



## Article

# The Experimental Study of Pangium Edule Biodiesel in a High-Speed Diesel Generator for Biopower Electricity

Teuku Azuar Rizal <sup>1,2</sup>, Khairil <sup>3</sup>, Mahidin <sup>4</sup>, Husni Husin <sup>4,\*</sup>, Ahmadi <sup>5</sup>, Fahrizal Nasution <sup>1</sup> and Hamdani Umar <sup>3</sup>

<sup>1</sup> Doctoral Program, School of Engineering, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia; azuarrizal@unsam.ac.id (T.A.R.); fahrizalnasut@gmail.com (F.N.)

<sup>2</sup> Department of Mechanical Engineering, Faculty of Engineering, Universitas Samudra, Kota Langsa 24416, Indonesia

<sup>3</sup> Department of Mechanical Engineering, Faculty of Engineering, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia; khairil@unsyiah.ac.id (K.); hamdani@unsyiah.ac.id (H.U.)

<sup>4</sup> Department of Chemical Engineering, Faculty of Engineering, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia; mahidin@unsyiah.ac.id

<sup>5</sup> Reaction Engineering and Catalysis Laboratory, Department of Chemical Engineering, Faculty of Engineering, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia; ahmadiyahmadi840@gmail.com

\* Correspondence: husni\_husin@che.unsyiah.ac.id

**Abstract:** Despite the rapid development of electric vehicles, the shrinking number of fossil fuels that are the source of electricity remains conventional. The availability of energy sources and technology is sometimes naturally limited, high-priced, and might be politically circumscribed. This leads to an increased desirability of biodiesel due to its modest and economically higher energy density in comparison to batteries. The palm oil industry accounts for 23% of total deforestation in Indonesia. Contrary to palm oil, pangium edule (PE) is considered more sustainable and it intercrops with most of the forest's vegetation while supplying biodiesel feedstock. A relatively higher pangium edule methyl ester (PEME) was delivered through PE feedstock, provided that it was processed with a heterogeneous catalyst, K<sub>2</sub>O/PKS-AC. This feedstock consumed a lower alcohol ratio and had a reasonably swift production process without sacrificing biodiesel quality. Therefore, this study aims to assess the performance of the PE biodiesel blend in a power generator. Furthermore, PEME was blended with diesel fuel in the variation of B0, B20, B30, B40, and B100. It was also tested with four-stroke single-cylinder diesel power generators to produce electricity. The B30 blend stands out in this experiment, achieving the highest engine power of 0.845 kW at a low load and dominating at a higher load with a minimum fuel consumption of 1.33 kg/h, the lowest BSFC of 0.243 kg/kWh, and second in BTE values at 21.16%. The result revealed that the main parameters, which include actual and specific fuel consumption, and the thermal efficiency of PE biodiesel performed satisfactorily. Although there was a slight decrease in the total power delivered, the overall performance was comparable to petroleum diesel.

**Keywords:** pangium edule biodiesel; K<sub>2</sub>O/PKS-AC; heterogeneous catalyst; performance; high-speed diesel power generator



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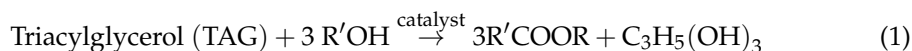
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## 1. Introduction

The world trends show the rapid development of electric vehicles intentionally planned to reduce and mitigate the emission impact from fossil fuels [1,2]. However, the dominant source of electricity in most countries, which is fossil fuel, currently remains conventional [3]. A recent study showed that accelerating vehicle electrification and scaling-up renewable electricity generation is considered a proper strategy for climate-adapted electric passenger vehicles [4]. Contrarily, high-profile energy production such as nuclear-powered electricity was claimed to have cleaner emissions and cost-effective

power generation. This was also only accessible to a limited number of countries with stringent scrutiny influenced by global political situations [5], despite its radioactive waste issues [6,7]. Relying on renewable sources such as solar and wind on a larger scale would be precarious due to high capital, relatively lower efficiency delivered, intermittency, and dependence on technology to store the energy [8]. Hydrogen, a promising clean energy after renewables, has shown quite good progress recently, as many photocatalysts to speed up production which potentially reduce the use of fossil fuel during production are continuously developed [9,10]. Furthermore, hydrogen with a much higher energy density than biodiesel is also presented with the same economic arguments due to most of its applied production technology being dependent on fossil fuel despite some challenges regarding its safe handling, which requires additional technological costs [11,12]. Compared to state-of-the-art lithium-air batteries, liquid or renewable fuel is twenty times greater in density energy storage ratio [13–15]. Moreover, a previous study discovered that energy use for battery manufacturing with current technology is about 97–180 kWh electricity per kWh battery [16]. Providentially, a more recent study shows that the most reasonable assumption for energy usage during the manufacturing of one Li-ion battery cell is 50–65 kWh of electricity per kWh of battery capacity [17], saving around 45% energy input compared to previous research. A lithium-based battery contained 0.57 kg  $\text{Li}_2\text{CO}_3$  or 0.54 kg  $\text{LiOH}\cdot\text{H}_2\text{O}$  per battery kWh [18]. Above all, the battery life degrades over time with a shelf life of 3–6 years. This indicates that biodiesel is unequivocally desirable as a future reliable source of energy.

