Vol 4, 2019 Issue, ISSN 2001-2837, Pages 9-15

International Journal of Technoscience and Development (IJTD)

Vol 4, 2019 Issue, ISSN 2001-2837

CONTENT

Vol 4, 2019 Issue, ISSN 2001-2837, Pages 9-15

IJTD
Is an open peer review journal that covers the reality producing field of technology and engineering in development contexts. The content is multi-, inter- and transdisciplinary and merges areas such as technology, engineering, ICTs and development. IJTD is part of the broader journal collection Technoscience.se.

The review process
IJTD is committed to a transparent, productive, and rigorous peer review process. Submissions are read by the editors of the special issue.

IJTD 's peer review process asks a great deal of the reviewers (and the authors) who participate in the online review process. Because of this, only original contributions will be published and contributions that have not been published, or submitted for publication, elsewhere.

Pre-Review: The editor of a given issue determines when an article is ready to go through the open peer review process. After approval from the editor the review process of external reviewers may begin.

Transparent and collaborative peer review: The editor of a given issue sends the submission to at least two reviewers. Reviewers are asked to submit their reviews within 30 days of receipt. The review process is transparent and visible for the reviewers and authors. The system is moderated by one of the editors at Technoscience.se

Vol 4, 2019 Issue, ISSN 2001-2837, Pages 9-15

Biogas digester performance measurement with changing temperature: A facile lab-scale evaluation using cow dung substrate

Ronald Kayiwa[1], Peter Okidi. Lating[2]

[1] PhD student, Department of Mechanical Engineering, Makerere University
P.O. Box 7062, Kampala, Uganda

Corresponding author: kronald@cedat.mak.ac.ug

[2] Professor, Department of Electrical and Computer Engineering, Makerere University
P.O. Box 7062, Kampala, Uganda

ABSTRACT

Biogas remains a relatively eco-friendly alternative energy source to the hazardous fossil fuels. It is produced anaerobically, and mainly composed of methane (CH4) and carbon dioxide (CO2) gases. Anaerobic processes are sensitive to environmental changes in temperature, pH, and C/N ratio besides other operational practices. Temperature regimes determine the well-being and co-existence of various archaeal communities in biogas systems. Moreover, shifts in temperatures have rendered some biogas systems passive due to unfavorable enthalpies for the anaerobes. In Uganda, no attempts have been made to either in-build or manually implement temperature-monitoring capabilities for these systems. This research aimed at finding out the effects that changes in temperature have on biogas systems performance particularly in terms of the amount of biogas output, the methane percentage composition. The effect of temperature was investigated through forced temperature variations imposed on 750 ml Perspex glass bottles loaded with 500 g of substrate. The temperature was varied using a thermostatically controlled water bath. This was done at a retention time of 22 days. The amount of biogas produced per day was measured using the method of downward displacement of water. The methane composition was measured using an Orsat gas analyzer. In this research, it was found that reactor performance in terms of biogas production and percentage composition of methane yields did not vary significantly at the different temperatures. The microorganisms present in these reactors must have a tolerance for a fairly wide range of temperatures. However, drops in biogas production and methane percentage compositions were realized at transition temperatures from mesophillic to thermopillic and reversely too. This could have been due to disruption of bacterial communities that are tolerant to a given temperature range. Where possible, digesters should be kept at thermophillic conditions (40-46 °C) since all peak values for biogas and methane percentage were in this temperature range.

Keywords: *Renewable energy, Anaerobic digestion, Biogas digesters, Temperature*

1.0 INTRODUCTION

1.1 Background

In early 1990's, the government of Uganda through Energy Resources Department, with assistance from IDA funds of the World Bank, started a national biogas pilot project that was not successful either due to poor maintenance and process control (World Bank, 2005). The project employed a World Bank hired technical advisor who was in charge of the project. In 2000, the Government of Uganda through Energy Resources Department implemented a biogas program in and around Kampala (Mccord et al., 2017). Twenty biogas digesters of 8 cubic meters capacity each were constructed in and around Kampala. Two of the bio-digesters were built at institutions and the rest at households. All the digesters were functional at the start. Another successful project has been the biogas program undertaken by the Department of Chemistry at Makerere University. This program has constructed 3 demonstration biogas digesters in Mityana District. These projects were generally successful at the start. However, currently very few are still functional.

