The use of gasoline for primary energy consumption can reduce crude oil, contained in the earth. The development of alternative fuels such as biogas and biofuel is very critical to overcoming this problem. Biogas requires purification to remove some contaminant particles that interfere with the combustion process. The packed column is generally applied to absorb and separate gas and liquid mixture. It is more efficient due to the liquid flows down the column of steam naturally without the supply of energy from outside the system. This study focuses on determining the effect of the packed column biogas purification process. Biogas is applied as an alternative fuel in spark-ignition engines (SIE). The test is carried out using a chassis dynamometer to obtain power and torque data. The use of the packed column for biogas fuel purification can produce higher performance compared to unrefined biogas. The unrefined biogas still contains impurities that can interfere with the combustion process. This condition is proven by measuring the power and torque of the vehicle on the chassis dynamometer, where the filtered biogas produces higher power and torque.

Tests were carried out both using the packed column and without the packed column. Variations from speed to torque, to power, to SFC and BMEP are considered. In this study, validation is in good agreement with previous studies. Overall, the results show that the average error between using the packed column and without the packed column for torque, power, SFC and BMEP is increased by approximately 7 %. Purification of biogas using the packed column using Ca(OH)$_2$ can bind CO_2 and obtain pure methane gas with a higher heating value.

In conclusion, the packed column for biogas purification as fuel for motorcycle injection systems can be applied

Keywords: biogas, packed column, torque, power, SFC, BMEP, motorcycles, injection, performance

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IMPLEMENTATION OF PACKED COLUMN FOR BIOGAS PURIFICATION AS FUEL FOR MOTORCYCLE INJECTION SYSTEMS FOR PERFORMANCE IMPROVEMENT

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1. Introduction

The use of diesel fuels causes disadvantages that are harmful to the environment with the resulting pollution. Besides, the use of gasoline fuel can reduce crude oil contained in the earth. The development of alternative fuels such as biogas and biofuel is very critical to overcoming this problem. Biofuels and biogas are fuel products derived from the anaerobic fermentation of organic material [1]. The type of residual material that is fermented into biogas affects the percentage of methane production in the composting process. In general, there are 3 types of materials composted by anaerobic bacteria, including: sewage sludge, yard waste and food waste. The composted sewage sludge produces a low percentage of methane and results in thick cell walls. Although the percentage of methane production can be increased by certain treatments on thermal, mechanical and chemical parameters, which are costly. Yard waste has a compact cell structure, so it can inhibit the fermentation process by anaerobic bacteria. This condition causes the digestion process to take a long time and the yield of biogas is low. Anaerobic digestion of food waste shows a very good level of methane productivity. However, process imbalances are frequent as indicated by high short-chain fatty acid (SCFA) levels and low pH values [2]. Biogas often still contains impurity gases, therefore it is very important to purify biogas from impurities. The largest content after methane gas is CO_2 gas, so a method is needed to separate CO_2 from biogas.

Anaerobic fermentation in biogas production results in 60 % methane gas (CH_4) and 40 % carbon dioxide (CO_2). Moreover, the fermentation process also produces small quantities of other substances such as H_2S, H_2, N_2, NH_3, O_2, CO, and particular impurities [3]. Methane is the main gas used for fuel from biogas fermentation. The biogas purification process is carried out in a specific process to separate specific impurities. Several methods are used to separate CO_2 from biogas, including Physical and chemical CO_2 absorption, Pressure Swing Adsorption (PSA), and Vacuum Swing Adsorption (VSA), Membrane separation, Cryogenic separation, and Biological methane enrichment [4]. The packed column is generally applied to absorb and separate gas and liquid mixture due to suitability for small installations, high liquid-gas ratio, low pressure drop, low cost and high efficiency [5]. Biogas can be used as a substitute for fossil fuels in motor vehicles. Biogas will provide lower exhaust emissions for motorized vehicles than fossil fuels and can help improve local air quality [6]. Although recent studies have investigated the use of biogas in motorized vehicles, information on the effect of biogas purification by the packed column and use as a motorcycle fuel has not been discussed yet.

This determines the relevance of scientific research, because the capabilities of the packed column method are expanding due to its advantages, among others, the high liquid-gas ratio, low pressure drop, low cost and high efficiency for purifying biogas used as motorcycle fuel.

