Performance On Operation of Greenhouse biogas Digester

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Abstract: South Africa is experiencing an energy crisis and is heavily depending on fossil fuels. The use of Renewable energy technologies can be a solution to the current electricity crisis in South Africa that have led to continuous load shedding. Waste-to-energy conversion is capable of contributing significantly to advancing economic development and health quality in society. One of the technologies that exploit waste-to-energy conversion is biomass technology. For optimum biogas production, solar energy can be used to provide suitable digester temperatures. In this study, a portable plastic biogas digester housed inside a greenhouse cavity was assembled and fed with cow dung. The pH, ambient temperature, slurry temperature, and temperature inside the greenhouse cavity were measured on a daily basis. The biogas yield was measured by the serial residential (SR) diaphragm biogas flow meter and the methane composition were measured with the use of the SAZQ biogas analyser. The influence of temperature on biogas fermentation was investigated in the study. The temperatures of the slurry, ambient and within the greenhouse cavity during the anaerobic digestion retention cycle was investigated in the study. The results depicted that the gas production rate of biogas fermentation increases with the increase of temperature within a certain range, and the maximum biogas production occurred when the pH was in the range of 6.84 to 7.03. The methane composition of the biogas was above 50%. It was concluded that a digester housed inside a greenhouse envelope could keep the slurry temperature within the optimal mesophilic temperature range of 34ºC–36ºC, which is ideal for anaerobic digestion.

Keywords: Greenhouse biogas digester, Waste-to-energy conversion, Anaerobic digestion, Biogas yield, Mesophilic temperature range

1. Introduction

The usage of traditional energy sources for power generation produces toxic pollutants that endanger human and environmental health worldwide. As a result, the production and application of primary energy, as well as the study of alternative renewable clean energy, have become global concerns. Anaerobic digestion of organic waste is an efficient method for producing biogas with a high energy value. This technology has recently gained popularity due to the added benefit of reducing greenhouse gas emissions. However, if the fermentation temperature is too low or the temperature swings too quickly during the process of biomass anaerobic fermentation, the gas production efficiency and methane content of the biogas produced are lowered [1]. The low-temperature condition has become one of the main reasons for the limited application of anaerobic digestion technology. Bio-digester heating is essential because the rate of microbial growth digestion, and gas production increase with temperature [2].

In the study conducted by [3] on microbial enrichment, it was found that low temperatures resulted in low biogas production and unstable operational performance in the anaerobic digestion system. In anaerobic digestion, the temperature can regulate microbial intracellular enzyme activity, thus affecting the metabolic activity of microorganisms and the anaerobic fermentation efficiency. In addition, changes in microbial metabolism or community dynamics affect the operation of the anaerobic digestion system [5,6]. It was reported that mesophilic conditions (30ºC–40ºC) have been generally adopted for the anaerobic digestion of agricultural organic waste and show good performance in biogas production [7]. During the winter season, it is cold for a long period, and the rate of biogas generation and raw material decomposition is low. As a result, it is vital to implement cost-effective heat preservation and warming techniques for biogas fermentation [8]. Biogas heating is mainly categorized into two methods namely direct heating in hot water or steam and indirect heating via a heat exchanger, where the heating medium is usually hot. The latter imparts heat while not mixing with the slurry.

Indirect heating can be achieved by heating the slurry in the digester on the floor, in-vessel, on-vessel, and ex-vessel [2]. Electric heating methods consume electrical energy and have a higher economic cost, whereas other heating methods do not convert enough thermal energy and require the combustion of fuel, which causes air pollution, thus defeating the purpose of an eco-friendly renewable [9]. [10] investigated the effect of plastic as an insulation medium rather than brick and stone on a methane digester in a solar greenhouse near Nilgiris, India. In comparison to the regular biogas digester, the interior temperature and gas production of the biogas digester are 22.4 o C and 34.6 kg /d, respectively, while the average annual temperature of the experimental biogas digester reached 26.3 o C and 39.1 kg /d.

