Physical and Chemical Properties of a Mixture Fuel between Palm Sap (Arenga pinnata Merr) Bioethanol and Premium Fuel

Ansar,* Sukmawaty, Sirajuddin Haji Abdullah, Nazaruddin, and Erna Safitri

ABSTRACT: Along with the development of motor vehicle industry technology at this time, the fuel demand is also increasing while the supply is running low. Thus, alternative fuels are needed to meet these energy needs. This study aims to explain the physical and chemical characteristics of a fuel mixture (MF) between palm sap bioethanol with premium fuel. The results showed that the higher the bioethanol concentration of the palm sap, the higher the MF’s viscosity, but the lower the heat of the fuel. This decrease is caused by differences in the heating value of the two fuels. The MF’s high heat burn value is blue, while the low heat value of the flame is reddish yellow. The results of this study are very important as a basis for the development of bioethanol from palm sap as an environmentally friendly vehicle-fuel substitute material.

1. INTRODUCTION

The human need for fuel is currently increasing along with the development of the motor vehicle industry.¹ The largest source of fuel used by motor vehicles is fossil fuels.² These fossil fuels cannot be expected to be around for a long period of time because their amount is limited and they cannot be renewed.³⁴ Bioethanol has been developed in many countries as an energy source for fossil energy substitution.⁵ Bioethanol production in the United States is developed from corn to apply bioethanol energy.⁶ Brazil has been developing bioethanol sourced from sugar cane by conducting tests on vehicles since 1925.⁷ China and Thailand develop bioethanol from cassava.⁸ South Korea has been developing biodiesel since 2002, and its consumption is estimated to increase by 0.5% per year.⁹

Brazil develops bioethanol from sugar cane at a low cost of 14 cents a dollar per liter, Thailand with tapioca, 18.5 cents a dollar per liter, and America using corn, 25.5 cents a dollar per liter.¹⁰ The success of Brazil in producing bioethanol from sugar cane on an industrial scale has led many countries to follow their strategic steps. Currently, in Brazil, motorists can fill fuel tanks with a mixture of 24% ethanol and 76% gasoline.¹¹ As for Indonesia, the government has given serious attention to developing bioethanol by issuing Presidential Instruction no. 1 of 2006 regarding the supply and use of biofuel as an alternative fuel.¹²,¹³ Bioethanol can be produced from various types of plants, such as sugar cane, cassava, corn, sorghum, palm sap, or other types of plants.¹⁸,¹⁹ Palm sap (Arenga pinnata Merr, A. pinnata) is very abundant in Indonesia (Table 1), so it has the potential to be processed into bioethanol.²⁰ This plant contains glucose,

Table 1. Estimated Area of Palm Sap in Indonesia²⁵

| province           | an estimate of the total area (ha) |
|--------------------|-----------------------------------|
| Nanggro Aceh Darussalam | 4081                              |
| North Sumatera     | 4357                              |
| West Sumatera      | 1830                              |
| Bengkulu           | 1748                              |
| West Jawa          | 13,135                            |
| Banten             | 1448                              |
| Central Jawa       | 3078                              |
| South Kalimantan   | 1442                              |
| North Sulawesi     | 6000                              |
| South Sulawesi     | 7293                              |
| Southeast Sulawesi | 3070                              |
| Maluku             | 1000                              |
| North Maluku       | 2000                              |
| Papua              | 10,000                            |
| total              | 60,482                            |

Bioethanol can be produced from various types of plants, such as sugar cane, cassava, corn, sorghum, palm sap, or other types of plants.¹⁸,¹⁹ Palm sap (Arenga pinnata Merr, A. pinnata) is very abundant in Indonesia (Table 1), so it has the potential to be processed into bioethanol.²⁰ This plant contains glucose,
fructose, and sucrose with a composition of approximately 0.4—0.5%, 0.5—0.6%, and 10—13%, respectively. The sugar content is quite high, so palm sap has the potential to be processed into bioethanol. So far, the use of palm sap is still very limited, namely, only in the manufacture of palm sugar. Bioethanol has become a very interesting topic and is always an updated study in various research communities in the world from the production process to compatibility with motor vehicles. Some advantages of using bioethanol include exhaust emissions that are more environmentally friendly compared to premium fuels and Pertamax. Bioethanol is a potential fuel because the raw material can be renewed.

