MODEL STUDY OF THE EFFECTS OF TEMPERATURE VARIABILITY ON BIOGAS PRODUCTION FROM COW DUNG AND CHICKEN DROPPINGS

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ABSTRACT
The pressure upon many nations of the world especially in the developing economies is the attainment of the Sustainable Development goals, one of which is Environmental Sustainability. A shift from fossil fuel to renewable alternative energy such as biogas has been identified as a key strategy for attaining this. The production of biogas from various substrates via anaerobic digestion has been extensively explored. The influence of variability in ambient and digester temperatures on biogas production from cow dung and chicken droppings was explored in this study. Anaerobic digestion of Cow dung and Chicken droppings for the production of high quality biogas was carried out at average ambient temperatures of 20.45±4 ^oC and 37.00±3 ^oC. The total biogas production for Cow dung and Chicken droppings were respectively 0.035444 m^3 and 0.210984 m^3 for the first temperature range and 0.183471 m^3 and 0.321066 m^3 for the second temperature range. The results of the daily and cumulative biogas production where subjected to the Modified Gompertz model. The total biogas yield for Cow dung and Chicken droppings based on the Modified Gompertz equation were respectively 0.0374 m^3 and 0.217 m^3 for the first temperature range and 0.181 m^3 and 0.322 m^3 for the second temperature range. This study demonstrated that there is a clear variation in the volume of biogas produced at lower and higher temperatures within the mesophilic range.

Keyword: *Biogas, Chicken droppings, Cow dung, Gompertz equation, Mesophilic, Temperature*

1.0 INTRODUCTION

Anaerobic digestion which is the controlled degradation of organic matter in the absence of oxygen and through the concerted action of a close-knit community of bacteria produces biogas that is primarily composed of methane and carbon dioxide as well as compost products suitable for soil fertility improvement (Alfa *et al.*, 2014b; Lyberatos and Skiadas, 1999). The digestion is a multistep process involving the action of multiple microbes (Owamah *et al.,* 2014a). Research into the development of alternative sources of energy has become increasingly necessary largely due to the non-renewable nature of fossil energy and the various attendant environmental challenges (Owamah *et al.,* 2014a). Biogas technology is fast becoming an acceptable alternative to mitigate the challenges of using fossil fuels. This is not unconnected to the fact that it is a clean, efficient, eco-friendly and renewable source of energy (Cheng *et al.,* 2014; Weiland, 2010; Yu *et al.,* 2008). This technology therefore could be a means of significantly reducing the energy deficiency, which has been a serious clog in the wheel economic development in Africa and other developing economy (Adaramola and Oyewole, 2011).

Significantly, biogas production is dependent on several factors such as temperature, pH of slurry, nature of biomass, Carbon-Nitrogen ratio, Hydraulic Retention Time (HRT), loading rate, amongst several other factors (Alvarez *et al.,* 2006; Raheman, 2002). Keeping other factors constant, the variation of atmospheric temperature is a crucial factor in the digestion of the same biomass feed material at the same loading rate. Various studies have established that higher atmospheric temperature results in higher gas production (Chae *et al.,* 2008; Climent *et al.,* 2007; Sreekrishman *et al.,* 2004). Recently, anaerobic digestion in the low temperature range is receiving significant attention (Alvarez and Lidén, 2009; Bouallagui *et al.,* 2004; Cha and Kim, 2001). Usually, the hydraulic retention time of a biogas plant is decided for a particular area based on the atmospheric temperature and the type of feeding material available (Bouallagui *et al.,* 2003; Raheman, 2002). More so, at least four different trophic types of microorganisms work together to bring about the degradation of organic waste for the production of methane (Cha and Kim, 2001). These four metabolic groups that operate in the anaerobic digestion process for biogas production are the hydrolytic bacteria, the hydrogen producing/acetogenic bacteria, the homoacetogenic bacteria, and lastly, the methanogenic bacteria. While the hydrolytic bacteria degrades a wide spectrum of complex organic molecules into a broad range of end products, the hydrogen producing/acetogenic bacteria (both obligate and facultative species) degrades organic acids larger than acetic and neutral compounds larger than methanol to hydrogen and acetate. The homoacetogenic bacteria degrades a very wide variety of multi or mono carbon compounds to acetate acid while the methanogenic bacteria on the other hand lastly ferments hydrogen/carbon dioxide, mono carbon compound and acetate into methane (Cha and Kim, 2001). Due to these wide microbial populations and operations in anaerobic digestion, a steady state condition of the process could stabilize the microbial activities. However, a sudden change in temperature could make the digestion unbalanced. This is due to the different response of the microbial group to the sudden temperature change (Cha and Kim, 2001; Chae *et al.,* 2008). It therefore implies that temperature difference/change could be a major factor that can significantly affect the digestion process and consequently, the biogas production.

