Statistical Analysis of the Performance of Aboveground and Underground Biogas Digesters via One-way ANOVA test

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Abstract- This study aims to compare the performance of the aboveground and underground biogas digester, thereby determining which of the systems design performs best. A total of 286 datasets was obtained over a monitoring period of 18 days on an hourly interval using CR 1000 data logger. The parameters considered the comparison were the predictors (pH, and temperature) and responses (methane and carbon dioxide) using one-way analysis of variance test. From the finding, it was revealed that there was a significant difference in the pH and gas production of 5% significance level between the underground and above ground biogas digester, while there was no significant difference in the gas and slurry temperature of the two digester systems (P-value > 0.05). This implies that no effect was observed and hence, the probability that the null hypothesis is true, statistically. It can be concluded that the underground biogas digester design outperformed the above ground biogas digester and should be recommended

Keywords: Carbon dioxide, Cow dung, Methane, pH, Temperature.

Nomenclature

Analysis of variance	ANOVA	Grams/litre	g/L
Caloric value	CV	High density polyethylene plastic	HDPE
Carbon dioxide	CO_2	Methane	CH_4
Chemical oxygen demand	COD	Non-dispersive infra-red	NDIR
Gas temperature	TGAS	Poly vinyl chloride	PVC
Gas temperature pressure monitoring system	GTMPS	Slurry bottom temperature	SBT
		Slurry top temperature	STT
Grams	g	Total solids	TS
		Volatile solids	VS

1. Introduction

Biodegradation of organic matter in the absence of oxygen to produce biogas is a promising renewable energy source. This degradation process also known as anaerobic digestion, usually occurs in a closed system called biogas digester [1]. Biogas digesters can be designed and built from a variety of materials such as cement, bricks, concrete, plastics, and metal and fibre composites [2]. In addition, it can be installed aboveground or underground with the aim of stabilizing the operating temperature. Biogas is mostly composed of methane (50-70%) and carbon dioxide (30-50%), as well as traces of other gases (nitrogen, oxygen, hydrogen sulphide). This biogas can be used for electricity generation and heat application or can be liquefied into fuel for automobiles. It has proven to be a promising and reliable technology which is feasible and cheap, thereby providing clean and reliable energy [3-4]. Generally, biogas production is usually influenced by a variety of factors, ranging from operational parameters to design parameters. These parameters if properly monitored will guarantee efficient biogas production. Hence, there is a need to monitor the performance of digesters in terms of these parameter to ascertain the parameter with the utmost impact.

As an example, Iweka et al. [5], statistically analysed the production of biogas from co-digestion of corn chaff and cow dung using python approach. The study obtained a P-value that is < 0.0001 indicating that the represented term is significant, which implies that the null hypothesis is accepted. In a similar study, Taus et al. [6], statistically assessed the suitability of using kitchen waste and agricultural crops as substrate for biogas production. A total of 854 dataset was analysed using one way ANOVA test. The obtained P-value < 0.0001 for methane production showed a significant effect on the individual substrate. Furthermore, Adeniran et al [1], compared the use of plantain peels and poultry dropping as substrate for biogas production. Response surface methodology (RSM) was employed in this comparative analysis. Similar to the present study, the predictor used in their study includes ambient, slurry and gas temperature. The authors reported that the P-value obtained was less than 0.05. This indicate that the regression and correlation model terms are statistically significant. Adepoju et al. [7], statistically analysed the biogas production from co-digestion of cornstalk with goat dung using response surface methodology. The biogas digester was constructed using galvanized steel because of its strength and the durability in acid and basic environment. Temperature was used as the predictor while biogas yield was assigned as the desired response. The obtained P-value (< 0.05) of the model terms represented were significant for both biogas and temperature. In this present study, the aim is to compare the performance of an aboveground and underground biogas digesters using statistical analysis (ANOVA test). This comparison will be based on temperature, pH and gas production. Notably, the design orientation and the ANOVA plot of the biogas digesters, provides the novelty of the study. This aspect seems to be lacking in most studies relating to the present study which are limited.

