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DEVELOPMENTAL AND CHARACTERIZATION STUDY OF A BIOGAS PLANT FOR POWERING OF A 32KW GENERATOR

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Abstract

Nigeria is currently facing a devastating energy crisis as a result of the removal of fuel subsidy on fossil fuels. There is now a concerted effort by energy researchers to finding alternative, sustainable energy sources. This study exploited Biogas as a green fuel that both contributes to the availability of sustainable energy and assists in reducing global warming. The objective of this study was to check the quality of the biogas in running a gas powered retrofitted 32Kw power generator for electricity supply. For this purpose, the compatibility of the biogas with this generating set was observed to determine the outcome. The result showed that the 32Kw power generator just like all Internal combustion engines have high quality fuel requirements. Presence of some component especially hydrogen sulphide (H2S), CO2 and water vapor in biogas posed a serious threat to the engine performance as well as the life span of the engine. Therefore, when the system was ran on a biogas partially cleaned of the undesirables, a 60% cost reduction, when compared to the use of petrol (premium motor spirit) was recorded. This work recommends refining of the gas in a refining system that incorporates desulphurization, condensation and carbonization. Refining (gas cleaning) will not only eliminate the undesirable components of the gas, but improves the overall fuel gas quality and combustion outcomes.

Keywords: Biogas; Generator; Biogas production; bio-digester; biogas to electricity

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1.0 INTRODUCTION

1.1 Background of Study

The current technological trend of increasing energy demand, insufficient grid electricity supply, increasing costs and shortage of fossil fuel resource which have been major drivers of energy supply in Nigeria and the attendant effects on the environment in form of pollutions, greenhouse gas emissions and general environmental imbalance are current topical issues and requires urgent intervention. The concern that fossil fuel resources are tending towards exhaustion require concerted efforts of all stakeholders towards finding new, sustainable and alternative energy sources (Mong et al., 2023). Demand for conventional fuels viz. petrol, diesel etc. has been increasing forever but their supply is limited. This has provoked the scientist to find alternatives to these fuels so as to compensate their shortage.We have successfully tried to tap biogas for small-scale production of electricity. Biogas is a clean and environment friendly fuel produced through the anaerobic digestion of organic wastes such as: cow-dung, vegetable wastes, municipal solid waste and industrial wastewater (Burke 2001, Dohanyos and Zabranska 2011). It is increasingly becoming important in domestic and industry as fuel due to its costs and cleanliness. The main component of the gas is methane, carbon dioxide, hydrogen, nitrogen and hydrogen sulphide. The renewable energy resources appear to be one of the most efficient and effective solutions of the shortage in fossil fuels. Biogas primarily composed methane (i.e., 55% -70% by volume) and carbon dioxide (i.e., 30% - 45%).Biogas may also include smaller amounts of hydrogen sulfide (i.e.,50-2000 parts per million[ppm]), water vapor, oxygen, and various trace hydrocarbons. The total biogas yields that could be 275 m3 per day from the 5 tons of waste .then the energy generation is 250 units per day (Gadakh 2021).

2.0 Review on conversion of biogas to electricity.

2.1 Conversion technologies

Various technologies to generate electricity from biogas on a household level are available. In principle, the chemical energy of the combustible gases is converted to mechanical energy in a controlled combustion system by a heat engine. This mechanical energy then activates a generator to produce electrical power. The most common heat engines used in for biogas energy conversion are gas turbines and combustion engines. For small-size heat engines, combustion engines are popular as they are more efficient and less expensive than small gas turbines. However, gas turbines may be more efficient when operating in a cogeneration cycle producing heat and electricity.

Aldo et al (2018) in their work on simulation of electricity generation from biogas for Ugandan rural community, a simulation of electricity generation from biogas for Ugandan rural community using Aspen HYSYS V8.8 for computational modeling was developed on thermodynamic concepts. Two systems were considered; a gas-turbine (GT) only system and a GT-with steam turbine (ST) in the bottom cycle, based on 71% methane - 29% carbon dioxide as inlet biogas composition. The results obtained showed that it is possible to obtain 2.5MW of electricity using a gas turbine (GT) only system and an additional 1MW when a combined cycle system (GT-ST) is considered. The system consists of three main components; the combustion chamber (G), compressor, and turbine-generator.

Admasuet.al (2022), Experimental and simulation analysis of biogas production from beverage wastewater sludge for electricity generation. This study assessed the biogas and methane production potential of wastewater sludge generated from the beverage industry.

Furthermore, the electricity-generating potential of biogas produced at room temperature (22.1 kWh at 24 days) and optimum temperature (18.9 kWh) at 40 days was estimated. The simulated model revealed great potential in terms of profit and electricity generation.

