Journal of Applied Engineering and Technological Science
Vol 5(1) 2023: 557-568

TRIGLYCERIDES OF CRUDE PALM OIL TO BIOKEROSENE: STUDIES ON ELECTROLYSIS AND ELECTROMAGNETIC EFFECT

Sri Rizki Putri Primandari[1]*, Krismadinata[2], Dori Yuvenda[3], Remon Lapisa[4], Andre Kurniawan[5], Mulianti[6], Muhammad Djoni Bustan[7], Sri Haryati[8], Gusni Sushanti[9], Tarig Elshaarani[10], Yus Donald Chaniago[11]
Centre for Energy and Power Electronics Research (CEPER), Universitas Negeri Padang, West Sumatera, Indonesia[12345]
Department of Mechanical Engineering, Faculty of Engineering, Universitas Negeri Padang, West Sumatera, Indonesia[13456]
Department of Chemical Engineering, Faculty of Engineering, Universitas Sriwijaya, South Sumatera, Indonesia[78]
Chemical Engineering Program, Graduate School of Advanced Science and Engineering, Hiroshima University, Hiroshima, Japan[9]
Institute of Chemistry & Nuclear Physics, Sudan Atomic Energy Commission, Khartoum, Sudan[10]
School of Energy and Chemical Engineering, Ulsan National Institute of Science and Technology, Ulsan, Republic of Korea[11]
sri.primandari@ft.unp.ac.id

Received : 24 August 2023, Revised: 23 November 2023, Accepted : 27 November 2023
**Corresponding Author*

ABSTRACT
Crude Palm Oil (CPO) is a potential feedstock for biokerosene. However, it is problematic when used directly because it is gummy, has a high viscosity and is degradable. Various conversion processes have been conducted that directly convert CPO into biokerosene, but it requires high temperature and pressure. Therefore, as a novelty, this study aims to develop the technology for converting triglycerides into biokerosene under relatively low operating conditions and producing similar petroleum kerosene by electrolysis-assisted and electromagnetic induction. In this study, the conversion technology process was conducted in three steps (i) converting triglycerides to Free Fatty Acids (FFA), (ii) converting FFA to alkanes, and (iii) converting alkanes to biokerosene. Step (ii) is assisted by the electrolysis process, meanwhile, step (iii) is assisted by electromagnetic irradiation. The finding showed that electrolysis obtained 73.47% yield of alkanes and electromagnetic irradiation obtained 78.02% yield of biokerosene. Biokerosene is almost close to kerosene-based petroleum in terms of colour Saybolt, flash point and Net Heating Value. The findings of this study may provide an alternate technology approach for biokerosene synthesis and solution kerosene scarcity.
Keywords: *Biofuel, Energy Conversion, Chemical Conversion, Technology*

1. Introduction

The more it is realized, the more fossil energy formed over hundreds of years will decrease. The current energy crisis is also due to the world's energy consumption which is experiencing an upward trend. Simultaneously with an increase in consumption, there is also a phenomenon like two sides of a coin where the level of production tends to decrease (Ezzati et al., 2021; Yuvenda, Sudarmanta, Jamaludin, et al., 2022). This shows a difference (deficit gap). The energy crisis is the tension that the supply of energy cannot fulfil the high level of demand and divert to renewable energy (Sani et al., 2023). Crude palm oil (CPO) as a renewable energy source is a vegetable oil that has the highest triglyceride content when compared to oils from other plants such as Jatropha curcas (Islam et al., 2017; Yuvenda, Sudarmanta, Wahjudi, et al., 2022).

In responding to the fulfilment of energy needs and saving the use of fossil fuels, it is required to diversify the utilization of alternative/renewable energy sources (Fauza et al., 2023; Setiyo, 2022). It is an effort to increase supply security and reduce the quantity of imported raw materials. This is attempted by diverting dependence on fossil energy sources towards diversifying other alternative energy sources, including biokerosene from CPO. Kerosene is one of the most important fuels in the world of aviation and is also a fuel for people's cooking (Afisna & Rahadi, 2022; Llamas et al., 2012).

The problems that occur when using CPO directly are gummy, relatively high viscosity, and degradable (Hendri et al., 2023; Primandari et al., 2021). Therefore, vegetable oil cannot be used directly as a substitution for kerosene using an ordinary stove. Various conversion processes have been carried out which directly convert vegetable oil into biokerosene. (Santos et al., 2020) directly cracked palm oil into methyl ester with a lack of selectivity of 0.3-3.5%, with relatively high operating conditions of 550-850^{o}C for 5 hours. It produced a methyl ester which only has physical properties similar to kerosene-based petroleum. (Khan et al., 2022) also carried out catalytic cracking of palm oil in a fixed bed reactor using the HZSM-5 catalyst. The process is carried out within 2.5 hours and at a temperature of 450^{o}C. The yield is relatively high at 56-78%. (Dupain et al., 2007) conducted direct cracking of rapeseed oil under FCC (fluidized catalytic cracking) conditions with operating conditions of 465-585^{o}C. However, the yield is relatively low around 15-34%. This process uses a mixture of Pt and ZSM-5 as a catalyst. (Neves et al., 2020) perform a conversion called BTL, and the biomass becomes liquid. This study used lignocellulosic as feed in a fixed bed-type reactor. This process uses nickel, vanadium, and precious metals as catalysts. The reaction time is slow at 4 days with a temperature of 560^{o}C and a high pressure of 150 atm to produce BTL-kerosene. It has perfect quality where the aromatic content is 8%, free of sulfur. However, the yield of BTL-kerosene is only 12%.

Previous studies conducted the direct cracking of vegetable oil into biokerosene that requires a relatively high operating condition (high pressure, high temperature) (Rahayu et al., 2022). Despite they have succeeded in producing biokerosene, however, biokerosene is a methyl ester that kerosene-like compounds (Gutiérrez et al., 2018; Souza et al., 2018). Thus, it is required to produce biokerosene-based petroleum by moderate operating conditions.

Electrolysis, as a method involving the use of electricity to drive chemical reactions, can potentially contribute to the breakdown of complex organic molecules found in biomass, including triglycerides (as main compound in CPO), into simpler compounds (hydrocarbon). Through electrolytic processes, some complex organic compounds can be disassembled into smaller molecules or intermediates, such as hydrogen, carbon monoxide, or other hydrocarbons (Rosa et al., 2024). The free fatty acids resulting from the hydrolysis of triglycerides might undergo further electrolytic processes (Chen et al., 2022). These fatty acids could potentially be converted into simpler hydrocarbon compounds, such as alkanes or other hydrocarbons resembling components of kerosene.

