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ORIGINAL ARTICLE

Analysis of the Combustion Characteristics and Performance of Lemon and Orange Peel Biomass Composite Fuel Diesel

Alaa MA Musalam[1], Abdel Fattah Qaraman[2], Nizam M. El-Ashgar[3], R.A. Kuchmambetov[4]

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The authors declare that this manuscript was approved by all authors in its form and that no competing interest exists.

Affiliation and Correspondence:

1- University College of Science and Technology Khan Yunis, Palestinian Territory.
2- Israa University, Palestinian Territory.
3- Chemistry Department, Islamic University of Gaza, Palestinian Territory.
4- National Aerospace University, Energy Saving Engineering, Kharkiv, Ukraine.

*__Corresponding Author Email:__
alaamusalam1@gmail.com

ABSTRACT:

Background: Orange and lemon peels are a type of biomass waste, as the demand for the production of these citrus species and their use in various food industries leads to their significant accumulation in the form of waste. This study was designed so that this waste is recycled to be added to diesel fuel and to verify its suitability as a composite fuel.
Method: This study aimed to investigate the thermal combustion behavior of lemon peel powder, LPP, and orange peel powder, OPP biomass composite fuel diesel. The citrus peel was dried and ground to a powder material of 450-750 µm in size, then mixed in different percentages with diesel fuel. Different parameters were controlled to improve the composite fuel characteristic. The pyrolysis experiments of the diesel/citrus composite fuel were conducted in an internal combustion engine.
Results: The results showed that the citrus/diesel composite fuel sustains its combustion properties at 30% of the added citrus peel powder, with a reduction of harmful emissions. The results showed that calorific values of diesel containing 30% LPP or 15% LPP + 15% OPP were very close to that of pure diesel. The maximum calorific values were obtained at α = 0.85, 0.80, and 0.90 for 30% OPP, 30% LPP, and 15% OPP + 15% LPP composite fuels respectively. It was found that the addition of homogenization material and combustion activator to the composite fuel raised the maximum temperature of combustion by 230 °C, 200 °C, and 330 °C for 30% OPP, 30% LPP, and 15% OPP + 15% LPP respectively. The TGA analysis of lemon and orange showed that the weight loss has proceeded in three stages, the first at 150°C – 200 °C due to water evaporation, the second at 400 °C due to hydrolysis of cellulose and hemicellulose, and the third at 600 °C due to combustion of fuel material forming carbon residue.
Conclusion: The composite fuel without additives showed the highest combustion temperature at about 600 °C, while the maximum combustion temperature for the composite fuel with additives was achieved at 800 °C at a shorter time.

KEYWORDS: Diesel fuel, orange peel powder, lemon peel powder, diesel composite fuel, diesel thermal behavior

INTRODUCTION:

The researchers focus these days on finding alternative energy sources to cover the shortage of electricity and the continuously increasing demand for power supply in the world (Al Farra, & Elaydi, 2019, Elblbeisi, & Shabat, 2023). The growth of the world population leads to an increasing growth in the agribusiness sector to meet the increase in demand for food overall in the world. Many countries that have economies based on agribusiness, contribute to the generation of biowaste resulting from the production processes. The biowaste may result in environmental pollution due to improper disposal (Marshall and Farahbakhsh, 2013).

To minimize the effect of biowaste environmental pollution, several studies suggest different applications of biowaste as a biofuel (Santos, et al., 2015) or composite fuel (Musalam and Qaraman, 2016 , Musalam et al., 2023) as it combusted exothermically when reacted with oxidants. This biowaste could be used as a supplement for the power capacity and may assist in providing a sustainable alternative (Ashok, 2020; Kok and Ozgur, 2013).

Renewable energy sources such as biodiesel, bioethanol, biomethane, and biomass from wastes or hydrogen have become the subjects of great interest (Reddy, et al., 2013).

The composite fuel is used to reduce the dependence on oil sources by adding solid or liquid materials that are abundantly available with liquid fuels such as diesel, so it is considered one of the methods used in countries that do not produce petroleum oil, such as Palestine.

Many valuable types of research studied composite fuel with solid materials such as coal powder in liquid fuels. The composite fuel was prepared and pumped into diesel engines, and it gave an acceptable thermal efficiency (Wamankar and Murugan, 2015; Musalam and Qaraman, 2016; Reddy, et al., 2013).

Other studies used the residues of oil pressing waste, such as olive waste, to produce a composite fuel used in different thermal fields, after comparing the thermal behavior of such composite fuels with the thermal behavior of diesel, this led to obtaining a composition of the composite fuel closer to diesel fuel (Çaynak et al, 2009; Musalam & Qaraman, 2010).

Vegetable oils were used as composite fuels to diesel in diesel car engines, but they need heat treatments and the addition of active materials to increase their efficiency and reduce their viscosity.

The oils used were sunflower oils, cottonseed oils, and soybean oils (Altın et al, 2001; Murayama et al, 2000; Musalam, 2014).

Orange peel has been used in the production of biodiesel in compression ignition engines by converting the extracted peel oil by transesterification (Olorunshol and Fasogbon, 2023). Sivalingam, et al. (2023) studied the effect of lemon peel oil with novel eco-friendly and biodegradable emulsion in un-modified diesel engines. There was a significant drop in HC, CO, and NOx emissions by about 20.68, 7.83%, and 27.7% respectively in comparison with diesel fuel. On the other hand, peel powder was used as a composite fuel with diesel in combustion engines, the results showed that mixing 30% of orange peel powder with diesel at a pressure of 235 bar gave the best performance and lower emissions in CO and HC (Purushothaman and Nagarajan, 2009; Reddy et al., 2013). The main chemical composition of citrus peel is phenols, sugars alkaloids, saponins, terpenes, resins, flavonoids, and tannins in addition to some trace metals (Reddy et al., 2013).

In the Gaza Strip, the cultivated area of the citrus crop reached 20,000 agricultural dunums, with a production of 35,000 tons for the agricultural season 2019/2020 (Alray, 2020). Gaza Strip has been suffering from many crises since 2007 in the field of energy and the production of electric power, due to the lack of fuel, especially since Palestine does not produce oil or fossil fuel sources. Also, Palestinian areas faced more severe economic circumstances as a result of the war in Ukraine, particularly when prices for petroleum goods rose. Figure 1 illustrates the increase in diesel costs brought on by the conflict between Ukraine and Russia (fuel price, 2022).

The investigation of the thermal behavior of lemon and orange peels combined with diesel is essential due to its potential implications for sustainable energy and environmental preservation. The utilization of agricultural waste, such as citrus peels, as a renewable resource for composite fuel, can offer several advantages. It may reduce the reliance on fossil fuels, promote waste valorization, and mitigate harmful emissions (Kumar, et al., 2020; Sivalingam, et al. 2023). The study attempts to investigate a suitable composite fuel composition consisting of citrus peel powder, which is abundantly available in the Gaza Strip, such as oranges and lemons, by mixing it with diesel, then studying the thermal properties of this composite fuel and comparing it with the thermal properties of 100% diesel through the combustion processes under combustion pressure as well as the combustion under the atmospheric pressure.