Aldo et al (2018) did a Simulation of electricity generation from biogas production was monitored over a period 25 days. Result showed that the waste produced maximum biogas within the slurry temperature range of 29°c-30°c. The purified gas was used in a modified 4-stroke Honda generator of 2.8hp and it operated smoothly with biogas fuel without any visible sign of knocking, misfiring, or change in sound at no-load condition. It was then used to power electric bulbs vary from 100-700 watts for 25 minutes of test operation. Th electric power out-put voltage of the engine was noted to be 220V - 190V.

Himabindu and RaviKrishna (2014) undertook a Performance Assessment of a small Biogas fuelled power generator prototype.The complete closed-loop control of the engine operation to maintained a steady engine speed of 3000 rpm (±5%) across the entire load range while maintaining an optimum fuel-air equivalence ratio is made possible by an electronic control unit (ECU) controlling the injection duration, ignition timing and throttle position. The results obtained from testing the prototype have been found to be satisfactory and show that biogas power generators for low power applications at an overall efficiency of 19% at electrical load of 640 W.

The prototype was estimated to produce an AC Voltage of 220V,AC output of 3KVA at a speed of 3000rpm and a prime mover of 6-7HP.

Choudhary and Abuthakeer(2018) designed a Compact Biogas Plant which uses starchy or sugary feedstock (waste grain flour, spoilt grain, over-ripped or misshapen fruit, non-edible seeds, fruits and rhizomes, kitchen waste, leftover food, etc.) and then subject it to the Compact Biogas plant for methane generation.

A two stroke force air cooled Reed valve engine was connected.The engine was started on petrol & runs for worm period of about 3 min. after this petrol supply cut off & engine is switch over. The gas flow valve is opened gradually & air supply is adjusted till engine runs smoothly. After the engine has been started. It can continue to run on biogas with 100% replacement. The rated AC output was 650W and a maximum rated AC output of 750W.

Akpojaro et al (2019) in their workr claimed to have successfully modified the internal combustion engine, which works smoothly without any sign of audible knocking during the entire experimentation. Comparatively, results show that 1.8kg of biogas runs for 127 minutes with a load capacity of 1400 watts while 1 liter of fuel runs on the power generating system with a load input of 1400 watt. 1 liter of fuel operated on the power generating system for a period of 42 minutes after which the system shutdown due to complete consumption of the available fuel.

COMPARISON OF BIOGAS AND Cooking gas (LPG which is Liquefied Petroleum Gas)

Biogas can be utilized in many of the same ways natural gas or LPG can be used such as cooking, heating, and lighting as well as to produce electricity. Methane is the component of

the biogas which supplies the energy. It is the useful part. The remaining components of the biogas include carbon dioxide, water vapour, and other trace elements such as nitrogen, oxygen, ammonia and hydrogen sulphide. Biogas is lower in methane than natural gas – biogas 50-75% to natural gas 90 – 98 %. The energy value of the biogas is dependent on a range of factors including the type of feedstock (raw material) used to generate the gas, temperature in fermentation, length of fermentation, and the specific plant design (Arshad et al 2022).

3.0 METHODOLOGY

3.1 Principles of Biogas Production

For the generation of biogas of an anaerobic digester is fabricated to convert biodegradable solid waste into biogas. The digester is a hard-plastic tank . The volume of the tank is 50litres designed based on the quantity of biodegradable solid waste produced per day. Cow dung or animal dung is added initially to introduce anaerobic bacteria into the digester. A Non-return valve (NRV) is fitted to both inlet and outlet pipes of the digester.

Then the absence of oxygen, microorganisms break down the organic matter into a stable residue, and generate the methane–rich biogas in the process. The generated biogas is being cleaned with the help of scrubbers. In this scrubbing process, the moisture and H2S contents and to certain extent CO2 gets removed to the acceptable level and then the purified biogas is stored in a biogas balloon, which is made up of Neoprene rubber. The purified biogas is then supplied to the converted biogas engine (run on 100% biogas) to generate electricity. The solid residue which can be separated through the slurry Drying Beds. About 30% of the liquid manure is then re-circulated in to the system, active anaerobic microorganisms (Gadakh 2021).

The chemical formula for biogas generation is:

$CH4 + CO2 + H2O \rightarrow CH3COOH + 3\ H2$

This equation shows the reaction of methane (CH4) and carbon dioxide (CO2) with water (H2O) to produce acetic acid (CH3COOH) and hydrogen gas (H2). The reaction is catalyzed by microorganisms in the biogas reactor. The acetic acid and hydrogen gas are then converted to biogas, which is primarily composed of methane and carbon dioxide.

3.1.1 Anaerobic Digestion:-Anaerobic digestion is the method of removing the high concentration organic waste. The advantages of this process over conventional aerobic process are low energy requirement for operation, a low initial investment cost and a low sludge production. Anaerobic digestions can be developed at different temperature ranges.

