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EFFECTS OF GROUND INSULATION AND GREENHOUSE MICROENVIRONMENT ON THE RATE AND QUALITY OF BIOGAS PRODUCTION

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ABSTRACT: *A study was conducted at Egerton University, Njoro, Kenya to establish the potential of plastic digester to produce biogas under natural and greenhouse microenvironment. The specific objectives were to evaluate the effects of greenhouse and ground insulation on the rate and quality of biogas generation. A greenhouse measuring 6m long, 4m wide and 2m high was constructed. Inside the greenhouse and the outside environment, three replications of thirty (30)-litre plastic biogas digester filled to two third capacity with slurry were used. The digesters were partially exposed to the environment and when fully buried in the ground. Biogas yields averaged 90.3 and 63.0 litres per kilogramme (l/kg) of volatile solids added for partially buried digesters under greenhouse and natural conditions, respectively. The corresponding digester temperatures averaged 27.5 and 22.2oC. The respective biogas yields averaged 312.8 and 226 litres per kilogramme volatile solid added, while the temperatures averaged 27.9 and 24.1oC for fully buried digesters. The average methane content in the biogas was 61.5% and 56.4% under greenhouse and natural conditions, respectively. At the 0.05 significance level, greenhouse effect was found to enhance both the quantity and quality of biogas generation from dairy cattle dung. The effects of ground insulation had a far much effect on the quantity of biogas generation as compared to the effects of greenhouse conditions. Therefore ground insulation of plastic biogas digester under greenhouse conditions significantly enhances biogas generation.*

Key words: *Anaerobic conditions, greenhouse, natural conditions, ground insulation, greenhouse effect*

INTRODUCTION

Most of rural populations depend on woodfuel as source of energy for cooking and most of these families have little light available at night (FARMESA, 1996). For these reasons there has been an increasing interest in the use of biogas systems in rural areas.

Biogas technology utilizes a wide variety of organic feedstock such as animal wastes, night soil, agricultural residues, aquatic plants and organic industrial wastes. The major constituents of biogas are the methane (CH_4) gas and carbon dioxide (CO_2) with traces of hydrogen (H_2) and hydrogen sulphide (H_2S). Biogas burns well when the relative proportions of methane to other gases are more than 50%. It can therefore be used as a substitute for kerosene, charcoal or firewood for cooking and lighting. The digested sludge is also a good soil stabilizer to improve land productivity.

Large scale biogas digesters notably the Chinese dome and Indian floating gasholder types have been promoted in the East African region over the years with varying degree of success. The main constraint to wide adoption of these digesters is the high cost, which makes the technology beyond reach of many smallholder farmers. In the early 1980s a low cost biogas digester, using plastic sleeves, was developed in Colombia to meet the economic concerns of rural farmers (FAO, 1992). The technology was widely adopted in Colombia and Vietnam and efforts to promote these systems in Tanzania, Kenya and Uganda showed promising results (FARMESA, 1996). Seasonal and diurnal temperature variations are deleterious to methane gas production and for this reason plastic digesters cannot work effectively in the highlands and other cooler areas (Lekule, 1996). Therefore this study was conducted to determine the performance of plastic biogas digester under natural and greenhouse conditions. The specific objectives were to: 1) evaluate the effect of greenhouse on the rate and quality of biogas production and; 2) evaluate the effect of ground insulation on biogas production.

MATERIALS AND METHODS

The study was conducted with the digesters partially buried and when fully buried in the ground. A total of five experiments were set. The first four experiments had the experimental digesters partially buried underground while in the fifth experiment the digesters were fully buried. The mean values of temperature and the corresponding gas yields were arranged in a two-stage 'nested' or hierarchical experimental design for analysis. Greenhouse and natural conditions were considered as factor A the temperature measurements as factor B. The gas yields formed the responses. There were *a* levels of factor A, *b* levels of factor B nested under each level of A, and *n* replicates. This is a balanced two-stage nested design, since there were equal numbers of levels of B within each level of A, and equal number of replicates. Since every level of factor B did not appear with every level factor A, there was no interaction between A and B as demonstrated by Montgomery (1976), Ott (1988) and Montgomery et al., (1998).