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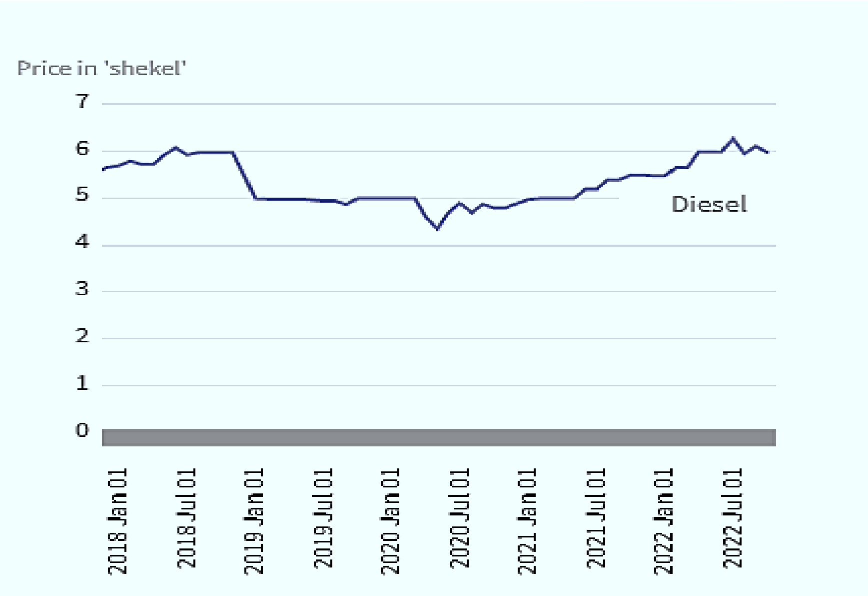

Figure 1. Historical fuel prices in Palestinian territories.

1. Materials and methods

Materials

The peel of citrus fruits which included oranges and lemons were collected as residuals from domestic use in the Gaza Strip. Diesel with heat of combustion 4.01×10^4kJ /kg was brought from local fuel stations. Alkyl phenol ethoxylate (APE) was supplied from Merck. Ethanol 95% and carboxymethyl cellulose (CMC) were purchased from Merck.

Composite fuel preparation

Citrus peel was well dried under sunlight at a temperature of 27 °C after washing with distilled water. The dry peel was crushed and ground using a mill and then sieved to obtain a powder of particle size in the range of 450-750 µm size. Different percentages of lemon and orange peel powder (10-30 %) by mass of total fuel composite were mixed with diesel with and without additives. The additives used were 0.05% alkylphenol ethoxylate (APE), 2.0% carboxymethyl cellulose (CMC), and 3.0% ethanol (95%). APE additive is a nonionic surfactant used as homogenizing, emulsifier, and the solubilizer CMC is used as an activator, while ethanol is used as a solubilizer.

The samples were preserved for 10 days at room temperature before the pyrolysis experiments.

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The fuel engine setup

The experimental fuel engine setup assembly of the fuel engine is given in Figure 2. The setup operation involves the following steps:

- **Fuel Mixture Preparation:** Different proportions of the composite fuel are prepared separately.
- **Initial Testing:** Each composite fuel mixture is tested in the engine individually. The engine is initially run using pure diesel fuel until it reaches stability. This process takes up to 5 minutes.
- **Thermal Measurements:** During the initial testing with pure diesel fuel, thermal measurements are taken to establish a baseline for comparison.
- **Composite Fuel Pumping:** After the engine reaches stability with pure diesel, the composite fuel mixture is gradually pumped into the engine.
- **Diesel Pumping Stop:** Once the composite fuel pumping starts, the pumping of pure diesel is stopped.
- **Waiting for Stability:** The engine is allowed to stabilize after introducing the composite fuel. Thermal measurements are taken during this stable state for analysis and comparison.

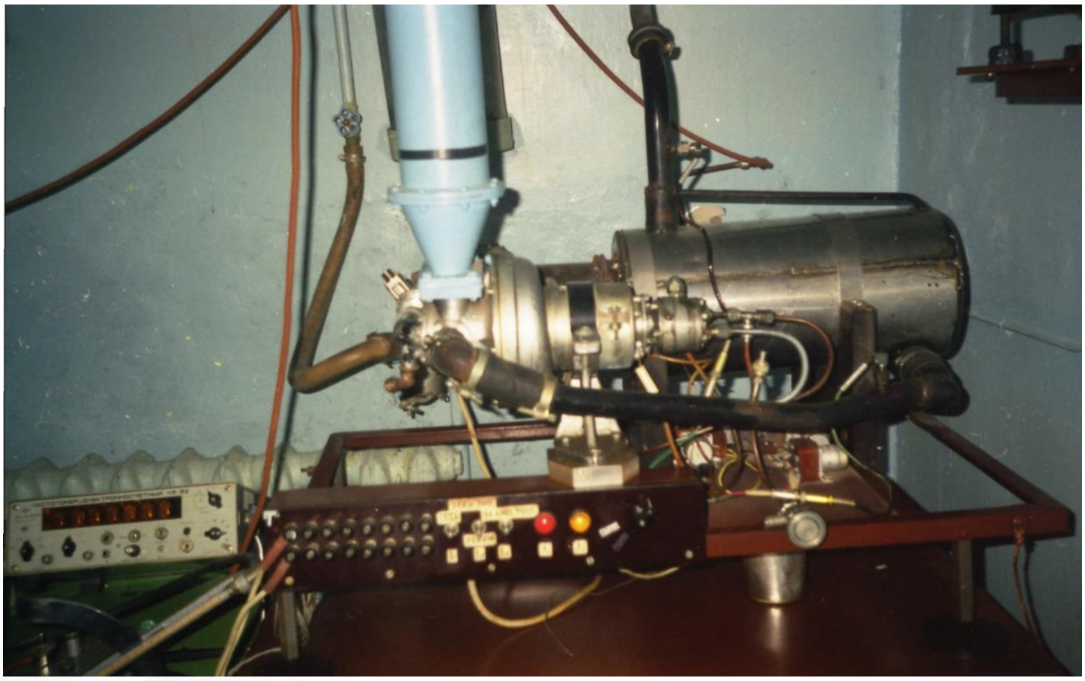

Figure 2. The fuel engine assembly

Figure 3 shows the schematic diagram of the combustion engine of the composite fuel which was initially run on pure diesel. When the engine became stable, the composite fuel was pumped at a pressure of up to 240 bar, and then the composite fuel was mixed with air through the compressor in variable proportions. The temperature of combustion was taken from the thermocouple sensors during the stable state.

The assembly involves both type B and type C thermocouples (Figure 3) which are designed to withstand high-temperature applications, and their respective temperature ranges cover the 2400 Kelvin temperature (approximately 2127°C). However, Type C thermocouples have a slightly higher upper-temperature limit, making them more suitable for this specific temperature range.