2. Materials and Method

2.1. Experimental Set-up

The biogas digester was fed on the first day by introducing 200 litres of cow dung. The slurry was obtained by diluting solid waste (cow dung) with water in the ratio of 1:1 (waste/water). Later, an inoculum (cow dung slurry) was introduced from the existing digestion tank, increasing the rate of decomposition or fermentation. After feeding the digester on the first day, it was necessary to open the valve of the gas connected to the digester chamber for 48 hours (2 days) to allow air to escape. In the subsequent feeding, 50 L of cow dung was introduced every three days from 9 am to 10 am [8]. Finally, with the use of biogas burner, the gas flammability was tested. In the fabrication and construction of the biogas digesters, the volume of the outlet chamber was greater than the inlet chamber. This was because as the biogas is produced at the top of the digester chamber, pressure is excited in the outlet chamber. In so doing, pressure in the outlet chamber is greater than that of the inlet chamber. In terms of the temperature, rate of biogas production usually reduced (up to 75% drop) during the winter when biogas digester is set up at a higher elevation or altitude. This is due to decrease in temperature experienced in such locations. Therefore, it is usually difficult to obtain optimum temperature of about 30 – 35ºC in a hilly or temperate zone. However, this was not the case in the present study because of the geographical condition of the study area.

2.2. Consideration of Parameters for Statistical Analysis Study

The predictor or input parameter used in the study includes the temperature of the gas (TGAS), slurry bottom temperature (SBT), slurry top temperature (STT) and pH. These were used in the development of the analysis study. These parameters are also known as indoor parameters, which were considered because they influence the response. The methane and carbon dioxide volume were referred as the desired responses. For simplicity, the gas temperature represents the temperature in the vicinity of methane produced inside the digester. The slurry bottom temperature is the slurry temperature located at the lower level within the digester. In contrast, the slurry top temperature is the temperature of the slurry situated at the upper level within the digester. pH is referred as the ratio of absolute pH to neutral pH at 7.00 [8].

2.3. Statistical Analysis

The data collected went through statistical evaluation/ analysis using MATLAB via one-way ANOVA. This was performed to compare variation in pH, temperature (gas, slurry bottom and slurry top), methane and carbon dioxide production of the aboveground and underground biogas digester. The pH and various temperature regions are referred to as predictors, while the methane and carbon dioxide is known as desired responses. The predictor's temperature was measured in degrees Celsius excluding pH. One-way ANOVA was used in this study because it is a statistical algorithm used to compare more than two parameters at a significance level of 5% for significant differences, as reported in Haque et al. [9]. Note that one-way ANOVA treats each dataset of a particular parameter as normal distribution and applies a null hypothesis test that assumes no significant difference between the two parameters if the P-value is equal to 0.05. The desired responses and selected predictors over the time of day for the average days of the entire monitoring periods was carried out using the ANOVA one way test

2.3.1. ANOVA Plots

The ANOVA plots was employed as a statistical toolbox to describe the data samples based on the parameters considered. They are useful for graphic comparison of many data samples. In these Figures, the tops and bottoms of each box are the 25th and 75th percentile of the dataset samples respectively. The red line in the middle of top and bottom box is the dataset samples median known as the interquartile range. This is the distance between the top and bottom box. Figures where the median is not in the cantered of the box, indicate a skewness. By skewness, it means the distortion that deviate from the normal distribution in each dataset. The tiny broken lines extending above and below each box are called whiskers. The whisker shows the extent of the rest of the dataset (unless there are outliers). They are drawn from the ends of the interquartile ranges to the furthest observation. However, a scenario where are no outliers, the maximum of the data sample is regarded as the top of the upper whisker while the minimum is the bottom of the lower whisker. An outlier is a value that is more than 1.5 times the interquartile range from the top or bottom of the box. Notches display the variability of the median dataset samples and is computed so that the box plot whose notches do not overlap have different median at 5% significance level. The 5% significance level is based on the normal distribution assumption. Hence, the comparisons of the median are said to be robust for other distribution, a case where the normality of the assumption is not valid [10].

