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The effect of fatty acid polarity on the combustion characteristics of vegetable oils droplets

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Abstract. The effect of fatty acid polarity on the combustion characteristics of vegetable oils droplets, CCO and CJO vegetable oil droplets have been studied experimentally with atmospheric pressure and room temperature. The role of intermolecular forces on the combustion characteristics of vegetable oils droplets. CCO and CJO are multicomponent vegetable oils, CCO represents saturated fatty acids while CJO represents monounsaturated fatty acids. The results showed that the burning rate of vegetable oil was influencing by the polarity of the fatty acids that compose it. CCO is dominated by polar fatty acids which shows a stable flame and around a flame shape. CJO which is dominated by non-polar fatty acids the results show an increase in the rate of combustion, the presence of microexplosion and the form of an elongated flame. The large CCO polarity causes the CCO to be more reactive, fast ignition of round and stable flame forms. The small CJO polarity causes the CJO molecules to be less reactive and slow to ignite. the shape of the flame on CJO extends upwards with microexplosion while in the CCO the way of the round flash. This is because of the different fatty acid content and geometry in each vegetable oils.

Keywords: Droplet, fatty acid, polarity, Crude Coconut Oil, Crude Jatropha oil, burning rate.

1. Introduction

Vegetable oil is composed of triglycerides consisting of three fatty acids combined with glycerol. This fatty acid contains a long carbon chain, connected by one bond, combined with hydrogen and ends with a carbonyl group [1]. An alkyl long string in fatty acids causes oil to be suitable for combustion with a compression ignition system [2]. The advantage of using vegetable oils is that they are available, renewable, low in sulfur and biodegradable [3]. The disadvantages of using vegetable oils are high viscosity and low evaporation rates. Vegetable oil has been using as an alternative fuel for diesel engines [4].

The characteristics of fuel combustion based on properties can be known by the method of attractive single droplet analysis [5]. The nature of combustion of droplets is very likely to be affected by fuel properties such as volatility, reactivity and molecular structure. The molecular fuel structure refers to the length and degree of unsaturation of the carbon chain, namely double and triple bonds [6]. Based on saturation, vegetable oils can be dividing into short chain saturated acids (short-chain fatty acids), a medium chain saturated fatty acids (medium chain fatty acids), and long-chain saturated fatty acids (long chain fatty acids).

Substances that are polar or non-polar are distinguishing at the level of electronegativity. The higher the electronegativity of a molecule, the colder extreme the electron is [7]. The polar and non-polar characteristics of triglycerides, the number of molecular masses and the instability of carbon-chain bonds have been discussed by [8]; [9]. Polar fatty acids dominate CCO (saturated fatty acids) and CSFO (polyunsaturated fatty acids) while non-polar fatty acids dominate CJO. CJO is non-polar, more saturated and stable, making it difficult for the catalyst to dissolve in oil. This phenomenon shows that non-polar CJO is more saturated than polar compounds [10].

The effect of adding Rh3 + catalyst to the combustion characteristics of vegetable oil droplets CCO, CJO, CSFO is discussed by [9]. The results show that the addition of a catalyst not only affects changes in triglyceride geometry but activates electrons because of the hydrogen attractions on the catalyst. But his research did not reveal the relationship of polarity with intermolecular force and its effect on the burning rate. The focus of this research is to examine the impact of fatty acid polarity on the characteristics of droplet burning, primary the burning rate. The vegetable oil chosen is CCO and CJO which represent saturated, and monounsaturated.

2. Experiments

2.1. Properties measurement

This study uses two kinds of Crude Vegetable Oils (CVO), namely Crude Coconut Oil (CCO), and Crude Jatropha Oil (CJO). CCO represents saturated, and CJO represents monounsaturated.

Tabel 1. Properties of crude vegetable oil

Properties	Crude Coconut Oil	Crude Jatropha Oil
Caloric value (cal/gr)	91.33	94.00
Density at 15^{o}C (gr/mol)	0.925	0.917
Viscosity at 40^{o}C (cSt)	36.5	35.52
Pour point (^{o}C)	18	-4
Cloud point (^{o}C)	28	3
Cetane mumber	28	30
Flash point	263	85
CCO and CJO[9]		