Various feed material ranging from animal waste to other agricultural waste materials have been explored and exploited for biogas production by various researchers in Africa (Mshandete and Parawira, 2009). Of particular note is the production of biogas from cow dung and chicken droppings investigated by various researchers in Nigeria and other developing economies of the world (Abubakar and Ismail, 2012; Adeogun *et al*., 2014; Ahmadu *et al.,* 2009; Alfa *et al*., 2014a; Alfa *et al*., 2013; Ojolo *et al*., 2007). This is largely due to the wide availability of these substrates across the nation. In addition, animal wastes especially poultry droppings and cow dung contains more easily degradable organic materials than other agricultural waste products. Thus, atmospheric temperature could be the major criteria for determining the hydraulic retention time of biogas plants (Raheman, 2002).

The purpose of this research therefore is to investigate the effect of temperature variability on the production of biogas from cow dung and chicken droppings within the mesophilic temperature range. Biogas modeled kinetics were developed using modified Gompertz models with cumulative biogas production.

2.0 MATERIALS AND METHODS

2.1. Substrate collection, Pre-treatment and characterization

The Substrates that were utilized in this research were cow dung obtained from Zaria Abattoir and Chicken droppings obtained from the National Animal Production Research Institute (NAPRI), Zaria and respectively transported to the research ground. The Waste characterization was done to ascertain the composition. This included physical, chemical biological composition with regards to volatile solids, total solids and elemental analysis for organic Carbon, Nitrogen, Moisture contents, pH, Chemical oxygen demand (COD), Phosphorus, *E. coli, Entereobacteriaceae,* Calcium, Sodium and Potassium in accordance with the standard methods described previously in (APHA 2012; Alfa *et al*., 2014a). The Substrates characterization prior to digestion is shown in Table 1. The analysis were carried out at two experimental runs within two distinct mesophilic temperature ranges T_1 and T_2.

Furthermore, after digestion in both experimental run, samples of the digestate from the both digesters were concentrated by centrifuging using a Rotofix 32 laboratory centrifuge at 4000 rpm (4226g) for 10 min. The solid residue composed majorly of fibers was analyzed for Total solids (TS), Volatile solids (VS), Chemical oxygen demand (COD), *Escherichia coli* and *Enterobacteriaceae* counts while the liquid portion was analyzed for COD, total ammonium nitrogen (TAN), orthophosphates, Volatile fatty acids (VFA), pH as well as *E. coli* and *Enterobacteriaceae* counts.