Electromagnetic irradiation or induction is primarily known for inducing electric currents or voltage in conductors through a changing magnetic field (Anggrainy et al., 2022; Basar et al., 2023).Induction heating enables precise and localized heating within reaction vessels or equipment, potentially improving the efficiency and selectivity of certain chemical reactions involved in biofuel production processes. Electromagnetic fields can potentially influence the behaviour of catalysts used in the conversion process (Kim et al., 2020). The electromagnetic field could influence the catalyst's surface or activation energy, potentially improving catalyst performance or selectivity in the desired reactions. Electromagnetic induction heating is often considered more energy-efficient than conventional heating methods. Utilizing this technology in the refining or upgrading steps of the process could contribute to energy savings and process optimization, indirectly impacting the overall efficiency of biofuel production (Ponomarev, 2023). However, electrolysis and electromagnetic irradiation are limited in biomass conversion to biofuel.

Thus, as a novelty, this study aims to develop a technological design for converting triglycerides into biokerosene through a process step that requires relatively low operating conditions prior to cracking directly. It has a carbon content equivalent to petroleum kerosene by considering technical aspects such as lower temperature and pressure. As a hypothesis, electrolysis and electromagnetic irradiation have significant effects on triglycerides of crude palm oil conversion to biokerosene.

2. Research Methods

This study is focused on the conversion of Crude Palm Oil triglycerides to biokerosene as a research object experimentally. The conversion of triglycerides to biokerosene was conducted in three steps; (i) converting triglycerides to Free Fatty Acids (FFA); (2) converting FFA to hydrocarbons; (3) converting hydrocarbon to biokerosene.

2.1 Converting triglyceride to FFA

This step is hydrolysis by H_2SO_4 solution as a catalyst. CPO was mixed by H_2SO_4 in a certain ratio and heated up to 120ºC. Subsequently, hot water (80ºC) was added and stirred in a Continuous Stirred Tank Reactor (CSTR) for 2 hours of reaction. This reaction produced three layers; FFA, glycerol and water (Jaya et al., 2021; Shehu et al., 2019). The bottom layer (glycerol and water) was drained from the reactor and the upper layer (FFA) was processed to the next step. Converting triglycerides to FFA as in Eq. 1.

$$\begin{array}{llllll} CH_2-O-CO-R_1 & & & CH_2-OH & & HO-CO-R_1 \\ | & & & | & & \\ CH-O-CO-R_2 & + & 3\,H_2O \rightleftharpoons & CH-OH & + & HO-CO-R_2 \\ | & & & | & & \\ CH_2-O-CO-R_3 & & & CH_2-OH & & HO-CO-R_3 \\ \text{Triglycerides} & & \text{water} & \text{Glyserol} & & \text{FFA} \end{array} \qquad \text{Eq. 1}$$

2.2 Converting FFA to Hydrocarbon (Electrolysis Assisted)

This step is conducted by electrolysis assisted with acetic acid as an electrolyte, Cu and Ag rods as electrodes. The conductivity controller and AC/DC Converter are set at various voltages. Record the value of changes in the increase in electrons (mS) and also the decrease in acidity (pH) in the solution every 20 minutes. Under certain conditions, the solution will reach the saturation stage so that the numbers on the measuring instrument indicate a stable or steady state (constant). The conditions obtained at this initial condition were used for the conditions in this step. FFA and CH_3COOH solution were mixed at a certain molarity and heated up to 130ºC for 2 hours with various voltages. Due to this decarboxylation process is a reaction that releases CO_2 from the carboxyl group, it is examined by flowing it into a colourless $Ca(OH)_2$ solution. If the solution turns cloudy, it shows that there is CO_2 occurs since the reaction between CO^2 and $Ca(OH)_2$ will produce $CaCO_3(s)$ which is milky white (Grimes et al., 2020). The reaction is shown in Eq. 2.

$$\underset{\text{FFA}}{R-\overset{\overset{\displaystyle O}{||}}{C}-OH} \rightleftharpoons \underset{\text{Hydrocarbon}}{R-H} + \underset{\text{Carbon dioxide}}{CO_2} \qquad \text{Eq. 2}$$

The best result of this step is chosen for the next step determined based on viscosity, ºAPI gravity, and characteristics factor (K).

2.3 Converting Hydrocarbon to Biokerosene (Electromagnetic Induction)

This step is conducted by electromagnetic induction. Since this step is catalytic cracking, activated zeolite is applied as a catalyst. Hydrocarbon from the previous step is mixed with methanol at a certain ratio (6:0.2; 6:0.4; 6:0.6). This mixed solution then flowed into the reactor and an electromagnet process was carried out for 30 minutes with an electromagnetic field strength varying from 2.89E+18 N/C to 7.24E+20 N/C. Next, it is heated up to 180ºC at atmospheric pressure for hours. Crude biokerosene is purified by degumming and bleaching (Dinul et al., 2023). Then, purified biokerosene is analyzed to determine the yield (Mahdi et al., 2021; Pujan et al., 2017). The flow step is shown in Fig. 1.