Tabel 2. Fatty acid composition

Chemical	Composition	Cn:db	Formula Structure	Composition %		molecular mass,g/mole
				CCO	CJO	
Caprylic	8:0	$C_8H_{16}O_2$	$CH_3(CH_2)_6COOH$	8.45	1.70	144.2114
Lauric	12:0	$C_{12}H_{24}O_2$	$CH_3(CH_2)_{10}COOH$	31.43	7.71	200.3178
Myristic	14:0	$C_{14}H_{28}O_2$	$CH_3(CH_2)_{12}COOH$	18.45	3.29	228.3709
Palmitic	16:0	$C_{16}H_{32}O_2$	$CH_3(CH_2)_{14}COOH$	8.4	14.62	256.4241
Stearic	18:0	$C_{18}H_{36}O_2$	$CH_3(CH_2)_{16}COOH$	1.65	7.36	284,4772
Oleic	18:1	$C_{18}H_{34}O_2$	$CH_3(CH_2)_7CH=CH(CH_2)_7COOH$	5.7	30.38	282,4614

CCO and CJO[9]

2.2. Experimental apparatus

This study aims to examine the characteristics of evaporation and ignition of droplet vegetable oils. The droplet test method uses 1 mm suspended droplets placed on the thermocouple end (2) then heated to a burn using a heater (3) which is 3 mm apart from the droplet. Thermocouple (2) used is type K with a diameter of 0.1 mm. The heater used is an electric coil in the form of a metal coil, made from Ni-Cr. The energy source of a heater is a 220-volt alternating current which is converting to 12-volt direct current. Droplets are made using microsyringes, and burning is doing at atmospheric pressure, and room temperature is standard. Fire temperature is measured using a thermocouple connected to a data logger (8), where the reading uses an excel program on a computer (7). The flame was taken using a Nikon D3300 camera (6).

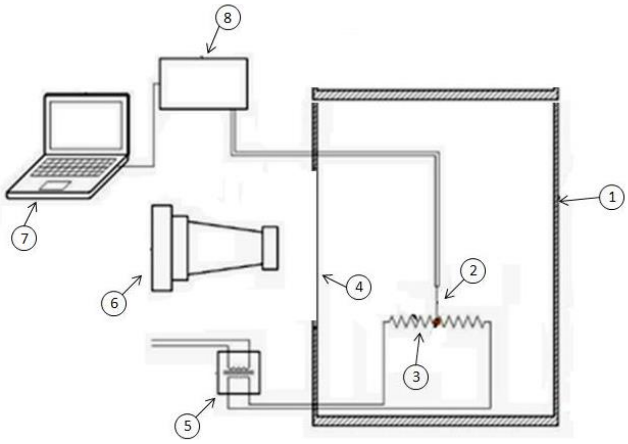


Figure 1. Eksperimental appartus.

3. Result and Discussion

Fig. 2 shows changes in CVO droplet diameter during combustion. The results showed that CVO diameter decreased linearly with time. Polar fatty acid dominated CCO because CCO is composed of short chain saturated fatty acids namely Lauric, Myristic and caprylic (table.2.). Due to the glacial fatty acid CCO, it causes the dipole-dipole attraction (Van der walls) style on the strong CCO. Strong dipole-dipole pull force causes CCO to be more stable than CJO. Fig. 2. the decrease in droplet diameter in CCO is more stable than in CJO. Burning rate on CCO takes a short time compared to CJO. The mass of a CCO molecule is smaller than CJO, so it evaporates quickly and is more flammable.

Non-polar fatty acid dominated CJO because CJO is composed of oleic, palmitic, stearic (table.2). On CJO the non-polar intermolecular force that occurs in London style. CJO has a large London style because of its large molecular mass. So that it is easily deformed because the outer electrons tend to be unbound (easily released). Thus the London style will be more easily formed. In addition to large molecules, CJO also has more atoms. The number of atoms in a molecule, the higher the strength of the London style. Because the Van der walls force is stronger than the London style, the CCO intermolecular force is stronger than CJO which results in CJO being less stable.

