

Research Paper

Characterizing of Nano Activated Bio-Carbon of Sago Waste as a Homogeneous Combustion Catalyst

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Abstract

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Alternative fuels were developed by blending crude coconut oil and bio-carbon nanoparticles. Bio-carbon, derived from sago waste via pyrolysis and ground using a ball mill, underwent FTIR testing to assess its energy absorption capabilities. SEM analysis was conducted to examine the surface morphology of bio-catalyst with and without crude coconut oil. The findings indicate that incorporating bio-catalyst can enhance mechanical properties, facilitating rapid heat absorption, as evidenced by reduced flashpoint and viscosity. In addition, the results show an increase in fuel mass, broadening of molecular contacts, increased reactivity, and increased heat absorption for easier ignition. This phenomenon indicates that bio-carbon of sago waste have great potential for biofuel use as a homogeneous combustion catalyst.

Keywords: Sago waste; Bio-carbon; Bio-catalyst; Nanoparticles; Mechanical properties

1. Introduction

Increasing fuel consumption and depleting fossil fuel reserves have increased the need for crude vegetable oil as an alternative fuel [1], [2]. This situation makes industrial activities in producing fuel continue to increase [3], but the negative impact is rising levels of pollution and greenhouse gas effects [4]. Therefore, solutions and policies are needed to provide environmentally friendly, natural-based alternative fuels that can be obtained using a simple, cheap, and environmentally friendly process [5]. Therefore, solutions and policies are needed to provide environmentally friendly, natural-based alternative fuels that can be obtained using a simple, cheap, and environmentally friendly process. However, crude coconut oil (CCO) is one of the natural ingredients that has the potential to be used as an alternative fuel [6]–[8]. Meanwhile, its saturated

and stiff nature makes the viscosity and flash point high so that the fuel is difficult to burn and even worsens the performance of the fuel, which is characterized by a decrease in the combustion rate and a long burning lifetime [9]–[11]. On the other hand, various studies have been conducted to reduce the adverse effects of exhaust gas pollutants and improve engine performance, including exhaust modification (muffler), engine geometry, and fuel engineering [12]–[15]. Fuel engineering has become one of the solutions that can be taken by adding catalysts to CCO, and several previous studies have proven that CCO has excellent potential to be used as an alternative fuel when mixed with catalysts [6], [16]–[20]. In addition, previous studies also used various types of nanoparticle catalysts used, including: Rhodium [21], platinum [22], aluminium oxides, magnesium oxides [23], copper, iron, aluminium, cobalt, boron, silver, cerium oxide [24], graphene and graphene oxide [25], [26] have been recently



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used in biodiesel fuel blends. Unfortunately, most do not use bio-catalysts made from natural ingredients; they all use metal-based catalysts, causing high production costs [27]. Therefore, this research uses natural bio-materials as a bio-catalyst, namely sago waste characterized and activated with ethanol, to become nano activated bio-carbon (NABc). The choice of NABc as a catalyst is due to its unique structure, composed of carbon chains, hydroxyl groups (OH), and aromatic rings, which have great potential to improve fuel performance [6], [28]. In addition, using micron-sized particles in fuel can cause aggregation and clustering in the fuel due to differences in mass and volume [29], thus dispersing micron-sized particles into liquid fuel [30]. Obstacles such as sedimentation, aggregation, clustering, flocculation, and agglomeration can be overcome using nanoparticles ranging from 1 to 100 nm, easily dispersed in liquid fuels [31].

On the other hand, NABc has a high heat absorption capability due to the porosity of the carbon surface. On the other hand, activated carbon can absorb heat due to the porosity on the carbon surface. It even has the potential to generate a magnetic field, thereby increasing the reactivity of bio-graphene molecules [32]. Moreover, in the presence of the OH group, it accelerates the hydrolysis process in the CCO triglyceride chain and increases hydrogen production [33]. In addition, when activated carbon is at nano size, its aromatic ring triggers its natural properties, namely excitation and electron transfer [34]. In addition, the presence of hydroxyl groups (OH) in NABc has the potential to form water molecules that can be used as coolants in the combustion chamber to produce environmentally friendly combustion products by reducing levels of exhaust emissions such as CO, NO_x, sulfur dioxide, CO₂, and smoke [6]. Therefore, based on these advantages of NABc, this research aims to reveal the role of NABc on fuel physicochemical properties, heat transfer characteristics, and their effect on fuel ignition characteristics.

2. Material and Method

The initial step begins with the pyrolysis process of sago waste dregs to produce sago waste charcoal and is continued with a refining process using a ball mill. Furthermore, 10 grams of carbon

sago waste is activated using 3 mol of absolute ethanol for analysis with a concentration of 99.9%, and the activation process begins with a stirring process using a glass stirring rod for 12 hours. After that, the separation process was carried out using filter paper, and washed with distilled water to obtain nanoparticles. Furthermore, NABc of sago waste was dried under adequate sunlight for two days; and it was dried in an oven for 3 hours at 105 °C. As an activating agent, ethanol can produce nano cracks in the NABc structure, thereby expanding the contact area between molecules [35].

