ABUAD Journal of Engineering Research and Development (AJERD)
ISSN (online): 2645-2685; ISSN (print): 2756-6811

Volume 4, Issue 2, 10-17

Temperature and pH Effects on Biogas Yield from Co-Digestion of Food Waste and Cow-Dung

Ochuko Mary OJO

[1]*Department of Civil and Environmental Engineering, the Federal University of Technology, Akure*
omojo@futa.edu.ng

Corresponding Author: omojo@futa.edu.ng, +2348035638438

Date Submitted: 12/05/2021
Date Accepted: 16/12/2021
Date Published: 31/12/2021

Abstract: *In this study, the effects of temperature and pH on biogas yield from co-digestion of food waste and cow-dung was assessed. 25 litres capacity mini-sized biodigesters were fabricated using locally available materials. The digestion process was evaluated over a 30-day retention period. The temperature and pH of the feedstocks within the digester were taken daily throughout the retention period of the experiment. During the retention period, the temperature ranged between 25.1 °C and 28.4 °C for cow dung single substrate digestion, 25.0 °C and 27.7 °C for food waste single substrate digestion, 25.2 °C and 27.8 °C for the co-digestion of cow dung and food waste. The pH varied ranged between 6.7 and 7.5 between day 1 and 10 for the single- substrate digestion of the cow dung, a decline in the pH was observed after day 10 to a lowest value of 5.4. During the single substrate digestion of food waste, the pH staggered between 3.4 and 4.6 between day 1 and 9, and a steady decline in the pH after day 10 was observed to a lowest value of 2.7. For the co-digestion of the cow dung and food waste, the pH staggered between 3.8 and 5.4 between day 1 and 18, while there was a decline in the pH after day 19 with the lowest value of 3.8 observed. Even though the digestion process took place within the mesophilic temperature range, the percentage methane in the biogas produced was very low. This may be due to the fact that the digestion process did not occur within the recommended pH range. Since most anaerobic bacteria including methane forming bacteria function optimally at a pH of 6.8 to 7.6, the rate of methane production may decrease if the pH is lower than 6.3 or higher than 7.8.*

Keywords: *Temperature, pH, co-digestion, methane, decline.*

1. INTRODUCTION

The process by which organic waste materials are converted into biogas which comprises mainly of methane and carbon dioxide is referred to as anaerobic digestion (AD). It involves the breakdown of organic matter by the concerted actions of a wide range of microorganisms in the absence of oxygen. The use of AD for treating organics is attractive for several reasons that involve economic as well as environmental aspects [1, 2]. This technology not only reduces the volume of material to be disposed and avoids soil and groundwater pollution, but also makes available a renewable and inexpensive energy, e.g., biogas. AD is known to be one of the few biotechnological processes that can generate bio-fuel, improve agricultural productivity through the use of its digestate as compost for organic farming and reduce environmental pollution [3].

The factors affecting the biogas production are mainly caused by the characteristics of the feedstock and operating condition of the process. In order for anaerobic reactors to perform at their best, they should be operated under acceptable pH and temperature conditions.

The digestion and co-digestion of food waste towards biogas generation is currently understudied as attention is usually given to the use of animal waste in biogas production. As food wastes is rich in rich in nutrients, its co-digestion with animal wastes may improve biogas yield. Co-digestion of waste materials usually improves the biogas yields from anaerobic digester due to positive synergy established in the digestion medium and the supply of missing nutrients by the co-substrates. The amount of biogas produced from the individual digestion of food and animal wastes can be improved by co-digesting them.

The degree of acidity or alkalinity of a solution is determined by its pH value. The pH value is represented as the logarithm of the reciprocal of the hydrogen ion concentration in gm equivalent per litre of solution. A pH value in the range 0-7 represents acidic solution and in the range 7-14 indicates the alkaline solution. The micro-organisms require a neutral or mildly alkaline environment – a too acidic or too alkaline environment will be detrimental. According to Yadvika *et al.* [4], the pH within the digester should be kept in the range of 6.8 - 8.0, similarly, Thy *et al.* [5] concluded that 6.0 -8.0 is the optimal pH for AD. The pH value below or above this interval may restrain the process in the reactor since micro-organisms and their enzymes are sensitive to pH deviation [4]. Ideal pH value is between 7.0–8.0 but can go up or down by a further 0.5. In the initial stages of acid forming stage of digestion, the pH value may be around 6.0 or less, however during methane

 ISSN (online): 2645-2685; ISSN (print): 2756-6811

formation stage the pH value higher than 7.0 is maintained since methane formers are sensitive to acidity. In broad terms, methanogenic bacteria are very sensitive to pH and do not thrive below a value of 6.0 [6].

