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## Combustion of Pure, Hydrolyzed and Methyl Ester Formed of Jatropha Curcas Lin oil

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**ABSTRACT:** The density and viscosity of vegetable oil are higher than that of diesel oil. Thus its direct combustion in the diesel engine results many problems. This research was conducted to investigate the flame characteristics of combustion of jatropha curcas lin in pure, hydrolyzed and methyl ester form. The results indicated that the combustion of pure jatropha curcas lin occurs in three stages, hydrolyzed in two stages and methyl ester in one stage. For pure jatropha curcas lin, in the first stage, unsaturated fatty acid burned for 0.265 s. It is followed by saturated fatty acid, burned for 0.389 s in the second stage. And, in the last stage is the burned of glycerol for 0.560 s. Meanwhile for hydrolyzed one, in the first stage, unsaturated fatty acid burned for 0.736 s, followed by saturated fatty acid, burned for 0.326 s in the second stage. And the last, for methyl ester is the burned for 0.712 s. The highest burning rate was for methyl ester which was 0.003931cc/s. The energy releasing rate of methyl ester, which was for 13,628.67 kcal/(kg.s) resembled that of diesel oil the most, while the lowest rate was for pure jatropha curcas lin which was 8,200.94 kcal/(kg.s). In addition, massive explosion occurred in the fuel containing unsaturated fatty acid and glycerol.

**Keywords:** combustion, jatropha curcas lin, hydrolyzed jatropha curcas lin, methyl ester, energy releasing rate

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### 1. Introduction

The high consumption of fossil fuel increases the production CO<sub>2</sub> gas and leads to the global warming issues. Those are the main reasons of the scientist conducting a research to improve the efficiency of the use of energy and to discover the new renewable energy sources.

Recently, the development of a new technology has a tendency to improve efficiency and energy management, as well as replacing the fossil fuel usage with renewable energy. This is attributed to the fact that renewable energy shows a more environmentally friendly energy. Thus, it contributes to the reduction of global warming issues. One of the most significant renewable energy is a vegetable oil. Vegetable oil is oil

with long carbon chain. However, the direct applications of this oil cause many problems in engine due to the higher density and viscosity compared to that of diesel oil. The density and viscosity can be decreased through the esterification and transesterification processes. Those processes transform vegetable oil into methyl ester form. Previous researches on the combustion of direct, hydrolysis or transesterification of pure vegetable oil have been conducted by other researchers. According to Wardana (2010), the combustion of droplet of jatropha curcas oil burned at thermocouple intersections occurs in two stages, (1) the burning of fatty acid, followed by (2) the burning of glycerol. Further, Wirawan (2013) showed that the burning

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velocity of premixed combustion of pure and hydrolyzed coconut oil decreased when the equivalent ratio increased. Contrary, Wardana (2011) showed that the combustion rate of *jatropha curcas* lin methyl ester improved when it burned at the junction of thermocouple under magnetic field.

In addition, previous researches in application of both methyl ester and its blend to the diesel engine have also been conducted. Demirbas (2008) has found that methyl ester has a higher viscosity compared to other type of oil. It also showed a slower nebulization and lower engine performance (Demirbas 2008). Contrary, according to Kinoshita, Hamasaki, and Takashi (2007), methyl ester coconut oil improved the combustion characteristics, of diesel engine. However, it decreased the emission as well as the opacity of diesel engine (Kinoshita, Hamasaki, and Takashi 2007). Other researches (Rakopoulos *et al.* 2008; Aydin and Bayindir 2010; Fattah *et al.* 2013) found that the opacity of diesel engine decreased when it was filled with methyl ester of cottonseed. In addition, other researchers have found that *jatropha curcas* lin methyl ester could be used as mixture of diesel oil without modifying diesel engines (Rakopoulos *et al.* 2008; Satyanarayana & Muraleedharan 2011).

Although there are several studies that investigate the combustion characteristic, most of the studies merely focused on the characteristic of diesel engine with methyl ester as fuel, only limited studies have been carried out investigating the combustion characteristic of methyl ester. Thus, this study reported the investigation results of the flame characteristic of pure, hydrolyzed, and methyl ester form of *jatropha curcas* lin oil.