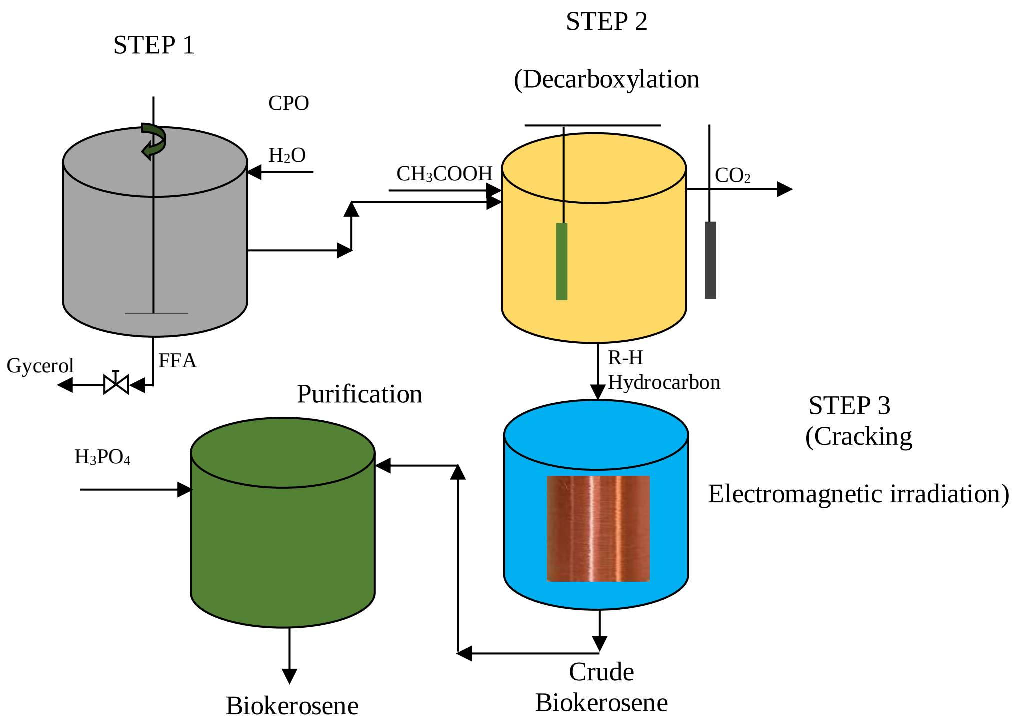

Fig. 1. Steps In CPO Conversion to Kerosene

2.4 Data Analysis

This study focuses on electrolysis and the electromagnetics effect on the conversion of triglycerides to biokerosene. Thus, data analysis was done on steps 2 (decarboxylation-electrolysis assisted) and 3 (Catalytic cracking-electromagnetic induction). The effect of electrolysis is determined by the molarity of concentration [FFA] in mol/L (0.5mol/L, 1mol/L, 1.5mol/L) and voltage on °API gravity, characteristics factor (K factor), Net Heating Value (NHV), and yield of hydrocarbon. Meanwhile, the effect of electromagnetic induction is determined by the ratio of hydrocarbon and methanol (L), electromagnetic field on °API gravity, characteristics factor (K factor), Net Heating Value (NHV), and yield of biokerosene. Further, biokerosene from this study is analyzed for its characteristics and compared to commercial kerosene from PT Pertamina (Indonesian Oil and Gas Company). The characteristics are specific gravity 60/60°F, colour Saybolt, flash point, and NHV. The specific gravity analysis was based on ASTM D-1298, the colour Saybolt was based on ASTM D-156, and the flash point was based on ASTM D-56.

3. Results and Discussions

3.1 Converting Triglycerides to Free Fatty Acids (FFA)

Triglycerides are the main compound in crude palm oil. They consist of three fatty acid molecules bound to one glycerol molecule. With H_2SO_4 solution as a catalyst, it can cause hydrolysis of triglyceride, which is the breakdown of triglycerides into free fatty acids and glycerol. In this study, the hydrolysis process occurs with the formation of three layers: FFA, glycerol and water (Jaya et al., 2021; Shehu et al., 2019). FFA is on upper layer, meanwhile, glycerol and water are in bottom layer. The separation of these components into layers occurs due to their differing polarities and densities. FFA is on the upper layer due to being less polar and more soluble in nonpolar substances, which tend to accumulate in the upper layer. This layer consists mainly of the less polar-free fatty acids resulting from the hydrolysis process. Meanwhile, glycerol and water are on the bottom layer, being more polar and hydrophilic, forming a separate bottom layer due to their higher affinity for each other and for water. They are less soluble in nonpolar substances, causing them to settle at the bottom. This separation into distinct layers happens because of the differing chemical properties of the substances produced during hydrolysis. Free fatty acids, being less polar, tend to remain in the upper layer where nonpolar substances accumulate, while glycerol and water, being more polar, form a separate layer at the bottom due to their higher affinity for water and less solubility in the upper nonpolar layer.

3.2 Converting FFA to alkanes

The qualitative variable in this study is the voltage variation applied during the electrolysis process. Its influences on hydrocarbon quality include °API gravity, characteristics factor (K factor), and NHV. Meanwhile, the quantitative variable is the molarity of concentration [FFA] that affects the increase in the percentage yield of hydrocarbon. The result of the effect of voltage and [FFA] on the yield of hydrocarbon is depicted in Fig. 2.

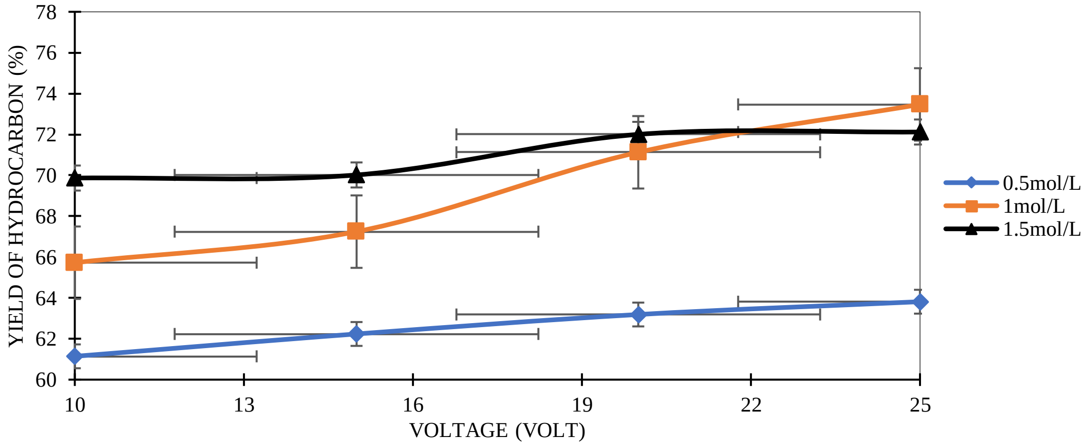

Fig. 2. Effect of Voltage and Molarity Concentration On Yield Of Hydrocarbon

Fig. 2 showed that molarity concentration [FFA] affects the amount of yield of hydrocarbon produced. The more concentrated the solution, the higher the yield is obtained (Rahmadiawan et al., 2022). It aligned with (Primo et al., 2021) and (Razak & Zulfia, 2023), the more concentrated the solution, the greater the amount of acetic acid, and the higher the voltage, the higher the ability to conduct electricity (Alves et al., 2021). When there are more ionized FFA, the acyloxy anions to be oxidized also increase, thus impacting the increasing hydrocarbon production.

The highest yield of 73.47% was produced from a molarity concentration of 1.5mol/L with a voltage of 25 Volts. The result of the effect of voltage and [FFA] on °API gravity is depicted in Fig. 3.