Temperature for fermentation greatly affects biogas production. Depending on prevailing conditions, methane can be produced within a fairly wide range of temperature. The rate of gas production increases with the increase in temperature but the percentage of methane reduces. It is found that mesophilic temperature between 32°C-35°C are most efficient for stable and continuous production of methane [7 - 13]. Biogas produced outside this range will have a higher percentage of carbon dioxide and other gases than within this range. The production of biogas is fastest during summer and it decreases at lower temperature during winter. If the temperature is lower than 20°C, the rate of gas production falls sharply and it almost ceases at about 10°C. Also, methanogenic microorganisms are very sensitive to temperature changes. A sudden change exceeding 30°C will affect production, and therefore one must ensure relative stability of temperature. Parker *et al.* [7] recommended an operating temperature in the middle of the mesophilic temperature range for improved performance with a high solids anaerobic digester using cattle manure. According to Erickson *et al.* [14], mesophilic treatment at 38°C reportedly destroys 99.9% of pathogens

Ojo and Babatola [13] studied the association between biogas quality and digester temperature for selected animal dung-aided water hyacinth digestion mixes was evaluated. The study revealed that the association between the temperature and gas quality was positive suggesting that an increase in temperature within the digestion leads to an increase in the quality of gas produced. This study is aimed at assessing the effects of temperature and pH on biogas yield from co-digestion of food waste and cow-dung.

2. METHODOLOGY

2.1 Design and Fabrication of Biodigester

Three 25 litres capacity mini-sized biodigesters were designed and fabricated using locally available materials.

The design is as follows:

The Total Volume of Digester (TVD) was calculated shown in Equation 1

$$\text{TVD} = 25 \text{ L} \quad (1)$$

Volume of the Digestion Chamber (VDC) was assumed to be $\frac{4}{5}$ the TVD to allow for gas collection.

Therefore, VDC was calculated using Equations 2 and 3

$$\text{VDC} = \frac{4}{5} \text{ x TVD} \quad (2)$$

$$\text{VDC} = \frac{4}{5} \text{ x } 25 = 20 \text{ L} \quad (3)$$

One-fifth of the TVD was allowed for gas collection, hence, the Volume of the Gas Chamber (VG) was calculated using Equations 4 and 5.

$$\text{VG} = \frac{1}{5} \text{ x TVD} \quad (4)$$

$$\text{VG} = \frac{1}{5} \text{x } 25 = 5 \text{ L} \quad (5)$$

The materials used in the fabrication of the digester include plastic containers, PVC pipes of different diameters, corks, elbows, control valves and rubber hose. The cross section of the digester is shown in Figure 1.

