SOYBEAN AND WASTE COOKING OIL FEEDSTOCKS FOR SUSTAINABLE BIOFUEL PRODUCTION

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ABSTRACT

Gas release from transportation activity raises concerns about pollution. Sustainable fuels from biomass sources can be converted to alternative fuels to generate electricity in the future. It is actively investigated with concern about the environmental effects of using conventional fuels from the reservoir of fossil fuels. Hence, to counter these consequences, sustainable biofuels (SF) are investigated as it is considered a renewable fuel source. Thus, this study aims to establish an experimental procedure to determine the suitability of biomass sources by using soybean and waste cooking oil as the feedstock. Sustainable biofuel is produced by using feedstock from different biomass, particularly from soybean oil, a first-generation edible feedstock and waste cooking oil, a second-generation non-edible feedstock. The transesterification method is used to produce sustainable biofuel by varying the Potassium Hydroxide, and KOH catalysts loading of 0.75%, 1%, and 1.5% by weight. The fatty acid methyl ester (FAME) yield from both feedstocks is shown different for the thermochemical properties such as density, kinematic viscosity, calorific value, and acid value are investigated. The results show that by using 0.75% of KOH loading weight, sustainable biofuel produces the most fuel for both feedstocks compared to the 1%, and 1.5% KOH loading weight. The density of biofuel for both feedstocks is between 0.87 g/cm^3 and 0.88 g/cm^3. The kinematic viscosity of the biofuel obtained is 5.34 mm^2/s and 4.47 mm^2/s for waste cooking oil (WCO) biofuel and soybean oil (SO) biofuel respectively. The average acid value of WCO biofuel and SO biofuel is 0.2806 mg KOH/g and 0.1871 mg KOH/g respectively. Biofuel has a gross calorific value of 39918 J/g for WCO biofuel and 40040 J/g for SO biofuel. As a result, the different loading weight of the catalyst used is a major controlling factor in the yield of biofuel. It is also noted that the first-generation edible feedstock of soybean oil produces greater quality biofuel. Nevertheless, first-generation feedstock still poses a food competition threat in comparison to second-generation feedstock. Therefore, establishment of the second-generation feedstock from waste cooking oil produces biofuel that is close to the quality of soybean oil is good for the future. Therefore, the former is a more preferred feedstock compared to soybean oil.

Keywords: *Feedstock; Soybean; Sustainable fuel; Transesterification; Waste Cooking Oil*

1.0 INTRODUCTION

The aviation industry is a growing industry both from an engineering standpoint and an economic standpoint. One of the most important discussions in the aviation industry is the energy source or fuel of the aircraft. With rising concern for the environment, engineers and researchers are trying to obtain a more renewable and green fuel [1]. This leads to the study of biomass fuel or biofuel. It is a well-known fact that the International Air Transport Association listed that it aims to reduce carbon dioxide emissions by 50% approaching 2050 [1]. Despite the effort, a review shows that before the COVID-19 pandemic, the annual fuel consumption in the aviation industry was roughly 343 billion litres but only 0.0015 billion litres are considered green fuel [2]. This means that less than 1% of the entire fuel used is from renewable fuel.

Sustainability has become a much-debated topic in recent years, this is due to the growing concerns about the environment such as global warming, CO_2 emission, and overfishing [3]. Therefore, the United Nations has adopted goals to counter this rising concern with seventeen (17) Sustainable Development Goals (SDGs). Among those goals, this study aims to tackle goal number 7 which is affordable and clean energy, 12 for responsible consumption and production and 13 for climate action. However, it will be advisable to first understand what sustainability is, a peer review summarized sustainability into three categories [4]. Those are operational sustainability, which explains that sustainability happens when more positive impact occurs than negative impact; the second one is stakeholder sustainability, which is a social sustainability affected by the decisions of stakeholder, and lastly, transformation sustainability, which promotes the idea of changing the human mindset to make improvements [4]. From this point of view, assessing sustainability is a large topic, and trying to tackle all the stated contributions will be impossible. Therefore, instead the Life Cycle Thinking (LCT) theory will be adopted. LCT evaluates the cumulative impacts of a certain operation, from obtaining the raw material to the end user and finally the discard [5]. This life cycle will be repeated, the question lies in whether it is possible to fully utilize the operation life cycle.