Private individuals leveraging expertise from local biogas engineers and technicians have made many Initiatives. However, these have not been successful due to reasons ranging from managerial to technical. Limited spread of this technology could be due to some social and economic issues.

1.2 Problem Statement

The global depletion of energy sources and the adverse effects of fossil fuels on the environment pose a challenge to engineers to devise alternative energy source. Among the efforts to combat the problem is the use of renewable energy sources of which biogas systems are part. In Uganda, the spread of this technology is still limited. Most of the biogas systems are no longer functional and those in operation are not performing to the expected outputs. Besides the economic and social factors is the poor control of anaerobic digestion parameters which are the pinnacle for any biogas system performance. Anaerobes are highly sensitive to enthalpy changes and this is one of the causes of gradual and abrupt passivity of biogas systems. The performance of biogas digesters under different temperature regimes has not been studied in Uganda. This study aimed at filling this research gap that could later yield into biogas systems maintenance manuals that are evidence based.

1.3 Study purpose

This batch study aimed at ascertaining the effect temperature has on the chemical reactions involved in each biogas production stage and establish any correlation with the percentage composition of the produced biogas.

1.4 Research question

What is the effect of temperature on performance of biogas digesters in Uganda?

1.5 Scope

This study entails the evaluation of performance of biogas digesters basing on the biogas output and the percentage composition of methane in the gas. It excludes the effect of temperature on the retention time.

1.6 Organization of the article

Section one is an overall introduction of the study including the background, problem statement, purpose of the study and the research question. Section 2 details the methods and materials used in the study. These include the substrate preparations, bio digesters, measuring instruments and the chemical analytics for the biogas quantity and quality. In section 3, the results for both the mesophillic and thermophillic digester performances are presented in both descriptive and graphical formats. A thorough discussion of the results in section 3 is presented in section 4. This gives a comparative analysis of the findings with related literature by past scholars. Conclusions and recommendations are presented in section 5 along with the study limitations and the policy implications of the findings and the drawn conclusions from the study.

2.0 METHODS AND MATERIALS

2.1 Feedstock Preparation

Fresh cow dung was collected from an abattoir near Malangala Sub-County headquarters in

Mityana district, Uganda. It was sorted to remove other indigestible materials like stones and metals. It was then kept covered in a heap with polythene bags at ambient temperature for two weeks before the experiment. This was to allow partial digestion before the actual experiment such that less time could be taken to monitor the different temperature shifts. Weighing of the feedstock was done using a digital weighing balance (Mettler PN 163); 500 g of feedstock were loaded in each of the reactors. 250 ml of water was added to the feedstocks. Two thermostatic water heaters (model: NPE-240A) were used to control the temperatures with in the required ranges.

2.2 Equipment

2.2.1 Biodigesters

The reactors used were old acid bottles. These were maintained at a constant desired temperature using hot water circulation around the reactors. Samples were withdrawn from sampling holes (Mixing was achieved by shaking the bottles twice daily in the morning and evening hours.

