A sustainability study of the processing of kitchen waste as a potential source of biofuel: Biodiesel production from waste cooking oil (WCO)

M.U.H. Suzihaque [a,b,*], Nur Syazwina [a,b], Habsah Alwi [a,b], Ummi Kalthum Ibrahim [a,b], Sureena Abdullah [c], Normah Haron [d]

[a] School of Chemical Engineering, College of Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
[b] Food Process and Engineering Research Group (FOPERG), Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
[c] Faculty of Chemical Engineering and Technology, Universiti Malaysia Pahang, 26300 Gambang, Pahang, Malaysia
[d] Department of Biotechnology Kuliyyah of Science, International Islamic University of Malaysia, 25200 Kuantan, Pahang, Malaysia

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ABSTRACT

One of the most concerned components in world's food system challenges is food waste, and it is particularly a critical issue in developed countries. Waste cooking oil (WCO) is one of the liquid food wastes that are recyclable. A proper recycling practice of WCO helps to reduce the adverse impact on environment and it can be reused by converting it into industrial products such as biodiesel and soap. With the rising in cost of crude oil in the global market and depletion of conventional fuel, the world also is in need of alternative fuel to fulfil the global rising of energy demands. This paper studies on the potential of WCO as a source of biofuel by converting it to biodiesel by transesterification process. The acid value of the WCO is determined using standard titration method, in which, if the percentage of FFA is more than 2%, in which the WCO needs to undergo pre-treatment process. Sodium hydroxide is used as a catalyst and methanol as the reacting alcohol in transesterification. The characteristics of the biodiesel produced were tested and compared with the standard specification of the biodiesel; ASTM D6751 and EN 14214. From the experiment conducted, more than 90% of biodiesel yield can be obtained from the waste cooking oil. The properties of biodiesel that undergoes more washing process, such as acid value, density, kinematic viscosity, and cloud and pour points have values typically close to the ASTM D6751 and EN 14214 biodiesel standards, which can be seen in Sample 1. Producing biodiesel from WCO is one of the alternatives of disposing these waste products as it gives beneficial impacts to the environment. Since WCO is biodegradable, economical, environmental friendly and always available, the economic feasibility of biodiesel production from waste cooking oil is viable.

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1. Introduction

Statistic obtained from Solid Waste Corporation of Malaysia (SWCorp) shows that in the year 2020, about 16,688 tonnes of food have been wasted daily in Malaysia [1]. More than 90% of food waste is biodegradable and recyclable [2]. However, the awareness on recycling and reduction of food waste are considered still below par among Malaysians. Waste cooking oil, categorized under food waste, is detrimental to human health and not environmentally friendly when it is improperly disposed to nature without undergo any treatment [3]. The management of oil and fats contribute to a notable challenge due to its non-sustainable disposal problems in which it may cause contamination and pollution to the water and land resources [4]. One of the solutions to recycle waste cooking oil is to convert it to biodiesel. Waste cooking oil is one of the potential sources for the production of biofuel, such as biodiesel. With the global crisis of the depletion in fossil fuel which is due to the increase in world energy demand, the rising in crude oil prices in the market has forced the researchers to search for alternative renewable energy sources. The dependency on these energy sources put a risk to energy security and affects economic growth,

* Corresponding author.
  E-mail address: suzihaque@uitm.edu.my (M.U.H. Suzihaque).