A hemispherical greenhouse measuring 6m long, 4m wide and 2m high was constructed using 36m^2 of transparent polyethylene sheet, 5 pieces of galvanized steel frames and pieces of timber to reinforce the structure. Inside the greenhouse and the outside environment three replications of 30-litre batch feed plastic biogas digesters were set.

Sampling port was made at one end of each test digester. A probe was inserted through this port and a thermocouple wire sensor was placed in such a way that its tip rested in the middle of the digester. The sensors were used for taking sludge temperature readings. A hole of 1cm diameter was made, on each digester, at approximately 10cm from the digester inlet end. PVC and rubber washers of 10cm diameter with 21mm central hole were cut and fitted on the flange of the male adapters. These adapters were then threaded through the said hole from the inside of digesters to the outside. A second PVC washer and rubber washer were put on the male adapter from the outside of the hole and secured tightly with female section. A gas outlet valve was inserted and secured into the same female section. Finally a flexible plastic hosepipe with 21mm internal diameter, for carrying gas, was attached to the gas valve.

Each experimental digester was fed through the inlet with 14 kg of fresh dairy cow dung thoroughly mixed with tap water to bring the weight of slurry to 20 kg. Mixing of dung and water was provided by a concrete mixer rotated by hand. The loading rate was determined using the procedure described by FARMESA (1996). The inlets were securely sealed and the complete assemblies of digesters carried and placed in trenches, which were dug under greenhouse (GH) and natural conditions (NC) to accommodate them. Provision for the agitation of the digester contents during the digestion process was not made because its effect on small-scale digesters is considered minimal (Barnett et al., 1978). Emptying of sludge was done through the inlet opening after elapse of a given hydraulic retention time.

Samples of the influent and effluent slurry from each experimental digester were taken for laboratory determination of total solids (TS), volatile solids (VS), total nitrogen (N) and organic carbon (C). The TS and VS were determined by heating the sample at 105^{o}C and 550^{o}C, respectively. The total nitrogen was determined by the standard micro kjeldahl method as described by APHA (1995) and total carbon by the Walkley-Black method as described by Walkley and Black (1947). The daily gas yields were measured using jar displacement method and the corresponding temperature using Delta-T logger device. The methane content in the biogas was analyzed by standard GC procedures described in APHA (1995). The measurement of the TS, VS, N, and C in the cow dung slurry was limited to partially buried digesters because constant trends were observed which made further measurements unnecessary.

Experimental Setup

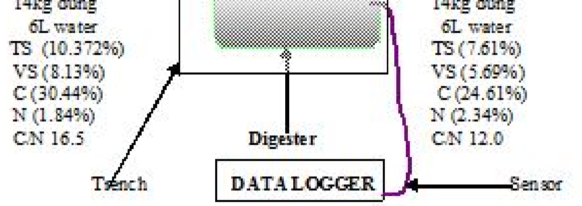

Figure 1: Experimental setup of biogas plant

In a batch digester the waste is put into the plant with a starter, if available, and the gas collected as it is given off. The time in which biogas production was simply negligible or equal for both sites was considered the hydraulic retention time. At this point the experimental digesters were stopped and their contents discharged. New slurry was then charged into the digesters.

Analysis of variance was run on the population means for the variables considered during the study. This was done using the general linear model and Duncan's multiple range test of the SAS procedure (SAS institute, 1998) at 95 percent confidence level. An F– test was used for hypothesis testing at probability value of 5%. Scatter plots of mean gas yields were plotted for the corresponding time (days) of observation and polynomial regression fitted to discern how well the coefficient of determination (r^2) explained the trend. The correlation between sites with respect to temperature and gas yields was determined using the general linear model (GLM) of the SAS procedure.

RESULTS AND DISCUSSION

Influent Slurry

The percent compositions of influent slurry are shown in Table 1.

