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Performance and Efficiency Comparison of Human Waste Biogas and LPG Production in Modified Water Pump Engines

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Abstract

As daily needs and fuel prices continue to rise and non-renewable natural resources diminish, alternatives are needed to replace these energy sources with renewable energy. Data from the National Energy Council shows that in Indonesia, only 16.358 household biogas digester units have been installed, or about 1.6% of the total potential that can be utilized. This research aims to compare the performance of biogas from human feces with liquefied petroleum gas (LPG) as fuel for water pump engines. The method used is experimental, involving the modification of the carburetor on the water pump engine, followed by direct measurement and analysis of the water pump results using variations of biogas and LPG fuels. A literature review indicates that biogas has great potential as a renewable energy source, but its utilization in Indonesia remains very limited. In this study, the test variables include variations in pump speed at 3800, 5300, and 6600 rpm. The test results show that the mass flow rate of biogas compared to LPG yields the highest discharge at 6600 rpm (0.118: 0.150 m^3/s). For both biogas and LPG fuels, the maximum shaft power of the water pump engine reaches 3.9 kW at 6600 rpm. The maximum waterpower generated by the water pump engine using biogas and LPG is 1.26 kW and 1.6 kW at 6600 rpm, respectively, while the maximum efficiency reaches 32% with biogas and 41% with LPG. Therefore, the higher the water pump engine speed, the higher the values of shaft power, engine power, discharge, and efficiency. The efficiency ratio comparison between biogas and LPG at 6600 rpm is 3:4.

Keywords: human waste; LPG; modified water pump engines; biogas.

1. Introduction

The economy relies on energy to function, while humans depend on it for their daily activities. To meet energy demands, natural resources both non-renewable and those that regenerate over long periods are utilized. In Indonesia, energy consumption has increased annually. According to Rajendran et al. [1], the country's coal, gas, and crude oil reserves are projected to last for approximately 82.59, and 23 years, respectively.

The Ministry of Energy and Mineral Resources' Data and Information Center reports that irresponsible fossil fuel consumption not only depletes energy reserves but also negatively impacts the environment by emitting greenhouse gases like CO_2. Based on the basic scenario and other methodologies referenced in Asankulova and Obozov study [2], CO_2 emissions in a business-as-usual (BAU) scenario were projected to reach nearly 1,000 million tons by 2020 and 2,129 million tons by 2030. However, under a CO_2 emission mitigation scenario, these numbers could be reduced to 706 million tons in 2020 and 1,219 million tons in 2030.

The decline in energy reserves and the recent fuel oil scarcity in Indonesia demand effective solutions, prompting the government to implement policies such as the conversion of kerosene to gas. However, replacing kerosene with fossil-based energy sources like liquefied petroleum gas (LPG) and liquefied natural gas (LNG)

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requires further consideration. These alternatives have limited reserves and are non-renewable, making the transition merely a temporary measure. As fossil fuel availability continues to decline while energy consumption rises. Therefore, researchers are actively exploring new alternative energy sources that are accessible, cost-effective, and environmentally friendly.

One key strategy to address energy scarcity is conservation, which involves both energy-saving measures and the development of renewable energy sources. Government policies that support sustainability are crucial in this effort. One promising alternative energy source in Indonesia is biogas. With a high calorific value of 4,800 - 6,700 kcal/m³ and a substantial methane (CH_4) content, biogas holds significant potential as a renewable energy solution [3]. Additionally, biogas is considered safer than LPG, as its methane content has a lower specific gravity (55), reducing the risk of leaks and explosions [2], [4]. Wahyuni and Yuanita [4] states that biogas can ignite at an energy level of 6,400 – 6,600 kcal/m³ [5]. One cubic meter of biogas provides energy equivalent to 0.62 liters of kerosene, 0.46 liters of LPG, 0.52 liters of diesel oil, 0.08 liters of gasoline, and 3.5 kg of firewood. Moreover, biogas is a clean fuel that does not produce smoke or charcoal, ensuring kitchen utensils remain clean and minimizing indoor air pollution [6].

