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IDENTIFYING THE EFFECT OF AROMATIC COMPOUNDS ON THE COMBUSTION CHARACTERISTICS OF CRUDE COCONUT OIL DROPLET

Helen Riupassa
Senior Lecturer*
Suyatno Suyatno
Associate Professor *
Hendry Yoshua Nanlohy
Corresponding author
Associate Professor*
E-mail: hynanlohy@gmail.com
*Department of Mechanical Engineering
Jayapura University of Science and Technology
Jalan Raya Sentani Padang Bulan,
Jayapura, Papua, Indonesia, 99351

For now, energy sources uses are still dominated by fossil fuels, whose availability is limited and continues to decline. Therefore, new alternative energy is needed to reduce dependence on fossil fuels. Crude vegetable oil is one alternative energy source that can be utilized as a substitute for fossil fuels because vegetable oil has a composition almost similar to fossil fuel. Crude coconut oil is an alternative to biodiesel to reduce dependency on fossil fuels. The combustion reaction of crude coconut oil is tricky because it has bonds saturated chain, so a substance is needed to weaken the carbon chain to increase the burning rate. The burning rate of coconut oil droplets has been investigated experimentally by adding clove oil and eucalyptus oil bio-additives. Tests were carried out with single droplets suspended on a thermocouple at atmospheric pressure and room temperature and ignited with a hot wire. The addition of clove oil and eucalyptus oil as bio-additives in crude coconut oil was 100 ppm and 300 ppm, respectively. The suspended droplet combustion method was chosen to increase the contact area between the air and fuel so that the reactivity of the fuel molecules increases. The results showed that the eugenol compounds in clove oil and cineol compounds in eucalyptus oil were both aromatic and had an unsymmetrical carbon chain geometry structure. Therefore, this factor has the potential to accelerate the occurrence of effective collisions between fuel molecules; thus, the fuel is flammable, as evidenced by the increased burning rate. Moreover, from the observations, it was found that the highest burning rate was achieved in both bio-additives with a concentration of 300 ppm

Keywords: droplet combustion, crude coconut oil, bio-additives, aromatic compound

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1. Introduction

Bio-additives' mechanisms in the crude coconut oil (CCO) diffusion burning process have not been widely disclosed [1]. They are still very complex, such as evaporation, ignition, and chemical reactions from combustion between fuel vapors and air [2, 3]. Meanwhile, crude coconut oil compounds contain multicomponent elements, i. e., saturated fatty acids, monounsaturated fatty acids, polyunsaturated fatty acids, and glycerol [4]. The uniqueness of CCO characteristics and complexity make the effect of bio-additives challenging to understand at the mechanical level [5, 6]. Therefore, studies on the bio-additive effects of clove oil and eucalyptus oil on the molecular geometry, physicochemical properties, and combustion characteristics of crude coconut oil are of scientific relevance.

2. Literature review and problem statement

Previous researchers have applied research using vegetable oils in internal combustion engines. However, even if applied research can be categorized as successful, much scientific information still has not been revealed, such as the behavior of fuel molecules and their interactions with oxygen when they are in a combustion chamber with a very high complexity [7, 8]. Furthermore, they stated that the fundamental things that have not been revealed are the interaction and molecular reactivity between fuel and air when it receives heat, especially about the behavior of polar and nonpolar atoms and molecules that are simultaneously present in the triglyceride carbon chain. This is reasonable because crude coconut oils have many complex factors, such as multi-component compounds with different roles and potential effects in the combustion process [9]. Moreover, the high viscosity of vegetable oils makes it challenging to ignite under normal conditions, such as diesel oil [10], which can be related to equipment settings and modifications. On the other hand, the increasing technology for utilizing fatty acid triglycerides or monoglycerides from vegetable oil and fat production waste also plays a significant role in it [11, 12]. Meanwhile, the atomization processes must always be pursued to produce fuel particles ideal for burning [13]. These particles are in the form of droplets that diffuse one another to create a flame propagation relationship that arises due to the interaction between the droplets during the spraying process [14]. In addition, convection flows such as eddies or buoyancy of highly dynamic fuels also play a role in generating this complexity [15], as well as normal gravity conditions such as pressure and temperature [16], and the composition of fuel molecules that have the potential have different reactivity [17].