especially in fuel importing countries [5]. In previous research, many researchers suggested that biodiesel is the best alternative in substituting petroleum-based diesel. This is mainly because it is an oxygenated, renewable, biodegradable, economically viable and environmentally friendly [6]. Unlike petroleum-based diesel, the characteristics and properties of biodiesel aids in decreasing the emission of carbon monoxide, hydrocarbon and particulate matter in the exhaust gas [6]. The cost of producing biodiesel can be cut down when WCO is used as the feedstock since the cost of WCO contributes to approximately 70 to 95% of the total cost of biodiesel production [3]. According to researchers, biodiesel helps in reducing the emissions of global warming gas such as carbon dioxide. It has no aromatics, almost no trace of sulfur and contains only 11% oxygen by weight. The use of waste cooking oil as an alternative risk to problems of containing high content of free fatty acid (FFA) which could retard the transesterification process. Hence, esterification process or the pre-treatment process is required to reduce the high FFA content present in waste cooking oil. It would not be easy for the conversion process when the feedstock with high FFA content, which is normally above 1%, is used [7]. It was suggested that the feedstock with high FFA content of more than 2% will have some difficulties when it is later converted by alkali transesterification [8]. The high FFA content tends to cause the formation of soap when it reacts with catalyst. Similarly, to the acid pretreatment steps, acid-catalyzed transesterification is where the reaction of a triglyceride (fat and oil) and an alcohol takes place in the presence of acid catalyst. The alkali-catalyzed transesterification is the process where triglyceride (fat and oil) is reacted with an alcohol in the presence of an alkaline catalyst such as alkaline metal alkoxides and hydroxides. The most common alkaline hydroxide used in this process is sodium hydroxide and potassium hydroxide to form esters that is biodiesel and glycerol. The advantage of this process is that it is able to react fast than the acid-catalyzed reaction. The alkaline catalysts are less corrosive than the acidic compounds. Hence, industrial processes favor this process than acid-catalyzed transesterification. However, the presence of water and high amount of free acid contributes to the increase in the reaction of saponification of oil and therefore, resulting in an incomplete reaction during the alkaline transesterification process due to the formation of emulsion and having difficulties in separating the glycerol. Researchers usually recommended using 6:1 methanol to oil ratio at the temperature of 65 °C with the reaction time of about 0.5 to 1 h for optimum yields [8]. Some researchers suggested that 1 %w/v of potassium hydroxide will be dissolved in 20% of methanol to oil volume ratio and the mixture will be heated at 60 °C [9]. If the FFA content in the oil is high, it will undergo a titration to determine the extra amount of alkali hydroxide needed to neutralize the FFA.

2. Methodology

The processes involved in this experiment are titration, esterification (if required), transesterification, washing and data analysis of biodiesel. The chemicals involved are sulfuric acid, methanol, phenolphthalein, sodium hydroxide, isopropyl alcohol, including waste cooking oil. Fig. 1 shows the process flowchart of the production of biodiesel from WCO.

2.1. Sample collection

A sample of waste cooking oil was collected from Dapur Sarawak restaurant located at Seksyen 7 Shah Alam. The waste cooking oil was used to cook various types of food and dishes, such as fried rice, noodles and other types of dishes. The suspended solids or the food residues in the waste cooking oil was filtered using filter cloth
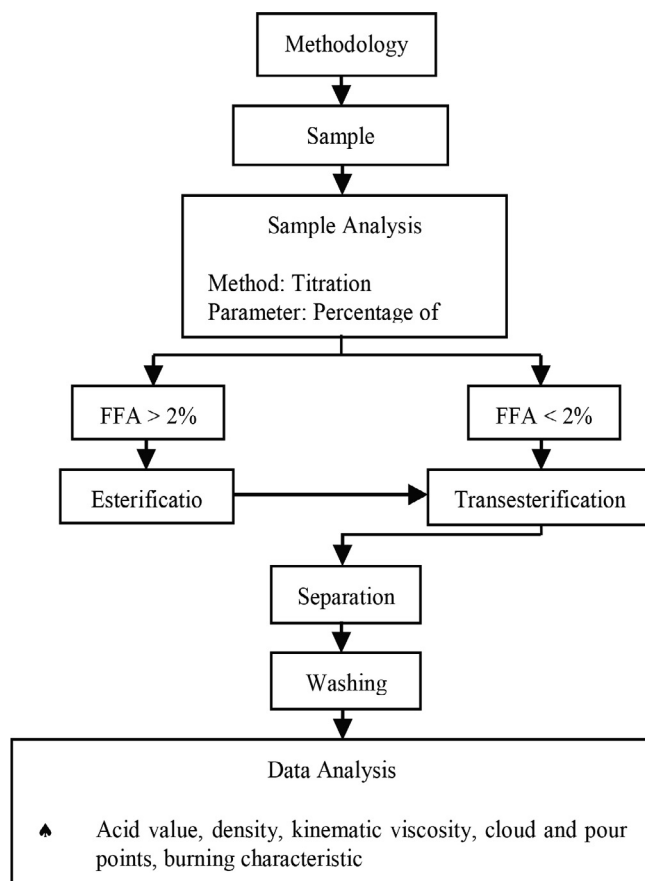

