

Calorimetry Study of Coconut Husk Biofuel

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Abstract

Malaysia as a tropical country, may tend to produce a biofuel. This research contributes to the country's biomass energy sector and understanding renewable energy sources. The coconut industry in Malaysia has generated a significant waste issue due to the accumulation of coconut husks from agriculture and industrial activities. Biofuel production from these husks presents a promising solution, reducing waste, developing renewable energy, and offering alternatives to fossil fuels. This study produced biomass pellets from coconut husks with the enhancement by additives such as of kerosene, petrol, and diesel as additives. Coconut husks were analysed using SEM-EDX and FTIR to assess their suitability for morphology structure, elemental composition, and functional group. SEM analysis revealed a rough and porous surface, while EDX showed 53.08% carbon and 44.72% oxygen. FTIR analysis indicated that the functional group for all additives mainly consists of hydroxyl and double bonds in coconut husk pellets, while kerosene, petrol, and diesel showed varying combinations of C-O, C=C, and C-H stretches. The Q-value of coconut husks biofuel pellets with different flammable additives was compared using the calorimetry measurement method. A comparison of the combustion test for all pellets with different additives shows the highest Q-values by diesel. Thus, diesel is more predominant for biofuel additives than kerosene and petrol.

1. Introduction

Malaysia has diverse ecosystems, including rainforests, agricultural lands, and coastal areas with marine life [1]. It has been recognised as a benchmark for studying biomass as a renewable energy source due to its abundant natural resources [2]. With its diverse forest cover, thriving agricultural sector, and palm oil industry, Malaysia offers possibilities to those seeking to unlock biomass's full potential as a renewable energy solution.

The agriculture in Malaysia is diverse and relevant for studies investigating coconut husk biofuel. The country has a significant coconut production sector that generates many coconut husks. These husks have enormous potential for producing biofuels, which good for the environment and easily accessible [3]. Malaysia is seeking environmentally friendly alternatives, including switching from fossil fuels to biofuels from coconut husk biomass to address the effects of climate change and lower greenhouse gas emissions [4]. This innovative approach has enormous potential to reduce the harmful effects of regular energy production on the environment. By tapping into the abundance of coconut husk biomass, Malaysia can reduce its contribution to global warming and speed up the shift to renewable energy sources [5]. This forward-thinking switch to biofuels aligns with international efforts to tackle climate change and sets Malaysia apart as a leader in adopting greener energy generation methods.

Biofuels from coconut husk biomass align with Malaysia's commitment to sustainable development and reducing carbon emissions [6]. By promoting biofuels in transportation, manufacturing, and electricity generation, Malaysia can contribute to the global fight against climate change, decrease reliance on imported fossil fuels, enhance energy safety and autonomy, and create new job opportunities in rural areas [7].

The study aimed to investigate the potential of coconut husk biofuel as an alternative energy source. The inclusion of additives in the research aimed to explore their potential impact on enhancing the eco-friendliness of coconut husk biofuel. This research has the potential to offer numerous advantages, such as creating a sustainable and renewable energy source, decreasing reliance on non-renewable fossil fuels, and promoting the use of agricultural waste for energy generation.

2. Materials and Methods

2.1 Sample Collection

The study revealed that yellow coconuts, specifically the Malayan Yellow Dwarf (MYD), have a higher energy density due to maturation and increased lignification of the fibres within their husks [8]. Consequently, yellow coconuts prove optimal for biofuel production. The yellow coconuts were collected from five locations just a few metres apart in Kampung Parit Keroma Darat, Muar, Johor, at coordinates $2^{\circ}02'23''\text{N}$ $102^{\circ}33'35''\text{E}$ as shown in Fig. 1.



