Nomograph for Determining Temperatures in Anaerobic Digesters from Ambient Temperatures in the Tropics

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ABSTRACT

A nomograph for determining temperatures inside anaerobic digesters from ambient temperatures irrespective of temperature control methods on digesters built above the ground was developed. Three of the mild steel digesters were lagged differently with foam, concrete and clay soil. Digestion was undertaken at the mesophilic temperature range. The correlation coefficient between the ambient and digester temperatures was calculated and found to be high enough as a result of which a graph of minimum digester temperatures versus minimum ambient temperatures, and maximum digester temperatures versus maximum ambient temperatures were plotted from which prediction equations were obtained. The measured temperatures were compared to the temperatures obtained by use of the prediction equations developed using t-test at $p \leq 0.05$ and no significant difference was found between them and so the prediction equations were used to develop the nomograph. The minimum and maximum temperatures could be predicted from the equations: $Y=0.58X+12.90$ and $Y=0.63X+15.94$ respectively. The nomograph provides an easy and direct method for the immediate determination of temperatures inside anaerobic digesters irrespective of temperature control methods on the digesters if the ambient temperature is known. Thus the management of digesters is enhanced and the possibility of digester failure greatly reduced when a likely digester temperature can be read from the nomograph based on the prevailing ambient temperature. A limitation, however, for the use of this nomograph is that it cannot be used for anaerobic digestion undertaken at the thermophilic temperature range.

Keywords: **N**omograph, anaerobic digester, biogas, lagged, temperature, tropics

1. INTRODUCTION

Biogas is a methane-rich gas that is produced from the anaerobic digestion of organic materials in a digester. Temperature is one of the most important factors that affect biogas production. This is because it affects the enzymatic activities of the microorganisms (anaerobes) responsible for the conversion of organic materials into biogas (Kaufman et al., 1982). Biogas can be produced by three classes of anaerobes that operate strictly at specific temperature ranges, outside which gas production is extremely low and uneconomical.

Biogas can be produced by the psychrophiles (< 20°C), mesophiles (20-45°C) and thermophiles (45-65°C). Digestion at the psychrophilic temperature is not encouraged because conversion within this range of temperature is slow and incomplete (Van velsen and Lettinga, 1979; Obayashi and Gorgan, 1985).

Anaerobic digesters producing biogas can be built below or above the ground. Anaerobic digesters built underground are not affected by diurnal and seasonal temperature fluctuation (Gutterer and Sasse, 1993) since the temperature of the earth below a depth of 1m is practically constant. However, in locations where digesters cannot be built underground and have to be built above the ground because of problems such as high water table and rocky formations, temperature fluctuations could occur even when digesters are lagged resulting in low and uneconomic biogas yield. This is because the response of methane-forming anaerobes (methanogens) to temperature changes is almost immediate since this affects the rate of their enzymatic-catalyzed reactions and causes shock on them (Hawkes, 1979; Itodo et al., 1997; Itodo and Philips, 2001)

The temperature inside a digester is influenced by the microbial activity on the organic matter inside the digester and to a larger extent by the ambient temperature, which is transferred into the digester through its wall. This is so because digesters are not built in enclosures or near trees and buildings or structures that may cast shadow on them. Most often, the measured temperatures of digesters is that read from thermometers placed on the wall of digesters and in few cases those read from thermometers that actually pass into the digester headspace. Although the later temperature reading is more realistic, the problem of making the digester airtight and avoiding leakage, which affects its anaerobic status, cannot be ensured. This often results in digester failure. It is therefore easier to determine the actual temperatures inside the digester from the ambient temperatures using a nomograph, which is easy to read and does not affect digester construction and operation. Makurdi the study area is located on latitude 7.7°N within the tropics. The objective of this study is to develop a nomograph for determining the temperatures inside anaerobic digesters from the ambient temperature in a tropical location like Makurdi, Nigeria.