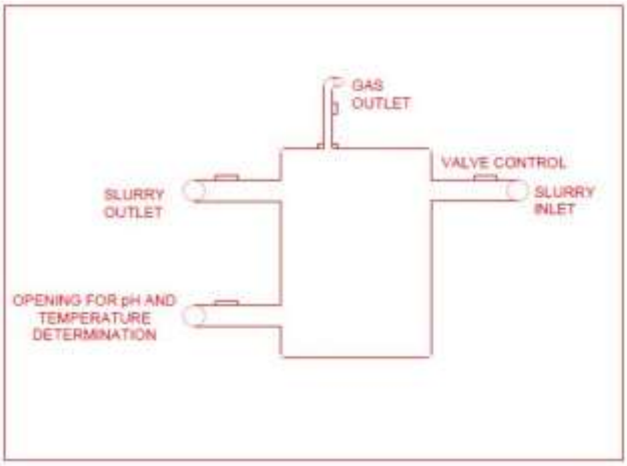

Figure 1: Cross section of the digester

ISSN (online): 2645-2685; ISSN (print): 2756-6811

2.2 Experimental set-up

The experiment was conducted at the Water Resources and Environmental Engineering Laboratory, Civil Engineering Department of the Federal University of Technology, Akure, Nigeria. The experimental set up consists of a plastic digester connected to a water displacement set-up. A hole was drillled at the side of the digester with a 12.5mm diameter PVC pipe where both the temperature and pH check point were fitted tightly with a rubber cork. A measuring cylinder filled with water to the brim was placed inverted in a bowl filled with water. A rubber hose was passed from the bio-digester to the measuring cylinder. Controlled by valves, the gas produced was then passed through calcium hydroxide solution ($Ca(OH)_2$)to remove the carbon (IV) oxide (CO_2)present in the biogas. The residual was then sent to the other measuring cylinder to measure the volume of methane produced. The displaced water was collected in the water collector. The volume of water displaced in the water collector was measured daily using the calibrations on the measuring cylinder.

The temperature and pH of the feedstocks within the digester were taken at 8: 00 am and 4: 00 pm daily throughout the retention period of the experiment. The daily average of the temperature and pH values was used in the data analysis.

2.3 Waste Collection

The food waste was collected from restaurants and hostels within and around the Federal University of Technology, Akure (FUTA) campus. FUTA lies within latitudes 7°17'03"N -7°19'06"N and longitudes 5°07'02"E -5°09'05"E. The food waste comprised of left-over cooked rice, beans, pounded yam and other Nigerian local delicacies. The cow dung was collected from the animal farm of FUTA.

2.4 Digestion and Co-Digestion of the Waste

10 kg of waste was mixed with 10 litres of water and digested in the biodigester for a retention period of 30 days in the ratio 1 : 1 of Waste : Water. In the first digester, 10 kg of food waste was mixed with 10 litres of water. In the second digester, 10kg of cow dung was mixed with 10 litres of water. In the third digester, 5 kg of food waste was co-digested with 5 kg of cow dung and 10 litres of water. The daily amount of biogas produced from the three digesters was measured using water displacement method.

2.5 Data Analysis

The data obtained were analyzed using Microsoft excel and presented in graphs.

3. RESULTS AND DISCUSSION

3.1 Effect of Temperature

The ambient temperatures ranged from 26.8°C to 28.3°C. The initial temperatures for the digestion of the cow dung, food waste, and the co-digestion of cow dung and food waste slurry were 28.5 °C, 28.9 °C and 27.9 °C respectively. During the retention period, the temperature ranged between 25.1 °C and 28.4 °C for cow dung single substrate digestion, 25.0 °C and 27.7 °C for food waste single substrate digestion, 25.2 °C and 27.8 °C for the co-digestion of cow dung and food waste. The temperature range was at variance with Owamah [15] who carried out the co-digestion experiments in computer controlled 10- liter anaerobic digesters at 37 ± 1 °C. The ambient temperature affects the rate of digestion due to the direct contact made with the wall of the digester, hence the digester walls absorb or loose heat depending on the relative temperature between the digester and its immediate environment. In the mesophilic temperature range (25°C and 35 °C), the reaction of the bacteria on the slurry is slower, therefore causing a slower biogas production. Figures 2 to 4 shows the daily temperature of the single substrate digestion of cow dung and food waste, and co-digestion of cow and food waste respectively.