Microorganisms use organic raw materials to make biogas during the methane fermentation process. Methane (CH_4) and carbon dioxide (CO_2) make up the majority of its components, with trace amounts of siloxanes, hydrocarbons (HC), ammonia (NH_3), hydrogen sulfide (H_2S), nitrogen (N_2), hydrogen (H_2), oxygen (O_2), and water vapor (H_2O) also being present [7], [8]. Various substrates, including organic waste from food sources, industry, or agriculture, as well as biodegradable fractions from municipal garbage, are used to produce biogas [9], [10]. Furthermore, research has been conducted in certain institutes on the utilization of alternative substrates, such as microalgae, for the production of biogas [11], [12].

Methane fuels include biogas, biomethane, and natural gas (high-grade natural gas, or LNG; CNG). In cogeneration systems, biogas is primarily used to produce heat and power [13], [14]. Following purification to meet biomethane quality standards, this gas can be fed into natural gas distribution networks or utilized as fuel for car engines that fire spark plugs (SP) and self-ignition (SI) [15]–[17]. Additionally, biogas can be used in fuel cells [18], [19] or to create syngas [20], [21], which are semi-finished products used in the manufacturing of other chemicals including hydrogen [22], [23] and dimethyl ether (DME) [24].

The discovery of simple applicative technology in producing biogas has made this technology already applied in the community because it is cheaper and easier to operate. Although its application as a new major as a stove fuel in households. For this reason, researchers are trying to further study the application of biogas as a fuel substitute in gasoline motors, both for generators and other mechanical drives. With the content of hydrogen sulfide in biogas, purification is necessary when used in motor vehicles so that it is not corrosive. In the previous research, it is necessary to make modifications to the carburetor, combustion chamber (increase the compression ratio) and propose during ignition in order to get perfect results and optimal engine work. This is because biogas has a higher-octane equivalent value and slower fire propagation ability. Thus, if the compression ratio is increased and the ignition is proposed, it will get optimal performance results [25].

Biogas fuel is a promising alternative due to its high octane number of 130, surpassing Pertamax (94), gasoline (92 and 98), LPG (112), and CNG (13 RON) [26]. Previous research has primarily focused on fuel comparisons, discharge rates, and track length, yet comprehensive studies on biogas efficiency in water pump engines remain limited. For instance, gasoline-powered water pumps typically produce a discharge of 0.0034 m³/sec, while kerosene yields 0.0026 m³/sec [27]. A comparative study on biogas fuel derived from animal manure versus Pertamax in water pump engines—analyzed using rpm variation and track length methods—revealed that at 3000 rpm and an 8-meter track length, biogas achieved a peak discharge of 0.0090 m³/sec, only slightly lower than Pertamax at 0.0092 m³/sec [28]. These findings highlight the potential of biogas as a viable and efficient fuel alternative. It can be useful method to give another choice using fossil fuels like LPG, also reducing the gas emission that have consequences.

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2. Experimental Methods

The materials used are organic solid waste and human feces that come from garbage shelters and public toilets. The anaerobic digestion process begins with a fermentation process in a digester without oxygen in the area around East Bekasi District, Bekasi City. Next, the research was carried out by the method of modifying the carburetor on the water pump engine part as well as direct measurement experiments and analysis of the calculation of water pump results using biogas and LPG fuels.

2.1. Organic Solid Waste as Fuel

The gas known as biogas is created when microorganisms break down organic waste in an anaerobic environment. Air weights 20% more than biogas. The temperature range at which biogas can be burned is 650–750°C. Biogas has no color or smell. It burns with a bright blue flame like LPG gas. Methane gas has a calorific value of 20 MJ/m^3 and a 60% combustion efficiency when burned in traditional biogas stoves [29]. The foundation of the biogas reactor is the anaerobic pollution process, which breaks down organic matter by activating Methaneorganic bacteria. These bacteria are naturally present in waste that contains organic matter, including human and animal dung as well as organic waste from homes [30]. Anaerobic processes occur in a variety of environmental settings where the detail illustrates operating ideal conditions seen in Table 1 and mechanism of fermentation process happened in anaerobic biogas digestion shown in Figure 1.