Bioethanol production must be focused on abundant plants, but its use is not for basic food needs. Brazil has been applying the bioethanol—gasoline mixture since the 1930s and increased its application by 50% in 1943. Indonesia as a country that has a relatively similar geographical condition to that of Brazil has the potential to follow Brazil’s path in utilizing abundant natural resources to meet domestic energy needs. This is in line with Indonesia’s transportation system, which mostly uses gasoline. Bioethanol can bring practical benefits if applied nationally in Indonesia.

It is very possible to mix the physical and chemical characteristics of bioethanol with those of gasoline. The need to meet energy demand with apprehensive environmental impacts and limited fuel stock from fossil fuels has led researchers to look for renewable and environmentally friendly energy resources, one of which is bioethanol. However, the bioethanol production process is more complex and requires a large investment. The main obstacle is that bioethanol must be compatible with motor vehicle combustion systems.

Based on the arguments above, in this paper, the focus of the study is on the physical and chemical properties of the fuel mixture of palm sap bioethanol with premium fuel (MF). Although there have been studies focusing on aspects of bioethanol production, it is still urgent to conduct research that focuses on explaining the physical and chemical properties of palm sap bioethanol after it is mixed with premium fuel.

Many researchers have developed palm sap into bioethanol as a fuel mixture for motor vehicles. However, no valid data has been found about the viscosity, calorific value, and flame after the palm sap bioethanol is mixed with premium fuel. Therefore, it is important to examine and reveal the viscosity, calorific value, and flame as physical and chemical characteristics of fuel for motor vehicles. Thus, the purpose of this study is to explain the physical and chemical characteristics of a fuel mixture between palm sap bioethanol and premium.

2. METHOD AND MATERIALS

2.1. Materials and Tools. The materials used are bioethanol from distilled palm sap (A. pinnata MERR) and premium-type fuel with an octane number of 88 obtained directly from refueling in Mataram, West Nusa Tenggara Province, Indonesia. These ingredients are mixed with various variations of the concentration (Table 2).

The tools used are a viscometer, C-5000 calorimeter bomb, thermometer, test tube, analytical balance, oxygen cylinder, oxygen regulator, oxygen hose, test tube, and LPG gas stove.

2.2. MF Viscosity Measurement. MF viscosity is measured using an open gravity capillary viscometer in the temperature range of 20—30 °C. Mathematically, the MF viscosity equation can be written as

\[ F = \eta A \frac{V}{L} \]  

with \( F \) as the force on the surface of the liquid, \( \eta \) as the coefficient of fluid viscosity (Ns/m²), \( A \) as the liquid area (m²), \( V \) as the moving wall velocity (m/s), and \( L \) as the distance of the two surfaces (m).

2.3. Measurement of the MF Calorific Value. MF burn calorie measurements were done using a bomb calorimeter, type IKA C-5000. The reaction that occurs in a bomb calorimeter can produce heat absorbed by water and bombs so that no heat is wasted into the air, so it can be written as

\[ r_{\text{reaction}} = - (q_{\text{air}} + q_{\text{bomb}}) \]

The amount of heat absorbed by water can be calculated using the formula

\[ Q_{\text{water}} = mc\Delta T \]
The signiﬁcance of metal ion elements in the MF of bioethanol and temperature change (°C) and the presence of metal ion elements in the MF liquid and then igniting it with the presence of metal ion elements in the MF of bioethanol and temperature change (°C), it means that there is a signiﬁcance level of 95%. The most inﬂuential variable can be identiﬁed using the DMRT (Duncan’s multiple-range test).

Figure 3. Palm sap bioethanol produced in this study.

