Technical feasibility studies for Langkawi WCO (waste cooking oil) derived-biodiesel

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A B S T R A C T

A study has been done to consider Malaysian WCO (waste cooking oil) generated in an eco-tourism island, Langkawi, Malaysia as an alternative feedstock for biodiesel production. This paper presents the results of the comprehensive technical feasibility study for production of biodiesel from WCO feedstock. The results have shown feasibility of recycling WCO into biodiesel that is compliant with international fuel standard ASTM D6751. The study has given an indication on the appropriate processing scheme to be developed for recycling WCO into biodiesel as a substitute fuel for diesel vehicles in Langkawi that would enable the promotion of alternative fuel in the energy mix for long term environment sustainability.

1. Introduction

Biodiesel is a RE (renewable energy) source derived alternative fuel for diesel engine application that is produced through the transesterification of vegetable oil, animal fats or waste vegetable oil with alcohol in the presence of catalyst. Biodiesel that meets international fuel standard such as ASTM D6751 or its equivalent has been accepted as an alternative for fossil diesel due to its property compatibility and comparable performance to diesel engine and most importantly because it is an environmental friendly source of energy [1]. The pursuit for RE source has promoted active use of edible oil as feedstock for biodiesel production due to its availability of supply and consistent quality. Consequently, this has created an aggressive competition between the land uses for production of edible oil for biodiesel feedstock and the land use for food production. The economical value of biodiesel production is highly dependent on the feedstock price which constitutes 70–95% of the overall production cost [2]. Being a commodity with higher price tag than petro diesel, the use of edible oil will definitely affect the economic viability of biodiesel as RE. On the other hand, WCO (waste cooking oil) which otherwise wasted, has been gaining prominence as an alternative feedstock for biodiesel production with a reduced cost [3] and prevent the competition in the world market between food and energy resource commodity. In addition, according to a report entitled “EPA’s (Environmental Protection Agency) Renewable Fuel Standard Program Regulatory Impact Analysis” released in February 2010, biodiesel produced from WCO has the potential to reduce the GHG (green house gases) emission for up to 86% compared to soy-based biodiesel which only results in 57% reduction of GHG compared to fossil fuel [4].

Nevertheless, the inconsistent supply quantity and quality of WCO have been the impending factors for WCO to be considered as a commercially viable feedstock for biodiesel production. In Malaysia, approximately 3 billion liters of cooking oil is consumed annually for which a conservative 30% recovery for biodiesel production is equivalent to 10% amount of diesel demand [5]. Looking at the potential for producing biodiesel from WCO, a research program to produce biodiesel from Malaysian WCO has resulted in a successful development of a microwave assisted rapid processing scheme that deploy single step base catalyst transesterification capable of producing biodiesel from WCO, which complied with the international standard ASTM D6751 specification for biodiesel that has comparable performance and significant reduction in exhaust emission compared to diesel. The promising outcome has motivated the idea of implementing a pilot project to deploy the mobile rapid processing scheme for recycling Malaysian WCO from an eco-tourism island, Langkawi. This study is aimed at to assess the feasibility of Malaysian WCO in Langkawi for production of biodiesel to partly substitute diesel utilization in the island.

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2. Objectives

The following are the objectives of this study:

i) To assess the quantity and quality of Langkawi WCO for biodiesel production

ii) To perform quality assessment to evaluate the compatibility of chemical and physical properties of biodiesel produced from Langkawi WCO and its blend with diesel in accordance to ASTM D6751 standard.

3. Methodologies

There are two main parts of the studies, for which the first part involves assessing the quantity and quality of Langkawi WCO for biodiesel production. This part involves physical sampling of WCO generated by food outlets in Langkawi and analyzing the quality and predicting the quantity available for biodiesel production from sampling and survey data. The second part involves deploying the rapid processing scheme to convert the collected samples and performing a fuel quality assessment of the derivative biodiesel and its blend with diesel. The methodology shown in Fig. 1 has been implemented in the current work:

3.1. Quantity and quality assessment of Langkawi WCO for biodiesel production

WCO sample collected from Langkawi has been first audited for quantity with reference of the period of collection. Approximately 140 outlets owners participated in this exercise to provide samples which included a mix of various WCO generators such as restaurants, food court, fast food outlets, training centers, hostels, hotels and schools. The data has been used to assess the annual quantity recoverable from each outlet and subsequently extrapolated to predict the total quantity available from the entire island. The quality of each sample has been also assessed for biodiesel process scheme suitability. Each collected sample is filtered using 1 mm mesh, followed by 0.5 mm mesh and finally 10 μm filter system. Next, the samples were tested for measurement of FFA (free fatty acid) percentage and moisture content. It was noted during filtration that approximately 8% of the samples volume have reduced in the form of solid particles, debris and other foreign material. The moisture content of the samples ranged between 500 ppm and 2,500 ppm depending on the usage. The amount of moisture content is not favorable for the base catalyst processing scheme that is deployed for this study [6]. The moisture content is reduced to below 500 ppm by heating up the samples above 110 °C. Base catalyzed biodiesel production scheme can allow to 1% moisture or water content without consuming the base catalyst toward saponification reaction [7].

Subsequently the WCO samples were aggregated and have been pretreated, processed into biodiesel using microwave assisted rapid processing scheme, post-treated and blended with diesel to produce fuel samples for further test to assess the quality with respect to ASTM D6751 standard. Fig. 2 shows the Langkawi WCO biodiesel production process.

3.2. Quality assessment Langkawi WCO derived biodiesel and its blend with diesel

To meet this objective, 12 key parameters have been evaluated for chemical and physical property of the fuel, which is divided into 2 categories. The first category of properties consisted of 7 parameters used to describe the physical properties, handling, and transportation safety of Langkawi WCO biodiesel. The other category consisted of 5 parameters that assess the performance and emission characterization of the fuel upon being utilized in a diesel engine. The results have been compared with the baseline fuel (diesel) and the limit as specified in ASTM D6751 standard.

For all the above tests, five (5) samples of fuel which consists of the following blend of biodiesel and diesel:

1) B100 – 100% biodiesel

2) B80 – biodiesel blend with diesel consisting of 80% biodiesel and 20% diesel,

3) B50 – biodiesel blend with diesel consisting of 50% biodiesel and 50% diesel

4) B20 – biodiesel blend with diesel consisting of 20% biodiesel and 80% diesel

5) B0 – 100% diesel

4. Results analysis and discussion

4.1. Langkawi WCO quantity and quality assessment

The quantity audit activity has resulted in collection of 2036.0 kg (2250 L) of WCO from 140 outlets during collection period of 14—21 days at off peak season. The study has indicated that an estimated 100,000—400,000 kg WCO collection in Langkawi annually between off peak and peak seasons respectively. This quantity has potential to substitute 17.8% diesel demand of power generation sector and approximately 1.6% of transport diesel demand in Langkawi which is also within the maximum warranty limit of 20%
allowed by most diesel engine manufacturer. Although this quantity may not be sufficient to substitute the entire demand of diesel in Langkawi estimated to be approximately 36 million liters annually, the effort to recycle the waste may be worthwhile to conserve the sanctity of the eco-tourism island from the adverse effects of pollution resulting from the improper disposal of WCO into water stream and landfill.

The subsequent quality assessment activity has concluded that the WCO collected from Langkawi are generally of good quality for biodiesel production where approximately 50.6% of WCO having FFA below 0.5% and 78.5% of WCO having FFA below 1.0%. This indicates that 78.5% of WCO in the island having WCO with low FFA percentage is suitable for the base catalyzed transesterification [8,9] and thus has potential to produce biodiesel yields between 80 and 85%. Table 1 shows the summary of yield percentage with respect to FFA value. The remaining 21.5% can be pretreated using esterification to reduce the FFA below 1% before continuing with transesterification [10].

For the subsequent studies, only 1200 kg (1326 L) of WCO having less than 1% FFA have been agglomerated and used for biodiesel production from which, 950 kg of refined biodiesel has been produced for further analysis to assess the quality of biodiesel and its blend with diesel, prior to be used for field trial among the taxi’s and fishing boats in Langkawi.

4.2. Langkawi WCO biodiesel quality assessment

It is important to verify the compatibility of Langkawi WCO biodiesel with respect to conventional diesel to prevent negative consequences upon utilization of the fuel in diesel engines, which is a concern for diesel engine manufacturers and diesel vehicle owners. Biodiesel properties evaluation is a crucial aspect in biodiesel production due to two reasons. First, the properties of the fuel produced must meet an established international standards requirement or its equivalent to ensure its quality. Secondly, it ensures that the fuel produced is qualified to undergo a performance test and subsequently emission test. Hence, for these purposes, the ASTM D6751 or ASTM D6751-02 standard (Standard Specification for Biodiesel Fuel (B100) Blend Stock for Distillate Fuels) is used as a reference standard for property evaluation.