Table 1. Operating conditions in the anaerobic digestion process

No.	Parameter	Value
1	Mesophilic temperature	35°C
2	Thermophilic temperature	54°C
3	pH	7-8
4	Alkalinities	2500 mg/L (minimum)
5	Retention time	10 – 30 days
6	Saturation rate	0.15 – 0.35 kg VS/m^3/day
7	Biogas yield	4.5 – 11 m^3/day VS
8	Methane content	60-70 %

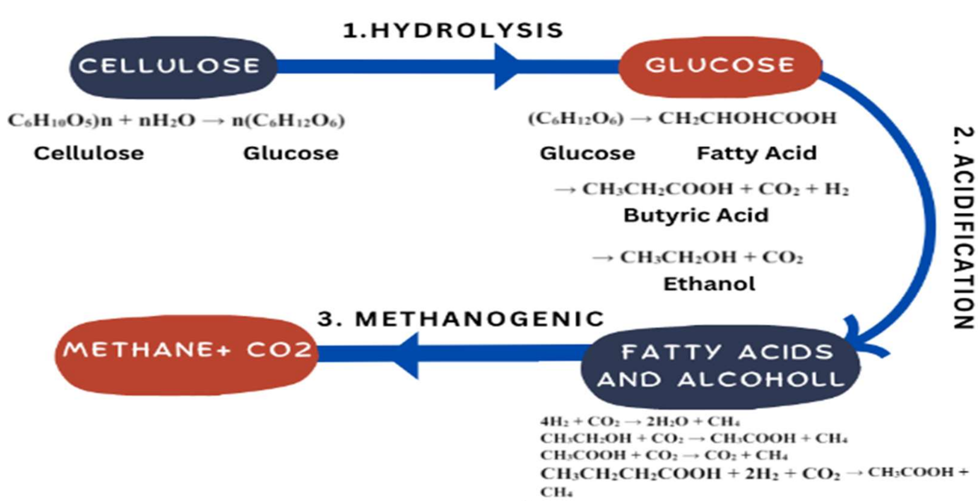

Figure 1. Flow diagram of the anaerobic fermentation process

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Three steps are involved in the formation of biogas: (a) hydrolysis, which is the breakdown of complex organic materials into simple forms by altering the polymer's structure into a monomer form; (b) acidification, which is the process where the monomer components (simple sugars) formed during hydrolysis become food for bacteria that produce acid. Acetic acid, propionate, format, lactate, alcohol, and a few grains of carbon dioxide gas, hydrogen, and ammonia make up the final product, which is essentially a straightforward reworking of sugars; fiber (C) Methaneorganic, where methane gas is formed during the methane organic stage. This process, which converts sulfate and other sulfur components to hydrogen sulfide, also involves sulfate-reducing bacteria.

Explanation of the procedure for overhauling cellulose till gas is shown in Figure 1. The bacteria involved in this anaerobic process are methanogenic bacteria that create methane from acetic acid, hydrogen, and carbon dioxide; hydrolytic bacteria that break down organic matter into sugars and amino acids; fermentative bacteria that turn sugars and amino acids into organic acids; and acidogenic bacteria that convert organic acids into hydrogen, carbon dioxide, and acetic acid [23].

Recently, biogas process optimization has been focused on the control process so that the microorganisms involved are in a balanced state. This accelerates the process by improving the digester design and fermentation operation at higher temperatures and by increasing the biogas produced from lignocellulose biomass base through initial treatment.

