Synthesis of non-edible biodiesel from crude jatropha oil and used cooking oil

Syazwana Sapee[1], *Ahmad Fitri* Yusop[1,2,*], *Mohammad Nazri* Mohd Jaafar[3], *Rizalman* Mamat[1], *Wan Asma* Ibrahim[4], *Hazir* Farouk[5], *Norwazan* Abdul Rahim[6], *Ilyia Syafira* Ab Razak[3], *Muhammad Syahiran* Abdul Malik[3] and *Zhang* Bo[7]

[1]Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
[2]Automotive Engineering Centre, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
[3]Institute for Vehicle System and Engineering (IVeSE), Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
[4]Forest Research Institute Malaysia (FRIM), Kepong, 52109 Selangor, Malaysia
[5]Department of Mechanical Engineering, Faculty of Engineering, Sudan University of Science and Technology (SUST), 11111 Khartoum, Sudan
[6]Department of Mechanical Engineering, Faculty of Engineering, Universiti Pertahanan Nasional Malaysia, Kem Sg. Besi, 57000 Kuala Lumpur, Malaysia
[7]School of Mechanical Engineering, Ningxia University, 750021 P. R. China

Abstract. This study focuses on a feasibility study of alternative non-edible crude oil such as jatropha and used cooking oil in biodiesel production. Crude jatropha oil (CJO) and used cooking oil (UCO) were converted to biodiesel using a two-step transesterification process with presents of acid-based and alkaline-based catalysts. Each three biodiesel blends (B5, B15 and B25) have been produced by blended with conventional diesel fuel (CDF). Determination of the fuel properties for each blend including CDF, Jatropha Methyl Ester (JME) and Used Cooking Oil Methyl Ester (UCOME) have been carried out. The average yield for jatropha and used cooking oil biodiesels production was 94.3% and 92% respectively. The increment of the percentage of JME or UCOME in its blends is proportional to fuels physical properties such as density, specific gravity, kinematic viscosity and surface tension, however inversely proportional to fuels calorific value. Based on the results of this study, it is acceptable to conclude that non-edible CJO and UCO are viable alternatives to edible oil as feedstock to renewable fuel in order to reduce the greenhouse gases produced.

1 Introduction

Fossil fuel has been the main source for energising almost all sectors including industrial, transportation and agricultural sectors. However, the resources are wiping out each day. Issues of global warming, fuel reserves shortage and raises of fuel prices, have driven scholars since decades ago to eagerly look up for the new solution of alternative fuels that

* Corresponding author: fitriy@ump.edu.my

are available, technically feasible, economically viable and environmentally acceptable [1-3].

One of the choices of alternative fuels is biodiesel. It is also known as fatty acid methyl ester (FAME), is an alternative to fuel that is renewable, biodegradable, non-toxic, and possess lower aromatic content which can be obtained from feedstock [4, 5]. Biodiesel is a group of ester-based oxygenated fuel produced from fatty acid triglycerides contained in animal fats, vegetable oils or waste vegetable oil, for instance, used cooking oil [6]. It is sustainable and due to the lighter carbon and sulphur contents compared to fossil fuel, they are environmentally friendly [7]. Biodiesel purest form is named B100, and it can be blended with petroleum or diesel at a different percentage, denoted as biodiesel blend [8]. It possesses higher density, viscosity and surface tension compared to conventional diesel fuel, that normally is used directly in an engine without modifications [9]. Usually, biodiesel feedstock is obtained from vegetable oils, for instance palm, sunflower, canola, and soy. But the production of biodiesel from edible feedstocks will somehow affect the food crops for the constantly growing population. Thus, the continuing and never-ending ‘food versus fuel’ debate throughout the world organisations.

Jatropha (Jatropha curcas L.) is a vegetable that contains non-edible oils [10]. The plantation of jatropha has many advantages as its ability to cultivate on dry land can increase the fertility on that particular land [11]. Its seed production is reported could produce around 0.8 kg seed per square meter per year [12]. The yield or conversion rate of CJO from its seed is said to be about 30% to 40% by weight whereas its kernel could produce CJO around 45% to 60% [13].

Another potential substitute to edible-vegetable-oil for biodiesel production is used cooking oil (UCO). UCO is categorised as non-edible feedstock plus has a lower price than pure feedstock such as palm oil, coconut oil and corn oil since it is a used product [14]. About 193,000 tons per year nationwide UCO is discarded into the dustbin, onto soil and into drainage system [15]. Besides recycling and reusing the UCO to reduce the wastage pollution, UCO also can be used as biodiesel due to its biodiesel production cost is competitive to petroleum diesel price. The production of biodiesel from UCO proves to be a right solution, efficiently and economically to utilise it.