Subsequently for biodiesel quality assessment, the free and total glycerin test has been conducted based on ASTM D 6584 to determine the level of glycerin in the biodiesel and this includes the free glycerin and the glycerin portion of any un-reacted or partially reacted oil or fat. Low levels of total glycerin ensure that complete conversion of the oil or fat into its mono-alkyl esters has taken place during the production process.

Next, the chemical compositions evaluation is performed to evaluate the chemical elements presented in the Langkawi WCO biodiesel for predicting combustion performance of the fuel. The elemental composition of a fuel is established through ultimate test which is used as a reference standard for property evaluation. According to Nazrain [11], this is one of the aspects that differentiate biodiesel from diesel because in diesel, the oxygen is not present. It is also worthwhile to note that only biodiesel produced from WCO has been reported to have higher that 15% oxygen compared to below 12% in biodiesel produced from fresh vegetable oil [11]. The pattern of the results shows that as the blending for biodiesel volumetric ratio increased (from B20 to B100), the oxygen content also increased.

The presence of high oxygen percentage is a very significant advantage for biodiesel produced from WCO. The presence of oxygen in biodiesel will make the combustion process more complete by complementing the oxygen supply from the air intake during the combustion process. This scenario is anticipated to contribute to lean combustion occurrence and less emission of carbon monoxide.

4.2.1. Total and free glycerin test result

Table 2 shows the results of Total and Free Glycerin Test. From the results obtained, it can be deduced that the biodiesel produced from Langkawi WCO meets the ASTM D 6584 standards and qualify to be used for performance, emission, and physical and chemical properties tests. In addition, these tests are also essential to confirm that the rapid process scheme deployed in biodiesel production is accurate and precise.

### Table 2

<table>
<thead>
<tr>
<th>Property tested</th>
<th>Max limits (% mass)</th>
<th>Average results (% mass)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total glycerin</td>
<td>0.24</td>
<td>0.02</td>
</tr>
<tr>
<td>Free glycerin</td>
<td>0.02</td>
<td>0.02</td>
</tr>
</tbody>
</table>

4.2.2. Ultimate test result

4.2.2.1. Carbon, C and hydrogen, H. The result of the comprehensive ultimate test is shown in Fig. 3. According to the results, the carbon and hydrogen composition in Langkawi WCO biodiesel samples are quite comparable to diesel with difference in weight percentage ranging from 14.2 wt% to 8.3% wt for carbon and 1.3 wt% to 0.7 wt% for hydrogen. Based on these results, it can be predicted that the emission of CO, CO2, and NOx will be lower for Langkawi WCO biodiesel and its fuel blend compared to diesel during the performance and emission tests.

4.2.2.2. Oxygen, O. Oxygen content of 16% has been detected in all the Langkawi WCO biodiesel samples, in contrast to the diesel fuel. According to Nazrain [11], this is one of the aspects that differentiate biodiesel from diesel because in diesel, the oxygen is not present. It is also worthwhile to note that only biodiesel produced from WCO has been reported to have higher that 15% oxygen compared to below 12% in biodiesel produced from fresh vegetable oil [11]. The pattern of the results shows that as the blending for biodiesel volumetric ratio increased (from B20 to B100), the oxygen content also increased.

4.2.2.3. Sulfur. Sulfur content in biodiesel (B100) has been detected to be very small, at 0.006 wt%. The value increases as the volumetric ratio for diesel increases where B80, B50, and B20 have 0.064 wt%, 0.133 wt%, and 0.213 wt% are of sulfur content respectively. Sulfur is a very crucial lubricative component in diesel engine application.
However, sulfur content is the main discourse in SO$_2$ emission, which contributes to the acid rain phenomenon. Lately, petrol companies have agreed to reduce the sulfur content from 0.5 wt% to 0.3 wt% [12] as an effort to reduce the pollution caused by diesel fuel. The most well known method to remove sulfur in diesel is hydrotreating (using hydrogen). However, hydrotreating results in the reduction of the lubricative properties of diesel due to the highly reactive hydrogen, and subsequently engine wear. Nevertheless, it has been proven worldwide that biodiesel has very good lubricative properties [13] inheritance. Based on this fact and the results obtained as shown in Fig. 3, it can be concluded that Langkawi WCO biodiesel is a very promising resource to substitute the application of low sulfur diesel in the future.