Biodiesel is commonly extracted from vegetable oil, animal fat, nonedible oil, and algae. The transesterification method is the most popular approach to converting alkyl ester content and lowering the viscosity to fit into acceptable diesel fuel characteristics [19]. During transesterification, oil feedstock is reacted with an alcohol, in the presence of a catalyst, to produce mono alkyl esters, as illustrated in Equation (1) [20].



Globally, biodiesel is projected to increase up to 50 billion liters in countries that rely on a specific type of feedstocks. In the past decades, many plants have been identified and exploited as primary feedstock. Table 1 shows the main biodiesel producers [21] in which the European Union (EU) surprisingly plays a dominant role in biodiesel production and is known to have palm oil as its leading feedstock. Furthermore, resources were imported from southeast Asia, mainly Indonesia and Malaysia. Indonesia, which is the leading palm oil supplier, substantially increases its total production capacity to supply world demand and fulfill mandatory increases in national biodiesel content [21,22]. This demand requires substantial land mass converted from tropical forest, which imposes on the primary and secondary forest coverage, alters the landscape, and degrades crop production due to the lack of effective implementation for sustainable intensification [23,24]. Palm trees are challenging to grow in dense vegetation compounds while sustaining higher oil yields due to maintenance and water requirements [25,26]. Alternatively, an example of a biodiesel source coexisting with forest vegetation is *kepayang*, *pangium edule* (PE), which has a great potential to become biodiesel feedstock [27–31].

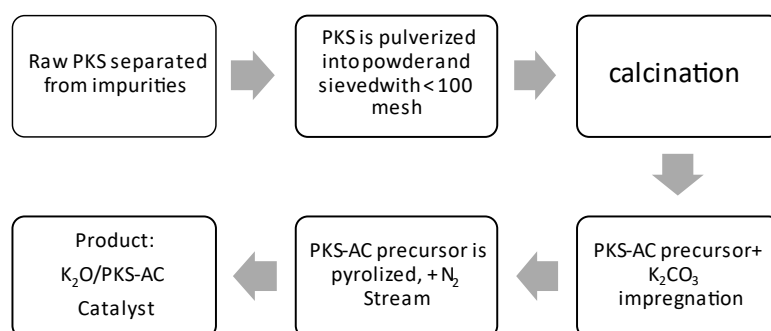
**Table 1.** Assorted types of primary biodiesel feedstocks for selected countries. Adapted with permission from ref. [21]. 2021, OECD.

Country	Rank	Production Rating (%)	Main Raw Materials
European Union	1	32.3	rapeseed oil/palm oil/used cooking oil
United States	2	18.1	soybean oil/used cooking oil
Indonesia	3	15	palm oil
Brazil	4	12.2	soybean oil
Canada	14	0.7	canola oil/used cooking oil/soybean oil
Paraguay	19	0.03	castor oil ( <i>Jatropha</i> )

Unfortunately, PE has never been nurtured and fostered to the same extent as oil palm nurseries. It grows naturally and it is conventionally used as cooking oil by indigenous communities throughout Southeast Asia and placed in the local delicacies of some Indonesian regions. Previous research in Aceh, Sumatera, found that PE trees, at their natural growth rate, can grow in a moist, tropical land with minimal maintenance. Locals believe that PE can be harvested once a year at potentially 52.6 kg of seeds per tree per year with 10% oil content [28]. Assuming a palm tree planting pattern was adopted for PE plantation, there are potentially 143 trees capable of yielding 752 kg of oil/ha/year. While in Jambi, Sumatera, with a more structured plantation and better manufacturing process, it has been reported that PE seed is harvested three times a year with oil content reaching a 30% yield [32]. Thus, hypothetically, roughly two tons of oil per hectare per year can be produced, equal to 76,000 MJ/ha/year. The panguim edule methyl ester (PEME) has a comparable energy content of 39.625 MJ/kg to palm methyl ester (PME) of 39.9 MJ/kg [27,33].

Since the beginning of the 2000s, biodiesel from PE feedstock has started to gain some attention among researchers. Moreover, the development and growth of biodiesel demands led to the catalyst technology flourishing due to the different reactions of each feedstock during the transesterification process, which influences biodiesel characteristics [34]. However, most of the research focuses on the identification of feedstock and the biodiesel characterization of PEME produced over transesterification methods using a homogenous catalyst and inorganic-based catalyst [29–31,35–37]. Each approach extends disadvantages due to many resources wasted during the process, which later encouraged the idea of saving and minimizing the usage of those valuable resources. Hence, recent research has tried to elaborate more on agricultural wastes and utilize them as heterogeneous catalysts in the transesterification of PE feedstocks [38,39], which offer more advantages and possess fewer hazards to the environment.