Fig. 1 Location for collecting the sample in Muar District, Johor

2.2 Sample Preparation

The coconut husks were first cleaned to prevent the potential growth of microorganisms facilitated by water in the samples. Subsequently, the husks were separated from the copra, ensuring that only husks were used for the research. The raw coconut husk samples underwent a carefully planned drying procedure, as depicted in Fig. 2 (a). This process aimed to remove moisture while maintaining the husks' integrity. Significantly, the drying temperature was adjusted from 110 degrees to 70 degrees, a step taken to prevent compromising the quality of the husks. Afterwards, the dried coconut husk samples were converted into fine powder using ball milling for 24 hours, which involved rotating cylindrical balls within a container to crush the husks into smaller particles, as illustrated in Fig. 2 (b). Next, Fig. 2(c) shows the powdered coconut husk was passed through sieves of varying aperture sizes, achieving a target particle size of 50 microns and ensuring uniform particle size distribution. In the last step, the powdered coconut husk was placed into a mould using a hydraulic compressor with a force of 5 tons for 10 minutes, as shown in Fig. 2 (d), creating pellets with a diameter of 1 centimetre.

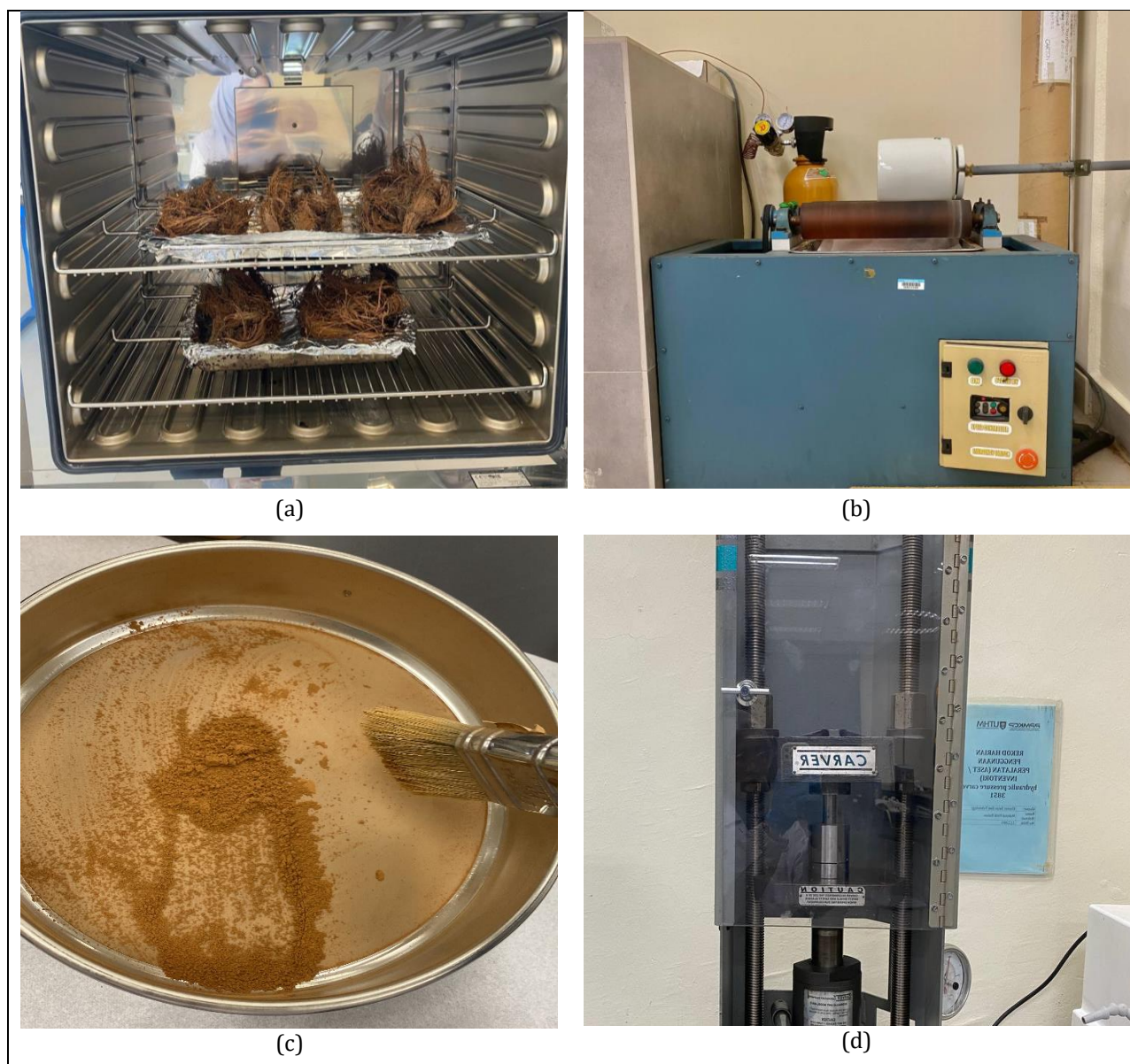


Fig. 2 The sample preparation for coconut husk, including (a) the drying process of coconut husk, (b) the ball milling process, (c) the sieving process, and (d) the pelletising process

2.3 Sample Characterisation

SEM-EDX was a surface analysis technique that offered valuable insights into the morphology and elemental composition of coconut husk powder. FTIR analysis identifies functional groups and provides insights into the molecular composition and structure of coconut husk biofuel pellets, both with and without additives.

2.4 Treatment with additives

The coconut husk samples were processed into biofuel pellets, and data was collected to ensure their effectiveness in the calorimeter experiment for determining Q-values. This thorough process facilitated their intended use.

In the initial step, the weight of coconut husk pellets was measured using a microbalance and recorded as m_1 . After additives like kerosene were added, the pellets of coconut husk were given an initial volume reading represented by V_1 . The pellets were soaked in 200 ml of kerosene for three hours before being left inside a beaker for two hours, as shown in Fig. 3, to absorb the kerosene and reach equilibrium.



