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Experimental Investigation of Air-to-Kapok Oil Ratio Effects on Flame Height and Morphology in a Bunsen Burner

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ABSTRACT

The growing global demand for energy highlights the limitations of fossil fuel resources. This makes innovation in alternative energy development crucial, and one promising avenue is the use of vegetable oils like kapok oil. Kapok oil has a complex chemical composition, composed of various triglycerides of fatty acids and glycerol, where each fatty acid component contributes unique combustion characteristics. The interaction of the complexity of this content as a whole affects the flame pattern of kapok oil. Furthermore, the air-fuel mixture ratio (AFR) plays a significant role in determining the characteristics of the resulting flame. Therefore, this study aims to explore in depth the effect of AFR variations on the combustion characteristics of kapok oil. Experiments were conducted by burning a mixture of kapok oil vapor and air on a burner with controlled AFR settings. The results showed that the variation of AFR significantly changed the flame height and morphology. Flame height initially increased with increasing AFR (from 1.34 cm at AFR 0.143:1 to 4.429 cm at AFR 1.526:1) before decreasing (to 0.264 cm at AFR 4.011:1) until it reached the lift-off condition and went out.

INTRODUCTION

Significant global dependence on fossil fuels raises crucial issues related to the depletion of conventional energy reserves and negative consequences for environmental quality through atmospheric pollutant emissions. Awareness of the urgency of energy source diversification encourages exploration of alternative fuels that are low-cost, easily available, and renewable. The potential of plant biomass, including kapok seed oil, in tropical climates such as Indonesia is very significant for biodiesel production and utilization in the form of pure oil as fuel. In addition to the seeds, various components of the kapok plant have utility values. Kapok fiber is commonly used as a filler material for bedding and upholstery products, and is applied as a thermal and acoustic insulator in the electronics and construction industries. Furthermore, kapok fiber has the potential as a filtration and oil separator material in the machinery sector, and can be processed into yarn for textile applications. Kapok processing residues can be used as animal feed, organic fertilizer, and fungal growth media. Kapok seeds themselves have the flexibility to be processed into soap, batik dye materials, and biodiesel precursors. The shells can even serve as a solid fuel source. Overall, kapok seeds show substantial potential for extraction into biofuels, offering a sustainable fuel alternative with a better environmental profile.

The relatively elevated acid content of kapok seed oil confers its potential as a natural preservative agent without detrimental health implications. Other applications of kapok seed oil encompass the cosmetic sector, the production of cooking oil and margarine, lubricant oil additives, as well as a feedstock for biofuel and biodiesel. The kapok plant itself represents a promising commodity for oil production. Each kapok fruit boll comprises approximately 26% seeds by weight, implying that every 100 kg of kapok bolls yields around 26 kg of seed by-product with a defined market value. Kapok seeds contain an oil fraction ranging from 18% to 25% by weight. This oil exhibits a density of 0.917 kg/L, an iodine value of 88, and a saponification value of 181. Compositional analysis of kapok seed oil reveals an unsaturated fatty acid content of approximately 71.95%, which is significantly higher than that of coconut oil. This elevated unsaturated fatty acid content renders kapok seed oil susceptible to oxidation and rancidity, thus making it less suitable for development as an edible oil. Nevertheless, kapok seed oil demonstrates significant potential as a substitute for diesel fuel.