Fig. 1. Process flowchart of the production of biodiesel from waste cooking oil (WCO).

before it was used for experiment in the production of biodiesel. The processes involved in this experiment are titration, esterification (if required), transesterification, washing and data analysis of biodiesel. The chemicals involved are sulfuric acid, methanol, phenolphthalein, sodium hydroxide, isopropyl alcohol, including waste cooking oil. Fig. 1 shows the process flowchart of the production of biodiesel from WCO.A sample of waste cooking oil was collected from Dapur Sarawak restaurant located at Seksyen 7 Shah Alam.

2.2. Sample analysis

The waste cooking oil sample was analysed using standard titration method to determine the characteristics of the oil before it can be used for biodiesel production. The titration method was conducted to; (i) determined the acid value and the percentage of FFA in the oil by using KOH, and (ii) to determine the amount of NaOH catalyst required in the transesterification process. As shown in the flowchart in Fig. 1, the experiment does not need to undergo esterification and can directly proceed to the transesterification process if the percentage of FFA is less than 2% [3]. With a percentage of FFA more than 2%, the waste oil needs to undergo the pre-treatment process, esterification, to reduce the FFA content in the waste oil to avoid the formation of soap during transesterification process. 10 ml of Isopropyl alcohol and phenolphthalein were used as the solvent and indicator respectively, mixed in 1 g of oil sample. The solution was titrated with KOH solution. The acid value and percentage of FFA can be calculated by using the equation below. Meanwhile, the amount of NaOH required is based

on the volume (ml) of NaOH used to titrate 1 ml of oil, added with 3.5 g/L basic amount of NaOH required.

$$Acid\ value\left(\frac{mgKOH}{g}\right) = \frac{MW_{KOH} \times C_{KOH} \times V_{KOH}}{m_{oil}}$$

$$FFA(\%) \approx \frac{Acid\ Value}{2}$$

2.3. Transesterification

The transesterification process can be carried out directly if the FFA content is less than 2% or after the oil has been esterified for pre-treatment. This process is also known as alkali (base) transesterification. This process usually involves the use of methanol as an alcohol and sodium hydroxide as a catalyst. The oil sample with low percentage of FFA is heated to 60 °C. The amount of catalyst sodium hydroxide (NaOH) that has been predetermined from the titration is dissolved in the required amount of methanol in a beaker and stirred for 30 min until the particles of NaOH cannot be seen. The amount of catalyst NaOH required to neutralize the FFA is determined from the titration method based on 1 ml of oil. The value obtained will then be added with the basic amount of NaOH required for the transesterification process using new vegetable oil which is 3.5 g per L of oil [10]. The amount of methanol is based on the ratio of methanol to oil which is 6:1 [7]. The mixture of catalyst NaOH and methanol will form a methoxide solution which is then ready to be added into the pretreated oil. The reaction is conducted for 2 h.

2.4. Separation

The resulting product from the transesterification process was transferred into a separatory funnel and left settled for 24 h at room temperature to separate the glycerin (bottom layer) and the biodiesel (top layer). These two layer fractions were collected in two separate conical flasks.

2.5. Washing

The washing process was carried out to remove the impurities present in biodiesel. After the biodiesel was separated from the glycerol, it was then washed with an adequate amount of distilled water to remove residual catalysts and traces of soaps. The obtained biodiesel from Experiment 2 (named Sample 1) was washed five times, from Experiment 3 (named Sample 2) was washed three times, and biodiesel from Experiment 4 (named Sample 3) did not undergo any washing process.