Fig. 3 The coconut husk pellets were soaked in additives

After soaking the coconut husk pellets in additives, the remaining volume of the pellets was measured as V_2 . This measurement helped to calculate the volume change caused by the absorption of additives. By comparing the initial volume value, V_1 , with the final volume reading, V_2 , it was possible to determine the difference, indicating the quantity of additives absorbed by the coconut husk pellets. The amount of additives absorbed into the pellet was calculated using equation (1).

$$V_3 = V_1 - V_2 \quad (1)$$

Where V_3 , additive volume in the pellet, V_1 , the volume of the pellet before soaking in an additive, and V_2 , the volume of the pellet after soaking in an additive. Analysing soaked coconut husk pellets helped quantify absorbed additives to assess their biofuel potential.

After soaking, the pellets were extracted from the beaker, carefully cleaned, and dried using tissue. Then, the microbalance was used to determine the mass of the coconut husk pellet, m_2 after adding additives. The difference in mass of the coconut husk pellet before and after it was soaked with additives was calculated using equation (2):

$$m_a = m_1 - m_2 \quad (2)$$

Where m_a , the mass of additive absorbed into the pellet, m_1 , the mass of the pellets before soaking in an additive, and m_2 , the mass of the pellets after soaking in an additive.

The pellets were mixed with additives and left to dry under sunlight for six hours, as shown in Fig. 4. This extended exposure aimed to ensure complete equilibrium absorption for the additives. Afterwards, the mass of the coconut husk sample, m_3 , was measured along with the mass of the additives, m_4 , which had vaporised. These values were calculated using an equation (3):

$$m_b = m_3 - m_4 \quad (3)$$

Where m_b , the mass of additive inside the pellet that evaporates into the air, m_3 , the additive mass inside the pellet before the drying process under sunlight, and m_4 , the additive mass inside the pellet after the drying process under sunlight. The mass of the vaporised additive was calculated with equation (4) after it was dried in sunlight.

$$m_c = m_a - m_b \quad (4)$$

Where m_c , the mass value of the vaporised additive from the initial value of the absorbed additive, m_a , the mass value of the additive absorbed into the coconut husk pellet, and m_b , the mass value of the additive inside the pellet that evaporates into the air.