On the other hand, previous studies have also used fundamental manner like the suspended single droplet combustion method by utilizing various vegetable oils, including coconut oil, jatropha oil, castor oil, sunflower oil, corn oil, palm oil, soybean oil, and glycerol [18, 19]. They found that vegetable oils have two components of carbon chains: fatty acids and glycerol, and they burn at different times, starting with fatty acids followed by glycerol. Moreover, they stated that crude vegetable oil has a long ignition delay resulting in a lower burning rate and a longer burning lifetime [20]. Therefore, overcoming these weaknesses requires additional bio-additives, such as clove oil and eucalyptus oil, which improve fuel performance [21].

However, not many studies have revealed scientific information about the role of the compounds of both oils on molecular perspectives and their impact on fuel performance. The previous studies found that it is not easy to see the role of fuel atoms and molecules through application research because it is only oriented to engine performance. Even the impact of the existence of multi-component fuel compounds, reactivity, and their role and effect on the diffusivity of flame in the combustion chamber. Furthermore, clove oil (CvO) contains eugenol compounds, while eucalyptus oil (EO) contains cineol compounds, and these are aromatic with bent geometric structures. The presence of aromatic rings potentially increases the reactivity of fuel molecules due to the carbon chain having a planar ring structure conjugated with delocalized pi-electron clouds [22]. The delocalized electrons create a magnetically induced field that can produce attractive interactions between the fuel molecules and potentially change the geometric design of the compounds next to them [23]. Changes in the carbon chain's geometrical structure increase the fuel molecules' reactivity so that they are flammable. Moreover, this is due to several things, including the distance between the carbon chains and the van der Waals bonds weakening so that the viscosity decreases [24].

The description above shows that the role of aromatic eugenol and cineol compounds is very significant in improving the performance of vegetable oil fuels. Therefore, it is necessary to investigate the droplet combustion phenomena of crude coconut oil (CCO) mixed with clove oil and eucalyptus oil bio-additives. The use of unrefined coconut oil is because of abundant raw materials, but it has weaknesses due to its being composed of saturated fatty acid carbon chains [25]. Saturated fatty acids tend to be rigid, so their viscosity and flash point are high, potentially hampering and reducing fuel performance [26].

On the other hand, the molecular structure of clove oil and eucalyptus oil has an asymmetrical carbon chain structure, side chains, and aromatic rings. The aromatic compounds contained in eugenol and cineol have the potential to generate magnetic fields obtained from electron resonance in their cyclic rings [27]. The molecular structure of the cyclic rings of eugenol and cineol can form conjugation bonds, which have the potential to cause the delocalization of electrons [28]. These factors can generate attractive forces between fuel molecules, which can potentially increase the reactivity of fuel molecules [29]. The discussion above shows that the presence and role of fuel atoms and molecules in fuel performance are exciting to reveal, especially about the interaction between the triglyceride carbon chain of CCO and the compound molecules in CvO and EO bio-additives. Moreover, it also includes the geometric structure and the role of eugenol and cineol compounds from clove oil and eucalyptus oil, which are crucial to reducing viscosity and flash point, thus potentially increasing the burning rate and fuel performance. All this allows us to assert that it is expedient to conduct more detailed research and observations were carried out on the working mechanism of the additive and its effect on the combustion characteristics of single droplet crude coconut oil by adding clove oil and eucalyptus oil as a homogenous combustion additive.

3. The aim and objectives of the study

The study aims to find out the combustion characteristics of crude coconut oil blended fuel with clove oil and eucalyptus oil as a bio-additive.

To achieve the aim, the following objectives were set:

– to provide the role of the cineole compound from clove oil towards the diffusion burning rate of crude coconut oil droplet;

– to provide the role of the eugenol compound from eucalyptus oil towards the diffusion burning rate of crude coconut oil droplet.

4. Materials and methods

The current research object is crude coconut oil as the primary raw bio-material, mixed with clove oil and eucalyptus oil bio-additives. The raw bio-material of CCO was obtained from traditional markets, further it was mixed manually with bio-additives. The blended fuel composition ratio is 100 ml: 100 ppm and 300 ppm. Mixing crude coconut oil and bio-additives by hand aims to cut the production chain through the transesterification process to save the conversion process of crude vegetable oil into fuel. On the other hands, to determine the composition of the compounds that make up CCO, CvO, and EO, the GCMS test was carried out, and the results are given in Tables 1–3.