4.2.2.4. Nitrogen. Nitrogen content is also significantly low for all Langkawi WCO biodiesel samples compared to diesel, with values ranging from 0.001 wt%, 0.0016 wt%, 0.0031 wt%, to 0.0044 wt% for B100, B80, B50, and B20 respectively. Meanwhile, the nitrogen composition for diesel was found to be at 0.02 wt%. Hence, the combustion of biodiesel from WCO is expected to contribute less fuel NO$_x$.

4.2.3. Distillation test result

The results obtained for distillation shown in Fig. 4, indicates that at 50% volume recovery, diesel has a rapid combustion compared to other fuel samples due to its lowest temperature value with 298 °C. It has also been observed that the temperature at 50% volume recovery increases as the ratio for Langkawi WCO biodiesel volumetric ratio increases in a linear trend.

A rapid combustion is expected to occur because of the low density and flash point, which makes diesel more flammable compared to biodiesel and its blend with diesel. However, at 90% recovery, B100 has proven that it has undergone a complete combustion process compared to the other fuel samples as the temperature at this point is lowest at 337.8 °C. The temperature increases as the volumetric ratio of diesel increases.

The results obtained can be explained by referring to the ultimate test results, as the oxygen content for B100 is the highest compared to the other. Indeed, oxygen has contributed toward a complete combustion process; hence, fewer residues are found at the end of the combustion process. The ASTM D6751 requirement for distillation is reported to be at 360 °C with 90% volume recovery.

Choo et al. [14], reported that the CPS (crude palm stearin) Methyl Ester and CPO (crude palm oil) Methyl Ester possessed less rapid combustion compared to diesel based on 50% distillation recovery curve result. However, at 90% recovery, the CPO Methyl Ester and CPS Methyl Ester showed a lower temperature, which meant less residual after combustion process, compared to diesel. These results indicate that the findings from the Langkawi WCO biodiesel study are in correlation with other similar research findings.

In short, the evaluation of chemical properties of Langkawi WCO biodiesel has indicated compatibility as a diesel substitute fuel. Therefore, it has been verified that biodiesel and its blend have complied with the specification requirements.

4.2.4. Physical properties test 1

The test results are presented in Table 3.
4.2.4.1. Acidity. The acidity value increased linearly as the volumetric ratio for Langkawi WCO biodiesel increased. According to ASTM D6751, the specification for biodiesel acidity value should not exceed 0.8 mg KOH/g and it has been verified that the acidity for all the fuel samples has complied with ASTM D6751 acidity specification. The lower the acidity value indicated the more stable and the better quality is the fuel. Therefore, as the diesel volumetric ratio increased, it was observed that the quality of the fuel had improved. Hence, Langkawi WCO biodiesel is within the allowable acidity limit specified by the standard reference, which is 1.0 mg KOH/g oil.

4.2.4.2. Flash point. The flash point is an indication of the possible presence of highly volatile and flammable materials in a relatively nonvolatile or nonflammable material. The results obtained were not as expected as it did not exhibit a linear pattern. B100, B80, B50, and B20 possessed a 157°C, 151.3°C, 137°C, and 127°C value of flash point respectively. Hence, it can be noted that B100, B80, and B50 have complied with the ASTM D6751 minimum limit, which is 130°C. Based on the flash point of the reference fuel (diesel), which was 98°C, the Langkawi WCO biodiesel was noted to be safer for handling and storage. However, due to the maximum allowable limit of 130°C, only B20 is recommended for the field trial.

4.2.4.3. Copper corrosion. Crude petroleum contains sulfur compounds, most of which are removed during refining. However, some of the sulfur compounds remaining in the petroleum product can have a corroding effect on various metals. The copper strip corrosive test has been used to assess the relative degree of corrosivity of a petroleum product where the degree of corrosiveness can be divided into four levels: (1) Slight Tarnish; (2) Moderate; (3) Dark, and (4) Corrosion. The result obtained indicates that all the fuel samples exhibited a slightly tarnished effect which implied the compliance with ASTM D6751 requirement.

4.2.4.4. Appearance. The appearance of all the samples is reported to be clear throughout the visual inspection. There is no specific requirement reported for ASTM D6751 on this requirement.