Fig. 4 Pellets with additives were dried under sunlight for 6 hours to reach absorption equilibrium

This experiment tests the potential of various coconut husk pellets as alternative fuel sources. Water was poured into a beaker on a stand and a coconut husk pellet with additives, as illustrates in Fig. 5. The water temperature was recorded as it heated up, and the time was measured when it boiled. The experiment has implications for energy and sustainability. The final water temperature was measured after the combustion, and the temperature difference was used to compare the heating capabilities of the pellets.



Fig. 5 The diagram for the calorimetry measurement

2.5 Heat capacity analysis using the calorimetry method

The experiment tested coconut husk pellets as alternative fuel sources. The water mass inside a beaker was measured, then filled to 50 ml. A pellet was placed beneath it and ignited, causing a temperature rise. The time from ignition to combustion end was recorded. After complete combustion, the final water temperature was noted, indicating a temperature change from the pellet's combustion.

$$Q = mc\Delta T \quad (5)$$

$$\Delta Q = \left(\frac{\Delta m}{m} + \frac{\Delta c}{c} + \frac{\delta T}{\Delta T} \right) \times Q_0 \quad (6)$$

$$Q = Q_0 - \Delta Q \quad (7)$$

Where Q_0 was the heat of combustion, m was the mass of the water, c was the specific heat capacity of the water, ΔT was the temperature difference, ΔQ was the uncertainty for the heat capacity of combustion, Δm was the uncertainty for a mass of water, Δc was the uncertainty for the specific heat of water, δT was the uncertainty for the temperature, and t was the time taken.

3. Results and Discussion

3.1 Sample composition and morphology analysis using SEM-EDX

The SEM analysis examined the outer layer of coconut husk powder. The SEM image showed a rough and porous surface with numerous cavities and protrusions, likely formed during milling. The increased surface area can enhance the powder's reactivity and adsorption capabilities. The SEM image also showed voids between particles and the tendency of particles to clump together due to the fibrous nature of coconut husk. Fig. 6 provides a visual representation of the SEM image.

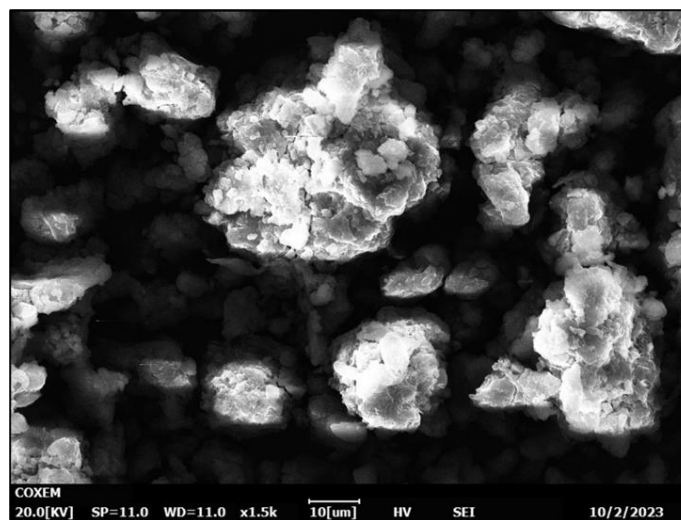


Fig. 6 The morphology structure of coconut husk from SEM analysis

EDX spectroscopy was used to analyse the elemental composition of coconut husk powder, as shown in Fig. 7. Carbon was the most abundant element in the sample, accounting for 53.08% of the atomic percentage. Oxygen was the second most abundant element, at 44.72% of the sample's atomic percentage. The results reinforce the notion that the coconut husk primarily comprises organic compounds [9].