2. Literature review and problem statement

The application of a dual-fuel engine, which consists of gasoline and biogas, can reduce emissions produced by spark-ignition engines. The use of dual fuel and stand-alone fuel gasoline results in different vehicle performance. SIE engines operated using raw biodiesel cause a decline in performance, which is indicated by an 18 % decrease in BEP even though there is an increase in BSFC by 66 % when tested under the same conditions in full-tank gasoline under the same speed range. A decrease in thermal efficiency up to 12% also occurs in vehicles filled with raw biodiesel. This reduction in performance is due to the unstable and less uniform supply of fuel and air to the combustion chamber [6]. Even there has been a decrease in vehicle performance, the application of biogas has a positive impact on emission reduction. The use of dual fuel can produce a reduction in emissions, especially in NO_X gas and an increase in torque of up to 50 % compared to single fuel – ethanol [7]. The decrease in torque and power of vehicles using biogas fuel is due to the low heat value (LHV) and lower biogas combustion temperature than fossil fuels. This condition causes combustion to occur in lower laminar flame conditions that result in unstable combustion [8]. The laminar combustion process causes combustion temperature decrement and leads to an incomplete combustion process and increases CO emissions [9]. Some modifications are made to overcome this problem, such as adjusting the injection timing, fuel port, air-fuel ratio (AFR) setting, and compression ratio. The use of dual fuel [6–9], gasoline & biogas, can produce emission reduction, but the use of biogas fuel purified from impurities has so far remained unexplored.

One method to remove CO_2 from biogas is pressure swing adsorption. Biogas requires purification to remove some contaminant particles that interfere with the combustion process. The biogas purification process aims to obtain a high percentage of methane gas. Pressure swing adsorption (PSA) is a biogas purification process by means of absorption and can produce more than 90 % methane. This process requires a very high cost so that an alternative step is needed to filter the biogas [10]. The cost of the biogas absorption process can be reduced using raw material and expanded perlite. The absorption process using perlite requires a lower desorption temperature (200 °C) for regeneration compared to active carbon, which requires a temperature of more than >400 °C. In addition, perlite has a fast desorption kinetics (20 min) and results in a cleaner production of biogas [11]. Additional purification can be performed using the packed column [5], water scrubber package with spoons carriage [12], biomass ash [13], and activated carbon [14]. Some of the weaknesses of this pressure swing adsorption method (PSA method) as reported by Minh Ho (2020), among others: limited adsorption and inability to handle CO_2 gas concentration, about 1.5 % compared to the packed column where the adsorption is greater.

The packed column is generally applied to absorb and separate gas and liquid mixture. It is more efficient due to the liquid flows down the column of steam naturally without the supply of energy from outside the system. The packed column has several advantages, including a large liquid transfer area, absorption speed, and higher efficiency than a spray and bubble column [5]. However, packed column applications are costly due to high pressure in the system, allowing leakage and deposition of precipitates on packing surfaces. The process of biogas purification in the packed column is carried out through 3 stages. The first is biogas separation with a traditional bottom column to avoid biogas bubble formation and leakage. Subsequently, the process water is recycled with a static mixer to enhance CO_2 desorption from the water, by using the technology development. The scrubbing system is the final process to absorb carbon dioxide [15]. This study focuses on determining the effect of the packed column biogas purification process. The biogas is applied as an alternative fuel in the spark-ignition engine (SIE). The test is carried out using a chassis dynamometer test to obtain power and torque data.

Research on biogas as a motorcycle fuel has been carried out by previous researchers. [16] studied the use of purified biogas based on the calcination method in motorized vehicles. In this study, biogas will be purified by varying the flow rate and tested for motor performance at 1,500 rpm, 2,500 rpm, 3,500 rpm and 4,500 rpm. Increasing levels of CH_4 gas in biogas after purification results in better power and lower fuel consumption than biogas before purification. [17] conducted research on the analysis of the performance of engine fuel with purified biogas based on Fe_2O_3 absorber in 2014. The results showed that the power produced by the engine increased with engine speed.

But there were unresolved issues related to contact areas and flow turbulence. The reason for this may be that some previous approaches were not equipped with packing to expand the contact area and flow turbulence. A way to overcome these difficulties can be the packed column. This approach was used in [18], however, all this suggests that it is advisable to conduct a study on the implementation of packed column for biogas purification as fuel for motorcycle injection systems to improve performance.