The biodiesel in this study was produced with a heterogeneous catalyst developed from palm oil industrial waste, i.e., palm kernel shell (PKS), due to the generation of greater biodiesel yield. The catalyst manufacturing begins with the homogenization of pure PKS precursor particle size with a <100 mesh screen, subsequently calcinated at 300 °C for three hours. The precursor was then impregnated with  $K_2CO_3$  solution at room temperature. Later, the wet precursors were dried once again at 110 °C before being pyrolyzed at 300 °C for three hours with nitrogen gas streamed to remove  $CO_2$  from the catalyst product. Figure 1 represents the brief schematic process of  $K_2O$ /PKS-AC catalyst synthesis.



**Figure 1.** Schematic of the main process during  $K_2O$ /PKS-AC catalyst preparation.

The optimum reaction condition was achieved after 1.5 h, with a methanol to oil ratio of about 9:1 and a 5% catalyst mass with a 96.65% yield.  $K_2O$ /PKS-AC also demonstrated the capability to produce more than 90% yield, even after being used four times, implying the potential for catalyst savings and an affordable biodiesel production scheme. Its potential to support an affordable biodiesel production scheme could save a tremendous amount of resources and promote renewable and biodegradable processes. Therefore, this study aims to further elaborate on the performance of the PEME biodiesel blend produced with a  $K_2O$ /PKS-AC heterogeneous catalyst in a diesel power generator.

Chemically, this catalyst was discovered to influence biodiesel quality, viscosity, density, and cetane number [40–42]. The atomization and formation of fuel bursts were essential in engine operation because coarser droplets on the bursts led to ineffective fuel mixing [43], incomplete combustion, and higher smoke emissions, especially in cold start operations [44]. Furthermore, fuel properties such as viscosity, density, and surface tension directly affect the process of burst formation immediately after fuel injection. High fuel viscosity dampens aerodynamic disturbances on the injected liquid jet surface through the nozzle and blocks flow interruption [45,46]. Meanwhile, the high surface tension and viscosity of biodiesel reduce cavitation intensity, turbulent kinetic energy, and radial velocity at the nozzle outlet, which narrows the aerodynamic spray cone angle [47]. A higher surface tension coefficient increases the cohesive force and prevents the formation of smaller droplets [48,49]. There is a reduction in engine net output power due to higher viscosity, which sucks up more energy by fuel pump drive [50]. Although the transesterification process significantly reduces biodiesel viscosity from the initial conditions in crude vegetable oil, it remains higher than diesel fuel viscosity [51]. Cetane number is an indicator of ignition quality, and its higher values are related to wax content in fuel. Therefore, fuel temperature drops of  $-8\text{ }^{\circ}\text{C}$  lead to some of the wax solidifying, which may block filters [52].

The concerns related to a higher biodiesel percentage utilization in diesel engines include soot deposited on the injector surface and the thermos-oxidation of fatty acid and oxygen, which lead to engine wear. Experts have suggested that combustion efficiency can be increased by optimizing fuel injection angle and pressure advances, using biodiesel B20 or B50, in addition to a higher biodiesel blend with antioxidants to moderate the reaction mechanisms [53]. Studies also revealed that PE seeds contain high antioxidants [54], which are beneficial for reducing the thermos-oxidation effect.

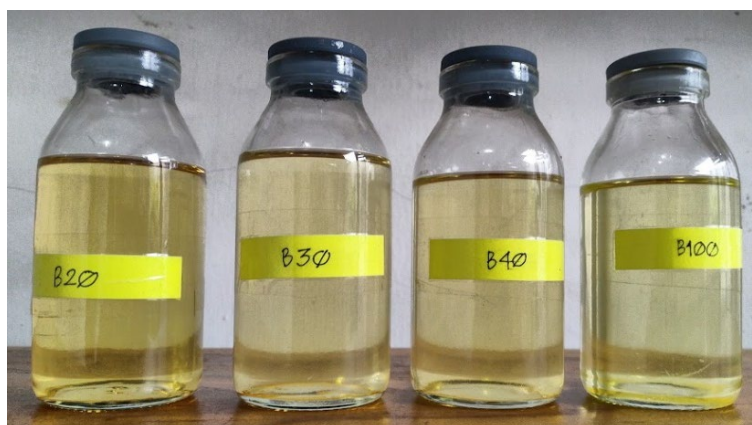
## 2. Materials and Methods

### 2.1. Biodiesel Blend Preparation

As previously highlighted, PEME or B100 was produced from PE feedstock reacted with potassium oxide embedded on palm kernel shell-activated carbon catalysts ( $\text{K}_2\text{O}/\text{PKS-AC}$ ) with optimum batch-reaction settings. Subsequently, the PEME was mixed with Pertamina-Dex (B0) in various percentages, i.e., 20%, 30%, and 40% *v/v*, later classified as B20, B30, and B40, respectively. The homogenization of biodiesel blends was prepared by stirring the mixture above its cloud point temperature for at least 2–3 min. There is no technical literature specifically discussing biodiesel–diesel mixing methods. However, there are four general methods to blend biodiesel–diesel with few disparities in their density on an industrial scale [55]. These are:

1. Splash blending: in this method, biodiesel and diesel fuel are loaded separately into a tank, while the mixing occurs during transport as the fuel is agitated along the road.
2. In-tank blending: fuels are loaded separately through a different incoming channel and the fuel rests without additional agitation.
3. In-Line blending: the biodiesel is added to a stream of diesel fuel as it travels through a pipeline, and the mixing process occurs during turbulent flow along the pipe.
4. Rack blending: the most straightforward mixing approach, where biodiesel is directly poured into the tank prior to use.