## 2. Material and Method

### 2.1 Composition and Physical Characteristic of *Jatropha Curcas* Lin

The chemical composition and physical properties of pure vegetable oil, hydrolyzed vegetable oil and methyl esters are shown in Tables 1, 2, and 3. Vegetable oil consists of triglyceride molecules containing 3 chained carbonate glycerol and 3 branches of fatty acid. As shown in Table 1, chemical substances of vegetable oil consist of saturated fatty acid, unsaturated fatty acid, glycerol and water. Saturated fatty acid has single bond on its hydrocarbon chain. Therefore the tensile strength of Vander Waals among its molecules is very strong (Brady 1990). This is due to the fact that each of its atom binds equally. Thus more energy is needed to separate molecules from saturated fatty acid. Meanwhile for unsaturated fatty acid which has doubled bond, because the doubled

and tripled on its edges are divided into two, the tensile strength of Vander Waals among its molecules is weak. As the result of it, the energy needed to separate its molecules is less than that of saturated fatty acid. The closer the doubled bond to its edge is, the weaker tensile strength of Vander Waals will be (Brady 1990).

Hydrolyzed vegetable oil is obtained from the first reversible reaction of pseudo-homogen orde. This reaction occurs in three steps, namely the hydrolysis of triglyceride to be diglyceride, followed by diglyceride to be monoglyceride, and the last is monoglyceride to be glycerol and fatty acid (Wirawan *et al.* 2013). Saturated fatty acid, unsaturated fatty acid and water are the chemical substances of hydrolyzed vegetable oil. As presented in Table 3 the content of the fatty acid and heating value of this kind of oil are less than that of vegetable oil. Meanwhile, compared to vegetable oil, it has higher pH. The remained water and released fatty acid during the process of hydrolyzed were the cause of this phenomenon.

Methyl ester was obtained from the transesterification triglycerides reaction, a reaction in which a long branched and chained molecule (triglyceride) was broken forming smaller straight and short chained molecule (Shereena and Thangaraj 2009). The flash point of methyl ester was lower than that of pure vegetable oil and hydrolyzed vegetable oil, but its cetana number is higher than that of diesel oil (Table 2). Methyl ester molecule contains vinegar acid ( $\text{COOCH}_3$ ) on one edge of it and methyl ( $\text{CH}_3$ ) on the other one. Thus the oxygen, hydrogen and carbon contained in methyl ester are higher compared to Fatty Acid (Table 2). Methyl ester is highly reactive, more flammable, and environmental friendly (Sastry *et al.* 2006).

### 2.2 Experiment apparatus

The experiments were conducted using experiment apparatus as shown schematically in Fig. 1. The droplets of pure *jatropha curcas* lin oil, hydrolyzed *jatropha curcas* lin oil, methyl ester, and diesel oil were dripped on stainless steel plate.

### 2.3. Measuring Technique

Pure *jatropha curcas* lin oil, hydrolized *jatropha curcas* lin oil, methyl ester and diesel oil were dripped by micropipete. Datalogger was used to measure temperature of stainless steel plate, and flame. The droplet diameter of all of those four types of oils were 1,75 mm which was equal to 0,0028 cc. It was then ignited on the heated plate with temperature of 270°C. The flames were recorded by a high speed Casio Camera ZR 200 at 420 frames/sec.

**Table 1**

The Composition of Pure Jatropha Curcas Lin and Hydrolyzed Jatropha Curcas Lin

Chemical composition types		Chemical formula	Chemical bond Structure	Chemical oil composition (%)	
				Pure jatropha curcas lin	Hidroylized Jatropha curcas lin
Saturated fatty acid	Caprylic	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>6</sub> COOH	8:0	1.62	2.13
	Capric	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>8</sub> COOH	10:0	1.84	2.25
	Lauric	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>10</sub> COOH	12:0	7.54	8.38
	Myristic	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>12</sub> COOH	14:0	3.48	4.22
	Palmitic	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>14</sub> COOH	16:0	9.55	10.25
	Stearic	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>16</sub> COOH	18:0	4.06	4.07
Unsaturated fatty acid	Oleic	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>7</sub> CH=(CH <sub>2</sub> ) <sub>8</sub> COOH	18:1	32.44	33.56
	Linoleic	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>4</sub> (CH=CHCH <sub>2</sub> ) <sub>2</sub> (CH <sub>2</sub> ) <sub>6</sub> COOH	18:2	31.35	34.42
	Glycerol	C <sub>3</sub> H <sub>5</sub> (OH) <sub>3</sub>	8:0	5.65	-
	Gum	C(CH <sub>2</sub> OH) <sub>4</sub>	10:0	2.31	-
	Water	H <sub>2</sub> O	-	0.55	0.71
Total saturated fatty acids				27.99	31.30
Total monounsaturated fatty acids				32.42	33.56
Total poly unsaturated fatty acids				31.15	34.42
Total unsaturated fatty acids				63.57	67.98
Fatty acid totals				91.56	99.28