2.6. Data analysis

The physical properties of the biodiesel are analyzed to determine the standard of biodiesel. Some of the properties analyzed are acid value, density, burning characteristic, kinematic viscosity, and cloud and pour points. The acid value was determined by using the standard titration method. The equipment used in determining the physical properties viscometer for kinematic viscosity, and cloud and pour points equipment. Each of the samples were then tested and analyzed to compare its properties with standard specification of biodiesel, American Society for Testing and Material (ASTM standard - D6751) and European Committee for Standardization (EN 14214) [11].

3. Results and discussion

3.1. Titration of oil sample by using KOH

In the first trial of mixing the oil with isopropyl alcohol, small beads of foam was seen in the mixture which indicates that the oil has solidified and the mixture was not properly mixed. The titrant KOH was added into the mixture drop by drop until the solution had turned light pink. This means that enough alkali has been added into the solution to neutralize the fatty acids in the oil. Table 1 shows the data obtained for the characteristic of waste cooking oil sample. From the calculation using the average weight of oil and average volume of KOH used, the reading for the acid value and percentage of FFA of the WCO are 3.014 mgKOH/g and 1.51% respectively. This value determines that the WCO does not need to undergo acid pretreatment or esterification process since the percentage of FFA of the WCO is less than 2% [3].

3.2. Titration of oil sample by using NaOH

From the titration, the average titrate value based on five samples were determined to be 1.5 ml of NaOH. This value was then converted in terms of weight, in which, 0.0015 g of NaOH is require for every 1 ml of oil sample. Hence, for a sample of 200 ml of oil to be used for transesterification, 0.3 g of NaOH plus 0.7 g of basic amount of NaOH will be used as the catalyst.

3.3. Transesterification

The transesterification process was carried out directly without the pretreatment process since the percentage of FFA is less than 2% [3]. The amount of catalyst added into the oil was very crucial for this process. The excessive addition of the amount of catalyst will cause the formation of soap and thus, resulting in no production of biodiesel. The basic amount of NaOH required for a sample of 1 Litre of oil is 3.5 g [10]. The experiment was repeated 3 more times with another batch of oil. After 1 h of reaction at 60 °C, the solution was transferred into a separatory funnel to allow separation. Table 2 shows the summary of results obtained in four experiments of transesterification.

3.4. Separation

After several minutes, two distinct layers slowly can be observed in the separatory funnel. The layers formed comprised of glycerol, the by-product which settled at the bottom of the funnel, and biodiesel (FAME), Biodiesel is less dense than the glycerol, hence, it settled as the top layer of the solution. The solution was left settled for 24 h to allow a complete settling before the glycerol was drained out. Fig. 2 shows the two layers that were left settled in the separatory funnels.

3.5. Washing

The obtained biodiesel from Experiment 2 (named Sample 1) was washed five times, from Experiment 3 (named Sample 2) was washed three times, and biodiesel from Experiment 4 (named Sample 3) did not undergo any washing process. This process helped to remove impurities and traces of soap in the biodiesel product to obtain a more translucent and much purer biodiesel. After adding an equal amount of water into Sample 1 and Sample 2, the samples were then transferred into a separatory funnel and left to settle for 24 h as shown in Fig. 3. As seen in Fig. 3, water settled at the bottom of the funnel and biodiesel settled as the top layer because it is less dense than water. During the first wash,

Table 1
The acid value and FFA content of waste cooking oil sample obtained from the titration method.

Titration	1	2	3	4	5	Avg.
Oil sample (g)	1.003	1.001	1.007	1.005	1.006	1.005
Volume of KOH used (ml)	0.60	0.60	0.50	0.50	0.50	0.54
Acid Value (mgKOH/g)	3.014					
FFA content (%)	1.51					

Table 2
Summary of results obtained in four experiments of transesterification.