Nevertheless, it is still important to try to develop a greener and more sustainable fuel for aircraft. A review by the Department of Mechanical Engineering of the University of Malaya has shown the pathway to achieving biofuel, some examples include hydrogenation, hydro-processing, gasification, Fischer-Tropsch method, transesterification, and pyrolysis [6]. With such a wide range of methods to achieve biomass fuel, some manufacturing companies would prefer one method over the other. This may be due to economic factors such as the catalyst price, hydrogen production cost and plant size [6]. One of the aviation industry's most important discussions in the aviation industry is the energy source or fuel of the aircraft. With many different types of aircraft such as the Diamond DA42 being diesel powered, and other aircraft running on jet fuels which are normally fossil fuels raise concerns for the environment, engineers and researchers are trying to obtain a more renewable and green fuel. This leads to the study of biomass fuel [7-8]. To produce biomass fuel, there are many methods that the industry deployed, transesterification and pyrolysis, is perhaps the two most well-known method [9]. The method is not the one with many options, feedstocks such as animal waste, vegetable oil, and algae have been studied [7]. In this research, the focus is on homogeneous base catalyst transesterification, due to its more economical in comparison to pyrolysis [9]. Therefore, this research aims to establish a preferred method to produce biofuel with good fuel characteristics by selecting a suitable process and preferred feedstock. All these objectives can help us understand the complexity of biofuel study while helping to establish some extra data for the community on the suitability and sustainability of biofuel for aviation purposes.

Based on the interest exploration and suitability of the feedstocks, those feedstocks that can be converted into biofuel have been categorized into four major generations. The first generation is produced from raw materials competing with the food and feed industry, while the fourth generation is derived based on high solar efficiency cultivation [7]. Currently, the third and fourth-generation feedstock are still in the developing stage as of the writing of this report. In this project, the focus will be on first-generation and second-generation feedstock, some feedstocks that are worth investigating include corn, coconut, waste cooking oil, waste diesel, soybean oil, and palm oil. Most of these feedstocks are considered abundant in Malaysia and can be easily sourced. Critically, the biggest question in the aviation industry is the sustainability of fuel. Sustainability includes all the topics discussed above (production, feedstock, environmental effects, economic effect) and how to maximize each process fully. Nevertheless, it is important to first understand the method and feedstock for producing biofuel to help gain a deeper understanding of the rest of the topic. The Malaysia National Biofuel Policy (NBP) [10] has made it mandatory that 5% of palm-based biodiesel needs to blend with conventional diesel. Research has shown that the usage of palm oil to produce biodiesel is noteworthy as it has good yield and is eco-friendly, causing a 38% reduction in CO_2 emission. Aside from that, the palm oil industry in Malaysia is considered one of the country's proudest industries, and with the increase in awareness for biofuel, the government has provided a RM 1.09 ($0.28/L) subsidy for the production of biodiesel [8]. This stimulates the motivation to explore alternative fuels for transportation including in the aviation industry.

To obtain biomass, high waste or estate is required. This could lead to over-farming and major deforestation. The method to derive biomass fuel has evolved into many methods, however, not all methods are considered equal in terms of yield or quality. For example, the pyrolysis process can be either slow pyrolysis or fast pyrolysis, the slow pyrolysis yields mostly solid biofuel, in the form of bio tar, while the fast pyrolysis will yield more bio-oil. Another example of the unpredictability of the feedstock is that high-energy crops like palm and coconut usually yield a higher amount of biofuel while waste cooking oil usually yields a much lower content of biomass fuel. The feedstock plays a significant role in determining the fuel density of the biofuel. The problem lies in that most of the feedstock yields a non-ideal percentage to be a sustainable source. The methods and procedures are also sensitive to the different feedstock, further complicating the result. Therefore, finding the most suitable method to convert biomass into alternative fuel and the perfect candidate feedstock is crucial [12].

In this current development, biofuel is preferred as the suitable method to convert biomass from soybean and waste cooking oil into biofuel. In the transesterification process, the main concern arises from the choice of catalysts used. Depending on the application and targeted usage, different catalysts may be deployed. This proved to be a problem, as there is no set of perfect catalysts to produce good quality and quantity biomass fuel through transesterification. This is a problem, as the fast processes may produce a good quality of biofuel but do not yield a satisfying amount of biofuel, while the slower process may produce a good quantity but will also produce many contaminants. Hence, it is important to establish an optimized process of transesterification in the production of biofuel.

2.0 METHODOLOGY

The study starts with the selection of feedstock such as soybean oil and waste cooking oil. After that, the feedstock needs to be prepared for a suitable quality to produce biofuel. During the production of biofuel, the parameter used for the investigation of the effect of biofuel production is KOH concentrations. The transesterification method was used to convert the feedstock to a suitable quality of biofuel. After the production of biofuel, the properties of the new fuel such as density, caloric value, kinematic viscosity, and acid value are determined.