3. The aim and objectives of the study

The aim of this study was to determine the effect of the biogas purification process using the packed column applied to a conventional motorcycle. The biogas purification process is carried out to obtain purified CH_4 gas. This purified CH_4 gas is used as motorcycle fuel and its performance is tested using a dynamometer test.

To achieve this aim, the following objectives were set:

– the validation process is carried out to determine the appropriate temperature for heating water with a biogas stove. The method used is the Water Test Boiling (WTB) method;

– the relationship between engine speed and torque for two different cases using the packed column and without the packed column;

– engine speed and power relationship of two different cases using PC and without PC;

– the relationship between engine speed and specific fuel consumption for two different cases using the packed column and without the packed column;

– engine speed and brake mean effective pressure for two different cases using PC and without PC.

4. Materials and methods

4. 1. Research variables

The research variable is the object that is the center of attention in this study. There are some data used in this study, among others:

1) data validation with the water boiling test method where biogas is used to heat the water. Water temperature data collection is carried out every 2.5 seconds and data on the relationship between temperature water versus time are plotted;

2) data on the performance of motorcycles using biogas fuel, both purified and without purification were also taken using Dynotest VR-Tech V1.5. The performance data were also collected including: torque, power, SFC and BMEP. Torque, power, SFC and BMEP data were collected for every rpm change. The rpm variation data in this study were 3,000 rpm, 3,100 rpm, 3,200 rpm, 3,300 rpm, 3,400 rpm, 3,500 rpm and 3,600 rpm. Furthermore, the data are plotted for the relationship between torque to rpm and so on using Tecplot 360.

4. 2. Research methodology for the performance of biogas-fuelled motorcycle

The research methodology for motorcycle performance is as follows. The preparatory step is to fill the fuel canister with biogas on a motorcycle. Place the motorcycle on the dyno test. Turn on the motor and leave it for a moment so that the engine reaches a certain temperature that is read on the computer. Operate the motor in gear/transmission 3, then run the motor until it reaches 3,000 rpm, press the START button on the computer, open the maximum throttle until the engine shows its maximum capability (maximum RPM). After the motor reaches its maximum capacity, immediately press the START button again, then on the PC monitor you can see the results in the form of graphs and tables of torque and power. The same way is done for SFC. For BMEP, calculations are carried out using the formula after the power data is obtained. Next, plot the data of Torque vs rpm, Power vs rpm, SFC vs rpm and BMEP vs rpm.

4. 3. Conversion kit

Conversion kit is a tool used to convert from gasoline fuel to biogas fuel. This conversion kit is installed on the motor vehicle that is being tested. The use of the conversion kit must be adjusted based on the type of use. There are 3 types of conversion kits, stand-alone gasoline fuel, dual fuel and mixed fuel. Fig. 1 shows the biogas flow through the conversion kit system. The components of the biogas conversion device consist of a biogas storage tank, a regulator, and an air-fuel mixer. In the conversion kit, a mixer installed in front of the throttle supplies biogas into the air stream that enters the cylinder and reacts to the pressure in the manifold to measure the amount of fuel supplied to the motor. Mixer selection is based on the air capacity required by the motor. If it is too small, the maximum power of the motor will not be achieved, while if it is too large, the motor performance at low rotation will drop drastically, even the motor is difficult to start. The gasoline flow shut-off valve (in dual fuel systems) is actuated by a solenoid from the fuel selector switch attached to the motor vehicle. When biogas is selected as fuel, this valve closes the flow of gasoline to the cylinder.