Table 1: Percent composition of feedstock in the influent slurry

(a) Partially buried digesters

Site	Sludge	TS	VS	N	C
NC	Influent	10.37a	8.13a	1.84a	30.44a
GH	Influent	10.42a	8.11	1.84a	30.50a

For a given site, values in the vertical column followed by the same letter are not different statistically (α = 0.05) according to Duncan's multiple range test.

(b) Fully buried digesters

Site	Sludge	TS	VS
NC	Influent	11.25a	8.78a
GH	Influent	11.25a	8.78a

The influent TS content of dairy cow dung was 10.37% and 10.42% under NC and GH, respectively. The VS in the influent was 78% of total solids (%TS). The average measured percent N in the influent slurry, which was taken on a dry weight basis, was 1.84 while the measured average %C in the influent slurry was 30.5 and 30.4 under GH and NC, respectively. The computed values of carbon to nitrogen (C/N) ratio in the influent slurry were 16.6 under GH and 16.5 under NC. It can be concluded from these results that all the respective parameters in the influent under each of the conditions tested were not statistically different. This implies that identical concentrations of the influent slurries were achieved under each of the test site.

3.2 Effluent Slurry

The effluent compositions of feedstock are given in Table 2(a) and (b) for partially and fully buried digesters, respectively.

Table 2: Percent composition of feedstock in the effluent slurry

(a) Partially buried digester

Site	Sludge	TS	VS	N	C
NC	Effluent	7.61a	5.69a	2.34a	24.61a
GH	Effluent	7.29b	5.52b	2.45a	24.24a

For a given site, values in the vertical column followed by the same letter are not different statistically (α = 0.05) according to Duncan's multiple range test.

(b) Fully buried digesters

Site	Sludge	TS	VS
NC	Effluent	7.23a	4.60a
GH	Effluent	6.71b	4.18b

The analysis of percent TS in the effluent sludge from partially buried digesters yielded the results indicated in Table 2(a). The percent effluent TS was 7.61 and 7.29 under NC and GH conditions, respectively. The percent mean effluent TS were statistically different for the two sites. In comparison with the influent values shown in Table 1(a), the effluent values correspond to reductions in %TS of 27% and 30% under NC and GH, respectively. In comparison with the influent VS, the percent VS in effluent sludge were 5.69 under NC and 5.52 in GH for partially buried digesters. These represent reductions of 30% and 32% of VS under NC and GH, respectively. As can be seen in Table 2 the mean effluent sludge under the two conditions were significantly different. This observation can be attributed to the difference in temperature and gas production rate between the sites as indicated in Tables 4 and 5, respectively.

Digesters that were fully buried as shown in Tables 1(b) and 2(b) achieved even higher percent reductions of 52% and 48% of VS under GH and NC, respectively. The mean %N in the effluent slurries for partially buried digesters was 2.34 and 2.45 under NC and GH, respectively. In comparison with the influent slurry as given in Table 1(a), it can be seen that there was increase in the effluent nitrogen content. The apparent increase in %N can be explained by the reduction in TS in the effluent sludge. This could also show that the nitrogen content in the digested slurry was retained and thus confirm the general hypothesis that digested slurry has readily available nitrogen and thefore good for growing crops. The study also shows an effective biodegradation of dairy waste materials. However, it should be noted that the amount of %VS reduced would depend on the nature of waste, temperature, pretreatment, HRT employed and the rate of gas production as found by Kalia et al. (2000), Singh et al. (1993) and Cho et al. (1995).

Slurry pH and Density

Table 3 shows the variation of slurry pH and density.

Table 3: Variation of Influent and Effluent pH and Density

(a) Influent slurry

Site	Sludge	pH	Density
NC	Influent	6.93a	1.03a
GH	Influent	6.93a	1.03a

For a given site, values in the vertical column followed by the same letter are not different statistically (α = 0.05) according to Duncan's multiple range test.

