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Improving Vegetable Oil Properties by Transforming Fatty Acid Chain Length in Jatropha Oil and Coconut Oil Blends

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Abstract: Efforts to improve the physical and chemical properties of vegetable oils as diesel fuels such as viscosity and calorific value are indispensable with the depletion of fossil oil reserves. Jatropha oil with long chain fatty acids and high degree of unsaturation is mixed with short chain saturated fatty acid coconut oil in various compositions. The mixture was heated and stirred for 30 min at 90 °C. This mixing leads to a decrease in viscosity which allows for the breaking of the bond. The fatty acid molecule structure undergoes transformation that changes the degree of unsaturation and the average length of the carbon chain. Consequently, the kinematic viscosity and flash point of the mixture decreases while its calorific value increases.

Keywords: fatty acid; heating value; viscosity; jatropha oil; coconut oil

1. Introduction

Vegetable oil is an alternative fuel and one of biodiesel's raw materials. In this decade, much research has been aimed at obtaining liquid fuels from renewable materials, including vegetable oils.

Vegetable oil can be used directly or mixed with diesel oil to operate a diesel engine. The use of vegetable oil and diesel oil blends has been tested by several researchers [1–3]. The use of 100% vegetable oil is also possible with slight modifications to the fuel system [4].

The weaknesses of vegetable oil as a diesel fuel include high viscosity, a high pour point, high flash point, high cloud point, high density and reactivity of unsaturated hydrocarbon chains [5], high NOx emissions, low oxidation stability, and a lower energy content [6].

The main problem related to the use of vegetable oil as fuel is the high viscosity [7–9]. The high viscosity of the fuel causes problems for engine operation [10,11]. In order for vegetable oil to be feasible as fuel, it is necessary to reduce its viscosity close to that of diesel fuel. In addition to transesterification, some methods to reduce the viscosity of vegetable oils are dilution, microemulsion, pyrolysis and catalytic cracking [10,12].

In addition, one important issue is that the calorific value of vegetable oil is lower than that of diesel oil. The heating value of vegetable oil is lower than that of diesel oil due to higher oxygen levels. The calorific value of diesel oil is 46 MJ/kg [13].

Vegetable oil is composed of triglycerides (90–98%) and a small amount of mono and diglyceride. Triglycerides are composed of three fatty acid molecules and one glycerol molecule. Triglycerides contain significant amounts of oxygen. The molecular structure of fatty acids has varying lengths of carbon chains and the number of double bonds [14].

The chemical properties and physical properties of vegetable oils are influenced by their fatty acid structure [15,16]. Some important properties for fuel that are affected by fatty acid structure include cetane number, heat value, viscosity, density, cloud point, pour point, iodine value, lubrication and oxidation stability [17].

The two most important features of the composition of fatty acids in determining fuel properties are fatty acid chain length and degree of unsaturation [18]. A longer carbon chain would increase a fuel's viscosity, freezing point, pour point, cold filter plugging point (CFPP), calorific value and cetane number. A higher degree of unsaturation would decrease them and oxidation stability. In addition, a high degree of unsaturation would increase a fuel's density and iodine value [17].

Based on the above description, improving the properties of vegetable oils as fuel, especially viscosity and calorific value, is necessary. Many studies have been conducted on jatropha oil as a potential non-edible raw material, combined with coconut oil, to obtain better vegetable oil as fuel properties. Jatropha oil is dominated by unsaturated fatty acids with carbon chain length between 16 and 24, while coconut oil is dominated by saturated fatty acids with a carbon chain length between 12 and 16. Mixture variation between the two oils is predicted to have more favorable properties. The purpose of this study is to improve some properties of jatropha oils such as viscosity and heat value by changing the oil mix composition to transform the fatty acid molecular structure.

2. Material and Methods

2.1. Material

Jatropha oil is composed of fatty acids, most of which are eicosatrienoic acid ($C_{20}H_{34}O_2$) and linolelaidic acid ($C_{18}H_{32}O_2$). Both types of fatty acids have double bonds or are unsaturated fatty acids. Coconut oil is composed of lauric acid ($C_{12}H_{24}O_2$) and myristoleic acid ($C_{14}H_{26}O_2$). Most of the constituent fatty acids are saturated fatty acids with medium chains. The properties of jatropha oil and coconut oil compared to diesel fuel can be seen in Table 1.

Table 1. Properties of jatropha oil, coconut oil and diesel fuel.

Properties	Diesel Fuel	Coconut Oil	Jatropha Oil
Calorific Value (MJ/kg)	46 [a]	31.255	36.398
Density at 40 °C (kg/m^3)	855.2 [a,b]	885.95	941.28
Kinematic Viscosity at 40 °C (cSt)	4.27 [a]	29.35	246.47
Flash Point (°C)	60 [a]	249	224

[a] [13]; [b] Density at 15 °C (kg/m^3).