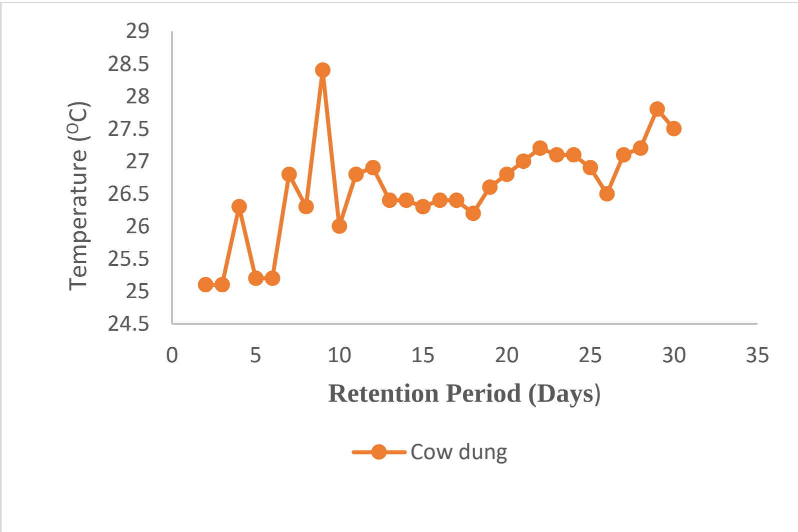

Figure 2: Daily temperature for the digestion of cow dung

ISSN (online): 2645-2685; ISSN (print): 2756-6811

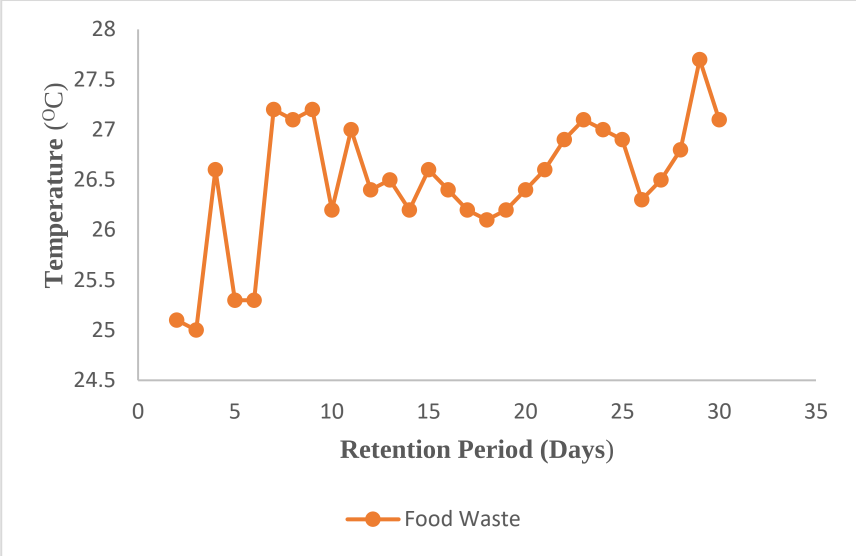

Figure 3: Daily temperature for the digestion of food waste

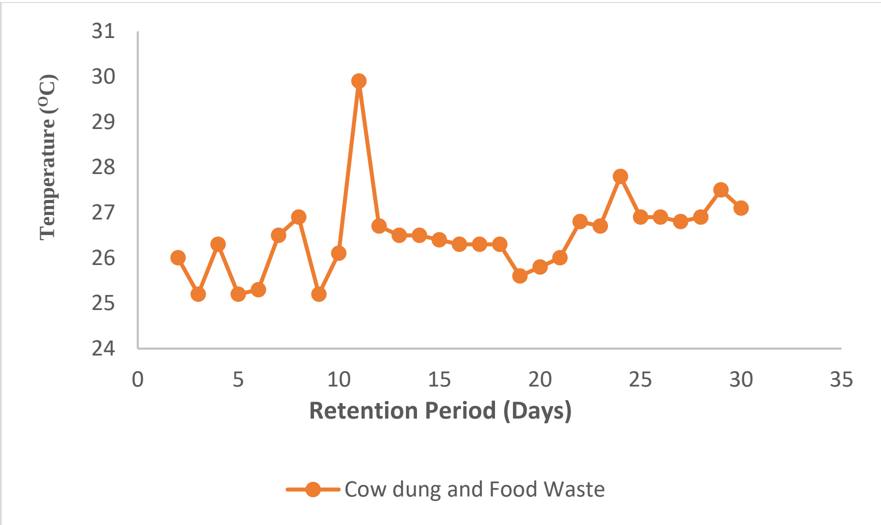

Figure 4: Daily temperature for the co-digestion of cow dung and food waste

3.2 Effect of pH

After thorough mixing of the feedstocks, the pH was determined for the samples before the commencement of the digestion process. A pH of 6.6 was observed for the cow dung slurry, 4.9 for the food waste slurry, and 6.1 for the co-digestion mix of the cow dung and food waste before the commencement of the digestion process. After feeding the digester with the slurry, daily monitoring of the pH was done and a decline in pH of the slurry was observed. The decline in pH at the early stage of the digestion process may be attributed to the fact that initially the acid forming bacteria were breaking down the organic matter which produces volatile fatty acids. As a result, the acidity of the medium increased and the pH gradually decreased to as low as 5.4, 2.7 and 3.8 for single substrate digestion of cow dung and food waste, as well as co-digestion of cow dung and food waste respectively. This low pH value allowed very little activity of methanogenic bacteria and is apparently responsible for the low production of methane gas. Methanogenic bacteria may continue to grow and produce high concentrations of volatile acids, leading to a decrease in the pH of the digester contents [16].