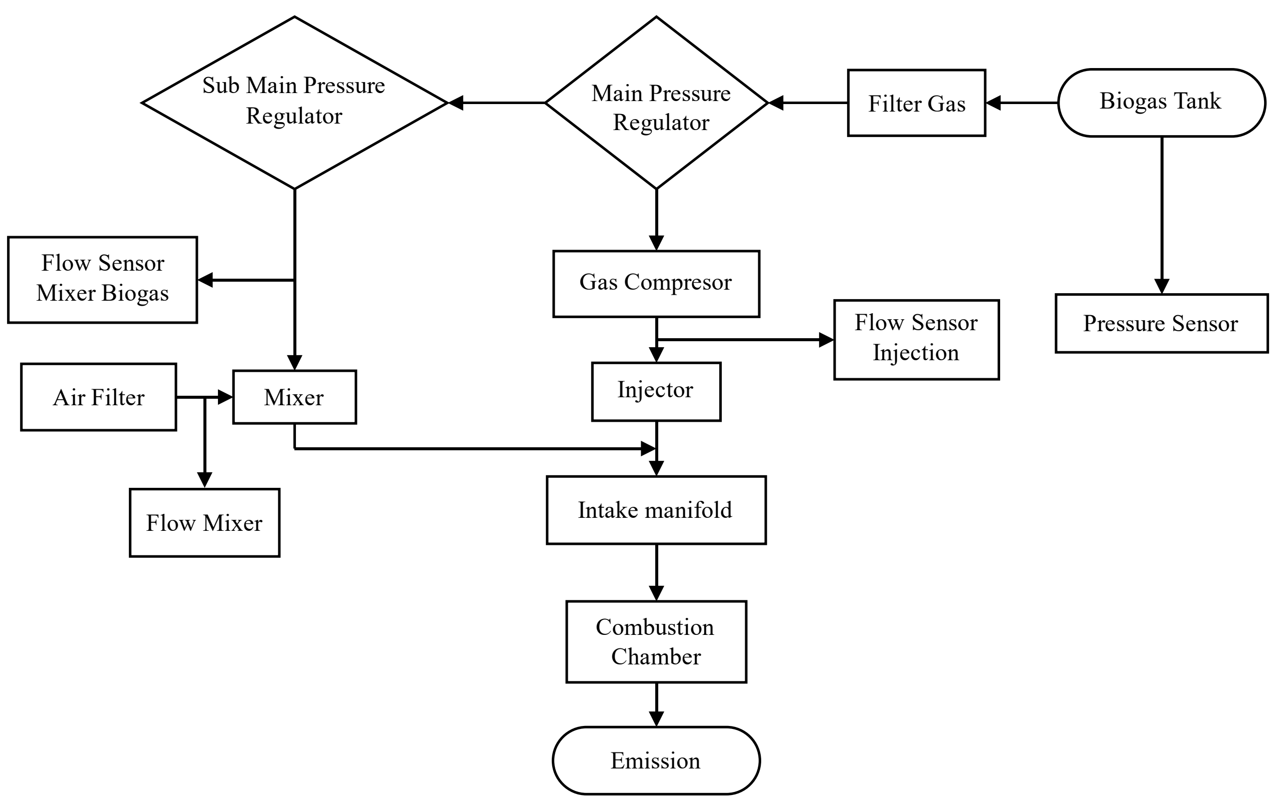

Fig. 1. Biogas flow through the conversion kit system

The process of composing biogas is carried out by anaerobic fermentation to form methane gas in a digester. The fermentation process of cow manure takes 7 to 10 days to produce biogas with an optimum temperature of 35 °C and an optimum pH in the range of 6.4–7.9. The biogas forming bacteria used are anaerobic bacteria such as Methanobacterium, Methanobacillus, Methanococcus, and Methanosarcina. Validation is carried out using WTB by heating water in a measuring cup using a stove that has been modified into a biogas-fuelled stove [19]. The validation is performed through the parameters of time and surface temperature in the WTB test. Fig. 2 shows the relation between time and temperature from the validation results of Muji's experiment study (2017–2018). This study produces a WTB trend line that is similar to the reference data. In general, the graph shows that in the WTB test, the temperature will increase with increasing water heating time. This is consistent with the theory of heat transfer, especially the theory of sensible heat $Q=M{\cdot}C_p{\cdot}\Delta T$ where the greater the Q, then automatically ΔT is also getting higher.

4. 5. Engine type

The specifications of the motorcycle used in this experiment are shown in Table 1.

Table 1

Tested motorcycle specifications

Specification	Honda Vario 125
Type of machine	4 stroke, SOHC, eSP
Stroke Volume	124.8 cc
Fuel Supply System	PGM-FI (Programmed Fuel Injection)
Diameter×Strokes	52.4×57.9 mm
Transmission Type	Automatic Otomatic, V-matic
Maximum Power	8.2 kW (10.8 HP)/8,500 rpm
Maximum Torque	10.8 Nm (1.1 kgf.m)/5,000 rpm

Table 1 provides specifications of the motorcycles tested. Specifications of motorcycles like this are often used for everyday purposes.

5. Research results of determining the effect of the biogas purification process using the packed column applied to a conventional motorcycle

5. 1. Validation of research results

Validation was carried out with previous researchers, namely [20]. The conditions were designed according to the experimental conditions of the previous researchers. Below is an image of the validation results Fig. 2.

