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Research Paper

# The Response of Adding Nanocarbon to the Combustion Characteristic of Crude Coconut Oil (CCO) Droplets

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## Abstract

One of the strong candidates for biodiesel is Crude Coconut Oil (CCO) but its high viscosity cannot be applied directly without treatment. Therefore, nanocarbon is added to reduce the viscosity of CCO. Nanocarbon is a natural material with semiconductor properties, a good heat conductor, and can attract other molecules. By adding nanocarbon, it is expected to reduce the viscosity of CCO. This study aimed to determine the combustion characteristics of droplets on CCO by adding nanocarbon by 1% and 5%. The method used was a true experiment with droplets, which dripped on the thermocouple with activation energy from the heater. The results showed that CCO burned 0.933s with a droplet diameter of 4.307mm, droplet diameter of 5.472 mm. By adding 5% nanocarbon to CCO, the CCO burned faster, more reactive, and the ignition was shorter than the pure CCO and 1% CCO.

**Keywords:** Crude Coconut Oil; Nanocarbon; Droplet; Combustion characteristic

## 1. Introduction

Vegetable oil and diesel oil have different characteristics in viscosity, where, vegetable oil has a higher viscosity than diesel oil. However, there is potential to reduce the viscosity of vegetable oils by chemical treatment so that they have similar characteristics to diesel oil [1]. The conversion of vegetable oil into biodiesel by transesterification process requires more energy and also production cost [2]–[5], so the use of non-transesterified needs to be reviewed [6].

Several studies to reduce the viscosity of vegetable oils include mixing propanol with butanol with rapeseed oil with a mixing percentage of 5%, 10% and 20%. With the addition of propanol and butanol with a percentage of 20%, the viscosity, density and flash point decreased [7], [8]. Misra & Murthy [9] conducted a study of mixing vegetable oil with diesel, in their research it produced different properties at the mixed level, the greater the percentage of castor oil, the greater the density.

Mixing vegetable oil with other fuels is one way to reduce the viscosity value, including by mixing nanocarbon, metal catalyst, etc [10]. Nanocarbon can be made from coconut shell. Nanomaterials can attract other materials due to their uniqueness in chemical, physical, and biological properties [11]. Nanocarbon has semiconductor properties, good heat conductors, and better treatment on nano-sized carbon than macro and micro-sized materials. Nanoparticles have amphoteric properties, which can bind oxygen. Nanomaterials are widely used in various applications because quantum mechanical effects cause differences in behavior at the nanoscale. The characteristics of combustion in the fuel mixture used the droplet method, several studies used its, such as in our previous study [12] that used 1.8 cineole to reduce the viscosity of vegetable oils, and Hendry et al. [13] used Rh¬+ Catalyst to reduce the viscosity of vegetable oil.

Single droplet is a simple, inexpensive analytical method to determine fuel characteristics based on the properties of the fuel

[14]. The study conducted by Y.C. Liu [15] reports experimental evidence of gas phase micro-convection induced by support fibers used in droplet combustion experiments. Shringi [16] conducted extensive computational modeling to investigate the effects of support fibers on vaporizing fuel droplets. Ghamari et al. [17] investigated and compared the diesel and jet-a stationary fuel droplets combustion with a fiber support arrangement and modified varying percentages of a long chain polymer (polybutadiene) to typical hydrocarbon behavior. Moreover, Ghemari, et al. [18] investigated burning of jet fuel droplet supported on a fibre added with micro and nano-sized particles to liquid fuels. Carbon nanoparticles, nanotubes, and nanoplatelets with diameters ranging from 2–3 nm to 100 nm were introduced to jet fuel at various ranges of mass concentrations.

Many studies on the mixing and combustion characteristics of vegetable oils have been carried out [12], [13], [17], [18], but there are still many that have not been disclosed because the combustion characteristics are very complex, in addition to this the addition of nanocarbons to vegetable oil droplets has never been carried out, so intensive research is still needed, especially on the combustion characteristics of vegetable oil droplets. with the addition of nanocarbons. So the focus of this research is the response of adding nanocarbon to the combustion characteristic of Crude Coconut Oil (CCO) droplets. This research can provide knowledge about the selection of suitable vegetable oil as an alternative fuel for biodiesel that is environmentally friendly and renewable fuel. Vegetable oil triglycerides are composed of different fatty acid carbon chains, so the addition of nanocarbons to vegetable oil will affect the combustion characteristics. The response of the addition of nanocarbons (fullerence) to vegetable oils is expected to weaken the structural strength of the triglyceride carbon chain molecules so that it has an impact on the physical properties and combustion characteristics of vegetable oils. The nanocarbon addition in coconut oil is expected to improve the combustion characteristics since the nature of nanocarbon is a good semiconductor or heat conductor [11]. So, this study aims to examine the characteristics of evaporation and ignition of CCO droplet mixing with nanocarbon.