According to the findings of [11], the temperature of the anaerobic reactor employing the innovative solar greenhouse was 7.61% greater than the typical anaerobic reactor. Based on the solar greenhouse, temperature growth and stability of temperature can boost biogas output and ensure gas production stability. Currently in South Africa, the primary heat preservation measures of a biogas digester involve digging a ring trench and covering the digester [12]. The surface of the biogas digester with firewood, heat preservation materials, solar greenhouse, and underground burial of the entire biogas fermentation system. The solar greenhouse is also an effective insulation technology. The study focused on the performance operation of a greenhouse solar-assisted bio-digester and the deployment of a data acquisition system to monitor the temperature profile for the retention period and the proportion of the biogas yield.

2. Method

The study methodology composed of an experimental setup. The quantitative data were obtained through experimental methods with the employment of sensors and data loggers. A balloon digester accommodated inside a greenhouse cavity was used for the anaerobic digestion of cow dung in this study.

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2.1. A Reactor design

The reactor known as the balloon biogas digester consists of three parts namely, the digester chamber, the inlet, and the outlet chamber as shown in figure 1. The digester chamber and gas storage have a cubic shape with a total volume of 3.0 m^3. The digester chamber is made up of PVC as shown in figure 1.

Figure 1: Diagram of the fabricated biogas digester

2.1.1. *Experimental design:* The paragraph text follows on from the subsubsection heading but should not be in italic. The study used the mono-digestion continuous mode of feeding. Cow dung was collected from the University of Fort Hare's dairy farm. Fresh dairy cow manure (which is known to contain obligatory methane-forming anaerobic microorganisms) was utilized to construct an improved substrate, which produced biogas within a few days of feeding [13]. The substrate was tested for total solids (TS), volatile solids (VS), ammonia-nitrogen (NH4-N), total alkalinity (TA), pH, and calorific value (CV) before being fed into the digester using a mass balance and an oven, an AL450 Aqualytic photometer with a variety of pre-programmed methods based on the proven range of Aqualytic® tablet reagents, liquid reagents, tube tests, The substrate was formed and the total solids slurry was 11%. The slurry was fed into the digester, for anaerobic digestion which occurred in the mesophilic temperature range [13]. The internal temperature of the digester, pH, and biogas production rate and composition were monitored as the anaerobic digestion process progressed using a Pasport PS-2125 temperature sensor coupled with a PS-2000 Xplorer, the Serial residential diaphragm biogas flow meter, and the SAZQ biogas analyser, respectively. A data logger and computer system recorded data on the composition of methane (CH_4), carbon dioxide (CO_2), and hydrogen sulphide (H_2S) in the biogas for examination. Table 1 illustrates the properties of the cow dung fed into the digester for digestion and performance evaluation

TABLE 1: Measured parameters for cattle manure

Parameter	**Value**
Calorific value (MJ/g)	26-30
pH (Max Biogas yield)	6.8- 7.2
Average Slurry Temperature (^{0}C)	35
Ammonium nitrogen (mg/L)	114 – 235

Two type-K thermocouples were airtightly placed through the plastic wall of the digester and in the space above the plastic vessel within the greenhouse to monitor the slurry temperature and the temperature of the air within the greenhouse. The pressure within the digester vessel was monitored using a pressure sensor.

3. Results and Discussion

3.1 Temperatures

Figure 2 shows the temperature variations with time measured at halh-hourly intervals over a period of two typical days during the hydraulic retention cycle. The days were chosen, because they are generally a true representation of the ambient temperature pattern for the full retention period (a whole month).