Furthermore, from Tables 1–3, it can be seen that lauric is the compound with the most significant content in CCO, equal to 31.43 %. In comparison, for eucalyptus oil, as much as 65.94 % is composed of 1,8-cineole; for clove oil, the most significant compound is eugenol, which is approximately 81.2 %. In addition, CCO, CvO, and EO are composed of multi-element components, where each element has different properties so that it has the potential to produce a unique and dynamic combustion process.

Table 1

The carbon chain compound of crude coconut oil

Compound	Formula	Composition, %
Caproic	$C_6H_{12}O_2$	0.6
Caprylic	$C_8H_{16}O_2$	8.45
Capric	$C_{10}H_{20}O_2$	6.1
Lauric	$C_{12}H_{24}O_2$	31.43
Myristic	$C_{14}H_{28}O_2$	18.45
Palmitic	$C_{16}H_{32}O_2$	8.4
Stearic	$C_{18}H_{36}O_2$	1.65
Oleic	$C_{18}H_{34}O_2$	5.7
Linoleic	$C_{18}H_{32}O_2$	1.4
Linolenic	$C_{18}H_{30}O_2$	0.05

Table 2

The carbon chain compound of eucalyptus oil

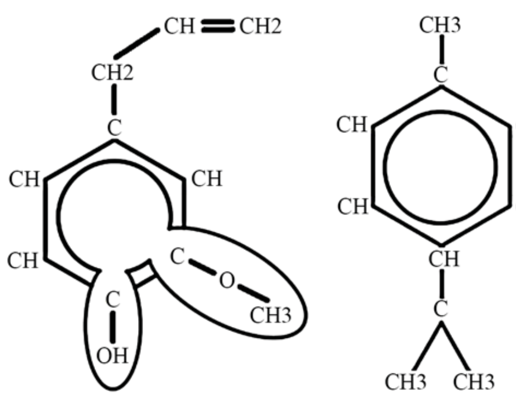
Compound	Formula	Composition, %
1,8-Cineole	$C_{10}H_{18}O$	65.94
γ-Terpinene	$C_{10}H_{16}$	7.37
Trans-Caryophyllene	$C_{15}H_{24}$	6.31
α-Terpinolene	$C_{10}H_{16}$	5.9
3-Cyclohexene	$C_{10}H_{18}$	5.85
α-Humulene	$C_{15}H_{24}$	4.11
Linalool	$C_{10}H_{18}$	2.57
α-Eudesmol	$C_{15}H_{26}$	1.95

Table 3

The carbon chain compound of clove oil

Compound	Formula	Composition, %
Eugenol	$C_{10}H_{12}O_2$	81.2
Caryophyllene	$C_{15}H_{24}$	16.42
Humulene	$C_{15}H_{24}$	1.52
3'-methoxyace-tophenone	$C_{18}H_{30}$	0.53
Caryophyllene oxide	$C_{15}H_{24}O$	0.33

In addition to the multi-component elements owned by CCO fuel and CvO and EO additives. From Fig. 1, it can also be seen that the possibility of attractive forces and magnetic induction between atoms is increasing with electron delocalization trajectories in eugenol and cineol compounds.



a *b*

Fig. 1. Electron delocalization trajectory: *a* — eugenol; *b* — cineol

Furthermore, based on Tables 1–3 and the bio-additive characteristics, a hypothesis can be developed that double bonds in eugenol and cineol compounds potentially cause electron delocalization, thereby increasing the attractive forces between atoms and resulting in an imbalance of bond energies in fuel molecules [30]. Moreover, the impact of this imbalance is the emergence of atomic resonance and increasing reactivity of fuel molecules. These factors can change the geometric structure of the CCO carbon chain so that it becomes weak and the fuel is easy to ignite and burn.

Meanwhile, simplification is needed to understand the flame behavior with the complexity of the combustion process in the combustion chamber. Therefore, to prove the hypothesis that has been described previously about the influence of bio-additives on the combustion characteristics of CCO, observations were made on the phenomena and characteristics of fuel combustion on a droplet. The droplet fuel combustion method is based on our previous research, as illustrated in Fig. 2 [31].