The application of cottonseed oil-based biofuel as an economical energy source can be implemented in various combustion systems, including premixed combustion configurations. The premixed combustion process, in which air and fuel are mixed before combustion initiation, is widely applied in systems such as Bunsen burners, Otto motors, and other combustion applications. The vapor temperature of cottonseed oil is a critical parameter that affects the characteristics of premixed combustion in the combustion chamber. An increase in vapor temperature correlates with an increase in the reactivity of the fuel and air mixture, facilitated by an increase in the frequency of collisions between molecules. Analysis of the temperature gradient during the heating process indicates different stages of vaporization and combustion, where the fatty acid fraction with higher volatility tends to vaporize and burn first, followed by glycerol vaporization (Wardana, ING., 2009:659). In the analysis of flame instability in premixed combustion, various methodologies are applied, including theoretical calculations and visualization-based optical techniques, such as photographic image analysis. The application of photographic methods allows for comprehensive and detailed characterization of the flame flow pattern in the context of instability studies. Further flame instability analysis provides deep insight into the fundamental characteristics of the flame. One of the crucial parameters that significantly contributes to the flame instability phenomenon is the air-fuel ratio (AFR). AFR is defined as the ratio of the mass of air to the mass of fuel, representing the quantity of air required for the combustion of a given amount of fuel. To enhance the utility of kapok seed oil as an environmentally friendly alternative fuel, this research is essential. Its objective is to study the flame characteristics of kapok seed oil by varying the air-fuel ratio.

RESEARCH METHODS

The methodology of this study adopted an experimental approach (true experimental research), which involves direct testing of the research object to identify cause-and-effect relationships. The experiment was conducted using a laboratory-scale device whose configuration is schematically presented in Figure 1. Whereas, the environmental condition are 1 atm pressure, 25^0C ambient temperature, and average humidity of approximately 70-74 %. In this study, the combustion of premixed cottonseed oil was carried out on a cylindrical Bunsen burner. The research system was designed with a biofuel tank heated in a boiler at a controlled temperature until the cottonseed oil turned into steam. The oil vapor from the boiler was then mixed with air from the compressor in the mixing chamber. The reactant mixture was then flowed to the nozzle. After that, The data acquisition procedure was as follows:

1. Assemble and prepare all equipment according to the planned experimental setup.
   a. Connect all equipment installations and ensure all connections are securely fastened.
   b. Adjust the compressor output to ensure the pressurized air entering the experimental setup meets the requirements and does not damage the installation.
   c. Position the air valve slightly open and the fuel valve fully closed as the initial setting.
   d. Adjust the position and focus of the camera to ensure proper framing during data capture.

   e. Set the thermostat temperature to 160°C.
2. Introduce kapok oil into the boiler, following these steps:
   a. Using a syringe, extract 20 ml of kapok oil from its container and inject it into the boiler through the inlet port.
   b. Repeat the above step three times, resulting in a total volume of 60 ml of kapok oil inside the boiler.
   c. Close the boiler inlet port with the provided cap.
3. Once all installations are ready and the kapok oil has been introduced into the boiler, double-check that the installation is correctly and safely assembled.
4. Turn on the camera and adjust its focus.
5. Connect the power cord to the outlet, activating the electric heater and the heat sensor.
6. Wait several minutes until the kapok oil vapor has fully formed, then adjust the fuel valve opening until the water level difference in the fuel manometer reaches the predetermined value, and maintain this position to ensure a constant fuel flow rate throughout the data acquisition process.
7. Ignite the mixture at the nozzle tip using a lighter until a flame is established.
8. Turn on the compressor and slowly open the air valve until the water level difference in the air manometer reaches the predetermined value based on the AFR calculations.
9. Photograph the resulting flame using the camera.
10. Repeat those step for the following AFR variations: 0.143:1; 0.978:1; 1.526:1; 1.980:1; 2.382:1; 2.750:1; 3.091:1; 3.413:1; 3.719:1; 4.011:1; 4.292:1