**Table 2**

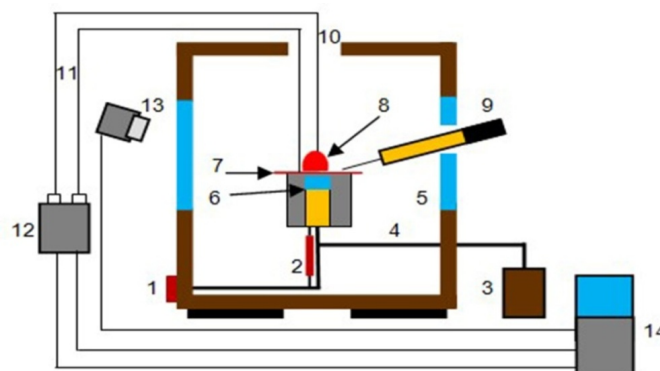
Chemical Composition and Physical Characteristic of Fatty Acid and Methyl Ester Jatropha Curcas Lin

No.	Types of fatty acid and methyl ester	Chemical formula	Chemical bond	Flash point	Cetana number
1.	Caprylic <sup>1)</sup>	$\text{CH}_3(\text{CH}_2)_6\text{COOH}$	8:0	186	-
	Methyl ester caprylic <sup>2)</sup>	$\text{CH}_3(\text{CH}_2)_6\text{COOCH}_3$	9:0	83	36.5
2.	Capric <sup>1)</sup>	$\text{CH}_3(\text{CH}_2)_8\text{COOH}$	10:0	197	-
	Methyl ester capric <sup>2)</sup>	$\text{CH}_3(\text{CH}_2)_8\text{COOCH}_3$	11:0	95	49.2
3.	Lauric <sup>1)</sup>	$\text{CH}_3(\text{CH}_2)_{10}\text{COOH}$	12:0	183	-
	Methyl ester lauric <sup>2)</sup>	$\text{CH}_3(\text{CH}_2)_{10}\text{COOCH}_3$	13:0	98	64.5
4.	Myristic <sup>1)</sup>	$\text{CH}_3(\text{CH}_2)_{12}\text{COOH}$	14:0	224	-
	Methyl ester myristic <sup>2)</sup>	$\text{CH}_3(\text{CH}_2)_{12}\text{COOCH}_3$	15:0	102	76.1
5.	Palmitic <sup>1)</sup>	$\text{CH}_3(\text{CH}_2)_{14}\text{COOH}$	16:0	223	-
	Methyl ester palmitic <sup>2)</sup>	$\text{CH}_3(\text{CH}_2)_{14}\text{COOCH}_3$	17:0	107	75.8
6.	Stearic <sup>1)</sup>	$\text{CH}_3(\text{CH}_2)_{16}\text{COOH}$	18:0	218	-
	Methyl ester stearic <sup>2)</sup>	$\text{CH}_3(\text{CH}_2)_{16}\text{COOCH}_3$	19:0	102	77.4
7.	Oleic <sup>1)</sup>	$\text{CH}_3(\text{CH}_2)_7\text{CH}=(\text{CH}_2)_8\text{COOH}$	18:1	183	-
	Methyl ester oleic <sup>2)</sup>	$\text{CH}_3(\text{CH}_2)_7\text{CH}=(\text{CH}_2)_8\text{COOCH}_3$	19:0	85	58.6
8.	Linoleic <sup>1)</sup>	$\text{CH}_3(\text{CH}_2)_4(\text{CH}=\text{CHCH}_2)_2(\text{CH}_2)_6\text{COOH}$	18:2	94	-
	Methyl ester linoleic <sup>2)</sup>	$\text{CH}_3(\text{CH}_2)_4(\text{CH}=\text{CHCH}_2)_2(\text{CH}_2)_6\text{COOCH}_3$	19:2	53	38.3