2.1 Material Preparation

This section aims to highlight the material preparation needed to kickstart the experiment. The soybean oil and waste cooking oil (WCO) feedstock are available in the combustion laboratory. Figure 1 shows the filtration process for WCO feedstock. The purpose of filtering the WCO is to filter the oil precipitate to make sure the WCO yield after the filtration can be used properly and produce good biofuel oil. In general, the WCO is poured through a filter to remove large particles, the mixture is then heated at a temperature of 100˚C for one hour, being consistently stirred by a magnetic stirrer to ensure even stirring. Once the WCO is less viscous, it is considered a ready feedstock to be used to produce biofuel. The clean and refined oil will then be allowed to cool down to room temperature. The same process of filtration was repeated using Soybean oil.

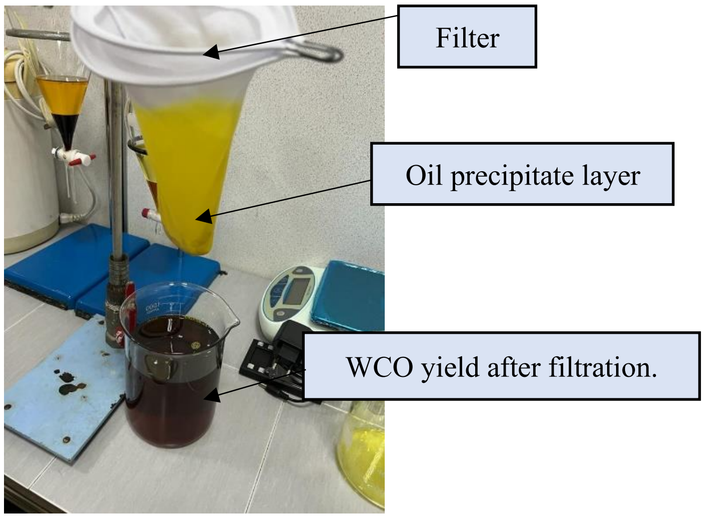
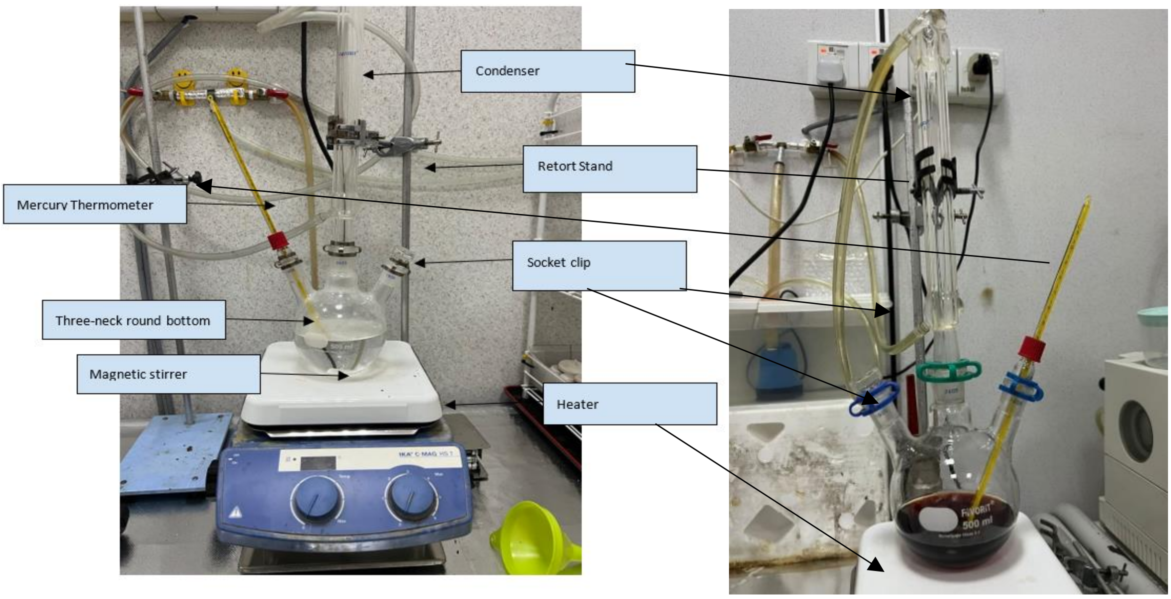


Figure 1. Waste cooking oil filtering process.

2.2 Experiment Set Up

This section aims to highlight the experiment process to produce the biofuel obtained from WCO and soybean oil as feedstock as shown in Figure 2. The experiment will be set up by using the homogeneous base catalyst transesterification method. The experiment uses KOH as the catalyst, and methanol as the main solvent. Soybean oil an edible source, and WCO an inedible source, are selected as the feedstock for the production experiment.



(a) Soybean (b) WCO

Figure 2. Transesterification process set up.