Organic solid waste and human feces from garbage shelters and public toilets then stored in the digester to be overhauled naturally in the digester with a vacuum or anaerobic state at a temperature of 35°C. On the formation of biogas on days 1-8, the first gas that comes out is CO_2 gas and must be disposed of, while on days 10-14 only methane (CO_4) and carbon dioxide (CO_2) are formed, on day 14 the gas formed can be used. The content in the biogas produced depends on the type of raw material used, for example the composition of several gaseous elements in general in the biogas output shown in Table 2.

Table 2. Gas composition (%) in biogas

No.	Types of gases	Cow manure (%)	Mixture of livestock manure and agricultural waste (%)
1	Methane (CH_4)	65.7	55 – 70
2	Carbon dioxide (CO_2)	27	27 – 45
3	Nitrogen (N_2)	2.3	0.5 – 3.0
4	Carbon monoxide (CO)	0	0.1
5	Oxygen (O_2)	0.1	6
6	Propane (C_3H_8)	0.7	-
7	Hydrogen sulfide (H_2S)	Unmeasurable	Very little
8	Level calor (cal/m^3)	6513	4800– 6700

2.2. Biogas System Mechanism

The raw materials for the anaerobic digestion process come from raw materials of organic solid waste and human waste in Indonesia. First, organic solid waste and human feces from garbage shelters and public toilets will enter directly into the inlet of biogas reactor. In this experiment there is no catalyst used. That is why it needs more time to process but effective in reducing the processing cost.

The organic raw materials are then stored in the digester to be overhauled naturally in the digester into an airtight or anaerobic condition at a temperature of 35°C. In the formation of biogas on 1-8 days, the first gas that comes out is CO_2 gas and must be disposed of, while on days 10-14 only methane and CO_2 gas are formed. On the 14th day, the gas formed can be used. With the existence of pipes and valves for the release of biogas in the digester, the formed biogas can be used to replace gasoline fuel in water pump engines after modification first. Meanwhile, the output from the remaining fermentation of hydrocarbon material will be used as fertilizer for surrounding plants.

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2.3. Experimental Systematics

The experiment was carried out by modifying the carburetor on the water pump engine part as well as direct measurement and analysis of the calculation of the results of the water pump using biogas fuel and LPG fuel. As shown in Figure 2, the systematics of the experiment were carried out in the village of Bekasi Jati in the city of Bekasi. Raw materials for organic solid waste and human feces from garbage shelters and public toilets are then processed in a digester to be converted to produce biogas.

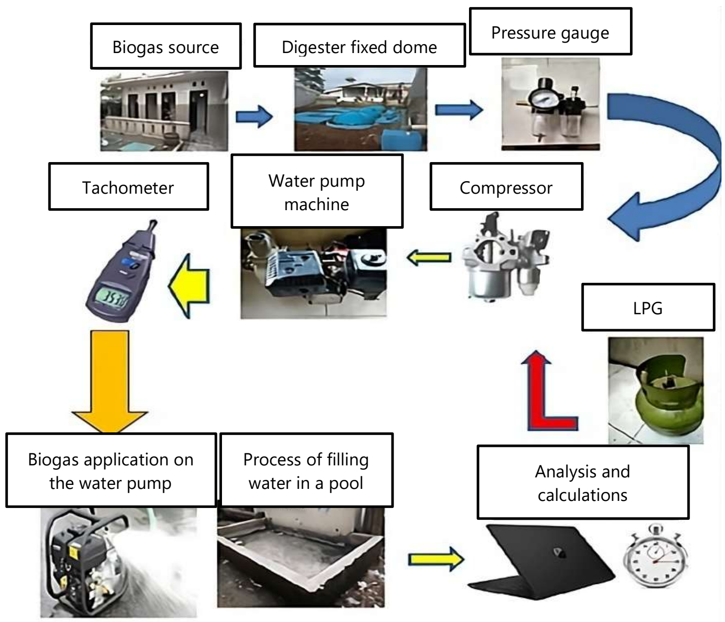

Figure 2. Schematic of experimental apparatus

Furthermore, biogas will flow through pipelines and valves before entering the carburetor and combustion chamber of biogas first through a pressure gauge. The pressure gauge, which functions as a pressure regulator as well as filtering the gas, will enter the carburetor. After passing through the pressure gauge, carburetor was then modified. Subsequently, the biogas will enter the combustion chamber and move the water pump machine so it can clean the pond with a volume of 1,318 m^3. It then will be analyzed for the results of discharge, shaft power, waterpower and the efficiency of the water pump machine using biogas fuel with a comparison of LPG fuel.