This analysis is confirmed from the data properties in

Table 1, where it can be seen that with NABc, the CCO flash point decreased from 215 °C to 198 °C so that the fuel burned quickly because the flame temperature of the fuel was easily reached. In addition, it can be seen that the density and viscosity also decrease, which indicates that nano-cracks occur in the molecular structure of the CCO fuel with NABc. Thereby weakening the Van der Waal bonding forces between the carbon chains, increasing the space for movement and the contact area, so that the fuel molecules become more reactive and easier to ignite.

Furthermore, the effect of NABc on the performance of CCO fuel was observed by testing the properties of CCO with and without NABc, shown in

Table 1. Conversely, CCO consists of various fatty acid carbon chain compounds with different properties, potentially impacting its performance as a fuel. Our research has identified the fatty acids present in CCO, as detailed in Table 2. Meanwhile, the molecular structures of NABc (see **Figure 1**) and CCO (see **Figure 2**) were simulated using the free chemistry software Avogadro 1.1.1.

3. Results and Discussion

Figure 3 shows the surface description of the interaction between NABc and the carbon chain of crude coconut oil. NABc is composed of carbon atoms bonded to oxygen atoms and OH hydroxyl groups. Furthermore, it shows that there are empty gaps in the NABc molecular structure. On the other hand, **Table 2** shows the fatty acids of crude coconut oil is composed of carbon chains with different lengths, geometric structures, and mass amounts [16]. Crude coconut oil contains

more short chains, resulting in lower mass. Weak binding forces between molecules lead to increased attractive interactions between atoms and molecules. The arrangement of the CCO and

Table 1. The main properties of CCO with and without NABc

Properties	CCO with NABc	CCO without NABc
Flash Point (°C)	198	215
Caloric value (cal/gr)	9948	9825
Density at 15 °C (gr/ml)	0.7924	0.7804
Viscosity at 40 °C (cSt)	1.517	1.541
Carbon residue (% wt)	0.13	0.30

Table 2. The main of fatty acid of CCO [6], [16]

Fatty acids	Composition (%)	Carbon chain structure
Caproic	0.6	CH ₃ (CH ₂) ₄ COOH
Caprylic	8.45	CH ₃ (CH ₂) ₆ COOH
Capric	6.1	CH ₃ (CH ₂) ₈ COOH
Lauric	31.43	CH ₃ (CH ₂) ₁₀ COOH
Myristic	18.45	CH ₃ (CH ₂) ₁₂ COOH
Palmitic	8.4	CH ₃ (CH ₂) ₁₄ COOH
Stearic	1.65	CH ₃ (CH ₂) ₁₆ COOH
Oleic	5.7	CH ₃ (CH ₂) ₇ CH=CH(CH ₂) ₇ COOH
Linoleic	1.4	CH ₃ (CH ₂) ₄ CH=CH(CH ₂)CH(CH ₂) ₇ COOH
Linolenic	0.05	CH ₃ (CH ₂)(CH=CHCH ₂) ₃ (CH ₂) ₆ COOH