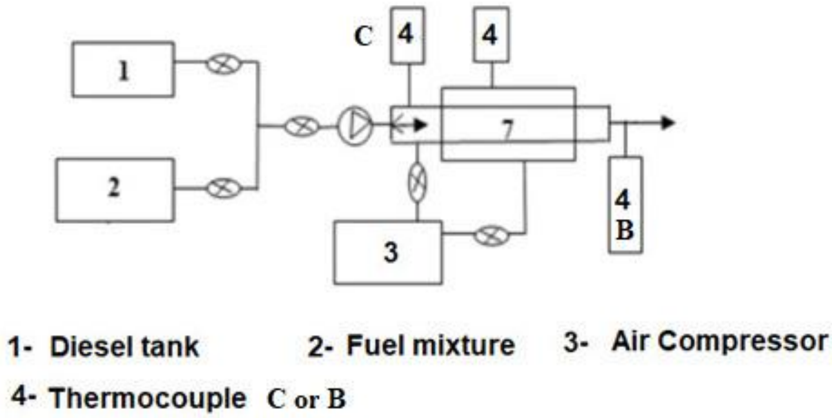

Figure 3. Schematic diagram of the experimental setup of the fuel engine.

The combustion of composite fuel at atmospheric pressure

The thermal behavior of the composite fuel and the effect of adding combustion activators and homogenization materials were followed by using the fuel combustion model at atmospheric pressure as shown in Figure 4.

For configuration of the multi-fuel combustion test facility at atmospheric pressure high-temperature applications like combustion engines, type K thermocouples are commonly used as they have a wide temperature range (-200°C to 1260°C) and good accuracy.

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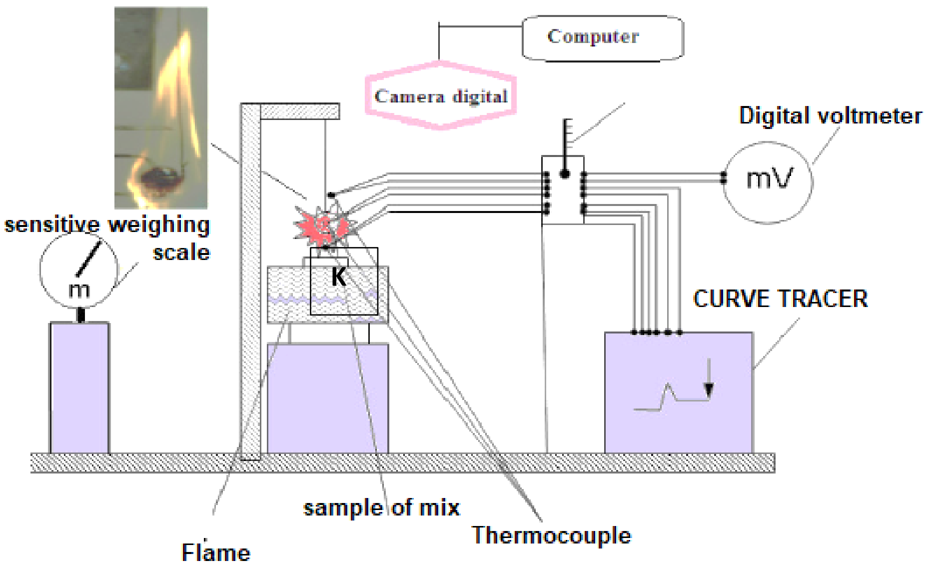

Figure 4. Configuration of the multi-fuel combustion test facility at atmospheric pressure

Results and Discussion

Comparison between the physical properties of pure diesel and composite diesel

Table 1 shows a comparison between the physical properties of the pure and composite diesel that was prepared by mixing with certain percentages of orange peel powder (OPP) or/and lemon peel powder (LPP).

From Table 1 it is observed that calorific values of 30% LPP/diesel composite and 15% LPP + 15% OPP/diesel composites are very close to the pure diesel calorific value compared with 30% OPP/diesel composites. This indicates that LPP gives similar calorific properties to diesel fuel and it could be used in diesel as an efficient fuel composite. The flash points of the composite fuels are higher than that of the pure diesel which is attributed to the presence of the peel particles which affect the rate of evaporation of diesel. The results show that the density of the three composite citrus fuels is higher than that of pure diesel fuel due to the compact properties of the solid citrus particles. The composite fuels show a slightly lower Cetane number than that of pure diesel fuel which indicates that the effect of the addition of citrus powder to the diesel fuel did not lead to a significant effect on the fuel efficiency and could be used as soft additives to the diesel without diminishing the fuel performance.

Table 1. Comparison of the physical properties of the pure diesel and the composite diesel

Physical property	Pure Diesel	30 %OPP/diesel	30% LPP/diesel	15%LPP+15%OPP/diesel
Calorific Value kJ/kg	45	39.34	43.47	41.58
Flashpoint, C	53	75	67	70
Density, kg/m^3	860	875	875	875
Cetane number	49	47	47	47

The composite fuel combustion in a diesel engine

Figure 5 shows the thermal behavior of diesel mixed with orange peel powder and OPP (composite fuel) at different percentages ranging between (0-40%). From Figure 5 it's clear that when the percentage of OPP increases in the composite fuel, the thermal behavior moves away from the behavior of pure diesel. The thermal behavior of the composite fuel at 15%, 20%, and 30% of OPP in the composite fuel converges at alpha between (0.85 and 1.0). The study showed that 30% of OPP in the composite fuel at a pressure of 235 bar gave the best results and reduced the harmful emissions, and almost matches with that of pure diesel, and it reached a maximum value at alpha 0.85.

It is also clear from Figure 5 that the thermal behavior increases with an increase in temperature (T) until reaches the maximum alpha value at about 0.85 then starts decreasing. This result is consistent with that given by Pathat (2007) and Purushothaman & Nagarajan, (2009).

Equation 1 shows the ratio of mixing air mass with a mass of fuel in the combustion chambers so that the mixing ratios range from 0.7 to 1.1 and the increase is in the direction of the air mass.

Alpha is a coefficient incompletion air:

$$\text{alpha} = \frac{G_{\text{air}}}{G_{\text{fuel}} * \text{af}} ------(Eq.1)$$

where: G_{air}: air mass, G_{fuel}: fuel mass and af = 1 the amount of air in kg needed to complete burning of 1kg diesel-like fuel" (Musalam, 2004).

In Figure 6, a comparison is made between the thermal behavior of pure diesel (0% LPP) and a composite fuel consisting of diesel mixed with lemon peel powder (LPP) at varying percentages, ranging from 15% to 40% LPP.