2.4. Operating Conditions of Biogas System

This research has an objective to compare fuels performance on water pumps using biogas and LPG fuels. It is necessary to modify the operation system on biogas and LPG fuels that use water pump engines that usually use gasoline fuel in liquid form. Complete process of anaerobic digestion as schematic operating condition shown in Figure 3. First, gas pressure must be equated with using a valve opening, biogas uses a valve opening of 180° while LPG is 40°. Modifications must be made if the fuel used is a gas type, then some components on the carburetor must be removed.

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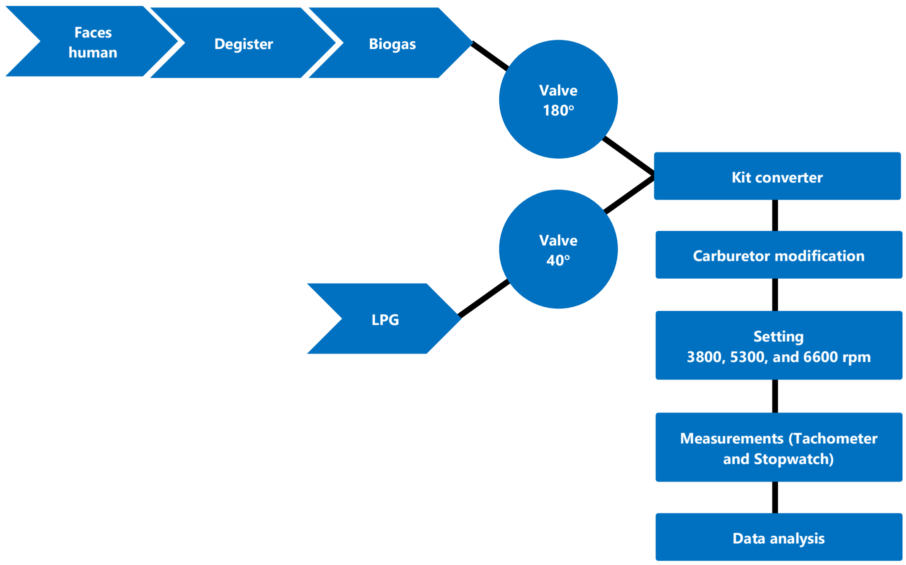

Figure 3. Schematic of operating conditions

This treatment is carried out because of the different type of fuel; liquid form is replaced to gaseous form, so there are several components that must be removed. These types of components include:

a. Float valve and float that function as a fuel height stabilizer.
b. The piston valve and jet needle function to regulate the amount of venturi in the carburetor.
c. Main jet which functions to supply the fuel that is saturated into the combustion chamber.
d. Slow jets that serve to supply fuel when stationary rotation must be closed.

The modification is carried out on the carburetor of the water pump engine. The composition of biogas, which cannot be determined, makes the amount of mixture between gas and air can only be adjusted manually. In addition, this study uses the variation of engine rotation between 3800, 5300 and 6600 rpm which can be seen with a tachometer for engine rotation adjustment. It has a function to find out the minimum and maximum results of the engine work test. In addition, the machine work test will be analyzed by filling the pool fully with a volume of 1,318 m^3. It is calculated for how long it takes to find out the water discharge produced by stopwatch. Thus, the discharge is produced, the next discharge is analyzed for shaft power, waterpower and water pump engine efficiency using a comparison of biogas fuel with LPG. In this research, there are some parameters examined such as water discharge, torque, the engine rotation and efficiency of water pump engine.