2. MATERIALS AND METHODS

Poultry (layers) waste was obtained under the cages from a private farm in Makurdi, Nigeria. Four batch-type mild steel anaerobic digesters each of 20-L volume were used in this study. Three of the digesters were lagged with foam, concrete and clay soil of about 20mm thick while the fourth was used as the control. The digesters were then loaded with 2kg waste, diluted to slurry of 10%TS and three replicates of this was digested for a period of 20 days. Digestion was undertaken at the mesophilic temperature range. The temperatures inside the digesters were measured from thermometers placed on top of the digesters but passing into the digester headspace while the ambient temperature was measured from a maximum and minimum thermometer. Temperatures were measured at 1400 h and 0600 h daily.

Correlation coefficients (equation 1) of the minimum and maximum temperatures of the different digesters was undertaken and found to be high enough to enable the combination of the temperatures from the different digesters into a mean temperature of the minimum and maximum temperatures respectively. A graph of daily minimum ambient temperature versus daily minimum digester temperatures and that of daily maximum ambient temperature versus daily maximum digester temperatures were plotted on a graph. Equations capable of predicting digester temperatures from the ambient were obtained from these graphs by determining the slope and intercept of the straight line. The measured temperatures were compared to the temperatures obtained from these prediction equations using the t-test at p≤0.05. The prediction equations were used to develop the nomograph when no significant difference was found between them using t-test at p≤0.05.

$$r = \frac{\sum XY - \left(\sum X \sum Y / n\right)}{\sqrt{\sum X^2 - \left(\sum X\right)^2 / n \times \sum Y^2 - \left(\sum Y\right)^2 / n}} \text{---(1)}$$

Where:
r = correlation coefficient; n = total number of readings
X = ambient temperature, °C, and Y = temperature inside digester, °C

3. RESULTS AND DISCUSSION

Figure 1 is the digesters minimum temperatures (^{o}C) against detention time (days) while figure 2 is the digesters maximum temperatures (^{o}C) against detention time (days). The mean ambient minimum and maximum temperature was found to be 22°C and 40.1°C respectively, while the mean digester minimum and maximum temperature was 25.6°C and 41.1°C respectively. This showed that the temperatures inside the digesters were slightly higher than that of the ambient, which may be because of the enzymatic reactions of the anaerobes on the substrates in the digesters in which heat may have been released.

The correlation coefficient of the minimum digester temperature with the ambient minimum temperature was as high as 0.7 (table 1). A correlation coefficient of the maximum temperatures of the digesters with the ambient maximum temperatures was 0.5 (table 1), which can be considered a good correlation. On the basis of this correlation coefficient values, the minimum and maximum temperatures of the digesters were each combined into mean values and analyzed with the ambient minimum and maximum temperatures respectively.

Figures 3 and 4 are the graphs of the minimum digester versus minimum ambient temperatures, and the maximum digester versus maximum ambient temperatures respectively in which a linear relationship was established. If the ambient temperature is known, the minimum and maximum temperatures inside the digester can be determined from the prediction equations of; Y= 0.58X+12.90 and Y= 0.63X+15.94 respectively. Table 2 is a comparison of the measured temperatures with the temperatures obtained by use of the prediction equations.

Table 3 is the result of the t-test analysis of this result at p≤0.05. The result showed that there was no significant difference between the measured and predicted minimum and maximum temperatures, which is an indication of the correctness of the prediction equations. Table 4 and table 5 shows the standard deviation (SD) and the standard error (SE) of mean for the minimum and maximum measured and predicted temperatures respectively. SD for the minimum temperature is 1.313 and 0.962 for the measured and predicted temperatures respectively, while the SD for the maximum temperature is 1.632 and 0.798 for the measured and predicted temperatures respectively.