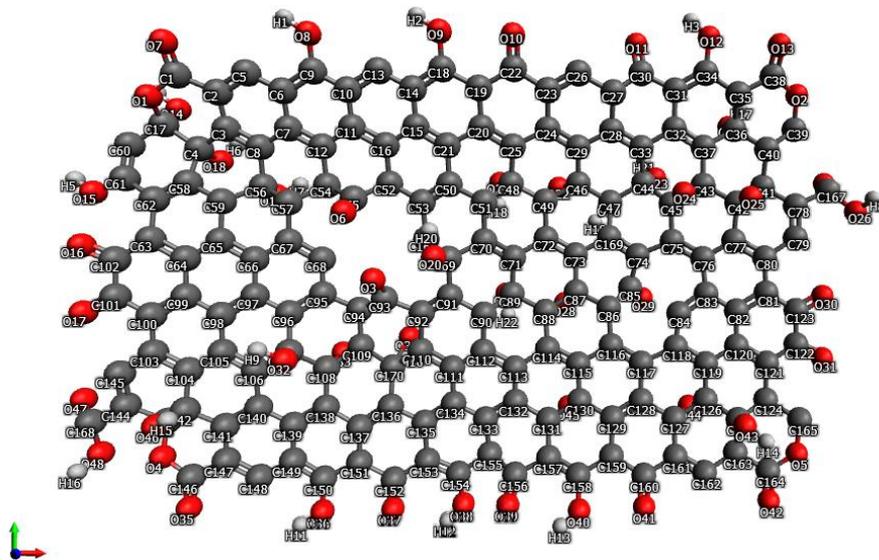


Figure 1. The carbon chain structure of NABc

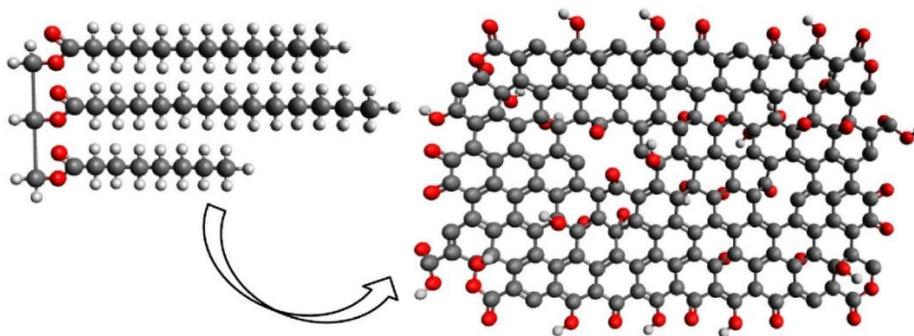


Figure 2. The illustration of surface interactions between carbon chain of CCO and NABc

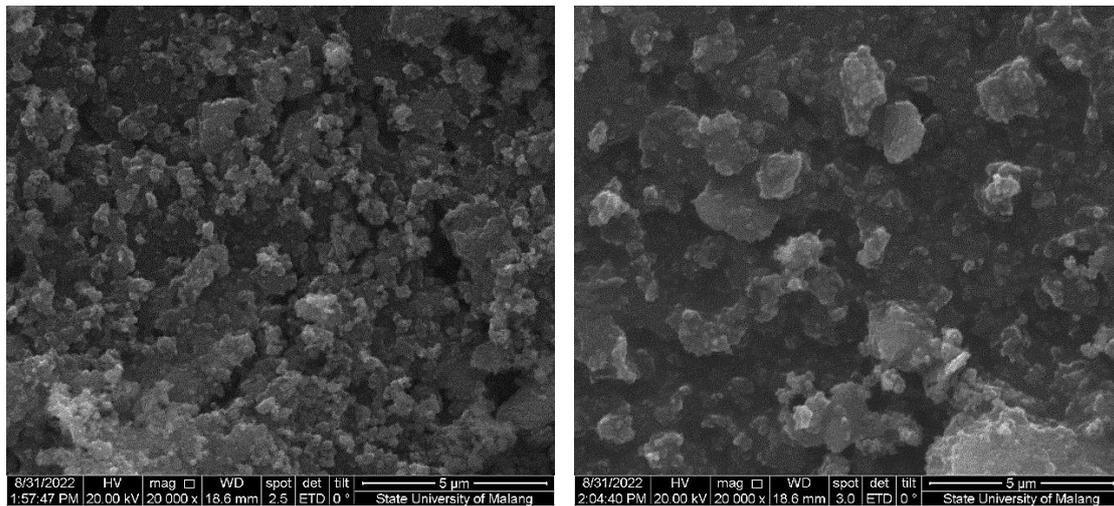


Figure 3. SEM morphology of NABc with (left) and without (right) CCO

NABc carbon chains can produce new molecular interactions and bonds, where the OH hydroxyl group can form the H₂O water molecule; and the interaction between the O and H atoms has the potential to create a new hydroxyl group. Furthermore, empty gaps in the NABc carbon chain structure can potentially become a trap for the crude coconut oil carbon chain; and this has the potential to happen because it is assisted by the reactivity of the short-chain CCO fatty acid compound, which allows attraction between molecules to occur. These molecular interactions can potentially influence the fuel's physicochemical properties and mass behavior when heated.

Table 1 shows the effect of adding bio-carbon on the properties of CCO fuel. It can be seen that the flash point decreases from 47 °C to 42 °C, and the heating value increases from 9825 cal/gr to 9838 cal/gr. Moreover, it can also be seen that the density increased from 0.7824 gr/ml to 0.7904 gr/ml, while the viscosity decreased from 1.541 cSt to 1.517 cSt. A decrease in flash point indicates that the flame temperature is easily reached so that the fuel will burn quickly. This analysis is very reasonable because the reduction in viscosity and increase in density shows that the CCO droplet molecular structure increases in width so that the contact area between molecules increases [21]. Which is caused by the density between fuel molecules becoming closer so that there is potential for attractive forces to occur between fuel molecules are intensive. This analysis is very reasonable because it follows several previous studies discussed in other perspectives [36].

Meanwhile, increasing the heating value of the fuel shows an increase in the fuel's energy content, indicating that the flame temperature of CCO with NABc fuel is higher than CCO without it.