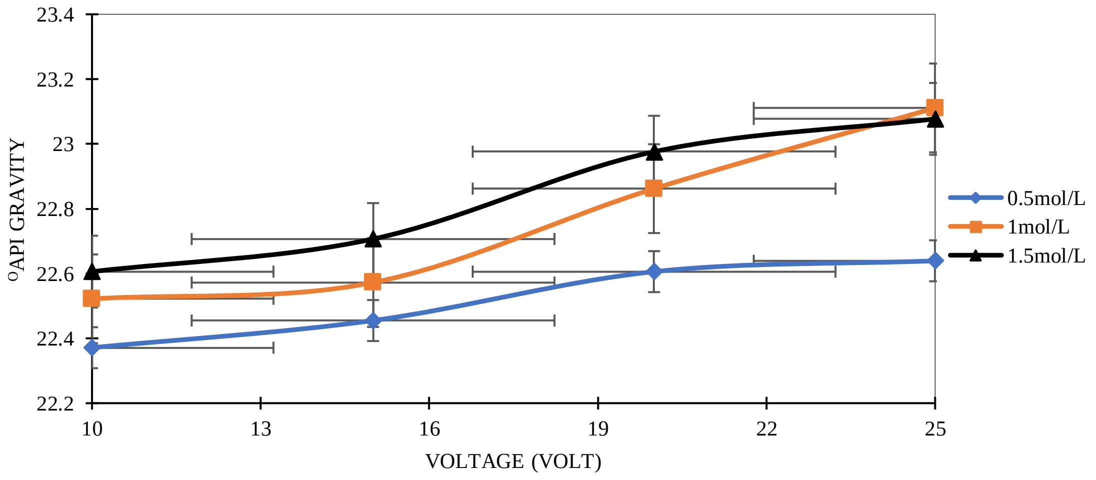

Fig. 3. Effect of Voltage and Molarity Concentration On °API gravity

An increase in concentration means an increase in methyl radicals so the possibility of forming short-chain alkanes also increases. The formation of a shorter alkane compound is characterized by a decrease in density which results in an increase in the °API gravity of the product (Baidoo et al., 2022). °API gravity can predict the characteristics of other fuel oils, including K factor, and Net Heating Value (NHV) (Yamamoto et al., 2006). The highest °API gravity (23.11) was obtained on a molarity concentration of 1mol/L and a voltage of 25 Volts. The result of the effect of voltage and [FFA] on K factor is depicted in Fig. 4.

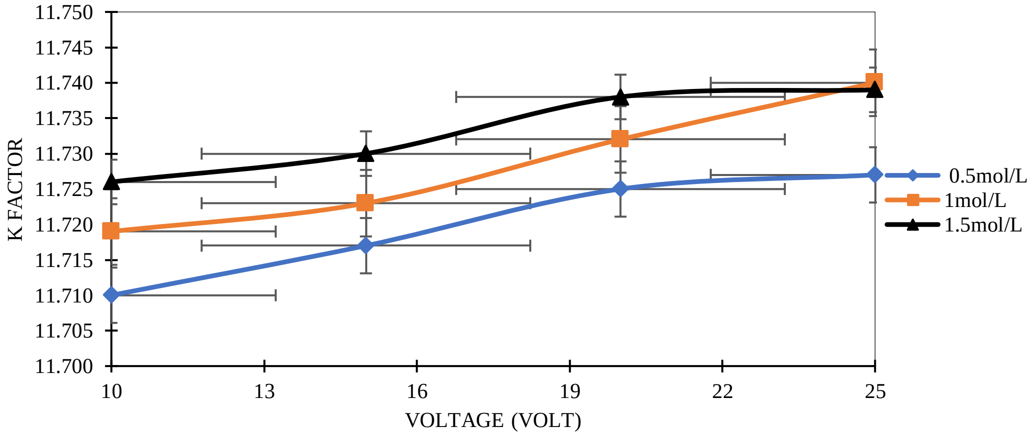

Fig. 4. Effect Of Voltage and Molarity Concentration on K Factor

By obtaining the °API gravity, it can predict a similar trend in the graphs for the K factor and Net Heating Value (NHV) since °API gravity has an associated relationship among NHV, and K factor (Nurdin et al., 2022; Yamamoto et al., 2006). The K factor in fuel cells represents the sensitivity of the cell's voltage output to changes in the current density. Higher K factors indicate better performance and efficiency, meaning that the cell can maintain higher voltages across various current densities. Voltage and molarity concentration play crucial roles in determining the K factor by affecting the kinetics of the electrochemical reactions and the cell's overall efficiency. The K factor is the characteristic value of the oil. It has been explained previously that the more concentrated the concentration, the more acetic acid ions and the greater the voltage, the greater the ability of electrons to disrupt bonds so the number of alkanes in this is paraffin as well. This is indicated by the higher K value. Where the best K value is 11.751 and the highest NHV is 17960.4083 btu/lb at a molarity concentration of 1mol/L and a voltage of 25 V.

The result of the effect of voltage and [FFA] on NHV is depicted in Fig. 5.

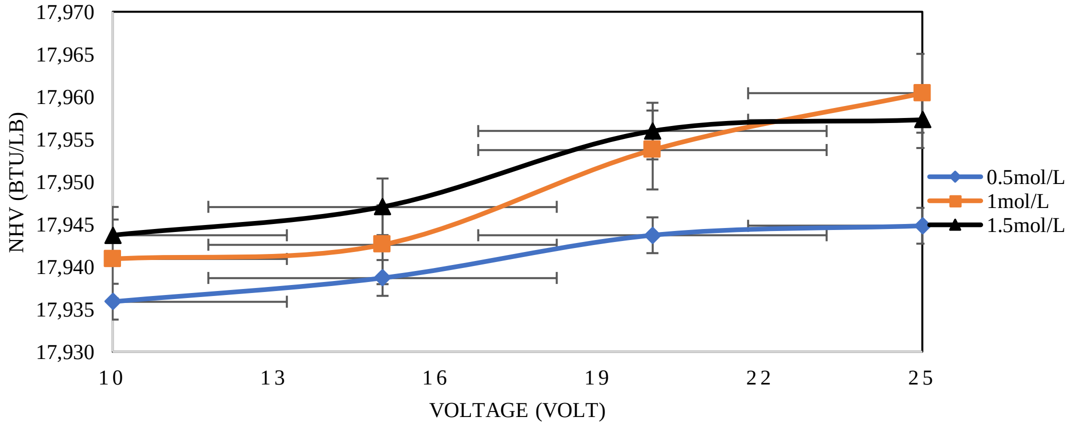

Fig. 5. Effect of Voltage and Molarity Concentration On NHV

The Net Heating Value (NHV) of a fuel refers to the amount of heat released when a fuel is completely combusted and is typically measured in energy per unit mass (e.g., joules per kilogram or BTUs per pound). Free Fatty Acids (FFA) in fuels, particularly in biodiesel or certain biofuels derived from natural sources, can affect the combustion properties and consequently the Net Heating Value. Higher FFA concentrations in biodiesel, for example, can lead to increased levels of impurities and contaminants in the fuel. This can affect the combustion process, potentially lowering the Net Heating Value due to incomplete combustion or the formation of byproducts that reduce the released energy.

Considering the result of electrolysis that includes yield, °API gravity, K factor, and NHV as parameters, thus an optimum condition for electrolysis assisted are molarity of concentration

1mol/L, and voltage 25V. Further, the product from the optimum condition proceeded to the next step.