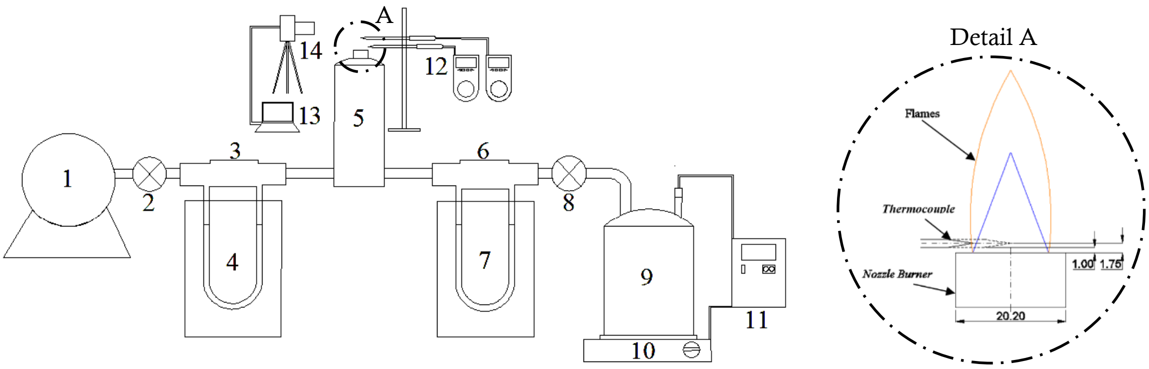

Figure 1. Research installation

Part List

1. Compressor 0.08 HP – 3 bar
2. Air valve
3. Air orifice
4. Air manometer
5. Burner
6. Fuel orifice
7. Fuel manometer
8. Fuel valve
9. Boiler
10. Electric stove 220 volt – 300 Watt
11. Thermostat
12. Thermometer
13. Computer Intel Core i3-2370M, 2.4 GHz
14. Camera HD movie, 1080p – 24fps

The combustion parameter that plays an important role is the air/fuel ratio (Air Fuel Ratio) of a reaction with equation (1) where n is the number of moles while mr is the molecular weight. Based on the AFR calculation in equation (1), the stoichiometric Air Fuel Ratio (AFR) of kapok oil is 12.303: 1.

$$(AFR)_{stoic} = \left(\frac{M_{udara}}{M_{bahan\ bakar}}\right)_{stoic} \quad (1)$$

$$AFR = \frac{n.(mr(O_2 + 3{,}76N_2))}{n1.(mr(C_{18} + H_{32} + O_2)) + n2.(mr(C_{18} + H_{34} + O_2)) + n3.(mr(C_{16} + H_{32} + O_2)) + n4.(mr(C_{18} + H_{38} + O_2))}$$

$$AFR = \frac{24{,}5045.(32+(3{,}76.28))}{0{,}574.((12.18)+32+32)+0{,}13.((12.18)+34+32)+0{,}287.((12.16)+32+32)+0{,}009.((12.18)+38+32))}$$

$$AFR = \left(\frac{3363{,}97776}{273{,}426}\right) = 12{,}303\ (kg_{udara}/kg_{bahan\ bakar})$$

The experimental procedure begins with preheating the cottonseed oil to form steam in the boiler. The fuel inlet valve is opened while the air inlet valve is closed, then ignition is performed at the burner tip to produce an initial diffusion flame. The height difference on the fuel flowmeter is recorded and kept constant. Next, the air inlet valve is opened gradually, and at each change in the height difference measured on the air flowmeter, the flame image is captured using a camera. Data collection and flame images are repeated at various air valve opening variations until the flame goes out. The constant height difference on the fuel and the height change on the air are used to calculate the actual air-fuel ratio. The evolution of the flame shape is recorded using a high-speed camera (400 fps) and processed using Free Video to JPG Converter software to produce a series of flame photo frames. These flame photo frames are then analyzed using ImageJ software, which is then transferred to AutoCAD to extract the geometric parameters of the premixed flame, namely the flame height.

