SAJAAS

Southeast Asian Journal of Agriculture and Allied Sciences

Volume 5 Issue 1

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pp. 21-34

SAJAAS | Southeast Asian Journal of Agriculture and Allied Sciences
www.sajaas.basc.edu.ph
sajaasjournal@basc.edu.ph

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Article History:
Received: *Feb. 05, 2025*
Accepted: *Apr. 02, 2025*
Published: *Apr. 15, 2025*

https://doi.org/10.63943/sajaas.vol5iss1art59pp21-34

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Abstract

Assessing rabbit manure's potential as a biofuel source for small-scale internal combustion engines was the primary objective of this study. The research utilized rabbit manure as feedstock, which was inoculated with carabao manure. A total of 60 kilograms of rabbit manure was subjected to treatment using a 1:1 water-to-manure ratio with a retention time of 25 days. Additionally, a microbial inoculant comprising 10% carabao manure was incorporated into the digestion process. The design consists of a split-type biogas digester with gasholder storage and a three-stage gas cleaning system, an internal combustion engine connected to a DC generator, and a simple lighting circuit. Findings indicated that the pH level recorded at 7.75 resulted in alkalinity which helped the biogas production by preventing the slurry from acidity. The total dissolved solids (TDS) were recorded at 3137 ppm, and it increased to 6980 ppm. For the performance evaluation in fueling the engine using biogas, the engine operated for 80 seconds and generates an average power of 31.66 watts.

Keywords: *bioenergy, rabbit manure, small internal combustion engine, water quality*

Introduction

The Philippines' economy and population are becoming bigger, putting pressure on the country's energy supply, as it solely depends on imported fossil fuels. Much like the rest of the globe, the Philippines must decide whether to continue relying on imported fossil fuels or to increase its renewable energy technologies (Lloyd & Nakamura, 2022). The intense pressure and practical development for optimizing bio-green technologies have become a solution for rising renewable energy. Agriculture is the main industry in the Philippines, which produces a significant amount of agricultural waste. In rural areas where farming is a primary source of income and energy is scarce due to limited or unreliable grid connectivity to fully extend the power in rural households, the Biofuels Law of the Republic Act 9367, encourages the use of bio-based fuel sources as an alternative fuel. It offers the potential to create a locally sourced renewable energy within the rural areas and to reduce community reliance on fossil fuels. The available technology to utilize the agricultural waste was the biogas; a mixture of gases by breaking down organic matter without oxygen, consisting of specific quantities of methane and other chemical compositions (Mattocks, 1984). Biogas is a good alternative source of energy for internal combustion engines due to its increased mixing ability with air, clean-burning nature, and high-octane number that resists knocking (Kukoyi et al., 2015).

According to Adewuyi et al. (2019), numerous livestock and poultry animals are being raised in the Philippines; these include carabao, chicken, cattle, pigs, sheep, goats, and ducks. Economically, these animals are raised on a small and large scales, and their waste or manure commonly utilized as fertilizer through direct application. Another classified source of livestock manure is the rabbit, a herbivorous animal that feeds on grasses. Rabbits have been found to exhibit growth and reproductive performance under Philippine conditions that are comparable to those in other tropical countries (Alejo & Nicolas, 2021). One of the research thrusts of the Bulacan Agricultural State College (BASC) is to advance studies on the rabbit industry, which is emerging as a growing livestock sector in the Philippines.

As the production of rabbits increases, their waste will contribute to the waste-to-energy solutions making it sustainable for the farmers. In recent years, researchers have conducted studies to determine the biogas production potential of various livestock animals; however, there is a lack of studies assessing the capability of rabbit manure and duck manure. According to Liangwei et al. (2010), rabbit manure has biogas potential per cubic meter of the kilogram in the total solids under normal conditions which is comparable to duck manure at 0.082 and 0.098, respectively. Another researcher states that the methane potential of rabbit manure was the highest among duck and horse manure in terms of liter per kilogram of volatile solids (Perez et. al., 2021) under mesophilic conditions, which the biochemical methane potential of rabbit manure (325.53±1.9 L/kg of VS) was the highest among horse manure (245.20±3.8 L/kg of VS) and goat manure (111.88±13.2 L/kg of VS). In line with this, the researcher is trying to prove the statement in the Philippine setting, that provides insight to support and expand the use of bio-based green technologies while promotes rabbit farming.

In biogas production, direct thermal application-such as cooking, and industrial heating- are commonly used at the small scale. In the Philippines, research on compressing biogas for use in power machinery is still in progress. A review of the literature revealed that only a few studies have explored the use of compressed biogas in internal combustion engine though these have shown successful outcomes (Hernandez & Villanueva, 2017). Consequently, using biogas as fuel for power generation (e.g., mechanical, or electrical) remains uncommon at the small-scale. Therefore, the researcher intends to develop a biogas system for generating power using rabbit manure as feedstock in a small-scale set-up.

Generally, the study aimed to design, fabricate, and evaluate a biogas digester using rabbit manure as feedstock. Specifically, it aimed to: (a) design and fabricate a split-type biogas digester; (b) determine the water quality of rabbit slurry inoculated with carabao manure; and, (c) determine the biogas capability as fuel in running the 4-stroke small internal combustion engine. If proven effective, the attempt to harness rabbit manure as a fuel source for biogas power generation may help the country to decrease its reliance on fossil fuels.