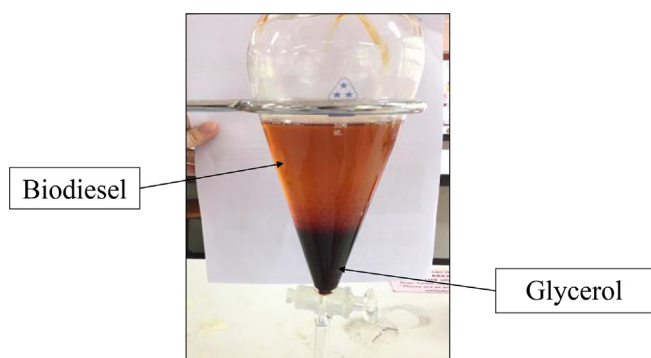| Experiment	1	2	3	4
Volume of oil (basis) (ml)	200	200	200	400
Weight of oil (g)	184.03	176.74	186.02	373.93
Weight of biodiesel (g)	failed	161.63	173.68	344.54
Percent yield (%)	failed	91.45	93.37	92.14

Fig. 2. Two distinct layers of biodiesel and glycerol.
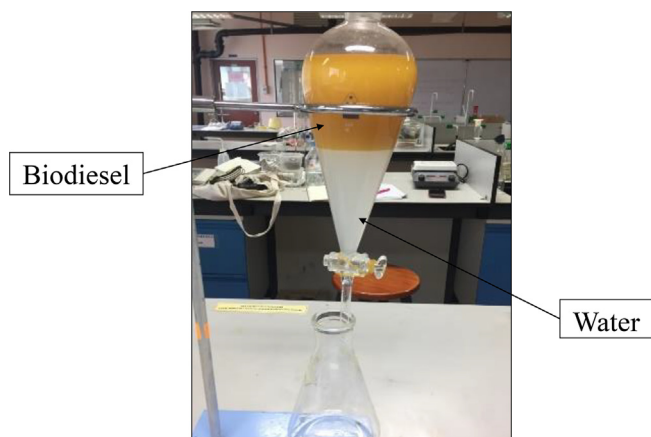

Fig. 3. The separation process of biodiesel and distilled water for Sample 1 (biodiesel sample that is washed 5 times).

the water used to wash the biodiesel was cloudy. This shows that the impurities in the biodiesel had been extracted and removed by water. The impurities in the biodiesel binds with the water as the water trickled down the biodiesel. However, the cloudy appearance of the water that settled at the bottom of the funnel shows that the biodiesel requires another round of washing process.

Each of these samples were then tested and analyzed to compare its properties with standard specification of biodiesel, American Society for Testing and Material (ASTM standard - D6751) and European Committee for Standardization (EN 14214).

3.6. Data analysis

Each of these samples were then tested and analyzed to compare its properties with standard specification of biodiesel, American Society for Testing and Material (ASTM standard - D6751) and European Committee for Standardization (EN 14214).

(a) Acid value

Initially, the average acid value of waste cooking oil was 3.01mgKOH/g as determined from titration earlier. After undergoing the transesterification and washing process (purification), the acid value in each sample of the product obtained has decreased. As seen in Fig. 4, the graph shows that the acid value will be much lower as it is washed more with distilled water. Among all three samples, Sample 1 has the closest value to the standard value of biodiesel, ASTM D 6751 and EN 14214, which is 0.50mgKOH/g maximum. The great concern on the acid number present in biodiesel is the possibility that the fatty acid may cause corrosion and deposits in the fuel injectors by catalyzing polymerization in hot recycling fuel loops.

(b) Density

Density is one of the important parameters that should be focused on as it plays an important role in the fuel quality. The density of biodiesel was measured by dividing mass of each sample by its volume which is fixed at 20 ml. As shown in Table 3, Sample 1 has a density of 0.834 g/cm^3, which is lower than Sample 2 and Sample 3. This could be because of the impurities and contaminants that are still left in biodiesel that was not washed enough
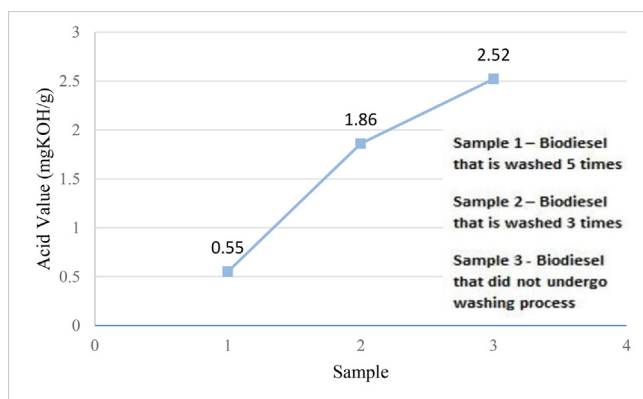

Fig. 4. The influence of washing process on the acid value in biodiesel.