3.3 Converting Alkanes to Biokerosene

The qualitative variables in this step are the electromagnetic field variation applied during the electromagnetic induction process. It influences on biokerosene quality include °API gravity, characteristics factor (K factor), and NHV (Purwanto et al., 2023). Meanwhile, the quantitative variable is the ratio of hydrocarbon and methanol that affects the increase in the percentage yield of biokerosene. The result of the effect of the electromagnetic field and the ratio of hydrocarbon and methanol on the yield of biokerosene is depicted in Fig. 6.

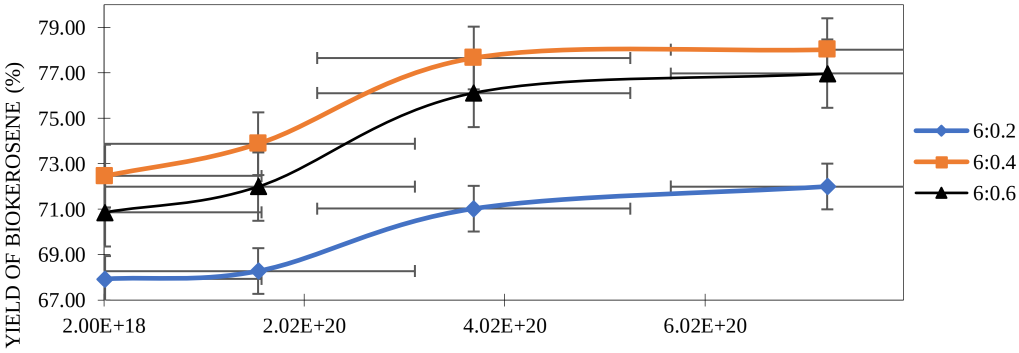

Fig. 6. Effect of Ratio of Hydrocarbon: Methanol And Electromagnetic Field on Yield of Biokerosene

Fig. 6 showed that yield increased aligned with electromagnetic field strength (Ayesha et al., 2023). The electromagnetic field has a significant effect on the yield of biokerosene. Abdel-Rehim (2019) reported that the higher the strength of the electromagnetic field, the greater the energy given to destabilize the C-C bonds in alkane compounds so that the yield is increased. Where the electromagnetic field strength of 7.24E+20 N/C obtained the highest yield. However, this did not happen due to the influence of the ratio of hydrocarbon and methanol, where the ratio was 6:0.6, the yield produced was on average lower than the ratio 6:0.4. It was due to the high mixing ratio resulting in the formation of short-chain alkanes resulting in a lot of alkane gas coming out of the reactor vent and resulting in the bottom product obtained containing more heavy oil (Guan et al., 2023). The oil produced at a ratio of 6:0.6 is thicker and darker in colour when compared to the product ratio of 6:0.4. The highest yield percentage of 78.023% was produced by an electromagnetic field strength of 7.24E+20 N/C with a ratio of 6:0.4. The result of the effect of the electromagnetic field and the ratio of hydrocarbon and methanol on °API gravity is depicted in Fig. 7.

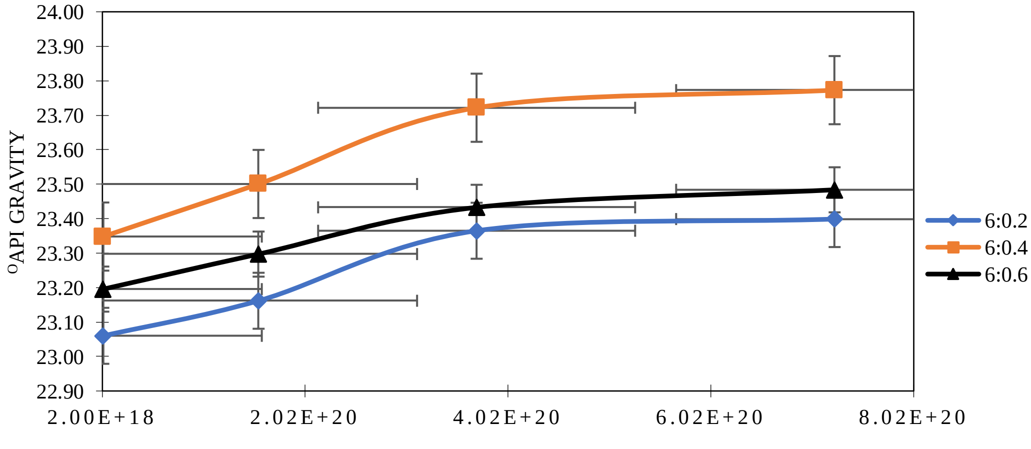

Fig. 7. Effect of Ratio of Hydrocarbon : Methanol and Electromagnetic Field on °API Gravity

Result showed that the electromagnetic field and the ratio of hydrocarbon and methanol has a significant effect on °API gravity of biokerosene. The highest °API gravity is obtained at a ratio of hydrocarbon and methanol 6:0.4 and an electromagnetic field strength of 7.24E+20. It is due to the electromagnetic field weakening the C-C bond making it easier to break the C-C bond. So that more alkanes with short chains can be obtained. If there are more short-chain alkanes, the product will have a lower density resulting in an increase in the ^{o}API gravity of the product (Khodadadi Azadboni, 2021).The effect of the ratio of hydrocarbon and methanol and electromagnetic field on K factor and NHV have the same tendency on ^{o}API gravity.

Fig. 8 describes the effect of the electromagnetic field and the ratio of hydrocarbon and methanol on K factor.

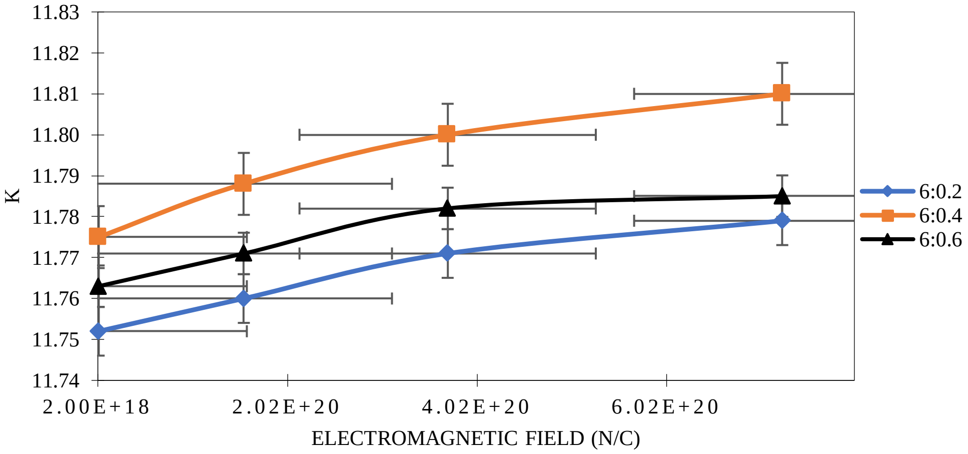

Fig. 8. Effect of Ratio of Hydrocarbon : Methanol and Electromagnetic Field on K Factor

Altering the ratio of hydrocarbon to methanol in a fuel mixture can change its overall composition and combustion characteristics. Methanol is a type of alcohol often used as an additive or as a primary fuel in certain applications due to its high octane rating and clean-burning properties. Changes in the combustion characteristics due to different ratios of hydrocarbon to methanol can lead to variations in the K factor. The K factor is a measure of a fuel cell's performance, specifically the relationship between voltage and current density. If the combustion characteristics change, it might affect the efficiency of energy conversion in fuel cells, thus impacting the K factor. Application of an electromagnetic field can influence the behavior of fuel molecules, potentially affecting their orientation, distribution, and reactivity.