The results are presumably in good agreement with previous studies.

5. 2. Relationship between engine speed and torque for purified biogas (packed column) and unrefined biogas (without packed column) as motorcycle fuel

Dynamometer test processes are classified as engine dynamometer and chassis dynamometer. Chassis power and torque dynamometers are measured by the engine and the entire vehicle chassis is fully installed. Chassis dynamometers are divided into two types, namely axle dynamometers and on-wheel chassis dynamometers. On the axle dynamometer, the axle will be connected to the dyno engine to find out the power and torque produced. While the on-wheel dynamometer, power and torque are obtained from the car wheels that rest on the roller on the dyno engine.

Measurement of vehicle power in this study was carried out using a chassis dynamometer as seen in the figure below. The chassis dynamometer test is carried out in the angular speed range of 3,000–3,700 RPM. The research results of the relationship between engine and torque for two different cases using the packed column and without the packed column can be seen in Fig. 3 below.

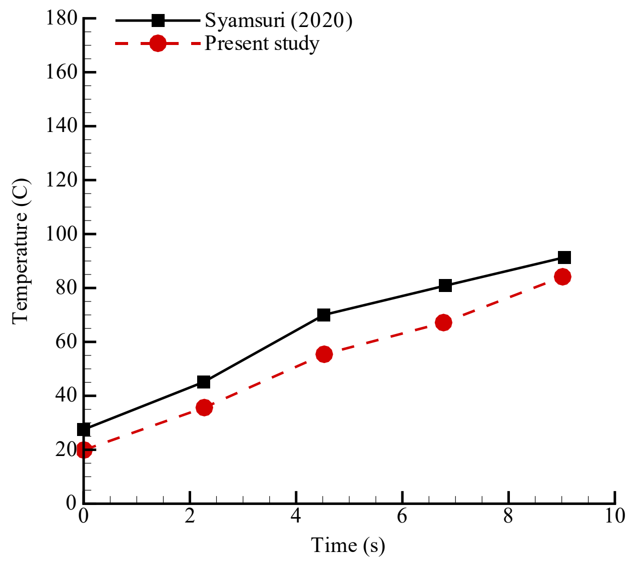

Fig. 2. Relationship between temperature and water heating time and compared to previous studies

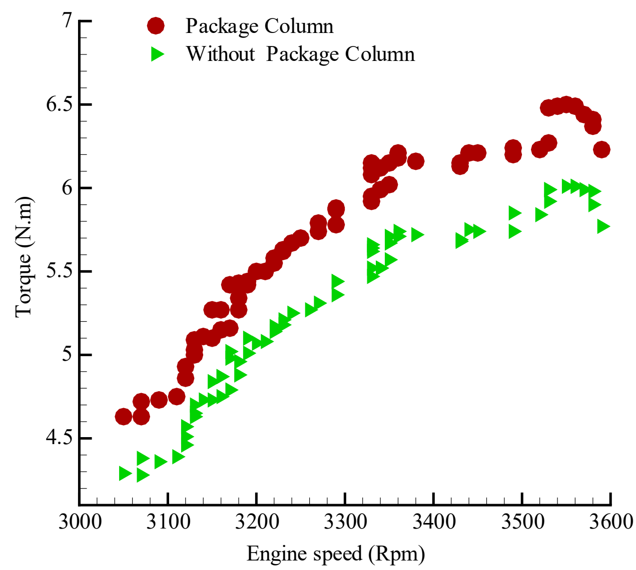

Fig. 3. Relationship between engine speed and torque for packed column and without packed column

Fig. 3 shows the relationship between speed and power with and without the packed column. In the graph, it can be seen that when the speed increases, the power also increases. In this study, when compared to fuels that use the packed column and without the packed column, it is generally seen that biogas that uses the packed column has greater power than without the packed column. This is because the packed column can absorb ignition inhibitor impurities such as CO_2 in the biogas so that the gas becomes purer and the calorific value of the fuel becomes high.

5. 3. Relationship between engine speed and power for purified biogas and unrefined biogas as motorcycle fuel

The research results of the relationship between engine and power for two different cases using the packed column and without the packed column can be represented in Fig. 4.