Hence, the feasibility study particularly their conversion rate on these two types of biodiesel production is necessary. This study practices the two-step transesterification process to convert CJO and UCO to Jatropha Methyl Ester (JME) and Used Cooking Oil Methyl Ester (UCOME) respectively. JME (also known as jatropha biodiesel) and UCOME (named as UCO biodiesel) are produced by using alcohol and catalyst in transesterification process to convert triglycerides into fatty acid alkyl ester [16]. This research will be in depth on the approaches of producing these biodiesel using acid and alkaline catalysts, as well as focusing on the physical properties of the biodiesels to meet the biodiesel standard including its production cost [4, 6, 17, 18].

2 Material and Methods

2.1 Feedstocks

Crude oils used as feedstock for this research were obtained from few resources. CJO were procured from Bionass Sdn Bhd, Kuala Lumpur, Malaysia. UCO was supplied from Forest Research Institute Malaysia (FRIM), Kuala Lumpur, Malaysia. CDF was purchased from PETRONAS petrol station in Johor Bahru, Malaysia.

2.2 Synthesis of biodiesel procedures

A two-step transesterification process was chosen to produce biodiesel in this study. The process started with pre-treatment of crude oil, and then acid catalysed esterification to produce esterified oil, followed by base catalysed transesterification, and finally post-treatment of unpurified methyl ester to obtain clear methyl ester/ biodiesel. Table 1 shown summary of a two-step transesterification process. Synthesis of biodiesel was conducted in-house at Gas Turbine Combustion Research Group laboratory, Universiti Teknologi Malaysia, Johor, Malaysia.

Table 1. Summary of a two-step transesterification process

Step	Process	Purpose	Product
1	Pre-treatment	To remove moisture	Refined oil
2	Esterification	To reduce the acid value of the crude oil	Esterified oil
3	Transesterification	To produce the methyl ester	Unpurified methyl ester
4	Post-treatment	To purify the produced methyl ester	Clear methyl ester

Pre-treatment process is an initial process to convert crude oil to biodiesel. Crude oils sometimes are exposed to surrounding and react with air, adding moist to the fuel. Thus, the purpose of this process is to remove the moisture contained in crude oil. The crude oil was heated using a magnetic hot plate in a beaker at 90-95°C for 1 hour under vacuum.

Esterification process is an additional step of biodiesel production to reduce the value of free fatty acid in the crude oil to 1% or below by weight using an acid catalyst. This study used methanol (MeOH) with alcohol to oil ratio is 12:1 molar ratio of 50% volume to volume. Sulphuric acid (H_2SO_4) is added with a catalyst to oil ratio is 1.5% volume to volume to enhance reaction condition and conversion rate of biodiesel. The reaction was started and maintained at 65°C for 3 hours at 400 rpm.

Transesterification process is one of the main methods that have been used due to low cost and easy to perform. In this process, triglycerides (the main component of natural fats and oil) reacts with alcohol in presence of a catalyst, produces methyl ester and by-product glycerin. This study used MeOH, with alcohol to oil ratio is 6:1 molar ratio of 25% volume to volume. Potassium Hydroxide (KOH) as a base catalyst is added with KOH to oil ratio is 1% volume to volume. Transesterification reaction was maintained at 60°C for 2 hours at 400 rpm.

(a) (b) (c)

Figure 1. (a) Esterification reaction, (b) KOH dissolved in MeOH, methoxide preparation for the transesterification process, (c) Post-treatment process of washing unpurified jatropha methyl ester.

Post-treatment process of two-step transesterification process is the final process to obtain methyl ester or biodiesel. The main purpose of this process is to purify the produced methyl ester from the transesterification process. The unpurified methyl ester is washed using 50% volume to volume distilled water at 50°C - 60°C repeatedly to remove excess alcohol, catalyst and residual glycerol. The methyl ester then needs to be dried at 70°C for about 30 minutes at 400 rpm to drive out any remaining methanol and moisture.

2.3 Blending test fuels

This research focuses on low proportion blends as test fuels, as it is significant in terms of economic and application in industries. In order to get a low percentage of blends, the blending process must be carried out between pure biodiesel and conventional diesel fuel (CDF) by volume. In this study, B5, B15 and B25 were chosen for both jatropha methyl ester (JME) and used cooking oil methyl ester (UCOME) blends. Blending process was conducted using simple manual blend techniques.