TABLE 1: CHARACTERISTICS OF SUBSTRATES BEFORE DIGESTION

Parameter	Unit	Substrate			
		Cow Dung		Chicken Droppings	
		T_1	T_2	T_1	T_2
pH	-	5.9±1.42	7.04±2.12	6.55±1.33	7.13±2.10
Total Solids	g/kg	135.55±200.12	154.49±433.4	71.43±4.96	67.35±3.96
Volatile Solids	g/kg	32.01±4.00	33.00±3.99	38.53±2.21	37.35±3.11
Total Kjeldahl Nitrogen	gN/kg	19.76±2.22	20.30±3.13	82.31±3.94	72.20±2.74
Organic Carbon	gC/kg	33.26±3.00	35.21±2.97	39.01±1.17	37.98±1.26
Moisture Content	%	52.12±5.37	41.20±3.55	62.21±3.28	59.01±3.97
COD	gO_2/kgTS	750.09±50.76	870.08±44.67	247.10±1.03	223.00±6.17
Total Phosphorus	gP/kgTS	7.17±1.04	3.27±1.02	8.19±0.13	5.08±0.11
Calcium	gC/kgTS	37.14±1.12	33.01±2.22	52.71±2.98	49.99±3.98
Sodium	gS/kgTS	4.02±2.21	3.02±1.01	5.66±0.04	4.74±0.01
Potassium	gK/kgTS	22.55±1.12	20.54±2.32	28.67±0.05	27.97±0.04
E. coli	Cfu/gTS	$7.23x10^5$±4.72	$9.11x10^5$±3.56	$9.34x10^5$±1.23	$11.34x10^5$±2.33
Enterobacteriaceae	Cfu/gTS	$1.07x10^4$±0.23	$1.21x10^4$±0.15	$1.02x10^6$±1.38	$1.15x10^6$±1.98

2.2. Experimental Deign and Set up

The Mesophilic digestion of Cow dung and Chicken droppings were carried using two identical 25-Litre cylindrical biogas reactors each connected to a gas collection system comprising of a 12.1 Litre gas holders inverted in a 14.3 Litre water Jacket as shown in Figure 1. The details of the design of the digesters and the gas collection system have been previously described in (Alfa *et al*., 2014a, Alfa *et al*., 2014b, Owamah *et al*., 2014b).

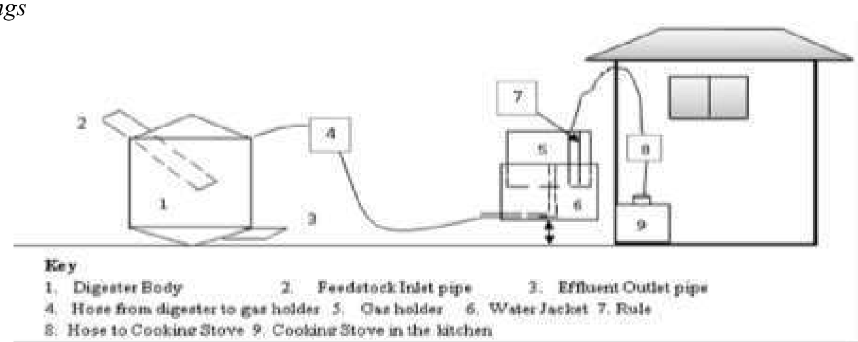

Fig. 1: Schematic View of Experimental Set up (Alfa, *et al.*, 2014a)

Batch anaerobic digestion tests were carried out on the Cow dung and chicken droppings in reactors A and B respectively. The cow dung and chicken droppings were sorted to remove non-biodegradable materials that may inhibit biogas production. This was done manually. Six (6) kg each of cow dung and chicken droppings were respectively mixed with 500 ml of water to form slurry after which they were introduced into reactors A and B respectively through an inlet pipe of 50 mm at the top of the reactor (Figure 1). The slurry was allowed to occupy three quarter of the digester space leaving a clear height of about 0.0625 m as space for gas production. A 100-ml of partly decomposed slaughterhouse waste (rumen content of cattle) was collected and used as seed material (inoculums) for all the reactors. A separate blank reactor containing only the inoculum and water was operated simultaneously with reactors A and B. This was used to correct the biogas volume produced from the experimental substrates. This also provided basis for the initial guess of the kinetic parameters for the Model study (Modified Gompertz equation). Total solids content of the three digesters was set at 7.5% as recommended by Momoh *et al.* (2013). The inflow was directed downward to cause the solids to accumulate at the bottom of the tank for easy removal after digestion. Before feeding the reactors, the flexible hose connecting the gas outlet from the reactor to the gasholder was disconnected, such that the gas outlet from the reactor was left open. This was done to prevent negative pressure build up in the reactor. The contents of the digesters were gently and manually agitated twice daily. The gas was collected from the digester through a 10 mm diameter flexible hose connected from the digester to the bottom of the gas collection system. The collected gas was allowed to pass through water and slaked lime respectively as scrubbers (Owamah *et al.,* 2014b; Chen *et al.,* 2004).