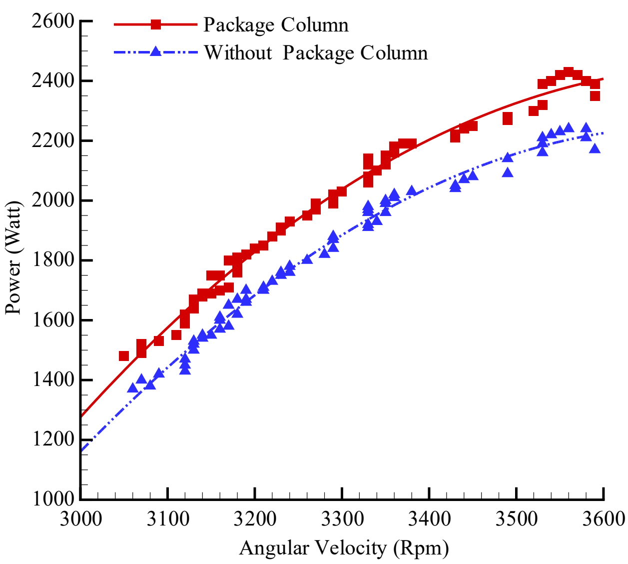

Fig. 4. Relationship between engine speed and torque for packed column and without packed column

Torque is a measure of the engine's ability to produce work, while power as stated above is the work done in a unit of time. In practice, the torque from the engine is useful for increasing the speed of the vehicle and power, which is useful for high speeds. Fig. 4 shows the correlation between speed and torque in biogas with and without the packed column. The chassis dynamometer test is carried out in the angular speed range of 3,000–3,700 RPM. The dynamometer test results show that an increase in angular velocity (RPM) causes an increase in vehicle torque. This is in accordance with the theory that when the power increases, the torque also increases.

5. 4. Relationship between engine speed and specific fuel consumption for purified biogas and unrefined biogas as motorcycle fuel

The research results of the relationship between engine and power of two different cases using the packed column and without the packed column can be observed in Fig. 5.

Fig. 5 shows the relationship between engine speed and SFC for the packed column and without the packed column. In Fig. 6, it can be seen that the value of the specific fuel consumption (SFC) has decreased to 3,134 rpm. Furthermore, the specific fuel consumption (SFC) is constant at 3,526 rpm and at a certain rotation of 3,580 rpm, SFC will come back up. The decrease in specific fuel consumption (SFC) is because at the beginning, the increase in speed requires fuel consumption then the fuel consumption is constant up to a certain rotation. After the speed exceeds 3,580 rpm, the specific fuel consumption (SFC) tends to increase. This is due to a large amount of power required for the fuel to be large as well.

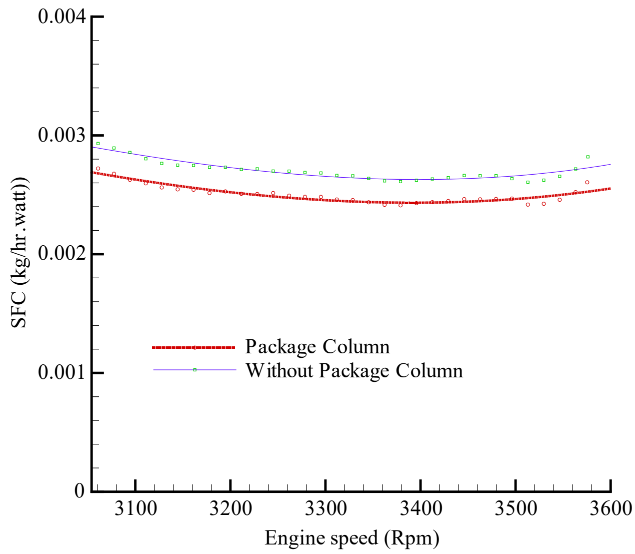

Fig. 5. Relationship between engine speed and SFC for packed column and without packed column

In general, the figure shows that with the packed column, the SFC is higher than without using it. For example, at 3333 rpm, the SFC for the packed column is 2.45 g/kWh. Meanwhile, the SFC without the packed column is equal to 2.66 g/kWh.

5. 5. Relationship between engine speed and brake mean effective pressure for purified biogas and unrefined biogas as motorcycle fuel

Next is a plot image of the relationship between engine speed and break mean effective pressure (BMEP) (Fig. 6).