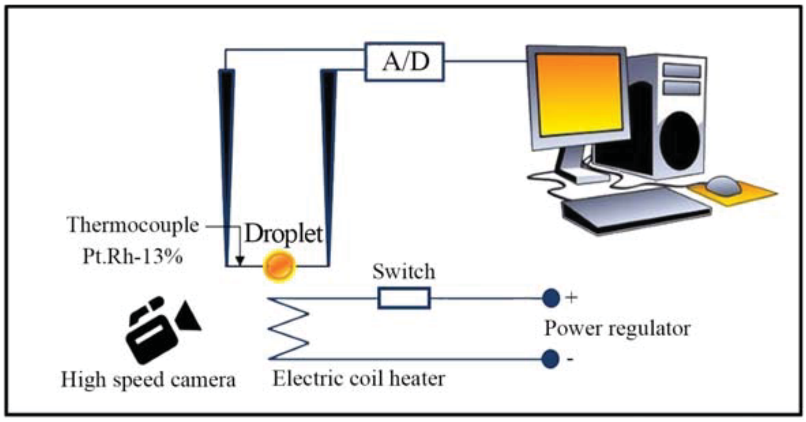


Fig. 2. The experimental apparatus

Furthermore, the single droplet combustion method is used as an assumption and simplifies the overall behavior and combustion characteristics of many droplets or fuel when injected into the combustion chamber. Fig. 2 shows the research scheme of the droplet combustion. The droplet hung on a thermocouple tip and ignited using an electric coil heater. Single droplet combustion is an attractive analysis, low utilization, and cost-effective method for combustion characteristics based on fuel properties.

5. Results of the effect of aromatic compounds on the combustion characteristics of crude coconut oil droplet

5. 1. The role of the cineole compound from eucalyptus oil towards the diffusion burning rate of crude coconut oil droplet

We observed the characteristics of the diffusion burning rate of crude coconut oil with the addition of clove oil and eucalyptus oil, which aims to determine the effect of aromatic eugenol and cineol compounds on fuel performance.

Fig. 3 shows a big view of the molecular interaction between aromatic eugenol and cineol compounds with the carbon chain of CCO triglycerides. The figure shows that the two aromatic compounds have different roles and influences on the combustion characteristics of CCO fuel.

Furthermore, Fig. 3 shows that the hydroxyl groups in cineol compounds can produce attractive interactions with the oxygen atoms in the triglyceride carbon chains, where the oxygen atoms are isolated and nonpolar. This analysis is very likely because Table 2 shows that most of the composition of eucalyptus oil is cineole, which is equal to 65.41 %. The formation of H_2O molecules has the potential to cause a natural transesterification process so that the carboxyl group on the triglyceride carbon chain breaks and separates from the fatty acids. This analysis follows previous studies, which used crude jatropha oil and palm oil droplets without additives but underwent a preheating process and magnetic field [32] to produce hot steam in the form of H_2O molecules, which contribute to breaking the carboxyl group from fatty acids [33, 34], and increase the reactivity of fuel molecules.

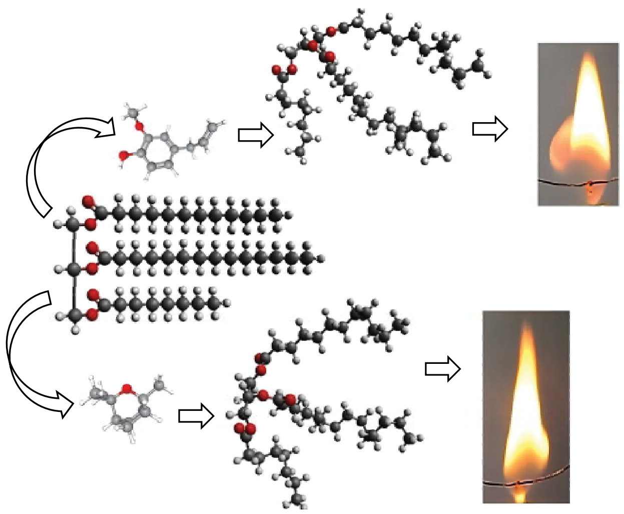


Fig. 3. Surface interaction between triglyceride of crude coconut oil with aromatic compounds of clove oil and eucalyptus oil

Moreover, when the fuel wants to be used again, the heating process must continuously be repeated to reduce its viscosity, so it takes a lot of time and money. On the other hand, the presence of eugenol compounds that produce new bonds that can potentially increase the mass and length of the carbon chain of CCO. This impact is that the distance between the fuel molecules becomes smaller, so the possibility for an effective collision is substantial. This phenomenon could increase the reactivity of the material molecules so that they are flammable and the diffusion burning rate increases. This analysis is confirmed by the test results, which can be seen in Fig. 4.