Source: <sup>1)</sup>Schreckenbach 2008), <sup>2)</sup>Bangboye & Hansen 2008**Table 3**

The Characteristic of Pure Jatropha Curcas Lin, Hydrolyzed Jatropha Curcas Lin, Methyl Ester and Diesel Oil

Physical Properties	Experiment method	Result			
		Pure jatropha curcas lin	Hydrolyzed jatropha curcas lin	Methyl ester jatropha curcas lin	Diesel oil
Density to T=20°C(kg/m <sup>3</sup> )	D1298	933	909	858	843
Viscosity to T=20°C(cSt)	D445	70.55	41.76	28.75	7.45
Heating value (kcal/kg)	D240	9,972.34	9,345.38	9,706.34	11,408.35
Flash point (°C)	D93	238	245	167	61
pH	D6423	4.7	6.1	6.5	6.8
Cetana number	-	-	-	55	49



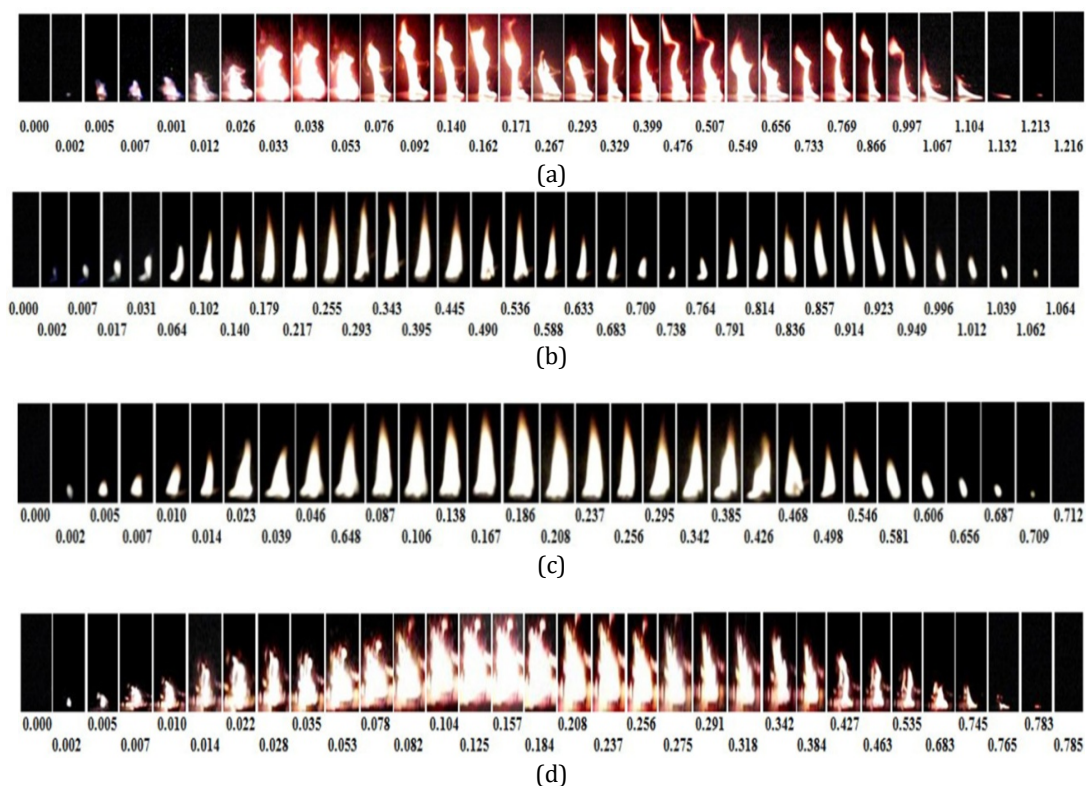
**Fig. 1.** 1. ON/OFF switch; 2. lighter; 3. L P G; 4. gas hose; 5. chamber wall; 6. heater; 7. heated stainless steel plate; 8. flame; 9. Micropipette; 10. chimney; 11. termocouple; 12. datalogger; 13. high speed camera; 14. computer

### 3. Result and Discussion

#### 3.1 Flame evolution

Figs. 2. a-d show the flame evolution of combustion of pure jatropha curcas lin oil, hydrolized

jatropha curcas lin oil, methyl ester, as well as diesel oil.