Effect of ratio of hydrocarbon and methanol and electromagnetic field on NHV is depicted in Fig. 9.

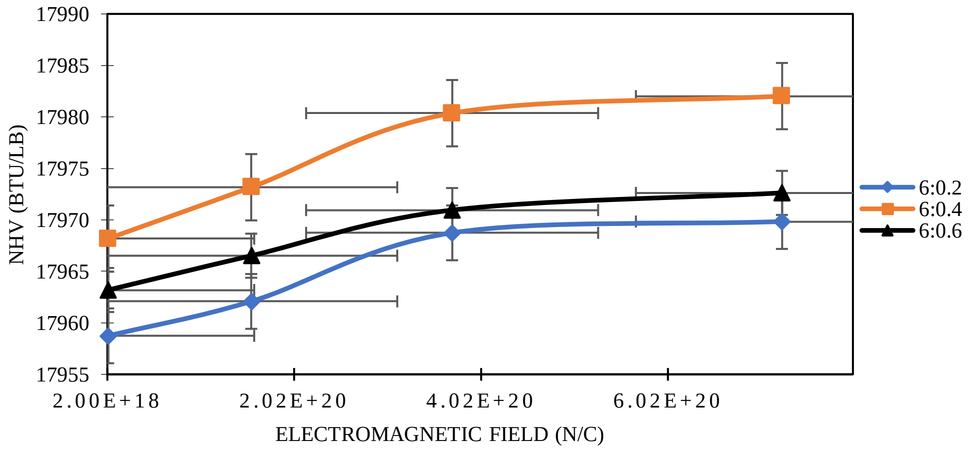

Fig. 9. Effect of Ratio of Hydrocarbon : Methanol and Electromagnetic Field on NHV

Fig. 9 showed that the K factor increased aligned with electromagnetic field strength. The electromagnetic field has a significant effect on the K factor of biokerosene production. (Zhang et al., 2023) reported that this tendency is caused by the associated relationship between these parameters. Changes in the hydrocarbon to methanol ratio can alter the composition and properties of the biokerosene produced. Higher ratios of hydrocarbons may lead to higher energy content in the biokerosene. The highest K value was 11.810 and the highest NHV was 17982.02

btu/lb which was obtained at an electromagnetic field strength of 7.24 E+20 N/C with a ratio of the added ratio of hydrocarbon and methanol of 6:0.4.

3.3 Comparison Between Biokerosene and Commercial Kerosene-based Petroleum

Biokerosene from this study is analyzed for its characteristics and compared to commercial kerosene from PT Pertamina (Indonesian Oil and Gas Company). The results are shown in Table 1.

Table 1 – Comparison Of Biokerosene and Kerosene-Based Petroleum PT Pertamina

No.	Characteristic	Biokerosene	Kerosene-based petroleum
1.	Specific gravity 60/60^{o}F	0.9107	0.835
2.	Colour ASTM	3.5	2.5
3.	Flashpoint, ^{o}F	> 160	100
4.	Net Heating Value (Btu/lb)	17995	18500

Table 1 showed that a higher specific gravity generally implies greater density. Biokerosene has a higher specific gravity compared to kerosene-based petroleum. The ASTM color scale measures the color of petroleum products. A higher number indicates a darker color. Biokerosene has a darker color compared to kerosene-based petroleum. A higher flashpoint suggests greater resistance to ignition. Biokerosene has a much higher flashpoint compared to kerosene-based petroleum. Kerosene-based petroleum has a slightly higher net heating value compared to biokerosene. This comparison demonstrates some differences between biokerosene and kerosene-based petroleum in terms of density, color, flashpoint, and net heating value. However, biokerosene from this study has characteristics almost close to kerosene-based petroleum.

4. Conclusion

Biokerosene has been produced by three steps at lower temperatures and pressures. The steps are (i) converting triglycerides to Free Fatty Acids (FFA), (ii) converting FFA to alkanes, and (iii) converting alkanes to biokerosene. Electrolysis and electromagnetic induction influence the conversion of triglycerides to biokerosene positively. This study obtains the optimum yield of hydrocarbon at a molarity concentration of 1mol/L, voltage of 25Volts, temperature of 130^{o}C, and atmospheric pressure for 2 hours. It produces a yield of hydrocarbon 73.468%, ^{o}API gravity of 23.110, NHV of 17960.4083 btu/lb, and K factor 11.740. Meanwhile, the optimum yield of biokerosene is obtained at ratio of hydrocarbon and methanol of 6:0.4, the electromagnetic field strength of 7.24 E+20 N/C, temperature of 180^{o}C, and atmospheric pressure for 2 hours. The optimum yield of biokerosene is 78.023%, ^{o}API gravity 23.7727, NHV of 17982.02 btu/lb, and K factor of 11.81. Despite the characteristics of biokerosene almost close to kerosene-based petroleum, this study has limitations such as unstable biokerosene and higher flashpoint. Further study is required to improve biokerosene quantitative and qualitative

References

Abdel-Rehim, A. A. (2019). The influence of electromagnetic field on the performance and operation of a PEM fuel cell stack subjected to a relatively low electromagnetic field intensity. *Energy Conversion and Management*, *198*, 111906. https://doi.org/10.1016/J.ENCONMAN.2019.111906

Afisna, L. P., & Rahadi, B. N. J. (2022). Analysis of the difference in biogas volume between continuous and semi-continuous systems. *Journal of Engineering Researcher and Lecturer*, *1*(1), 12–16. https://doi.org/10.58712/jerel.v1i1.5

Alves, G. M., da Silva, J. L., & Stradiotto, N. R. (2021). A novel citrus pectin-modified carbon paste electrochemical sensor used for copper determination in biofuel. *Measurement*, *169*, 108356. https://doi.org/10.1016/J.MEASUREMENT.2020.108356