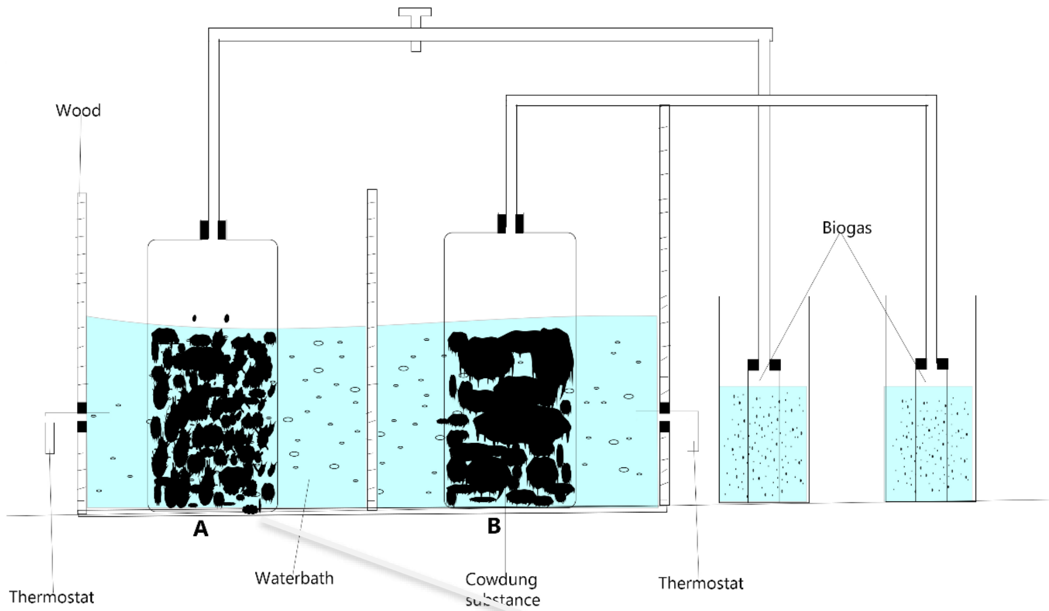

Figure 1: Experiment set up

The responses of the performance of the processes to changes in temperature were investigated in the two reactors A and B; A with temperatures being adjusted from the mesophillic to thermophillic range (37° C to 55°C) and B in a counter trend (55 °C to 37°C). Forced temperature variations were imposed on the digesters using the same mixture of manure in a semi-continuous process in both reactors. A thermostatically controlled water bath was used to maintain the temperature in the digesters at the desired level. The water bath was built out of plywood and was divided into two watertight compartments so that two experiments could be run simultaneously at different temperatures. The temperature of the 37°C (mesophillic) reactor was increased up to 55°C gradually by 3°C at intervals of 3 to 4 days, while the temperature of the 55°C (thermophilic) reactor was decreased until it reached 37°C again by 3°C at the same interval. After each temperature change the reactor was left at the new temperature until a steady state was achieved. This took at least 3-4 days before the next temperature shift. The 37°C reactor was operated at 37, 40, 43, 46, 49, 52 and 55°C for 3, 4, 4, 3, 4, 4 and 3 days, respectively. The 55°C reactor was operated at 55, 52, 49, 46, 43, 40 and 37°C for 4, 3, 4, 4, 3, 3 and 4 days, respectively. It was considered that a steady state had been achieved when the levels of biogas production rate varied by less than 3% for about 4-6 hours.

2.2.2 Chemical analysis

The gas volume was measured using displacement of acidified water (pH 2-3) and methane percentage composition was measured using an Orsat analyzer. For methane (CH4) analysis, the reagent used was potassium hydroxide solution 400 g/dm3, with absorbing power of 40 ml/CH4 per dm3 of solution. The percentage by volume of methane in each gas sample produced was calculated as follows:

$$\text{Volume of constituent} = V_1 - V_2 \quad (1)$$

Where V_1 = burette reading (ml) before removal of methane,
V_2 = burette reading (ml) after removal of methane.

$$\text{Percentage of methane} = [(V1-V2)/V1]\ 100 \quad (2)$$

3.0 RESULTS

The responses of the performance of the processes to changes in temperature were investigated in the 37°C and 55°C reactors (A and B respectively) at a retention time of 22 days. After changing the temperature, only minor changes in the operating processes were observed in phase 1 with either reactor.

3.1 Effect of temperature shifts on the performance of the mesophillic to thermophillic reactor.

The results illustrate that the performance of reactor A changed insignificantly in terms of any of the measured parameters as the temperature was raised to 40°C and 43°C. Biogas production was 0.46 - 0.58 L of gas/day and methane % composition 54-60% as shown in Figure. 2. For the first 2 days the biogas production was approximately 0.55 -0.56 L/day which is fairly close to the peak value of 0.58 L/Day recorded on day 3. The methane percentage composition for the first 2 days was 32 %. However, a sharp drop in the methane composition was realized on day 3 that had the peak biogas volume. The subsequent methane percentage compositions from day 4 to day 8 increased tremendously with further fluctuations realized there after. The peak value of the methane composition was attained on day 17.

