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# The Combustioncharacteristics of Vegetable Oil Methyl Esters

**Muhaji[1)], I.N.G. Wardana[2)], Lilis Yuliati[2)] MegaNurSasongko[2)]**
*muhaji61@unesa.ac.id; wardana@ub.ac.id; lilies_y@ub.ac.id; megasasongko@ub.ac.id*
*[1)]Doctoral Candidate of the Brawijaya University, Mechanical Engineering Department, Malang 65145, Indonesia.*
*[1)]Surabaya State University,Mechanical Engineering Department, Engineering Faculty 60231, Surabaya, Indonesia*
*[2)]Brawijaya University,Mechanical Engineering Department, Engineering Faculty 65145, Malang, Indonesia*

## Abstract

Transesterification is the process in which a longchainedand branched molecule (triglyceride) is broken forming smaller straight and short chained molecule (methyl ester). Methyl ester which contains more oxygen, hydrogen and carbon, has vinegar acid ($COOCH_3$) at one edge of which, while methyl ($CH_3$) at the other one. Methyl ester is a very promising biofuel because it contains higher oxygen, hydrogen and carbon. Thus, the purposeof this research is to investigate the flame characteristics of this vegetable oil methyl ester. The results indicate that the flame characteristic of methyl esters obtained from jatrophacurcaslinnaeus is the most similar to that of diesel oil, while that made from coconut oil was the least. Furthermore, the combustion rate of methyl esters is higher than that of diesel oil. Diesel oil has the highest energy releasing rate meanwhile the lowest is for methyl ester from coconut oil.

**Key words:** combustion, methyl esters, vegetable oils, flame evolution

## Introduction

While the demand for fossil fuels increases, sources decreases. This phenomenon affects significantly toward the availability of the fossil fuel. Therefore the invention of the renewable energy source is urgently needed.At present, although the availability of the renewable fuel source produced from the vegetable oil in Indonesia is abundant, compared to other countries, the number of insignificancy between the production and the use of it, is obviously clear. The number of total consumption of

Indonesia is 0.2% while Germany, France, Italy, USA, and Denmark are 56% from Brassica napus and sunflowers, 19% from Brassica napus, 17% from Bassicanapus and sunflowers, 4% from maize, and 4% from rapeseed respectively [1].

Renewable energy from vegetable oils can be used as fuel through the process of transesterification.According to [2,3], methyl ester is renewable source having efficient burning and good lubrication properties, low aromatic content, high flame point and,more importantly, no sulphur and carcinogenic compounds [4]. Besides, it islow carbon emissions and odorless. It also has a high cetana number which can reduce 25% of pollution number. Furthermore its waste can be used as organic fertilizer which eventually improves rural economic [1,5,6,7]. However, some drawbacks of the direct use of methyl ester to the diesel engine might appear, suchas: having higher viscosity levels, higher nitric-oxide emissions, and higher decanting as wellas clouding points. Moreover its energy content is lower than that of diesel oil.It also has lessfuel atomization and can lower engine performance [1].Yet,coconut oil methyl ester can improve combustion characteristics while at the same time, lower CO, HC, NOx emissions and opacity of one cylinder diesel engine [8].Other researches [9,10, 11] also found that cottonseed methyl ester reduced engine efficiency.In addition,jatrophacurcaslinnaeus methyl ester could be used to replace diesel without modifying diesel engines [11,12].

Yet other research found that when jatrophacurcaslinneous oil burned at thermocouple junction, the combustion occurs in 2 stages, namely, the burning of fatty acid then followed by glycerol [13].The fuel components of vegetable oils have divergent boiling points, flash points and reactive properties, causing some components burn and thus requiring more time for complete combustion [13,14].Whereas, when jatrophacurcaslinnaeusoil methyl esters is burned at the thermocouple junction using magnetic field, the burning rate improved and both contraction andflame size increased [15].The purpose of this study is to investigate the flame characteristics of vegetable oil methyl esters (ceibapentandra, jatrophacurcaslinnaeus, cottonseed, and coconut), with the view to advancing their use as alternatives to diesel fuels.

