [4] if the WCO is being reused for foods. The process of reheating the cooking oil will deteriorate the quality of the cooking oil and it may lead to unwanted diseases such as hypertension, diabetes and vascular inflammation [5]. In Malaysia, deep fried hawker foods are easily found in many food stalls. Therefore, WCO is easily abandoned by those food stall workers. According to the preliminary survey on the management of WCO from Universiti Sains Malaysia (USM), local citizens have lack of awareness about proper WCO management. Local citizens mostly reuse the WCO more than 3 times before disposing or using the WCO until depletion [1].

WCO is easy to obtain from household to food manufacturer. Furthermore, as the population increases, the production of WCO will be even more to fulfill the demand. In order to operate the biodiesel production at low temperature and pressure condition, oil with free fatty acid (FFA) lower than 1% is required [6]. Therefore, WCO with low FFA is considered, otherwise, pretreatment to eliminate FFA from the WCO is required before proceeding to the conventional transesterification process [7].

In accordance with the issue, attention to the research in biodiesel has never been silenced till now. Also, biodiesel production with element of simplicity, efficiency, and environment friendly often act as the guidance to lead the researchers to achieve their objective. In the study, a mini plant custom was fabricated in order to determine the properties of the biodiesel produced from WCO and crude palm oil (CPO).

2 Literature Review

The biodiesel production has to be understood before conducting the production. Thus, several researches were studied to understand the suitability of feedstock for biodiesel production and the effect of process to the properties of biodiesel produced. The studies of the researches were majorly from journals and articles as well as related books.

Besides, to justify the result, there must be a standard for us to refer. In the field of biodiesel, ASTM (American Society for Testing and Materials Standard) and EN (European Standard) are mostly taken by researchers as references. Standard is important to many expects such as safety, quality, performance, accuracy, and many more.

2.1 Preparation of Feedstock

Feedstock is important before the biodiesel production is started to avoid unwanted wastes such as chemical, manpower and time taken. Usually, water content and level of Free Fatty Acid (FFA) need to be considered and has to make sure that the feedstock going that are used will not affect the efficiency during chemical reaction.

There are many sources which can be used for biodiesel production. These raw materials majorly come from plants and animals. The raw materials for biodiesel production can be classified into three main captions: oil-yielding plants, animal fats, and used cooking oil.

2.2 Waste Cooking Oil (WCO)

WCO is the used cooking oil that heated at least once or the expired cooking oil that the quality of the cooking oil is degraded. Production of WCO usually contains high amount of oil concentration as the deep fried foods required full immersion and cooks at high temperature. WCO is in dark color with unfavorable smell and also high in acidic level. Thus pretreatment process is needed before having a finalize biodiesel production process.

Pretreatment for WCO is usually for the purpose of storage. WCO existing food residue will cause various situations to occur in the oil such as grow of microorganism, rise in acidic value and putridness. Thus, in general, pretreatment for WCO involves filtration, drying, and de-acidification.

Filtration is to remove the solidified impurity out from the oil. However, the WCO was filtered before it will be collected from the food manufacturers. In biodiesel production, filtration process is advised to be carried out at a temperature higher than 60˚C where the carbonaceous reaction occurred from those burnt foods and removed [8]. Also, those solid fats with lower melting point are eliminated. For the filtering nylon mesh, it is advised to be as tiny as possible. Tinier mesh may require high pressure to speed up the filtering process.

Drying process is involved to remove the water content inside the WCO. Water molecules exist inside the WCO react with the triglyceride form FFA molecules and affect the efficiency of transesterification during conversion of triglyceride to biodiesel. Besides, during base-transesterification, FFA causes saponification with alkaline catalyst forming salt of fatty acids (soap) [9]. In addition, eliminating water molecules do reduce the growth of microorganisms during storage period [10]. The drying process is simple that the WCO is heat up to more than 100˚C for around 1 and half hour as the boiling point of water is 100˚C and any substance with boiling point lower than that will also be eliminated [10].

De-acidification or esterification is to remove the free fatty acid (FFA) content from the feedstock as it will affect the efficiency of biodiesel fuel conversion. These indirectly affect the yield % of biodiesel. According to [11] the best condition in esterification was alcohol-to-oil volume ratio 55:100, 1% vol. of sulfuric acid to oil at 60˚C temperature, 30 minutes' reaction time and 800 rpm stirring speed. This condition reduces the FFA content to the lowest percentage and efficiently boosts the yield to the highest percentage.