Anggrainy, R., Ruslan, W., Zariatin, D. L., Gilart, R. A., & Syam, T. (2022). Effect of gasoline vaporizer tube (GVT) with magnetic field on spark-ignition engine: Investigation, discussion, and opinion. *Mechanical Engineering for Society and Industry*, *2*(2), 98–106. https://doi.org/10.31603/mesi.7075

Ayesha, S., Abideen, Z., Haider, G., Zulfiqar, F., El-Keblawy, A., Rasheed, A., Siddique, K. H. M., Khan, M. B., & Radicetti, E. (2023). Enhancing sustainable plant production and food security: Understanding the mechanisms and impacts of electromagnetic fields. *Plant Stress*, *9*, 100198. https://doi.org/10.1016/J.STRESS.2023.100198

Baidoo, M. F., Adjei, E. A., Opoku, R., & Aidam, G. S. K. (2022). Rubber seed oil: Potential feedstock for aviation biofuel production. *Scientific African*, *17*, e01393. https://doi.org/10.1016/J.SCIAF.2022.E01393

Basar, A. R., Jalil, S., & 'Afiat, A. N. H. , & G. R. H. (2023). Computer network design using the simple queue method in maximising network performance in companies. *Journal of Computer-Based Instructional Medi*, *1*(2), 73–87.

Chen, B.-S., Zeng, Y.-Y., Liu, L., Chen, L., Duan, P., Luque, R., Ge, R., & Zhang, W. (2022). Advances in catalytic decarboxylation of bioderived fatty acids to diesel-range alkanes. *Renewable and Sustainable Energy Reviews*, *158*, 112178. https://doi.org/10.1016/j.rser.2022.112178

Dinul, F. I., Nurdin, H., Rahmadiawan, D., Nasruddin, Laghari, I. A., & Elshaarani, T. (2023). Comparison of NaOH and Na_2CO_3 as absorbents for CO_2 absorption in carbon capture and storage technology. *Journal of Engineering Researcher and Lecturer*, *2*(1), 28–34. https://doi.org/10.58712/jerel.v2i1.23

Dupain, X., Costa, D. J., Schaverien, C. J., Makkee, M., & Moulijn, J. A. (2007). Cracking of a rapeseed vegetable oil under realistic FCC conditions. *Applied Catalysis B: Environmental*, *72*(1–2), 44–61. https://doi.org/10.1016/J.APCATB.2006.10.005

Ezzati, R., Ranjbar, S., & Soltanabadi, A. (2021). Kinetics models of transesterification reaction for biodiesel production: A theoretical analysis. *Renewable Energy*, *168*, 280–296. https://doi.org/10.1016/J.RENENE.2020.12.055

Fauza, A., Qalbina, F., Nurdin, H., Ambiyar, A., & Refdinal, R. (2023). The influence of processing on the mechanical properties and emissions of recycled polyolefin. *Teknomekanik*, *6*(1), 21–28. https://doi.org/10.24036/teknomekanik.v6i1.21472

Grimes, Christopher. J., Hardcastle, T., Manga, M. S., Mahmud, T., & York, D. W. (2020). Calcium carbonate particle formation through precipitation in a stagnant bubble and a bubble column reactor. *Crystal Growth \& Design*, *20*(8), 5572–5582. https://doi.org/10.1021/acs.cgd.0c00741

Guan, D., Wang, F., Zhang, X., Dou, W., & Sun, Y. (2023). Comprehensive study on catalytic coating tubular reactor with electromagnetic induction heating for hydrogen production through methanol steam reforming. *International Journal of Hydrogen Energy*. https://doi.org/https://doi.org/10.1016/j.ijhydene.2023.07.316

Gutiérrez, J., Galán, C. A., Suárez, R., Álvarez-Murillo, A., & González, J. F. (2018). Biofuels from cardoon pyrolysis: Extraction and application of biokerosene/kerosene mixtures in a self-manufactured jet engine. *Energy Conversion and Management*, *157*, 246–256. https://doi.org/10.1016/J.ENCONMAN.2017.12.006

Hendri, H., Arief, Y. Z., & Syukur, A. (2023). Testing of palm oil-based electric power transformer insulation oil as a renewable energy source. *Jurnal Pendidikan Teknologi Kejuruan*, *6*(1), 56–63. https://doi.org/10.24036/jptk.v6i1.32323

Islam, A. K. M. A., Yaakob, Z., Anuar, N., Primandari, S. R. P., & Ghani, J. A. (2017). Properties of jatropha hybrid seed oil and its suitability as biodiesel feedstock. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, *39*(16), 1707–1717. https://doi.org/10.1080/15567036.2013.821546

Jaya, H. S., Wardana, I. N. G., Hamidi, N., & Widhiyanuriyawan, D. (2021). Hydrolysis reaction utilizing cavitation from high pressure water jet impinging into palm oil bath. *Ain Shams Engineering Journal*, *12*(4), 3905–3918. https://doi.org/https://doi.org/10.1016/j.asej.2021.03.023

Khan, S., Qureshi, K. M., Kay Lup, A. N., Patah, M. F. A., & Wan Daud, W. M. A. (2022). Role of Ni–Fe/ZSM-5/SAPO-11 bifunctional catalyst on hydrodeoxygenation of palm oil and triolein for alternative jet fuel production. *Biomass and Bioenergy*, *164*, 106563. https://doi.org/10.1016/J.BIOMBIOE.2022.106563

Khodadadi Azadboni, F. (2021). Quantum effects role on the electromagnetic instability growth rate in turbulent state of the fuel fusion. *Chinese Journal of Physics*, *71*, 375–384. https://doi.org/10.1016/J.CJPH.2021.03.008

Kim, D.-W., Im, K.-K., Kim, H. J., Lee, D. H., Kim, Y. A., Choi, J., & Yang, K. S. (2020). Effects of electromagnetic irradiation on low-molecular-weight fraction of fluidized catalytic cracking decant oil for synthesis of pitch precursor. *Journal of Industrial and Engineering Chemistry*, *82*, 205–210. https://doi.org/10.1016/j.jiec.2019.10.014

Llamas, A., García-Martínez, M., Al-Lal, A.-M., Canoira, L., & Lapuerta, M. (2012). Biokerosene from coconut and palm kernel oils: Production and properties of their blends with fossil kerosene. *Fuel*, *102*, 483–490. https://doi.org/https://doi.org/10.1016/j.fuel.2012.06.108

Mahdi, H. I., Bazargan, A., McKay, G., Azelee, N. I. W., & Meili, L. (2021). Catalytic deoxygenation of palm oil and its residue in green diesel production: A current technological review. *Chemical Engineering Research and Design*, *174*, 158–187. https://doi.org/10.1016/J.CHERD.2021.07.009