RESULTS AND DISCUSSION

The discussion is conducted by identifying trends and correlations based on experimental data obtained from the study of combustion characteristics of kapok oil vapor and air mixtures at various air-fuel ratios (AFR). Figure 2 illustrates the evolution of the flame height with increasing AFR, at variations of 0.143:1; 0.978:1; 1.526:1; 1.980:1; 2.382:1; 2.750:1; 3.091:1; 3.413:1; 3.719:1; 4.011:1; and 4.292:1, with the measured flame heights of 1.34 cm, 2.584 cm, 4.429 cm, 3.747 cm, 2.617 cm, 2.02 cm, 1.307 cm, 0.602 cm, 0.43 cm, and 0.264 cm, respectively. Increasing AFR implies increasing air flow rate to the nozzle with constant fuel flow rate, which results in increasing air mass fraction in the reactant mixture. This phenomenon is correlated with an increase in the flame height in the AFR range of 0.143:1 to 1.526:1. However, the opposite trend is observed at AFRs between 1.980:1 to 4.011:1, where a decrease in the flame height occurs. This decrease is attributed to the transition to a more stoichiometric or near-perfect combustion condition. In this condition, the quantity of unburned fuel that then diffuses with the surrounding air decreases, so that the contribution of diffusion combustion to the overall flame height decreases. The dominance of premixed combustion is increasingly strengthened, limiting the flame reaction zone to only a few centimeters near the nozzle outlet.

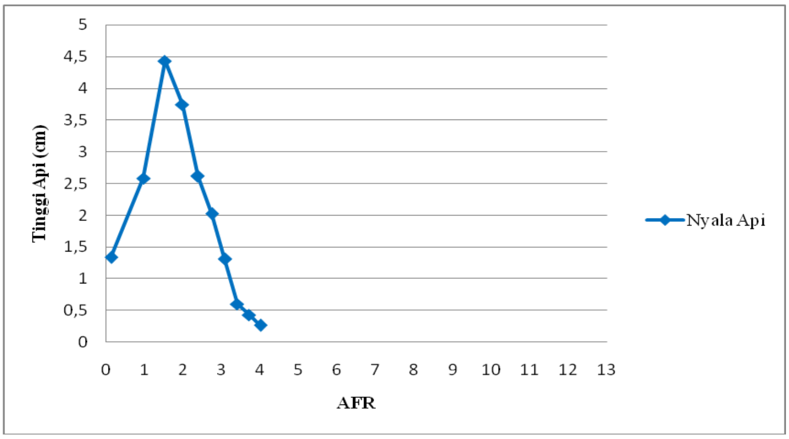

Figure 2. The correlation between Air Fuel Ratio and flame height

The flame pattern image in Figure 3 indicates an increasing trend of flame dimension with increasing AFR from 0.143:1 to a maximum at AFR 1.526:1, followed by a gradual decrease in dimension until lift-off and extinguishment. The expansion of the flame dimension with the addition of air is interpreted as a result of the increasing interaction between air and fuel molecules, which increases the fuel fraction at the flame surface. This increase in fuel fraction contributes to the incomplete initial combustion, so that the quantity of fuel burned through diffusion with the surrounding air increases, resulting in vertical elongation of the flame. The addition of air also triggers an increase in the reactant velocity and mass diffusivity. The increase in the kinetic energy of the air-fuel mixture molecules causes more intense collisions and high nozzle outlet flow velocities, which potentially result in some of the fuel not being completely burned and then burning by diffusion downstream. After exceeding AFR 1.526:1, starting from AFR 1.980:1, the flame dimension shows a progressive decreasing trend until it finally extinguishes. This phenomenon is associated with combustion conditions that are increasingly close to stoichiometric, which causes the diffusion flame contribution to gradually decrease until the premixed flame dominates.