2.3 Crude Palm Oil (CPO)

CPO is used as feedstock for biodiesel production in common. Inside CPO does consist

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of a few unwanted components that must be removed before proceed 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. Phospholipid is usually referred 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 component (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 the 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 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 particular parameter. TOP degumming is the combination of water degumming and acidic degumming with specified condition.

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.

2.4 Transesterification

For basic concept of transesterification, the process is to transform triglyceride in to methyl ester. However, there is a side product produced if FFA 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 Fig. 1. The functional groups, represented by R1, R2, and R3 are long chain fatty acid consisting of the carbon-hydrogen bonds.

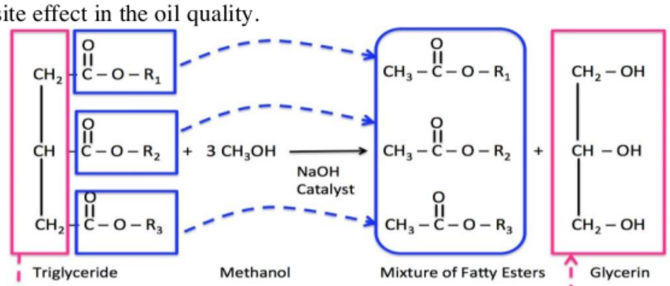

Fig. 1. Transesterification Process of Triglyceride

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2.5 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, ability to handle emulsification, methanol probably is easier and faster in dissolving the emulsified oil molecules and effectively separated 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].

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. Molar ratio of 9:1 and 12:1 gave the good result too. However, molar ratio higher than 15:1 will have the difficulty during separation process.

2.6 Catalyst

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

From the study of [8,14] 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 do not increase the rate of reaction, but increase 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.

2.7 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 element.

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 heats 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].

2.8 Separation Process

For the whole biodiesel production process, there are three times of 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.

Lastly is after washing process, this separation process is to drain out the washed water for better purity of biodiesel.

3 Methodology

Fig. 2 shows the flow chart of biodiesel production. The beginning was the pretreatment for WCO and CPO and FFA value analysis. Second part was the core process for biodiesel production. Last part was the washing and drying process and properties analysis.

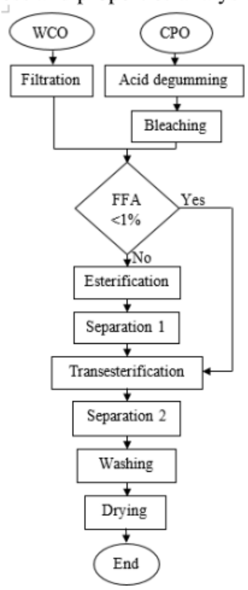

Fig. 2. Flowchart for WCO and CPO Biodiesel Production

3.1 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 selling 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 chemical. They were methanol (CH_3OH), sulfuric acid (H_2SO_4), isopropanol (C_3H_8O), bleaching earth, phosphoric acid (H_3PO_4), phenolphthalein, and sodium hydroxide (NaOH).

3.2 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.

For CPO biodiesel, the pretreatment involve were degumming and bleaching process. In 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 hold 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.

3.3 FFA Value Analysis

Titration solution was prepared by mixing 1 gram of NaOH and 1 litter 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).

$$V_t = V_o - V_f \quad (1)$$

$$FFA\% = \frac{V_t}{1.3} \quad (2)$$

Where; V_t:Total volume titrated (ml)
V_o: Initial volume (ml)
V_f: Final volume (ml)

3.4 Esterification

Both of the 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 H_2SO_4. Operated at temperature 60˚C, 30 minutes' reaction time, and 800 rpm stirring speed.