2.5. Water Pump Comparison Parameters

The data obtained directly from the test results are: (a) rotating speed of the water pump machine, (b) volume of the pool, (c) time needed to fill the pool, and (d) head pump. From the measured data, it can be processed to calculate various water pump comparison parameters, including:

a. Water discharge [31]

$$Q = \frac{V}{t} \tag{1}$$

where Q is the water discharge (m^3/s), V is the volume of water (m^3), and t is the time (s).

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b. Power shaft [31]

$$P = \frac{2\pi N\tau}{60 \times 1000} \quad (2)$$

where P is the shaft power (kW), N is the rotational speed (rpm) and τ is the torque on the shaft (Nm).

The torque obtained from:

$$\tau = (5252 \times p)/N \quad (3)$$

c. Water power [31]

$$P_w = Y.g.Q.H \quad (4)$$

where Pw is the waterpower (kW), Y is the specific weight of the fluid (typically 1000 kg/m^3 for water), g is the gravitational acceleration (9.8 m/s^2), Q is the water discharge (m^3/s), and H is the total head (m).

d. Pump efficiency [25], [32]

$$\eta = \frac{P_w}{P} \times 100\% \quad (5)$$

3. Result and Discussion

3.1. Water Pump Discharge on Biogas and LPG fuels

Figure 4 presents the analysis results of discharge calculations in relation to variations in the water pump machine's rotation. The direct measurements were made for the time and volume of water filling using a tank measuring 1,318 m^3 with a specification of (2.7 × 1.4 × 0.34 m). It was found that the water discharge produced by the water pump machine on the highest biogas fuel was 0.118 m^3/s at 6600 rpm. Meanwhile, the highest discharge LPG produced was 0.150 m^3/s. Thus, it can be concluded that the higher the engine speed, the faster the water discharge will be. The result of LPG fuel water discharge has a higher value than biogas in the same engine rotation because the flow of LPG gas is larger and constant than the flow of biogas that comes out of the digester.

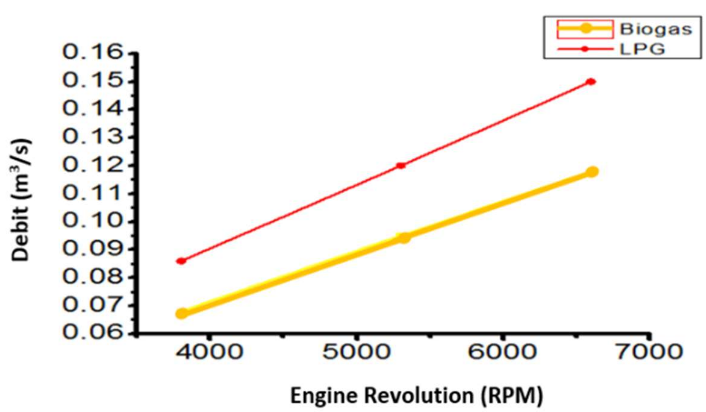

Figure 4. Discharge analysis results on water pump

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A related study by Samnur and Irfan [23] suggests that biogas-powered water pumps can achieve comparably discharge rates with Pertamax (gasoline), which also point out the substantial essence of utilizing biogas to obtain optimal outcomes. The discharge rates at an engine rotating speed of 2500 rpm of biogas and Pertamax were determined to be 0.4758 and 0.5113 m^3/min, respectively, indicating a small difference. It implies for comparison consideration; the maximum discharge rates of the biogas remain competitive with that of the LPG under certain conditions albeit the LPG is likely always going to be superior at higher speeds. In addition, the study of Abdel-Galil et al. [25] underscores that biogas can efficiently drive water pumps, in most cases under relative positive efficiencies in excess of conventional fueling, such as petrol and kerosene, under low-speed operating conditions. Although LPG can reveal better performance figures at instantaneous velocities, biogas still can be used also on engines designed to run with LPG not to mention its applications for overcoming Nox emissions somewhere running on CNG. Overall, while LPG shows better discharge potentials in high-speed applications, biogas provides a sustainable alternative that can be competitive if the parameters are tuned optimally. This agrees with studies in the literature regarding alternative fuels of irrigation agricultural systems which highlights that performance and environmental impact assessment are necessary when selecting a fuel combination for water pumping applications.