Consequently, five fuel blend variations resulted in engine performance tests, including B0, B20, B30, B40, and B100. The biodiesel blends show slight color differences, as depicted in Figure 2. Typically, B100 is mainly used as a blend stock for producing lower blends of biodiesel fuel [56]. In this research, the performance of pure biodiesel was also investigated. In previous research, biodiesel performance and those with a 20% mixture were discovered in other studies to perform equally in comparison to the pure petroleum version without sacrificing designed performance.



**Figure 2.** Pure PEME and its blend variations.

Empirically, the energy content of two types of biodiesel blends was calculated by summing the contents of type-A biodiesel percentage with another portion of type-B, expressed in Equation (2). The same approach was applied for the determination of density and viscosity in Equations (3) and (4), respectively [57].

$$H_{AB} = (H_{LHV_A} \cdot \% Vol_A) + (H_{LHV_B} \cdot \% Vol_B) \quad (2)$$

$$\rho_{AB} = (\rho_A \cdot \% Vol_A) + (\rho_B \cdot \% Vol_B) \quad (3)$$

$$v_{AB} = (v_A \cdot \% Vol_A) + (v_B \cdot \% Vol_B) \quad (4)$$

where:

$H_{AB}$  = blended fuel energy content (MJ/kg), and  $H_A$  and  $H_B$  = specific energy content of each fuel fraction.

Through a similar approach:

$\rho_{AB}$  = density of blended biodiesel (kg/m<sup>3</sup>), calculated individually, and

$v_{AB}$  = viscosity of blended biodiesel (cSt), calculated individually.

Furthermore, both B0 and B100 were used as calculation references during the analysis. The total energy content differences between B0 and B100 reached 29% and dropped around 3% for every addition of 10% *v/v* biodiesel into the blend. There was also an increase in viscosity and density of the blend for every addition of biodiesel percentage to the mixture, as simplified in Table 2. The difference between each main property is shown in Figure 3.

**Table 2.** Properties of diesel and biodiesel fuel blends used in this experiment.

Fuel Parameters	Unit	B0 [58]	B20 *	B30 *	B40 *	B100
Kinematic Viscosity	mm <sup>2</sup> /s (cSt)	2.0–4.5	2.62	2.93	3.24	4.4–5.1
Density	kg/m <sup>3</sup>	820–860	845.9	848.85	851.8	851–888
Calorific Value	kcal/kg	13,495	12,683	12,277	11,871	9411

\* The result was empirically derived.

## 2.2. Experimental Setup and Instrumentation

In this study, the power generator subjected to the test procedure was a KIPOR KDE6700T. This generator mainly consisted of an alternator KDE6700T driven by a KM186-FAGET diesel engine. Furthermore, the power generator type was selected due to its small class, relatively low cost, and prevalence among small and medium enterprises (SMEs) and households in the region. The engine type was an air-cooled direct injection diesel engine with a vertical four-stroke single cylinder and 4.5 kVA power output. It also had a fuel consumption of 275.1 g/kW h at 3000 rpm designed for commercial diesel in the B0 to B20 category. During experimentation, the engine was subjected to various biodiesel blends, and its performance was observed. Table 3 shows detailed technical parameters of

the KDE6700T power generator specification. Inside this generator, its engine was coupled with a KDE6700T alternator constructed in single phases and worked at a rated current of 19.6 A and 230 V with a power factor of 1.



Figure 3. The main properties of the biodiesel blends gradually change with increasing biodiesel content in the mixture.

Table 3. Technical parameters of KM186FAGET and KDE 6700 T alternator. Adapted with the permission from [59], 2022, KIPOR UK.