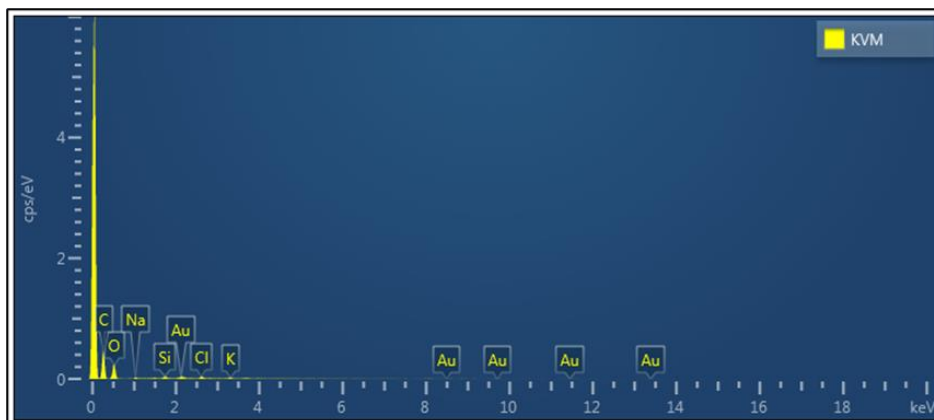


Fig. 7 The morphology structure of coconut husk from SEM analysis

Table 1 Elemental analysis of coconut husk

Elements	Atomic %
C	53.08
O	44.72
Cl	0.49
Na	0.74
Si	0.51
Au	0.21
K	0.25

Table 1 displays coconut husks containing carbon, oxygen, and some trace elements, including silicon (Si), chlorine (Cl), sodium (Na), potassium (K), and gold (0.21% atomic percentage). The gold was added through a standard preparatory procedure called sputtering, which enhances the specimen's conductivity for SEM imaging. Si indicates the potential existence of silicates or silicon-based materials within the organic matrix. The other trace elements may be contaminants, processing residuals, or minor constituents in the material.

3.2 Functional group analysis using FTIR

The experiment analysed the infrared absorption of coconut husk samples with and without additives. FTIR was used to study the chemicals and measure the wavenumber. The data was collected in the mid-infrared range from 400 cm^{-1} to 3900 cm^{-1} . Fig. 8 displays the FTIR spectrum for the non-additives and the presence of kerosene, petrol, and diesel additives.

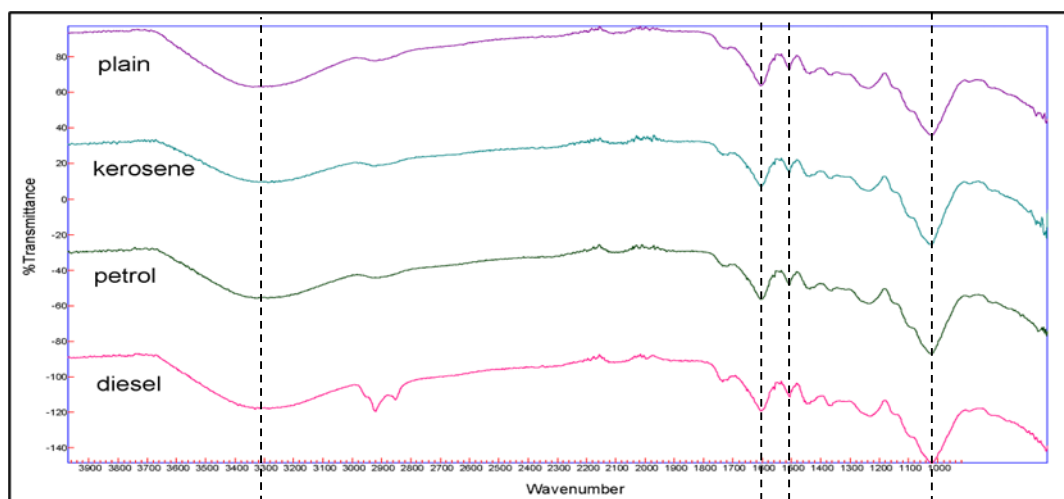


Fig. 8 Superimpose of FTIR spectrum for non-additives and inclusion of kerosene, petrol and diesel additives