Materials and Methods

Design and Fabrication

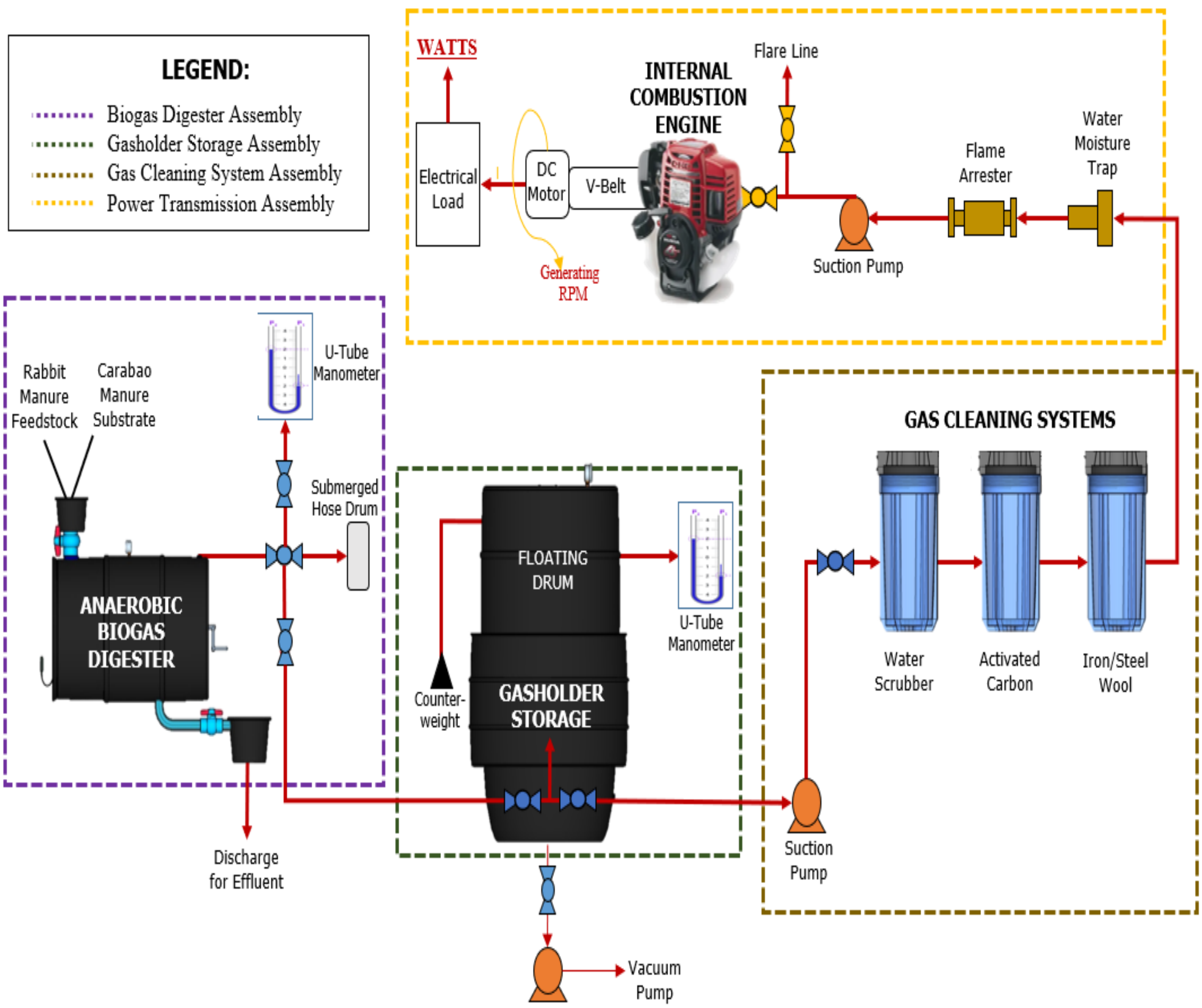
Design Set-up

The schematic setup presents a visual representation of the study's flow of operation. Starting from the biogas digester assembly which was responsible for the generation of biogas. Usually, the biogas digester is constructed with brick masonry, stone masonry, ferro-cement, mild steel sheet, and fiber-reinforced plastic (Bai & Kumar, 2005). Thus, plastic has been widely used as it is non-corrosive, good insulators, cheaper, and easy to fabricate and maintain. The gasholder storage assembly was needed to control and store the generated raw biogas. It also used high-density polyethylene (HDPE) drum, as low-pressure holders-typically under 10 kilopascals-are commonly adopted for stability when utilizing biogas for power generation (Bharate et al., 2020).

The gas cleaning systems was designed to filter and purify raw biogas. While it primarily consists of methane and carbon dioxide, it may also contain small amounts of impurities. These impurities can affect the engine for biogas utilization by causing corrosion and mechanical wear problems. Therefore, biogas must be purified to meet relevant standards and requirements before use (Deng, Wang, & Yi, 2020). Lastly, the power transmission assembly's main function is to convert the clean biogas into mechanical power using an internal combustion engine and then transform it into electrical power, as shown in Figure 1.

Figure 1.

Schematic Diagram of the Study



Principle of Operation

Anaerobic digestion (AD) is a bacterial process in which organic carbon is transformed to its most oxidized state, CO_2, and its most reduced form, CH_4, via a series of oxidations and reductions. (Angelidaki & Kougias, 2018). The digestion process encompasses four stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis, and the organism involved in each step is categorized as hydrolyzer, acidogen, acetogen, and methanogen, respectively (Divya et al., 2014). The methanogenic bacteria produced methane and carbon dioxide from the acetates and hydrogen by the methanogenesis process (Gerardi, 2003). A week later, the raw biogas can be transferred to its gasholder storage by opening the valve as methanogens starts to occur (Angelidaki & Kougias, 2018). The slurry temperature and system pressure are monitored over the 25 days retention time.