(b) Effluent slurry

Site	Sludge	pH	Density
NC	Effluent	7.42a	0.98a
GH	Effluent	7.41a	0.98a

Variation in pH

The measured pH value for influent and effluent are shown in Tables 3(a) and (b). From the Table, the influent pH values were often lower than effluent pH values. This apparent difference observed, could be explained by the role methane producing bacteria play in ensuring that volatile fatty acids (VFA), which are responsible for low pH, are converted into primarily methane (CH_4) and carbon dioxide (CO_2). In anaerobic digester a large quantity of CO_2 is produced during methane formation (Price and Cheremisinoff, 1981). The high pH values obtained in the effluent sludge, therefore, is normally maintained with a bicarbonate buffer system, which is responsible for neutralizing the acid. The best range of pH values of slurry is widely quoted as 7 to 8.5. This means that if the value of slurry varied too high or low, from this range the output and quantity of gas would be affected. In the present study the average pH of 7.4 attained under both GH and NC falls under the normal range. This implied that the conditions in the digesters were stable.

3.5 Slurry Density

As shown in Table 3(a), the density of influent slurry was about 1.03 grammes per cubic centimetres (g/cc). At the effluent the density, as given in Table 3(b), averaged 0.98 g/cc. This was 5% less than the value of the influent. The decrease in the density of slurry could be attributed to a decrease in the total solids content from about 10.4% in the input to about 7.4% in the effluent sludge. From the laboratory analysis, the density of dry matter was 50kg m^{-3}.

3.6 Effects of Greenhouse on Temperature

The effects of greenhouse on sludge temperature can be deduced from Table 4 (a) and (b) and Figures 3 and 6 for partially and fully buried digesters, respectively.

Table 4: Mean sludge temperatures for digesters partially and fully buried across the test sites

(a) Partially buried digesters

Block	Site	Temperature (^oC)
1,2,3&4	GH	**27.51**a
	NC	**22.19**b

For each block, values in the vertical column followed by the same letter are not different statistically (α = 0.05) according to Duncan's multiple range

(a) Fully buried digesters

Block	Site	Mean Temperature (^oC)
5	GH	**27.92**a
	NC	**24.11**b

For each block, values in the vertical column followed by the same letter are not different statistically (α = 0.05) according to Duncan's multiple range test.

As indicated in Table 4 (a) and (b) the mean sludge temperatures for digesters that were partially buried were 27.51°C and 22.19°C under greenhouse and natural conditions, respectively. Similarly the corresponding mean sludge temperature values for digesters fully buried were 27.92°C and 24.11°C. These values were statistically different across the test sites at $\propto$=0.05 according to Duncan's multiple range tests (DMRT) of the SAS procedure. The optimum temperature range for fermentation of between 25°C to 40°C was attained under greenhouse conditions. During the day elevated digester temperatures of between 40°C to 60°C were recorded in digesters that were partially buried. Ordinarily temperature within this range would favour or enhance gas production because it is within both the mesophilic and thermophilic conditions. These conditions were, however, not sustainable or adapted throughout the day. It emerged that at night and early morning temperatures dropped to below 20°C resulting in sudden high thermal variations. Methane producing bacteria are known to be sensitive to sudden temperature fluctuations (Fulford, 1988 and FAO 1992). They (methane bacteria) become inactive or stop working when such conditions develops. For optimum process stability, therefore, temperature should be maintained within a narrow range of operating temperature conditions. Although the temperatures under the conditions studied were significantly different the observed high temperature variation affected the rate of gas production in partially buried digesters.

Effect of Insulation on Biogas yield

Ground insulation involved burying the experimental digesters fully underground. Fully buried digesters were used to cushion high temperature variations encountered in digesters that were partially buried. The results showed (Table 4b) increased mean sludge temperatures and the corresponding gas discharge (Table5b) under both conditions. In comparison with digesters partially buried, the mean sludge temperature of digesters under natural conditions increased by about 2°C and small increase in temperature of 0.4°C was observed under greenhouse conditions (Tables 4a and b). More importantly, however, burying the digesters underground appeared to stabilize sludge temperatures above 20°C under natural conditions and above 25°C under greenhouse condition as indicated in Figure 6. From Table 5(b) it can be seen that the mean daily gas yields also increased by 5.6 litres and 7.6 litres under natural and greenhouse condition, respectively compared to similar digesters that were partially buried underground (Table 5a).