**Figs. 2.** Flame evolution of jatropha curcas lin oil: (a) pure, (b) hydrolyzed, (c) methyl ester and (d) diesel oil in second

Each combustions process of pure jatropha curcas lin, hydrolized jatropha curcas lin, methyl ester as well as diesel oil had different characteristic. As

shown in fig. 2 (a), for pure jatropha curcas lin oil, the combustion occurred in three stages. In the first stage, unsaturated fatty acid burn 0.002 s up to 0.267 s. It

was followed by saturated fatty acid, burning in 0.267 s up to 0.656 s in the second stage. In the last stage, the burning of glycerol in the 0.656 s up to 1.216 s. Fig. 2 (a) showed that the combustion of pure *jatropha curcas* lin oil took longer time (1.113 s). This was due to the fact that pure *jatropha curcas* lin oil consisted of triglyceride molecules containing glycerol with three carbon chains and three fatty acid branches. Whereas, saturated fatty acid contains single bond on its hydrocarbon chain. Moreover it has zig-zag chains enabling them to bind. As a result, the tensile strength of Vander Waals among its molecules became very strong (Brady 1990). Therefore more energy was needed to separate its molecules. When the oil was heated, three reactions occurred. The first reaction was the hydrolysis of triglyceride molecules to be fatty acid and glycerol by the water contained in the oil. The second reaction was the combustion of unsaturated fatty acid due to its lower flash point (Table 2). At high temperature, unsaturated fatty acid was highly flammable due to its volatile and highly reactive characteristics. In addition it has faster reactions. It was also highly flammable when heated. Besides, the atomic bond of unsaturated fatty acid was more ignites and fragile in the gas phase (Bangboye & Hansen, 2008). The third reaction was the combustion of saturated fatty acid due to its higher and lower flash point than that of unsaturated fatty acid and glycerol respectively as shown in Table 2. When heated in the gas phase, the atomic bond of saturated fatty acid is firm, due to its stable and not reactive characteristic. The last process was the combustion of glycerol. It was due to the fact that it has highest flash point among the previous ones, less reactive, and very stable characteristic. Furthermore, it can only burn in the high temperature since its atomic bond in the gas phase is very firm. Fig. 2 (b) shows that the combustion of hydrolyzed *jatropha curcas* lin oil is faster than that of pure *jatropha curcas* lin oil, yet slower than that of methyl ester and diesel oil, as shown in (Figs. 1 c and d). This is as the result of saturated fatty acid, unsaturated fatty acid and hydroxyl ion ( $\text{-OH}$ ) contained in the hydrolyzed oil as in Table 1. Hydroxyl ion contained in this oil is the main factor which makes it has lowest heating value (Table 2), and smallest flame (Figs. 2. a-d) among other types of oils.

Methyl ester, compared to that of pure *jatropha curcas* lin oil, hydrolyzed *jatropha curcas* lin oil, and diesel oil, has the fastest combustions process (Figs. 2. a-d). There were four factors causing this phenomenon. First is, the similarity of methyl ester and diesel oil. It is as the result of smaller and straighter hydro carbonate molecule that methyl ester has. Second is,  $\text{COOCH}_3$  contained at one edge of molecule of methyl ester, and methyl ( $\text{CH}_3$ ) at the other one, enabling it to have more oxygen, hydrogen,

and carbon. Third is their volatile and highly reactive characteristic. Due to this fact, the molecule of methyl ester needs less external air to burn. Thus it is more flammable (Sastry *et al.* 2006). Fourth is, its higher cetana number (Table 2) which allows it to have faster oxidation process. Whereas glycerol burns in the last stage due to its firm hydrogen bond among its molecules. This is the reason of its very firm tensile strength of Vander Waals among its molecules, making it has very high melting and flash point ( $345^\circ\text{C}$ ).