The plain pellet infrared spectrum showed a peak at 3382.334 cm^{-1} , indicating the presence of O-H stretching vibrations linked to hydroxyl functional groups and another peak at 1605.131 cm^{-1} , which could be either C=C stretching vibrations from alkenes or aromatic C=C ring stretching vibrations. In the kerosene spectrum, the highest peak at 1028.179 cm^{-1} corresponds to C-O bond stretching vibrations, the peak at 3291.809 cm^{-1} indicates the presence of alcohols, phenols, or water contamination, and the peak at 1606.428 cm^{-1} could be attributed to C=C stretching vibrations. The petrol spectrum peaks at 2925.521 cm^{-1} , indicating C-H stretching vibrations, and a potential peak at 1604.674 cm^{-1} , corresponding to the C=C stretching vibrations typically associated with the alkene functional group. The diesel spectrum shows its highest peak at 3031.511 cm^{-1} , attributed to C-H stretching vibrations, and a potential peak at 1735.275 cm^{-1} , corresponding to C=O stretching vibrations.

3.3 Q-values analysis using calorimetry method

The experiment measured the heat released during combustion in a calorimeter to obtain the Q value. This was done by repeating the experiment five times with 50 ml of water and then calculating the average value. The average Q-value for each pellet burned during the process, as shown in Fig. 9.