The loading weight of catalyst, KOH is changed from 0.75% to 1% and 1.50% to help in investigating the ideal percentage of catalyst on the yield and qualities of biofuel. A total of 18 samples are collected, nine samples for soybean oil and nine for WCO to help identify the best batch and ideal method to produce biofuel. The transesterification process will be conducted at 60°C for 120 minutes and a distillation process takes about 24 hours after production to yield clean biofuel. Figure 2 shows the full experimental set-up to produce the biofuel oil using soybean oil (Figure 2(a)) and WCO (Figure 2(b)). This process is repeated for the soybean oil. The apparatus was used such as a three-neck round bottom flask, 500 ml measuring cylinder, 1000 ml beaker, 110°C mercury glass thermometer, 50 mm cylindrical magnetic stirrer socket slip and glass socket. The final product of the transesterification experiment is shown in Figure 3, the value of the yield can be calculated using the following Equation (1).

$$Yield(\%) = \frac{M_{afterproduction}}{M_{pureoil}} \times 100 \quad (1)$$

Where
$M_{afterproduction}$ = Mass of the clean fuel (g)
$M_{pureoil}$ = Mass of the feedstock before being processed (g)

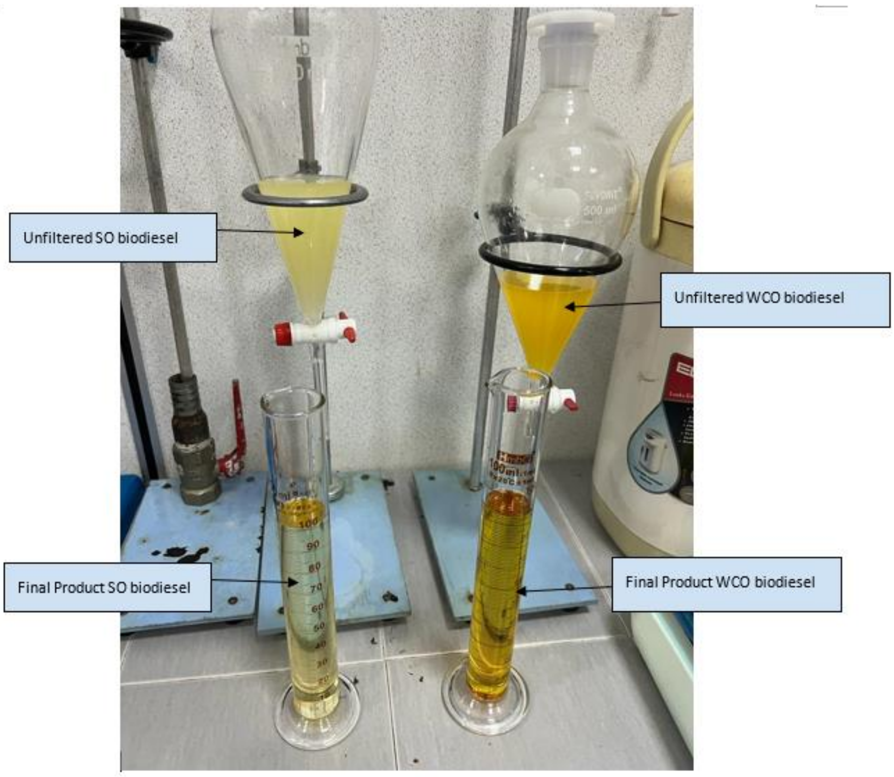


Figure 3. The final product of biodiesel of Soybean Oil (left) and Waste Cooking Oil (right).

The yield is sustainable fuel from WCO and soybean are characterized to determine the properties of density, kinematic viscosity, calorific value and acid value. The density value of the yield can be calculated using the following Equation (2) and Equation (3).

$$Volume\ calibrated = \frac{M_{water} - M_{air}}{\rho_{water} - \rho_{air}} \quad (2)$$

$$Density = \frac{M_{biofuel} - M_{air}}{V_{calibrated}} + \rho_{air} \quad (3)$$

Where:
$M_{biofuel}$ = mass of sustainable fuel
M_{air} = mass of empty pycnometer
$V_{calibrated}$ = calibrated volume
ρ_{air} = density of air at the point of measurement

Figure 4 shows the measurement equipment to measure the biofuel mass using a pycnometer. The apparatus used such as weight scale and a 100 ml beaker.

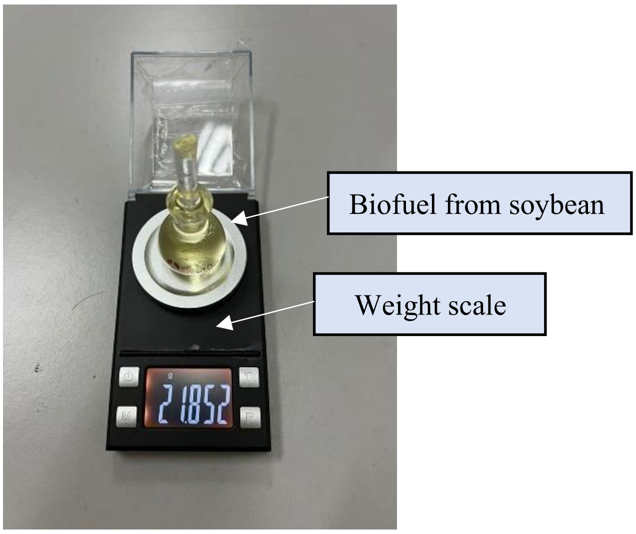


Figure 4. Biofuel from soybean oil is measured using a pycnometer.