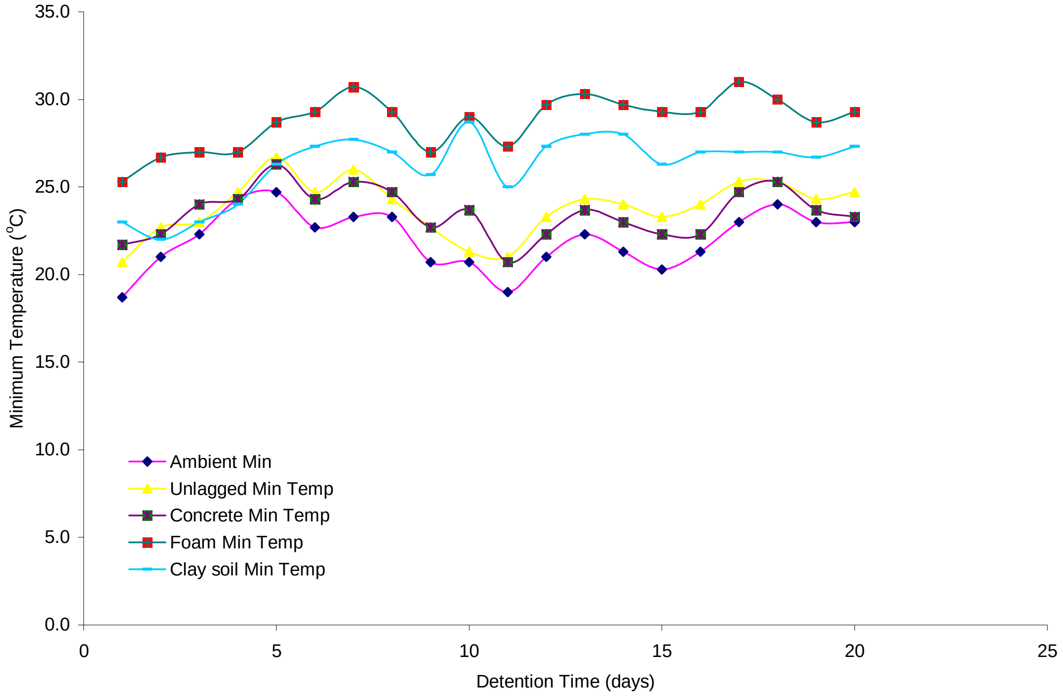

Figure 1: Minimum Temperature (°C) against Detention Time (Days)

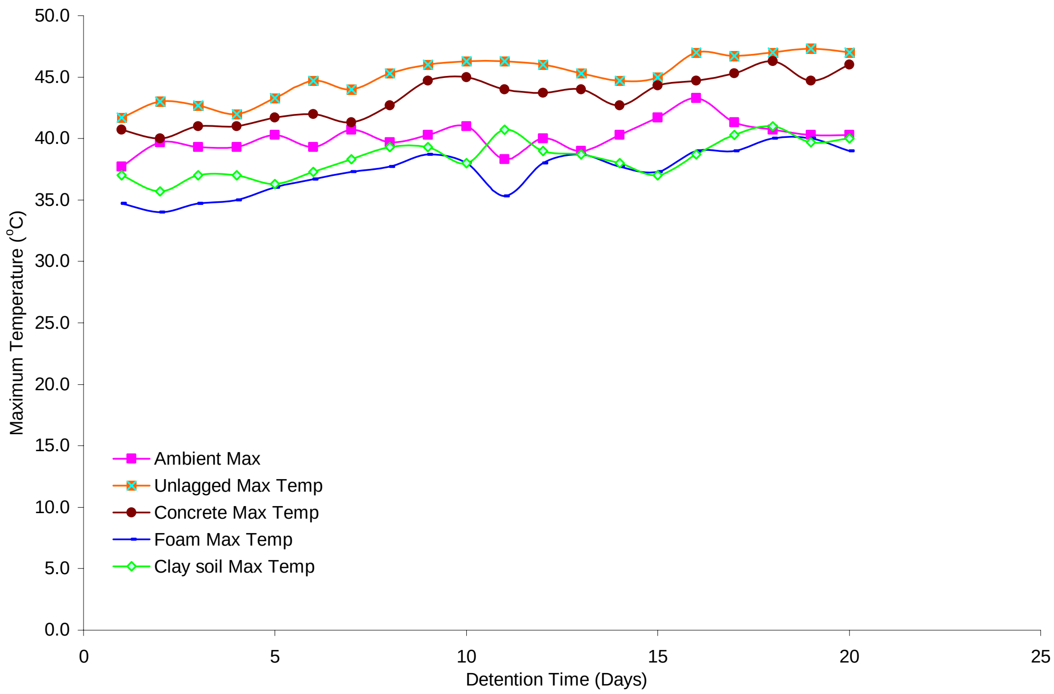

Figure 2: Maximum Temperature (°C) against Detention Time (Days)