2.2. Fatty Acid Composition

The fatty acid composition of jatropha oil and coconut oil was tested using Gas Chromatography. A comparison of the fatty acid composition of both vegetable oils is shown in Table 2.

The content of fatty acids in jatropha oil and coconut oil is presented in Table 2. Jatropha oil is mainly composed of oleic acid (C 18:1) of 14.78% and eicosatrienoic acid (C 20:3) of 80.66%. Pure coconut oil is mainly composed of lauric acid (C 12:0) of 47.22%, myristoleic acid (C 14:1) of 18.55%, and palmitoleic acid (C 16:1) of 9.41%.

Table 2. Fatty acids contents (%).

Fatty Acid	Molecular Formula	Abbreviation	Coconut Oils	Jatropha Oils
Caproic	$C_6H_{12}O_2$	C 6:0	0.35	-
Caprilic	$C_8H_{16}O_2$	C 8:0	6.49	-
Capric	$C_{10}H_{20}O_2$	C 10:0	5.79	-

Table 2. *Cont.*

Fatty Acid	Molecular Formula	Abbreviation	Coconut Oils	Jatropha Oils
Lauric	$C_{12}H_{24}O_2$	C 12:0	47.22	-
Tridecanoic	$C_{13}H_{26}O_2$	C 13:0	0.7	-
Myristoleic	$C_{14}H_{26}O_2$	C 14:1	18.55	-
Pentadecanoic	$C_{15}H_{30}O_2$	C 15:0	0.19	-
Palmitic	$C_{16}H_{32}O_2$	C 16:0		1.79
Palmitoleic	$C_{16}H_{30}O_2$	C 16:1	9.41	
Cis-9-Oleic	$C_{18}H_{34}O_2$	C 18:1		14.78
Linoleic	$C_{18}H_{32}O_2$	C 18:2	3.08	2.17
Linolelaidic	$C_{18}H_{32}O_2$	C 18:2	8.23	
Cis-11,14-Eicosadienoic	$C_{20}H_{36}O_2$	C 20:2		0.6
Cis-8,11,14-Eicosatrienoic	$C_{20}H_{34}O_2$	C 20:3		80.66

2.3. Experiments

Jatropha oil and coconut oil were processed into samples by mixing, heating and stirring. 900 mL of jatropha oil was mixed with 100 mL of coconut oil so that the total volume was 1000 mL (90%:10% volume ratio). The mixture was placed in a beaker glass. Furthermore, the mixture was stirred and heated using the apparatus as shown in Figure 1. Stirring was conducted at 90 °C for 30 min.

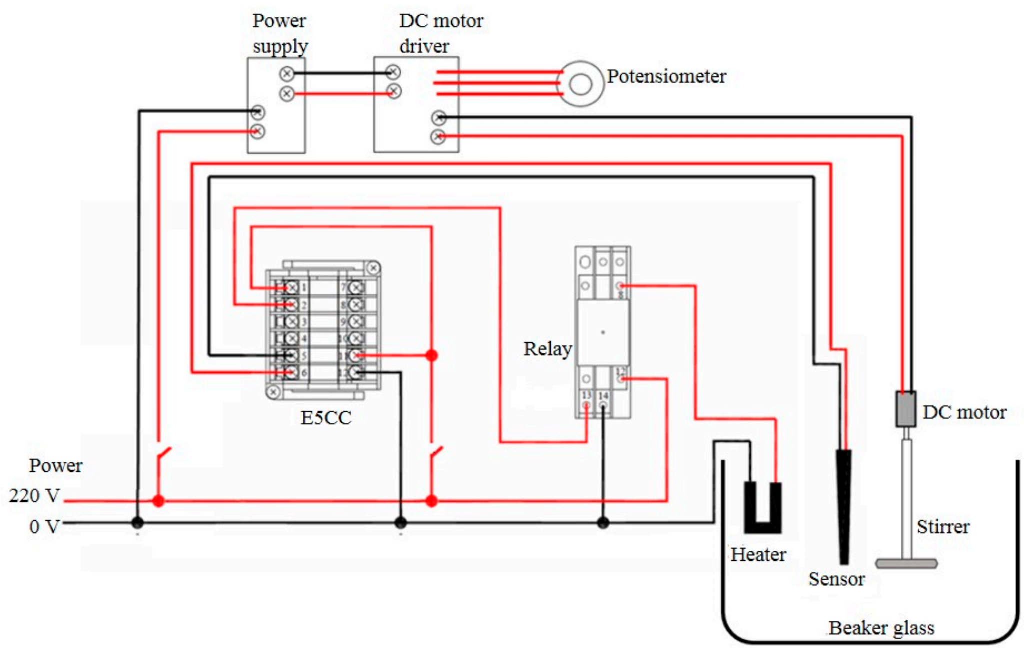


Figure 1. Heater and stirrer.