### 3.2 Explosion Characteristic

Figs. 3 a-c shows the flame explosion characteristic of pure *jatropha curcas* lin oil and diesel oil. Figs. 3a-c shows the explosion characteristic and flame evolution of four types of oils. Pure *jatropha curcas* lin oil exploded once in 0.038 s while diesel oil explosion was in 0.157 s. Yet, explosion did not occur on hydrolyzed *jatropha curcas* lin oil and methyl ester. The high amount of unsaturated fatty acid which contained in pure *jatropha curcas* lin oil triggered the explosion reaction, Table 1 (63.57 %). This was due to the fact that unsaturated fatty acid had volatile and highly reactive characteristic. Besides, in the gas phase when temperature was improved, its hydrogen's atomic bond becomes more breakable. Thus it was more explosive. Meanwhile the explosion of diesel oil was caused by 75% hydrocarbon fatty acid contained in it. Its volatile and highly reactive characteristics made hydrocarbon explodes when burned (Schreckenbach 2008).

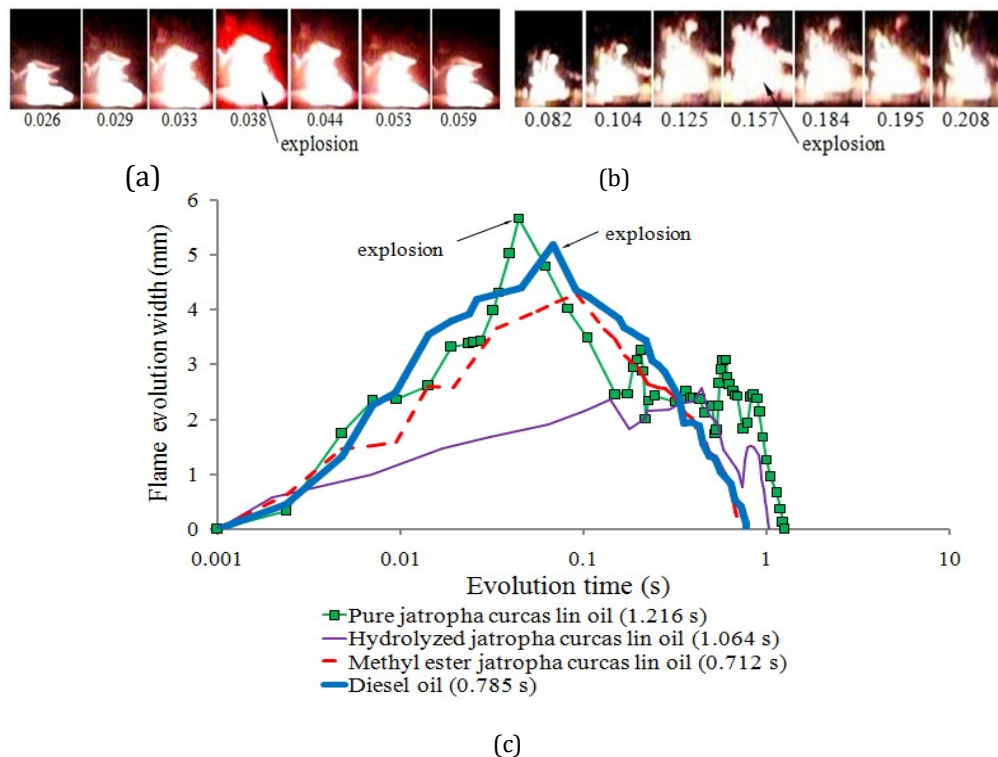
### 3.3 Flame size

Flame evolutions of combustion of pure *jatropha curcas* lin oil, hydrolyzed *jatropha curcas* lin oil, methyl ester and diesel oil are shown in the Fig. 4.