## 2. Fuel Preparations and Experimental Setup

In this study, the CCO mixing material used was carbon from the pyrolysis of coconut shells, a non-graphitic type of carbon but can be used as graphite by the graphitization process. Charcoal from coconut shell was crushed and sieved to less than 74 m [11]. A shaker ball mill machine was used to change the carbon size from coconut shell to nano size. The machine is made for the high-energy milling (HEM) process. The machine principally works to move a tube containing carbon and steel balls with more than one axis of motion. The oxides in the milling process can form carbon fibers. The morphology of the carbon fiber resembles that of fullerene-like nanocomposites. Fullerenes were composed of pure carbon elements totaling 60 (C60), uniquely shaped like a ball, connected by chemical bonds of the type sp3. The vegetable oil used was CCO obtained from the extraction process by dissolving using hexane and then separated using a distillate [12], [19].

The droplet test method used a thermocouple measuring instrument. The thermocouple was connected to a data logger, which was read using the excel program on the computer. The thermocouple used was type K with a diameter of 0.1 mm, made of Ni-Cr, and has a diameter of 0.9 mm, a length of 40 mm, and a resistance of 1.02 ohms. This thermocouple was used to measure the droplet temperature during the ignition and burning process. A droplet measuring 1 mm was placed on the end of the thermocouple, 3 mm from the droplet. The droplet was made using a microsyringe, which was conducted at standard atmospheric pressure and room temperature. The research also used a 12 volt energy source with a current of 8 amperes, a resistance of 8 ohms, and a power of 50 watts.

**Figure 1** shows the installation of research conducted to determine the effect of the addition of carbon nano on droplet combustion characteristics. This study used three samples of mixed variations, namely pure CCO, 1 PPM CCO, 5 PPM CCO. From the sample, a droplet with a size of 1mm was formed, which was dripped on a thermocouple that works as a sensor. Therefore, when combustion occurred, the temperature would be captured and forwarded by a data logger, with the results would be shown on the laptop. The combustion characteristics observed were the temperature captured by the thermocouple and datalogger, burning rate, height, and width of the fire obtained from the video recording using a CANON EOS 600D camera with a 60 fps setting.

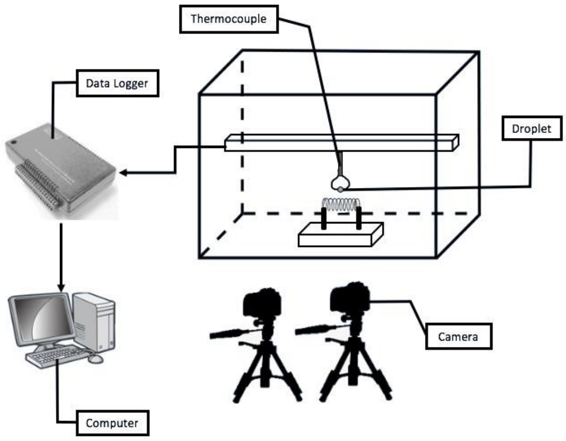


**Figure 1.** Experimental apparatus

## 3. Result and Discussion

Vegetable oils contain fatty acids, which were tested using GCMS to determine the fatty acid content of vegetable oils. **Table 1** is the content of fatty acids and their percentage in CCO. Based on the table, the highest content of CCO is in lauric acid ($C_{12}H_{24}O_2$), myristic ($C_{14}H_{28}O_2$), and caprylic ($C_8H_{18}O_2$), which results are in accordance with research [9], [14]. The three fatty acids have short, straight, saturated chains and a small molecular mass so that CCO is more polar, according to the research results from [12], [19].

In **Table 1**, the droplet diameter size between CCO, CCO1, and CCO5 when the droplet was attached to a thermocouple with the same size, the droplet diameter was different. In pure CCO, the diameter was smaller than CCO, mixed with 1PPM (CCO1) and 5 PPM (CCO5) nanocarbon. It happened because pure CCO that has not been mixed with nanocarbon has a greater viscosity. Meanwhile, CCO1 and CCO5 have a lower viscosity because they are already mixed with nanocarbon. The more the nanocarbon is mixed, the lower the viscosity, so the larger the diameter of the dripped droplets.