Table 3. MF Viscosity at Various Concentrations between Bioethanol and Premium Fuel

| comparison of fuel mixtures (%) | bioethanol of palm sap (mL) | premium (mL) | viscosity of MF (mm²/s) |
|---------------------------------|-----------------------------|-------------|------------------------|
| no. 1                           | 10                          | 90          | 5.4                    |
| 2                               | 15                          | 85          | 5.4                    |
| 3                               | 20                          | 80          | 4.6                    |
| 4                               | 25                          | 75          | 4.5                    |
| 5                               | 30                          | 70          | 4.3                    |

where \( m \) is the mass of water (g), \( c \) is the heat type of water (J/kg °C), and \( \Delta T \) is the temperature change (°C).

The amount of heat absorbed by the bomb calorimeter can be calculated using the formula

\[
q_{\text{bomb}} = \epsilon_{\text{bomb}} \Delta T
\]

(4)

where \( q_{\text{bomb}} \) = heat capacity of bomb (J/g °C) and \( \Delta T \) is the temperature change (°C).

2.4. MF Flame Test. Flame tests were carried out to detect the presence of metal ion elements in the MF of bioethanol and premium fuel by dipping cotton buds washed with hydrochloric acid in the MF liquid and then igniting it with fire (Figure 2). This ﬂame test is to provide qualitative information on the colors arising from the combustion process based on the light spectrum of the electromagnetic radiation elements present in the sample. The ﬂame that arises will be adjusted to the table of chemical elements with their ﬂames.

2.5. Data Analysis. The effect of variations in the concentration of palm sap bioethanol and premium fuel on the physical and chemical characteristics of the MF was analyzed using analysis of variance. If the \( F \)-count value is greater than the \( F \)-crit, it means that there is a signiﬁcant difference in the signiﬁcance level of 95%. The most inﬂuential variable can be identiﬁed using the DMRT (Duncan’s multiple-range test).

3. RESULTS AND DISCUSSION

3.1. Viscosity of MF. Palm sap bioethanol produced in this study is shown in Figure 3. The MF viscosity in various concentrations of bioethanol and premium fuel is shown in Table 3. In the table, it appears that the higher the concentration of the palm sap bioethanol, the higher the MF’s viscosity. Fuel viscosity can affect the fogging process. Fuels that have high viscosity are diﬃcult to atomize. Conversely, fuels with low viscosity are easier to atomize. Fuels that are more easily atomized are also easier to ignite and also more perfect for combustion.

The result of the bioethanol test of palm sap was a value of 4.7 mm²/s, while that of the premium fuel was 7.2 mm²/s. After mixing, the data obtained showed that the higher the concentration of palm sap bioethanol, the lower the MF’s viscosity (Table 3). This is thought to be inﬂuenced by the viscosity of bioethanol, which is lower than the premium viscosity. These results are in line with research reported by Tazi and Sulistiana in that the higher the addition of bioethanol, the lower the viscosity of the fuel.

The results of the two-factor variance analysis show that the calculated \( F \)-value (153.963) is greater than the \( F \)-table value (3.490). This means that the variation in the concentration of palm sap bioethanol has a signiﬁcant effect (\( p > 0.5 \)) on the MF’s viscosity (Table 4).

3.2. MF Caloriﬁc Value. The caloriﬁc value of the fuel shows the heat produced from the combustion process. If the combustion is perfect, then the optimal thermal energy can be obtained. Separate test results obtained show that the caloriﬁc value of palm sap ethanol is 10.126 kcal/g, while that of the premium is 11.414 kcal/g. After mixing, the highest heating value of the MF was 11.107 kcal/g and the lowest was 9.445 kcal/g (Table 5). Table 5 shows that the higher the concentration of palm sap bioethanol added to the premium fuel, the lower the MF’s caloriﬁc value. This decrease is caused by the diﬀerence in the heating value between the two fuels. The results of this study are in line with the research of Budiprasojo and Pratama who reported that the low heating value of fuel can affect the high heating value if mixed.

The National Standards Agency (BSN) has set bioethanol quality standards with a minimum heating value of 5000 kcal/g. Based on the quality standards set by BSN, the MF bioethanol and premium produced in this study were following the standards.