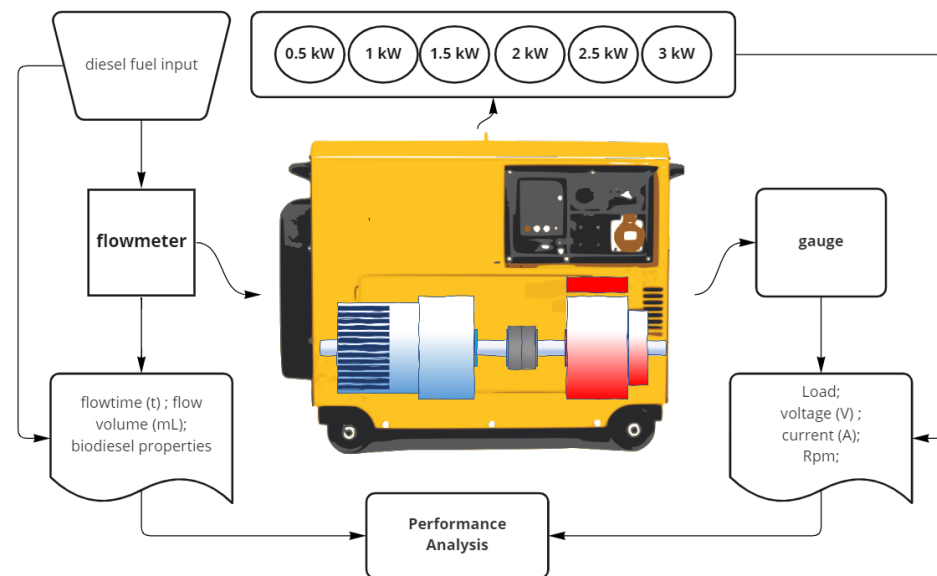
Diesel Engine		Alternator	
Parameter	Description	Parameter	Description
Engine Model	KM186FAGET	Model	KDE6700T
Engine Type	Single cylinder, vertical, four-stroke, direct injection	Rated frequency (Hz)	50–60
Cylinder Number	1	Rated output (kVA)	4.5–5.0
Bore (mm)	86	Max. output (kVA)	5.0–5.5
Stroke (mm)	72	Rated Voltage (V)	115/230–120/240
Compression ratio	19:1	Rated current (A)	39.2/19.6–4 1.7/20.8
Rated rotation speed (r/min)	3000–3600	Rated rotation speed (r/min)	3000–3600
Combustion system	Direct injection	Phase NO.	Single phase
Cooling system	Air-cooled	Power factor (Cos Φ)	1.0
Continuous running time (hr.)	6		

Furthermore, the power generator was equipped with instruments and gauges to record data during the experiment. The main parameters that characterized the performance of a diesel engine, namely brake power (P) and specific fuel consumption (SCF), were investigated during this experiment. SFC is defined by the mass flow rate of fuel consumed per power output unit. It is evaluated by measuring the fuel flow rate supplied to the engine with a fuel flow meter. The generator’s default fuel line system was modified to bypass the fuel tank and a new external fuel system was attached to the flow meter. Therefore, the biodiesel blend could easily be refilled and changed without emptying the fuel tank, as seen in Figure 4, which represents a power generator with a modified fuel line. The data required for performance calculations include voltage, current, fuel consumption, and engine rotation.

The experiment was carried out by obtaining all data, namely voltage, current, fuel flow, and rpm, based on the load provided to the generator. This data and the increased engine subjected load were recorded. The number of powered lamps indicated the total power consumed by the engine during the test. Six lamps are used for current and voltage measurement, each of which consumes 0.5 kW power and can be added up to a 3.0 kW load. A multimeter and clamp meter were deployed during the test to record variable readings. Figure 5 presents the simplified schematic of the experimental setup in this study.



**Figure 4.** Experimental test apparatus: (a) KDE 6700T power generator and test instruments (b) modified external fuel line system bypassing default fuel tank.



**Figure 5.** Schematic illustration of the experimental flow and data recording procedure.

The performance analysis was carried out through the measurement of the actual fuel mass consumption (FMC), engine brake power (P) calculations, brake-specific fuel consumption (BSFC) calculations, and thermal efficiency ( $\eta_{th}$ ) of the power generator. Equations (5)–(8) signify the calculation formula specifically developed to analyze the engine attached to an alternator [60,61]. Equivalent methods were elaborated in the research conducted by Khairil et al. during the examination of engine performance run on biodiesel and waste plastic pyrolysis oil (WPPO) [57,62].