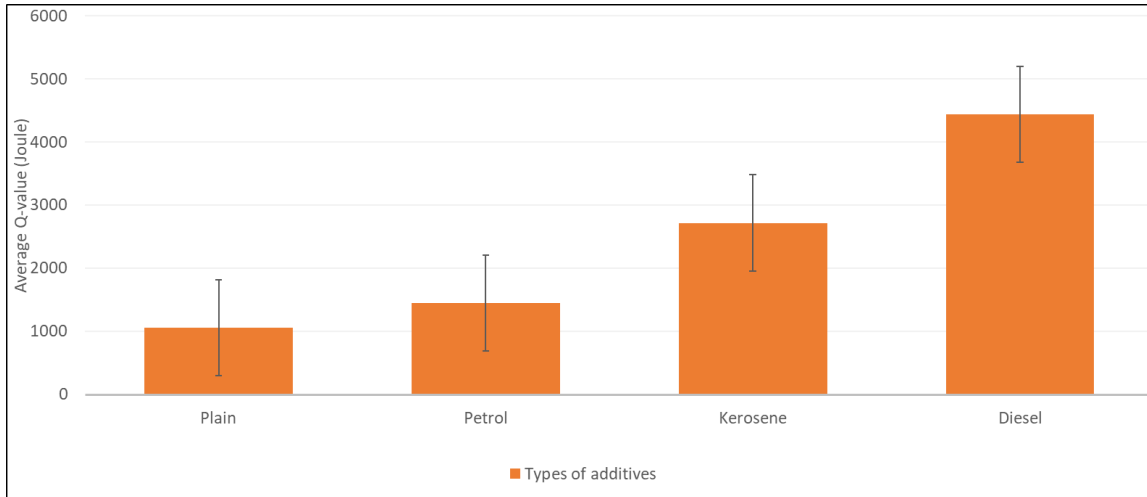


Fig. 9 The average Q-value for all types of additives for boiling 50 ml of water

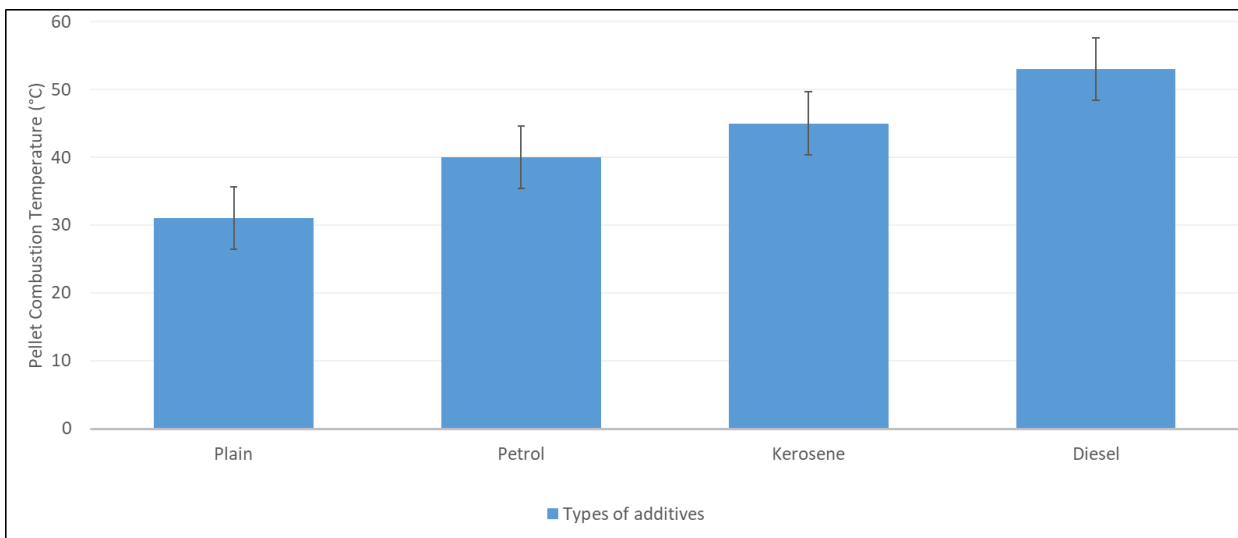


Fig. 10 The pellet combustion temperature for all types of additives for boiling 50 ml of water

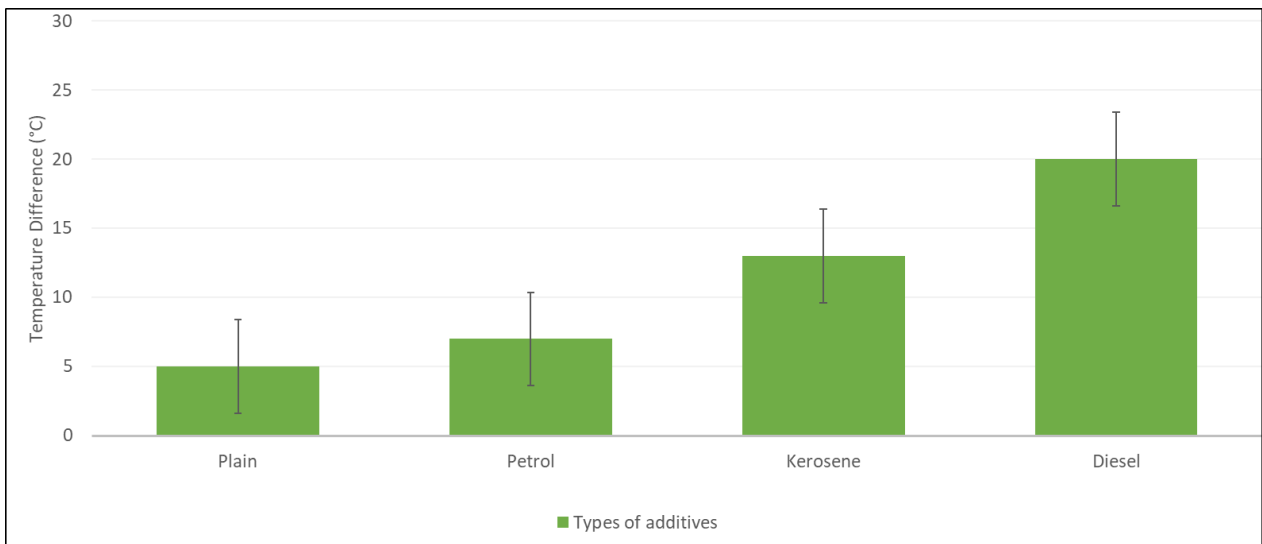


Fig. 11 The temperature difference for all type of additive for boiling off 50 ml of water