## Material and Methods

### Chemical Structure of Vegetable Oil Methyl Esters and Its Properties

The methyl ester was made from vegetable oils using a transterification, a process in whicha long chained with branched molecule (triglyceride) is broken forming smaller straight and short chained molecule (methyl ester) [16]. This process of separation is induced by a triglyceride with metanol reaction using an acid or a base catalyst. The process occurs in 3 stages. First, triglyceride is changed into diglyceride. Second,diglyceride becomes monoglyceride and third, monoglyceride becomes 3 mol methyl ester molecules and 1 mol glycerol molecule. Carbon methyl ester chains contain medium enterprise carbon chains (C8-C12) as well as long carbon chains (C14-C21). The size of the methyl ester molecule hidrocarbon chains range from 8 to 21 carbon atoms and can reach as high as 12-18 carbon atoms per molecule (C12-

C18) [17]. Methyl esters contains more oxygen, hydrogen and carbon in which at one edge of the molecular chain there is vinegar acid ($COOCH_3$) and at the opposite edge there is methyl ($CH_3$), this fact makes it more flammable, cleaner and environmentally friendly [18].

The composition and properties of vegetable oil methyl esters are shown in Tables 1, 2, 3 and 4.

**Table 1:** Vegetable Oil Methyl Ester Composition

| Types of methyl ester | Chemical Formula | Chemical Bond Structure | Methyl Ester Composition | | | |
|---|---|---|---|---|---|---|
| | | | Ceibapen tandra oil | Jatrophac urcaslinn aeus oil | Cotton Seed oil | Coconut oil |
| Caprylic | $CH_3(CH_2)_6COOCH_3$ | 9:0 | - | 1.87 | - | 3.45 |
| Capric | $CH_3(CH_2)_8COOCH_3$ | 11:0 | - | 1.82 | - | 4.04 |
| Lauric | $CH_3(CH_2)_{10}COOCH_3$ | 13:0 | - | 3.91 | 0.61 | 34.88 |
| Myristic | $CH_3(CH_2)_{12}COOCH_3$ | 15:0 | - | 4.81 | 1.09 | 13.72 |
| Palmitic | $CH_3(CH_2)_{14}COOCH_3$ | 17:0 | 26.21 | 11.63 | 23.69 | 10.49 |
| Stearic | $CH_3(CH_2)_{16}COOCH_3$ | 19:0 | 9.29 | 4.67 | 8.05 | 3.93 |
| Arachidic | $CH_3(CH_2)_{18}COOCH_3$ | 21:0 | - | - | - | 0.10 |
| Oleic | $CH_3(CH_2)_7(CH=CHCH_2)(CH_2)_6COOCH_3$ | 19:1 | 21.93 | 26.69 | 27.65 | 18.47 |
| Linoleic | $CH_3(CH_2)_4(CH=CHCH_2)_2(CH_2)_6COOCH_3$ | 19:2 | 41.16 | 25.43 | 38.91 | 10.79 |
| Linolenic | $CH_3CH_2(CH=CHCH_2)_3(CH_2)_6COOCH_3$ | 19:3 | 1.38 | 19.15 | - | 0.06 |
| Eicosanoic | $CH_3(CH_2)_5(CH=CHCH_2)(CH_2)_{10}COOCH_3$ | 21:1 | - | - | - | 0.06 |
| Total saturated fatty acids | | | 35.50 | 28.71 | 33.44 | 70.61 |
| Total monounsaturated fatty acids | | | 27.93 | 26.69 | 27.65 | 18.47 |
| Total polyunsaturated fatty acids | | | 36.54 | 44.58 | 38.91 | 10.91 |
| Total unsaturated fatty acids | | | 64.47 | 71.27 | 66.56 | 29.38 |

The physical properties of the main types of vegetable oil methyl esters and diesel oil are shown in Tables 2,3 and 4 below:

**Table 2:** Vegetable Oil Methyl Ester Characteristics

| N | The types of methyl Ester | Chemical Formula | Chemical Bond Structure | Molecular weight (gr/mol) | Flash point (°C) | Cetana Number | Heating value (kcal/ mol) |
|---|---|---|---|---|---|---|---|
| 1 | Caprylic[1)] | $CH_3(CH_2)_6COOCH_3$ | 9:0 | 158.24 | 81 | 35.1 | 1346 |
| 2 | Capric[1)] | $CH_3(CH_2)_8COOCH_3$ | 11:0 | 186.29 | 110 | 47.9 | 1615 |
| 3 | Lauric[2)] | $CH_3(CH_2)_{10}COOCH_3$ | 13:0 | 213.34 | 143 | 61.1 | 1920 |
| 4 | Myristic[1)] | $CH_3(CH_2)_{12}COOCH_3$ | 15:0 | 242.29 | 172 | 73.5 | 2250 |
| 5 | Palmitic[2)] | $CH_3(CH_2)_{14}COOCH_3$ | 17:0 | 270.53 | 175 | 74.4 | 2385 |
| 6 | Stearic[2)] | $CH_3(CH_2)_{16}COOCH_3$ | 19:0 | 298.49 | 178 | 76.3 | 2696 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 7 | Arachidic[1)] | $CH_3(CH_2)_{18}COOCH_3$ | 21:0 | 326.57 | 181 | 77.1 | 2975 |
| 8 | Oleic[2)] | $CH_3(CH_2)_7CH=(CH_2)_8$ $COOCH_3$ | 19:1 | 296.46 | 111 | 57.2 | 2828 |
| 9 | Linoleic[2)] | $CH_3(CH_2)_4(CH=CHCH$ $_2)_2(CH_2)_6COOCH_3$ | 19:2 | 294.48 | 66 | 36.8 | 2794 |
| 10 | Linolenic[2)] | $CH_3CH_2(CH=CHCH_2)_3$ $(CH_2)_6$ $COOCH_3$ | 19:3 | 292.47 | 53 | 21.6 | 2750 |

[1)][19],[2)][20]

**Table 3:** Vegetable Oil Methyl Esters and Diesel oil Properties

| N | The kinds of methyl esters | Molecular weight (gr/mol) | Boiling point (°C) | Flash point[1)] | Cetan Number |
|---|---|---|---|---|---|
| 1 | Ceibapentandra oil methyl esters[2)] | 2285.7 | 115 | 171 | 57 |
| 2 | Jatrophacurcaslinnaeusoil methyl esters[2)] | 2065.4 | 324 | 163 | 60 |
| 3 | Cottonseed oil methyl esters[2)] | 2233.6 | 193 | 166 | 58 |
| 4 | Coconut oil methyl esters[3)] | 1665.6 | 252 | 175 | 62 |
| 5 | Diesel oil[3)] | 440.72 | 386 | 60 | 47 |

[1)][present data],[2)][21],[3)][22]

**Table 4:** Laboratory Test Results–Vegetable Oil Methyl Esters and diesel oil Physical Properties

| Properties | Method | Instrument Type | Make | Value | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Cieba pentan dra oil methyl esters | Jatropha curcasli nnaeus oil methyl esters | Cotton seed oil methyl esters | Cocon ut oil methyl esters | Diese l oil |
| Density T=30°C ($kg/m^3$) | D1298 | Hydrometer | Nikky, Japan | 489 | 448 | 471 | 465 | 849 |
| Kinematic Viscosity T=30°C (cSt) | D445 | Kinematic Viscosmeter | Leybold Didactic, Germany | 27.48 | 24.46 | 26.68 | 22.48 | 8.11 |
| Heating value (kcal/kg) | D240 | Bomb Calorimeter | Parr Instuments, UAS | 39,038 .339 | 40,640. 757 | 39,684 .599 | 40,243 .607 | 47,43 1.236 |
| pH | D6423 | pHep Tester | HANNA Instrumens, UAS | 5.3 | 4.9 | 5.5 | 5.9 | 6.6 |

## Experimental Apparatus

The experiments were conducted by using experimental apparatus as shown schematically in Figure1.Methyl esters vegetable oil was dripped on to 0.3mm thick and 3.5mm diameter stainless steel plate. Thestainless steel plate was heated until 270°C.