3. Results and Discussions

3.1. One-way ANOVA Test for The Predictors

The crucial predictors include the pH and temperature. The temperature covers the gas, slurry top and slurry bottom of the above-ground digester and the underground digester. *3.1.1. One-way ANOVA test for the pH* pH affects the microbial process that convert organic waste into methane. Different microorganism's groups present in anaerobic digestion propagate at varying pH values. Substrate pH fluctuations cause instability and acid accumulation, leading to reduced methanogenesis and failure of the biogas digester. A detailed demonstration on this can be found in Obileke et al. [11] study, which provides a correlation between the yield of biogas and biogas digester pH value. This study clearly revealed that pH at neutral value leads to increase in biogas yield. Figure. 1 shows the ANOVA plot of the pH of both the above-ground and underground digester. The mean pH value of 7.135 in the underground digester throughout the monitored period was higher than that of the aboveground digester with a value of 7.048. This may be attributed to the high concentration of volatile fatty acid, which in turn can inhibit the hydrolysis process [12]. The mean pH value reported in the study is similar to that of Achuka et al. [13] study was 6.990 to 7.163 was obtained. The P-value of the group mean between the underground digester and the above ground digester was 6.4 x 10^{-3}

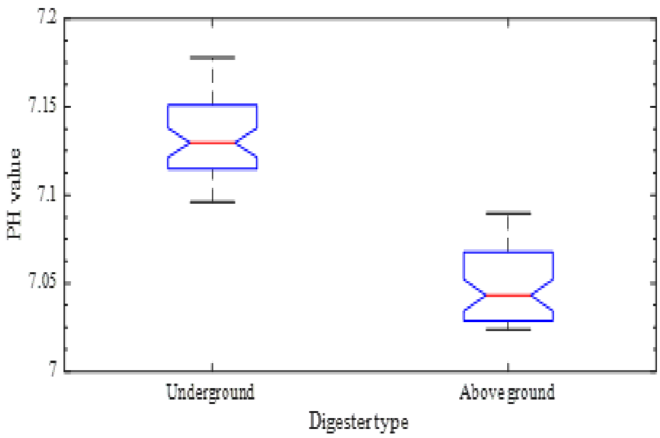

Fig. 1: One-way ANOVA plot of pH for underground and aboveground biogas digester

3.1.2. One-way ANOVA Test for The Temperature

This section includes the one-way ANOVA test for the various temperature region located inside the biogas digester. These are, gas temperature, slurry bottom temperature and slurry top temperature. During anaerobic digestion process, temperature is regarded as an important parameter of consideration. However, the plot of the gas temperature of the underground and above-ground digester using ANOVA is presented in Figure 2.

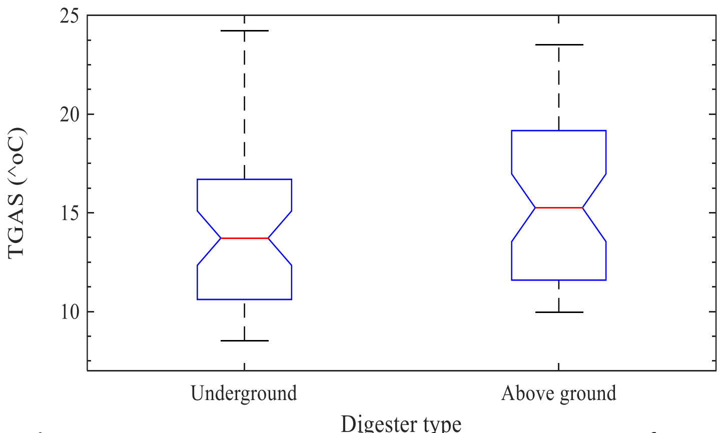

Fig. 2: One-way ANOVA plots of gas temperature for underground and aboveground biogas digester

In Figure 2, the mean gas temperature in the underground digester was 14.475°C which is lower than the above-ground digester of mean temperature 15.515°C. The P-value of the group mean between the underground digester and the above-ground digester was 0.256. Noting that the P-value was greater than the threshold P-value of 0.05 which is the same with Hongguang et al [16] and Milliken and Johnson [17]. This shows there is no significant difference in the gas temperature between the underground digester and the above-ground digester. According to Iweka et al. [5], there is no insignificance. Statistically, the probability that null hypothesis is true. Figure 3 shows the ANOVA plot of the slurry bottom temperature of both the underground and above ground digester.