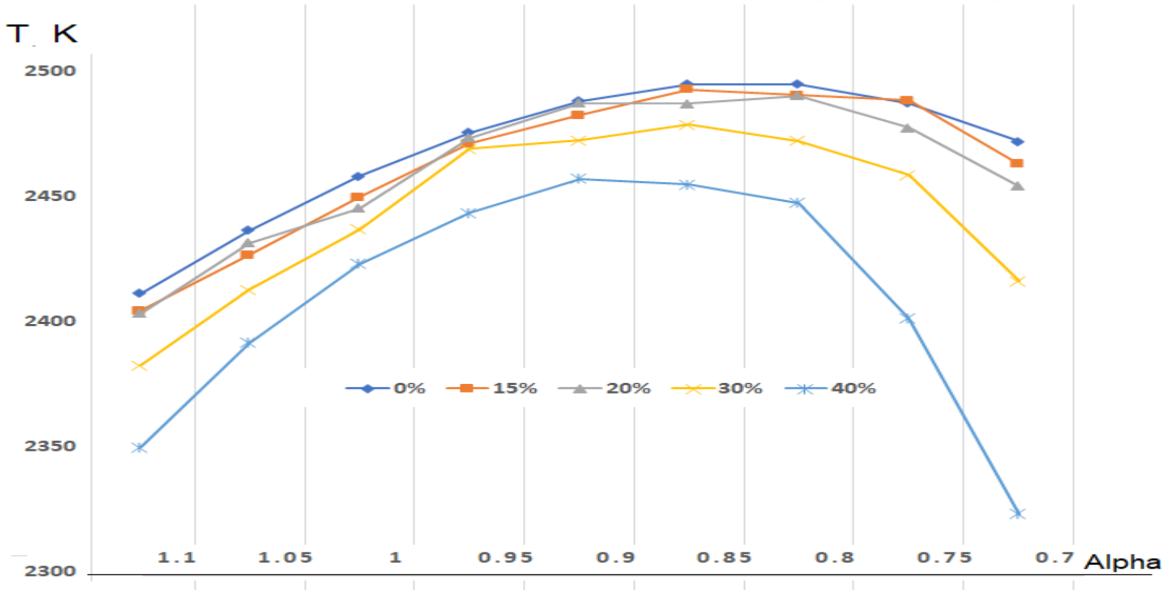

Figure 5. Thermal behavior of composite diesel fuel at different percentages of OPP.

The results indicate that the thermal behavior of the composite fuel is affected by the percentage of LPP added to diesel. The thermal behavior of the composite fuel with 30%, 20%, and 15% LPP tends to converge at an alpha value ranging between 0.8 to 1.0. Alpha represents the air-to-fuel ratio.

At an alpha of 0.8, it is observed that the composite fuel containing 30% LPP exhibits the best thermal behavior and is close to the thermal behavior of pure diesel. This suggests that the blend with 30% LPP in diesel has the highest thermal efficiency among the tested compositions.

However, it is noted that as the percentage of LPP in diesel increases, the thermal efficiency of the composite fuel decreases. Despite the reduction in thermal efficiency, an improvement in the fuel economy factor is observed. This indicates that the higher percentage of LPP in the composite fuel contributes to better fuel economy, even though the thermal efficiency is slightly lower.

The findings in Figure 6 provide important insights into the trade-off between thermal efficiency and fuel economy when using different proportions of LPP in diesel. The composite fuel with 30% LPP appears to strike a balance between these factors, making it a favorable option for optimizing performance and fuel economy simultaneously.

These results are valuable for understanding the impact of citrus peel powder on the thermal behavior and overall performance of composite fuels, which can aid in designing more efficient and eco-friendly fuel blends for practical applications.

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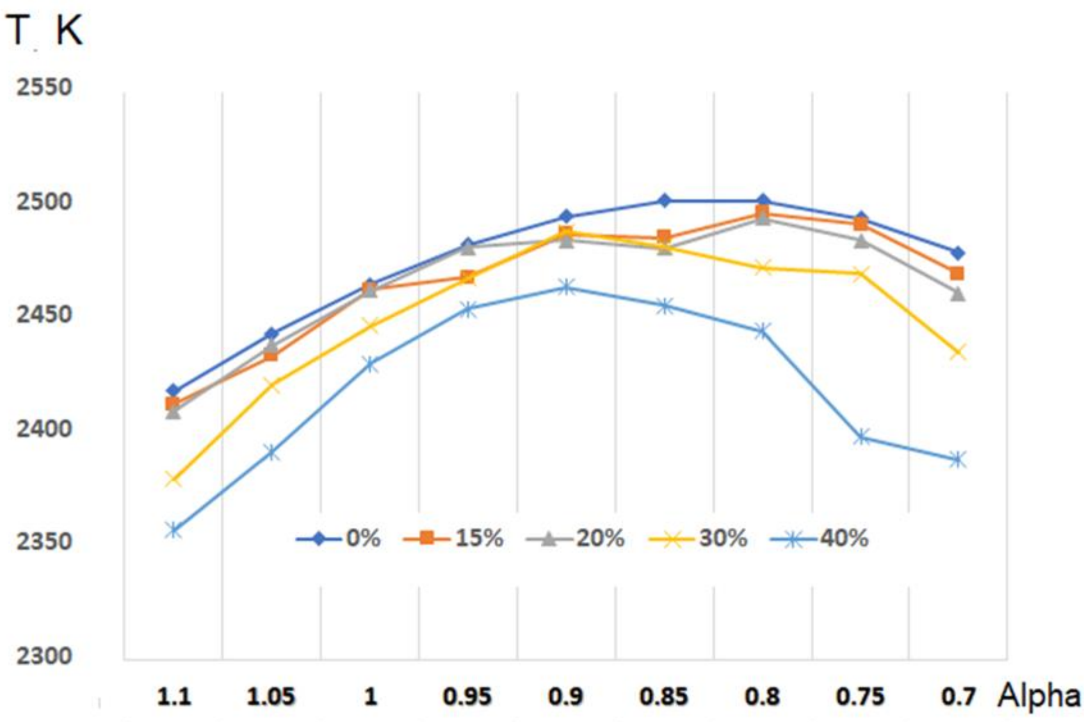

Figure 6. Thermal behavior of composite diesel fuel at different percentages of LPP

It is clear from Figures 5 and 6, that the thermal behavior of citrus peel powder diesel composites (lemon and orange) is similar.

In Figure 7, the thermal behavior of different fuel compositions is compared. Three types of fuel are analyzed: one composed of lemon peel powder (LPP), another composed of orange peel powder (OPP), and a third composed of a combination of both OPP and LPP along with diesel.

Based on the results, it can be observed that the fuel composed solely of LPP powder shows irregular thermal behavior that is closer to the thermal behavior of diesel fuel. This suggests that LPP powder, when used as the sole additive, has a more consistent thermal response resembling that of conventional diesel fuel.

On the other hand, the fuel composed solely of OPP powder exhibits irregular thermal behavior, which means it deviates more from the thermal behavior of diesel compared to LPP powder.

The third type of fuel, which is a combination of diesel, OPP, and LPP, exhibits intermediate thermal behavior. It shows properties that are different from both the LPP and OPP fuels. However, when the mixture is optimized at an alpha coefficient of 0.9 (air ratio to fuel), the thermal behavior of the triple

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mixture comes after the thermal behavior of the composite fuel composed of LPP powder.

These findings indicate that the combination of LPP and diesel yields more stable and predictable thermal behavior compared to the other compositions. The results are essential for understanding how different proportions of OPP, LPP, and diesel influence the thermal properties of the fuel, which can be valuable for designing more efficient.