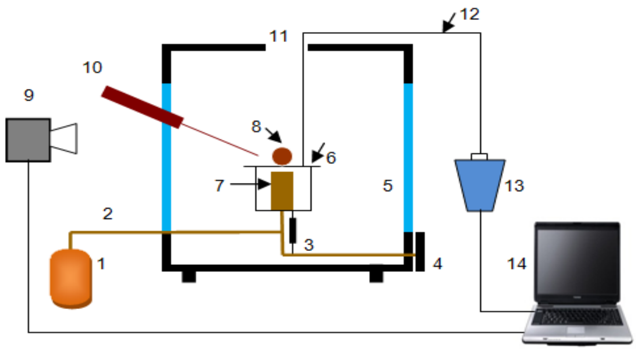



**Figure 1:** Experiment apparatus: 1. LPG; 2. Gas hose; 3. Igniter; 4. Switch; 5. Burning chamber wall; 6 Stainlesssteelplate; 7. Bunsen burner; 8. Methyl esters droplet; 9. Camera; 10. Micropipette; 11.Chimney; 12.Thermocouple; 13. Multilogger; 14. Computer

### Measuring Techniques

The stainlesssteelplate temperatures were measured by a multilogger thermometer with a recording range of -200$^{o}$C to 1372$^{o}$C at an accuracy of ± 0.35$^{o}$C. The distance from the thermometer to the stainlesssteelplate was ± 300mm.The flames were recorded by a high speed Casio Camera ZR 200 at 420 frames/second.Initially, the methyl esteroil droplets had diameters of 1.75 mm and a temperature of 28$^{o}$C.The droplet diameters and flame dimensions were measured by dipping the picture camera file in a Photoshop software.

## Result And Discussion

### Flame Characteristics

The flame characteristics of the methyl esters oil droplets on the stainlesssteelplate was recorded by a high speed camera, shown in figure2,3, 4and 5 compared with those of dieseloil(Figure 6).