Furthermore, Fig. 4 shows that the CCO fuel mixture achieves the fastest burning rate with 300 ppm EO, followed by CCO with 100 ppm EO, and the last is CCO without EO bio-additives. These results indicate that eucalyptus oil is suitable for use as a bio-additive because it has succeeded in increasing fuel performance, as evidenced by the increasing rate of fuel combustion. The presence of the hydroxyl group in the eugenol compound plays a significant role in this result, where Fig. 3 indicates an interaction between the hydroxyl group of the eugenol compound and the oxygen atom present in the carboxyl group of CCO. This interaction results in weak van der Waals bonds that can increase the reactivity of fuel molecules.

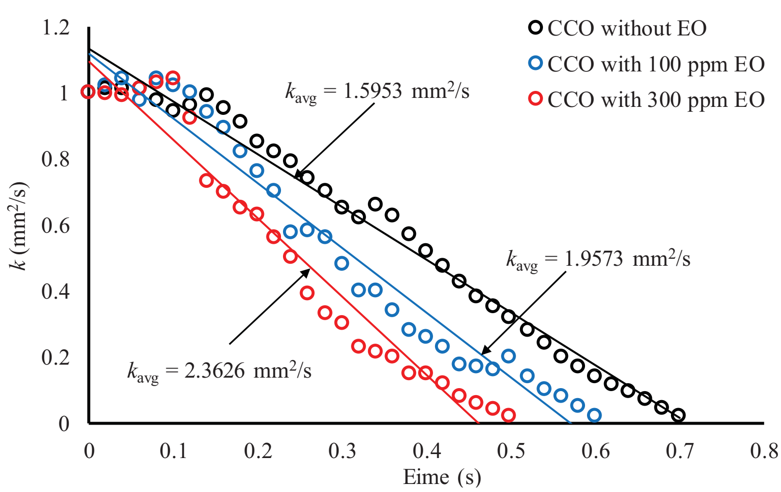


Fig. 4. Burning rate evolutions of crude coconut oil droplet with and without eucalyptus oil

In addition, from Fig. 4, it can also be seen that immediately after burning, there is a surge in energy that is marked by an increase in combustion rate. In addition, it can be seen that the energy surge occurred without being accompanied by a micro explosion, whereas for CCO with bio-additives, it happened faster, around 0.1 seconds. In contrast, CCO without bio-additives was seen slower, namely about 0.15 seconds. In general, it is also seen that the burning rates of the three fuels coincide with high volatility, as evidenced by the highly fluctuating burning rate lines. This analysis is clarified in Fig. 5–7. It can be seen that the evolution of flames without bio-additives looks calmer (Fig. 5). On the other hand, with bio-additives (Fig. 6, 7), it appears that the flame form is more volatile. This phenomenon indicates that the presence of aromatic compounds in CCO fuel can increase the reactivity of fuel molecules. Moreover, it was also shown by the emergence of micro explosions in CCO fuel with bio-additives, which occurred at different times and burning rates. The asymmetrical shape of the flame shows this micro-explosion phenomenon and indicates that fuel molecules have high reactivity [35], one reason being the presence of bio-additives in CCO. This analysis is possible because the presence of eugenol and cineol compounds can increase the effective collision between fuel molecules caused by three factors: the increase in the mass and length of the carbon chain and the closer distance between the fuel molecules. This analysis follows previous research using kerosene, coconut oil with areca nut extract, and liquid metal [16, 17]. Furthermore, they found that volatility due to the satellite particles is indicated by the appearance of a micro-explosion [14, 36].

Fig. 5. Flame evolution of CCO without bio-additives

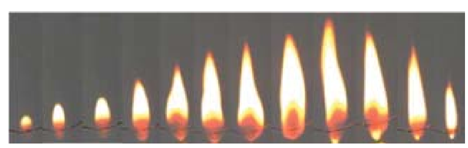


Fig. 6. Flame evolution of CCO with 100 ppm EO

Fig. 7. Flame evolution of CCO with 300 ppm EO

On the other hand, when compared to eugenol compounds, cineol has a different role in fuel performance. Based on the structure and molecular composition of the cineol compound, it can be seen that the chances of molecular bonding with the triglyceride carbon chain of crude coconut oil are complicated. This analysis is possible because from Tables 1, 3, it can be seen that the majority of fatty acid compounds contained in CCO and EO are stable and saturated. Furthermore, from Fig. 8, we can see that the durable and watery nature of the EO compound has the potential to change the geometry of the CCO carbon chain.