Effects of Greenhouse on Biogas yields

The mean daily gas yields in millilitres per day (ml/day) from the test digesters are shown in Tables 5 (a) and (b) for partially and fully buried digesters, respectively. The data represent the means of daily samples from replicate experimental digesters at different hydraulic retention time (HRT).

Table 5: Mean gas yields for partially and fully buried digesters across two sites

(a) Partially buried

Block	Site	Mean Gas Yields (ml/day)
1	GH	2119.07a
"	NC	1453.70[b]
2	GH	4558.30a
"	NC	2337.80b
3	GH	4596.70a
"	NC	3128.80b
4	GH	5120.50a
"	NC	4680.60a
MEANS	**GH**	**4304.00**a
	NC	**3017.80**b

For each block, values in the vertical column followed by the same letter are not different statistically (α = 0.05) according to Duncan's multiple range test.

(b) Fully buried

Block	Site	Mean Gas Yields (ml/day)
5	GH	**11881.90**[a]
	NC	**8585.20**[b]

The results from Table 5 (a) showed biogas yields of 4.30 litres/day (l/d) and 3.02 l/d under GH and NC, respectively. These correspond to 90.3 l/kg of VS added and 63 l/kg of VS added under greenhouse and natural conditions, respectively. The results from the test digesters that were fully buried are shown in Table 5 (b). The average gas yield under GH environment was 11.9 l/day corresponding to 312.8 l/kg of VS added. The average gas yield under natural conditions was 8.6 l/d corresponding to 226 l/kg of

VS added. The gas yields were statistically different between the test sites. The corresponding mean temperatures were also significantly different. Under elevated temperatures, as shown in Figures 3, 4 and 6, the rate of gas production appeared to be enhanced. This agreed with the common assertion that the higher the temperature the higher the rate of gas yields. By burying digesters fully underground increased digester temperature was achieved. This explained the enhanced gas yield observed.

The results from digesters that were fully buried compare reasonably well with the literature (National Academy of Science, 1977; Moorhead and Nordstedt, 1993; Chen and Hashimoto, 1980; Chen et al., 1980; Hashimoto et. al., 1980; Chen and Hashimoto, 1978 and Kalia et al., 2000). In comparison with the results from previous studies, the results from digesters that were partially buried appeared low. The low values obtained did not suggest failure of the system. It revealed the effect of high temperature fluctuations on gas yields. The relatively higher biogas yields in the previous studies were achieved using a mixture of input materials (El-mashad, H. M and Zhang, R., 2007), different HRT and type of waste material. In addition the use of pretreated input materials and the operation of digesters at optimum sludge temperatures could have enhanced gas yields.

Variation of Gas with Time

Temporal plots of the mean volumetric biogas yields are depicted graphically as shown in Figures 4 and 5, for partially and fully buried digesters, respectively under each of the condition tested. The plot of polynomial fits of order two gave relatively strong responses. The gas production coefficients of determination (r^2) for partially buried digesters were 0.85 and 0.88 under greenhouse and natural conditions, respectively. In comparison the gas coefficient of determination for fully buried digesters were 0.86 and 0.90 under GH and NC. The intercepts of the polynomial fits (equations) were forced to zero because a positive intercept would imply positive gas discharge at zero HRT and therefore the polynomial fits would be unrealistic. In this case zero retention time definitely results in zero gas discharge.

In the batch feed digester used the results indicated a general increase in gas discharge with increase in HRT. A peak value was obtained followed by a general decline in gas production. There were also subsidiary peaks and sharp oscillations noticed in the daily gas production curves. These patterns were more pronounced in digesters under greenhouse conditions.