Furthermore, **Figure 3** show the surface morphology characteristics of NABc with and without CCO. Before adding CCO, it can be seen that the NABc surface is less dense and seems to have empty gaps or distances between one plane and another. On the other hand, after NABc was added to the CCO, it was seen that the void space was significantly reduced, and the distance between one plane and another was getting closer. These results show that adding NABc to CCO increased the density between fuel molecules. This analysis is very reasonable because it clarifies the increasing density of CCO fuel (see

Table 1).

Moreover, this phenomenon also indicates that CCO molecules fill the empty gaps in NABc. This surface interaction makes the CCO geometric structure bent. These results are per previous research, which discussed oil mobility and physicochemical interactions due to the influence of NABc catalysts [37].

However, through the depth observations of the surface morphology of NABc, it shown that the increased density indicates that the potential for increased interactions and attractive forces between molecules is getting bigger. This analysis is possible because the result of the interaction between molecules is the increasing reactivity of the fuel molecules so that the viscosity decreases. From

Table 1, it is clarified that the mixture of NABc and CCO managed to reduce the viscosity from 1,541 cSt down to around 1,517 cSt. The decrease in viscosity indicates that the intermolecular bonding forces are diminished or weakened so that the reactivity of the fuel molecules is higher, which causes greater electron mobility. This analysis is possible because, based on **Table 2**, it can be seen that most CCO compounds are unsaturated, even though their chains are straight. This is due to the fact that short-chain compounds have a small mass, so reactivity can only be achieved with less energy. Moreover, from **Figure 4**, it can be seen that the surface area of NABc with CCO is wider than NABc without CCO; it is even clear that NABc with CCO has a greater density and a larger thermal surface area in where the reddish-orange color indicates that the electrons are excited and attracted to the surface. This phenomenon also confirms a polarity on the surface charge, which triggers an attractive force between fuel molecules, which shows that the dark blue part at the bottom is a negative charge. However, the reddish-orange part is a positive charge. Moreover, this analysis makes sense because the force (F) is inversely proportional to the distance and directly proportional to the mass, which shows that the closer the density between the fuel molecules, the greater the attractive force. This is also clarified in **Table 2**, which shows that short, straight carbon chains make up the majority of crude coconut oil compounds. This makes the surface area of bio-graphene larger than that of NABc without CCO so that it widens the contact area between fuel molecules and is easily ignited.

However, in **Figure 5**, the FTIR test results clearly demonstrate that the presence of an aromatic ring group triggers the delocalization of electrons, leading to attractive solid forces between fuel molecules [38]. Furthermore, the conjugation and delocalization of electrons between atoms unequivocally reduce the energy of fuel molecules, making it significantly easier to heat, vaporize, and ignite the fuel. Moreover, the structure of the CCO carbon chain compound (see **Table 2**), which is composed and dominated by short carbon chains with little mass (Lauric 31%, Myristic 18.45%, caprylic 8.54%, palmitic 8.4%), makes it polar so that it has the potential to increase the attractive and attractive interactions and reactivity of these molecules. This analysis is by some of our previous studies [21], [39], [40] which also used CCO as fuel, Morinda citrifolia oil, as well as crude jatropha oil and crude sunflower oil, and this analysis even clarified from the graph of FTIR test results (see **Figure 5**). It can be seen that the CCO fuel molecules with NABc begin to absorb transmittance (T) of infrared (IR) energy at around 104%T, whereas without NABc, it is around 89%T. These results prove our previous hypothesis, which states that adding NABc to CCO effectively increases fuel molecules' attractive interactions and reactivity. Moreover, CCO molecules with NABc can absorb stronger IR energy, as indicated by more profound peaks that occur around waves 1450, 1750, 2400, and around waves 2750 to 3000. Furthermore, it can also be seen that there are aromatic rings around waves