The results of the two-factor analysis of variance show that the calculated \( F \)-value (144.894) is greater than the \( F \)-table value (3.490) (Table 6). This means that the variation in the

Table 3. MF Viscosity at Various Concentrations between Bioethanol and Premium Fuel

| comparison of fuel mixtures (%) | bioethanol of palm sap (mL) | premium (mL) | viscosity of MF (mm²/s) |
|---------------------------------|-----------------------------|-------------|------------------------|
| no. 1                           | 10                          | 90          | 5.4                    |
| 2                               | 15                          | 85          | 5.4                    |
| 3                               | 20                          | 80          | 4.6                    |
| 4                               | 25                          | 75          | 4.5                    |
| 5                               | 30                          | 70          | 4.3                    |

Table 4. Results of the Two-Factor Analysis of Variance of MF Viscosity Parameters

| source of variation | SS       | df | MS       | \( F \) | \( P \) value | \( F \) crit  |
|---------------------|----------|----|----------|--------|--------------|-------------|
| rows                | 1.223    | 4  | 0.30575  | 0.007  | 0.999        | 3.259       |
| columns             | 19625.3  | 3  | 6541.7653| 153.963| 7.647 × 10⁻¹⁰| 3.490       |
| error               | 509.869  | 12 | 42.48903 |        |              |             |
| total               | 20136.39 | 19 |          |        |              |             |
3.3. MF Flame Test. MF flame test results on variations in the concentration of palm sap bioethanol and premium fuel showed two different types of flame colors, namely, blue and reddish yellow. MF that contains low concentrations of palm sap bioethanol, produces a blue flame while, with high concentrations, produces a reddish yellow flame. This is in line with the report of McLinden et al.45 in that the flame from bioethanol is not only blue but also reddish yellow. The same thing was reported by Polikarpov et al.46 in that, at the time of combustion, not only blue but also reddish yellow. The same thing was reported by Polikarpov et al.46 in that, at the time of combustion, a blue flame appeared at the bottom and a reddish yellow one appeared at the top.

The blue combustion results indicate that the methane \((\text{CH}_4)\) in the MF was completely burned. The results of this study are in line with the research of Susanto et al.47 who reported that methane gas was marked with a blue flame. However, the reddish yellow fire means incomplete combustion and that the flame is unstable. Cahyani48 also reports that the color of the blue flame indicates high ethanol levels.

A comparison of the physical and chemical characteristics of the mixed fuel between the palm sap bioethanol and premium fuel from this study with several other studies is shown in Table 7.

The results of the two-factor variance analysis show that the calculated \(F\)-value (68.308) is greater than the \(F\)-table value (3.490) \((\text{Table 8})\). This means that variations in the concentration of palm sap bioethanol and premium fuel affect the MF’s flame. The blue flame color indicates high ethanol content.

### Table 6. Results of Two-Factor Variance Analysis for MF Calorific-Value Parameters

| source of variation | SS     | df  | MS        | \(F\)  | \(P\) value | \(F\) crit |
|---------------------|--------|-----|-----------|--------|-------------|------------|
| rows                | 0.870752 | 4   | 0.217688  | 0.005  | 0.99994     | 3.259      |
| columns             | 18509.81 | 3   | 6169.936  | 144.894| 1.09 \times 10^{-9} | 3.490      |
| error               | 510.9863 | 12  | 42.58219  |        |             |            |
| total               | 19021.66 | 19  |           |        |             |            |

### Table 7. Comparison of Physical and Chemical Characteristics of Mixed Fuel

| combined of fuel mixes | value | references |
|------------------------|-------|------------|
|                       | viscosity at \(40^\circ\) C (mm³/s) | calorific (kcal/g) | flame test (color) |
| premium of RON 88      | 7.2   | 11.141     | reddish yellow | 41 |
| 20% bioethanol of liquid polypropylene–80% Gasoline | 11.340 | reddish yellow | 39 |
| 20% bioethanol of pineapple–80% premium | 7.331 | reddish yellow | 46 |
| 30% bioethanol of cassava flour–70% gasoline | 23 | yellow | 38 |
| 30% bioethanol of sugar molasses–70% gasoline | 2.2 | yellow | 37 |
| 30% palm sap bioethanol–70% premium | 4.7 | 10.126 | reddish yellow | this research |