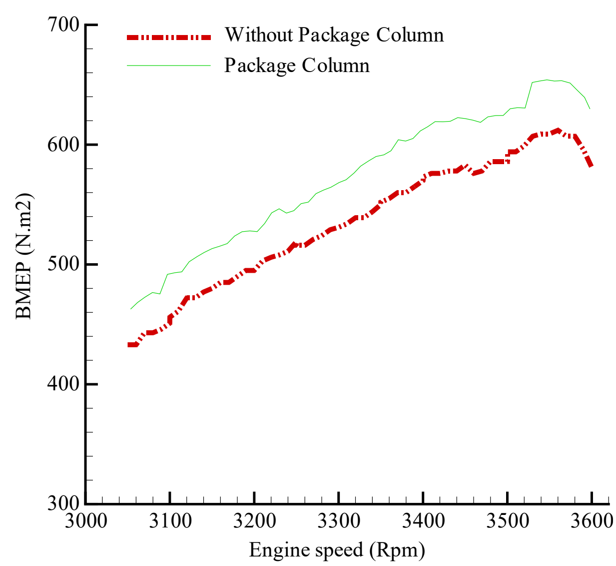

Fig. 6. Relationship between engine speed and BMEP for packed column and without packed column

BMEP calculations are also carried out to see the theoretical constant pressure on the piston during the working stroke which results in net work per cycle. This BMEP works along the stroke volume of the piston so as to produce power equal to the effective power. Fig. 6 shows the relationship between speed and BMEP. It can be seen that the greater the speed, the greater the BMEP. In general, it looks that with the packed column (PC), the resulting BMEP is greater than without the packed column. This is because with PC, the biogas fuel is purified and the calorific value of the biogas fuel is higher than without the packed column.

6. Discussion of experimental results of determining the effect of the biogas purification process using the packed column

Biogas is an alternative energy that can reduce fuel consumption, especially to save crude oil. Biogas is obtained from the fermentation of organic matter using anaerobic bacteria. The fermentation process was carried out in the digester and it took 13 days in this study. Before being used in a motorcycle (spark ignition engine), some of the biogas produced by the fermentation process is purified using a packed bed. Then in this study, the effect of using purified and imported biogas was tested on a vehicle using a chassis dynamometer.

The occupation of H_2S in the combustion chamber causes a delay in fuel auto-ignition at high pressure [19]. The occurrence of auto-ignition in the fuel/air mixture in the gas engine combustion chamber causes engine knocking. The emergence of knocking is indicated by the appearance of a loud explosion sound in the engine. This condition causes a decrease in engine performance and engine failure. In addition, combustion of fuel containing H_2S can produce SO_2 as residual combustion. Besides, unfiltered biogas also contains a high percentage of CO_2 gas. The CO_2 content in the biogas in the combustion process can reduce the quality of the fire produced by the combustion process. Biogas impurities contain about 37.22 % CO_2, but after the purification process, the CO_2 content in the biogas drops to 18.66 %. The high CO_2 content in biogas causes a red flame to appear in combustion [21].

If the availability of oxygen for the oxidation reaction is sufficient, then the hydrocarbon fuel will be oxidized as a whole, that is, carbon dioxide becomes carbon dioxide (CO_2) and hydrogen is oxidized to carbon dioxide (CO_2) and water (H_2O). Such combustion is referred to as stoichiometric combustion and the chemical reaction equation for the stoichiometric combustion of a hydrocarbon fuel (HC) with air is written as follows:

$$CH_4+2(O_2+3.67N_2)\text{------>}CO_2+2H_2O+7.52N_2. \quad (1)$$

For biogas fuel, it has a different composition. The composition of biogas is shown in Table 2 below.

Table 2

Biogas composition [22]

No.	Gas	Chemical Formula	Amount
1	Methane	CH_4	54–70 %
2	Carbon Dioxide	CO_2	27–45 %
3	Nitrogen	N_2	3–5 %
4	Hydrogen	H_2	0–1 %
5	Carbon Monoxide	CO	0.1 %
6	Oxygen	O_2	0.1 %
7	Hydrogen Sulfide	H_2S	<1 %

It can be seen that the content of CO_2 in the biogas is still very large.

For this reason, efforts are needed to bind CO_2 so that the methane fuel produced by this biogas becomes purer and has a higher calorific value. Packed column aims to bind CO_2 so that pure fuel is obtained from CO_2.