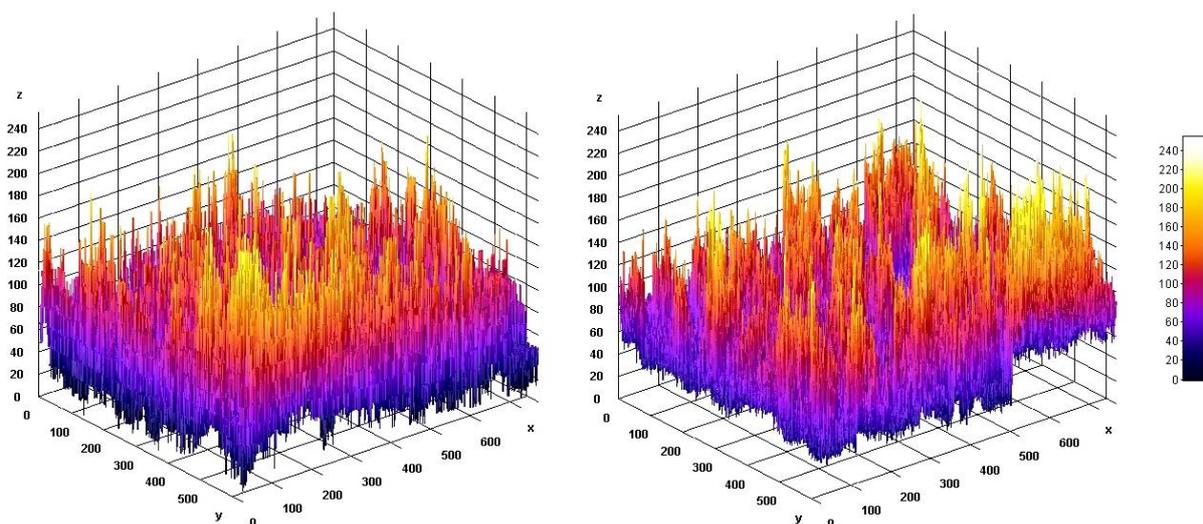
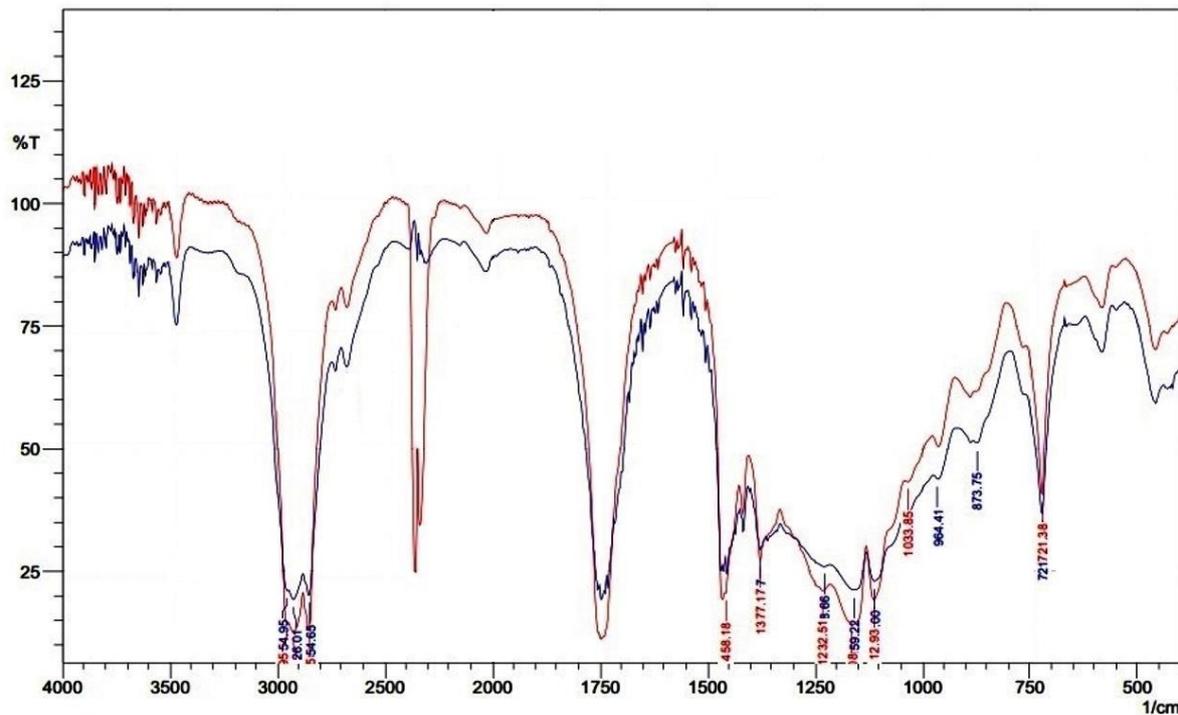


Figure 4. Thermal surface of NABc with CCO (left) and without CCO (right)**Figure 5.** The response of CCO molecules to IR heat. The blue line for CCO with NABc; and the red line for CCO without NABc

875 to 1700, which have an enormous potential to produce magnetic fields because of the nature of the electrons in aromatic molecules, which are easily delocalized [5]. These advantages allow CCO molecules with NABc to absorb more heat energy, allowing the fuel to be easily ignited. These results indicate that adding a NABc to CCO weakened the bonding forces between carbon chains and increased the reactivity of fuel molecules so that the fuel quickly absorbs heat and ignites. This analysis is supported by the fuel viscosity test (see [Table 1](#)), which shows that with NABc, the viscosity achieved is around 1.517 cSt. In contrast, without NABc, it is around 1.54 cSt.

4. Conclusions

A study on the effect of NABc bio-catalyst from sago waste on the physicochemical properties of alternative fuels for crude coconut oil has been completed. Therefore, several significant findings can be concluded, including:

a. The addition of NABc succeeded in changing the physicochemical properties of the fuel, which positively impacted fuel performance as

evidenced by the decrease in flash point, viscosity, and success in increasing the density and heating value.