4.2.4.5. Vapor pressure. Vapor pressure is also used as an indirect measure of the evaporation rate of volatile petroleum solvents, which makes it closely related to the flash point, indicating that the lowest temperature at which a combustible mixture can be formed above the liquid fuel is dependent on both the lean flammability limit of the fuel as well as the vapor pressure of the fuel constituents. The result obtained is the Reid vapor pressure, which differs from the real vapor pressure due to some small sample vaporization and the presence of water vapor and air in a confined space. The result obtained for the Reid vapor pressure test is less than 0.05 psi (0.25 kPa) for all the fuel samples. This is considered low, which indicates that biodiesel is not highly flammable and safe in terms of fuel handling.

4.2.4.6. Cloud point. The cloud point is an index of the lowest temperature of the fuel's utility under certain applications. Operating at temperatures below the cloud point for a diesel fuel can

Table 3
Physical properties test result (for parameters related to storage, transportation and handling.

<table>
<thead>
<tr>
<th>No</th>
<th>Properties</th>
<th>Standard</th>
<th>Unit</th>
<th>ASTM D6751</th>
<th>B100</th>
<th>B80</th>
<th>B50</th>
<th>B20</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Acidity</td>
<td>ASTM D664</td>
<td>mg KOH/g</td>
<td>0.80 max</td>
<td>0.21</td>
<td>0.18</td>
<td>0.14</td>
<td>0.10</td>
<td>0.25</td>
</tr>
<tr>
<td>2</td>
<td>Flash point</td>
<td>ASTM D93</td>
<td>°C</td>
<td>130 min</td>
<td>157</td>
<td>127</td>
<td>137</td>
<td>127</td>
<td>98</td>
</tr>
<tr>
<td>3</td>
<td>Copper corrosion</td>
<td>ASTM D130</td>
<td>—</td>
<td>No 3 max</td>
<td>No 1 (slight tarnish)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Appearance</td>
<td>ASTM 1525</td>
<td>—</td>
<td>—</td>
<td>Yellow w/out contamination</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Vapor pressure</td>
<td>ASTM D323-99a</td>
<td>psi</td>
<td>—</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>—</td>
</tr>
<tr>
<td>6</td>
<td>Cloud point</td>
<td>AOCS Cc6-25</td>
<td>°C</td>
<td>—</td>
<td>12</td>
<td>10</td>
<td>10</td>
<td>9</td>
<td>—</td>
</tr>
<tr>
<td>7</td>
<td>Ash content</td>
<td>ISO 2098</td>
<td>wt%</td>
<td>0.02 max</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Fig. 4. Distillation test result.
result in fuel filter clogging due to the wax crystals. The cloud point is an important property for biodiesel since biodiesel fuels typically have higher cloud points, i.e., crystals begin to form at a higher temperature than standard diesel fuel. This feature has implications on the use of biodiesel in cold weather applications [15]. The results obtained shows that the cloud point of all the Langkawi WCO biodiesel samples is quite high. In evaluating Langkawi WCO biodiesel and its feasibility to be used as fuel in Langkawi, the cloud point is not a major concern, considering that the ambient temperature at Langkawi is above 25°C.

4.2.4.7. Ash content. Ash is the residue left behind when the fuel is heated to a sufficiently high temperature that, combustible material burns and leaves as CO$_2$ and H$_2$O. It can be used to indicate the presence of inorganic compounds and their oxides. These materials consist of inorganic compounds and their oxides. These materials can be abrasive and contribute to engine wear. Diesel fuels are generally very low in ash and test method ASTM D 975 allows no more than 0.01%, by weight. The results obtained indicate that the ash content in all Langkawi WCO biodiesel fuel samples complied with ASTM D6751. The speciﬁcation requirement is ten times higher, compared to the results obtained and this indicates that, by using Langkawi WCO biodiesel, the engine wear is expected to be minimal and prolongs the engine life span.

4.2.5. Physical properties test

The second category of the comprehensive properties test results are for the properties which have signiﬁcant effect when the fuel is tested in a diesel engine. Five tests have been performed and the results are presented in Table 4.

4.2.5.1. Moisture content. The results obtained indicate that B100, B80 and B50 samples do not comply with ASTM D6751 speciﬁcation, which is at maximum 0.05 wt%. However, the B20 having 0.0235 wt% moisture content, successfully complied with the speciﬁcations. According to a publication by Malaysian Palm Oil Board (MPOB) [16], the surfactant theory of frying suggests that frying is a dehydration process that occurs on the item being cooked. Therefore, moisture is transferred and dissolved into the cooking oil during this period. This explains why the moisture content for Langkawi WCO biodiesel is higher compared to fresh cooking oil biodiesel.