$$FMC = \frac{m_f}{t} \quad (5)$$

$$P = \frac{V \cdot I \cdot \cos \varphi}{746 \cdot \eta_{eg}} \quad (6)$$

$$BSFC = \frac{FMC}{P} \quad (7)$$

$$\eta_{th} = \frac{P \cdot 632.5}{m_f \cdot LHV} \quad (8)$$

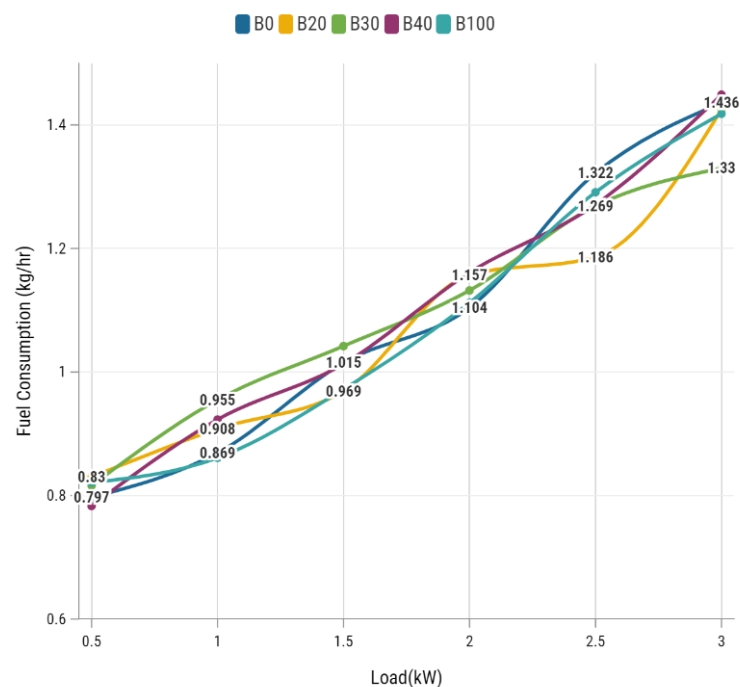
where:

$FMC$  = fuel mass consumption (kg/hr.),  $P$  = engine brake power (kW),  $BSFC$  = brake-specific fuel consumption (kg/kWh) and  $\eta_{th}$  thermal efficiency (%),  $m_f$  = mass of fuel (kg),  $t$  = time (hr.),  $V$  = voltage (volt),  $I$  = current (Ampere),  $\cos \varphi$  = power factor of single-phase alternator = 1,  $\eta_{eg}$  = efficiency of electric generators (which is between 87 and 89% for engines < 50 kVA), and  $LHV$  = lower heating value or fuel calorific value (kcal/kg).

### 3. Results

#### 3.1. Fuel Consumption

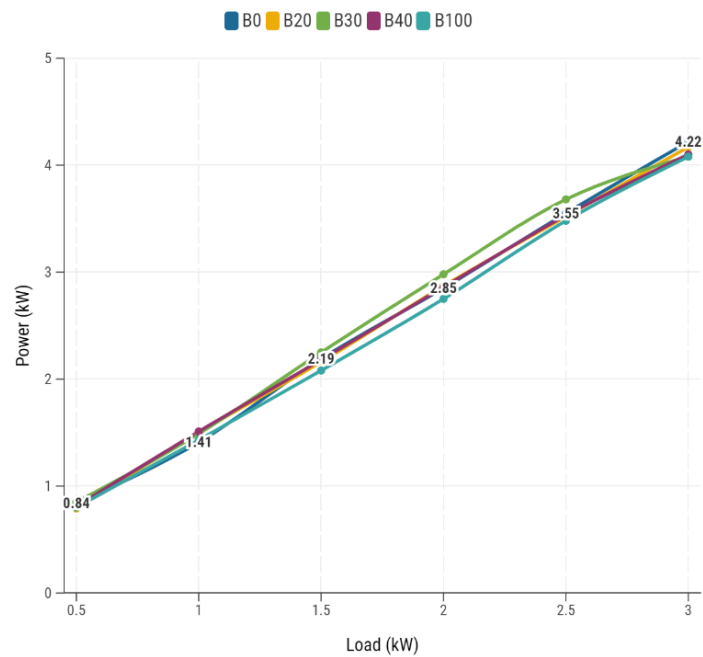
Figure 6 shows the fuel consumption test results of a power generator with a biodiesel blend burning at a nearly similar pace. Interestingly, at a higher load, B30 burned at 1.3 kg/h, which is 8.27% and 6.9% lower compared to the B0 and B20 blends, respectively. This implies that the total fuel consumption of B30 is lower than other biodiesel blends. It also shows a more balanced performance and efficiency at a higher load, which fulfills the economical criterion for a high-speed diesel power generator, such as 3000 rpm and around 3.0 kW workload.