Design Consideration

The internal combustion engine must have the smallest displacement (cubic centimeter) available. The piston displacement was considered for choosing an engine as it determined how much fuel it could intake in the combustion chamber. The smaller the piston displacement, the less fuel the engine can intake, which consequently results in less air required for combustion. The engine was a Honda GX35T with 35.8 cubic centimeters of piston displacement that had a 4-stroke, single-cylinder gasoline engine. The gas must be purified so that it is compatible with the engine. A locally available small electric air pump was needed to suction out the store biogas in the gasholder storage, as well to deliver the purified biogas continuously to the engine without knocking. To prevent the backfire of the biogas, flare line was installed together with water moisture trap before delivering the purified biogas to engine. The importance of these installations is to prevent mechanical damage to the carburetor, which may occur due to biogas containing roughly 40% hydrogen and 60% methane when used for power generation (Mattocks, 1984).

The size of the digester was selected from the locally available drum size. The biogas production potential data for rabbit manure was the basis for the calculation of the biogas in terms of gas production. Table 1 presents the design data and parameters needed for sizing the biogas digester.

Table 1.

Design Data and Parameters

Design Requirements	Data Requirements	References
Average Rabbit Manure Weight	0.039 kg	Gerardi (2003)
Rabbit Manure Total Solids	30%	Al Seadi et al, (2008)
Rabbit Manure Volatile Solids	66% of TS	
Biogas Production Potential for Rabbit Manure @ 25°C ± 1°C	0.174 m^3/kg	Liangwei et al. (2010)
Density of Rabbit Manure	950 kg/m^3	Gerardi (2003)
Density of Water	1000 kg/m^3	PAES 414-1 (2002)
Mesophilic Temperature	38°C	Kangle & Kore, (2014)
Volume Ratio of Solid to Gas	7:3	IRENA (2016)
Manure to Water Mixing Ratio	1:1	PAES 413 (2001)
Biogas Consumption of Gasoline Engine @ rated kW	0.398 m^3/hr.	Tambong, (1992)

Parts and Assembly

The biogas digester was responsible for the anaerobic digestion process. Since the gas comes with impurities, it must undergo a series of gas cleaning and conditioning processes. The engine also requires a stable amount of biogas, and a gasholder storage was needed as shown in Figure 2.

The batch-type biogas digester tank was made up of a 200-liter standard-size high-density polyethylene plastic drum. The feed funnel serves as the point of entry for the slurry, which later falls through the inlet tube. A stainless agitator was also inserted to prevent scum formation. The dimensions of the frame for the biogas digester were determined based on the size of the drum and its braces were positioned along the sides of the frame to reduce the drum's movement. The inlet funnel was also supported by a U-bolt attached to an angle bar. The temperature gauge measured the temperature occurring within the digester and gasholder. A probe temperature was installed to measure the temperature of the slurry in the digester. A U-tube manometer was used to monitor daily pressure changes for safety purposes. The biogas produced was then pumped to the gas cleaning and conditioning assembly, shown in Figure 3.

Figure 2.