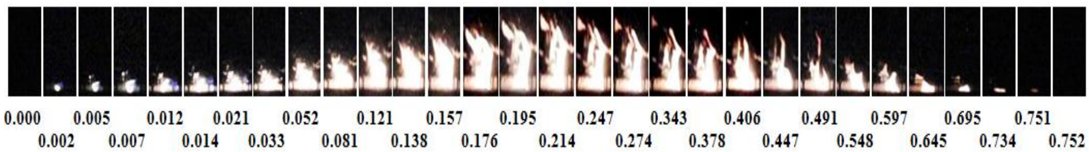



**Figure 2:** Ceibapentandra oil methyl esters flame evolution in seconds

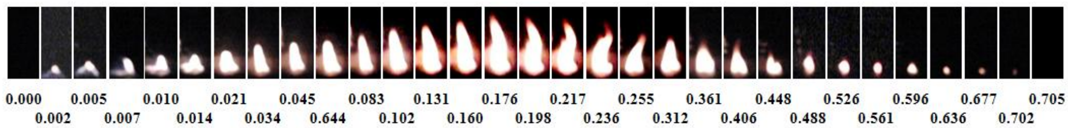



**Figure 3:** Jatrophacurcaslinnaeus oil methyl esters flame of evolution in seconds

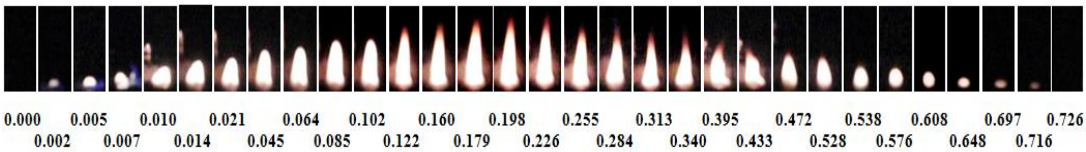



**Figure 4:** Cottonseed oil methyl esters flame evolution in seconds

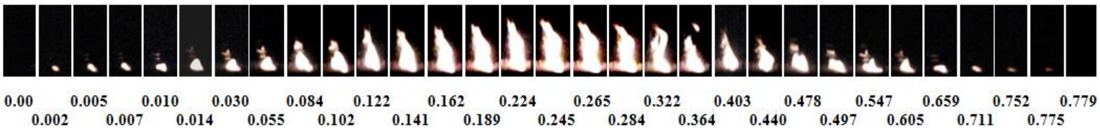



**Figure 5:** Cconut oil methyl ester flame evolution in seconds

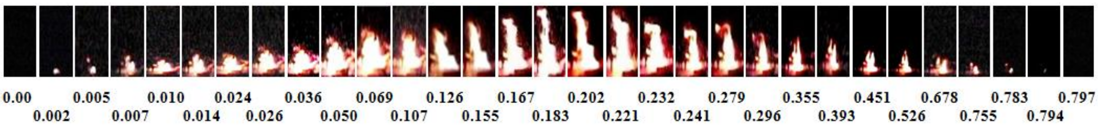
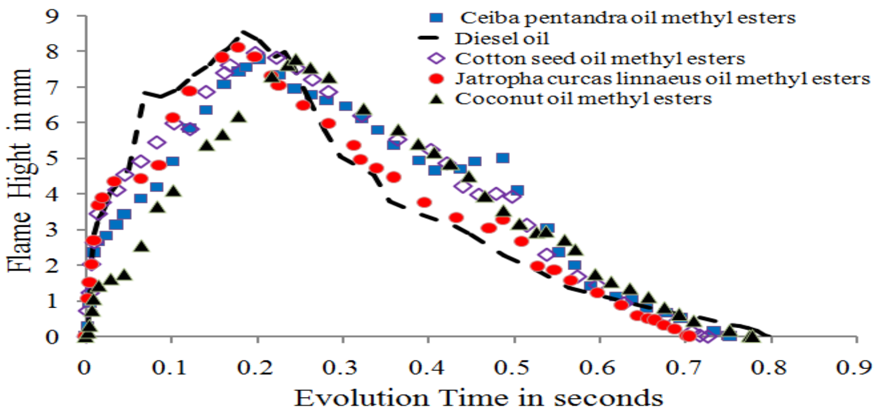



**Figure 6:** Diesel oil flame evolution in seconds

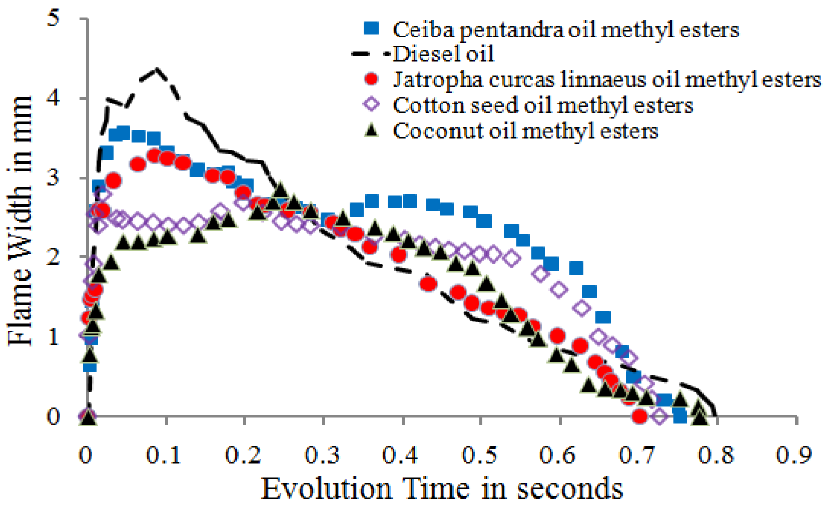
The combustion processes of vegetable oil methyl esters and diesel oil are shown in Figures 2 to 6. Both have much in common, namely, that they burn in one stage due to the fact that vegetable oil methyl esters have very similar simple hydrocarbon and ring molecular structures with diesel fuel [23].The only difference is on their flame characteristics, i.e., the flame color and the combustion speed (Figures 2-6). The combustion process of vegetableoil methyl esters is faster than that of diesel oil, for example, that of ceibapentandraflared in 0.752 seconds, jatrophacurcaslinnaeusflared in 0.705 seconds, cottonseed flared in 0.726 seconds, coconut oil flared in 0.779 seconds and diesel oil flared in 0.797 seconds.This is due to the fact that methyl esters molecules contain vinegar acid ($COOCH_3$) on one edge and methyl ($CH_3$) on the other. First, besides, they have more oxygen, hydrogen and carbon which makes them more volatile and highly reactive; they need less external air which make it more flammable [18].Second, the carbon chains of methyl ester molecule are long (C14-C21) with single, double and triple bond in their methyl esters; the closer the bond to methyl ester is, the more reactive it will be (Table 1: oleic, linoleic and linolenat methyl esters). Thus methyl esters is inherently volatile, highly reactive and easily oxidized.Vegetable oil methyl esters molecules have hydrocarbon size between 8 to 21 carbon atoms per molecule. The highest number of carbon atoms per molecule was between 12 and 18 atoms [17]. Whereas, diesel oil has hydrocarbon size between 8 up to 32 carbon atoms per molecule.Thehighest composition of the distribution of the number of carbon atoms occurred at about 13-19 carbon atoms per molecule [24].Third, the cetana number of methyl esters is higher than diesel oil (Tables 2 and 3) so that the ability to oxidize would be faster. The color of methyl ester flames is duller than those of diesel oil which are reddish and sooty. This is due to the fact that diesel oil contain a hydrocarbon poly aromatic which would forms soot on combustion [23,25].