### Table 8. Results of Two-Factor Analysis of Variance of the MF’s Flame Value

| source of variation | SS     | df  | MS        | \(F\)  | \(P\) value | \(F\) crit |
|---------------------|--------|-----|-----------|--------|-------------|------------|
| rows                | 155.0324 | 4   | 38.75809  | 0.408  | 0.799       | 3.259      |
| columns             | 19472.58 | 3   | 6490.86   | 68.308 | 8.23 \times 10^{-8} | 3.490      |
| error               | 1140.277 | 12  | 95.02309  |        |             |            |
| total               | 20767.89 | 19  |           |        |             |            |

4. CONCLUSIONS

The high concentrations of palm sap bioethanol cause the MF viscosity to also be higher, but too difficult to obscure. The higher the concentration of palm sap bioethanol, the lower the heating value of MF. The MF flame test results on variations in the concentration of palm sap bioethanol and premium fuel showed two different types of flame colors, namely, blue and reddish yellow. The blue color indicates high ethanol content, while the reddish yellow color indicates low ethanol content.

The physical and chemical properties of MF fuels still need to be studied comprehensively by conducting MF trials on various types of motorized vehicles. Besides, further research is needed on mixing palm sap bioethanol with other types of fuel.

## AUTHOR INFORMATION

### Corresponding Author

**Ansar** — Department of Agricultural Engineering, Faculty of Food Technology and Agroindustries, University of Mataram, Mataram 83115, Indonesia; Email: ansar72@unram.ac.id

### Authors

**Sukmawaty** — Department of Agricultural Engineering, Faculty of Food Technology and Agroindustries, University of Mataram, Mataram 83115, Indonesia

**Sirajuddin Haji Abdullah** — Department of Agricultural Engineering, Faculty of Food Technology and Agroindustries, University of Mataram, Mataram 83115, Indonesia

**Nazaruddin** — Department of Food Science and Technology, Faculty of Food Technology and Agroindustries, University of Mataram, Mataram 83115, Indonesia

**Erna Safitri** — Department of Agricultural Engineering, Faculty of Food Technology and Agroindustries, University of Mataram, Mataram 83115, Indonesia

Complete contact information is available at: https://pubs.acs.org/10.1021/acsomega.0c00247

### Notes

The authors declare no competing financial interest.

### ACKNOWLEDGMENTS

This work was supported by the University of Mataram through the Student Joint Research (SJR) scheme under contract no. 1954/UN/2019 so this research activity could be carried out. Acknowledgments are also conveyed to all those who have helped carry out this research.
REFERENCES

(1) Mahlia, T. M. I.; Syazmi, Z. A. H. S.; Moeljmur, M.; Abas, A. E. P.; Bilad, M. R.; Ong, H. C.; Silitonga, A. S. Patent landscape review on biodiesel production: Technology updates. Renewable Sustainable Energy Rev. 2020, 118, 109526.

(2) Tazi, I.; Sulistiana. Test the heating fuel of a mixture of bioethanol and used cooking oil. Journal of Neutrino 2011, 3, 163–174.

(3) Rijanto, M. W.; Armawi, A. The role of youth and the community in the development of renewable alternative energy to support energy security. Journal of National Resilience 2011, 16, 35–52.

(4) Moefijur, M.; Hasan, M. M.; Mahlia, T. M. I.; Rahman, S. M. A.; Silitonga, A. S.; Ong, H. C. Performance and emission parameters of homogeneous charge compression ignition (HCCI) engine: a review. Energies 2019, 12, 35–57.

(5) Balat, M. Global bio-fuel processing, and production trends. Energy Explor. Exploit. 2007, 25, 195–218.

(6) Guigou, M.; Lareo, C.; Pérez, L. V.; Lliberas, M. E.; Vázquez, D.; Ferrari, M. D. Bioethanol production from sweet sorghum: evaluation of post-harvest on sugar extraction and fermentation. Biomass Bioenergy 2011, 35, 3058–3062.

(7) Gupta, A.; Verma, J. P. Sustainable agro-residues: bio-ethanol production from a review. Renew. Sustain. Energy Rev. 2015, 41, 550–567.