Main Assembly

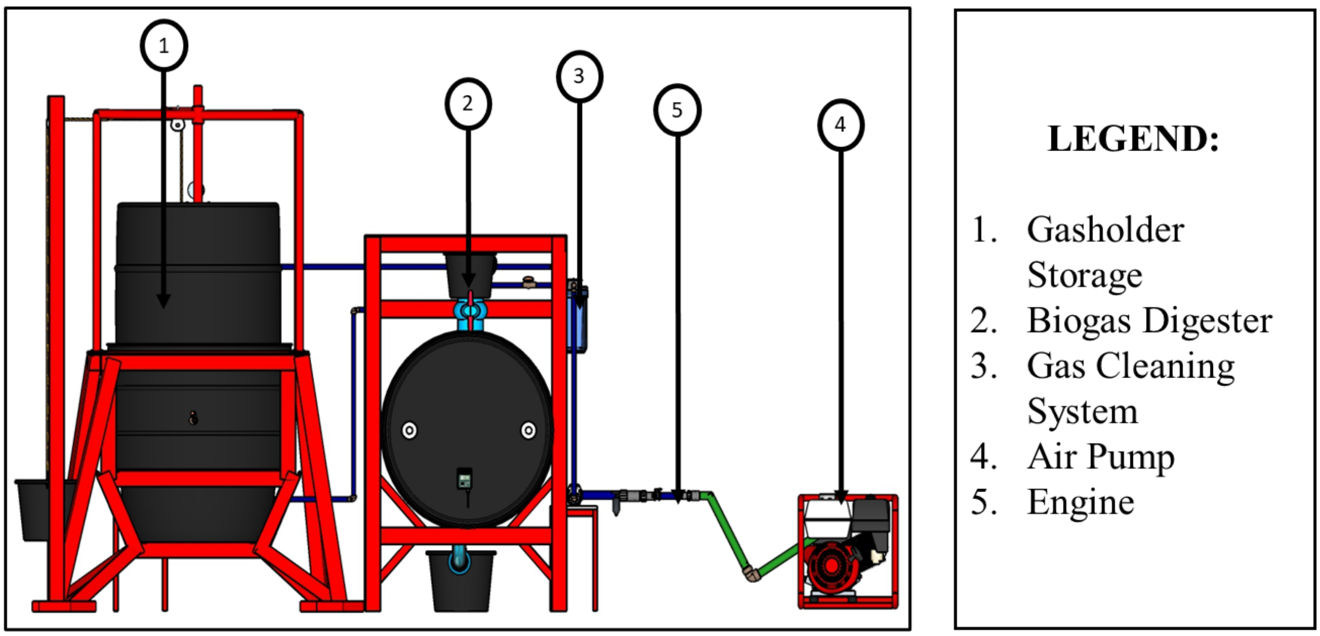
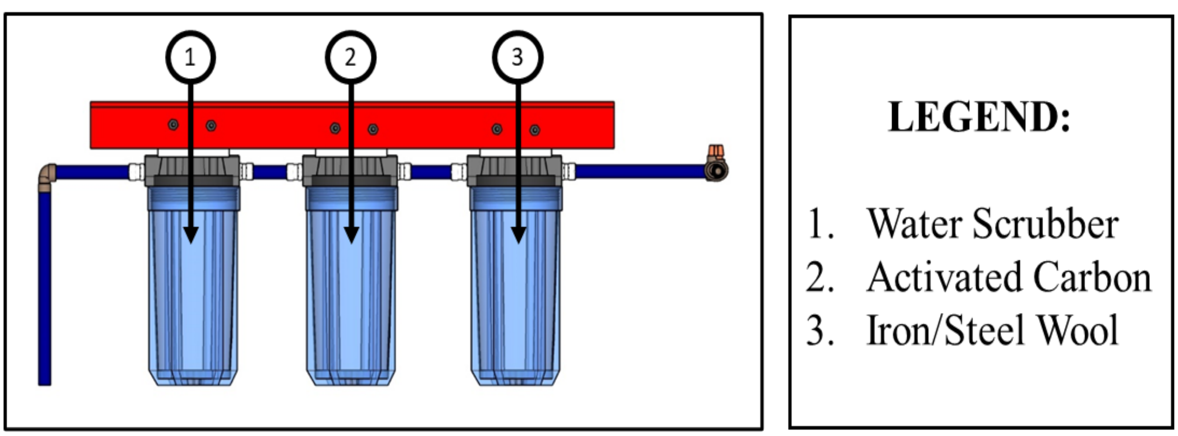


Figure 3.

Gas Cleaning Assembly

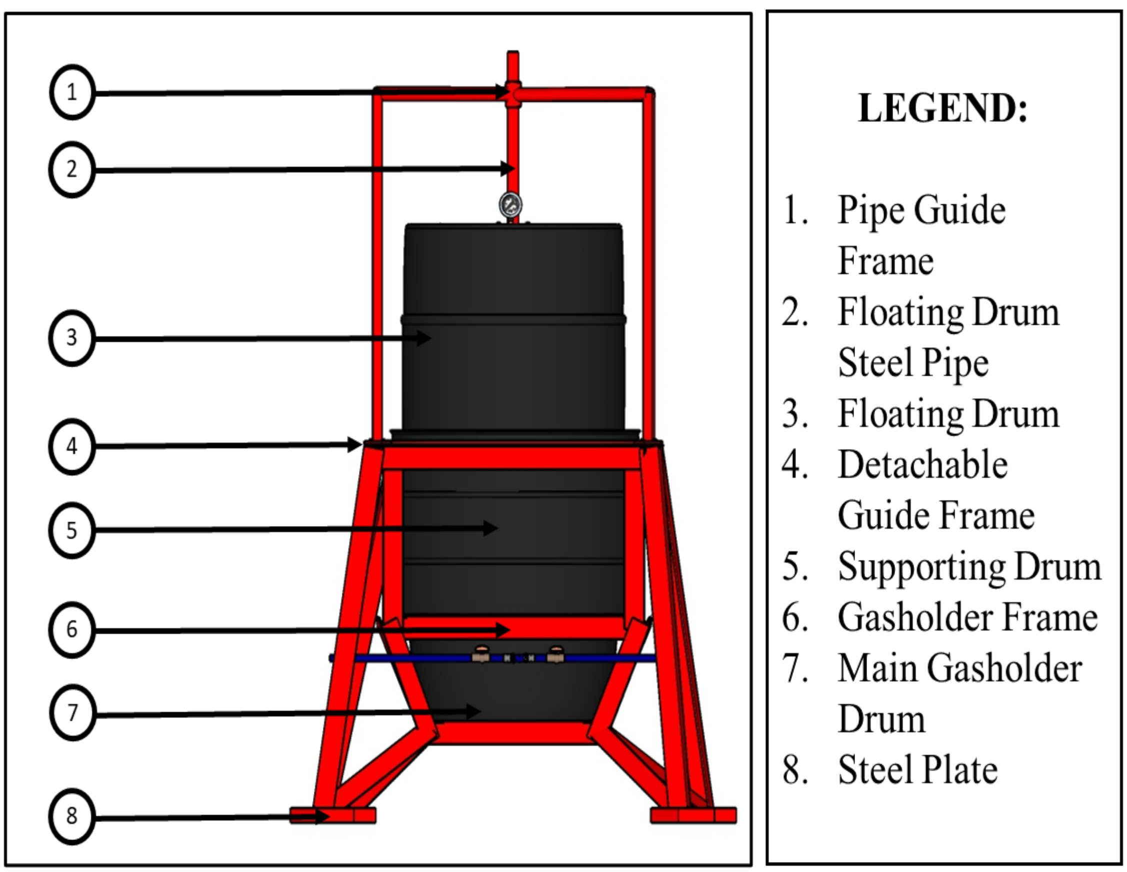


The water scrubber was intended to remove carbon dioxide for biogas upgrading and remove the saturated vapor of the raw biogas. The gas then passes through the second filter which is an activated carbon; a material that removes moisture and remaining impurities. It comprised a ½-inch Solutherm water filter, a ½-inch blue PVC pipe, a male adaptor, and a supporting frame for the water filter. The water filter was connected to an 8mm x 25mm stainless steel bolt with washer and knots. The procedure for sealing the digester pipelines and fittings involved the use of Teflon and PVC cement. Lastly, the gas entered the third filter with an iron/steel wool to remove hydrogen sulfide and abrasive properties.