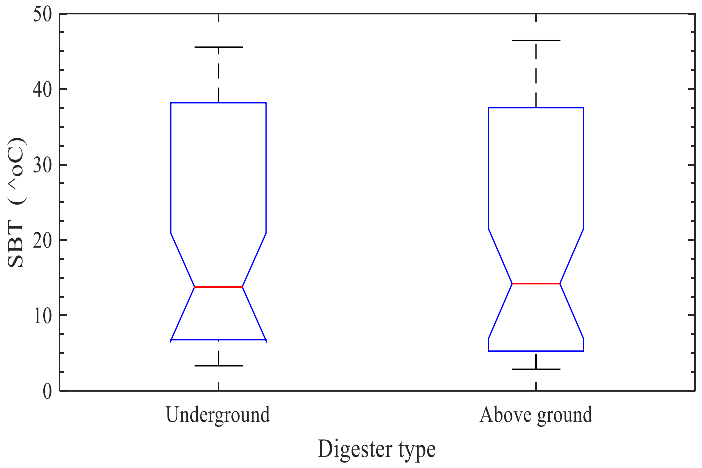

Fig. 3: One-way ANOVA plots of slurry bottom temperature for underground and aboveground biogas digester

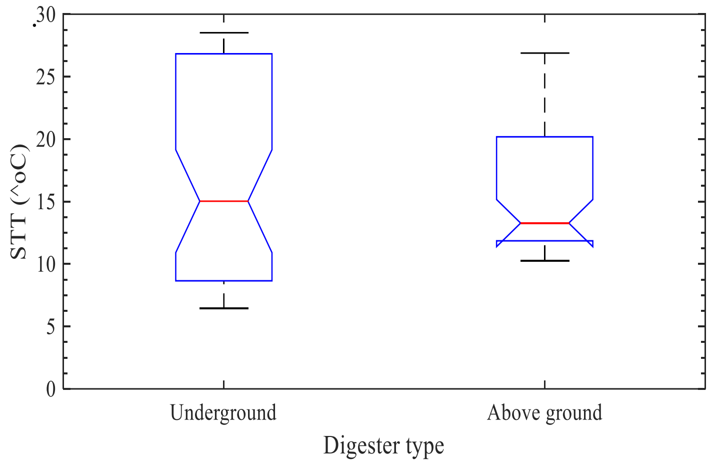

Fig. 4: One-way ANOVA plots of slurry top temperature for underground and aboveground digester

The mean slurry bottom temperature in the underground digester for the full monitored period was 20.580˚C and was slightly higher than that of the above-ground digester, which was 20.332ºC. The group mean's P-value between the underground digester and the above ground digester was 0.939. The P-value was greater than the 0.05 which is the threshold p-value; this affirms that there was no significant difference in the slurry bottom temperature between the underground digester and the above-ground digester. The obtained findings are slightly different from the study that investigated the effect of temperature on biogas production using different domestic organic waste [18]. The author reported a mean temperature of 34.996°C and P-value of 0.03 ($P < 0.05$). This implies that by one way ANOVA test, there was a difference in the mean temperature. Therefore, the temperature significantly differed on the digester that generates the biogas.

Figure 4 shows the ANOVA plot of the slurry top temperature of both the underground and above ground digester

A mean slurry top temperature of 17.107˚C was obtained for the underground digester which is higher than the above ground digester value of 15.807˚C. The P-value of the group mean between the underground digester and the above-ground digester was 0.374. The P-value was greater than the 0.05 (threshold P-value), so there was no significant difference in the slurry top temperature between the underground digester and the above-ground digester.

3.2. One-way ANOVA Test for The Desired Responses.

The desired responses are methane and carbon dioxide production. Methane and carbon dioxide are the main gases composed in biogas, comprising 55 – 70% methane and 30 – 45% carbon dioxide [19].

3.2.1. One-way ANOVA Test for CH_4

The ANOVA plot of the of methane production for both the underground and aboveground digester is presented in Figure

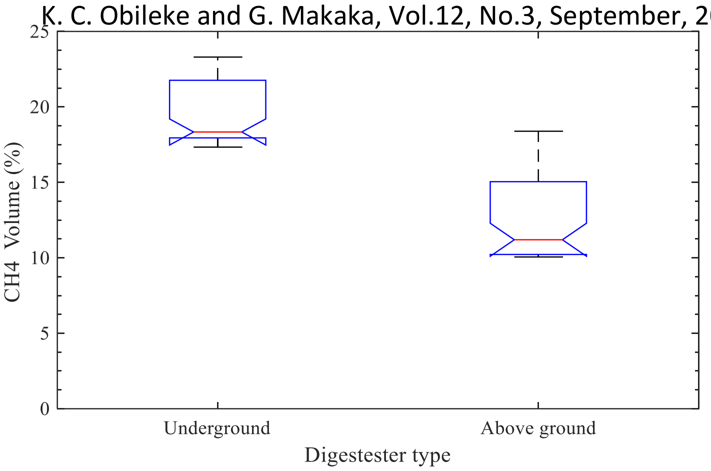

Fig. 5: One-way ANOVA plots of the volume of methane for above ground and underground digester