Moreover, based on the results obtained, it was observed that as the diesel volumetric ratio increased, the moisture content decreased linearly. This finding is very important because it is an alternative solution to overcoming the problem with high moisture content. During the performance test, the fuels with a higher blend amount of Langkawi WCO biodiesel is expected to consume more fuel, as the high moisture content will cause emulsion of the fuel during storage. However, the effect may not be very significant because the energy burn per liter will be lower due to the high density value, which is also caused by the presence of high moisture content. Therefore, the property test results have shown a limitation, that the volumetric blend ratio of Langkawi WCO biodiesel shall not exceed 60% in order to meet ASTM D6751 standards.

4.2.5.2. Density. The results obtained indicate that, as the volumetric ratio of Langkawi WCO biodiesel increased, the density increased proportionally. The amount of moisture content present is closely related to the density value as the higher the moisture content, the denser the fuel, which explains why B100 has the highest value for density compared to others. The density for conventional diesel is reported to be at 0.833 g/cm$^3$ and no speciﬁcation limit has been stated by ASTM D6751 standards. Masjuki et al. [17] reported that a high-density value would contribute to a better fuel atomization due to heavier fuel droplets during the fuel injection in the combustion chamber, which will result in better combustion. The high-density value is expected to reduce the energy burn per liter during performance test [18] (Masjuki et al.). In addition, although the energy burn per liter will be higher for fuel with higher biodiesel volumetric ratio due to the low value in gross heat of combustion, the high density will help to reduce the energy burn per liter value slightly, hence minimizing the fuel consumption.

4.2.5.3. Viscosity. According to Gerpen et al. [17], biodiesel is more viscous than diesel fuel but only by a small amount. The fatty acid, which is 90% of the total mass for triglyceride, have a great influence on viscosity of biodiesel depending on the chain length, position, number, and the nature of its double bonds [19]. The results obtained corresponds with the findings of Gerpen et al. [15], as all the tested fuel samples showed a higher value compared to diesel and complied with the ASTM D6751 requirement excellently. It is predicted that all the fuel samples will produce comparable results in the performance test because the viscosity for fuel with a higher amount of biodiesel is high. The higher viscosity will help to minimize the fuel leakage at the plunger during compression at fuel injection stage, hence minimizing power loss. However, the high viscosity will lead to inferior atomization compare to diesel fuel which is very crucial for oxygen and fuel mixture to enhance combustion efficiency. Nevertheless, the presence of high percentage of oxygen offsets the weakness of atomization due to a slight higher viscosity of biodiesel [20].

4.2.5.4. Gross heat of combustion. Biodiesel fuels do not contain aromatics but they contain fatty acids with different levels of unsaturation. Fuels with more unsaturated fatty acids tend to have a slightly lower energy content (on a weight basis) while those with greater saturation tend to have higher energy content [15]. The results obtained shows that the gross heat of combustion increases linearly as the volumetric ratio for diesel increases, because the gross heat of combustion for diesel is 45,800 kJ/kg, which is the highest among all the fuel samples and blending it with B100, which possesses the lowest gross heat of combustion, will help to make the gross heat of combustion of the blended fuel higher than

<table>
<thead>
<tr>
<th>Table 4</th>
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<tbody>
<tr>
<td>Physical properties test result (for parameters affecting performance and exhaust gas emissions).</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
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<tr>
<td>4</td>
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<td>5</td>
</tr>
</tbody>
</table>
B100 but still lower compared to diesel. Gross heat of combustion is an important parameter for performance indication. Based on the results, it can be predicted that fuel with a higher Langkawi WCO biodiesel volumetric ratio will have a low brake power (b.p) and high fuel consumption. However, it is important to note that the results for b.p and fuel consumption are also dependent on other properties parameters such as density, viscosity and the fuel compositions of the fuel.

Koji et al. [21] found that the gross heat of combustion for used corn oil is slightly higher than other vegetable oils with 42,300 kJ/kg and for used rapeseed oil it is slightly lower with 36,700 kJ/kg. Besides that, Ghassan et al. [22] found that the biodiesel derived from waste animal fats is slightly lower with 38,765 kJ/kg. These findings correlate with this study due the use of waste oil. It is also recognized that the used or waste vegetable oils, which consist of high moisture content as a result from the frying process, has reduced the energy content of the biodiesel compared to fresh oils.