(8) Deesuth, O.; Laopaiboon, P.; Klaopsoi, P.; Laopaiboon, L. Improvement of ethanol production from sweet sorghum juice under high gravity and very high gravity conditions: effects of nutrient supplementation and aeration. Ind. Crop Prod. 2015, 74, 95–102.

(9) Zhang, C.; Xie, G.; Li, S.; Ge, L.; He, T. The productive potentials of sweet sorghum Ethanol in China. Appl. Energy 2010, 87, 2360–2368.

(10) Gnanousou, E. Production and use of lignocellulosic bioethanol in Europe current situation and perspectives. Bioresour. Technol. 2010, 101, 4842–4850.

(11) Szkoło, A.; Schaeffer, R.; Delgado, F. Can one say ethanol is a real threat to gasoline? Energy Policy 2007, 35, 5411–5421.

(12) Kusumaningsih, T. Making Biodiesel from Jatropha Oil: Effect of temperature and length of fermentation on bioethanol production from aren plant (Arenga pinnata MERR). Int. J. Adv. Sci. Eng. Inf. Technol. 2013, 3, 244–247.

(13) Kismurtono, M. Fed-batch alcoholic fermentation of palm juice (Arenga pinnata MERR): Influence of the feeding rate on yeast, yield, and productivity. Int. J. Technol. 2012, 2, 795–799.

(14) Victori, L.; Orsat, V. Characterization of Arenga pinnata (palm) sugar. Sugar Tech 2018, 20, 105–109.

(15) Effendj, D. S. Prospect of aren tree development (Arenga pinnata MERR) to supporting bioethanol need in Indonesia. Perspective 2010, 9, 36–46.

(16) Zhang, Q.; Weng, C.; Huang, H.; Achal, V.; Wang, D. Optimization of bioethanol production using the whole plant of water hyacinth as a substrate in the simultaneous saccharification and fermentation process. Front. Microbiol. 2016, 6, 1–9.

(17) Ong, H. C.; Masjuki, H. H.; Mahlia, T. M. I.; Silitonga, A. S.; Chong, W. T.; Yusaf, T. Engine performance, and emissions using Jatropha curcas, Ceiba pentandra and Calophyllum inophyllum biodiesel in a CI diesel engine. Energy 2014, 69, 427–445.

(18) Silitonga, A. S.; Masjuki, H. H.; Ong, H. C.; Sebayang, A. H.; Dharma, S.; Kusumo, F.; Milano, J.; Daud, K.; Mahlia, T. M. I.; Chen, W.-H.; Sugiyanto, B. Evaluation of the engine performance and exhaust emissions of biodiesel-bioethanol-diesel blends using kernel-based extreme learning machine. Energy 2018, 159, 1075–1087.

(19) Tan, L.; Sun, Z.-Y.; Okamoto, S.; Takaki, M.; Tang, Y.-Q.; Morimura, S.; Kida, K. Production of ethanol from raw juice and thick juice of sugar beet by continuous ethanol fermentation with flocculating yeast strain KF-7. Biomass Bioenergy 2015, 81, 256–272.

(20) Soccol, C. R.; de Souza Vandenbergh, L. P.; Medeiros, A. B. P.; Karp, S. G.; Buckeridge, M.; Ramos, L. P.; Pitarleo, A. P.; Ferreira, Leitão, V.; Gottschalk, L. M. F.; Ferrara, M. A.; da Silva Bon, E. P.; Moraes, L. M. P. D.; Araújo, J. D. A.; Torres, F. A. G. Bioethanol from lignocellulosics: Status and perspectives in Brazil. Biorenew. Technol. 2010, 101, 4820–4825.

(21) Ong, H. C.; Silitonga, A. S.; Masjuki, H. H.; Mahlia, T. M. I.; Chong, W. T.; Boosroh, M. H. Production and comparative fuel properties of biodiesel from non-edible oils: Jatropha curcas, Sterculia foetida, and Ceiba pentandra. Energy Convers. Manage. 2013, 73, 245–255.

(22) Xuan, F.; Chai, D.-J.; Su, H. Local density approximation for the short-range exchange free energy functional. ACS Omega 2019, 4, 7675–7683.

(23) Sun, P.; Gao, G.; Zhao, Z.; Xie, C.; Li, F. Stabilization of cobalt catalysts by embedment for efficient production of valeric biofuel. ACS Catal. 2014, 4, 4136–4142.