**Figure 2** shows the ignition delay of coconut oil without the addition of nanocarbon and with the addition of 1 PPM (CCO1) and 5 PPM (CCO5) nanocarbon. CCO5 burned shorter than CCO and CCO1 because CCO5 has the highest mixture concentration with nanocarbon, 5 ppm. Thus, the CCO5 was more reactive, and the ignition delay of the CCO5 was shorter (**Figure 3**). CCO, which includes polar fatty acids, has a large intermolecular force so that the molecular density is large (small intermolecular distance). When CCO was added 1 PPM of nanocarbon and 5 PPM of carbon, the ignition delay will be shorter with the addition of more nanocarbon. For droplet size, seen on several occasions, CCO1 exceeded CCO5. It can be identified by microexplosion in the CCO1 at the beginning of the ignition, and the peak point before the ignition finally ended. In CCO, the ignition delay was the longest because there is no addition of nanocarbon. So, it can be concluded that adding nanocarbon to CCO will shorten the ignition delay time. It was because the viscosity of CCO was getting lower, so it was easy to burn. As


**Figure 2.** Droplet diameter with a percentage variation of nanocarbon mixture

**Table 1.** Composition of CCO (Crude Coconut Oil) fatty acids [12], [19]

| Chemical Composition | Cn:db | Formula | Structure | Composition % | | | | Molecular mass |
|---|---|---|---|---|---|---|---|---|
| | | | | CCO | CPO | CJO | CSFO | ($g.mole^{-1}$) |
| **Caproic** | 6:0 | $C_6H_{12}O_2$ | $CH_3(CH_2)_4COOH$ | 0.6 | - | - | - | 116.1583 |
| **Caprylic** | 8:0 | $C_8H_{16}O_2$ | $CH_3(CH_2)_6COOH$ | 8.45 | - | 1.7 | - | 144.2114 |
| **Capric** | 10:0 | $C_{10}H_{20}O_2$ | $CH_3(CH_2)_8COOH$ | 6.1 | - | 1.66 | - | 172.2646 |
| **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 | 0.08 | 228.3709 |
| **Palmitic** | 16:0 | $C_{16}H_{32}O_2$ | $CH_3(CH_2)_{14}COOH$ | 8.4 | 40-47 | 14.62 | 0.6 | 256.4241 |
| **Palmitoleic** | 16:1 | $C_{16}H_{30}O_2$ | $CH_3(CH_2)_5CH\text{-}CH(CH_2)7COOH$ | - | 0-0.6 | 1.47 | 0.1 | 254,4042 |
| **Stearic** | 18:0 | $C_{18}H_{36}O_2$ | $CH_3(CH_2)_{16}COOH$ | 1.65 | 3-6 | 7.36 | 3.08 | 284,4772 |
| **Oleic** | 18:1 | $C_{18}H_{34}O_2$ | $CH_3(CH_2)_7CH{=}CH(CH_2)_7COOH$ | 5.7 | 36-44 | 30.38 | 17.31 | 282,4614 |
| **Linoleic** | 18:2 | $C_{18}H_{32}O_2$ | $CH_3(CH_2)_4CH{=}CH(CH_2)\ CH(CH_2)_7COOH$ | 1.4 | 6-12 | 35.42 | 73.31 | 280.4455 |
| **Linolenic** | 18:3 | $C_{18}H_{30}O_2$ | $CH_3(CH_2)\ CH{=}(CH_2)3(CH_2)_6COOH$ | 0.05 | 0-0.5 | 0.2 | 0.11 | 278.4296 |

a result, it shortened the ignition delay time. Furthermore, the properties of nanocarbon, which have semiconductor properties, namely good heat conduction properties, and the treatment of nano-sized carbon are much better than those of macro and micro-sized materials [11].