- b. As a bio-catalyst, NABc has succeeded in changing the shape of the carbon chains and increasing the distance between the carbon chains of crude coconut oil so that the contact area between fuel molecules increases. This increases the density between fuel molecules, thereby increasing the attractive forces between fuel molecules.
- c. The addition of NABc was successful in making CCO fuel have an excellent ability to absorb heat and release energy quickly, where it is proven that the rate of mass loss occurs so quickly, accompanied by an increase in the ignition rate of the fuel.
- d. The complex and multi-component molecular structure of NABc and crude vegetable oil provides an exciting opportunity for further discussion, especially regarding their molecular dynamics properties, including bond, atom, and bond angle properties and their impact on fuel combustion characteristics.

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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.

References

- [1] X. Wang, Y. Lu, C. Chen, X. Yi, and H. Cui, "Total-factor energy efficiency of ten major global energy-consuming countries," *Journal of Environmental Sciences*, vol. 137, pp. 41–52, Mar. 2024, doi: 10.1016/j.jes.2023.02.031.
- [2] M. Setiyo, "Alternative fuels for transportation sector in Indonesia," *Mechanical Engineering for Society and Industry*, vol. 2, no. 1, pp. 1–6, 2022, doi: 10.31603/mesi.6850.
- [3] L. Janota, K. Vávrová, and R. Bízková, "Methodology for strengthening energy resilience with SMART solution approach of rural areas: Local production of alternative biomass fuel within renewable energy community," *Energy Reports*, vol. 10, pp. 1211–1227, 2023, doi: 10.1016/j.egy.2023.07.057.
- [4] A. W. Rennuit-Mortensen, K. Dalgas Rasmussen, and M. Grahn, "How replacing fossil fuels with electrofuels could influence the demand for renewable energy and land area," *Smart Energy*, vol. 10, no. December 2022, p. 100107, 2023, doi: 10.1016/j.segy.2023.100107.
- [5] A. Janzwood and K. Harrison, "The political economy of fossil fuel production in the Post-Paris Era: Critically evaluating Nationally Determined Contributions," *Energy Research & Social Science*, vol. 102, p. 103095, Aug. 2023, doi: 10.1016/j.erss.2023.103095.
- [6] H. Riupassa, S. Suyatno, and H. Y. Nanlohy, "Identifying the Effect of Aromatic Compounds on the Combustion Characteristics of Crude Coconut Oil Droplet," *Eastern-European Journal of Enterprise Technologies*, vol. 2, no. 6–122, pp. 6–14, 2023, doi: 10.15587/1729-4061.2023.272289.
- [7] H. Y. Nanlohy and H. Riupassa, "An Experimental Study on the Ignition Behavior of Blended Fuels Droplets with Crude Coconut Oil and Liquid Metal Catalyst," *Automotive Experiences*, vol. 3, no. 2, pp. 39–45, 2020.
- [8] A. Sule, Z. A. Latiff, M. A. Abbas, I. Veza, and A. C. Opia, "Recent Advances in Diesel-Biodiesel Blended with Nano-Additive as Fuel in Diesel Engines: A Detailed Review," *Automotive Experiences*, vol. 5, no. 2, pp. 182–216, 2022, doi: 10.31603/ae.6352.
- [9] H. Y. Nanlohy, I. N. G. Wardana, N. Hamidi, L. Yuliati, and T. Ueda, "The effect of Rh3+ catalyst on the combustion characteristics of crude vegetable oil droplets," *Fuel*, vol. 220, pp. 220–232, 2018.
- [10] Wardoyo, A. S. Widodo, W. Wijayanti, and I. N. G. Wardana, "The Role of Areca catechu Extract on Decreasing Viscosity of Vegetable Oils," *Scientific World Journal*, vol. 2021, 2021, doi: 10.1155/2021/8827427.
- [11] M. Setiyo, D. Yuvenda, and O. D. Samuel, "The Concise Latest Report on the Advantages and Disadvantages of Pure Biodiesel (B100) on Engine Performance: Literature Review and Bibliometric