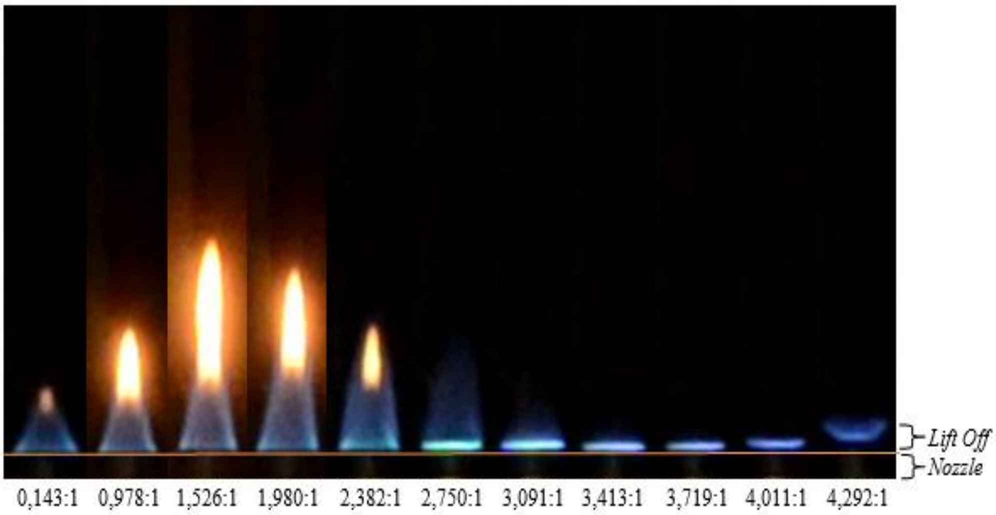

Figure 3. Flame height dynamics for each Air Fuel Ratio (AFR)

Further observation of the flame pattern images revealed that flame extinction occurred before the stoichiometric AFR was achieved. This is strongly suspected to be due to the cooling effect induced by excess air, where the excess air flow absorbs heat from the initial combustion reaction zone. Consequently, the activation energy of the air-fuel mixture molecules becomes insufficient to sustain the chain reaction, resulting in lift-off and flame extinction. In addition, this study also resulted in the visualization of several unique flame geometries from kapok oil combustion, which offer interesting opportunities for further analysis of its combustion characteristics.

Combustion in a Bunsen burner involves a chemical reaction between fuel (in this test, the fuel refers to kapok oil vapor produced by heating kapok oil to 160^0 Celsius) and oxygen (from the air). The stoichiometric air-fuel ratio (AFR) is the ideal ratio where all fuel reacts completely with all available oxygen, producing combustion products like carbon dioxide (CO_2) and water (H_2O), along with maximum heat release. In this stoichiometric state, no fuel or oxygen remains. When the AFR is very high (more air than stoichiometrically required fuel), the mixture becomes lean or oxygen-rich. This excess air can cool the reaction zone and reduce the concentration of fuel molecules per unit volume.

Despite abundant oxygen, the limited fuel molecules can slow down the combustion reaction rate. This slower reaction rate and the cooling effect from excess air can lead to less intense heat release per unit time. Consequently, the flame height can decrease because the energy produced isn't sufficient to maintain a tall, stable combustion zone. At very high AFRs, the flame can even lift-off (detaching from the burner) or extinguish completely as the mixture's flow rate exceeds the flame propagation speed. Conversely, when the AFR is low (more fuel than stoichiometrically required air), the mixture becomes rich, meaning there's an excess of fuel and a shortage of air or oxygen. This results in incomplete combustion, forming byproducts such as carbon monoxide (CO) and soot (unburned carbon particles). These byproducts occur because there isn't enough oxygen to oxidize all the fuel. The resulting flame typically appears yellow and is more luminous due to the incandescent soot particles. Further discussion on rich fuel mixtures also affects flame height. Initially, as the AFR increases from a very rich condition (which might produce a small, dirty flame), the addition of air enhances oxygen availability and promotes more efficient combustion. This leads to an increase in flame height as more energy is released and the combustion speed increases. However, if the AFR continues to decrease (becoming increasingly rich), even with abundant fuel, oxygen availability becomes the dominant limiting factor, which can again reduce the flame height because combustion becomes highly inefficient and much of the fuel remains unburned.