The optimum daily gas peaks were attained at different HRT across two sites. Digesters under GH conditions, on average, attained peak values on the 17th day and 20th day in natural conditions. It should be remarked that the high and subsidiary peaks and sharp oscillations appeared somewhat cushioned when means of gas yields was used to plot the resultant graphs as shown below. There was a lag time before the first gas was given off. In the first experiment a lag time of 5 days was recorded while in the second, third fourth and fifth experiments a lag time of two days each was recorded. Thus faster gas discharge was achieved in the subsequent studies probably because the digesters were using seed cultures for startup from the previous experiments. Both Chowdhury (1987) and Maramba 1978) also found that biogas plants using starter sludge had very short lag time.

Correlation of Temperature and Gas

Table 6: Correlation of temperature and gas

(a) Partially buried digesters

Site	Variable	Temp	Gas
1	Temp	1	0.15
		0.00*	0.006*
		324	324
	Gas	0.15	1
		0.006	0
		324	324
2	Temp	1	0.14
		0.00*	0.0126*
		324	324
	Gas	0.14	1
		0.0126*	0.00*
		324	324

* Probability level

(b) Fully buried digesters

Site	Variable	Temp	Gas
1	Temp	1	0.82
		0.00*	0.0001*
		138	135
	Gas	0.82	1
		0.000*	0.00*
		135	135
2	Temp	1	0.83
		0.00*	0.0001*
		138	135
	Gas	0.83	1
		0.0001*	0.00*
		135	135

From Table 6, the correlation coefficient between temperature and gas for fully buried digesters was significantly higher at 0.83 and 0.82 under GH and NC, respectively compared to 0.15 and 0.14 for partially buried digesters under GH and NC. This could suggest that the effect of temperature on gas yields would be more pronounced when biogas digester were insulated. It could be suggested, therefore, that by insulating biogas digester increased temperature and gas yields are achieved.

Quality of Gas

The quality of methane gas under greenhouse conditions varied at 55.7% after retention period of 14 days and 68.4% after 21 days. In comparison the methane gas content under natural conditions was 51.6% and 61.2%, respectively. The apparent difference in the methane content across the test sites could be attributed to the temperature difference.

Variation of Methane with Time

The effect of increased temperature and time on methane content in a biogas can be discerned from Fig.2. The effect of temperature on methane content in the biogas manifested itself after the 10th day. After this day the methane content under greenhouse condition was higher than in natural condition. The difference between methane content under the conditions studied could be attributed to observed temperature difference.