Table 3
The density of biodiesel in each sample.

Sample	1	2	3
Density (g/cm³)	0.834	0.862	0.918

(Sample 2) and does not undergo washing process (Sample 3). The density of biodiesel in Sample 1 and Sample 2 were both within the limit of standard value of density specified in ASTM D6751 and EN 14214 which is between 0.82 and 0.90 g/cm³ [12]. Biodiesel with high density has a significant impact on fuel pumps performance, fuel filters and air–fuel mixing behavior of compression ignition (CI) engine [13]. Injection systems, pumps and injectors must ensure the amount of fuel is accurately adjusted to ensure proper combustion, which is influenced by the density of biodiesel.

(c) Kinematic viscosity

Kinematic viscosity is a measure of resistance to flow of a liquid, in which high viscous materials flow with great difficulty, while less viscous ones flow easily. This is due to internal friction of one part of a fluid moving over another. The kinematic viscosity of biodiesel can only be read at a constant temperature of 30 °C when using the viscometer in the laboratory. Graph in Fig. 5 shows the kinematic viscosity of biodiesel in Sample 1, Sample 2 and Sample 3 obtained, which are 8.21, 8.40 and 9.13 mm²/s respectively. All respective readings obtained exceeded the standard specification of kinematic viscosity for biodiesel based on ASTM D6751 and EN 14,214 which are 1.9–6.0 mm²/s and 3.5–5.0 mm²/s respectively, both read at 40 °C. The temperature affects the kinematic viscosity value, in which the kinematic viscosity of the biodiesel decreases with increase in temperature. Both high and low viscosity of biodiesel has negative impacts on the engine's performance. High viscosity may cause damage in pump and filter clogging, poor combustion and increase in emissions. It also causes operational problems due to poor atomization of the fuel in the engine's combustion chambers. The formation of large droplets on the injection is also caused by high viscosities which in turn results in poor combustion, raised in exhaust smoke and emissions. However, viscosity that is too low can cause excessive wear to some injection pumps due to insufficient lubrication for the precision fit of fuel injection pumps, and power loss that is caused by leakage of pump or injector [14]. A research done by some researchers suggested that one way to improve the kinematic viscosity value is by increasing the biodiesel volume fraction in biodiesel-diesel blends [15].

(d) Cloud and Pour Points

The fluidity at low temperature describes the cold flow properties of biodiesel. These properties can be determined through cloud
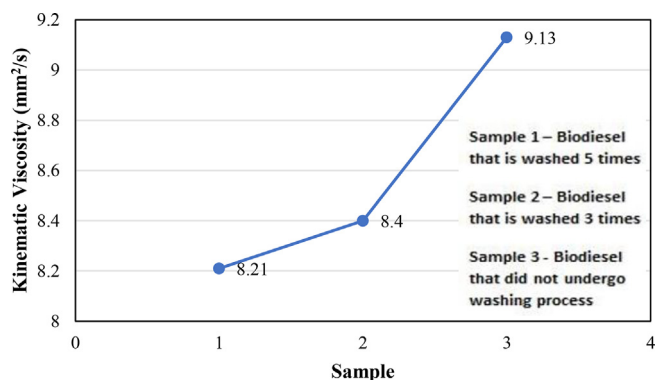
point and pour point using Cloud and Pour Point equipment. As seen from Table 4, the biodiesel starts to cloud at 17 °C and gel at 8 °C. For Sample 2, the cloud point and pour point of biodiesel were obtained at 15 °C and 10 °C respectively. Meanwhile for Sample 3, the biodiesel first turned cloudy at 14 °C and completely solidified at 11 °C. These values compare well with pure biodiesel as the reading of cloud point and pour point obtained by [16] are at 12.8 °C and 0 °C respectively; though there are no limits specified in both ASTM D6751 and EN 14214 standards. The lower the cloud point, the lower the temperature at which the biodiesel is operable, hence, the higher the quality of biodiesel. Fig. 6 show the cloud formed at cloud point and the biodiesel become completely solidified at pour point respectively for Sample 1.