The same procedure was done on the other mixture variations in which the volume ratio of jatropha oil: coconut oil was 80%:20%, 70%:30%, 60%:40%, 50%:50%, 40%:60%, 30%:70%, 20%:80% and 10%:90%.

A further test was also carried out to determine the density, viscosity, fatty acid composition, flash point, and heat value of the mixture. Density testing was done by weighing 50 mL samples at 40 °C using Fujitsu FS-AR210 (Fujitsu Quality Laboratory Limited, Kanagawa, Japan) digital scales. The density (ρ) was obtained by calculating the mass over the volume of the sample.

Viscosity measurements of the sample were made using an NDj 8 S Viscometer (WANT Balance Instrument Co., Ltd., Changzhou, China). A total of 800 mL of sample was placed in a beaker glass and conditioned at 40 °C. The rotor type and rotation speed of the rotor were adjusted to the approximate viscosity.

The fatty acid composition of the mixture was tested using Shimadzu Gas Chromatography (GC) 2010 (Shimadzu Corporation, Kyoto, Japan). The test step was that 0.5 mL of sample was added to 1.5 mL of methanolic sodium solution, heated at 70 °C for 5–10 min and shaken. The sample was then left to cool, and 2 mL of Boron trifluoride metanoic was subsequently added and heated at 70 °C for 5–10 min. It was left to cool again, and then it was extracted with 1 mL of Heptane and 1 mL of saturated NaCl. The top layer was moved, then the sample was put into an Eppendorf, and as much as 1 µL was injected into GC.

The calorific value test was performed according to the ASTM D 240-02 method, using Bomb Calorimeter Parr 6050 (Parr Instrument Company, Moline, IL, USA). The combustion heat (calorific value) was obtained by burning samples in an oxygen calorimeter bomb.

Flash points were measured using the Cleveland Open Cup method. The oil sample was heated to the specified level and the correct size of the test flame was periodically directed to the vapor of the sample. The temperature of the oil in which the steam explodes was marked as a flash point.

3. Results and Discussion

3.1. Fatty Acid Composition

Jatropha oil has a fatty acid composition that is dominated by unsaturated fatty acids, while coconut oil is dominated by saturated fatty acids with relatively short chains. The fatty acid composition of the oil mixtures is presented in Table 3.

Table 3 shows that eicosatrienoic acid is the main constituent of jatropha oil. Eicosatrienoic acid is a long chain fatty acid with a carbon chain of 20 and has 3 double bonds. The molecular weight of an eicosatrienoic acid is 306.48. Since it is a long-chain fatty acid, the interaction forces between molecules are relatively strong, so eicosatrienoic acid has a high viscosity.

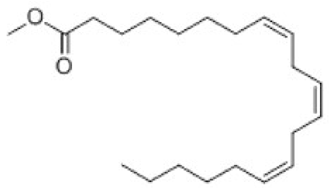
Coconut oil contains 47.22% lauric acid, which is a saturated chain fatty acid with a carbon chain length of 12. Lauric acid's molecular weight is 200.32, its kinematic viscosity is 2.43 mm^2/s, its density is 0.8694 g/cm^3 and its heating value (HV) is37.968 MJ/kg [19,20]. Because it is a medium-chain fatty acid, the interaction forces between molecules are relatively smaller, so lauric acid has a lower viscosity.

The dominant fatty acid in jatropha oil is cis-8,11,14 eicosatrienoic acid (see Table 2). This fatty acid is a long chain fatty acid having three double bonds. The positions of the double bonds are on the 8th, 11th and 14th chains. The heating and stirring of pure jatropha oil causes a change of the double bond positions to the 11th, 14th and 17th chains. Table 3 shows that heated and stirred pure jatropha oil contains cis-11,14,17 eicosatrienoic acid of about 87.19%. The change of double bond position in eicosatrienoic acid is shown in Figure 2. This heating process does not cause the carbon chain bond to break.