Vol 4, 2019 Issue, ISSN 2001-2837, Pages 9-15

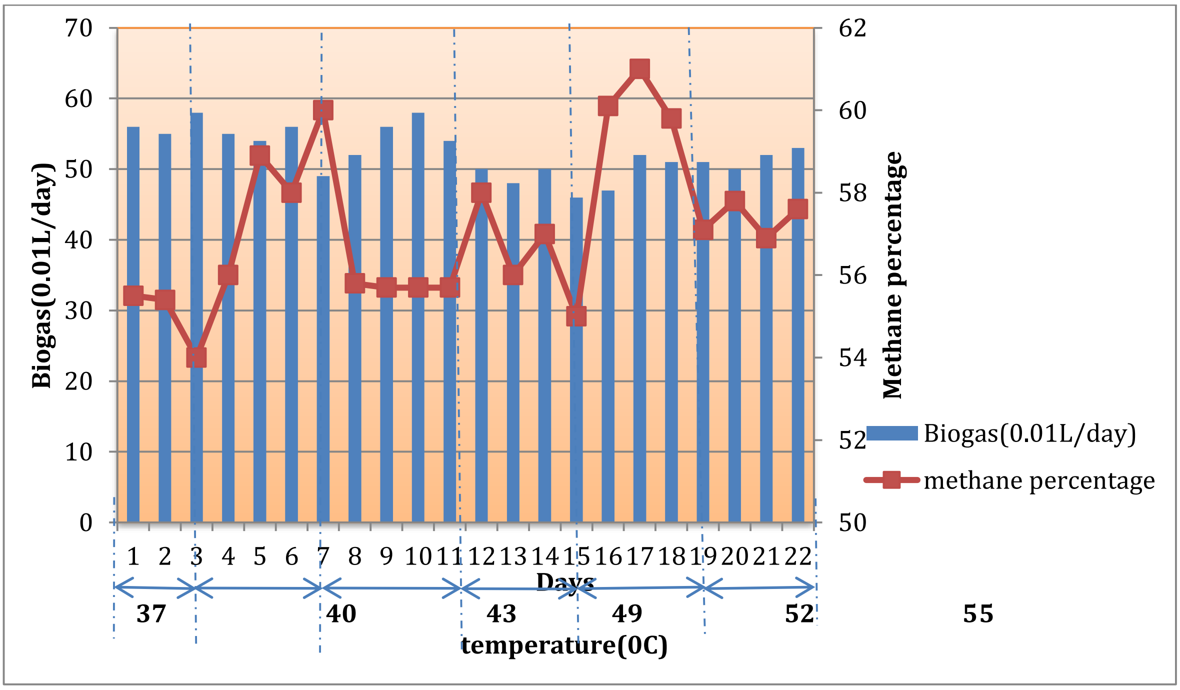

Figure 2: Biogas output and methane % variation with temperature for reactor A

3.2 Effect of temperature shifts on the performance of the thermophillic to mesophillic reactor.

The 55°C reactor, operated over the reducing temperature range of 52°C, 49°C and 46°C also produced only minor changes as shown in Figure.3. The biogas production varied from 0.48 - 0.56 L/day and methane production ranged from 0.292-0.342 L/day. However, when the temperature was reduced from 46°C to 43°C the efficiency of the process became lower with a significant drop in methane (0.193 L/day) and biogas productions (0.41 L of gas/day). At each 3°C temperature shift from 55°C to 52°C, 49°C, 46°C and 43°C, there was a rapid initial drop in biogas production rate that was quickly reversed over a few days.