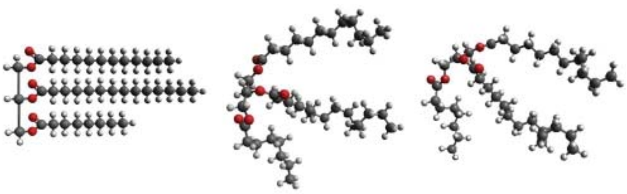


Fig. 8. Triglyceride chain evolution due to the molecular interaction with eugenol

The analysis makes sense because when the cineol and the CCO fatty acid are close to each other. This can generate a magnetic field induction resulting in an electromagnetic force that causes an attractive pressure and repels the fuel molecules. This factor can change the geometric structure of the CCO carbon chains, whereby the infiltration of cineol compounds between CCO triglycerides, a bulky system, is formed, causing the distance between the fatty acid carbon chains to widen. This analysis follows previous studies using noni seed oil and discusses it from a different perspective [37]. Meanwhile, when the distance between the carbon chains gets wider and farther (Fig. 8), the van der Waals bonds weaken, and the viscosity decreases, causing the fuel to burn quickly and the diffusion burning rate to increase. This analysis is clarified from the results of the combustion test data (Fig. 9).

5. 2. The role of the eugenol compound from clove oil towards the diffusion burning rate of crude coconut oil droplet

From Fig. 9, it can be seen that CCO achieves the fastest burning rate with 300 ppm CvO, and then CCO with 100 ppm CvO and the slowest is CCO without CvO. These results prove that the presence of cineol compounds in CCO can increase the reactivity of fuel molecules to affect the fuel burning rate positively. These results are strongly confirmed by the flame evolution shown in Fig. 10, 11, where it can be seen that the droplet flame evolution of CCO with 300 ppm CvO is shorter when compared to CCO with 100 ppm CvO.

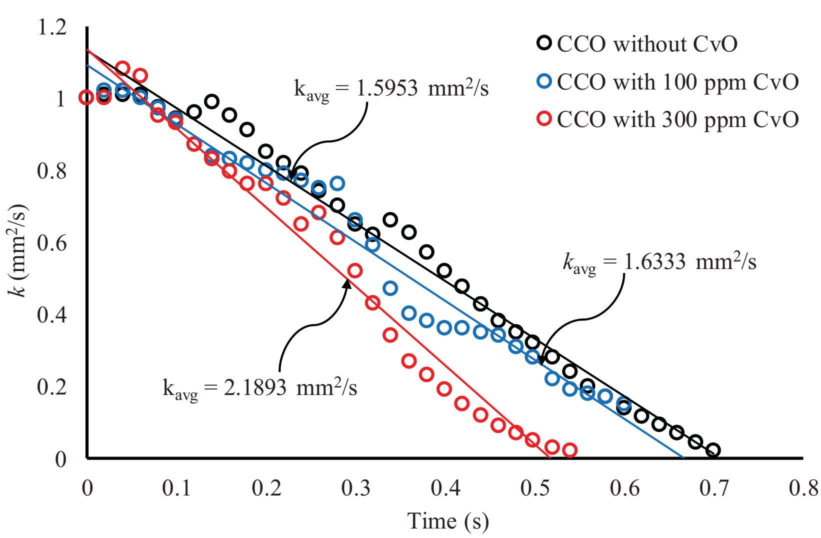


Fig. 9. Burning rate evolutions of crude coconut oil droplet with and without clove oil

Fig. 10. Flame evolution of CCO with 100 ppm CvO

Fig. 11. Flame evolution of CCO with 300 ppm CvO

In addition, for CCO fuel with 300 ppm CvO, the burning rate is shown to increase by 0.1 mm^2/s shortly after the fuel burns. This phenomenon shows that energy absorption occurs at the beginning of fuel ignition and is followed by a rapid release of energy, which is about 0.55 s faster when compared to CCO with 100 ppm CvO around 0.6 s and CCO without CvO about 0.7 s. In addition, it is generally seen that the increase in the burning rate occurs in both fuels with additives at different times. This phenomenon is due to the fuels being composed of multicomponent compounds (Tables 1, 2), and each blend has different properties and flash points. In addition, these results also indicate that 300 ppm CvO is the best composition as a bio-additive to be added to CCO compared to 100 ppm.