The biogas production was measured with aid of the meter rule attached to the gasholder (Figure 1). Details of the method of measurement of biogas volume have been described previously in (Alfa *et al.,* 2014a; Owamah *et al.,* 2014b). Measurement of biogas production was done daily until the end of the retention time.

The gases collected were used to boil water using Ahmadu Bello University biogas stove burner (Igboro *et al.,* 2011), in order to test for the flameability of the produced biogas from the two reactors during the two experimental runs. Each experimental run was monitored for 30 days retention period.

The first experimental run designated T_1 was carried out at an average ambient temperature of 20.45±4 ^oC while the second experimental run designated T_2 was carried out at an average ambient temperature of 37.00±3 ^oC. The digester temperatures and pH were monitored daily using the temperature and pH probes inserted.

The scope of the model study in this research was restricted to the studying of the cumulative biogas Production using the modified Gompertz equation. Thus, Modified Gompertz equation was used to model cumulative biogas production from cow dung and chicken droppings at the two experimental runs (T_1 and T_2). Equation 1 shows modified Gompertz equation

$$Y(t) = A\exp\left[-\exp\left(\frac{\mu\times e}{A}(\lambda - t) + 1\right)\right] \qquad (1)$$

where:

Y (t) = Cumulative of biogas produced (m^3) at any time (t)

A = Biogas production potential (m^3),

μ = Maximum biogas production rate (m^3/day),

λ = Lag phase period (days), which is the min time taken to produce biogas or time taken for bacteria to acclimatize to the environment

t = Cumulative time for biogas production (days) and

e = Mathematical constant (2.718282) (Matheri *et al.,* 2015; Yusuf *et al.,* 2011)

The constants A, μ and λ were determined using the non-linear regression approach with the aid of the solver function of the Microsoft Excel Tool Pack.

The Modified Gompertz equation has been extensively used by researchers to study the cumulative biogas/methane production as well as bacteria growth in both biogas and biogas production studies (Budiyono *et al.,* 2010; Lay *et al.,* 1996; Matheri *et al.,* 2015; Syaichurrozi and Sumardiono, 2013; Yu *et al.,* 2013; Yusuf *et al.,* 2011; Zwietering *et al.*, 1990).

3.0 RESULTS AND DISCUSSION

In this study biogas was produced from cow dung and chicken droppings at a lower and upper mesophilic temperature ranges. The effect of this difference in temperature on the volume of gas produced was investigated. The biomethane potentials and bio-chemical kinetics were assessed. The results obtained are presented as follows. Table 2 shows the result of the characterization of the digestate at the end of the digestion process in both experimental run.

TABLE 2: CHARACTERISTICS OF SUBSTSTRATES AFTER DIGESTION

Parameter	Unit	Substrate			
		Cow Dung		Chicken Droppings	
		T_1	T_2	T_1	T_2
Residue (fibre)					
Total Solids	g/kg	76.4481293	87.13±12.04	40.3656392	38.06±3.00
Volatile Solids	g/kg	19.4097	20.01±3.98	19.57963588	18.98±3.09
COD	gO_2/gTS	451.77991	524.05±53.67	119.9930897	108.29±3.15
E. coli	Cfu/gTS	3.94E+03	$4.97.11x10^3$±3.06	686910.0529	$8.34x10^5$±2.39
Enterobacteriaceae	Cfu/gTS	1.03E+03	$1.16x10^3$±0.09	104660.8696	$1.18x10^5$±0.07
Liquid Portion					
Ph	-	7.21±8.71	7.94±7.87	7.15±5.43	8.16±3.17
COD	gO_2/m^3	6.68E+02	775.09±115.67	198.3559238	179.01±15.07
Orthophosphates	gP/m^3	3.54E+02	161.27±8.11	329.0832283	204.12±13.05
TAN	gN/m^3	1.37E+03	1219.95±2.13	2078.370378	1971.12±2.99
Volatile Fatty Acid	g/m^3	1095.1785	1129.05±345.07	2038.190578	1975.77±298.78
E. coli	Cfu/cm^3	5.31E+05	$6..69x10^5$±2.76	7.40E+05	$8.98x10^5$±2.73
Enterobacteriaceae	Cfu/cm^3	9.37E+02	$1.06x10^3$±0.91	1.04E+05	$1.17x10^5$±1.01

The average ambient temperatures for Samaru during the first and second experimental run were 20.45±4 ºC and 37.00±3 ºC respectively. The results of the dialy digester temperatures monitored in this study for cow dung and chicken droppings are presented on Figures 2 and 3 respectively.