**Flame Size Evolution**

The height and width of vegetable oils methyl ester flames at evolution of various diesel oil burned on a stainless steel plate recorded by a high speed camera are shown in Figures 7 (a) and (b).




(a)




(b)

**Figure 7:** The vegetable oil methyl esters and diesel oil evolution flame size (a) flame height and (b) flame width

From the various flame evolution of vegetable oil methyl esters and diesel oil, jatrophacurcaslinnaeus is the earliest one reaching its peak, namely, in 0.176 seconds. It was then followed by diesel oil in 0.183 seconds, cottonseed oil in 0.197 seconds, ceibapetandra in 0.214 seconds and that of coconut oil methyl esters in 0.2452 seconds (Figures 2-6).The highest flame evolution, 8.554mm was achieved by diesel oil, whereas, of the four vegetable oil methyl esters, the highest was from jatrophacurcaslinnaeus at 8.114 mm, succeedingly followed by coconut oil at 7.996mm, cottonseed at 7.977mm and finally ceibapentandra oil methyl estersat 7.784mm.In addition, jatrophacurcaslinnæus oil methyl ester flame evolution reaches its peak faster due to its content which is doubled or tripled molecular bonds of unsaturated fatty acids that is more than those of the other methyl esters (Table 1). Doubled or tripled molecular bonds of unsaturated fatty acids of methyl ester makes them unstable, highly reactive and oxidize more readily, all of which causes them burn faster. The size of the flame evolution shows the power of the combustion process both of vegetable oil methyl esters and diesel oil.But,the evolution of diesel oil flame created a higher pressure than the others Figures 6 (a) and (b). After reaching its peak of 8.554mm and horizontal spread of 4.357mm, the diesel oil flame proceeded faster than that of the others, while the other methyl esters reached their peaks more quickly but produced lower pressures. Whereas, at first, the height and the width of flame evolution of ceibapentandra oil methyl ester were similar to diesel oil but it became slow and different from that of diesel oil afterward. However at the beginning as well as the end, the height and the width of jatrophacurcaslinnæus oil methyl ester were very close to that of diesel oil. For cottonseed methyl esters, at onset the flame evolution height resembled that of diesel oil, whereas its width was less and at the end its burning rate was faster. While for coconut, both the beginning and end of the flame evolution were different from those of diesel oil.The height of the diesel oil flame evolution was caused by the high content of unsaturated hydrocarbons (75%) (aromatic and olefin hydrocarbons). Theproperties of these hydrocarbons are volatile and very reactive which can produce high pressures when was burning [24]. In addition, they have a high calorific value (table 4) reaching 11,307.2 kcal/kg.Whereas, the rapid flame evolution of vegetable oil methyl esters is due to their high content of unsaturated methyl ester, which has 1, 2 and 3 double bonds on their carbon chains.The closer the bonds are to molecule edge, the more unstable they will be. It makes them very reactive, and flammable with oxygen which eventually produces higher pressure. Also their high cetane number (Table 3), the higher the cetane number is, the faster the ignition delay will be. Thus, the combustion is faster, and the power is greater [25].Furthermore, the lower the flash point is (Table 3), the faster the flame expansion, both upwards and side ways, will be.