Moreover, for CCO with 100 ppm CvO, we can see that the burning rate is lower, indicating that the practical collision between the fuel molecules does not occur optimally. This phenomenon is due to the fact that the amount of bio-additive mass content in CCO is insufficient to produce an optimal contact distance between the fuel molecules. This analysis is possible and follows previous research [38] on the effect of bio-additives on the burning of crude vegetable oil, which is discussed from different perspectives.

Furthermore, to reveal other effects and phenomena of the eugenol and cineol compounds, the two bio-additives were mixed simultaneously into CCO in the same volume as the two previous fuel samples (CCO with EO and CCO with CvO), namely 100 ppm and 300 ppm. From Fig. 12, it can be seen that, in general, the addition of bio-additives has the same effect as the two previous samples. These results indicate that CCO with 300 ppm EO and CvO is the ideal composition for functioning as an additive to crude vegetable oil fuel. This phenomenon is supported by the results of the droplet flame evolution, which can be seen in Fig. 13, 14, which show that the flame volatility is quieter, and the droplet burning lifetime is faster.

However, from Fig. 12, it can be seen that the burning rate increased, especially for bio-additives with 300 ppm, which is around 0.47 s, faster than the CCO sample with CvO and CCO sample with EO. On the other hand, for a mixture of 100 bio-additives and pure CCO, the burning rate appears to be the same, which is about 0.5 for 100 ppm and 0.7 for CCO. This result has the same phenomenon in the two previous samples, namely the CCO sample with CvO and CCO sample with EO. These results indicate that at 300 ppm, the fatty acid compounds CCO, eugenol, and cineol are in ideal conditions to interact. This phenomenon suggests that the fuel molecules have an effective collision distance due to the presence and role of cineol compounds.

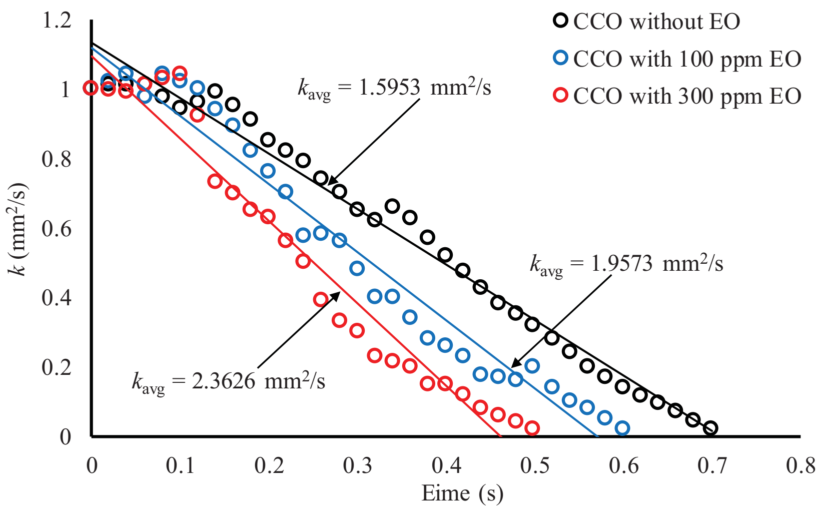


Fig. 12. Burning rate evolutions of crude coconut oil droplet with and without clove oil and eucalyptus oil

Fig. 13. Burning rate evolutions of CCO with CvO and EO

Fig. 14. Burning rate evolutions of CCO with CvO and EO

6. Discussion of the effect of clove oil and eucalyptus oil bio-additives on the combustion characteristics of crude coconut oil droplet

From the test results presented in section 5, it is proven that the addition of clove oil and eucalyptus oil biomaterials has succeeded in improving fuel performance. From Fig. 4, it can be seen that CCO with 300 ppm EO has the fastest burning lifetime. This phenomenon was clarified from the evolution of CCO droplet flames with and without bio-additives. This result is also confirmed by Fig. 5–7, where it can be seen that CCO with 300 ppm EO is more volatile when compared to the other two fuels. Moreover, it can be seen that the droplet evolution takes place in a faster time, which is around 0.5 seconds, while CCO with 100 ppm EO takes about 0.6 seconds, and the last one is CCO without EO, around 0.7 seconds. This analysis is possible because it is seen that CCO with 300 ppm EO has a faster average burning rate when compared to other fuels (Fig. 5–7).