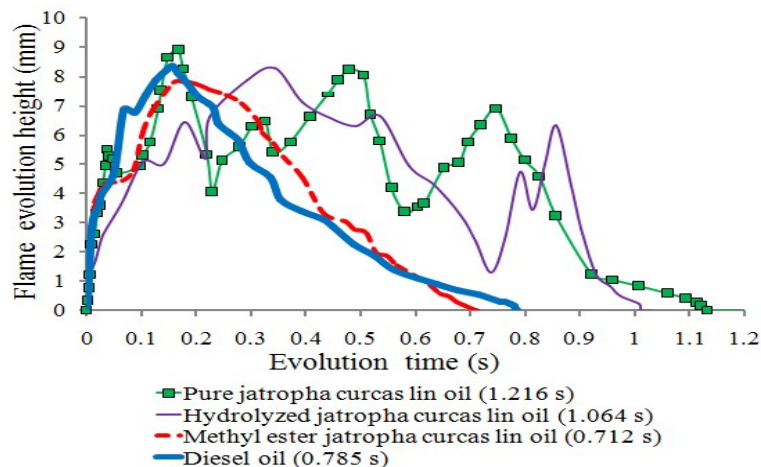
Fig. 4 shows the height of flame evolution of all types of oils, which are pure *jatropha curcas* lin oil, hydrolyzed *jatropha curcas* lin oil, methyl ester and diesel oil. The height of flame evolution indicated the energy releasing rate of oil combustion. The flame of diesel oil, displayed in thick blue line, showed the quick vertical increase and decrease. It indicated how vast the releasing energy of diesel oil is. It happened as the result of heating value of diesel oil which was higher (11,307.26 kcal/kg) than that of other types of oils (Table 2). This was followed by the increase of flame evolution of methyl ester *jatropha curcas* lin oil, reflected in red dotted line. While the increase of flame evolutions of pure *jatropha curcas* lin oil and hydrolyzed *jatropha curcas* lin oil were reflected in the green and purple fluctuated waving figure. These figures indicated that releasing energy of

those two types of oils were volatile. This was caused by the different flash point of saturated fatty acid, unsaturated fatty acid and glycerol contained in pure

jatropha curcas lin oil and hydrolyzed jatropha curcas lin oil, making it cannot burn in the same time.



**Figs. 3.** (a) characteristic of flame explosion of pure jatropha curcas lin oil (b) flame explosion of diesel oil and (c) the width of explosion of pure jatropha curcas lin oil shown in green line and diesel oil in blue line.



**Fig. 4.** The height of flame evolutions of pure jatropha curcas lin oil, hydrolyzed jatropha curcas lin oil, methyl ester and diesel oil

### 3.4 Burning Rates

The burning rate was measured by the burning fuel volume, divided by the duration of combustion

(Figs. 2. a-d). Burning rates of pure jatropha curcas lin oil, hydrolyzed jatropha curcas lin oil, methyl ester and diesel oil are shown in Fig. 5.

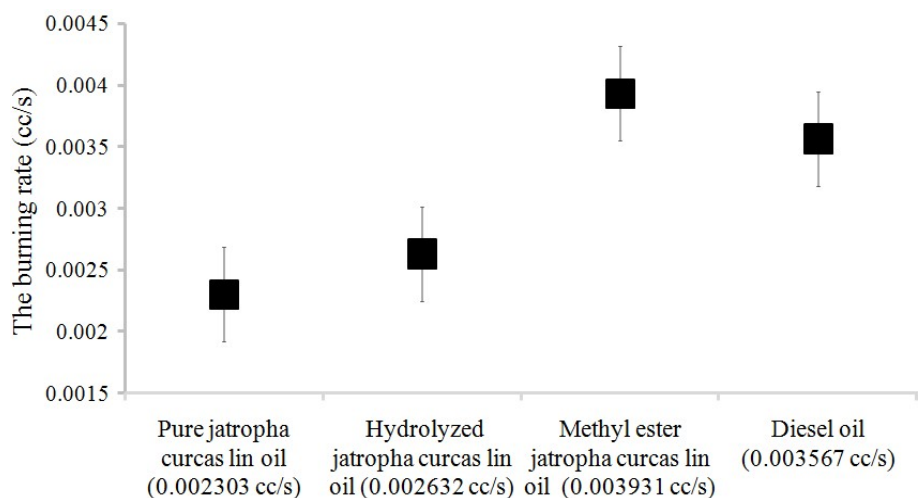


Fig. 5. Burning rate of pure jatropha curcas lin oil, hydrolyzed jatropha curcas lin oil, methyl ester, and diesel oil