The gasholder storage has a total capacity of 360 liters which has a support guide frame to provide alignment for the floating drum. A meter line was put in place to assess the height of the gasholder drum. To optimize the thermal conditions for the microbial community, the drums were coated with enamel black paint and red oxide to its frame. The support guide frame provided alignment to the floating drum, which was attached to the movable frame. The steel plate was attached to the drum using four bolts, and a steel pipe was inserted into the guide frame. The guide frame's detachability was achieved through an 8mm x 25mm black iron bolt, with a washer and knots, which was affixed to the primary frame of the gasholder. The floating drum was equipped with a supporting drum that consisted of a 1/2-inch blue PVC ball valve to discharge the digestate. A 1/2-inch blue PVC ball valve was installed beneath the gasholder storage to vacuum the air inside the gasholder. The circular flat bar was formed to the supporting drum as it provides support during the biogas generation. The construction of the gasholder frame involves using 1/4 x 1-1/2-inch angle bars, while the guide frame comprises 1/2 x 3/4-inch black iron pipe. A 1/2 x 1/2-inch squared steel plate was the foundation for the gasholder frame. The researcher installed a U-tube manometer and temperature gauge to assess the pressure and temperature within the retention time while, a digital thermo-hygrometer was also used to monitor the outdoor conditions of the system such as ambient temperature and relative humidity. The design setup was shown in Figure 4.

Figure 4.

Gasholder Storage Assembly



Slurry and Substrate Preparation

The fresh rabbit manure was collected from the College of Agriculture Rabbitry Demo Farm in Bulacan Agricultural State College, Pinaod, San Ildefonso, Bulacan. Before being loaded into the digester, the material underwent size reduction through mechanical means to enhance the surface area for reaction. After reducing the manure's size, the foreign materials including paragrass, sawdust, rabbit fur, and other unrelated materials, were manually removed shown in Figure 5a.

Figure 5.

Rabbit Manure Pre-Treatment: (a) manually removal of foreign materials, (b) manually feeding the digester

(a)

(b)

A total of 135 liters of rabbit slurry mixed with substrate were subjected to treatment in a biogas digester. Carabao manure was utilized as an inoculant to enhance the performance of the biogas digester. The mixture comprised 60 liters of rabbit manure and 60 liters of water, and a carabao microbial inoculant of 15 liters was manually fed in the digester as shown in Figure 5b.

Water Quality Analysis

The water quality analysis was performed before and after the biogas production. The pH value expresses the acid concentration in aqueous systems. It should be presented as fewer than seven acid solutions while alkaline solutions are higher than seven. For the acetic acid decomposer bacteria to grow and develop properly, neutral pH promotes the growth of methane bacteria (methanogens), which has an impact on the biogas produced (Astuti et al, 2014). The study used a water quality tester that can quantify the pH level and total dissolved solids.

Engine Evaluation

Engine Generator Set-up and Retrofitting

A 24-volt DC motor running at 500 RPM was connected to an internal combustion engine. An engine with an idle speed of 3,100 rpm can power the DC motor. The transmission system was fabricated at the engineering machine shop, as shown in Figure 6a. The DC generator's design pitch diameter was 4 inches, while the engine pulley had a diameter of 2 inches with an A-single sieve belt 25 inches in length.

The carburetor was modified by incorporating a new biogas line. The connection used a 1/4-inch x 2-inch G.I. nipple, a 1/4-inch tee, and a 1/4-inch brass valve for the fitting as shown in Figure 6b.

Figure 6.