The chemical reaction of the packed column process is as follows:

$$Ca(OH)_2+CO_2\text{----->}CaCO_3+H_2O. \quad (2)$$

This purification uses $Ca(OH)_2$ because this substance is able to bind CO_2 well. CO_2 gas will be absorbed by the $Ca(OH)_2$ absorber to reduce the level of CO_2 contained in biogas. With this purification, the methane gas produced is purer and has a higher calorific value, the power generated will be higher as well.

As a result, when the engine speed increases, the power also increases.

Generally, the power using the packed column has a higher value than without the packed column. This finding is in agreement with previous research by [16] showing the same trend. When the engine is started, the power is expected to increase with increasing acceleration, which is given as compensation from the increase in the amount of fuel entering the combustion chamber. More fuel causes more energy to be consumed and converted into heat and mechanical energy with sufficient air. Energy makes engine power greater according to the load given to the engine. Ideally, for constant engine speed, power will increase in proportion to the increase in load. For 12.5 % to 100 % load ideally, the power increase is linear.

By the research results for torque, when the engine speed increases, the tension also increases. Overall, the torque using the packed column is higher than without the packed column. The results of this study are in agreement with previous researchers by [16] with the trend of the results, which are the same. Torque is a measure of the engine's ability to produce work. In fact, the torque of the engine is used to overcome resistance when a load is applied to the engine shaft or when accelerating, so that it can be concluded simply that the torque will be greater if the load given is also greater. This is in accordance with the equation:

$$Ne=2\pi\cdot T\cdot n/60, \quad (3)$$

where Ne is power (Watt), T is torque (Nm) and n is speed. The calorific value also determines the pressure generated in the combustion chamber. If the pressure in the combustion chamber is high, the torque produced is also high.

By the proposed solution/result of brake mean effective pressure (BMEP), if the engine speed increases, the BMEP also increases. Generally, the BMEP using the packed column is higher than without the packed column. This result is in good agreement with previous research by [23, 24]. For testing motorcycles with biogas fuel, the results show that by increasing the engine speed, the resulting BMEP also increases. The BMEP value is influenced by the value of effective power and engine speed. According to the theory, if the effective power increases in the same cycle, then the BMEP will also increase. This happens because, according to the formula, the BMEP is directly proportional to the effective power. Vice versa, if the effective power increases and the engine speed also increases but the percentage increase in effective power is lower from the increase in engine speed, the BMEP will decrease [20]. In this study, biogas fuel with the use of packed column (PC) produces a greater BMEP than without the PC. PC can bind CO_2 and impurities so that it comes out of this PC, the fuel becomes purer and has a higher calorific value.

By the results of specific fuel consumption (SFC), if the engine speed increases, the SFC also increases. Commonly, using the packed column, the SFC first decreases and after that increases when the engine speed grows. These findings support previous research by [17], which stated the same thing.

Specific fuel consumption (SFC) is defined as the amount of fuel consumed per unit power per operating hour. SFC decreases with increasing engine speed. This happens because at low speeds such as 2000–4000 rpm, the composition of the fuel-air mixture is too rich due to the greater loading on the dynamometer, so there are lots of unburned fuel. With increasing engine speed, more air enters, so the air-fuel mixture is getting better and the SFC will increase.

The limitation in this study is that biogas fuel cylinders are installed on motorized vehicles of the Honda Vario 125 CBS type, which are 100 percent biogas fuel and have been purified. Because 100 % biogas is used as fuel, the resulting speed is in the range of 3,000 rpm to 3,600 rpm with low horsepower (*hp*) so it cannot be used for test drives in the open field. This test equipment needs development on the side of mixing air and biogas. Settings on the carburetor need to be done. This research is suitable for testing in the dynotest only. The purified biogas fuel is filled in a 25 liter tube and tested, it will take 20 seconds until the fuel runs out.

7. Conclusions

1. The validation results are in accordance with previous studies.

2. Torque test results show that the torque increases compared to the torque before biogas purification. For torque, the increase is approximately 7.47 %.

3. Based on the test results, the increase in CH_4 levels in biogas after purification results in a greater power. In general, the results show that the increase in power is approximately 7 %.

4. According to the research data, the SFC value for purified biogas fuel has decreased compared to the SFC value without purification, where the difference is around 7.467 %.

5. The calculation results for BMEP show that there is an increase in BMEP from purified biogas fuel compared to BMEP before purification. The difference from the increase in BMEP is approximately 7.09 %.

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