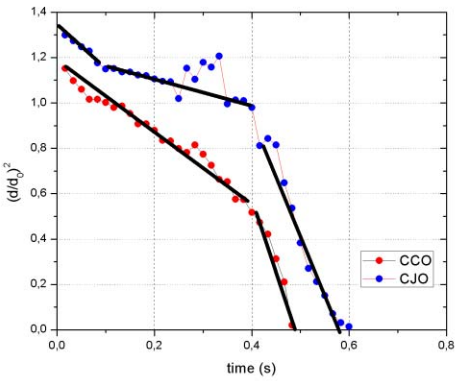
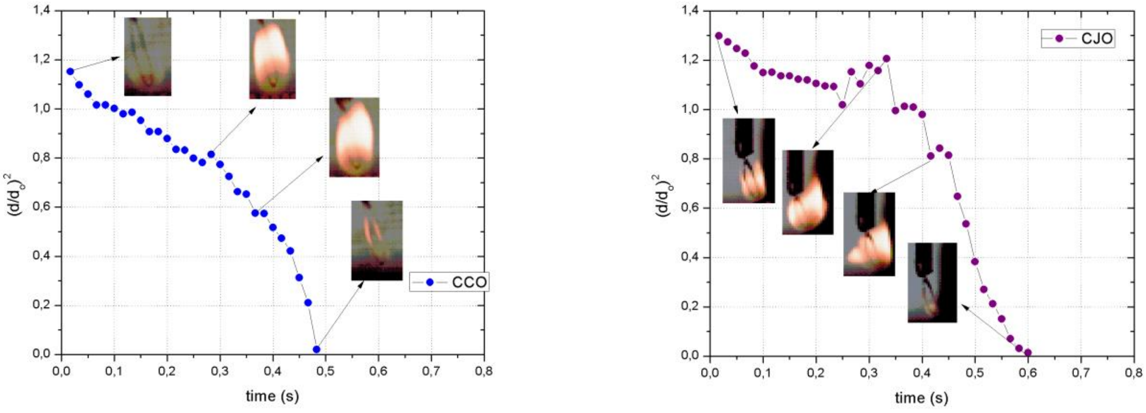


Figure 2. The d^2 plot for burning rate droplets of CCO and CJO

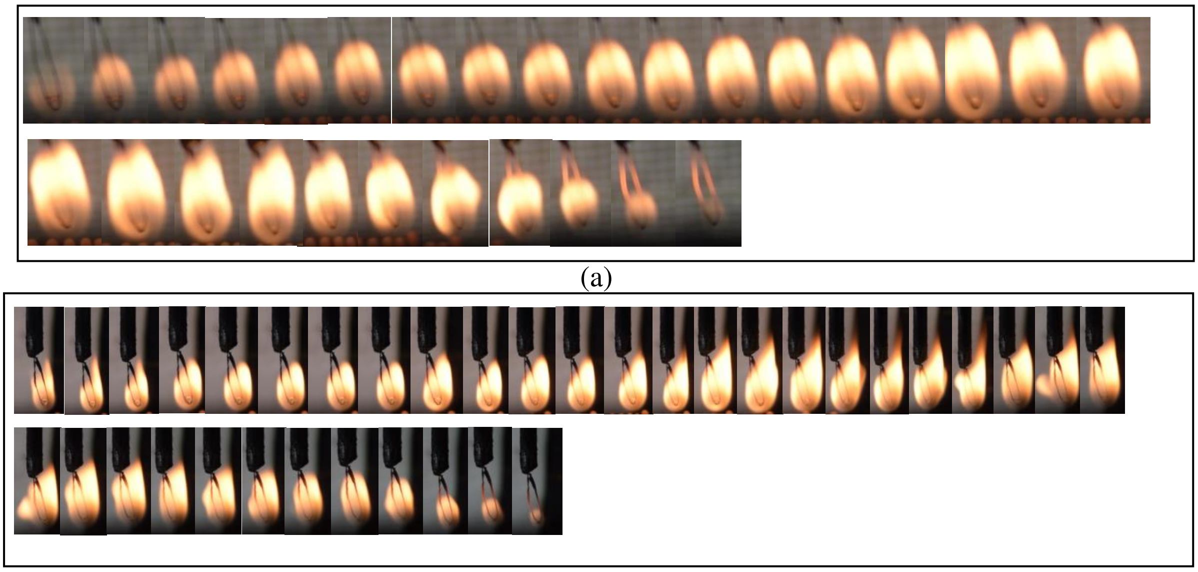
Seen in a more stable form of fire CCO, the burning rate starts from a low flame and ends with a small flash (see Fig.3.a.). Because the constituents of CCO are all straight and short fatty acids (Lauric, Myristic and Caprylic). The geometry of the same fatty acid in the CCO which causes the fire in the CCO to be more rounded and no microexplosion occurs. Whereas in CJO the form of light is more reactive, the burning rate starts directly with a massive fire (see Fig. 3.b). The most abundant fatty acids composing CJO vary, oleic crooked chains (monounsaturated), palmitic and stearic straight chains. This difference in the geometry of fatty acids in CJO results in the form of fire in CJO being more reactive, more elongated and microexplosion occurring.