- Analysis," *Indonesian Journal of Science and Technology*, vol. 6, no. 3, pp. 469–490, 2021, doi: <https://doi.org/10.17509/ijost.v6i3.38430>.
- [12] R. Manimaran, T. Mohanraj, and R. Ashwin, "Green synthesized nano-additive dosed biodiesel-diesel-water emulsion blends for CI engine application: Performance, combustion, emission, and exergy analysis," *Journal of Cleaner Production*, vol. 413, Aug. 2023, doi: [10.1016/j.jclepro.2023.137497](https://doi.org/10.1016/j.jclepro.2023.137497).
- [13] S. R. Ariyanto, S. Suprayitno, and R. Wulandari, "Design of Metallic Catalytic Converter using Pareto Optimization to Improve Engine Performance and Exhaust Emissions," *Automotive Experiences*, vol. 6, no. 1, pp. 200–2015, Apr. 2023, doi: [10.31603/ae.7977](https://doi.org/10.31603/ae.7977).
- [14] W. Anggono et al., "Engine Performances of Lean Iso-Octane Mixtures in a Glow Plug Heated Sub-Chamber SI Engine," *Automotive Experiences*, vol. 5, no. 1, pp. 16–27, Nov. 2021, doi: [10.31603/ae.5118](https://doi.org/10.31603/ae.5118).
- [15] A. Yudianto and P. Li, "Influence of Compression Ratio on Flywheel Dimension for a Naturally Aspirated Spark Ignition Engine: A Numerical Study," *Automotive Experiences*, vol. 3, no. 2, May 2020, doi: [10.31603/ae.v3i2.3530](https://doi.org/10.31603/ae.v3i2.3530).
- [16] H. Y. Nanlohy, I. N. G. Wardana, N. Hamidi, L. Yulianti, and T. Ueda, "The effect of Rh³⁺ catalyst on the combustion characteristics of crude vegetable oil droplets," *Fuel*, vol. 220, 2018, doi: [10.1016/j.fuel.2018.02.001](https://doi.org/10.1016/j.fuel.2018.02.001).
- [17] C. Jin et al., "Effect of nanoparticles on diesel engines driven by biodiesel and its blends: A review of 10 years of research," *Energy Conversion and Management*, vol. 291, p. 117276, Sep. 2023, doi: [10.1016/j.enconman.2023.117276](https://doi.org/10.1016/j.enconman.2023.117276).
- [18] B. V. Bot, P. J. Axaopoulos, E. I. Sakellariou, O. T. Sosso, and J. G. Tamba, "Energetic and economic analysis of biomass briquettes production from agricultural residues," *Applied Energy*, vol. 321, p. 119430, Sep. 2022, doi: [10.1016/j.apenergy.2022.119430](https://doi.org/10.1016/j.apenergy.2022.119430).
- [19] A. T. Mohammed, M. F. M. Said, N. Othman, A. C. Opia, and I. Veza, "Feasibility Study of Biofuel Incorporated Nanoparticles as Sustainable IC Engine Fuel: Opportunities and Challenges - An overview," *Automotive Experiences*, vol. 6, no. 1, pp. 94–121, Apr. 2023, doi: [10.31603/ae.7846](https://doi.org/10.31603/ae.7846).
- [20] "No Title," doi: [10.31603/ae.10311](https://doi.org/10.31603/ae.10311).
- [21] H. Y. Nanlohy, I. N. G. Wardana, M. Yamaguchi, and T. Ueda, "The role of rhodium sulfate on the bond angles of triglyceride molecules and their effect on the combustion characteristics of crude jatropha oil droplets," *Fuel*, vol. 279, p. 118373, 2020, doi: <https://doi.org/10.1016/j.fuel.2020.118373>.
- [22] S. Lopatin, A. Elyshev, and A. Zagoruiko, "Catalytic device for environmentally friendly combustion of liquid fuels on the base of structured glass-fiber catalyst," *Catalysis Today*, no. September 2020, 2021, doi: [10.1016/j.cattod.2021.02.010](https://doi.org/10.1016/j.cattod.2021.02.010).
- [23] M. Mukherjee, G. Goswami, P. K. Mondal, and D. Das, "Biobutanol as a potential alternative to petroleum fuel: Sustainable bioprocess and cost analysis," *Fuel*, vol. 278, no. May, p. 118403, 2020, doi: [10.1016/j.fuel.2020.118403](https://doi.org/10.1016/j.fuel.2020.118403).
- [24] M. E. M. Soudagar, N. N. Nik-Ghazali, M. Abul Kalam, I. A. Badruddin, N. R. Banapurmath, and N. Akram, "The effect of nano-additives in diesel-biodiesel fuel blends: A comprehensive review on stability, engine performance and emission characteristics," *Energy Conversion and Management*, vol. 178, pp. 146–177, Dec. 2018, doi: [10.1016/j.enconman.2018.10.019](https://doi.org/10.1016/j.enconman.2018.10.019).
- [25] M. E. M. Soudagar et al., "The effects of graphene oxide nanoparticle additive stably dispersed in dairy scum oil biodiesel-diesel fuel blend on CI engine: performance, emission and combustion characteristics," *Fuel*, vol. 257, p. 116015, 2019, doi: [10.1016/j.fuel.2019.116015](https://doi.org/10.1016/j.fuel.2019.116015).
- [26] S. Daud, M. A. Hamidi, and R. Mamat, "Design of Experiment to Predict the Effects of Graphene Nanoplatelets Addition to Diesel Engine Performance," *Automotive Experiences*, vol. 5, no. 3, pp. 467–476, Sep. 2022, doi: [10.31603/ae.6263](https://doi.org/10.31603/ae.6263).
- [27] M. S. Gad et al., "A comprehensive review on the usage of the nano-sized particles along with diesel/biofuel blends and their impacts on engine behaviors," *Fuel*, vol. 339, May 2023, doi: [10.1016/j.fuel.2022.127364](https://doi.org/10.1016/j.fuel.2022.127364).