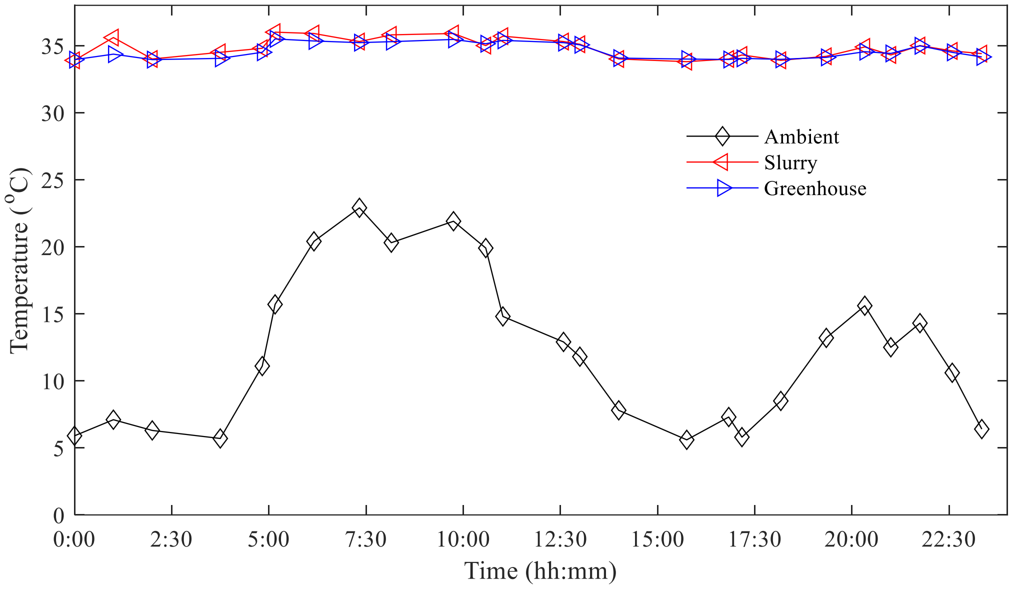

Figure 2. Ambient, greenhouse, and slurry temperature

The greenhouse cavity temperature was greater than the ambient temperature *($T_a > T_{amb}$)* at any given time, due to the greenhouse effect and the insulation against heat loss. According to [13]., $T_s > T_{amb}$ is always due to the greenhouse effect and bacterial activity aiding exothermic processes within the digestive chamber. At night and early hours in the morning, the slurry temperature was greater than the greenhouse cavity temperature ($T_s > T_a$) due to the absence of solar radiation during the night. The slurry has a higher heat capacity than the air within the greenhouse, therefore, it was able to retain heat better than the air.

Figure 3 shows the variation in the production of CH4, CO2, H2O, and other gases.