2.4 Determining fuel physicochemical properties

All of the physicochemical properties tests were conducted in-house at Universiti Teknologi Malaysia by considering many international standard procedures and testing. Properties of the test fuels determined were density, specific gravity, kinematic viscosity, surface tension at room temperature, as well as calorific value. Table 2 shows measuring devices that were utilised in this study, which comply with ASTM (American Society for Testing and Materials) standard specification.

Table 2. Measuring standards and devices for fuel properties determination

Properties	Standard	Measuring Device
Density (g/cm^3)	ASTM D941	A&D N92 balance and Pycnometer
Specific Gravity	ASTM D891	Hydrometer
Kinematic Viscosity @ 40°C (mm^2/s)	ASTM D445	Anton Paar stabinger viscometer SVM3000
Surface Tension (mN/m)	ASTM D971	Kruss K20Tensiometer
Calorific Value (kJ/kg)	ASTM D240	IKA C2000Bomb Calorimeter

3 Result and discussions

3.1 Synthesis of biodiesel

Figure 2 shows a sample of JME and UCOME produced. Both methyl esters were produced by conversion from crude oil via a two-step transesterification process. In term of physical appearances, both biodiesels have darker colour compared to diesel fuel due to their crude oils' colour. Yield or conversion rate is a ratio of quantity end product produced to amount provided at first. From the production, the average yield percentage of JME is 94.3% whereas UCOME is 92.0%. The conversion rate of biodiesel production is depending on parameters such as the ratio of methanol to crude oil, the ratio of catalyst, reaction temperature and time. Human error factor during handling the product also considered as one of the contributions to total conversion rate.

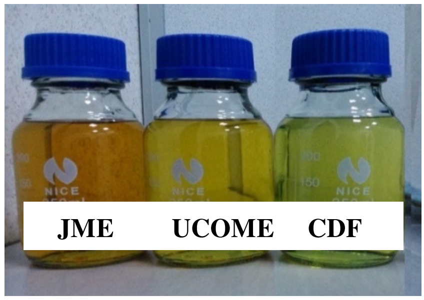

Figure 2. Samples of JME, UCOME and CDF

3.2 Fuel physicochemical properties

The fuel physical properties acquired are compared to the diesel standard (EN 590) and biodiesel standard (EN 14214). Table 3 shows the summary of the test fuels physical properties. Calorific value is defined as the energy content in a fuel and thus their efficiency [19]. From the table, it is observed that biodiesels have lower calorific value, which indicated that they contain lower energy as compared to diesel. A fuel with very high viscosity will destruct the fuel injector then vaporise poorly, resulting in high quantity of carbon build up [20]. Despite high viscosity, both B100 biodiesels produced complied to biodiesel standard EN14214. Surface tension is the molecules force of attraction, affecting fuel atomization in combustion [21]. Biodiesel's surface tension is higher than diesel. As surface tension increases, fuel atomization is degrading. Besides surface tension and viscosity, density and specific gravity of biodiesel blends is increase with the increases of biodiesel content in diesel fuel.

Table 3. Fuel Physiochemical Properties

Physical Properties	**Density (kg/m^3)** ASTM D941	**Specific Gravity** ASTM D891	**Kinematic Viscosity (mm^2/s)** ASTM D445	**Surface Tension (mN/m)** ASTM D971	**Calorific Value (kJ/kg)** ASTM D240
EN 590	820-845	-	2.0-4.5	-	-
Diesel (CDF)	830.1	0.835	3.5020	29.5	45.29
B5 JME	833.8	0.839	3.5802	29.7	44.83
B15 JME	837.4	0.840	3.6795	29.9	44.21
B25 JME	841.0	0.843	3.7110	30.1	43.59
B100 JME	868.0	0.865	4.4761	31.6	39.52
B5 UCOME	827.4	0.836	3.5833	29.7	44.93
B15 UCOME	830.5	0.837	3.6520	29.9	44.35
B25 UCOME	833.5	0.840	3.7511	30.0	43.73
B100 UCOME	858.7	0.853	4.5184	32.1	39.50
EN 14214	860-900	-	3.5-5.0	-	-

4 Conclusions

Biodiesel could be produced from two-step transesterification process. The conversion rate for biodiesels production is 94.3% for JME and 92.0% of yield percentage for UCOME. As the increment of the percentage of biodiesel in its blends, the physical properties of fuel such as density, specific gravity, kinematic viscosity and surface tension are also increasing. On the other hand, it is not applied to the calorific value.

The percentage of biodiesel in its blends are inversely proportional to test fuels calorific value. All in all, JME blends and UCOME blends show a promising future in solving not only our food problem but also waste and pollution problems regardless of lower effectiveness compared to the current conventional fuel.

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