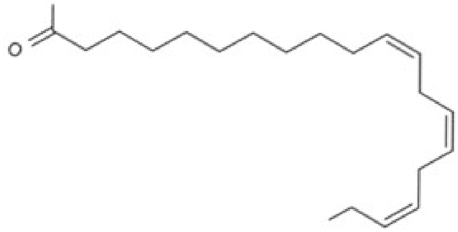
However, by heating and adding 10% coconut oil there is a breaking of carbon bonds, where cis-11,14,17 eicosatrienoic acid (C 20:3) turns into fatty acids with shorter chains. Mixing between the jatropha oil and coconut oil accompanied by heating causes the breaking of the C bond around the double bond. This happens because the electrons in the double bond move more freely, so the double bonds are more unstable and more easily to react. The viscosity of coconut oil is much lower than the viscosity of jatropha oil. Mixing coconut oil with jatropha oil causes the initial viscosity of the oil mixture to be lower than the viscosity of pure jatropha oil. This provides for the ease of breaking the bond at the specified heating temperature. The coconut oil contains polar fatty acids, so it has a greater interaction force. The heating and assistance from by the intermolecular force of the polar molecule of the coconut oil makes it easier to break carbon bonds around the double bond. The fatty acids formed from the cis-11,14,17 eicosatrienoic acid change are mainly linolelaidic acid (C 18:2), linoleic acid (C 18:2), palmitoleic acid (C 16:1), and lauric acid (C 12:0). As can be seen in Table 3, on mixing between 90% jatropha oil and 10% coconut oil, the eicosatrienoic acid content decreases drastically to 0.98%, and the linolelaidic, linoleic, palmitoleic, and lauric acid content becomes 43.17%, 7.28%, 9.45%, and 21.57%, respectively. Figure 2 shows the change in the structure of cis-8,11,14 eicosatrienoic acid to a shorter fatty acid.

Table 3. Fatty acid composition of jatropha oil and coconut oil mixture.

Fatty Acid.	Formula	Percentage of Jatropha Oils										
		0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Caproic	C 6:0	0.38	-	-	-	-	-	-	-	-	-	-
Caprilic	C 8:0	6.80	6.53	6.56	6.41	5.97	5.85	5.71	5.22	3.9	2.82	-
Capric	C 10:0	6.03	5.8	5.78	5.61	5.37	5.18	4.92	4.44	3.54	2.34	-
Lauric	C 12:0	48.46	47.44	47.06	45.82	44.85	43.11	40.66	37.6	32.39	21.57	-
Tridecanoic	C 13:0	0.32	-	-	-	-	-	-	-	0.23	-	-
Myristoleic	C 14:1	18.35	18.55	18.33	17.83	17.55	16.87	15.82	14.43	12.75	7.99	-
Pentadecanoic	C 15:0	0.11	-	-	-	-	-	-	-	-	-	-
Palmitic	C 16:0	-	-	-	-	-	-	-	-	-	-	1.20
Palmitoleic	C 16:1	8.90	9.46	9.44	9.44	9.57	9.65	9.6	9.46	9.73	9.45	-
Cis-9 Oleic	C 18:1	7.72	-	-	-	-	-	-	-	-	-	9.82
Linoleic	C 18:2	2.93	12.17	3.2	3.4	3.19	3.67	4.2	4.8	5.79	7.28	-
Linolelaidic	C 18:2	-	-	9.56	11.32	13.17	15.33	17.9	23.06	30.63	43.17	1.42
Linolenic	C 18:3	-	-	-	-	0.1	-	0.18	-	-	0.84	-
Cis-11 Eicosenoic	C 20:1	-	-	-	-	-	-	0.23	-	-	0.92	-
Cis-11,14 Eicosadienoic	C 20:2	-	-	-	-	-	-	-	-	-	-	0.37
Cis-8,11,14 Eicosatrienoic	C 20:3	-	-	-	-	-	-	0.24	0.28	-	0.98	-
Cis-11,14,17 Eicosatrienoic	C 20:3	-	-	-	-	-	-	-	-	-	-	87.19
Docosanoic	C 22:0	-	0.07	0.1	0.18	0.25	0.36	0.56	0.73	1.05	2.26	-



(**a**) cis-8,11,14-eicosatrienoic acid (C 20:3): pure jatropha oil before heating



(**b**) cis-11,14,17-eicosatrienoic acid (C 20:3): pure jatropha oil after heating

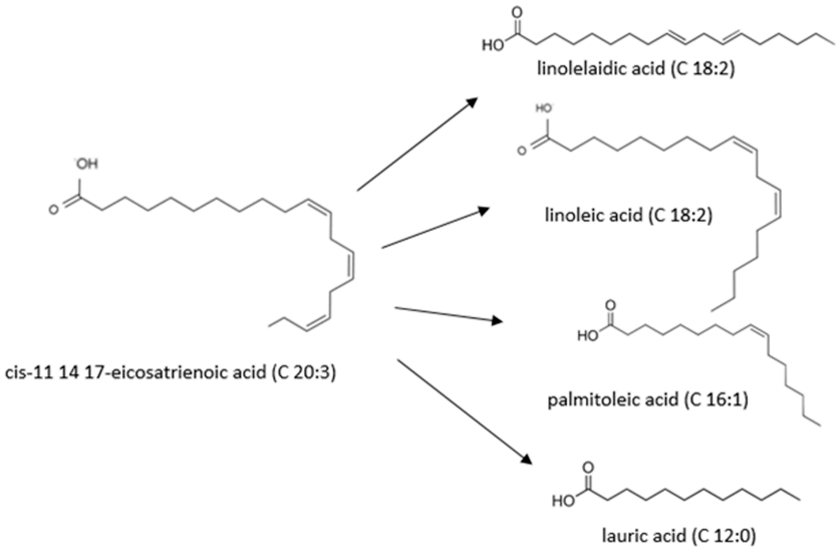


Figure 2. Changes in the position of the double bond and changes in the structure of cis-8,11,14 eicosatrienoic acid to a shorter fatty acid.