Table 1. Prediction equations and correlation between minimum and maximum temperatures of the different digesters with the minimum and maximum ambient temperatures respectively

Temperature	Correlation coefficient	Prediction equation
Minimum	0.7	Y=0.576X + 12.90
Maximum	0.5	Y=0.626X + 15.94

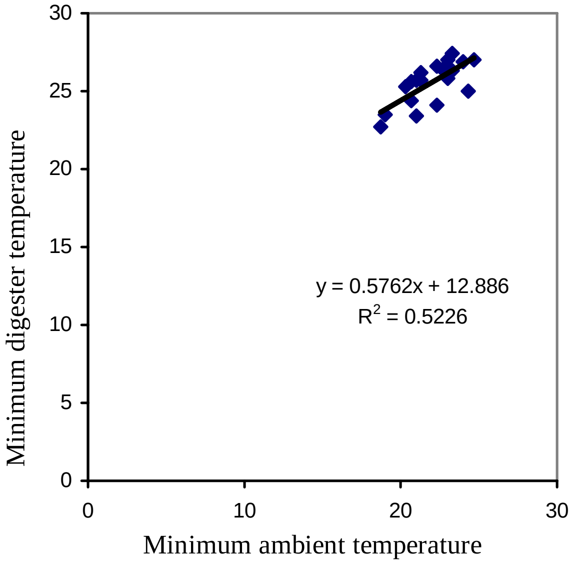

Figure 3-Minimum digester temperatures versus minimum ambient temperatures

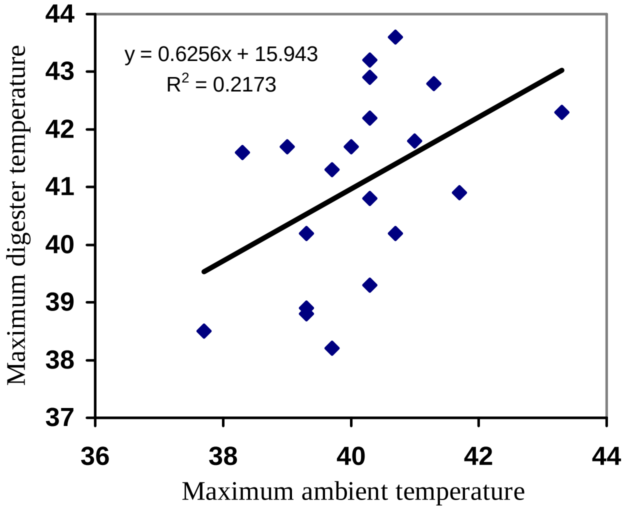

Figure 4-Maximum digester temperatures versus maximum ambient temperatures

Table 2. Measured and predicted minimum and maximum temperatures

Detention Time (Days)	Minimum Temperature (°C)			Maximum Temperature (°C)		
	Ambient	Measured	Predicted	Ambient	Measured	Predicted
1	18.7	22.7	23.7	37.7	38.5	39.4
2	21.0	23.4	25.0	39.7	38.2	40.7
3	22.3	24.3	25.8	39.3	38.8	40.5
4	24.3	25.0	26.9	39.3	38.8	40.5
5	24.7	27.0	27.1	40.3	39.3	41.2
6	22.7	26.4	26.0	39.3	40.2	40.5
7	23.3	27.4	26.4	40.7	40.3	41.4
8	23.3	26.3	26.4	39.7	41.3	40.7
9	20.7	24.5	24.8	40.3	42.2	41.2
10	20.7	25.7	24.8	41.0	41.8	41.6
11	19.0	23.5	23.9	38.3	41.6	39.9
12	21.0	25.7	25.0	40.0	41.7	40.9
13	22.3	26.6	25.8	39.0	41.7	40.3
14	21.3	26.2	25.2	40.3	40.8	41.2
15	20.3	25.3	24.6	41.7	40.9	42.0
16	21.3	25.7	25.2	43.3	42.3	43.1
17	23.0	27.0	26.2	41.3	42.8	41.8
18	24.0	26.9	26.7	40.7	43.6	41.4
19	23.0	25.8	26.2	40.3	42.9	41.2
20	23.0	26.2	26.2	40.3	43.0	41.2