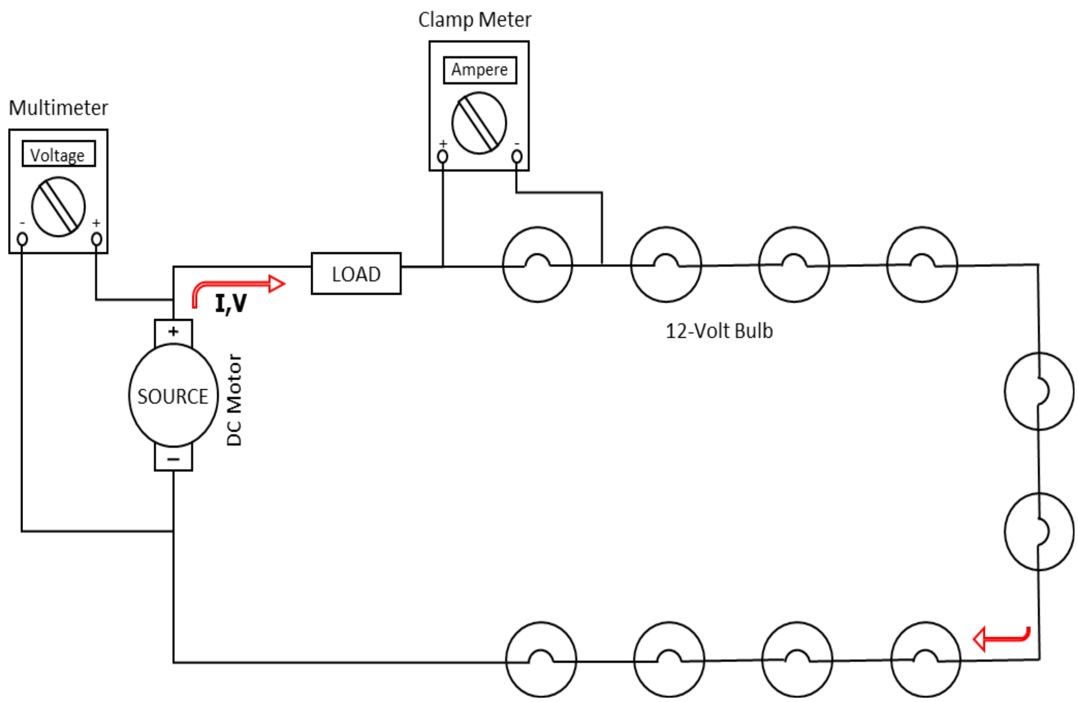
Engine Generator: (a) engine set-up with transmission system, (b) retrofitting

(a) (b)

Electrical Load

Figure 7.

Schematic Electrical Circuit Set-up



Before the operation of biogas, an electrical load was needed to ensure the flow of the current and voltage across the series circuit was working. The study used a 500 revolution per minute (RPM) of DC motor to produce electrical power which was subsequently distributed to a load side consisting of a 12-volt bulb. In the series circuit, the load side was measured using a clamp meter. The positive probe of the clamp meter was attached to the connection, while the negative probe was attached to the bulb's connection to measure the current flowing through it. On the other hand, the multimeter's negative probe was attached to the source's ground line and, the positive probe connected to the circuit's load side, both of which were used to measure the voltage being distributed. The voltage output was recorded using a digital multimeter and clamp meter for the amperage as shown in Figure 7.

Engine Test Procedure

Figure 8.

Engine test instrument set-up with simple lighting circuit.

The procedure for the evaluation of internal combustion engine performance for fueling the biogas started by ensuring all connections and fittings in the gasholder storage and gas cleaning system were intact, connecting the standard gas hose to the flame arrester line along with the air pump. Next, the electrical circuits were prepared and connected to a digital multimeter, which was then linked to the DC motor wires. To see if the multimeter detects the voltage and ampere flowing to it, the internal combustion engine was running, and checked if bulbs were all working.

While the engine was running, the biogas flare valve was monitored to see if a flame appeared. If so, gradually open the engine's retrofit valve line to slowly mix the biogas with air for its combustion process. In case of an unforeseen situation during the testing evaluation, a fire extinguisher was also taken into consideration as shown in Figure 8. Then, wait till the engine stops and start data analysis.

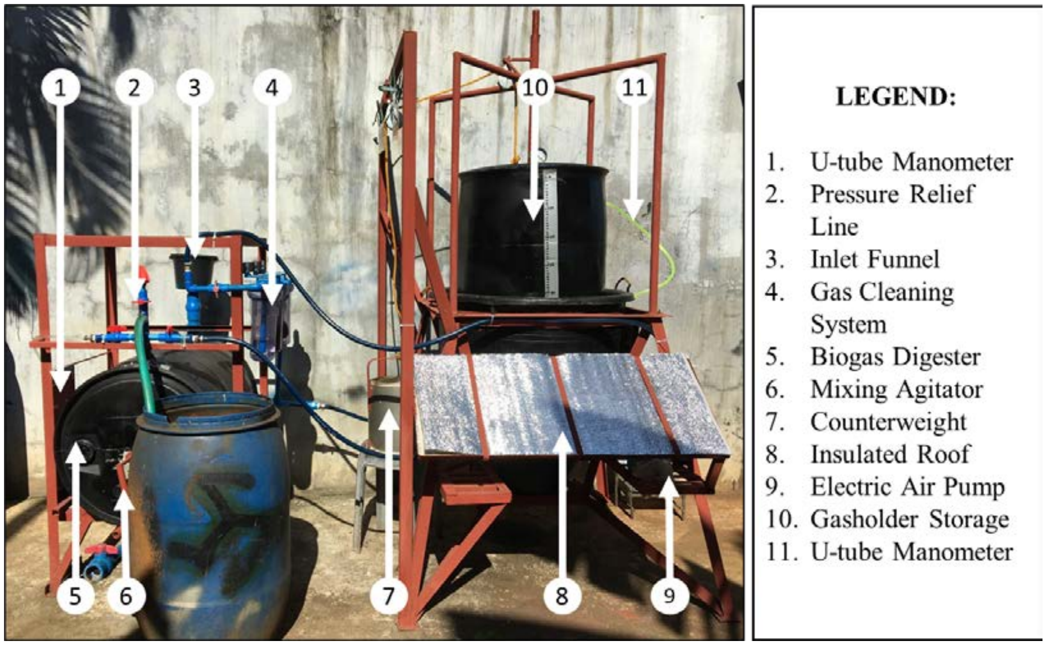
Results and Discussion

Design and Fabrication

The design fabricated setup presented in Figure 9 includes a biogas digester U-tube manometer, pressure relief line, inlet funnel, gasholder storage, gas cleaning system, electric air pump, and gasholder U-tube manometer. Insulated roof installation was also considered, as the air pump may be exposed to direct sunlight, leading to damage. The study also took into account the following: a counterweight with a pulley to ease the floating drum's movement when biogas production occurs; a pressure relief line drum as a safety precaution to ascertain whether biogas was generated through air bubbles; and a mixing agitator with the potential to prevent slurry in the scum formation.