In an oil mixture with 10% to 40% coconut oil, the higher the coconut oil percentage, the lower the initial viscosity of the oil mixture. This is due to the higher percentage of lauric acid formation that reduces quite drastically the percentage of polyunsaturated fatty acids (Table 4). However, in a mixture in which coconut oil is dominant, the initial viscosity is relatively much lower, as is the amount of eicosatrienoic acid, so the change is not significant. The above conditions also affect the degree of unsaturation and the average length of the carbon chain as shown in Table 5.

Table 4. The content of saturated mono-unsaturated, and unsaturated fatty acids for each composition of the oil mixture.

Molecular Structure	**Percentage of Jatropha Oil**										
	0%	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**
Saturated	62.10	59.84	59.5	58.02	56.44	54.50	51.85	47.99	41.11	28.99	1.20
Mono-unsaturated	34.97	28.01	27.77	27.27	27.12	26.52	25.65	23.89	22.48	18.36	9.82
Poly-unsaturated	2.93	12.17	12.76	14.72	16.46	19.00	22.52	28.14	36.42	52.27	88.98

Table 3 shows that with an increasing percentage of jatropha oil, the percentage of linolelaidic acid (C 18:2) also increases. Linoleaidic acid is a fatty acid with a C 18 chain length and two double bonds. While the percentage of coconut oil increases, the percentage of lauric acid (C 12:0) and myristoleic acid (C 14:1) also increases.

The increase of linolelaidic acid level means that the unsaturation degree of the oil mixture and the average length of the carbon chain. Conversely, the higher percentage of lauric acid means a lower unsaturation degree of the mixture and a lower average chain length.

Table 4 shows the percentage of polyunsaturated fatty acids, mono-unsaturated fatty acids, and saturated fatty acid in each oil-mixture composition. It shows that pure coconut oil is dominated by saturated fatty acids, while pure jatropha oil is dominated by unsaturated fatty acids. A high percentage of jatropha oil in the mixture causes a decrease in the saturated fatty acid content. Mono-unsaturated fatty acids are more dominant in non-polar fats, while saturated fatty acids and poly-unsaturated fatty acids are more dominant in polar lipids [21,22].

The unsaturation degree and average length of the carbon chain of each oil mixture composition is calculated on the basis of Gas Chromatography testing. The Kay rule mixing equation can be used for the calculation [23]. Equations (1) and (2) are used to calculate the carbon chain length and the unsaturation degree of the oil mixture, respectively.

$$\text{Carbon chain length} = \sum_i \frac{n_i C_i}{100} \quad (1)$$

$$\text{Degree of unsaturation} = \sum_i \frac{n_i B_i}{100} \quad (2)$$

For each fatty acid component, n_i is the weight percentage of fatty acid, C_i is the number of carbon atoms in the fatty acid and B_i is the unsaturation degree of fatty acid in the component.

Table 5. The average length of the carbon chain and the degree of unsaturation of fatty acids in the composition of the oil mixture.

Parameter	Percentage of Jatropha Oils										
	0%	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**
Average Chain Length	12.95	13.11	13.15	13.27	13.40	13.56	13.81	14.14	14.71	15.79	19.73
Degree of Unsaturation	0.408	0.523	0.533	0.567	0.601	0.645	0.711	0.804	0.953	1.247	2.750

The results of the calculations are shown in Table 5. It is seen that the higher the percentage of jatropha oil in the mixture, the higher is the unsaturation degree of the mixture and the higher is the average length of the carbon chain. However, the change of average length of the carbon chain and of degree of unsaturation is not linear with the change of percentage of mixture of both oils. This reinforces the results presented in Table 4.

3.2. Density

The amount of fuel mass that can be injected into the combustion chamber depends on the density of the fuel. Thus the air-fuel ratio (AFR) and the energy content of the fuel entering into a combustion chamber is affected by the density of the fuel.

The density of pure coconut oil at 40 °C is 0.886 kg/L, while the density of pure jatropha oil is 0.941 kg/L. The density of the oil mixture increases with a higher percentage of jatropha oil. Figure 3a,b illustrate the density of the oil mixture, compared with the degree of unsaturation and the average length of the carbon chain.