Fig. 9 illustrates that the plain pellet exhibited the lowest Q-value among those containing flammable additives, as anticipated due to the absence of compounds promoting combustion. The plain pellet's average Q-value registered at 1060 J, reflecting its deficiency in encouraging combustion. This absence of explosive elements resulted in a marginal increase in the water temperature, merely raising it by 5 °C from its initial 21 °C to 26 °C, as depicted in Fig. 10. The limited rise in water temperature at the conclusion of the control pellet's combustion indicates its minimal capacity to generate heat beyond modestly warming the water.

The petrol pellet ranked as the second lowest in terms of Q-value among the four coconut husk pellet variants, averaging at $Q = 1466.8$ J. Despite its lower Q-value compared to kerosene and diesel pellets, it surpassed the plain pellet due to the inclusion of petrol, known for its volatile nature, which quickly dissipates during combustion. This rapid evaporation limits the heat generated, resulting in insufficient warmth to effectively heat the 50 ml of water. Consequently, the water's final temperature reached only 28°C, marking a modest 7°C increase.

In the heating process involving 50 ml of water, the kerosene pellet exhibited the second highest Q-value at 2719 J. Compared to the plain and petrol pellets, the kerosene variant displayed significantly greater combustion, although it remained lower than that of the diesel pellet. Kerosene, a highly combustible chemical liquid, contains hydrocarbons similar to diesel but with differing ignition and burning rates. Despite this, the combustion of the kerosene pellet efficiently raised the water temperature from 21°C to 34°C, resulting in a 14°C temperature difference, albeit smaller than that achieved by the diesel pellet.

The diesel pellet stands out with the highest average Q-value among the four types, recording a substantial $Q = 4439$ J. Significantly, it produced the most heat during the combustion process, elevating the final water temperature to 43°C from an initial 21°C, marking a notable 20°C difference, as depicts in Fig. 11. Diesel, primarily composed of hydrocarbons, vaporises under heat, and becomes flammable when combined with surrounding air. Its fuel quality is often assessed using the cetane number, a crucial metric [10].

4. Conclusion

The coconut husk was a highly reliable and cost-effective energy source in Malaysia. The coconut husks were collected, dried, pelletised, and then mixed with flammable additives such as petrol, kerosene, and diesel to create pellets that could be burned for energy.

SEM-EDX was conducted to analyse the morphology structure and elemental composition of coconut husk. SEM image revealed that the surface of the coconut husk had a rough and porous texture. Additionally, the EDX spectra confirmed 53.08% carbon and 44.72% oxygen, with potential traces of silicates and minor elements introduced during analysis. The coconut husk pellets exhibit specific vibrations, such as O-H and C=C vibrations, making distinguishing between alkenes and aromatic rings difficult. Kerosene has C-O and C=C vibrations, indicating unsaturated hydrocarbons and aromatic compounds. Petrol has C-H and potential C=C vibrations, while diesel has C-H and C=O vibrations.

Last of all, the analysis showed that diesel pellets have higher Q-values compared to other pellets. This outcome can be attributed to the molecular structure of diesel fuel, which has a higher number of carbon atoms arranged in a rigid formation. Overall, using coconut husk as an energy source in Malaysia has proven to be a promising alternative to traditional fossil fuels.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: study conception and design, data collection, methodology, analysis and interpretation of results: Azyan Izzati Amran and Zaidi Embong. All authors reviewed the results and approved the final version of the manuscript.

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