Figure 9.

Fabricated Set-up



Water Quality Analysis

The initial total dissolved solid (TDS) results were 3137 parts per million (ppm), and it increased to 6980 ppm measured using a water quality tester as shown in Table 2. The increase difference of 3843 ppm means that there was an increase in TDS. According to Zwain (2019), this could be due to the thermal environment for the rapid breaking down of the accumulated solids in the digester. The study recorded the daily digester temperature of 60°C from 10:00 am to 2:00 pm, indicating that it falls within the thermophilic temperature range. Another study by Ferrer et al. (2008) observed a similar finding in which TDS concentration increased after thermal pre-treatment of sludge at 70°C and the ability to dissolve organic compounds under thermophilic conditions resulted in a nearly tenfold increase in dissolved solids. The presence of toxic and harmful chemicals in the slurry suggests that it may not be suitable for direct application to soil. Prior treatment may be necessary.

Table 2.

Water Quality Analysis

	Before Loading	After Loading	Result/Average Reduction Rate
pH Level	6.83	7.75	7.14
Total Dissolved Solids (parts per million)	3137	6980	-122.50

A pH value of 6.83 was obtained before, and after being treated with biogas for 25 cumulative days, the pH level increased to 7.75. The experiment of Astuti et al. (2013), demonstrated that methanogenic bacteria work best in a pH range of 7.5-8.3.

System Condition Observation

As highlighted in Table 3, which falls within the optimal range for mesophilic bacterial growth, according to Cheng et al., (2013). Mesophilic bacteria typically perform well at temperatures between

28°C and 45°C, indicating active production of methanogenic bacteria. Furthermore, Sarong et al. (2016) reported a reduction in CO_2 and N_2 concentrations at 45°C, which supports the growth of methanogens and Methanobacterium.

Table 3.

Slurry Temperature Reading

Slurry Temperature Reading											
Day	7am	8am	9am	10am	11am	12nn	1pm	2pm	3pm	4pm	5pm
1	27.5	27.0	26.3	21.7	30.0	29.8	30.6	31.3	31.2	30.8	30.6
2	26.3	25.2	23.8	29.2	29.9	30.2	30.1	30.2	31.1	30.5	30.7
3	25.9	24.7	22.4	20.1	30.6	31.6	31.5	30.9	32.3	32.3	31.5
4	27.3	26.8	26.7	27.0	28.5	28.4	28.5	28.4	29.9	30.2	29.9
5	25.9	26.4	22.1	22.7	22.6	31.5	31.7	32.1	31.7	31.7	31.9
6	28.1	27.4	28.3	29.1	30.5	28.4	29.4	31.1	31.3	31.3	30.8
7	25.4	24.1	20.3	24.7	28.2	29.6	31.9	32.1	33.1	32.5	33.1
8	25.3	24.9	21.8	26.5	29.4	29.6	32.3	32.8	31.3	32.7	32.4
9	26.5	25.4	22.1	28.3	30.1	31.6	32.6	33.5	33.2	33.3	32.9
10	26.4	25.2	22.4	22.9	30.7	31.8	33.1	33.2	33.8	33.1	32.3
11	26.1	25.2	23.4	26.3	30.6	31.8	32.9	34.1	34.3	31.7	30.5
12	26.8	26.9	27.8	28.2	30.1	31.9	34.4	34.5	34.1	33.4	32.9
13	26.9	26.1	23.7	26.9	30.3	31.4	33.5	33.7	34.3	33.6	33.4
14	26.5	25.4	23.5	26.2	28.3	28.3	30.2	34.5	33.1	34.6	31.5
15	27.1	26.2	23.1	26.3	30.7	31.6	35.5	35.4	36.1	34.2	33.6
16	28.2	27.2	24.3	29.3	30.4	33.4	35.7	36.3	35.1	35.4	35.2
17	26.3	28.3	23.5	29.1	32.8	34.2	33.1	36.7	35.7	35.2	34.7
18	29.2	29.1	26.7	31.2	32.2	33.7	35.8	35.6	34.9	35.1	34.6
19	27.6	27.8	28.0	28.1	32.8	34.4	36.0	35.6	36.0	36.4	35.8
20	28.2	27.6	28.8	31.3	33.7	35.7	35.8	36.7	32.2	35.1	34.4
21	27.9	27.8	26.7	29.6	32.2	34.5	35.3	36.0	36.2	36.3	35.6
22	28.3	27.7	27.2	30.1	31.9	32.6	33.2	34.3	35.3	34.9	34.3
23	26.6	26.9	25.8	25.3	28.3	33.7	42.8	36.2	36.4	35.8	35.7
24	29.3	28.6	28.9	27.5	28.3	34.9	35.7	36.5	36.2	35.1	35.8
25	28.2	27.6	28.8	31.3	33.7	35.7	35.8	36.7	32.2	35.1	34.4

Figure 10.

Post-observation: (a) water went down in the floating drum, (b) drum was flattened and, (c) negative pressure in gasholder

(a) (b) (c)

As illustrated in Figure 10a, the gasholder underwent flattening, resulting in the decrease of water from the floating drum yet, one of the advantages of HDPE drums is their economic and versatile nature with regards to deformation. The observed condition can be attributed to the quantity of biogas that was being drawn into the gas cleaning systems indicated in Figure 10b. As shown in Figure 10c, the pressure reading of the gasholder became negative due to the depletion of most of its gas.