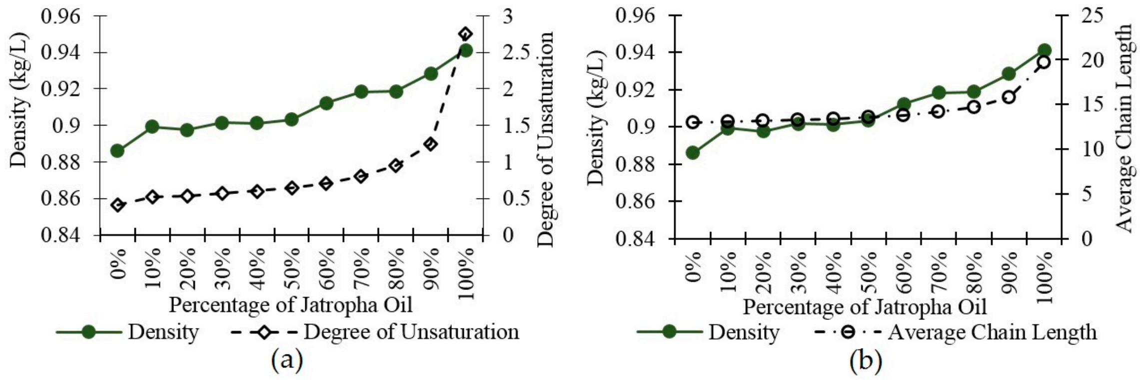


Figure 3. (**a**) Density of jatropha oil and coconut oil mixture and degree of unsaturation; (**b**) Density of jatropha oil and coconut oil mixture and average chain length.

The density of the oil mixture is affected by the unsaturation degree. The higher the unsaturation degree of the oil is, the higher the density is [17]. Figure 3a shows the density and degree of unsaturation of coconut oil, jatropha oil and their mixtures. Polyunsaturated fatty acids are more likely to be polar [21,22], and the interaction force between molecules that occur are dipole-dipole interactions. These interaction forces are greater than the interaction of non-polar molecules, causing the distance between molecules to be closer and therefore the density to be higher. Figure 3a shows that the higher the unsaturation degree, the higher the density.

Figure 3b shows the density and average carbon chain length of coconut oil, jatropha oil, and their mixtures. The longer the carbon chain, the larger the molecular size is. This results in higher densities [24].

The density of the mixture of palm and soybean oils in the previous study was reported as ranging from 0.909 g/mL to 0.925 g/mL [25]. The insignificant change may due to the insignificant difference in carbon chain length and the degree of unsaturation of both oils.

3.3. Viscosity

Viscosity is one of the most important properties in fuel because it affects the fuels' spray. High viscosity leads to a larger size of the spray droplets, the greater difficulty of vaporizing the fuel, and narrower of vapor injections [14].

Viscosity is affected by the degree of unsaturation and fatty acid chain length. A longer carbon chain leads to an increase in viscosity, and a decreasing degree of unsaturation also leads to an increase in viscosity [17]. However, in this research, the opposite occurs, where viscosity increases with increasing levels of unsaturation. This happens because the molecular weight is more influential on viscosity than the degree of unsaturation [26]. Vegetable oil is composed of several fatty acid molecules. The fatty acids can mix in a liquid state because of the interaction between the molecular forces called van der Waals forces. The van der Waals forces are influenced by polarity, molecular size, number of atoms and molecular shape. Viscosity is influenced by the interaction forces between these molecules.

Mixing jatropha oil with coconut oil causes a change in fatty acid composition. The change in the composition affects the viscosity of the blend oils. Figure 4a,b show the kinematic viscosity of jatropha oil, coconut oil, and their mixtures. The viscosity of coconut oil at 40 °C is 29.35 mm^2/s. Compared to coconut oil, jatropha oil has a relatively high viscosity of 246.47 mm^2/s at 40 °C, almost 9 times higher than that of coconut oil. The viscosity of coconut oil and jatropha oil still does not meet the biodiesel viscosity standard.

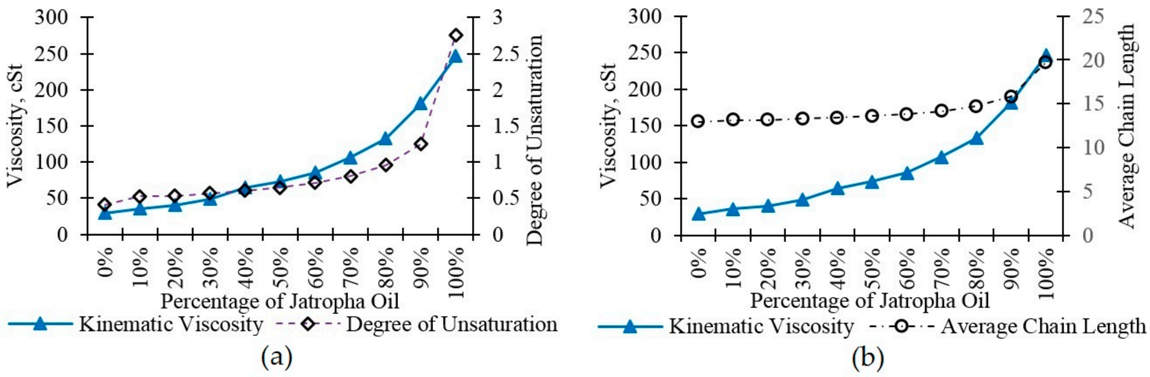


Figure 4. (**a**) Viscosity of mixture of jatropha oil and coconut oil and degree of unsaturation; (**b**) Viscosity of mixture of jatropha oil and coconut oil and average chain length.