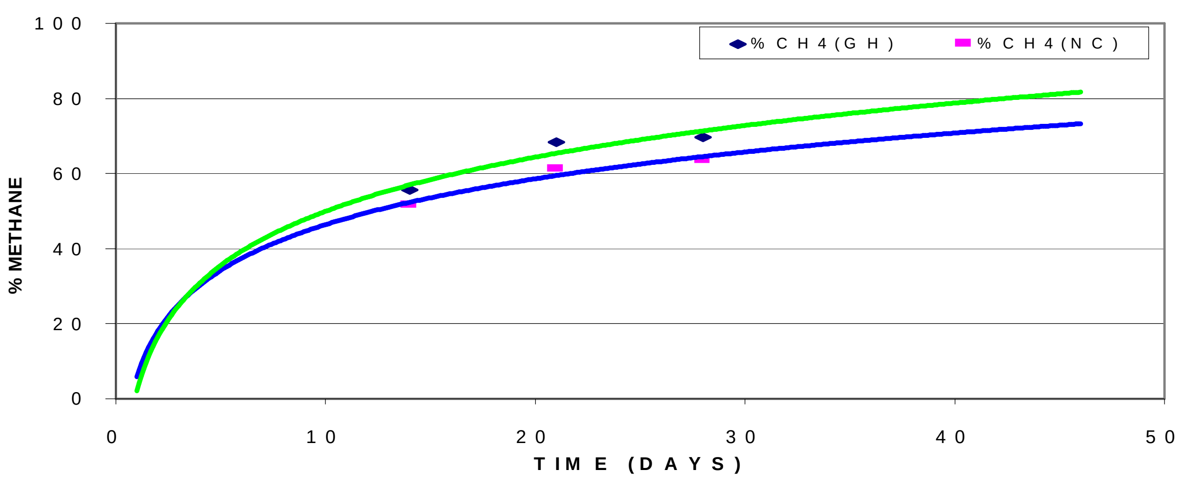

Figure 2: Daily variation of methane in biogas under GH and NC

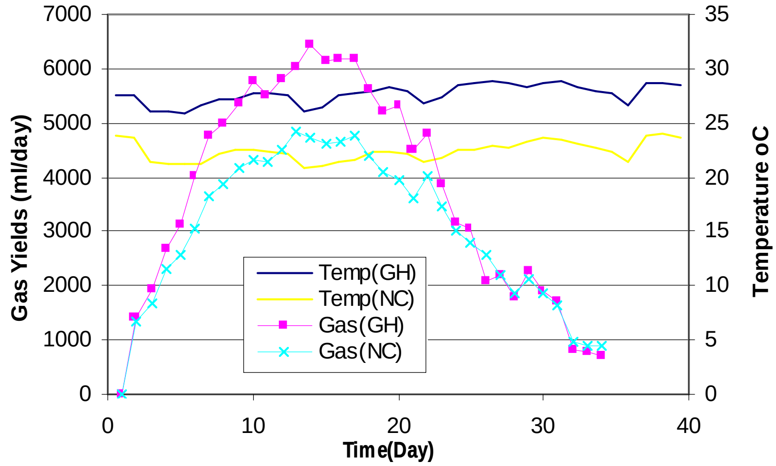

Figure 3: Temporal volumetric gas yields and digester temperature under greenhouse (GH) and natural condition (NC)

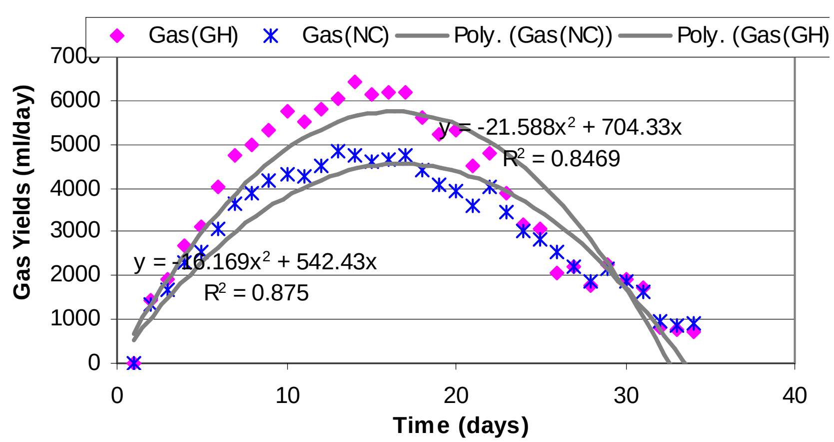

Figure 4: Plots of gas yields and polynomial equations for the corresponding time under GH and conditions NC