**Burning Rates**

Theburning rates comparison of vegetable oil methyl esters and diesel oil are shown in Figure 8.The highest burning rate for these methyl esters was that for jatrophacurcaslinnæus oil at 0.003974cc/second, followed by that for cottonseed oil was 0.003857cc/second, that for ceibapentandra oil 0.003723cc/second, and coconut oil methyl esters 0.003598 cc/second, and diesel oil 0.003523cc/second at last. The burning rates of methyl esters are influenced by several factors. First onflash point;Jatrophacurcaslinnæus oil methyl esters has the lowest flash point (Tables 2 and 3) where the lower flash point is, the faster combustion will be [14].Second oncetane numbers;the higher the cetane number is, the faster the ignition delay as well as the combustion rate will be [26].Third on unsaturated methyl ester;the higher the content of unsaturated methyl ester is, the faster the evaporation will be. Due to this fact, the methyl ester oxidizes more readily and therefore increases burning rates [27]. Fourth on the energy of bond disassociations from methyl esters; the energy of unsaturated methyl esters is lower than that of saturated methyl esters [15].The smaller the chemical bond disassociation energy of an atom in the gas phase is, the more readily it breaks its chemical bond and ignites when heated.The laston pH level; the lower the pH is, the faster the reaction rate is and the quicker the combustion rate will be (Table 3).