The mean percentage of methane production in the underground digester throughout the monitored period was 19.544 % which is higher compared to the aboveground digester value of 12.574 %. The difference in methane production was attributed to the difference in temperature stability. In another study conducted by Taus et al. [6], the analysis of variability of methane production using ANOVA one way test reported 49 – 67.5% with an average value of 59.5%. However, the study did not mention if the biogas digester was installed underground or aboveground. Also, the P-value of the group mean between the underground digester and the above ground digester was 1.0 x 10^{-24}. In Figure 7, notably, the P-value is much smaller than the threshold P-value of 0.05 (P-value < 0.05), indicating a significant difference in the yield of methane between the underground digester and the above-ground digester. The P-value reported is the same with that of Imologie et al. [20] for co-digestion of feedstock. This implies that the represented terms are significant [5]. Also, the obtained P-value was the same as the study conducted by Adepoju et al. [7], in which P-value of < 0.05 were significant for the methane production using RSM. This significant effect experienced is attributed to the nutrient which enhances solubilization, digestion and biomethane by the action of ameliorating the antagonistic and synergistic effect of the sludge. On the contrary, in Hanafiah et al. [21] study, the one-way ANOVA analysis had a significant difference of methane with a P-value of < 0.0001, when the digester was fed with fresh slurry faeces. Nwankwo et al. [22] revealed that the methane volume significantly increased (P-value<0.05). The significance rate of produced methane reported in the current and previous studies in biogas digestion tanks results from the specific growth rate of methane-producing bacteria in biogas digestion tanks. This allows the uses carbon to form methane, leading to the low methane production.

3.2.2. One Way ANOVA Test for CO_2.

Figure 6 illustrates the ANOVA plot of the production of carbon dioxide produced from both the underground and above ground digester.

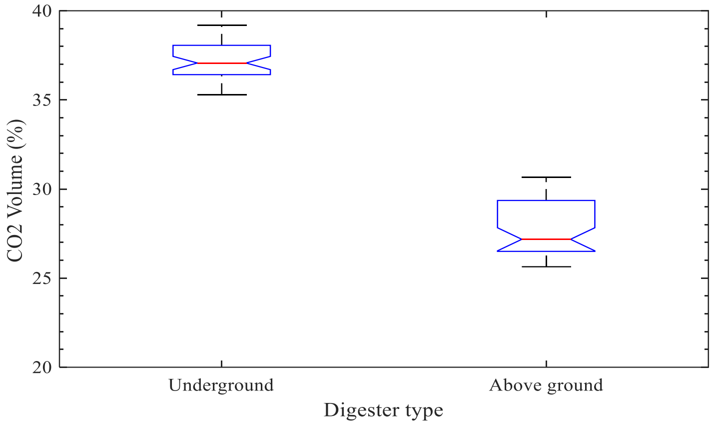

Fig. 6: One-way ANOVA plots of the volume of carbon dioxide for aboveground and underground digester

The mean volume of carbon dioxide produced in the underground digester and above ground digester was 37.210 % and 27.789 % respectively. The result is almost the same with Nwankwo et al. [22] where 25.15 % mean volume was reported for the aboveground biogas digester. The growth rate of methanogenic bacteria in the biogas digester which allow the use of carbon to form methane is said to be responsible for the obtained volumes. In addition, the P-value of the group means between the underground digester and the above-ground digester was 9.4 x 10^{-56}. The obtained value shows there was a significant difference in the volume of carbon dioxide produced between the underground digester and the bove ground digester. This is similar to Hanafiah et al. [21], whereby there were significant differences in the measurement of carbon dioxide having P-value of < 0.