3.2. Waterpower in Biogas and LPG Fuels

Figure 5 presents the analysis results of waterpower calculations in relation to variations in the water pump machine's rotation. An analysis was carried out of the water discharge that had been produced with a specific gravity of 1000 kg/m^3 of liquid, a graffiti force of 9.8 m/s^2 and the height of the pump. The highest waterpower produced by the water pump machine on LPG fuel is 1.6 kW, biogas is 1.26 kW at 6600 rpm. So, it can be concluded that the greater the discharge produced by the water pump machine, the greater the waterpower produced. In the waterpower product, LPG fuel has a higher value than biogas in the same engine rotation, because the higher the discharge produced, the greater the waterpower will be.

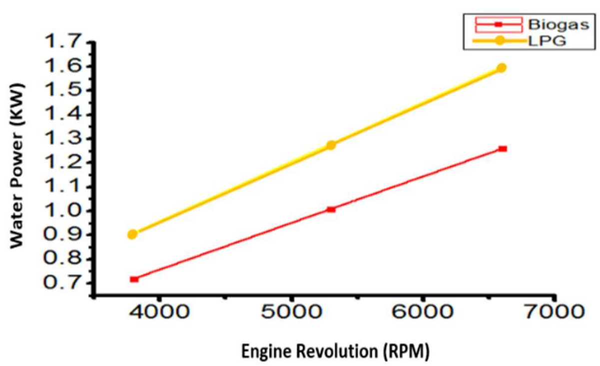

Figure 5. Waterpower analysis results of water pump machine

Regarding on the findings reported by Perdana et al. [32], other experimental investigations on the use of biogas as a fuel for water pump engines have demonstrated comparable performance outcomes. At an engine speed of 2500 rpm, the pump operating on biogas achieved a flow rate of 0.4758 m^3/min, which is only marginally lower than the 0.5113 m^3/min recorded when using Pertamax (gasoline) fuel. At 2500 rpm engine speed, a pump powered by the biogas was able to deliver a flow rate of 0.4758 m^3/min, still not much below that achieved using the Pertamax (gasoline) variant of fuel (0.5113 m^3/min). At high speeds or operating conditions, the low performance of biogas compared to conventional fuels like LPG or gasoline indicates that biogas is only suitable for low-speed water pumps. There is interesting result that the potential of biogas delivers comparative performance to conventional fuels across different applications, especially highlighting its environmental and sustainability credentials. The result concludes that LPG can provide superior PE performance, however biogas

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could potentially be a better target in a mediums-long term agricultural society especially when biomass and renewables are common in a region [25]. In other word, it shows that while LPG is better at providing more power for less, biogas is still an important green fuel that has tangible benefits to environmental impact mitigation and green practice.

3.3. Water Pump Shaft Power on Biogas and LPG Fuels

Figure 6 shows the inverse relationship between speed and the torque of the pump engine. The smaller the torque value, the smaller the rotation. Meanwhile, the greater the torque result is obtained from engine power compared to engine rotation, where engine torque analysis is carried out against engine rotation. The result of constant engine shaft power on biogas and LPG fueled is the same value, which is 3.9 kW every rotation (rpm). In addition, the constant shaft power value is affected because the valve opening of biogas and LPG is equalized in comparison. The engine rotation of biogas and LPG fuel has the same rotation speed. Therefore, it can be concluded that due to the same torque value of biogas and LPG fuel for each variation of engine rotation, the power of the biogas and LPG fuel shaft is also constant.