- [28] A. A. Azahar, M. D. Nurhafizah, M. R. Omar, N. Abdullah, and A. Ul-Hamid, "Biographene production from oil palm shell waste valorised through sequential thermal and catalytic means," *Carbon Trends*, vol. 9, 2022, doi: 10.1016/j.cartre.2022.100225.
- [29] V. W. Khond and V. M. Kriplani, "Effect of nanofluid additives on performances and emissions of emulsified diesel and biodiesel fueled stationary CI engine: A comprehensive review," *Renewable and Sustainable Energy Reviews*, vol. 59, pp. 1338–1348, 2016, doi: 10.1016/j.rser.2016.01.051.
- [30] V. Saxena, N. Kumar, and V. K. Saxena, "A comprehensive review on combustion and stability aspects of metal nanoparticles and its additive effect on diesel and biodiesel fuelled CI engine," *Renewable and Sustainable Energy Reviews*, vol. 70, pp. 563–588, 2017, doi: 10.1016/j.rser.2016.11.067.
- [31] T. Sathish *et al.*, "Pore size variation of nanoporous material fixer on the engine bowl and its combined effects on hybrid nano-fuelled CI engine characteristics," *Fuel*, vol. 345, Aug. 2023, doi: 10.1016/j.fuel.2023.128149.
- [32] E. Taer *et al.*, "Production of Activated Carbon Electrodes from Sago Waste and its application for an Electrochemical Double-Layer Capacitor," *International Journal of Electrochemical Science*, vol. 13, no. 11, pp. 10688–10699, Nov. 2018, doi: 10.20964/2018.11.27.
- [33] Suyatno, H. Riupassa, S. Marianingsih, and H. Y. Nanlohy, "Characteristics of SI engine fueled with BE50-Isooctane blends with different ignition timings," *Heliyon*, vol. 9, no. 1, p. e12922, Jan. 2023, doi: 10.1016/J.HELIYON.2023.E12922.
- [34] Y. Duan, A. Zhong, Z. Huang, and D. Han, "Theoretical study on hydrogen abstraction reactions from cyclopentanol by hydroxyl radical," *Fuel*, vol. 297, no. March, p. 120766, 2021, doi: 10.1016/j.fuel.2021.120766.
- [35] Y. Feng *et al.*, "The mechanism of ethanol blending on the variation of chemical heat sink in n-decane thermal cracking process," *Fuel*, vol. 353, p. 129204, Dec. 2023, doi: 10.1016/j.fuel.2023.129204.
- [36] H. Y. Nanlohy and Trismawati, "The role of fatty acid of Morinda citrifolia oil as surface-active chemicals on the deinking process of waste paper," *Materialia*, vol. 23, p. 101436, Jun. 2022, doi: 10.1016/J.MTLA.2022.101436.
- [37] A. O. Yusuff, N. Yahya, M. A. Zakariya, and S. Sikiru, "Investigations of graphene impact on oil mobility and physicochemical interaction with sandstone surface," *Journal of Petroleum Science and Engineering*, vol. 198, p. 108250, Mar. 2021, doi: 10.1016/j.petrol.2020.108250.
- [38] G. E. Yergaziyeva, Mambetova, and K. Dossumov, "Influence of preparation method on the activity of molecular sieve KA catalysts modified with zinc and phosphorus oxides in the non-oxidative thermocatalytic conversion of ethanol to aromatic hydrocarbons," *South African Journal of Chemical Engineering*, vol. 43, pp. 60–66, Jan. 2023, doi: 10.1016/j.sajce.2022.10.001.
- [39] H. Y. Nanlohy, I. N. G. Wardana, N. Hamidi, and L. Yuliati, "Combustion characteristics of crude jatropha oil droplets using rhodium liquid as a homogeneous combustion catalyst," in *IOP Conference Series: Materials Science and Engineering*, 2018, vol. 299, no. 1, p. 12090.
- [40] H. Y. Nanlohy, "Comparative Studies on Combustion Characteristics of Blended Crude Jatropha Oil with Magnetic Liquid Catalyst and DEX under Normal Gravity Condition," *Journal of Mechanical Engineering Science and Technology*, vol. 5, no. 2, pp. 79–88, 2021, doi: 10.17977/um016v5i22021p079.