The fastest burning rate was demonstrated by methyl ester while the slowest burning rate was showed by the pure jatropha curcas lin oil. Burning rate was influenced by several factors, i.e. flash point, cetana number (Table 2) and the combustion duration of oil (Fig. 2). In flash point factor the lower flash point of oil is, the faster combustion will occur. Thus, a lower flash point will make the oil burned faster (Fig. 1). Further, the higher cetana number means the faster combination rate will take place (Johan, Hoon, & Suyin 2010). Furthermore, the higher the content of unsaturated fatty acid is, the faster the evaporation will be. Due to this fact, the methyl ester oxidized more readily (Rao 2011). The final factor was on the energy of chemical bond disassociations. Methyl ester had

smallest disassociation energy among the other types of oils. The smaller the chemical bond disassociation energy of an atom in the gas phase is, the more readily its chemical bond to break and ignites when heated (Wardana 2011).

### 3.5 Energy Releasing Rate

Energy releasing rate was measured by the heating value of fuel combustion (Table 2) divided by the duration of combustion (Figs. 2. a-d). Energy releasing rates of pure jatropha curcas lin oil, hydrolyzed jatropha curcas lin oil, methyl ester and diesel oil are shown in Fig. 6.

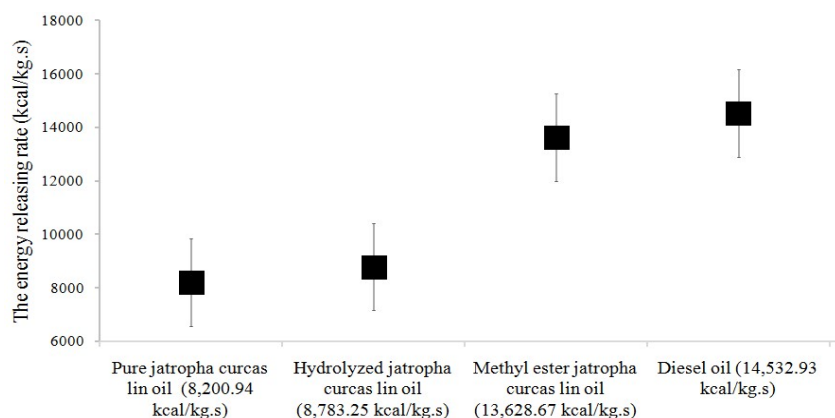


Fig. 6: Energy releasing rate of pure jatropha curcas lin oil, hydrolyzed jatropha curcas lin oil, methyl ester, and diesel oil

Fig. 6 shows an energy releasing rate of methyl ester jatropha curcas lin of 13,630.48 kcal/(kg.s). This was lower than that of diesel oil which showed a rate of 16,696.69 kcal/(kg.s). Energy releasing rate was influenced by three factors, i.e. flash point, heating value (Table 2) and combustion duration (Figs. 2. a-d). The energy releasing rate of diesel oil was very high due to its highest content of carbon among those other types of fuels, and shortens the duration of combustion. These factors made oil diesel has the highest heating value. While, the pure jatropha curcas lin oil showed the lowest energy releasing rate due to the saturated fatty acid, unsaturated fatty acid and glycerol contained in it. Those three substances had high flash points (Table 2), thus it took more time to burn Fig. 2 (a).

#### 4. Conclusions

The experiment findings on the combustion of pure jatropha curcas lin oil, hydrolyzed jatropha curcas lin oil, methyl ester, and diesel oil which were recorded by high speed camera, can be conclude as follows:

1. The combustion of pure jatropha curcas lin oil, hydrolyzed jatropha curcas lin oil and methyl ester occurred in three stages, two stages and one stages respectively.
2. One explosion occurred in the pure jatropha curcas lin oil, due to its high content of unsaturated fatty acid.
3. The highest combustion rate was for methyl ester jatropha curcas lin, while the lowest jatropha curcas lin oil demonstrated the lowest combustion rate.
4. The energy releasing rate of methyl ester jatropha curcas lin resembled as diesel oil, while pure jatropha curcas lin showed the contrary.

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