**Figure 6.** Comparison of fuel consumption at different loads.

#### 3.2. Brake Power

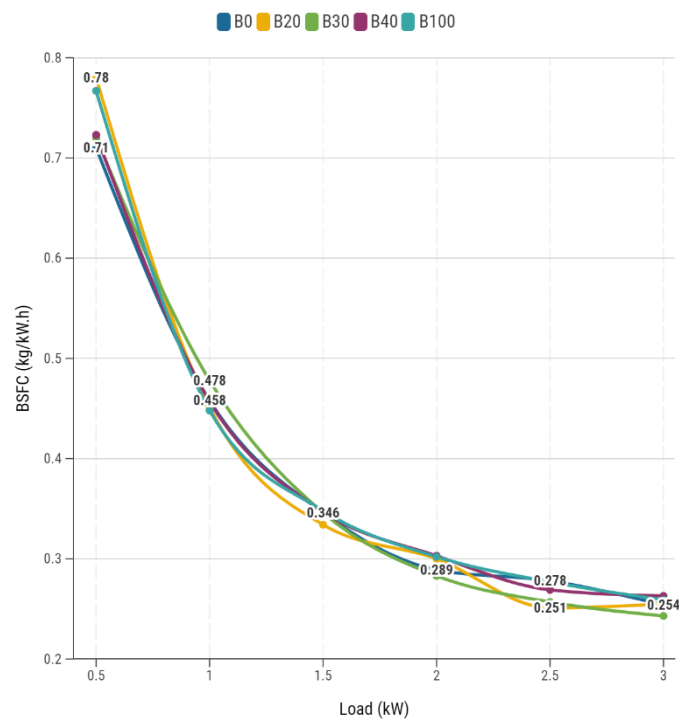
In Figure 7, the brake power shows a comparable phenomenon for the amount of biodiesel flow and the load given during engine runs. Essential fuel characteristics, namely density, calorific value, and viscosity, affect engine performance. Furthermore, biodiesel has a lower calorific value and higher kinematic viscosity and density which consequently alter fuel spray and atomization patterns, which lead to a change in power and brake-specific fuel consumption (BSCF) [63–65]. At a 3.0 kW load, B0 obtained the highest brake power at 5.659 HP, which is equal to 4.162 kW out of a 5.5 kW total engine power, according to the manufacturing design. A 20% BPE blend came after and delivered 4.53 kW of power. This power tends to reduce with an increase in biodiesel fraction within the fuel blend.



**Figure 7.** Engine power at different loads.

### 3.3. Brake-Specific Fuel Consumption, BSFC

BSFC characterizes the fuel efficiency of an internal combustion engine (ICE) and indicates the level of engine efficiency required to convert fuel supplied into useful work. It is also inversely proportional to the calorific value, which denotes that more fuel is required to generate the rated power output [66]. Figure 8 shows that BSFC tends to exhibit a high ratio, ranging between 0.71 and 0.78 kg/kWh for lower loads, which signifies that it is inversely proportional to the load. The minimum BSFC in this study, which occurred at a 3.0 kW load, was 0.243 kg/kWh for a 30% biodiesel fuel blend.



**Figure 8.** BSFC at different load.

### 3.4. Brake Thermal Efficiency

The BTE efficiency of a diesel engine is determined by the change of a fuel’s chemical energy into valuable work [67]. Figure 9 shows the effect of biodiesel blend percentage and engine load on BTE, which increases with applied load for all fuel and blends. This phenomenon is indicated by the reduction in heat loss and increased power developed and load [67]. A 100% BPE Blend obtained a BTE of 25.92%, which was the highest for every load in this study.

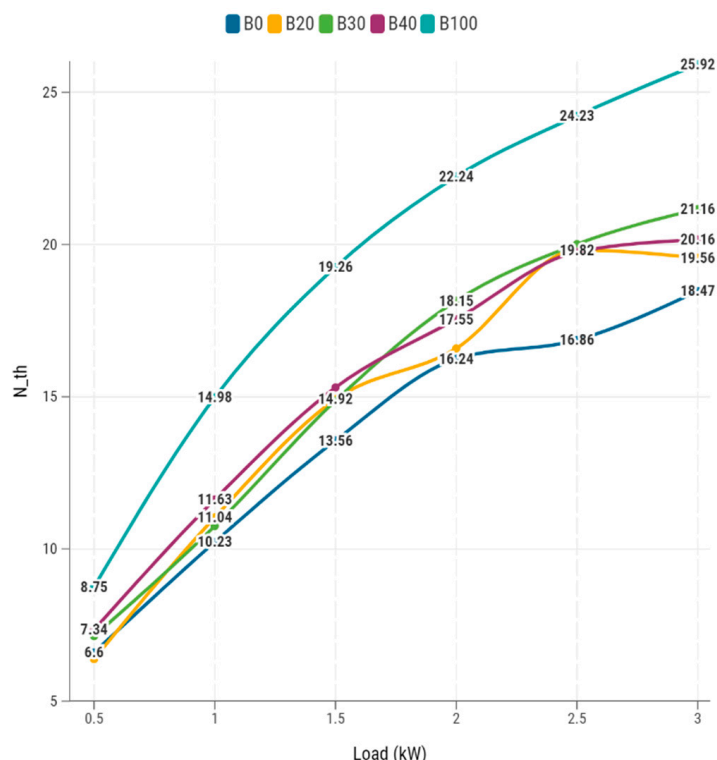


Figure 9. BTE at different loads.

### 4. Discussion

The experiment on PEME biodiesel blends for the high-speed power generator, KIPOR KDE6700T, was successfully carried out. Biodiesel produced from the transesterification process with a heterogeneous catalyst of palm kernel shell works perfectly in commercial electric generators. Furthermore, the B30 biodiesel blend stands out in most performance test analyses, achieving the highest engine power of 0.845 kW at low load, and the lowest, highest, and second-highest fuel consumption, BSFC and BTE values of 1.33 kg/h, 0.243 kg/kWh, and 21.16%, respectively, at a high load. Table 4 summarizes the test results, emphasizing the requirement of biodiesel according to each performance parameter.

Table 4. Recapitulation of fuel selection considering the performance test results.