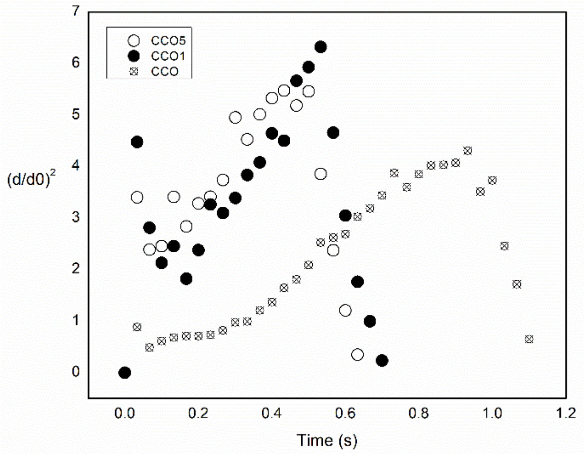


**Figure 3.** Ignition time for droplet CCO,CCO1 and CCO5

The combustion of vegetable oil occurred in four processes: heating, evaporation, ignition, and combustion [9]. **Figure 4** shows the relationship between $(d/do)^2$ and temperature with time on CCO. The highest temperature is at the maximum droplet size, and the highest temperature is the ignition temperature. The heating process began with the heat transfer from the heater to the droplet surface, which lowered the droplet surface tension lower than in the droplet. As a result, the fuel component moved to the droplet surface and took heat for preheating the fuel in the droplet [9]. The evaporation phase occurred when the heating conditions were sufficient, where the gasification process occurred in each fuel component. When CCO was added, nanocarbon

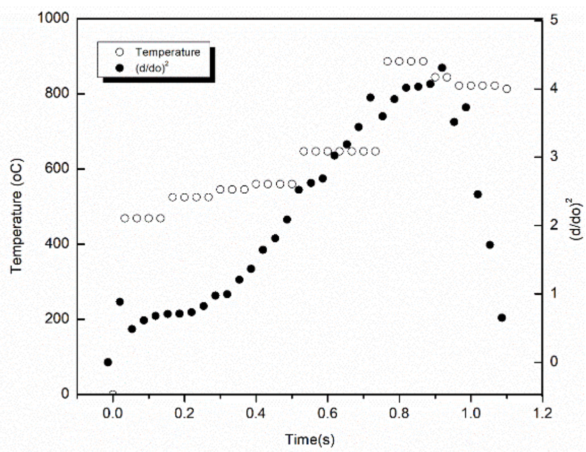


**Figure 4.** The d² plot for the heated droplets of CCO

had a shorter evolution and smaller droplet size than the CCO, which did not add nanocarbon. CCO burned about 0.933 s with a droplet diameter of about 4.307 mm, CCO1 burned about 0.533 s with a droplet diameter of about 6.323 mm, and CCO5 burned 0.433 s with a droplet diameter of 5.472 mm.

Furthermore, pure CCO had the smallest droplet size when it was about to burn, and the largest droplet size was in CCO1. It demonstrates that the addition of nanocarbon increased the droplet size. In contrast to CCO5, the droplet size was smaller than CCO1 because of frequent microexplosion in CCO5. The large bubble growth on CCO1 indicates that CCO1 has a small surface tension due to weaker intermolecular forces.

Then, **Figure 5** illustrates the relationship between $(d/do)^2$ and temperature versus time in CCO, and the highest temperature was at the maximum droplet size. Compared to CCO and CCO2, the temperature of CCO1 was the lowest. This happened because CCO1 had the largest droplet diameter compared to CCO and CCO5. In addition, internal gasification resulted in the growth of larger bubbles [5], [20]. As the evaporation rate increased, combustion occurred at a lower temperature. A large amount of heat energy was converted into latent heat used for phase changes during the evaporation stage.

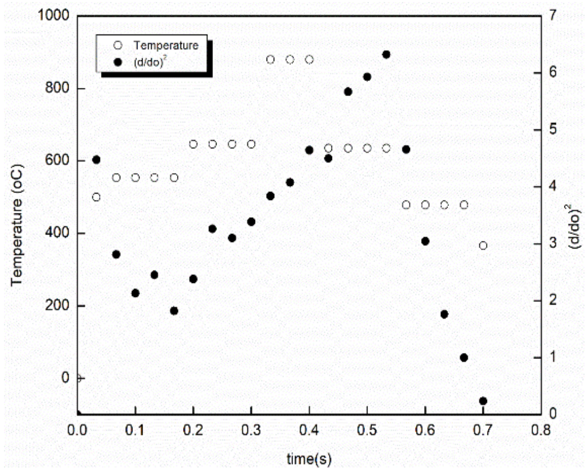


**Figure 5.** The d² plot for the heated droplets of CCO1

**Figure 6** confirms that CCO5 temperature is higher than CCO and CCO1. In addition, the time required for ignition was shorter than CCO and CCO1. It proves that the percentage of addition of nanocarbon more shortens the evaporation time, increasing the temperature to a higher level. Short evaporation indicates that the viscosity of CCO5 is lower due to the addition of the highest percentage of carbon nano. With the addition of a higher percentage of carbon nano, the CCO5 was more reactive so that the ignition delay was shorter.