- Psychrophilic (12 -16 0C, e.g. in landfills, swamps or sediments)
- Mesophilic (35 -38 0C, e.g. in the rumen and in anaerobic digester)
- Thermopile conditions (55-60 0C; e.g. in anaerobic digesters or geothermal heated ecosystems) (Gadakh 2021).

Chemical Reaction: The above process can be described through the generalized reaction as under:- Organic matter + Combined Oxygen Anaerobs

New Cells + Energy for Cells+ CH4 +CO2 + Other End Products

The chemical composition of raw biogas is shown in table below:

Components	Symbol	Percentage
Methane	CH4	50-60%
Carbon Dioxide	CO2	45-48%
Hydrogen Sulphur	H2S	<0.2%

Table 1: chemical composition of raw biogas

3.2 Energy generation



Fig 1: Experimental Set-up for Biogas to Electricity

Energy production: In order to estimate the amount of electricity and heat that can be generated from the biogas produced, the efficiency of the CHP unit for electricity and heat generation must be known. The electrical efficiency typically varies from 30% to 40%. While the corresponding thermal efficiency is normally 35–55% (Lantz 2012).

To calculate the electrical energy in a biogas to electricity system, you need to know the following:

- The biogas production rate (m^3/day or m^3/hour)

- The electrical efficiency of the generator (usually between 25-30%)

- The calorific value of the biogas (kJ/m^3)

- The electrical load (kW or kWh)

Electrical Energy (kWh) = (Biogas Production Rate (m^3/hour) x (Calorific value of the biogas (KJ/m^3)) × (Electrical. Load (KW or KWh)).

3.3 Experimentation

The fig 1 is the experimental set-up is an improvised fixed-dome type "Bio-Gas" plant. During the process, the micro-organisms transform biomass waste (slurry of cattle dung and water) into biogas (mainly methane and carbon dioxide) and digestate. This biogas from the outflow hose is then fed to gas powered 3200Watt power generator after a minor purification process.

4.0 RESULTS AND DISCUSSION

4.1 Conversion of Petrol Engines to biogas Combusted Engine

Internal combustion engines have high requirements in terms of fuel quality. Components like hydrogen sulphide in biogas can damage the engine and so quality should be controlled. To manage fuel quality, production process should yield clean biogas but where it is possible, use of appropriate and robust components. Theoretically, all engines designed for cars, trucks, and ship can run on biogas as a fuel.

Spark ignition engines or Otto cycle systems, can operate on can be on biogas alone. In practice, a small amount of petrol (gasoline) is often used to start the engine. This technology is used for very small generator sets of capacity about 0.5-10 kW as well as for large power plants. For small scale biogas to electricity production, combustion engines are a better option because they have higher efficiency and low cost compared turbines of similar capacity. These results are in agreement with Kabeyi and Olarenwaju (2020).

The result showed that the 32Kw power generator just like all Internal combustion engines have high quality fuel requirements. Presence of some component especially hydrogen sulphide (H2S), CO2 and water vapor in biogas posed a serious threat to the engine performance as well as the life span of the engine. Therefore when the system was ran on a biogas partially cleaned of the undesirables, a 60% cost reduction, when compared to the use of petrol (premium motor spirit) was recorded.

5.0 CONCLUSION

Generation of electricity from biogas can be made a reliable renewable energy source with average calorific value of biogas being about 21-23.5 MJ/m^3, 1 m^3 of biogas is equivalent to 0.5-0.6 liters of diesel fuel or 6 kWh energy content. The generator will perform optimally with a high quality biogas.

For biogas to be suitable of use in an engine for power generation, it must meet the following general requirements: methane percentage should be as high as possible, water and CO2 composition should be as low as possible for high caloric value while the sulphur content should be as low as possible since it is converted to acids by condensation and combustion. The moisture content can be reduced by condensation in the gas storage or along the gas path while hydrogen sulphide (H2S) content can be reduced by chemical, biological, or physical techniques (Energypedia, 2016).

CHALLENGES

The biogas needs to be de-humified and purified before use in the prime mover, thereby requires the installation of biogas purifier in between the biogas plant and the generator.

Therefore there must be adequate provision of purifier, but the investment on adequate biogas purification does not rob on the economic and environmental gains of biogas to electricity generation. Note that the generator was petrol combusted generator converted to gas combusted system. Also, in practice, Spark ignition engines or Otto cycle systems operating on biogas alone need a small amount of petrol (gasoline) to start the engine because of low calorific value of biogas.

This work recommends refining of the gas in a refining system that incorporate desulphurization, condensation and carbonization. Refining (gas cleaning) will not only eliminate the undesirable components of the gas, but improves the overall fuel gas quality and combustion outcomes.

CONFLICT OF INTEREST

Authors have declared that no competing interests exist.

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