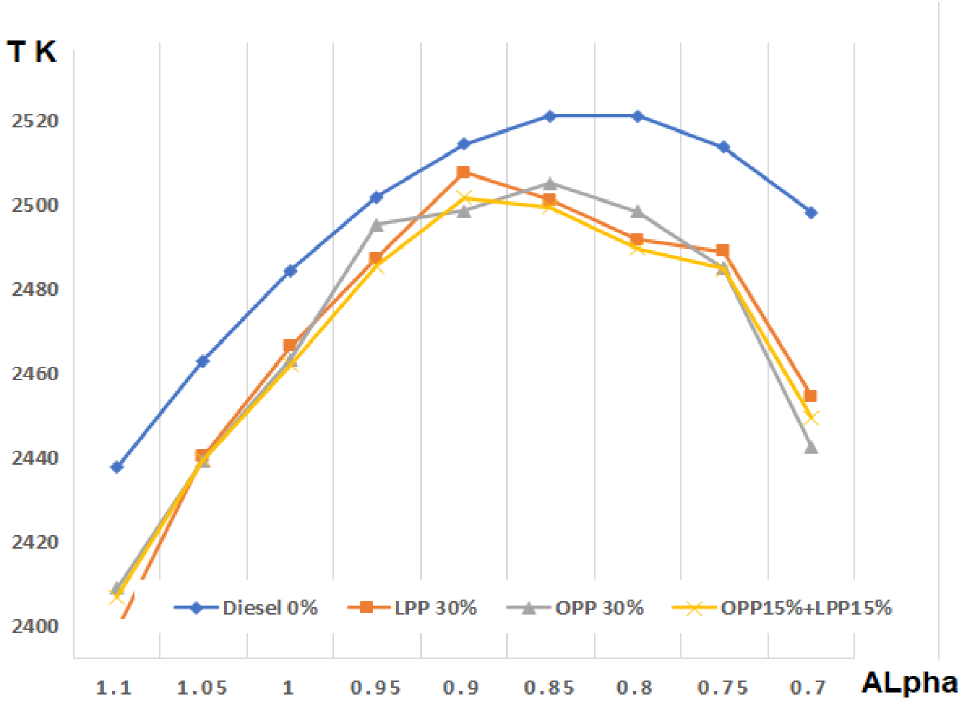

Figure 7. The thermal behavior of composite fuels at different ratios of orange and lemon peel powder with diesel.

In Figure 8, the thermal behavior of different compound fuels, each consisting of a combination of citrus peel components (lemon powder and orange powder) blended with diesel, is compared. The analysis is performed at an alpha value of 0.9, which represents the air-to-fuel ratio.

The results show that all compound fuels from citrus peels are relatively close to each other in terms of thermal behavior at an alpha of 0.9. This suggests that, at this specific air-to-fuel ratio, the composite fuels have comparable thermal characteristics.

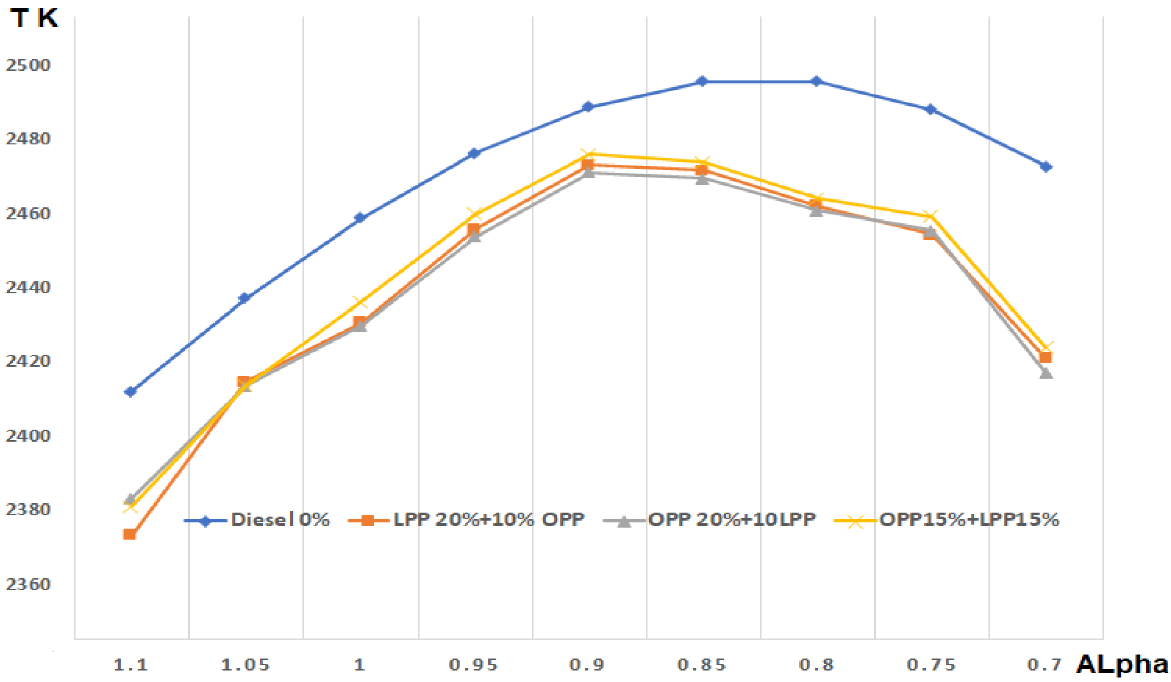

Figure 8. Thermal behavior of different Citrus Peel powder composite fuel and pure diesel.

Among the compound fuels, the blend containing 15% lemon peel powder (LPP) and 15% orange peel powder (OPP) in diesel demonstrates the best thermal behavior closest to that of pure diesel. Following that, the blend with 10% LPP and 20% OPP, and then the blend with 20% LPP and 10% OPP exhibit the subsequent thermal behavior, respectively.

Despite these similarities, there is still a significant difference between the thermal behavior of all the compound fuels and that of pure diesel. This implies that even though the blends perform well at an alpha of 0.9, they have not completely matched the thermal behavior of diesel. Further research and optimization might be required to achieve thermal behavior that more closely resembles that of diesel.

Comparison of thermal behavior of composite fuel 30% OPP, 30% LPP, and 15% OPP + 15% LPP with and without additives.

The thermal behavior of composite fuels 30% OPP, 30% LPP, and 15% OPP + 15% LPP with and without combustion activator and homogenization material to composite fuel was investigated, the results are shown in Figures 9 -11.

It appears from Figure 9 that the thermal behavior of composite fuels containing homogenization

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material and combustion activator increased the combustion heat of the composite fuel which may have resulted from an increase in the combustion of the solid matter, which raised the maximum temperature of combustion from 650 C° to 880 C° in favor of the homogeneous fuel.

The same result appeared when adding a combustion activator and homogenization material to the composite fuel (30% LPP), as shown in Figure 10, where the maximum combustion heat increased from 550 C to 750 C°.