Figure 4b shows the viscosity and average length of the carbon chain on the composition of the oil mixture. As the viscosity level increases, the amount of long fatty acid chains increases as well. The higher the percentage of jatropha oil is, the more fatty acids with long chains there are. The longer the molecular chain, the relatively stronger the interaction force between molecules is. This results in higher viscosity [20].

Considered from the perspective of the kinematic viscosity of jatropha oil, the kinematic viscosity of the mixture is decreases with an increasing percentage of coconut oil mixture. The viscosity of the oil mixture varies between 35.59 mm^2/s and 180.94 mm^2/s. It corresponds to the unsaturation degree and carbon chain length. Since the average length of the carbon chain and degree of unsaturation are not linear with the percentage of the oil mixture, the change in the viscosity of the mixture is also not linear with the percentage of the oil mixture. Mixing jatropha oil with coconut oil with a ratio of 90%:10% decreases the viscosity of jatropha oil about 27.59% while mixing with an 80%:20% ratio decreases the viscosity around 47.41%. This is due to drastic changes in the length of the chain and the level of unsaturation in the composition (see Table 5). The decreased percentages of saturated fatty acids and poly-unsaturated fatty acids that tend to be polar cause a weakening of the interaction force between molecules, resulting in decreased viscosity.

From the previous study, the viscosity of the mixture reported was changed linearly from 29.3 cP for pure palm oils up to 36.7 cP for pure soybean oils [25]. Unlike the fatty acid of the soybean oil which is dominated by polar fatty acid, the polar fatty acid content of palm oil was not dominant. In addition, there is no significant difference in carbon chain length and degree of unsaturation in both oils.

3.4. Heating Value

The calorific value of jatropha oil is 36.4 MJ/kg, while for coconut oil is 36.2 MJ/kg. The calorific value of jatropha oil increases after mixing it with coconut oil with a volume ratio of 90%:10% and so on. Similarly, the calorific value of coconut oil increases significantly after being mixed with jatropha oil.

Figure 5a,b show the calorific value of the mixture of jatropha oil and coconut oil. In this oil mixture, the higher the percentage of jatropha oil, the higher the average length of the carbon chain and the degree of fatty acid unsaturation. Both of these matters affect the calorific value of oil so that the calorific value of the mixture is higher than that of the pure oil. The calorific value of the oil mixture increases, but is almost the same in all mixture compositions. This is because a longer carbon chain would increase the heating value, while on the other hand, a higher degree of unsaturation would slightly lower the heating value.

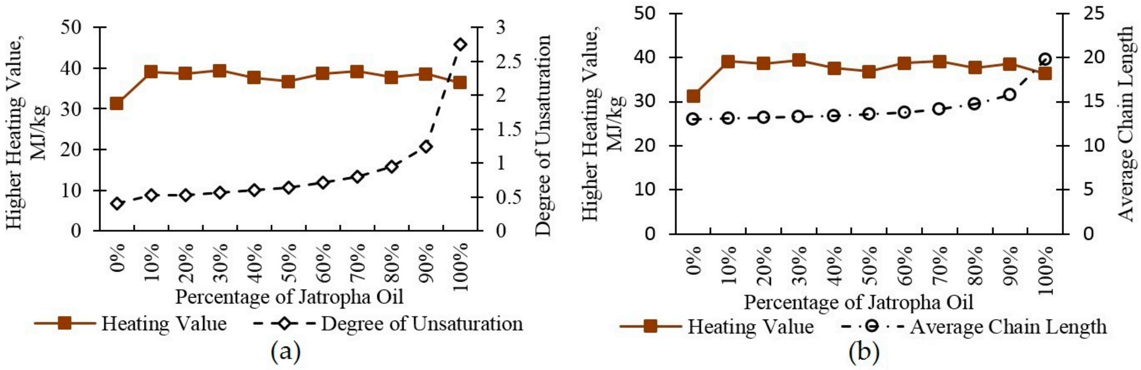


Figure 5. (**a**) Heating value of the jatropha oil and coconut oil mixture and the degree of unsaturation; (**b**) Heating value of the jatropha oil and coconut oil mixture and the average carbon chain length.

Previous studies have shown that the higher the average carbon chain length of a fatty acid, the higher the calorific value of the oil, is, so a higher degree of unsaturation of fatty acids would have little effect on the reduction of the oil's calorific value [17].