(24) Dayma, G.; Halter, F.; Fouché, F.; Togbé, C.; Mounaim-Rousselle, C.; Dagua, P. Experimental and detailed kinetic modeling study of ethyl pentanoate (ethyl valerate) oxidation in a jet stirred reactor and laminar burning velocities in a spherical combustion chamber. Energy Fuels 2012, 26, 4735–4748.

(25) Galletti, Robert; Antonetti, C.; Ribechni, E.; Colombini, M. P.; Nasso Di Nasso, N.; Bonari, E. From giant reed to levulinic acid and gamma-valerolactone: A high yield catalytic route to valeric biofuels. Appl. Energy 2013, 102, 157–162.

(26) Kon, K.; Onodera, W.; Shimizu, K.-I. Selective hydrogenation of levulinic acid to valeric acid and valeric biofuels by a Pt/HMFI catalyst. Catal. Sci. Technol. 2014, 4, 3227–3234.

(27) Ademiluyi, F. T.; Mepba, H. D. Yield, and properties of ethanol biofuel produced from different whole cassava flours. ISRN Biotechnol. 2013, 1–6.

(28) Jia, Z.; Illumini, M.; Hakuri, B.; Safaei, B.; Ganji, D. D. Experimental investigation of performance improvement and emissions reduction in a two-stroke SI engine by using ethanol additives. Propulsion Power Res. 2013, 2, 276–283.

(29) Budiprasoso, A.; Pratama, A. W. The heating value of premium blends with polypolyne fuel resulting from the pyrolysis process. Journal of Ilmiah Inovasi 2016, 1, 122–127.
(40) Laesecke, A.; Fortin, J. D.; Splett, J. D. Density, speed of sound, and viscosity measurements of reference materials for biofuels. *Energy Fuels* 2012, 26, 1844−1861.

(41) Niemeyer, K. E.; Daly, S. R.; Cannella, W. J.; Hagen, C. L. A novel fuel performance index for low-temperature combustion engines based on operating envelopes in light-duty driving cycle simulations. *J. Eng. Gas Turbines Power* 2015, 137, 101601.

(42) Yuliyanto, D.; Widodo, E. Test the heating fuel of a mixture of bioethanol and used cooking oil. *J. Manuf. Energy Eng.* 2018, 3, 1−5.

(43) Ansar; Nazaruddin; Azis, A. D. Effect of vacuum freeze-drying condition and maltodextrin on the physical and sensory characteristics of passion fruit (Passiflora edulis Sims) extract. In *IOP Conference Series: Earth and Environmental Science*; IOP Publishing: 2019, 355 012067. DOI: DOI: 10.1088/1755-1315/355/1/012067.

(44) Aditiya, H. B.; Chong, W. T.; Mahlia, T. M. I.; Sebayang, A. H.; Berawi, M. A.; Nur, H. Second generation bioethanol potential from selected Malaysia’s biodiversity biomasses: A review. *Waste Manage.* 2016, 47, 46−61.

(45) McLinden, M.; Bruno, T.; Frenkel, M.; Huber, M. Standard reference data for the thermophysical properties of biofuels. In *Biofuels*; ASTM International: 2011, 7, 1−18.

(46) Polikarpov, E.; Albrecht, K. O.; Page, J. P.; Malhotra, D.; Koech, P.; Cosimbescu, L.; Gaspar, D. J. Critical fuel property evaluation for potential gasoline and diesel biofuel blend stocks with low sample volume availability. *Fuel* 2019, 238, 26−33.

(47) Susanto, R.; Jaya, H.; Mulyanto, A. Analysis of the effect of fermentation time and distillation temperature on physical properties (specific gravity and caloric value) of bioethanol made from pineapple (ananas comosus). *Mech. Eng. Dyn.* 2013, 3, 91−100.

(48) Cahyani; Anisah. Effect of enzyme volume on alcohol content and caloric value of bioethanol made from yam tubers (Dioscorea hipsida dentist). *J. Agric. Eng. Trop. Biosystems* 2015, 3, 35−42.