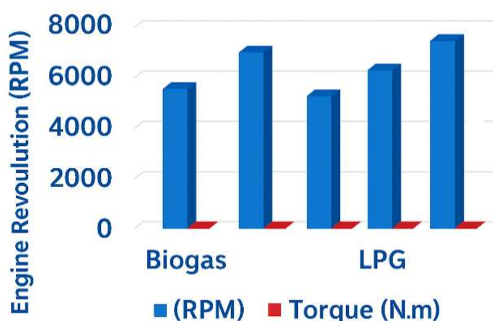

Figure 6. Torque measurement at different engine revolution variations

The power output from a generator set using biogas and LPG is shown to be rather close. Negligible changes are found in performance measures like torque and specific fuel consumption (SFC) when comparing to other research, such as the study by Artayana et al. [33]. For example, Artayana et al. [33] found that the biogas-powered generator generated about 0.2444 kW at a load of 200 W is in good agreement with the analysis's conclusions of consistent power production. Additionally, the work of Sunaryo [34] found that although LPG often performs better in terms of fuel efficiency because of its higher calorific value, biogas's total efficiency is still competitive when sustainability and environmental benefits are taken into account. Furthermore, a recent study showed that the fuel type had a considerable impact on engine performance parameters including torque and power, with LPG showing marginally higher thermal efficiency than biogas. The study, however, highlights that biogas may be used efficiently with the right engine design changes to maximize performance. It can be confirmed that both fuels can produce equivalent outcomes under controlled circumstances. In conclusion, even if LPG might be more efficient in some situations, biogas is still a good substitute fuel for water pump applications because, when used in identical circumstances, it produces comparable power and torque.

3.4. Efficiency of Water Pumps on Biogas and LPG Fuels

Figure 7 presents the analysis results of the water pump machine's efficiency concerning variations in its rotational speed. Efficiency obtained from the analysis of shaft power is divided by waterpower and produced by the pump, where the maximum efficiency obtained is 32% in biogas and 41% in LPG. It can be concluded that the faster the rotation of feeding machine, the greater the waterpower produced. Meanwhile, the greater the waterpower produced, the greater the efficiency of the pump engine will be, because the engine shaft power is constant.

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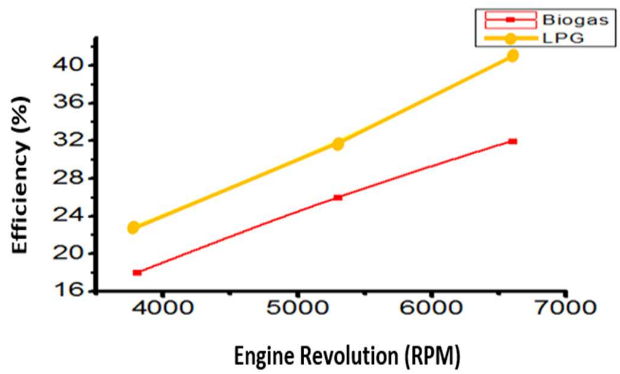

Figure 7. Efficiency analysis results of the water pump engine

4. Conclusion

Performance testing of biogas and LPG fuel application was successful to run the pump engine. The performance characteristics of the highest discharge generated by the water pump engine were obtained at engine speed 6600 rpm, where the biogas fuel amounted to 0.118 m^3/s and LPG amounted to 0.150 m^3/s. The highest torque was obtained at engine speed 3800 rpm which amounted to 7.6 Nm. Moreover, the greater the engine speed, the smaller the torque value. The maximum shaft power of the water pump engine using biogas and LPG fuel is the same, which is 3.9 kW at 6600 rpm. However, the highest waterpower produced by the water pump engine at 6600 rpm, on biogas fuel amounted to 1.2 kW and LPG amounted to 1.6 kW. In conclusion, the comparation energy efficiency of biogas fuel is 32% and LPG 41% at 6600 rpm water pump engine rotation. Biogas is considered as a viable and efficient as alternative fuel. It can be useful implication for economical aspect of reducing the gas emission that can be consequences of fossil fuels.

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