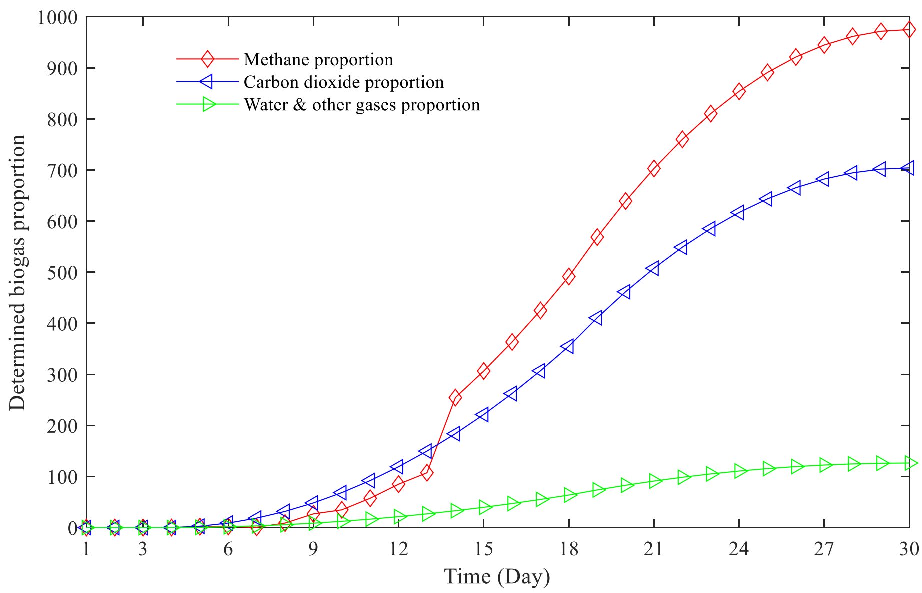

Figure 3: Variation of the production of CH_4, CO_2, H_2O and other gases

The existence of some aerobic bacteria in the digester before biogas generation, aided the interaction of O_2 with carbohydrates to make CO_2. Acidogenic bacteria converted organic feed to fatty acids, which were then degraded by acetotrophic methanogens to CH_4 and CO_2.

$$CH_3COOH \rightarrow CH_4 + CO_2 \quad [1]$$

CO_2 levels dropped because of O_2 depletion in the digester vessel and the conversion of some CO_2 to CH_4 by hydrogenotrophic methanogens.

$$CO_2 + 4H_2 \rightarrow CH_4 + CO_2 \quad [2]$$

On Day 10, CH_4 production began and gradually grew to a steady proportion of 55%. No CH4 was produced before Day 10 because the methanogenic bacteria waited till the formation of fatty acids on which they feed to produce methane [14;15].

Table 2: CH_4, CO_2 and H_2O and other gases composition in biogas

Biogas composition under investigation	**Composition (%)**
Methane (CH_4)	55-60
Carbon dioxide (CO_2)	30-40
Water (H_2O) and other gases	0-10

4. Conclusion

The usage of a greenhouse portable biogas digester for anaerobic waste digestion for the biogas generation boosts digestion efficiency and methane yield. The usage of a greenhouse biogas digester considerably reduces the primary difficulty of inadequate temperature control, which leads to poor methane output. With a methane yield of between 55-60% from dairy cattle dung, which is comparable to the 50% found in the literature for other digester designs such as the fixed dome with sawdust insulation, the greenhouse biogas digester becomes a more appealing option owing to it portability and relative ease of installation in any given location (rural, urban, multi-story, and rocky terrains), and can operate at a higher optimum temperature of 35ºC due to the heating effect by the green technology. It has an added benefit that it is cheap to construct and parts are locally available. The use of a greenhouse for temperature control in small digester operations is an appealing solution to the problem of inadequate temperature control. Solar radiation is transmitted through the greenhouse cover inside a greenhouse structure housing a digester, and part of the transmitted radiation is absorbed by the digester and transferred into the substrate slurry as thermal energy, raising the slurry temperature. The remaining part is emitted as heat radiation back into the greenhouse space. Because thermal radiation has a longer wavelength and lower frequency than solar radiation, it cannot be reflected into the atmosphere by the greenhouse cover. Therefore, thermal energy builds within the greenhouse.

5. Recommendation

A feasibility analysis on the cost of using the solar energy as an assisted heating source for a greenhouse biogas digester versus other conventional methods of digester heating such as electrical heating should also be done at the recommended scale to reveal the cost-effectiveness and applicability of the innovative greenhouse biogas digester. Dairy cow dung from the University of Fort Hare dairy farm was used to evaluate digester performance in this study. Other substrate types, such as home wastes, kitchen wastes, vegetable wastes, pig manure, and co-digestion, should be digested using the greenhouse digester design for a more thorough evaluation of the greenhouse biogas digester's effectiveness. Semi-continuous digester feeding and the use of various kinds of inoculum at digester start-up should also be done for further digester performance evaluation since in this work only the batch digestion mode was used for experimental purposes. A mathematical model of this digester design should be developed and used in the determination of optimum biogas production parameters using the design under various feeding and operating conditions.

Acknowledgement
Authors would like to thank the Department of Science and Innovation and Technology Innovation Agency (DSI-TIA) and The Govan Mbeki Research Development Centre (GMRDC) office and the research office of University of Fort Hare, South Africa for the financial support that enable the implementation of the study

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