Figure 4 illustrates the morphology of the cellular structure (cells) in the flame (circled area), which is a manifestation of combustion instability induced by the difference in combustion rates between various fatty acid components in kapok oil fuel. The light blue area indicates the zone where the highly reactive components have been burned. In contrast, the dark area represents the region where combustion has not occurred, indicating the presence of unreacted fuel. The dark blue zone surrounding the light blue area indicates the condition of insufficient air supply for optimal premixed combustion, so that the proportion of fuel burned through the diffusion mechanism becomes more dominant in the region.

Figure 4. Morphology of cellular flame structure (cells flame)

CONCLUSION

The air-fuel ratio or also called Air Fuel Ratio (AFR) has a significant effect on the flame height, which is correlated with fundamental parameters such as mass diffusivity, fuel fraction in the mixture, and reactant velocity. The results showed that the variation of AFR resulted in a non-linear change in the flame height. The flame height was observed to increase with increasing AFR, reaching a maximum of 4.429 cm at an AFR of 1.526:1. However, after reaching this peak value, there was a progressive decrease in the flame height until the lift-off condition and flame extinction occurred at a higher AFR. The morphology of the cellular structure (cells) observed in the flame (circled area) is an indication of combustion instability triggered by the disparity in combustion rates between the fatty acid components that make up the kapok oil fuel. For kapok oil to be a viable long-term fuel alternative, its impact on combustion system components needs thorough evaluation. Future research should investigate not only assessing the corrosive or erosive effects of kapok oil and its combustion products on burner materials, fuel lines, and other system components over extended periods, but also Studying the potential for coking or fouling in fuel injectors and combustion chambers due to the higher molecular weight and potential for thermal degradation of kapok oil.

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REFERENCES

Adoe, D. G. H., Talo, P., Pah, J. C. A., Tobe, A. Y., and Riwu, B. N. (2022). Karakteristik Pembakaran Premixed dari Campuran FAME (Fatty Acid Methyl Ester) dan Solar Murni. Lontar Jurnal Teknik Mesin Undana, 9(2), 47-52.

Aristyanto, A. (2020). Peranan Variasi Perforated Plate Burner Pada Pembakaran Premixed Minyak KelapaMurni Terhadap Karakteristik Nyala Api. Mechonversio: Mechanical Engineering Journal, 3(1), 18-22.

Dharma. (2013). The effect of equivalence ratio variation on the combustion flame characteristics of premixed castor oil on a perforated burner.

Dhiputra, Kartika, I. M. (2010). Experimental Study of Flame Lift-up Phenomenon. Department of Mechanical Engineering. Faculty of Engineering. University of Indonesia. Jakarta. Indonesia.

Dwinanda, A., Mufarida, N. A., and Finali, A. (2019). Pengaruh Variasi Debit Aliran Terhadap Karakteristik Api Pembakaran Difusi LPG dan CNG. J-Protecsion Jurnal Kajian Ilmiah dan Teknologi Teknik Mesin, 3(2), 11-14.

Groff, E.G. (1982). The cellular nature of confined spherical propape-air flame, combustion, and flame. 48:51-62.

Handoyo, R., Anggraini, Ananta A., Anwar, Saiful. "Biodiesel dari Minyak Biji Kapok (Biodiesel from Kapok Seed Oil),"Jurnal Injiniring Pertanian, vol. 1, no. 5, pp. 1-8, 2007.

Kumar, S., Paul, P.J., Mukunda, H.S. (2005). Investigations of the scaling criteria for a mild combustion burner. Proceedings of the Combustion Institute, 30(26), 13-21.

Listiyadi, S. D., Ilminafik, N., Sutjahjono, H., Vicca, D. T., and Farisi, S. A. (2020). Premixed Combustion Characteristics Between Biosolar That Producted Pertamina with Biodiesel from Coconut Waste (Cocos Nucifera). Journal of Engineering and Applied Sciences, 15(6), 1502-1507.

Merlo, N. et al. (2014). Combustion characteristics of methane-oxygen enhanced air turbulent non-premixed swirling flames. Exp. Therm. Fluid Sci., 56:53–60.