Another thermochemical property to be determined is the kinematic viscosity. Both the final product of the WCO and the soybean sample need to be sent to the Faculty of Chemical Engineering for specific equipment. The equipment uses the fuel flow machine to calculate the viscosity and the result needs to be comparable and achieve close to the ASTM D445-94 standards procedure. The value of kinematic viscosity can be calculated based on Equation (4) where 0.01303 is the capillary tube constant from the equipment.

$$Kinematics\ Viscosity(cSt) = 0.01303 \times Flow\ Duration \quad (4)$$

The value of energy for the sustainable fuel yield can be calculated using Equation (5). In this study, the IKA C2000 bomb calorimeter was also used to determine the calorific value as shown in Figure 5.

$$E(J) = M_2 c \Delta T \quad (5)$$

Where

M_2 = weight of the fuel sample (g)
c = specific heat capacity of oil ($Jg^{-1}K^{-1}$)
ΔT = temperature different in process (K)

Figure 5. The IKA C2000 Bomb calorimeter.

The acid value can be calculated using Equation (6) and the properties measurement shown in Figure 6. During the measurement, a 100 ml beaker with a 30 mm magnetic stirrer is filled with 50 ml of ethanol in a measuring cylinder.

$$Acid\ value(AV) = \frac{(V_o - V_i) \times N \times 56.1}{W_{oil}} \quad (6)$$

Where

V_o = initial burette reading before titration (ml)

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V_i = final burette reading after titration (ml)
N = KOH solution concentration for 0.1 mol = 56.1 of molecular weight
W_{oil} = weight of sustainable fuel (1g)

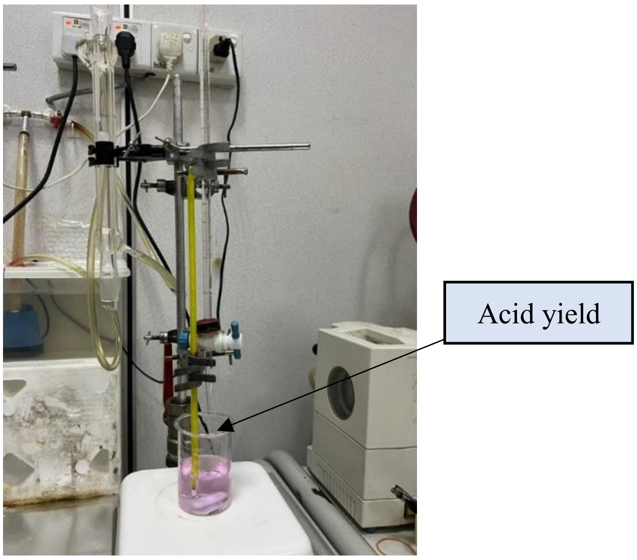

Figure 6. Acid value experiment set up.

Next, gas chromatography was used to determine the fatty acid methyl ester (FAME) contents of the product. The GC–MS chromatogram of sustainable fuel shows the type and percentage of fatty acid methyl esters (FAME) present in sustainable fuel, the capillary column used is of BP5MS with dimensions 30 m in length, 25 mm internal diameter, and 0.25 µm film thickness.

3.0 RESULTS AND DISCUSSION

The results for WCO biofuel yield can be summarized in Table 1 for 9 samples and maximum temperature reached between 63°C and 95°C for three different KOH catalyst loading of 0.75%, 1% and 1.5%, while the yield for SO biofuel can be summarized in Table 2 also for 9 samples and maximum temperature reached is between 62°C and 75°C for same loading of KOH. The average yield for WCO biofuel is 90.92% while for SO biodiesel is 94.44%, both producing a yield of more than 90% which is good. There is a clear difference between the biofuel before it goes through the filtration process and after the filtration process. The colour of WCO biofuel is much more yellowish than SO biofuel, which is no surprise as WCO was used intensively before being repurposed as biofuel. Reemphasizing that 0.75% KOH loading is the most ideal concentration for biodiesel production [13].