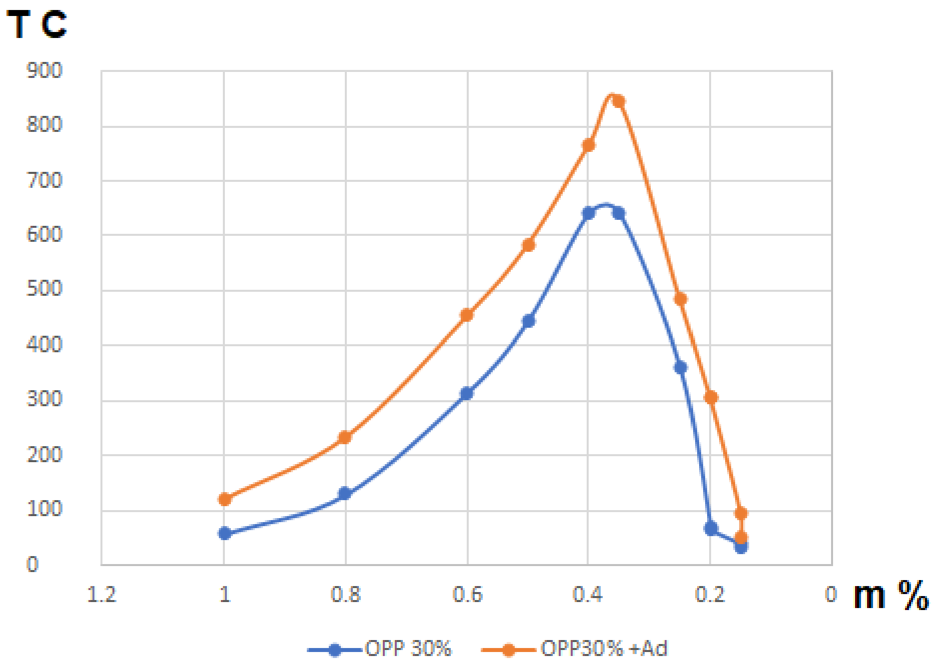

Figure 9. Thermal behavior of 30% OPP composite fuel with and without combustion activator and homogenization additives.

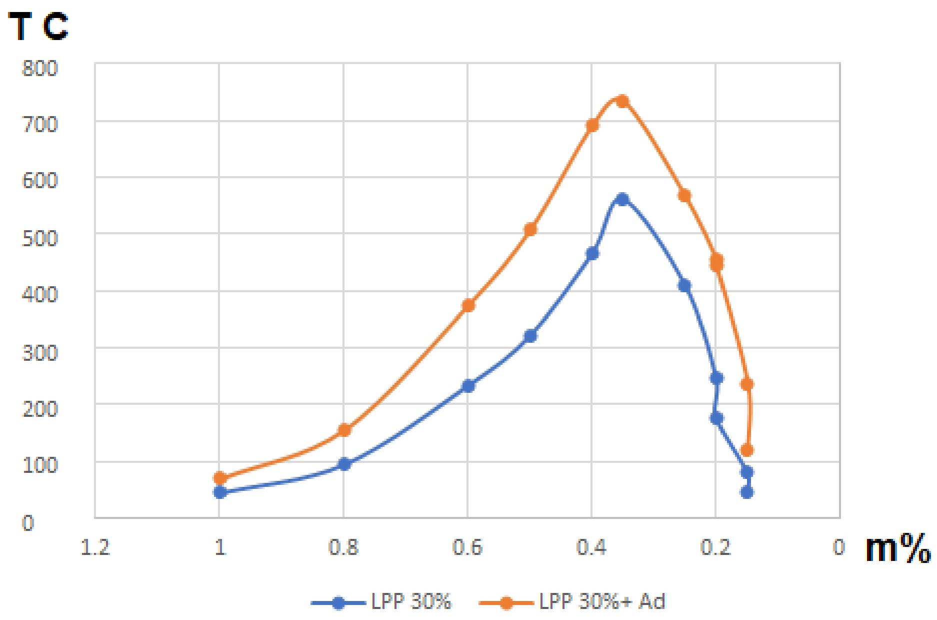

Figure 10. Thermal behavior of 30% LPP composite fuel with and without combustion activator and homogenization additives.

Figure 11 shows the thermal behavior of the composite fuel combustion consisting of 15%OPP+15%LPP with and without combustion activator and homogenization material. The additives increased the temperature of combustion from 530 C° to 860 C°.

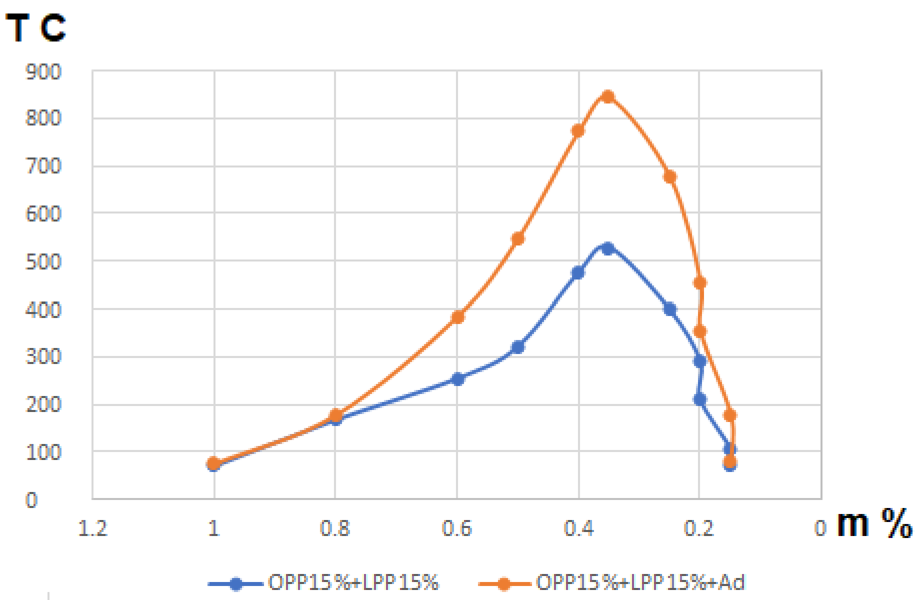

Figure 11. Thermal behavior of 15% OPP + 15% LPP composite fuel with and without combustion activator and homogenization additives.

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By comparing the behavior of the composite fuel in the three mixtures 30% OPP, 30% LPP, 15 %OPP+15%LPP which is shown in Figure 12, it appears that the thermal behavior of the mixture 30% OPP and 15 %OPP+ 15%LPP is close to each other with a little preference for 30% OPP.

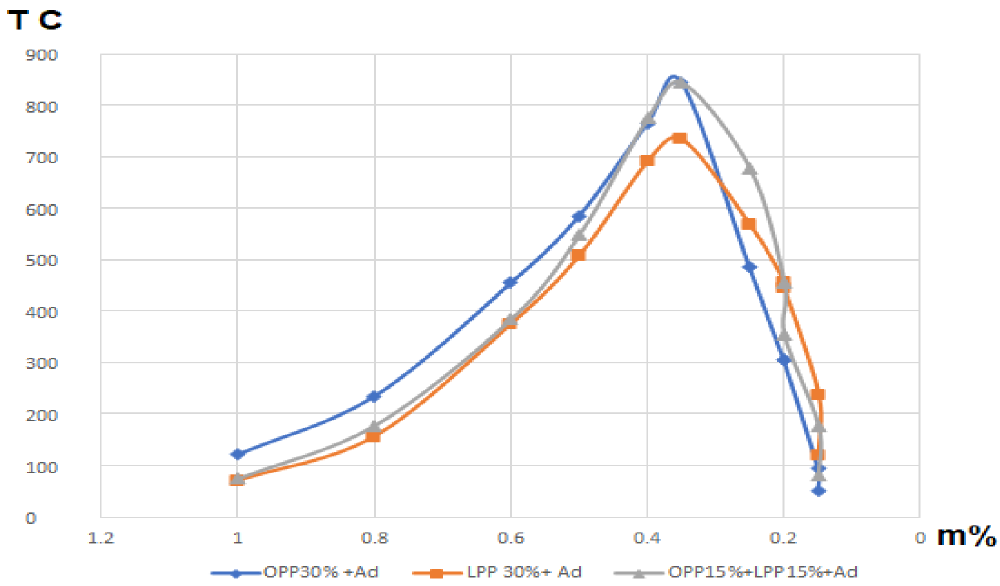

Figure 12. Comparison of thermal behavior of the 30% OPP, 30% LPP, 15 % OPP + 15% LPP

Generally, it is obvious from the results that homogenization material increases the homogeneity of the mixture by reducing the surface tension between the different components, which increases the area exposed to the combustion activator; as a result, the combustion of the homogeneous material is increased.