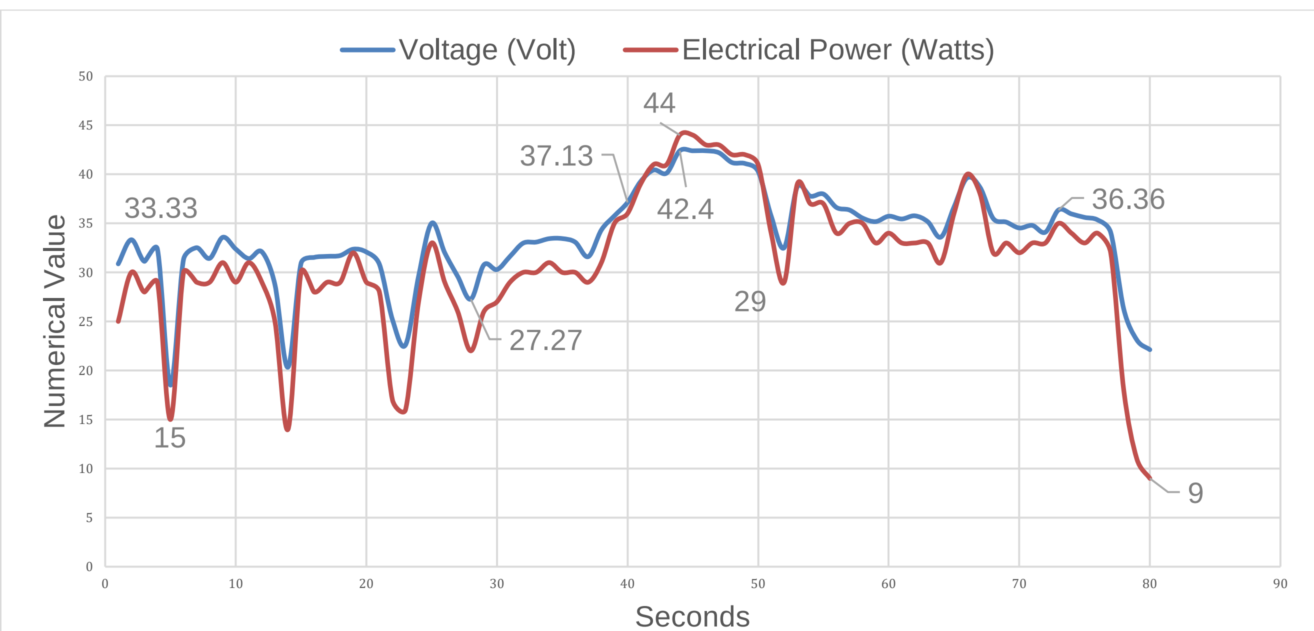
Engine Performance

The results indicated that during the trial, a voltage of 33.33 volts was supplied and a voltage drop of 15 volts occurred within 5 seconds of running. However, it was observed that the voltage dropped to 27.27 volts and then gradually increased to 37.13 volts over a period of 40 seconds, and a continuous increase in voltage to 42.40 volts. Hence, the generated average power was recorded at 44 watts in 45 seconds of runtime as it stopped generating at 9 watts in 80 seconds as shown in Figure 11.

The observed increase in power can be attributed to the higher energy input from the combustion of biogas in the engine. According to Bora et. al. (2014), it explains that as the biogas flows inside the combustion chamber, the engine speed increases due to the additional energy that biogas has. At that point, the electrical power from the circuit abruptly stopped. Based on the observation, this occurred because the biogas had been fully consumed. The combustion of the biogas inside the engine was operational until the engine shuts down at approximately 80 seconds. From the study of Kukoyi et al. (2015), excessive air intake during biogas combustion in internal combustion engines (ICE's) was a potential cause of reduced engine efficiency and concerns regarding biogas air to fuel intake for spark ignition engines.

Figure 11.

Electrical Output Profile



Conclusion

The biogas can significantly contribute to the increasing demand for renewable energy as rabbit slurry, when used as feedstock inoculated with carabao manure, had the potential to fuel a 4-stroke small internal combustion engine. The designed split-type biogas digester with gasholder storage was effective in producing biogas with rabbit manure as its feedstock. The piston displacement rate equation was considered in choosing the internal combustion engine's 35.8 cm^3 piston displacement. Blue flames were observed during biogas flaring, indicates the complete combustion of methane and carbon dioxide. The electrical output was recorded at a current of 0.928 amperes and supplied a peak voltage of 42.40 volts, which generated an average power of 31.66 watts at 80 seconds of run time.

With this finding, when a rabbit farm has 60 kilograms of rabbit manure, which is subjected to biogas production at 25 days of retention time, it can provide mechanical power of at least 32 watts and can scale up the system to explore the possibility of harnessing the rabbit manure towards power generation.

Recommendations

Future studies may investigate different mixing ratios of rabbit manure with a microbial substrate to quantify the most efficient inoculant. The design setup could incorporate new feedstock for biogas generation. In terms of the air-to-fuel ratio for fueling the biogas in an internal combustion engine, it is crucial to determine the optimal air-to-fuel ratio for efficient combustion within the combustion chamber. Additionally, a gas analysis should be conducted to characterize the biogas, specifically to quantify the levels of methane and carbon dioxide it generates.

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