Performance	Load (kW)	Requirement	1st Selection	2nd Selection		
FMC, (kg/h)	Low	Lowest rate	B40	0.783	B0	0.797
	High		B30	1.33	B100	1.418
P, (kW)	Low	Highest rate	B30	0.845	B0	0.837
	High		B0	4.219	B20	4.174
BSFC, (kg/kW.h)	Low	Lowest rate	B0	0.71	B30	0.72
	High		B30	0.243	B0	0.254
BTE, (%)	Low	Highest rate	B100	8.75	B40	7.34
	High		B100	25.92	B30	21.16

Fuel mixtures containing 30% biodiesel have been recognized as potential candidates for use in high-rpm diesel power generators. Most small-class power generators work at higher rpm, i.e., >3000 rpm, therefore, biodiesel with a 30% PEME mixture will hypothetically require a more dominant role in the mandatory B30 biodiesel program. Assuming B30 shares the same price as subsidized bio-solar with a burning rate of 8.27% less than the B0 mixture, there would be a conceivably potential resource-saving of around 39–45% in the total national budget for the fuel provision sector.

Furthermore, regarding the injector, which is a crucial part of the IC engine, a previous study demonstrated that the dimensions of the nozzle holes, fuel atomizer, and surfaces in contact with the B30 fuel flow did not encounter any substantial alterations, even after 360 h of operation [68]. Another study on a diesel-powered electric powerplant utilizing B30 blended fuel did not show any sign of complications and disturbances or interference in engine performance; however, there was a slight SFC increase [63]. Emissions of SO<sub>2</sub>, CO, and particulate exhaust from the use of B30 were lower in comparison to the use of HSD fuels [63].

The result showed the equal performance of fossil-based fuels compared to biodiesel blends and pure versions. It was also proven that PEME extracted from local vegetation, which naturally coexisted with tropical forest vegetation, could deliver comparable performance when used in a power generator. These research findings apparently support and feasibly stimulate the energy transition process through the recommendation of the elaboration of PE as a local resource for more sustainable energy production, supplementary to the global energy transition strategy. Regarding the energy issue, the United Nations General Assembly in 2015 shared a common understanding related to 17 goals in SDGs, particularly SDG 7, which is to ensure access to affordable, reliable, sustainable, and modern energy for all [69]. This goal also implies that each country is urged to reconsider its current centralized energy policy and shift into a decentralized energy policy.

Local natural and human resources should be more elaborated in the energy transition program to cope with the carbon-neutral target by 2060. This will create a new opportunity to develop a local industry based on pangium edule vegetation for the provision of a sustainable biodiesel feedstock. This program will potentially boost the multiplier effect through job creation and local economic development by employing local resources as clean energy sources. Using local resources could significantly cut the operational budget and lower capital manufacturing costs. Meanwhile, the energy transition process will require a remarkable budget and involve massive local human resources, subsequently supporting the sustainability of the community in the long run, as targeted in the SDGs.

To provide a more comprehensive understanding related to the impact of PE on energy transition strategies, furthermore, a detailed highlight of the economic and environmental benefits of applying PEME in the biodiesel sector should potentially be elaborated on in future research. However, implementing pure biodiesel for engine application will significantly impact the cost of production and possibly stimulate significant drawbacks to the environmental issue [70]. The mandatory involvement of PEME blends into biodiesel benefits the environment through reduced emissions and coexistence with forest vegetation, which preserves biodiversity while bioenergy is provided.

## 5. Conclusions

The PE biodiesel feedstock that was successfully manufactured using potassium oxide over palm kernel shell-activated carbon worked flawlessly in a high-speed electric power generator. The B30 biodiesel blend dominated the majority of parameters in the performance analysis. The B30 blend delivered the highest engine power of 0.845 kW at low loads and dominated at higher loads with a minimum fuel consumption of 1.33 kg/h, the lowest BSFC of 0.243 kg/kWh, and second in BTE values at 21.16%. Overall, this research proposes a competitive result among biodiesel blend variations. This modest situation facilitates a new opportunity to increase and enhance the biodiesel–diesel mixture since more biodiesel means more sustainable energy feedstock will be produced while

reducing more emissions to the atmosphere. The experiment itself has been subjected to an engine that is not fully developed for higher biodiesel content. Thus, this led to the prospect of enhancing the diesel engine performance with an increased biodiesel–diesel ratio. Nevertheless, this will require more detailed research in the engineering field solely for developing engines capable of optimizing the combustion of fuel with more biodiesel content. Infinitesimal changes in each variable were recorded during the experiments and operational conditions led to the need for the upcoming study data and calculation to be carried out with a more state-of-the-art methodology. Furthermore, PE plants that are intercropped with many tropical plants may become an alternative for the provision of bio-renewable energy feedstock. A more modern and sustainable energy cultivation method with this type of feedstock should be considered since it offers a better approach to reducing the impact of environmental drawbacks due to monoculture cultivation methods, as practiced in the current global scheme.

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