0001.The different in P-value might be attributed to the type of feedstock used in the different studies. This was not the case in Nwankwo et al. [22] study, whereby the carbon dioxide volume decreased significantly (P-value < 0.05). Having looked at the statistical comparison of the underground and aboveground biogas digester via one way ANOVA test, it is interesting to determine which of the systems design performed better. Figure 7 presents the average daily performance of selected parameters monitored during the period of the experiment, given rise to biogas production. It is observed from Figure 7 that the methane content was almost 40% for the underground digester compared to 25% for the aboveground system as well as the carbon dioxide of 37% for the underground as opposed to 27% for the aboveground biogas digester. This behaviour is because of the presence of readily biodegradable organic matter in the cow dung as well as presence of methanogens. The high methane yield in the underground biogas digester is an evident that the methanogenesis process of the anaerobic digestion is attaining its optimum stage at a fast rate indicating full activities of the methane formers. However, for the various temperature regions (gas, slurry bottom and slurry top), the underground system had a value of 12°C, 20°C and 16°C relative to 15°C, 20°C and 14°C for the aboveground system respectively. The obtained temperature reading is because of the rate of heat loss and heat gain from the biogas digester chamber which affects the microbial activities in the slurry inside the digester chamber. The pH of the underground bio-digester (pH of 7) is a little bit higher than the aboveground bio-digester (pH of 6.8). This might be attributed to the presence of acidogenesis reaction that takes place inside the digester and the high presence of volatile fatty acid [23]. It is evident from Figure 8 that the underground biogas digester design performs best in the study based on the average daily performance.

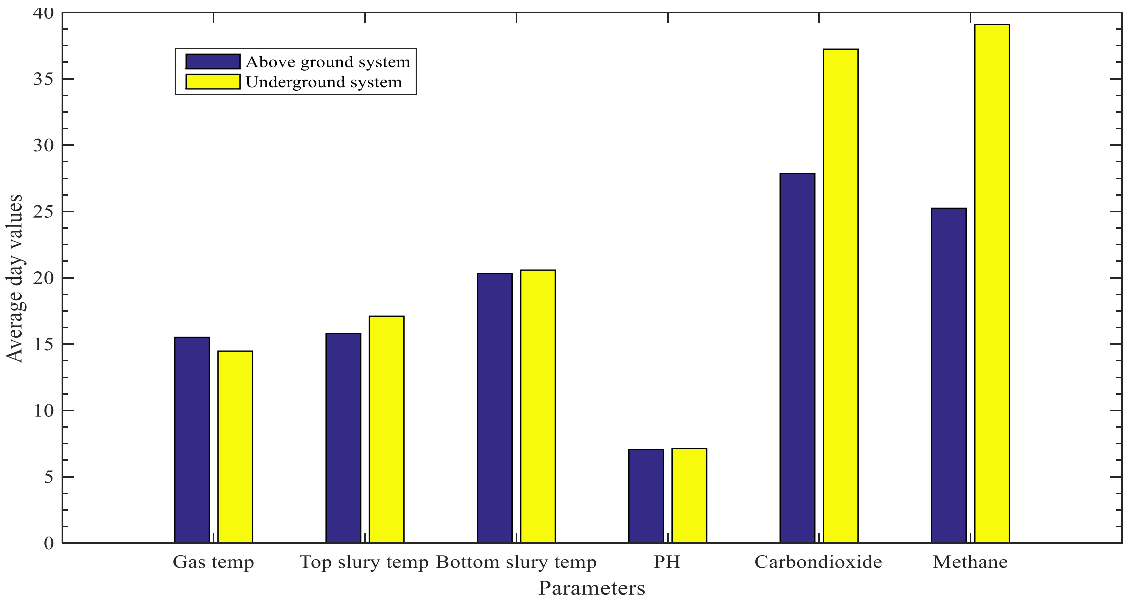

Fig. 7: Average daily performance for the aboveground and underground biogas digester systems

4. Conclusion

The study has successfully evaluated the performance of the above ground and underground biogas digesters, using statistical analysis, thereby presenting them in ANOVA plot. From the P-value, it was found that there was significant difference in the pH while there was no significant difference in the gas and slurry temperature of both digesters with respect to the biogas production. In addition, there was a significance difference at 5% for the gas production (desired response), with the underground digester outperforming the above-ground digester. Further, on the daily performance of the pH, temperature and gas production, the underground was revealed to perform better than the aboveground. Conclusively, the temperature and pH interact and complement one another in biogas production as both are regarded as strong biogas yield drive.

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