It is clear also that the homogenization material and the combustion activator enhanced the temperature of combustion in the case of 15% OPP+15 %LPP more than other mixtures of composite fuel. This behavior may be explained as follows: the additives enhanced the homogeneity of the mixture due to the difference in the size of the lemon and orange powder particles and thus increased the surface area which allow the activator to increase the combustion rate.

From Figures 9, 10, 11, and 12 it is clear that the maximum values of the temperature appear at approximately equal to 0.37 mas fraction of powder. This convergence in the behavior of the three mixtures can be attributed to the fact that the main and largest component is diesel with a percentage of 70%.

Figure 13 shows a comparison between the three mixtures of composite fuel 30% OPP, 30% LPP, and

15% OPP+15%LPP with homogenization material and combustion activator, where the combustion is conducted at atmospheric pressure.

Figure 13 illustrates that the composite fuel mass is decreased over time, it can be noted that the composite fuel 15% OPP+15%LPP shows the best behavior and the least percentage of the remaining mass. This result confirmed the previous conclusion that the additives enhanced the homogeneity of the mixture due to the difference in the size of the lemon and orange powder particles and thus increased the surface area which allowed the activator to increase the combustion rate thus the remains decrease.

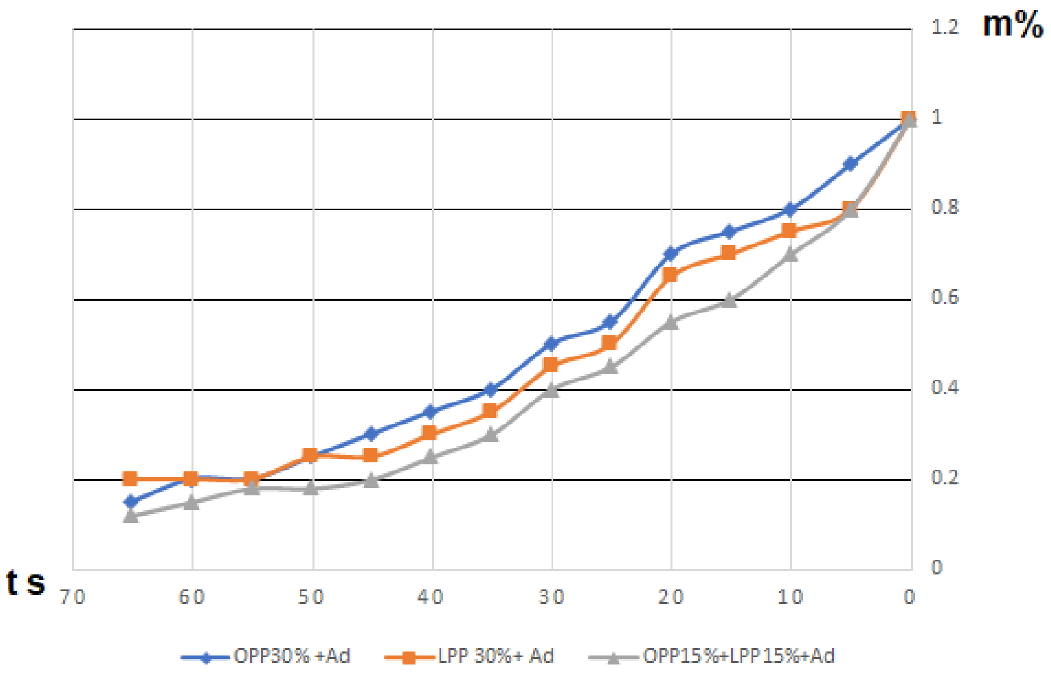

Figure 13. Comparison of the residual masses of combustion of the three composite fuels mixtures over time.

Thermogravimetric analysis of lemon and orange peel powder

The thermogravimetric analysis (TGA) of lemon and orange peel powder was investigated and it was noted that the weight loss of the volatile materials of the peel proceeded in three stages. The first stage is between 150C° – 200 C° for water evaporation. The second stage at 400 C° represents a second weight loss which corresponds to the hydrolysis of cellulose and hemicellulose. The third stage of weight loss after 600 C° is observed due to the presence of fixed carbon (Pathak et al., 2017).

The physical phases of the composite fuel combustion

From the combustion experiments in the atmospheric pressure, it can be noted the formation of three physical phases during the combustion, which are:

1. The combustion of volatile materials in the fuel composition, takes the first 25 seconds from the start of the process.
2. The combustion of liquid materials (diesel) with a part of the solid (powder), which takes 15 seconds.
3. Solids combustion with active materials, takes an average time of 15 seconds to reach stability.

Figure 14 shows the three phases of the composite fuel (15% OPP and 15% LPP)/diesel without additives (homogenization and combustion activator). It can be noted from Figure 14 that the highest combustion point was in the second phase after 35 seconds, where the maximum combustion temperature reached ~600 C° which is comparable with the citrus peel combustion temperature.