4.2.5.5. Cetane index. Cetane index is the quality index related to the ignition delay of a fuel in a diesel engine [23], which is very useful to give an indication on the NOx emission because it relates to fuel quality, knocking characteristics, besides the ease of starting at lower temperature. Hence, a lower NOx emission will produce a better fuel quality at a higher Cetane index value.

The results show that B100 possesses a poor Cetane index value compared to other Langkawi WCO biodiesel samples. However, this value is sufficient to comply with ASTM D6751 standard specification, which requires 47 as its minimum value. As the blending ratio for diesel increased, the Cetane index value increased in direct proportion, indicating that the quality of the fuel has improved.

Cetane index is also a very useful tool to approximate the performance of the fuel because it gives an indication of the fuel quality. Based on the results obtained, it is concluded that diesel shows a better quality as fuel for diesel engine application, followed by B20, B50, B80, and B100. In addition, the NOx emission has been approximated to be higher for the fuels with a lower Cetane index value. However, the approximation also depends on other parameters such as the fuel composition, viscosity, and density of the fuels, which are considered as compulsory requirement for evaluating the combustion characteristics. Alcantara et al. [24], notified that biodiesel derived from WCO from a mixture of olive oil and sunflower oil possessed a Cetane index value of 52.91. The difference in FFA composition of the raw material has contributed to the difference of the findings. The high presence of saturated compound will lead to a higher value of Cetane index; hence contributing to a better fuel quality.

The physical properties test evaluation indicated that Langkawi WCO biodiesel has the compatibility to be used as fuel for diesel engine applications. However, the requirement limit for flash point as specified in ASTM D6751 has given an indication that only up to 20% of Langkawi WCO biodiesel should be used for commercial diesel engine application. It is important that this limitation is observed to avoid warranty related consequences, which is in agreement with most engine manufacturer’s warranty, which recommend only up to 20% biodiesel blend ratio.

5. Conclusions

The followings are the conclusions from this study:

i) Langkawi WCO quantity assessment:
Based on the WCO collected within the island during off-peak season, it can be concluded that the feedstock is sufficient to produce biodiesel for not more than 20% of market segment within the allowable substitution limit by the diesel engine manufacturer if blended with diesel.

ii) Langkawi WCO quality assessment:
The study has found that approximately 78.5% of WCO collected has the potential to produce biodiesel with high yield percentage which proved the production viability of the feedstock deploying base catalyzed transesterification with average yield percentage of 85%.

iii) Langkawi WCO biodiesel quality assessment:
Langkawi WCO biodiesel produced meets the ASTM D 6584 standards and qualify to be used for performance, emission, and physical and chemical properties tests. In addition, this also confirmed that the process used in biodiesel production is accurate and precise.

iv) Langkawi WCO biodiesel (and its blends with diesel) chemical and physical properties assessment:
The properties evaluation of Langkawi WCO Biodiesel has shown that a 20% volumetric blend limit with diesel (B20) would meet all the parameters limit of ASTM D6751 standards and thus is the recommended blend for diesel substitute.

In a nutshell, this study has shown that it is technically feasible to implement a pilot project to convert Langkawi WCO into biodiesel. The project implementation would receive acceptance and support from the WCO generators and Diesel consumers in Langkawi. The project implementation would support the sustainability agenda by reducing environmental pollution related to WCO disposal and partly meet the energy demand through waste recycling.

6. Further work

Within the vicinity of the Langkawi Island, there is proven viability and feasibility of implementing a RE source derived from locally available WCO. This should be seen as a potential for the waste to become a resource for energy generation rather than a burden on the environment. Furthermore, the reuse of WCO for other purpose for example for making recycle cooking oil imposed unhealthy food preparation which could lead to serious health problems. In Malaysia, currently there has not been a directive or formally published act that governs the control of WCO end use. A practical WCO management system shall be implemented for a systematic waste collection that is able to harmonize the effort of local authorities with the proactive involvement from eco-tourism operators, food catering establishment operators as well as the local people in the island. With a systematic collection mechanism, a better data on the feedstock availability could be established and optimum diesel substitution will be more feasible. In the long run, a steady source of WCO for biodiesel production would provide better feedstock supply security, thus improving the economic viability and market stability for biodiesel as RE.

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