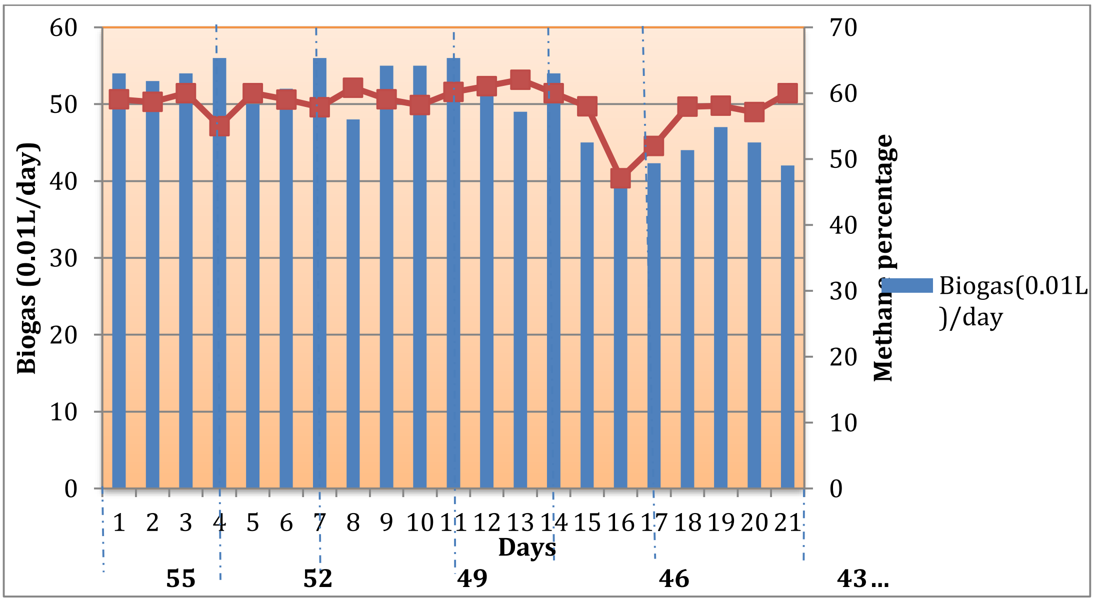

Figure 3: Biogas output and methane % variation with temperature for reactor B

4.0 DISCUSSION OF RESULTS

These results showed insignificant shift in the biogas output with changes in temperature for both the mesophillic and thermophillic reactors. The 55°C reactor was quite sensitive to the temperature disturbances, probably due to induction of a temporary unbalance of the microorganisms in the reactor. For reactor A: The drop in the methane percentage composition could be due to decrease in the number of methanogens that had developed due to the ambient environment the cow dung had been in for 2 weeks prior to the study (Tian et al., 2018). These had been adaptive to room temperatures (25 to 28 °C) and hence 37 °C could have been harsh for them. Later on thermotolerant mesophiles developed hence the increased methane percentage composition. These mesophiles are able to withstand thermophilic conditions but are not thermophiles hence the reason for the drop in Methane composition as temperatures shift from 40 to 43 °C(Tian et al., 2018). Likewise the drop in biogas output and the methane percentage composition for reactor B could have been due to the shift from thermophillic to mesophillic conditions, which affected the thermophiles.

Speece (1996) reported that methanogens are more sensitive to temperature changes than acidogens. It maybe that the rate at which the methanogens converted the fatty acids to methane was initially reduced far more than the rate at which the acidogens produced acids whenever a temperature shift occurred. Also the methane production and yields did not vary significantly at these different temperatures. It seems therefore that temperature shifts do not directly affect the gas composition. From these results, we can conclude that the microorganisms present in these reactors must have a tolerance for a fairly wide range of temperatures. Boušková, Dohányos, Schmidt, & Angelidaki, (2005) proved that a one time shift from mesophillic to thermophillic temperature range is a faster strategy than gradual increase of temperature increments. This may be attributed to the presence of thermotolerant organisms that can quickly adapt to any newly imposed temperature change (Salam, Biswas, & Rabbi, 2015). Chen (1983) reported that the development of a bacterial community involved in the degradative system could be related to the percentage of mesophilic and thermophilic bacteria in the initial sludge. Moreover manure fibers provide the surface area for LCFAs to adsorb and decrease their concentration in solution, thereby providing stability to the thermophilic process (Labatut, Angenent, & Scott, 2014). (Tian et al., 2018)also suggested that an upward temperature shift might lead to the development of a culture dominated by thermotolerant mesophilic organism rather than true thermophiles. Moreover, both reactors could be operated successfully at 43°C, which is considered to be the optimal changeover temperature from mesophiles to thermophiles (Tian et al., 2018). An option of catalyzing the system maintained at 40-43 °C throughout could be viable so as to maintain the bacteria community that is already adaptive to this temperature (Salam et al., 2015).