The pH ranged between 6.7 and 7.5 between day 1 and 10 for the single- substrate digestion of the cow dung. A decline in the pH was also observed after day 10 to a lowest value of 5.4.

During the single substrate digestion of food waste, the pH varied between 3.4 and 4.6 between day 1 and 9, and a steady decline in the pH after day 10 was also observed in which the lowest was observed to be 2.7.

For the co-digestion of the cow dung and food waste, the pH varied between 3.8 and 5.4 between day 1 and 18, while there was a decline in the pH after day 19 with the lowest value of 3.8 observed. Figures 5 to 7 shows the daily pH reading of the digestion cow dung, food waste, and co-digestion of cow and food waste respectively.

ISSN (online): 2645-2685; ISSN (print): 2756-6811

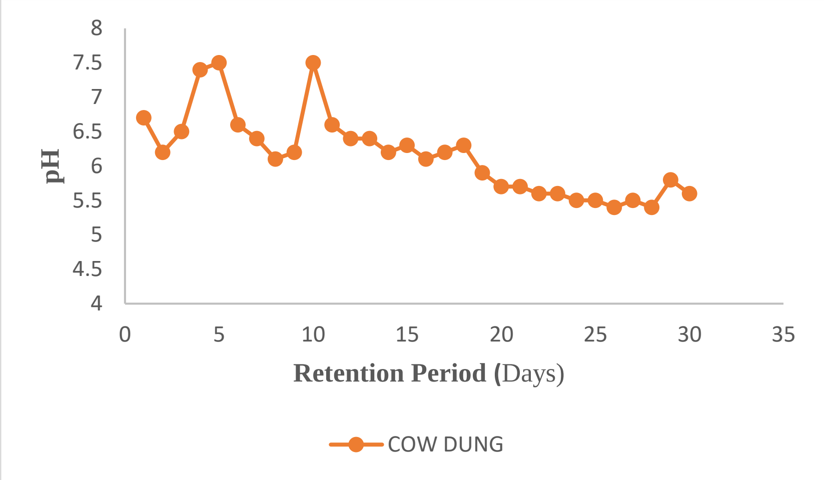

Figure 5: pH for the digestion of cow dung

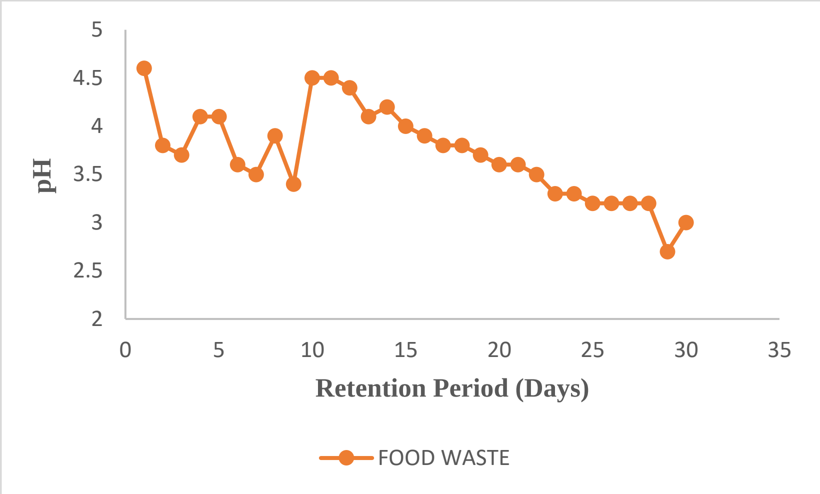

Figure 6: pH for the digestion of food waste

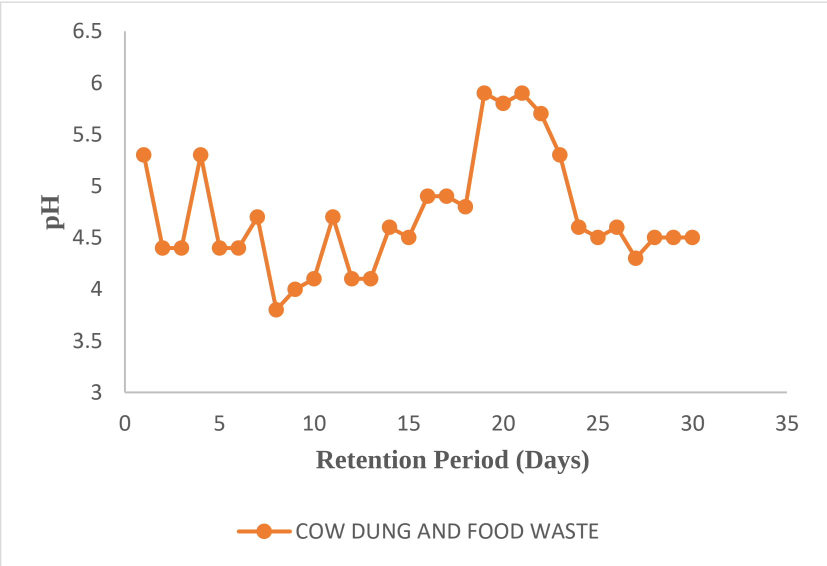

Figure 7: pH for the co-digestion of cow dung and food waste

3.3 Comparison of Temperature within the Digester

Temperature is a very important factor having influence on the composition of microorganism population and the intensity of their activities. If the temperature is higher, organic matter is degraded more rapidly and microorganisms use nutrients quicker. The digesters used in this work were all placed in a laboratory and hence were protected from experiencing sharp