Table 1: The biodiesel production data from Waste Cooking Oil (WCO)

Transesterification (WCO)					
Condition	Weight (100ml) (g)	Weight (after production) (g)	Volume after production (ml)	Yield (%)	Mean WCO yield (%)
1% KOH	92.17	79.43	92.2	86.18	88.43
	91.15	80.11	90.8	87.89	
	91.58	83.30	96.4	90.96	
0.75% KOH	87.81	79.97	91.1	91.07	90.92
	90.91	82.88	94.1	91.17	
	91.81	83.11	95.5	90.52	
1.5% KOH	90.82	76.35	88.4	84.07	85.42
	91.92	77.59	87.8	84.41	
	89.96	78.97	91.1	87.78	

Table 2: The biodiesel production data from Soybean Oil (SO)

Transesterification (SO)					
Condition	Weight (100ml) (g)	Weight (after production) (g)	Volume after production (ml)	Yield (%)	Mean SO Yield (%)
1% KOH	91.55g	84.85g	95.6	92.68	92.39
	90.70g	82.47	93.5	90.93	
	89.22g	83.47	94.1	93.56	
0.75% KOH	91.43g	87.76	98.9	95.99	94.44
	89.20g	83.39	95.5	93.49	
	92.96g	87.22	99.1	93.83	
1.5% KOH	91.91g	79.67	89.3	86.68	85.93
	91.58g	77.47	88.1	84.59	
	90.73	78.49	88.8	86.51	

Observed that the yield decreases when the percentage of KOH increases as shown in Figure 7. This happens due to the rate of conversion of WCO and SO from Free Fatty Acids (FFAs) and triglycerides to Fatty Acid Methyl Ester (FAME) by enhancing the catalyst loading. The glycerol is removed during the filtration process hence there should be no glycerol remaining in the WCO and SO biofuel. A good argument is that WCO biofuel produces a good yield and good conversion based on the amount of FAME products and FAME concentration percentage. The FAME WCO concentration percentage is 89.63% (refer to Table 3) with Hexadecenoic acid methyl ester being recorded as the most dominant FAME in the WCO biofuel as shown in Figure 8 from the GC-MS result. Although the conversion is good and is nearly complete, there are still some unconverted components left in the WCO biofuel. This unconverted composition may be a product of the amount of catalyst used, in which the concentration of catalyst of 0.75% does not result in 100% conversion of FFA and triglycerides to FAME. It can also be an effect of the column used, as mentioned the capillary column used is BP5MS which detects and predicts different composition. Nevertheless 88.81% (refer to Table 3) conversion concentration of FAME contents for SO biofuel recorded as the most dominant based on the result of GC-MS as shown in Figure 9 are acceptable [13-14].

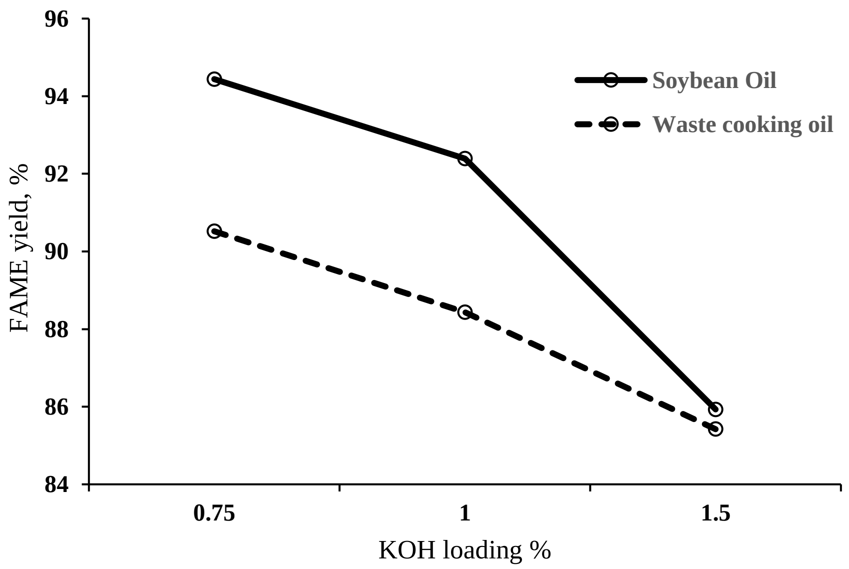

Figure 7. FAME yield (%) for different KOH loading percentages.