After esterification process, the catalyst was removed before proceed to transesterification. Chemical equation (3) shows the product formed between H_2SO_4 and NaOH. From the equation clearly displayed that the comparison among the

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moles of chemical was 1 mole of H_2SO_4 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 H_2SO_4 was calculated.

$$H_2SO_4+2NaOH \rightarrow Na_2SO_4+2H_2O \quad (3)$$

$$mole\ H2SO4 = \frac{massH2SO4}{98.08} \quad (4)$$

$$mole\ NaOH = 2 * mole\ H2SO4 \quad (5)$$

$$mass\ NaOH = mole\ NaOH * 40 \quad (6)$$

3.5 *Transesterification*

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, 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. From MSDS, the molecular mass for methanol is 32.04 g/mole. The weight of methanol got calculated based on the formula (7) to (9).

$$mole\ CPO = \frac{weight\ CPO}{848.24} \quad (7)$$

$$Mole\ methanol = mole\ CPO * 6 \quad (8)$$

$$Weight\ methanol = mole\ methanol * 32.04 \quad (9)$$

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

Fig. 3. Location of Condensing Chamber

3.6 *Washing and Drying Process*

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 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.

4 Results and Discussions

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

4.1 *Pretreatment for Both of the Biodiesel Production*

For the first cycle of the production, WCO was filtered using vary levels of filtering mesh from 200micron to 25micron before the production is started. Fig. 4. shows the appearance of filtered WCO. After the WCO is 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 was gone through acid degumming and bleaching process. For acid degumming process, CPO was preheated to 100^0 C and 20ml of H_3SO_4 was added into it. The process was hold 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 is done. Fig. 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 hold for 30 minutes and moderate stirring speed. After that, the mixture was filtered using 75micron filtering mesh. Fig. 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.

Fig. 4. Appearance of filtered WCO

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

Fig. 6. Appearance of the CPO after Bleaching Process

4.2 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%.

4.3 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 the glycerin and the top layer is the biodiesel. Glycerin was drained out and the remaining biodiesel was process to washing process.

4.4 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. Fig. 7 and Fig. 8 shows the appearance of both of the biodiesel for every washing cycle and the final product.

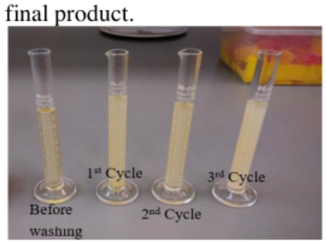

Fig. 7. Appearance of Biodiesel for Every WashingCcycle for WCO

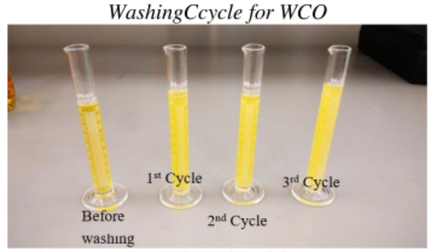

Fig. 8. Appearance of Biodiesel for Every Washing Cycle for CPO

4.5 Product Analysis

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

(i) Kinematic viscosity

For kinematic viscosity analysis, viscometer was used to test the samples as stated in ASTM D445. As the 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 in between 1.9 to 6.0 mm2/sec. Fig. 9 shows the setup for kinematic viscosity analysis.

Fig. 9. Setup for kinematic viscosity analysis

(ii) Flash Point

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 of the samples met the ASTM D93 that the minimum value is 93°C. Fig. 9 shows the Pensky-Martens (PMA 4) Machine that to analysis flash point (closed cup).

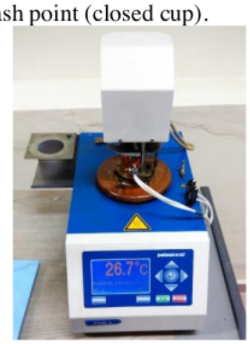

Fig. 10. Pensky-Martens (PMA 4) Machine

(iii) Moisture Content

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. Fig. 11 shows the moisture analysis was in process.

Fig. 11. Mettler Toledo Moisture Analyzer in Process

(iv) Acid Number

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. Fig. 12 shows the acid value analysis process that titrating process must be stopped when the color sample changed.

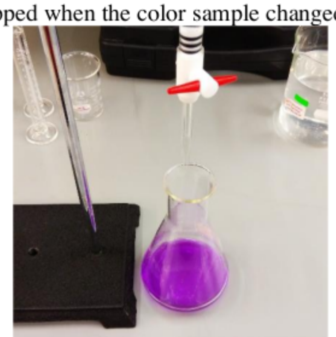

Fig. 12. Sample Color Changed During Titration

(v) Water and Sediment

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. Fig. 13 shows the setup of Karl Fischer Compact Titrators.