Neves, R. C., Klein, B. C., da Silva, R. J., Rezende, M. C. A. F., Funke, A., Olivarez-Gómez, E., Bonomi, A., & Maciel-Filho, R. (2020). A vision on biomass-to-liquids (BTL) thermochemical routes in integrated sugarcane biorefineries for biojet fuel production. *Renewable and Sustainable Energy Reviews*, *119*, 109607. https://doi.org/https://doi.org/10.1016/j.rser.2019.109607

Nurdin, H., Wagino, W., Sari, D. Y., & Siregar, B. M. (2022). Characteristics of calorific value of briquettes made from cymbopogon citratus waste as an alternative fuel. *Teknomekanik*, *5*(1), 42–47. https://doi.org/10.24036/teknomekanik.v5i1.12572

Ponomarev, A. V. (2023). Direct conversion of methane to heavier gaseous alkanes using an electron beam. *Chemical Engineering Journal Advances*, *15*, 100513. https://doi.org/10.1016/j.ceja.2023.100513

Primandari, S. R. P., Arafat, A., & Veny, H. (2021). Optimization of waste cooking oil's FFA as biodiesel feedstock. *Teknomekanik*, *4*(1), 14–21. https://doi.org/10.24036/teknomekanik.v4i1.9072

Primo, C. M., Buffon, E., & Stradiotto, N. R. (2021). A carbon nanotubes-pectin composite for electrochemical determination of copper in aviation biokerosene by anodic stripping voltammetry. *Fuel*, *302*, 121180. https://doi.org/10.1016/J.FUEL.2021.121180

Pujan, R., Hauschild, S., & Gröngröft, A. (2017). Process simulation of a fluidized-bed catalytic cracking process for the conversion of algae oil to biokerosene. *Fuel Processing Technology*, *167*, 582–607. https://doi.org/https://doi.org/10.1016/j.fuproc.2017.07.029

Purwanto, W., Su, J. C. T., Rochman, M. L., Waluyo, B., Krismadinata, K., & Arif, A. (2023). Study on the addition of a swirling vane to spark ignition engines fueled by gasoline and gasoline-ethanol. *Automotive Experiences*, *6*(1), 162–172. https://doi.org/10.31603/ae.7981

Rahayu, S. M. N., Hananto, A. L., Herawan, S. G., Asy'ari, M. Z., Sule, A., Idris, M., Hermansyah, D., Balogun, S. A., & Ali, E. A. B. (2022). A review of automotive green technology: Potential of butanol as biofuel in gasoline engine. *Mechanical Engineering for Society and Industry*, *2*(2), 82–97. https://doi.org/10.31603/mesi.7155

Rahmadiawan, D., Ilhamsyah, F., Abral, H., Laghari, I. A., & A, Y. (2022). Effect of sonication to the stability properties of carboxymethyl cellulose/uncaria gambir extract water-based lubricant. *Teknomekanik*, *5*(2), 97–102. https://doi.org/10.24036/teknomekanik.v5i2.16972

Razak, M. A., & Zulfia, A. (2023). Synthesis optimization of cathode precursor Ni0,5 Mn0,4 Co0.1 $(OH)_2$ with coprecipitation method. *Jurnal Pendidikan Teknologi Kejuruan*, *6*(1), 1–8. https://doi.org/10.24036/jptk.v6i1.30523

Rosa, L. F. M., Röhring, K., & Harnisch, F. (2024). Electrolysis of medium chain carboxylic acids to aviation fuel at technical scale. *Fuel*, *356*, 129590. https://doi.org/10.1016/j.fuel.2023.129590

Sani, W. N. H. M., Jaya, R. P., Bunyamin, B., Al-Saffar, Z. H., & Arbi, Y. (2023). Waste motor engine oil – the influence in warm mix asphalt. *Jurnal Pendidikan Teknologi Kejuruan*, *6*(4), 248–255. https://doi.org/https://doi.org/10.24036/jptk.v6i4.34623

Santos, M. R., Arias, S., Padilha, J. F., Carneiro, M. C. N., Sales, E. A., Pacheco, J. G. A., & Fréty, R. (2020). Catalytic cracking of palmitic and oleic acids pre-adsorbed on γ-alumina. *Catalysis Today*, *344*, 234–239. https://doi.org/10.1016/J.CATTOD.2019.04.005

Setiyo, M. (2022). Alternative fuels for transportation sector in Indonesia. *Mechanical Engineering for Society and Industry*, *2*(1), 1–6. https://doi.org/10.31603/mesi.6850

Shehu, U. E., Chow, T. Q., Hafid, H. S., Mokhtar, M. N., Baharuddin, A. S., & Nawi, N. M. (2019). Kinetics of thermal hydrolysis of crude palm oil with mass and heat transfer in a closed system. *Food and Bioproducts Processing*, *118*, 187–197. https://doi.org/https://doi.org/10.1016/j.fbp.2019.09.009

Souza, T. G. dos S., Santos, B. L. P., Santos, A. M. A., Souza, A. M. G. P. de, Correia de Melo, J., & Wisniewski, A. (2018). Thermal and catalytic micropyrolysis for conversion of cottonseed oil dregs to produce biokerosene. *Journal of Analytical and Applied Pyrolysis*, *129*, 21–28. https://doi.org/10.1016/J.JAAP.2017.12.010

Yamamoto, T., Kanazu, T., Nambu, M., & Tanosaki, T. (2006). Pozzolanic reactivity of fly ash – API method and K-value. *Fuel*, *85*(16), 2345–2351. https://doi.org/10.1016/J.FUEL.2006.01.034

Yuvenda, D., Sudarmanta, B., Jamaludin, Muraza, O., Putra, R. P., Lapisa, R., Krismadinata, Zainul, R., Asnil, Setiyo, M., & Primandari, S. R. P. (2022). Combustion and emission characteristics of CNG-diesel dual fuel engine with variation of air fuel ratio. *Automotive Experiences*, *5*(3), 507–527. https://doi.org/10.31603/ae.7807

Yuvenda, D., Sudarmanta, B., Wahjudi, A., & Hirowati, R. A. (2022). Effect of adding combustion air on emission in a diesel dual-fuel engine with crude palm oil biodiesel compressed natural gas fuels. *International Journal of Renewable Energy Development*, *11*(3), 871–877. https://doi.org/10.14710/ijred.2022.41275

Zhang, B. S., Wang, Y., Zhang, N., Zhu, J., Ji, W., Chen, F., Chen, X., Yu, Y., & Zhang, B. (2023). Electromagnetic field-assisted low-temperature ammonia synthesis. *Science Bulletin*. https://doi.org/10.1016/J.SCIB.2023.07.037