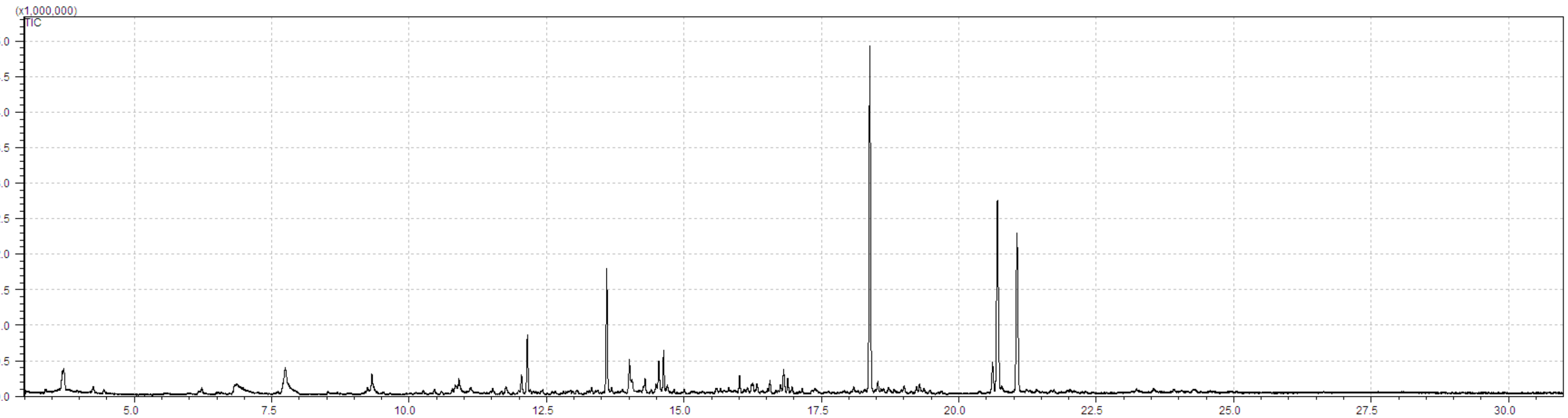

Figure 8. Example of the GC-MS chromatogram result to determine the FAME contents for WCO using 0.75% KOH loading. The highest composition compound found is Hexadecenoic acid, methyl ester, $C_{17}H_{34}O_2$. The molar mass of the methyl ester is 270.45g/mol and estimated weight is 26.89g.

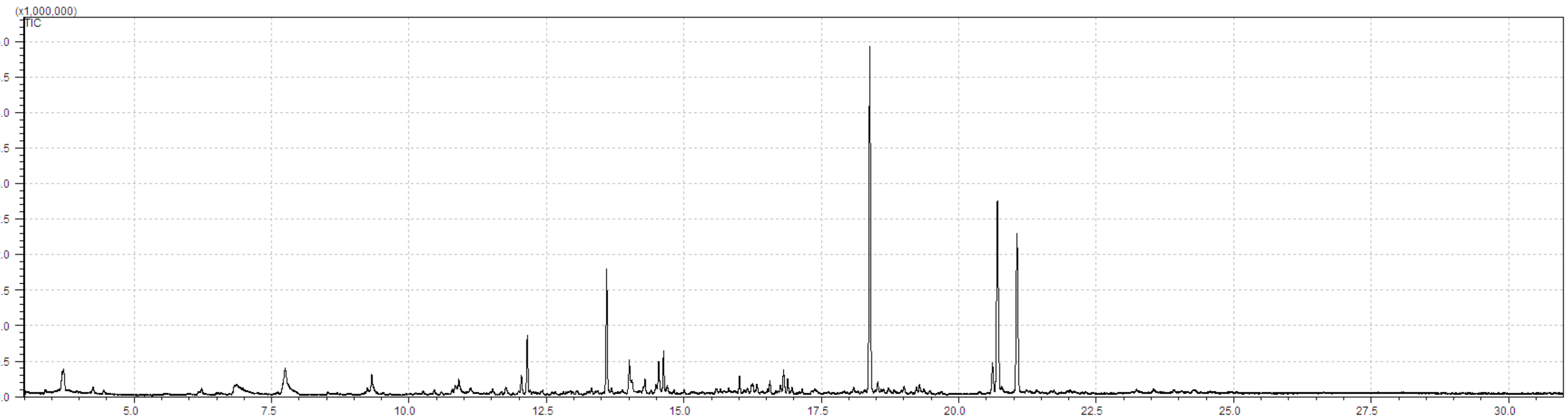

Figure 9. Example of the GC-MS chromatogram result to determine the FAME contents for SO using 0.75% KOH loading. The highest composition compound found is Hexadecenoic acid, methyl ester, $C_{17}H_{34}O_2$. The molar mass of the methyl ester is 270.45g/mol and estimated weight is 19.66g.