ISSN (online): 2645-2685; ISSN (print): 2756-6811

variations in the temperature. The digester temperature fell within the mesophilic temperature range. Figure 8 shows the graphical representation of the temperature within the digester for the single substrate digestion of cow dung and food waste and the co-digestion of cow dung and food waste.

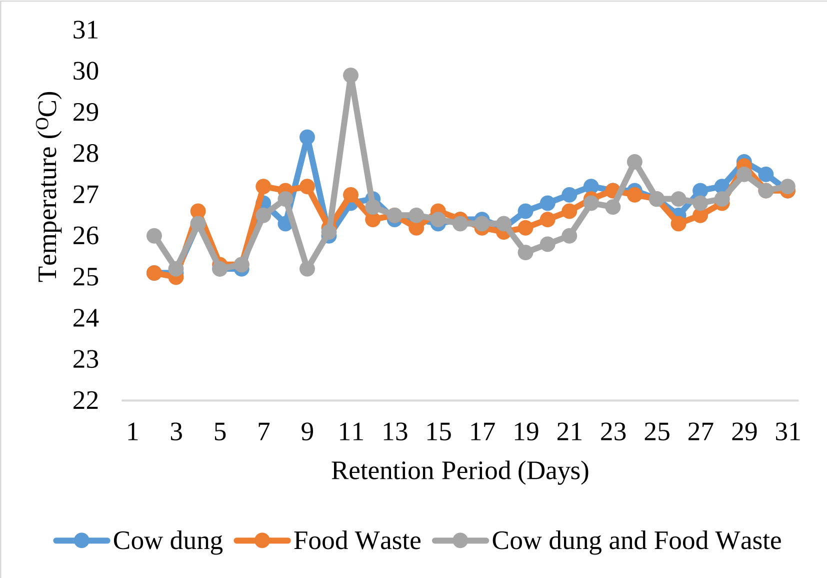

Figure 8: Comparison of different temperature within the digester

3.4 Comparison of pH of the Substrates

Low pH value allows very little activity of methanogenic bacteria and is apparently responsible for releasing of carbon (II) oxide as the main product from the food wastes. Methanogenic bacteria will cease activity or die when conditions in the digester are not right. When methane forming bacteria die, the acid-formers may continue to grow and produce high concentrations of volatile acids, leading to a decrease in the pH of the digester contents [16]. Figure 9 shows the graphical representation of the pH of the single substrate digestion of cow dung and food waste as well as the co-digestion of cow dung and food waste.