The cold flow properties are very important as it helps to determine the performance of fuel flow system. Operating a diesel engine especially in cold weather countries with a low temperature is difficult due to high viscosity of fuel. The solidified particles of biodiesel will clog the fuel filter [16]. For biodiesel, the cloud point temperature is one of the important parameters because biodiesel is always blended with petroleum diesel, hence; the cloud point of biodiesel gives a significant impact on the final blend properties [17]. High cloud point temperature may be caused by contaminants such as unreacted feedstock, monoglyceride and diglyceride intermediates, and residual free glycerol in biodiesel fuel.

(e) Burning characteristic

The burning characteristic of biodiesel is tested using the oil lamp by the observing the duration of flame when biodiesel is used as the burning source. The biodiesel is then compared with the burning performance of petrodiesel. 20 ml of each sample of biodiesel and petrodiesel were filled in the oil lamp cup, and the wicks of each cup were lit. From the test conducted, the flame from biodiesel of Sample 1 burned longer than other samples. The duration of burning for each sample are tabulated in Table 5. Biodiesel in Sample 1 burns more efficient than Biodiesel in Sample 2 and Sample 3. This shows the importance of washing process for raw biodiesel

Table 4
The cloud point and pour point for all samples of biodiesel.

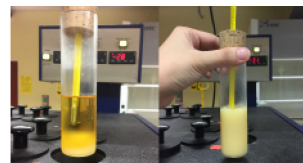| Sample	Cloud point (°C)	Pour point (°C)
1	17	8
2	15	10
3	14	11

Fig. 6. The cloud formed in the biodiesel at cloud point of 17 °C and solidified biodiesel at pour point of 8 °C.

Table 5
The burning duration of fuel source.

Source	Burning duration (min)
Biodiesel Sample 1	24
Biodiesel Sample 2	16
Biodiesel Sample 3	10
Petrodiesel	36

Fig. 5. Kinematic viscosity of biodiesel in Sample 1, Sample 2 and Sample 3 at 30 °C.

product in order to remove the impurities and thus, improve its characteristic and quality. Biodiesel that did not undergo any washing process has a very low quality which affects its performance as a biofuel. Petrodiesel, a commercial fuel, has the longest burning duration as compared to biodiesel from Sample 1, Sample 2 and Sample 3. The burning characteristic or performance of biodiesel is normally measured by flash point or cetane number. The lowest temperature at which the fuel gives off sufficient flammable vapors in mixture with air and easily ignited is defined as flash point [18]. Meanwhile, cetane number is often used to determine the diesel fuel quality, in which it measures the readiness of the fuel to ignite automatically when it is injected into the engine [19].

4. Conclusion

High FFA content in feedstock, such as waste cooking oil, will result in low yield of biodiesel and interfere with the transesterification process. Meanwhile, low FFA content in the feedstock limits the catalyst depletion and difficulties during separation which is due to saponification reaction (producing soap). The excessive amount of catalyst used in the transesterification will cause formation of soap and hinder the completion on the formation of biodiesel, hence yielding low percentage of biodiesel. The quality of the feedstock also influences the properties of biodiesel in which its quality should fall within the limits specified in American Society for Testing and Material (ASTM standard - D6751) and European Committee for Standardization (EN 14214). The biodiesel shows a better performance as a fuel when it is blend with petro-diesel. As previous research indicate that all fuels have similar behavior, but the quality depends on the blend ratio of biodiesel and diesel [12,20]. Typically, biodiesel is blended with 20% biodiesel and 80% petroleum diesel, namely B20, which is used in most conventional. WCO is a more sustainable way of disposing these waste products as it gives beneficial impacts to the environment. The economic feasibility of biodiesel production from waste cooking oil is viable, since WCO is biodegradable, economical feedstock, environmental friendly and always available.

Declaration of Competing Interest

Acknowledgements

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