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Fig. 13. Karl Fischer Compact Titrator

(vi) Calorific Value

To determine the calorific value, 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. Fig. 14 shows the setup for bomb calorimeter and the status of the nichrome fuse wire after the test was done.

Fig. 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, mm^2/sec	1.9-6.0	5.40	5.10	5.10
Water and sediment, %	0.05 max.	0.008	0.036	0.055
Acid value, mg KOH/g	0.50 max.	2.383	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 [15]. In this study, the final kinematic viscosity value of the B100 has to be within the specified range. Fig. 14 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 [15].

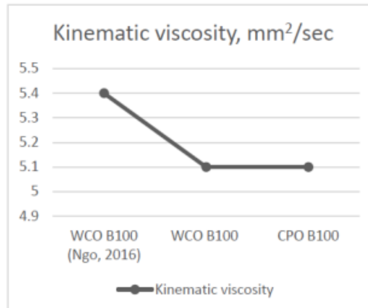

Fig. 14. Graph of kinematic viscosity

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. Fig. 15 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.

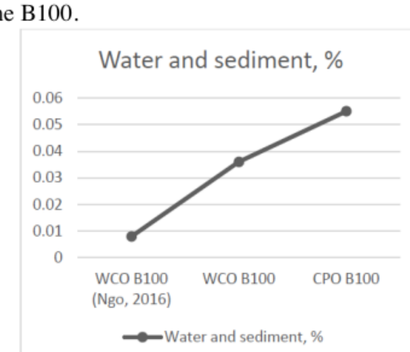

Fig. 15. Graph of Water and Sediment

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]. Fig. 16 shows the trend of the acid value in graph for this study with the previous researcher. From the result, there was a large decrement in

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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.

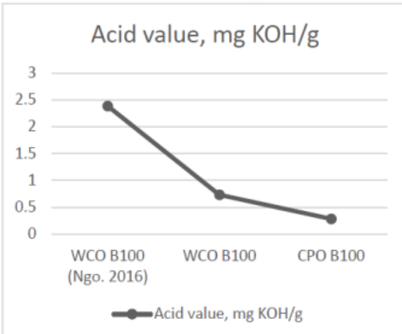

Fig. 16. Graph of acid value

Flash point indicated the minimum temperature on the surface of the flammable liquid to get ignited [16]. The ignition was due to the evaporated vapor on the surface of the volatile liquid. Fig. 17 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 researcher that had indicated the B100 produced in this study was less flammable and safer.

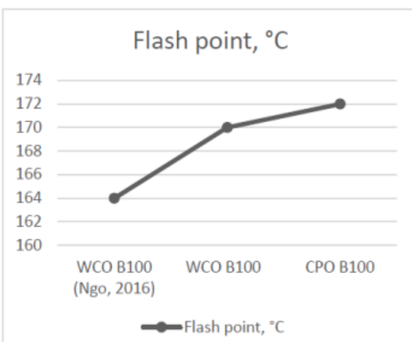

Fig. 17. Graph of flash point

The calorific value indicated the total energy produced during combustion in the engine per liter of the fuel consumed [17]. Fig. 18 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.

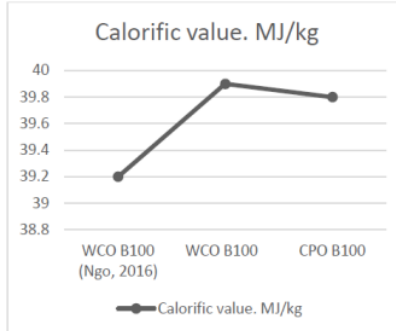

Fig. 18. Graph of Calorific Value

From Fig. 19, 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.

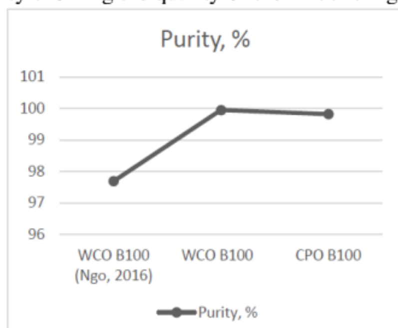

Fig. 19. Graph of Purity

5 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 met 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 H_2SO_4, 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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