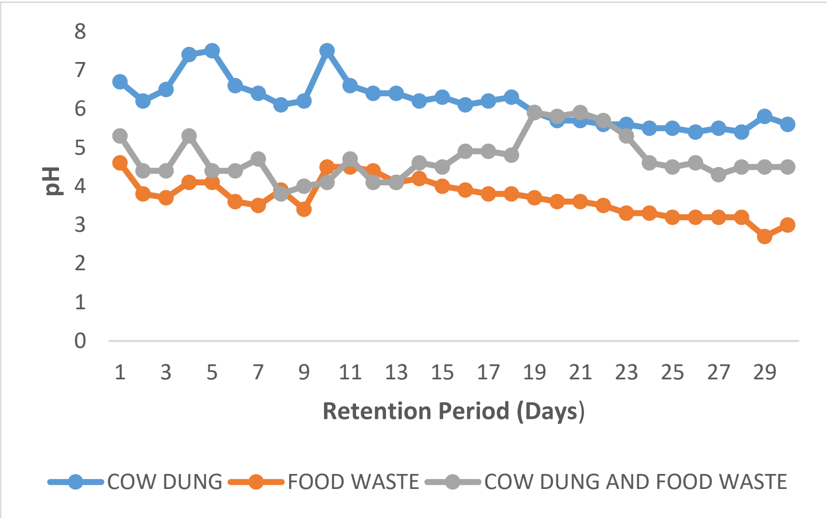

Figure 9: Comparison of the pH of the substrates

The factors affecting the production of methane are mainly caused by the operating temperature of the process and nature of the slurry. In order for anaerobic reactors to perform at their best, they should be operated under steady state conditions. The volume of methane yield from the biogas produced depends on the nature of the slurry and the operating temperature of the digester. The methanogenic bacteria reacting on the slurry affects the volume of the methane produced.

3.6 Effect of Temperature and pH on Biogas Yield

Biogas and methane yields fluctuated greatly during the 30-day retention period. For the single substrate digestion of cow dung and food waste, biogas production started on day 8 and got to its peak on day 18, thereafter a decline occurred till the

ISSN (online): 2645-2685; ISSN (print): 2756-6811

end of the retention period. Similarly, for the co-digestion of cow dung and food waste, biogas production started on day 5 and got to its peak on day 20, thereafter a decline occurred till the end of the retention period. The cumulative biogas produced for the single substrate digestion of cow dung was 7. 98 L whereas the cumulative biogas produced for the single substrate digestion of food waste was 7. 74 L. The cumulative biogas produced for the co-digestion of cow dung and food waste was 16.48 L. The results revealed that the co-digestion of cow dung and food waste produced the highest cumulative volume of biogas.

Even though the digestion process took place within the mesophilic temperature range, the percentage methane in the biogas produced was very low. This may be due to the fact that the digestion process did not occur within the recommended pH range. Since most anaerobic bacteria including methane forming bacteria function in a pH range of 5.5 to 8.5, but optimally at a pH of 6.8 to 7.6, the rate of methane production may decrease if the pH is lower than 6.3 or higher than 7.8 [16]. Figure 10 compares the percentage cumulative volume of methane produced from the three digestion processes evaluated in this study. It is evident from the chart that the co-digestion of cow dung and food waste produced the highest volume of methane yet the percentage volume of methane produced was low.