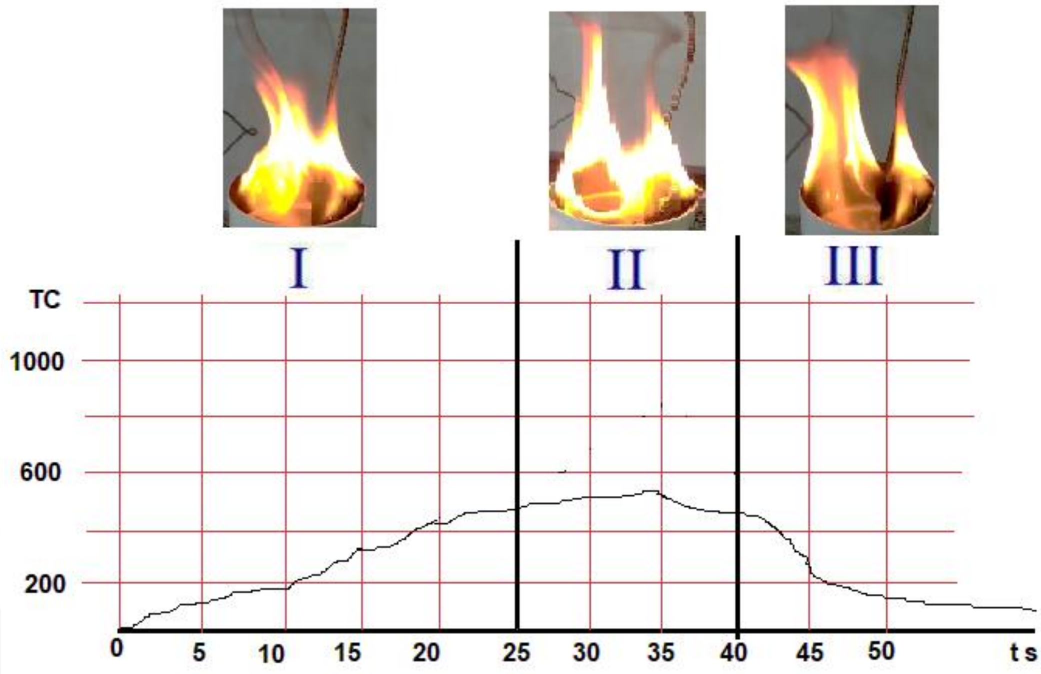

Figure 14. The three phases of the composite fuel, 15% OPP +15% LPP with diesel

Figure 15 shows the three phases of the composite fuel 15% OPP +15% LPP/diesel with additives, it is observed that the highest combustion point was in the second phase after 30 seconds, where the maximum combustion temperature reached 800 C°. Comparing this result with the combustion of 15% OPP +15% LPP/diesel without additives (Figure 14) where it was at 600 C°, it can be seen that adding homogenizing and combustion activators to the composite fuel rose the temperature of combustion by about 200 C°. Also, the maximum combustion temperature was achieved at a shorter time as the peak maximum appeared at 30 seconds. This reinforces the result we obtained previously from Figure 11.

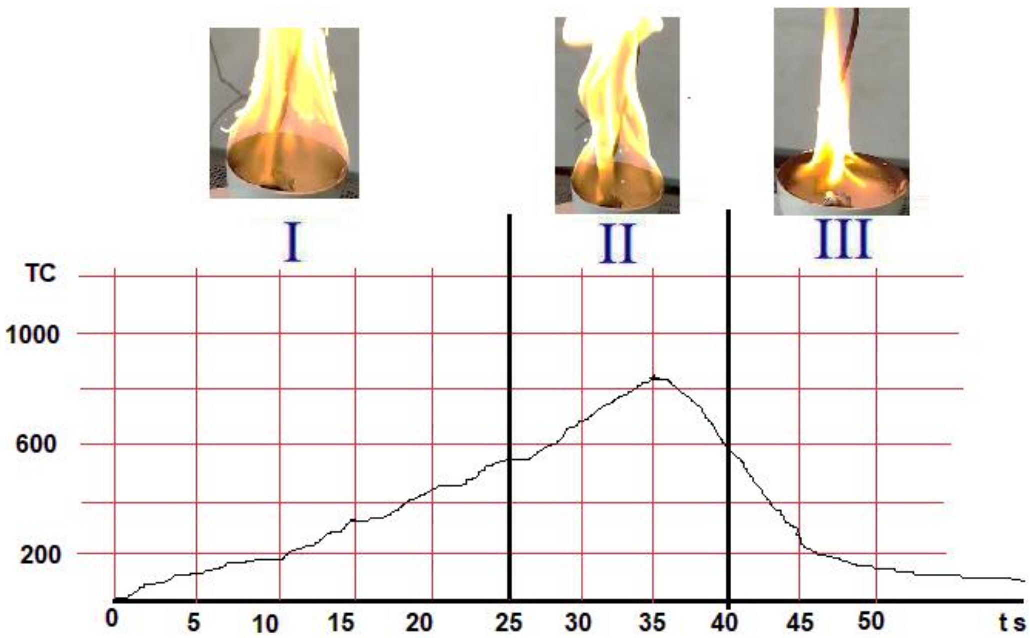

Figure 15. The three phases of the composite fuel are 15% OPP and +15% LPP with additives .

By modifying Mendeleev's equation (Equation 2) (Muslim, 2004; Maslov, 2016) it is possible to calculate the net thermal energy which is equivalent to the thermal energy of the original fuel (diesel) plus the thermal energy of the added citrus peel powder which varies between 5%-25%. The latter depends on the type, amount, and efficiency of the active substances added.

$$Q_H^P = 0.19\, C^P + 0.39\, H^P + 0.17\, (S^P + O^P) + (\%0.05 - 0.25\%) Q_{Ad} \dots \dots \dots \dots (Eq. 2)$$

Where Q_{Ad}=0.34 C^P +0.57 H^P +0.114 O^P

The net thermal energy is the sum of the composite fuel energy and additives materials; it is given in

Equation 3 (Muslam, 2004; Maslov, 2016).

$$Q_H^P = Q_F + Q_{Ad} \dots \dots \dots \dots \dots \dots \dots (Eq.3)$$

The mathematical representation of the three combustion phases in combustion chambers is given in Equations 4 & 5 (Muslam, 2004; Maslov, 2016).

$$Q^p{}_H = \sum_{i=1}^{n} N_i Q^p{}_{H_i} = N_{\mathrm{I}} Q^p{}_{H_{\mathrm{I}}} + N_{\mathrm{II}} Q^p{}_{H_{\mathrm{II}}} + N_{\mathrm{III}} Q^p{}_{H_{\mathrm{III}}} - - - - (Eq.4)$$

$$\sum N = 1 - - - - (Eq.5)$$

Where:

C^P:	carbon content
H^P:	hydrogen content
S^P:	sulfur content
O^P:	oxygen content
Ad^P:	Additive materials content
Q_F:	Thermal energy from fuel (diesel + peel powder)
Q_{Ad}:	Thermal energy released by the additive materials
N:	Content of the combustible component in fuel
$N_{\mathrm{I}} Q^p{}_{H_{\mathrm{I}}}$:	The combustion of volatile substances in the composite fuel
$N_{\mathrm{II}} Q^p{}_{H_{\mathrm{II}}}$:	The combustion of liquid materials (diesel) with a portion of the solid (powder)
$N_{\mathrm{III}} Q^p{}_{H_{\mathrm{III}}}$:	combustion of solids with active materials

Conclusion

Lemon and orange peels powder composite diesel fuels with variable percentages were prepared and tested for pyrolytic combustion and compared with pure diesel under combustion pressure as well as the combustion under atmospheric pressure. The optimized contents of powder/diesel composite were 30% LPP/diesel, 30% OPP/diesel, and 15% LPP + 15% OPP/diesel where the highest calorific values were obtained with a reduction of harmful emissions. The thermal behavior of the composite fuel increases with increasing temperature of combustion and reaches a maximum value at α = 0.85, 0.8, and 0.9 for 30% LPP/diesel, 30% OPP/diesel, and 15% LPP + 15% OPP/diesel respectively. The thermal behavior of the composite fuels containing homogenization material was more efficient than that without additives as the combustion temperature elevated by 230Co, 200 Co, and 330 Co for 30% OPP, 30% LPP, and 15% OPP + 15% LPP respectively.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

All authors contributed to the idea of work and all have co-written the manuscript. All authors approved the final version of the manuscript.

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