The overall properties result of the biofuel for both feedstocks is summarized in Table 3 by choosing the 0.75% concentration KOH is the best condition of biofuel production. According to Konge KL and Sabnis AS., (2013) [15] the density of WCO biofuel must be in the range of 0.872 g/cm^3 - 0.877 g/cm^3. However, based on the ASTM standard the density of the biofuel from any feedstock should be in the range of 0.860 g/cm^3- 0.900 g/cm^3. Hence, this study produced WCO and SO biofuels with densities of 0.875 g/cm^3 and 0.884 g/cm^3 which are acceptable based on the ASTM standards [16]. Next, the kinematic viscosity based on the ASTM standards D445-94 [17] under the condition of 40°C is in the range of 4.1 to 6.0 mm^2/s, thus, in this study, the kinematic viscosity of WCO biofuel produced was approximately 5.34 mm^2/s and for SO was 4.47 mm^2/s are acceptable. The results of acid values for WCO and SO biofuel are 0.2806 mg KOH/g and 0.1871 mg KOH/g, respectively. A safe range for acid value is less than 0.5 mg KOH/g. Considering that the WCO and SO acid values are less than 0.5 mg KOH/g, WCO and SO biofuel meet the standard when comparing the acid value of WCO and SO biofuel obtained from a previous study by Razuki et al., (2023) [18] obtained 0.23 mg KOH/g. In comparison, the obtained acid value of WCO biodiesel is 0.2806 mg KOH/g which is quite close to the established data. Comparing the acid value of SO biofuel obtained from testing versus a research study by Konge KL & Sabnis AS, 2013 [15], which obtained an acid value of 0.1 mg KOH/g, it is still under the standard range and acceptable. For the calorific value, this study obtained WCO and SO calorific values of 39.92 MJ/kg and 40.04 MJ/kg, respectively. By comparing with the established data of WCO and SO, the calorific values were 39.76 MJ/kg and 40 MJ/kg close to the established data from EN14213 [19]. Hence, the calorific value of WCO and SO biofuel aligns with other studies and meets the minimum standard requirement that can replace conventional fuel in future [19-21]. To increase the accuracy of the properties data, the experiment was conducted three times to ensure a more consistent result which proved to be more practical.

Table 3: Summarized result of biodiesel properties

WCO yield (%)	Density (g/cm^3)	Kinematic viscosity (mm^2/s)	Acid value (mg KOH/g)	Calorific value (J/g)	FAME WCO concentration (%)
90.92	0.875	5.34	0.2806	39918	89.63

SO yield (%)	Density (g/cm^3)	Kinematic viscosity (mm^2/s)	Acid value (mg KOH/g)	Calorific value (J/g)	FAME SO concentration (%)
94.44	0.884	4.47	0.1871	40040	88.81

Nevertheless, both feedstocks meet the ASTM D6751 standard and EN 14214 standard in which the summary of the standard is listed in Barabás and Todoruț study 0. Therefore, when choosing a feedstock that is more sustainable for the environment, WCO biofuel is still a better choice compared to SO biodiesel. This is because there is more abundance of WCO waste in Malaysia, which contributes to water and land pollution. If efforts are made, WCO can be recycled, and this could help reduce waste and pollution. Not only that WCO is a cheaper option in comparison to soybean, making it more sustainable financially. Lastly, WCO is considered a food waste where it has no food value and can be repurposed to biofuel, while soybean, in general, has food value as it can be used to make oil, tofu, and soy milk. This means when using soy-based biofuel, a conservative mindset needs to be in place to not pose any threat to the food chain [12]. Despite the inferior quality of WCO biodiesel, WCO biofuel still meets the standard and can be used as biofuel, while being the more sustainable one, both economically and environmentally.

4.0 CONCLUSION

In conclusion, this study shows that the weight loading of the catalyst used is a major factor in the yield of biofuel. It is also noted that the first-generation edible feedstock of Soybean Oil produces greater quality biodiesel. Nevertheless, first-generation feedstock still poses a food competition threat in comparison to second-generation feedstock. In this study, the qualities of biofuel vary depending on the amount of catalyst used which affects the overall yield of the product. In this experiment the greatest yield was obtained when using the lowest concentration of catalyst, KOH, at 0.75%. The physical properties of biofuel also vary depending on the feedstock. Soybean oil biofuel proved overall a higher quality fuel due to the clear advantage in kinematic viscosity value, acid value, but the qualities of waste cooking oil biofuel are not far, with a density of 0.875 g/cm^3, kinematic viscosity of 5.34 mm^2/s, acid value of 0.2806 mg KOH/g, a gross calorific value of 39918 J/g and a FAME conversion of 89.63%. All properties meet the ASTM standards requirement. When compared to conventional diesel, the properties are similar, which suggests the suitability of biofuel as an alternative to diesel. Thus, the establishment production procedure for the second-generation feedstock, waste cooking oil produces biofuel that is close to the quality of soybean oil, it is a more preferred feedstock compared to soybean oil. More importantly, WCO is a second-generation feedstock which means it does not have any food value, unlike soybean. It is also remarkable to choose WCO biofuel as one of the alternative feedstocks to produce the alternative fuel for aviation industry fuel usage.

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