The increase in calorific value of the oil mixture is 1.65–8.9% compared to the calorific value of pure coconut oil. Meanwhile, when viewed from the perspective of pure jatropha oil, the increase in calorific value of the oil mixture is 1.06–8.27%.

In the mixture of mahua and simarouba oils which contains 46.3% and 59.1% oleic acid, it was found out that the effect of the mixture ratio on the calorific value of the oil was not significant. The calorific values (higher heating values) of biodiesels obtained from different mixtures of oils were very close to each other and were around 37 MJ/kg as compared to 42.5 MJ/kg for High Speed Diesel (HSD) [27].

3.5. Flash Point

The flash point is one of the important properties in liquid fuels. The flash point is the lowest temperature where a liquid produces a sufficient amount of steam to ignite. A higher flash point makes the fuel more difficult to burn.

The tests show that, the flash point of jatropha oil is 224 °C, while the flash point of coconut oil is 249 °C. Mixing the two oils in various mixed compositions gives a flash point that is a bit lower than that of the pure oils. The values of the flash points of the oil mixtures can be seen in Figure 6.

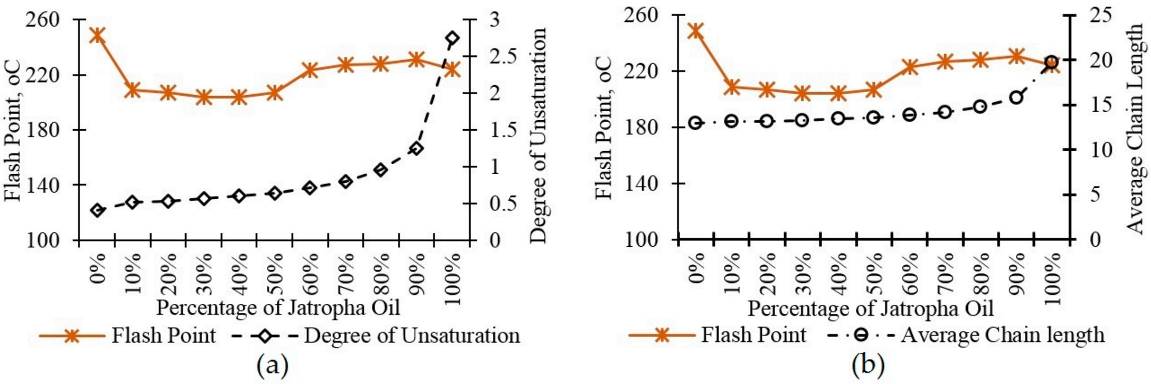


Figure 6. (**a**) Flash points of jatropha oil and coconut oil blends and degree of unsaturation; (**b**) Flash points of jatropha oil and coconut oil blends and average chain length.

The flash point decreases after the two oils are mixed. For the 10% mixture of jatropha oil, the flash point drops to 209 °C. The decrease of flash point continues up to the levels of 50% jatropha oil. For the 10% to 50% mixture of jatropha oil, the percentage of saturated fatty acids and poly-unsaturated fatty acids is less than that of the 60–100% mixture. This causes the van der Waals forces to decrease. The lower the van der Waals force, the less energy needed to evaporate the oil. This causes the flash point to drop [28].

The current results are consistent with those reported by Mejia for palm-castor biodiesel blends. The flash point of the mixed oil increases with the increase of castor biodiesel content. At 20 vol % palm biodiesel content, the flash point was increased significantly. The flash point of pure palm biodiesel is 164 °C, while that of pure castor biodiesel is 286 °C [29].

4. Conclusions

Jatropha oil is mainly composed of eicosatrienoic acid which causes it to have high density and viscosity. Many efforts have been done successfully to improve the properties of jatropha oil by heating and mixing with coconut oil. Both of the oils are dominated by polar fatty acids. The polar fatty acids provide an intermolecular force that facilitate the disconnection of carbon bonds during heating. Heating and stirring can cause fatty acid molecules to break up into shorter molecules. As a result of this process, eicosatrienoic acid consisting of three double bonds turns into linoleic acid, linoleic acid, palmitoleic acid and lauric acid.

Thus, in each mixed composition there is a change of degree of unsaturation and average length of the carbon chain. The shorter the carbon chain, the smaller the molecular size. This leads to decreasing density. The shorter carbon chain also causes a decrease in the interaction forces between molecules, resulting in lower viscosity. The changes in the length of the chain and the degree of unsaturation have the effect of increasing the heating value of the mixture.

With this mixing and heating method, the kinematic viscosity of jatropha oil decreases while the calorific value increases, resulting in a better oil mixture. The benefits of this mixture in practical use are as diesel fuel, either directly in a dual fuel engine or mixed with diesel oil.

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