Min J., Baillot F., Guo H., Domingues E., Talbaut M., Patte-Rouland B. (2011). Impact of CO.N or Ar diluted in air on the length and lifting behavior of a laminar diffusion flame. Proceedings of combustion and flame institute, 33:1071-1078.

Muhaya, S. B. L., Wardana, I.N.G., Widhiyanuriyawan, D. (2015). Pembakaran Premixed Minyak Nabati pada Bunsen Burner Type Silinder. Jurnal Rekayasa Mesin, 6(1), 45-50.

Murdianto, I. T. (2019). The Effect of Pressure Variation on Spray Combustion of Pure Coconut Oil Fuel on Angle, Flame Length, Droplet Diameter, Flashback. Mechonversio Mech. Eng. J., 2(1), 25, doi: 10.51804/mmej.v2i1.820.

Qiao, L., Gan, Y., Nishiie, T., Dahm, W. J. A., and Oran, E. S. (2010). Extinction of premixed methane/air flames in microgravity by diluents: Effects of radiation and Lewis number. Combustion and Flame, 157:1446-1455.

Pratama, B. W., Soebaktiyo, G., Hermawan, D. (2023). Karakteristik Nyala Api dan Air Fuel Ratio Minyak Nabati Terhadap Pembakaran Premixed. Jurnal V-Mac, 8(1), 20-27.

Ray, J., Najm, H.N., Milne, R.B., Devine, K.D., and Kempka, S. (2000). Tripple flame structure and dynamics at the stabilization point of an unsteady lifted jet diffusion flame. Proceedings of the combustion institute, 28:219-226.

Rokhim, A., A., Endahwati, L., Sutiyono, S. (2024). Utilization of Thermal Energy Using Thermoelectric Generator with Peltier Variation. Flywheel Journal, 14(1), 19-23.

Roring, A.G., Soebiyakto, G., Farid, A., Hermawan, D. (2025). The Effect of Nozzle Diameter Variation on Droplet Dimension, Spray Angle, and Spray Distance Using Pertalite Fuel. Flywheel Journal, 16(1), 7-12.

Rozaqi, M. F. (2019). The Effect of Nozzle Hole Diameter Variation on Droplet Dimension, Spray Angle, Spray Distance, and Flame Shape of Cottonseed Oil Fuel. Mechonversio Mech. Eng. J., 2(1), 17, doi: 10.51804/mmej.v2i1.819.

Solichi, A., Risdianto, N., Suwandono, P., Wicaksono, L.H. (2024). Simulation of Burner Position Configuration to Optimize Heat Treatment Pressure Vessel. Flywheel Journal, 15(1), 44-53.

Wahyudi, D. and Prasetiyo, D. H. T. (2022). Uji Karakteristik Pembakaran Premixed pada Methyl Ester Schleichera Oleosa Sebagai Campuran Bahan Bakar Diesel. Mechonversio: Mechanical Engineering Journal, 5(1), 1-6.

WA W. (2020). Analysis of Nozzle Hole Diameter Variation on Spray Characteristics of Coconut Oil with Kapok Oil (B50) in Diffusion Combustion. Mechonversio Mech. Eng. J., 3(1), 1, doi: 10.51804/mmej.v3i1.832.

Wardana, I.N.G. (2008). Fuel and Combustion Technology. PT. Danar Wijaya, Brawijaya University Press. Malang.

Vedharaj, S., Vallinayagam, R., Yang, Chou, S. K., and Lee, P. S. (2015). Effect of Adding 1,4-Dioxane With Kapok Biodiesel On The Characteristics of A Diesel Engine. Journal Applied Energy, 136(1), 1166-1173.

Vedharaj, S., Vallinayagam, R., Yang, W. M., Saravanan, C. G., and Lee, P. S. (2015). Optimization of Combustion Bowl Geometry for The Operation of Kapok Biodiesel – Diesel Blends In A Stationary Diesel Engine. Journal FUEL, 139(1), 561-567.