The T_1 digester temperature for the cow dung set up fluctuated between 12 ºC and 26 ºC while the T_2 digester temperature fluctuated between 27ºC and 36 ºC (Figure 2). For the chicken droppings set up on the other side, T_1 digester temperature fluctuated between 14 ºC and 26 ºC while the T_2 digester temperature fluctuated between 29ºC and 38 ºC (Figure 3). The fluctuation in digester temperature in both cases was dependent on the fluctuation of the ambient temperature of the set up environment which influences the metabolism of the participating organisms. Furthermore, the feedstock pH showed a general increase with minimal fluctuation (Figure 4 and 5).

The daily biogas production during the respective temperature ranges for both cow dung and chicken droppings are presented on Figures 6 and 7.

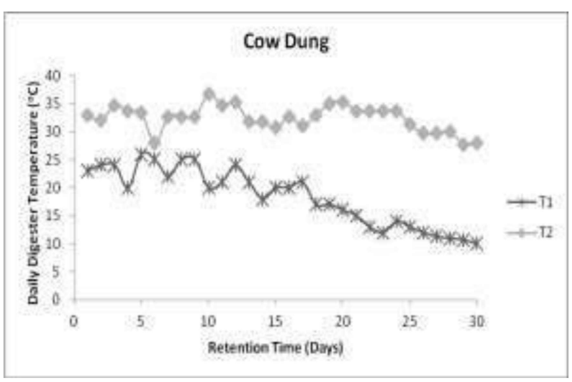

Fig. 2: Daily Digester Temperatures (Cow Dung)

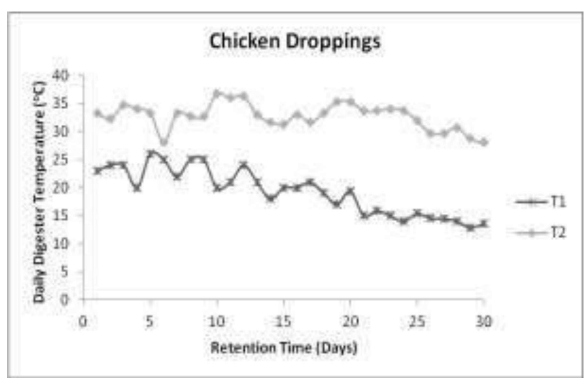

Fig. 3: Daily Digester Temperatures (Chicken Droppings)