However, this could be different for some few substrates like duck weed which was reported to produce more biogas in the mesophillic range (Ramaraj & Unpaprom, 2016).

4.1 Policy implications of the study

In bid to devise alternative energy sources under the rural electrification initiative by the government of Uganda, biogas digesters should be maintained under thermophillic conditions for maximum biogas output. Therefore there is need for mass sensitization for both commercial and home use biogas plant maintainers on how to monitor, adjust and maintain thermophillic temperature regimes of the digesters.

4.2 Limitations of the study

Conducting experiments was so cumbersome and a lot of time was spent manually monitoring parametric changes due to lack of an automated lab scale digester.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Thermophillic conditions (40 - 46°C) fairly favor biogas production from cow dung as a substrate. This is because peak values for biogas produced and the methane percentage compositions were realized in this range. However operating a digester at least at 37°C can be effective since the changes in temperatures gave no significant changes in the amount of biogas and relative percentage composition of methane. The changes in temperature do not have significant changes on the methane composition of biogas. For any temperature change there are always smaller drops in methane composition that are corrected to normal values in less than a day. Increasing temperature increases the rate at which biogas is produced.

5.2 Recommendations

Biogas digesters should be maintained at thermophillic conditions since they are ideal for high production rates and digesters are capable of producing thermotolerant mesophiles. This can be done by concentrating radiation from the sun on to digesters by use of solar collectors or by use of any other controlled heat source.

REFERENCES

Akpinar A., Kömurcu M. I., Kankal M., Özolcer I. H., Kaygusuz K., (2008). Energy situation and renewables in Turkey and enevironmental effects of energy use: *Renewable and Sustainable Energy Reviews* 12, 2013-2039.

Boušková, A., Dohányos, M., Schmidt, J. E., & Angelidaki, I. (2005). Strategies for changing temperature from mesophilic to thermophilic conditions in anaerobic CSTR reactors treating sewage sludge. *Water Research*, 39(8), 1481–1488. https://doi.org/10.1016/j.watres.2004.12.042

Chen, Y. R. (1983): Kinetic Analysis of Anaerobic Digestion of Pig Manure and its Design Implications. *Agricultural Wastes*, Vol. 8, 65 – 81

Boušková, A., Dohányos, M., Schmidt, J. E., & Angelidaki, I. (2005). Strategies for changing temperature from mesophilic to thermophilic conditions in anaerobic CSTR reactors treating sewage sludge. *Water Research*, 39(8), 1481–1488. https://doi.org/10.1016/j.watres.2004.12.042

Labatut, R. A., Angenent, L. T., & Scott, N. R. (2014). Conventional mesophilic vs. thermophilic anaerobic digestion: Atrade-off between performance and stability? *Water Research*, 53, 249–258. https://doi.org/10.1016/j.watres.2014.01.035

Mccord, A. ., Stefanos, S. A., Tumwesige, V., Lsoto, D., Meding, A. ., Adong, A., … Larson, R. . (2017). The impact of biogas and fuelwood use on institutional kitchen air quality in Kampala , *Uganda. Indoor Air*, 27(12390), 1067–1081. https://doi.org/10.1111/ina.12390

Ramaraj, R., & Unpaprom, Y. (2016). Effect of temperature on the performance of biogas production from Duckweed. *Chemistry Research Journal*, 1(1), 58–66.

Salam, B., Biswas, S., & Rabbi, M. S. (2015). Biogas from mesophilic anaerobic digestion of cow dung using silica gel as catalyst. *Procedia Engineering*, 105(Icte 2014), 652–657. https://doi.org/10.1016/j.proeng.2015.05.044

Tian, G., Yang, B., Dong, M., Zhu, R., Yin, F., Zhao, X., … Cui, X. (2018). The effect of temperature on the microbial communities of peak biogas production in batch biogas reactors. *Renewable Energy*, 123, 15–25. https://doi.org/10.1016/j.renene.2018.01.119

World Bank. (2005). *World Bank Group Progress on Renewable Energy and Energy Efficiency*: 1990–2004. Group.