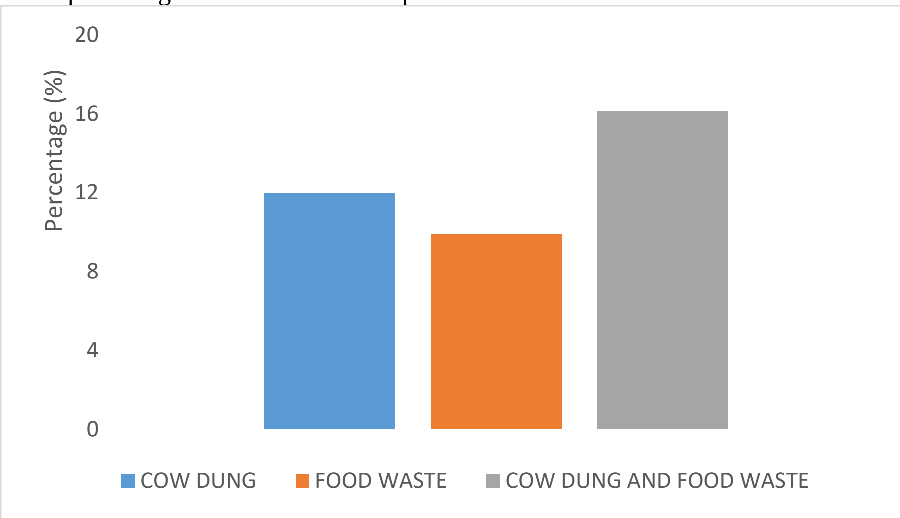

Figure 10: Comparison of volume of methane produced by different substrates

4. CONCLUSION

This study has affirmed that the pH of the substrates and temperature within the digester have effects on the quantity and quality of gas produced during anaerobic digestion. The results obtained revealed that the digestion process took place within the mesophilic temperature range, however, the percentage methane in the biogas produced was very low. The reduction in the quality of biogas produced may be due to the fact that the digestion process did not occur within the recommended pH range. In order to enhance the digestion and co-digestion process of food waste and cow dung, it would be necessary to control these digestion parameters.

ACKNOWLEDGMENT

The author wishes to acknowledge the Federal University of Technology Akure, who created an enabling environment to carry out this study

REFERENCES

[1] Lettinga, G. (2001) Digestion and Degradation, Air for Life. *Water Sci Technol*., 44:157–176
[2] Barton J. R., Issaias I. & Stentiford E. I. (2008). Carbon-making the right choice for Waste Management in Developing Countries, *Waste Manage.*,28:69–76.
[3] Zhang, Q., Hu, J. & Lee, D. (2016). Biogas from Anaerobic Digestion Processes: Research Updates, *Renew. Energy*, 98:108-119.
[4] Yadvika, S., Sreekrishnan, T. R., Kohli, S & Rana, V. (2004). Enhancement of Biogas Production from Solid Substrates using Different Techniques – a review, *Bioresour. Technol*., 95: 1 - 10.
[5] Thy, S., Preston, T. R. & Ly, J. (2003). Effect of Retention Time on Gas Production and Fertilizer Value of Biodigesters Effluent, *Livest. Res. Rural. Dev*., 15(7): 1 – 24.
[6] Karki, A. B., Shrestha, N. J. & Bajgain, S. (eds) (2005). Biogas as Renewable Energy Source in Nepal: Theory and Development. Nepal, BSP. Obtainable on www.snvworld.org
[7] Parker, D. B, Williams, D. L, Cole, N. A, Auvermann, B.W. & Rogers, W. J. (2002). Dry Heated Anaerobic Biogas Fermentation using Aged Beef Cattle Manure, ASABE Meeting Paper No. 024142.

ISSN (online): 2645-2685; ISSN (print): 2756-6811

[8] Shuler, M. L. & Kargi, F. (2002). *Bioprocess Engineering: Basic Concepts*, Second Edition.Upper Saddle River, New Jersey. Prentice Hall Inc.
[9] Knottier, M. (2003). Integration of Biogas Technology, Organic Farming and Energy Crops: The future of Biogas in Europe II, European Biogas Workshop. University of Southern Denmark.
[10] Deublein, D. & Steinhauser, A. (2008). *Biogas from Waste and Renewable Resources: An Introduction*, Wiley VCH, Weinheim, Germany.
[11] Wang, H., Lehtomaki, A., Tovanen, K. & Puhakka, J. (2009). Impact of crop species on bacteria community structure during anaerobic co-digestion of crops and cow manure. *Bioresour. Technol*., 100: 2311-2315
[12] Ojo, O. M., Babatola, J. O. & Akinola, A. O. (2018). Regression Analysis of Biogas Production from the Co Digestion of Water Hyacinth and Pig Dung, *FUOYEJET*, 3(2): 141 – 144.
[13] Ojo, O. M. & Babatola, J. O. (2020). Association between Biogas Quality and Digester Temperature for Selected Animal Dung-Aided Water Hyacinth Digestion Mixes, *J. Appli. Sci. Environ. Manage*., 24 (6): 966-959
[14] Erickson, L. E., Fayet, E., Kakumanu, B. K. & Davis, L. C. (2005). Anaerobic Digestion. National Agricultural Biosecurity Center, Kansas State University, Kansas
[15] Owamah, H. I. (2019). Optimization of Biogas Production through Selection of Appropriate Inoculum-to Substrate ((I/S) Ratio, *Niger. J. Technol. Dev.*, 16 (11): 17 – 24.
[16] Gerardi, M. H. (2003). *The Microbiology of Anaerobic Digesters.* John Wiley &Sons, Inc. Hoboken, New Jersey.