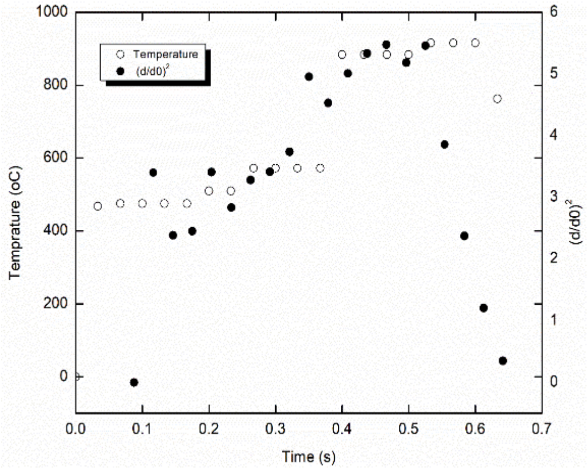


**Figure 6.** The d² plot for the heated droplets of CCO5

**Figure 7** shows the relationship of temperature and time to the percentage addition of nanocarbon and CCO fuel. CCO5 has the highest temperature, followed by CCO, and the lowest is CCO1. Meanwhile, the shortest time required from evaporation, ignition, and burning was in CCO, followed by CCO5, and the longest is CCO1. Pure CCO already has a high temperature because CCO is a straight fatty acid, requiring much energy for relaxation before ignition [12]. The temperature will be higher when added with nanocarbon because it requires more energy [21].

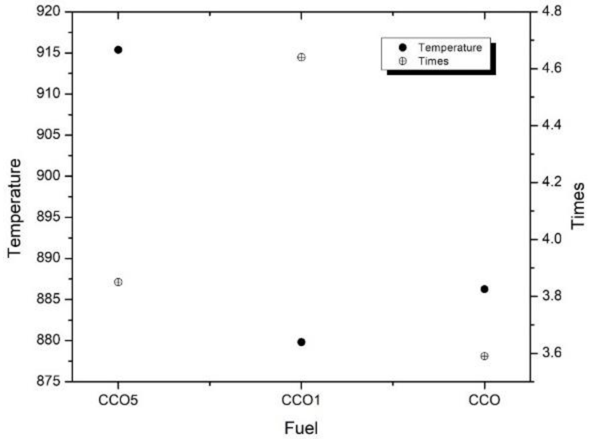


**Figure 7.** The d² plot for the heated droplets of CCO, CCO1, CCO5

Finally, **Figure 8**, **Figure 9**, and **Figure 10** demonstrate the evolution of the droplet flames of CCO, CCO1, and CCO5 shows that the addition of nanocarbon greatly affects the flame width as in CCO1 and CCO5, where the flame is wider than CCO. This is due to the addition of nanocarbon, which made CCO fuel burn faster. Furthermore, the CCO5 was wider and extended upward, which is called microexplosion. Microexplosion begins with a prominent flame shape, then in a short time, the oval flame lengthens. This phenomenon is in accordance with research [5]. Moreover, there were more CCO5 microexplosions than CCO1 and CCO. Thus, CCO5 has a relatively short burning time, which is in line with the statement [22]; in the presence of a micro explosion, the combustion time will be shorter.

**Figure 8.** Flame evolution of CCO droplet

**Figure 9.** Flame evolution of CCO1 droplet

**Figure 10.** Flame evolution of CCO5 droplet

## 4. Conclusion

The major conclusions are summarized as follows. The addition of carbon nano 5% (CCO5) is more reactive so that the ignition delay was shorter and affects the visualization of the flame compared to without nanocarbon. Then, the addition of nanocarbon results in high temperatures, because the energy required is greater. Finally, micro-explosions resulted in CCO5 having a short burning time. The results of this study complement the literature on optimizing the use of CCO for diesel oil substitution for now and in the future, towards 100% renewable fuel.


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## Author's Declaration

### Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.


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### Availability of data and materials

All data are available from the authors.

### Competing interests

The authors declare no competing interest.

### Additional information

No additional information from the authors.

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