(a) (b)

Figure 3. The d2 plot for burning droplets of CVO. (a). CCO (b). CJO

Seen in Fig. 4 fire visualisation when burning rate. In CCO the form of stable flame is round (Fig.4.a), whereas in CJO the kind of flash extends and microexplosion occurs (Fig. 4.b). The occurrence of microexplosion on the CJO causes the second atomization process. The CJO burning rate is longer than the CCO. The result is a correlation with [11]. Microexplosion shows that there is a difference in the boiling point between the fatty acid components and the different geometric shapes of the fatty acids that make up the CJO. The result is consistent with previous studies which stated that microexplosion occurs due to differences in evaporation rates, droplet size and concentration in the mixed fuels [12]; [13]; [5]. The heating of components causes microexplosion with high volatility in sweltering conditions trapped in droplets [14]; [15]. The occurrence of microexplosion can increase atomization and increase the burning rate. The shape of the flame on the CJO is shaping like a pointed spike due to the high temperature in the CJO. CJO's burning rate starts from a temperature higher than the CCO (fig. 5) which starts from 415 degrees Celsius while the CCO begins at 282 degrees Celsius. The highest temperature of CJO and CCO shows the end of the combustion process until the droplet runs out, the fire goes out then followed by a decrease in temperature. Increased temperature occurs because of the increased evaporation rate and the increase in surface area, thereby changing the behaviour of the molecules. When the evaporation rate increases the droplet diameter decreases.In the initial CJO, a reduction in viscosity occurs due to the active movement of the particle. An increase in temperature indicates the reduction in thickness. The active molecule happens because vegetable oil which is a non-polar molecule experience the weak intermolecular force, these forces are named instantaneous dipole-induced dipole or simply forces.



(a)

(b)

Figure 4. Flames evolution of CVO droplets (a). CCO (b). CJO

Figure 5 at the beginning of burning CJO absorbs more energy, while CCO at the end of combustion. Evidenced by the CJO temperature at the start of combustion is higher than CCO but at the end of burning a higher CCO temperature. CCO requires a hot time that is longer than CJO. Because the CCO has a higher viscosity and the CCO is saturated, which is composed of most short and rigid molecules. Long burning time on CCO due to CCO must pass through several stages until the droplet burns out. Results are correlating with [11] which states that CCO burns in three phases, starting with the burning of unsaturated fatty acids, followed by saturated fatty acids then ending with glycerin. Whereas CJO burns in two stages, fatty acids then glycerin. The CJO constituent fatty acids which consist of various geometric forms of fatty acids, namely oleic (monounsaturated), palmitic and stearic straight chains cause very high heating, due to continuous heat in the droplet. Starting from the burning of oleic acid, followed by stearic acid then ending with palmitic acid. The statement is stating by [14], that multi-fuel components in droplets can achieve very high heating because the volatility of various fuel components causes continuous evaporation in the droplet.

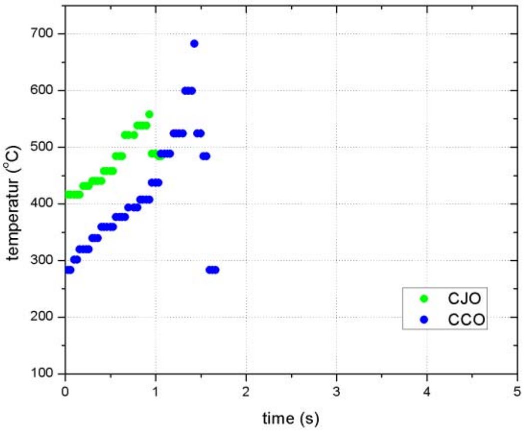


Figure 5. Temperature evolution in the centre of droplet CCO and CJO

4. Conclusions

1. Molecular polarity affects the large intermolecular forces of vegetable oil.
2. Polar fatty acid dominated CCO because it is composed of short and straight chain fatty acids which result in a quick burning rate on the CCO. CJO is dominated by monounsaturated non-polar fatty acids so that the burning rate on CJO is longer.
3. Burning rate is not only influenced by molecular polarity, but by the geometric form of fatty acids that make up vegetable oil. CCO burns in 3 stages, while CJO burns in 2 steps.
4. CJO absorbs more energy at the beginning of burning, while CCO absorbs more power at the end of combustion, due to the influence of the fatty acid geometry form the CVO.

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