As for CCO with CvO, it can be seen that the best performance of fuel occurs with a composition of 300 ppm. The burning speed shows that the most incredible power from CCO with CvO occurs with 300 ppm composition. This phenomenon has been clarified from the evolution of the droplet flame, which can be seen in Fig. 10, 11. Furthermore, Fig. 10, 11 show that CCO with 300 ppm CvO looks more volatile than CCO with 100 ppm and CCO without bio-additives. Moreover, the short diffusion time burning rate indicates that the fuel has high power, which is reasonable because the energy force (combustion power) is inversely proportional to time [39]. These results prove that the presence of cineol compounds in CCO can increase the reactivity of fuel molecules to affect the fuel burning rate positively, as shown in Fig. 10, 11, where at 300 ppm, it has the fastest average burning rate. Moreover, these results indicate that at 300 ppm, the fatty acid compounds CCO, eugenol, and cineol are in ideal conditions to interact. This phenomenon suggests that the fuel molecules have an effective collision distance due to the presence and role of cineol compounds [40]. However, from the phenomenon of droplet flame evolution presented in Fig. 10, 11, it is also seen that the flame volatility has decreased, which indicates another role that the cineol and eugenol compounds have, namely as a turbulence damper during the diffusion of flame propagation through the combustion process. This analysis follows previous research, which is discussed from a different perspective [41, 42].

Moreover, it is generally seen that at certain times there are several energy spikes marked by an increase in the burning rate. This indicates that the compounds that make up CCO with and without buffering burn at different times, which is caused by different flash points of each combination. This follows previous studies, which stated that crude vegetable oil burns in several stages, starting from unsaturated and long-chain carbon chain compounds [43], followed by polar saturated carbon chains.

However, bio-additives from clove oil and eucalyptus oil are limited to fundamental research. They have not yet been developed into applied research where the fuel is directly used in internal combustion engines. Meanwhile, given the dependency on fossil fuels and their increasingly limited availability, CCO with bio-additives has the potential to be used. Therefore, the thing that must be considered when using clove oil and eucalyptus oil is that they are expensive, which will negatively affect the production cost and efficiency. However, the good news is that with a better burning rate performance of CCO with clove oil and eucalyptus oil, it is inevitable that it can be an alternative for bio-additives to meet fuel needs. In addition, by eliminating the transesterification [44] and pre-heating [45] processes, using eucalyptus oil and clove oil as bio-additives can save energy and production costs. Furthermore, based on the discussion above, CCO fuel with CvO and EO bio-additives has excellent potential for application in diesel engines with a volume ratio of 70 % CCO: 30 % bio-additive. Moreover, from the results, it has the potential to increase the reactivity of fuel molecules so that it directly influences engine performance, where engine power and speed increase and produce environmentally friendly exhaust emissions.

Furthermore, to maximize the role of CvO and EO as bio-additives, it is necessary to conduct further research using other crude vegetable oils such as castor oil, sunflower seed oil, cotton oil, and other crude oil vegetable oils. In addition, analysis can also be carried out on the phenomenon of crude vegetable oil spray hitting a wall as a simplification of the behavior of fuel when it is injected and hits the combustion chamber wall.

7. Conclusions

1. The cineole compound of clove oil effectively improved the performance of CCO fuel, which is marked by an increasing burning rate. Consecutively, the fastest average burning rate (k_{avg}) was obtained by CCO with 300 ppm CvO, around 2.1893 mm^2/s, next was CCO with 100 ppm CvO, around 1.6333 mm^2/s, while the slowest is CCO without additives, with an average burning rate of around 1.5953 mm^2/s. This phenomenon indicates that cineol compounds increase the effective distance between fuel molecules so that the potential for effective collisions between fuel molecules increases. This causes the viscosity to decrease, and the fuel is easily ignited.

2. The hydroxyl group in eugenol compounds acts as a hydrogen acceptor to break the hydroxyl groups of fatty acids to present a natural transesterification process. Even though coconut oil is saturated and rigid, the eugenol compounds manage to weaken the van der Waals bonds between carbon chains. Therefore, the reactivity of the fuel molecules increases due to the bulky geometry of the triglyceride structure. These factors affect increasing fuel performance, which can be seen from the faster fuel burning rate. Consecutively, the highest burning rate occurred in CCO with 300 ppm EO, which was around 2.3626 mm^2/s, while for CCO with 100 ppm EO, it was lower, namely 1.9573 mm^2/s.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Data cannot be made available for reasons disclosed in the data availability statement.

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