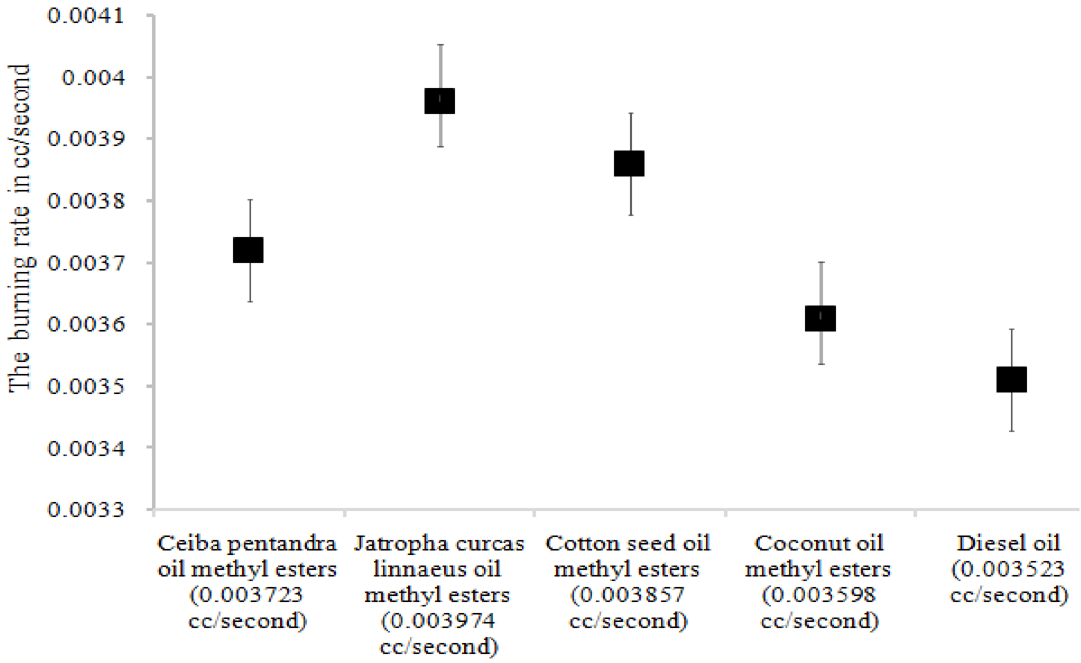



**Figure 8:** Thevegetable oil methyl esters and diesel oil burning rate

**The Energy Released Rate**

The energy released rates from the combustion of vegetable oil methyl esters and diesel oil are shown in Figure 9.The highest energy releasing rate is diesel oil (59,623.723 kJ/kg.second),followed by jatrophacurcaslinnaeus oil (57,892.817 kJ/kg.second), cottonseed oil (54,661.982 kJ/kg.second), ceibapentandra oil (51,912.686 kJ/kg.second) and last by coconut oil methyl esters (51,660.599 kJ/kg.second).Even though the combustion process of diesel oil takes more time, its energy released rate is the highest. This is because diesel oil has the highest heating value (47,341.236 kJ/kg, Table 4).In addition, it can be seen from the flame evolution characteristics (Figures 6. a and b). Diesel oil’s flames are wider and higher than the others.Moreover, diesel oil is 75% unsaturated hydrocarbons (both aromatic and olefin hydrocarbons), which are unstable and exteremely reactive and when burnt produce high pressure [24]. The second highest energy releasedrates wasjatrophacurcaslinnaeus oil methyl ester (57,892.817 kJ/kg. second). It is due to its contentof 71.27% double bond unsaturated methyl ester (Table 1) as well as their unstable and very reactive characterics causing a quicker burning rate. Besides, its calorie content is relatively high (40,640.757kJ/kg, Table 4).Cottonseed oil methyl esters had the third highest energy released rates (54,661.982 kJ/kg.second). It is due to its content of (66.56%, Table 1) double bond unsaturated methyl ester and its relatively high heating value (39,684.599 kJ/kg, Table 4).Whereas, both ceibapentandra and coconut oils methyl esters had nearly the same energy released rates respectively (51,912.686 and 51,660.599 kJ/kg.second). It is because heating value engine of ceibapentandra oil mehtyl esters is lower (39,038.339kJ/kg) and the process of burning is 0.752 seconds.Meanwhile, coconut's oil methyl esters heating value is quite high at (40,243.607kJ/kg), but the burning process is very long, 0.779 seconds.

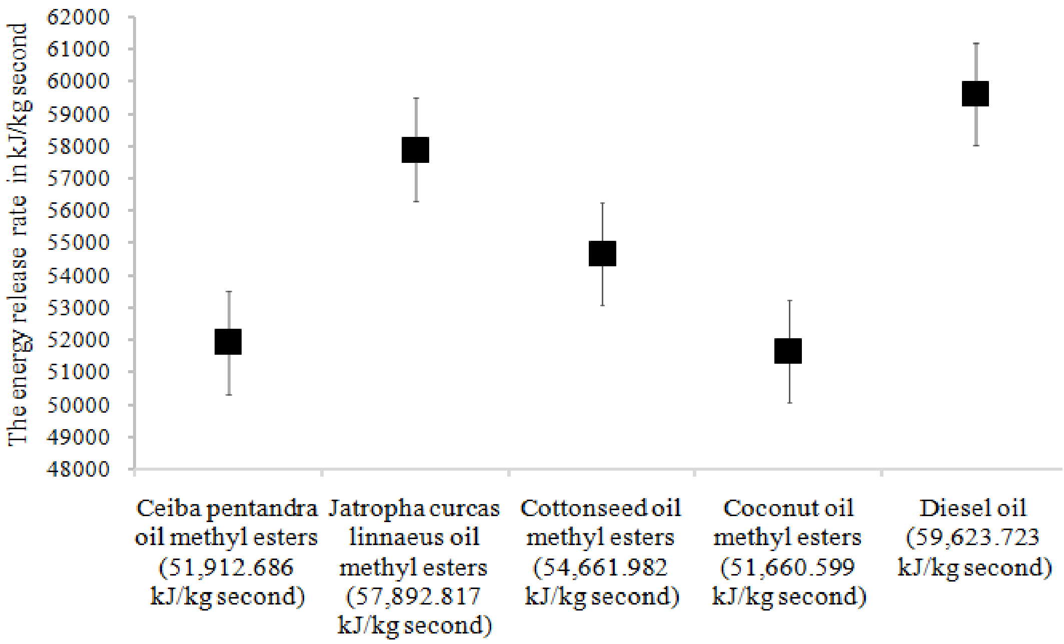



**Figure 9:** The vegetable oil methyl esters and diesel oil energy releasedrate

## Conclusion

To conclude, the findings of the experiments concerning methyl esters droplets combustion on a hot stainless steel plate were as follows:

1. Compared to the other flame characteristics, jatrophacurcaslinnaeus oil methyl esters' and diesel oil's are alike.
2. The flame characteristics of coconut oil methyl esters were found to be the most dissimilar to those of diesel oil.
3. Jatrophacurcaslinnæus oil methyl ester had the fastest combustion process of the vegetable oil methyl esters and the slowest was that of coconut oil methyl esters.

4. The combustion rates of ceibapentandra, jatrophacurcaslinnæus, cottonseed, and coconut oil methyl esters were faster than that of diesel oil, however, the pressures produced were lower than that of diesel oil.
5. The energy released rate of diesel oil was higher than that of all the vegetable oil methyl esters, and the lowest rate was that of coconut oil methyl esters.

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