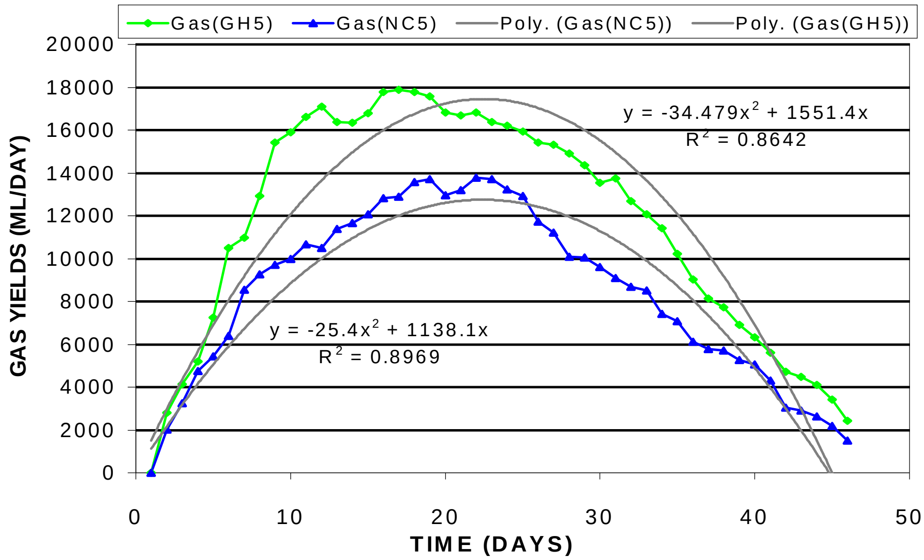

Figure 5: Plots of gas yields and polynomial equations for the corresponding time under GH and NC

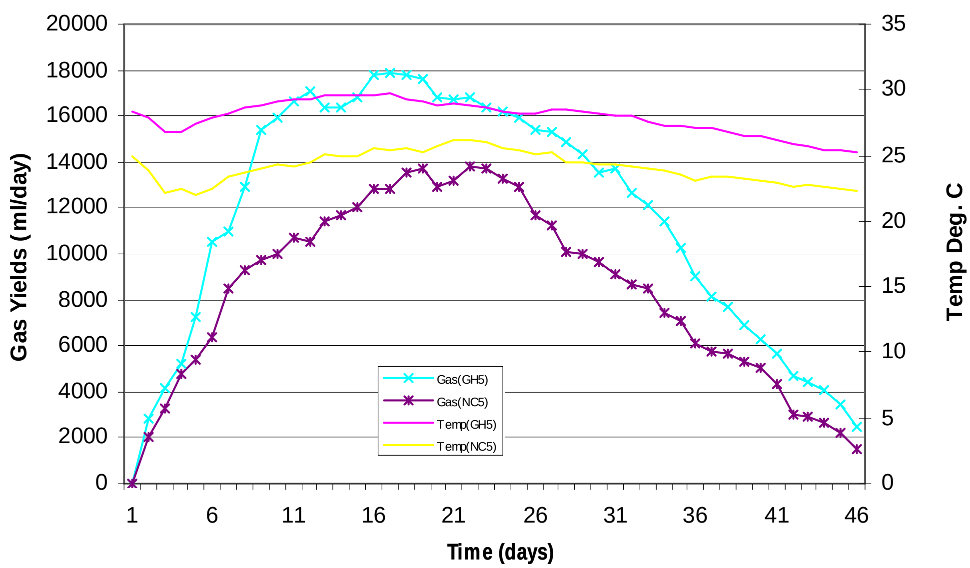

Figure 6: Plots of gas yields and temperature for the corresponding time of under GH and NC

Digester Size

Based on the results of study, the size of biogas digester suitable for the output of four cows and operated under temperature of 28°C for twenty days would be 3.2m^3. The daily amount of gas generated from the digester would be 2.4 m^3. This corresponds to the energy production of 31 MJ per day and is further equivalent to 9 kWh per day or 360 W. The reduced size of digester could provide adequate energy for cooking and lighting for a typical Kenyan family of six people.

CONCLUSION

Since identical influent loading concentrations were achieved for each of the test digesters, the high gas yields observed under greenhouse was attributed to elevated temperature. The methane content in the biogas was relatively higher under greenhouse compared to natural conditions. These findings testify that the methane content in a biogas is a function of temperature. For a batch feed digester the trend of daily gas discharge can be strongly predicted using polynomial regression equations. Apart from overflow of the digested slurry and low gas pressure, a plastic biogas digester is easy to operate and requires virtually no maintenance problems. Insulating biogas digesters cushioned the adverse effect of high thermal fluctuations. Heating and insulating the digester under greenhouse enhanced the digestion process, reduced retention time and digester size made smaller than for the biogas unit under natural conditions. The energy generated from the reduced sized digester is sufficient for cooking and lighting for a family of six persons. Therefore greenhouse effects reduces the size of digester and hence the cost of the digester. Ground insulation of biogas plants under greenhouse conditions is recommended.

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