Table 3. Summary of t-test for the measured and predicted minimum and maximum temperatures

Temperature	t_{cal}	t_{tab}
Minimum	0.073^{ns}	2.093
Maximum	0.031^{ns}	2.093

ns-not significant at $p \leq 0.05$

Table 4. Statistical analysis of the minimum measured and predicted temperatures

Variable	Number of pairs	Correlation coefficient	2-tail Significance	Mean	SD	SE of Mean
Measured	20	0.729	0.000	25.5800	1.313	0.294
Predicted				25.5950	0.962	0.215

Table 5. Statistical analysis of the maximum measured and predicted temperatures

Variable	Number of pairs	Correlation coefficient	2-tail Significance	Mean	SD	SE of Mean
Measured	20	0.487	0.029	41.0550	1.632	0.365
Predicted				41.0550	0.798	0.178

Table 6 is a nomograph for determining minimum and maximum temperatures inside anaerobic digesters from ambient temperatures. For example, at the ambient temperature of 35°C, the minimum and maximum temperatures inside an anaerobic digester can be predicted to be 33.1°C and 37.7°C respectively.

Table 6. Nomograph for determining minimum and maximum temperatures inside anaerobic digesters from ambient temperatures during mesophilic digestion.

Ambient temperature	Minimum temperature	Maximum temperature
15°C	21.6°C	24.9°C
20°C	24.4°C	28.1°C
25°C	27.3°C	31.3°C
30°C	30.2°C	34.5°C
35°C	33.1°C	37.7°C
40°C	36.0°C	40.9°C
45°C	38.8°C	44.6°C

4. CONCLUSION

Biogas is a cheap source of energy and energy planners in developing countries are beginning to emphasize its use. The technology for its production is greatly influenced by environmental factors such as temperature. This is more pertinent for biogas-producing anaerobic digesters built on the ground. The influence of ambient conditions on such digesters cannot be completely eliminated irrespective of temperature control methods employed. The mean ambient minimum and maximum temperature was found to be 22°C and 40.1°C respectively, while the mean digester minimum and maximum temperature was 25.6°C and 41.1°C respectively. It is concluded that the temperatures inside the digester were slightly higher than the ambient. Prediction equations were developed and these were used to develop the nomograph. The minimum and maximum temperatures could be predicted from the equations: $Y = 0.58X + 12.90$ and $Y = 0.63X + 15.94$ respectively. The nomograph developed provides an easy and direct method for the immediate determination of temperatures inside anaerobic digesters irrespective of temperature control methods incorporated into the digesters if the ambient temperature is known. Thus the management of digesters is enhanced and the possibility of digester failure is greatly reduced, because the energy planner is able to read off any likely digester temperature from the nomograph or calculate from the prediction equations. A limitation, however, for the use of this nomograph is that it cannot be used for anaerobic digestion undertaken at the thermophilic temperature range.

5. REFERENCES

Gutterer, B. and L.Sasse. 1993. *Criteria for the dissemination of biogas plants for agricultural farm and household systems*. Bremen Overseas Research and Development Association, GTZ, Germany.

Hawkes, D.L. 1979. Factors affecting net energy production from mesophilic digestion. *Anaerobic Digestion*. Applied Science Publishers Ltd. 131-150

Itodo, I.N., E.B. Lucas and E.I. Kucha. 1997. The effect of using solar energy in the thermophilic digestion of poultry waste. *Journal of Engineering for International Development* 3 (1): 15-21.

Itodo, I.N. and T.K. Philip. 2001. Determination of suitable materials for anaerobic biogas digesters. *Proceedings of the Annual Conference of the Nigerian Institution of Agricultural Engineers*. 23:437-441

Kaufman, R., K. Salter and A. Wellinger. 1982. Low temperature methane generation from animal manure. In: *Energy conservation and use of renewable energies in the bio-industries*. F.Vogt (ed.). Pergamon Press, 371-382.

Obayashi, A.W. and J.M. Gorgan. 1985. *Management of Industrial pollutants by anaerobic processes*. Lewis Pub. Inc. Michigan, USA.

Van velsen, F. and G. Lettinga. 1979. Effect of feed composition on digester performance. *Anaerobic digestion*. Applied science publishers Ltd. London. 113-130