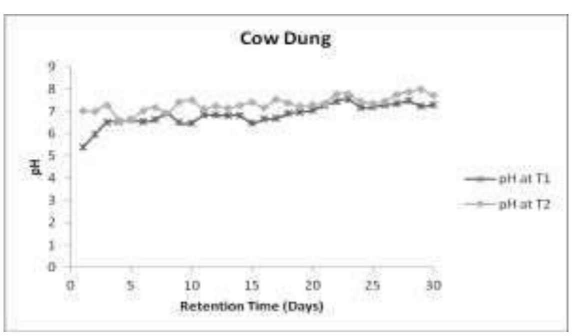

Fig. 4: pH of Cow Dung Slurry at T1 and T2

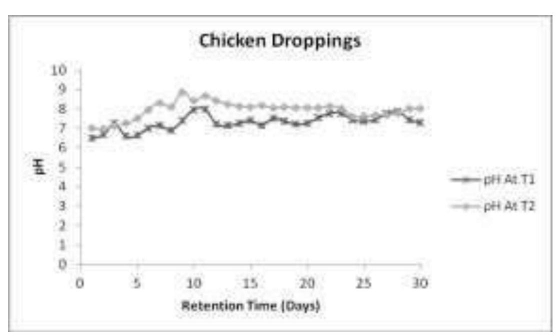

Fig. 5: pH of Chicken Droppings Slurry at T1 and T2

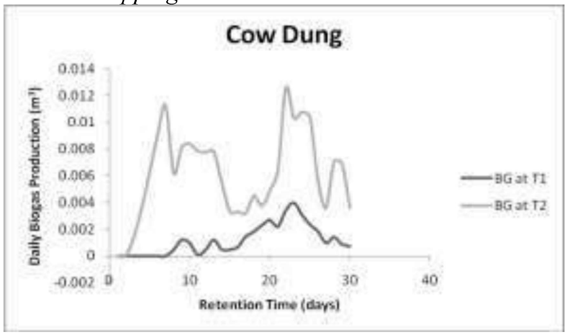

Fig. 6: Daily Biogas Production from Cow Dung

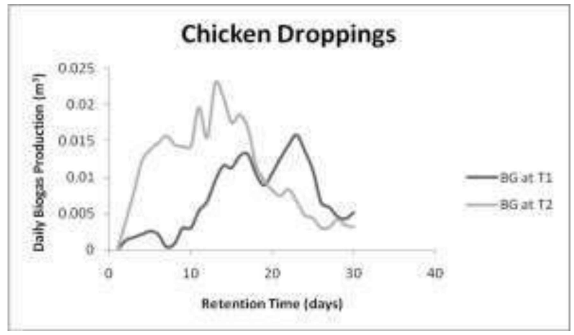

Fig. 7: Daily Biogas Production from Chicken Droppings

Figure 6 shows that biogas production for cow dung at T_1 started on the 8th day of set up while that of T_2 started on the 3rd day. The low ambient temperature and digester temperatures could be the reason for the slower rate of production at T_1. Figure 7 on the other hand shows that biogas production for chicken droppings at both T_1 and T_2 started on the 2nd day of set up. Unlike the case of cow dung, the difference in temperature did not affect the start up of biogas production except that the rate was slower at the first temperature range which may not be unconnected with slower metabolism of the participating bacteria due to the low temperature.

Furthermore, Table 3 shows the total biogas yield from cow dung and chicken droppings at both experimental run as well as their respective yied per day, yield per kg of substrates and yield per kg of substrates per day. The results of the cumulative biogas production from cow dung and chicken droppings during respective temperature ranges are presented on figures 8 and 9.

Chicken droppings

The cumulative (total) biogas production for Cow dung and Chicken droppings were respectively 0.035444 m^3 and 0.210984 m^3 for the first temperature range and 0.183471 m^3 and 0.321066 m^3 for the second temperature range as can be seen on Table 4 and Figures 8 and 9. The modified Gompertz model was used to fit the cumulative biogas production which was observed to adequately describe the biogas production from these substrates as shown in Figures 8 and 9.

The total biogas volume as well as the estimated kinetics parameters evaluated using non-linear regression is shown in Table 4. During the first experimental run (T1), cow dung had a biogas production potential (A) of 0.053125 m^3 at a maximum biogas production rate (μ) of 0.002439 m^3/day with a lag phase (λ) of 13.60425 days. During the second experimental run (T2) cow dung had a biogas production potential (A) of 0.256808 m^3 at a maximum biogas production rate (μ) of 0.007491 m^3/day with a lag phase (λ) of 4.198522 days. Chicken droppings at T1 had a biogas production potential (A) of 0.274183 m^3 at a maximum biogas production rate (μ) of 0.012397 m^3/day with a lag phase (λ) of 10.10817 days while at T2, it had a biogas production potential (A) of 0.336828 m^3 at a maximum biogas production rate (μ) of 0.019490 m^3/day with a lag phase (λ) of 3.99795 days. The total biogas volumes of 0.037384 m^3, 0.180722 m^3, 0.216594 m^3 and 0.321842 m^3 obtained for cow dung at T1 and T2, chicken droppings at T1 and T2 respectively were comparable with the experimental values. This implies that the modified Gompertz equation adequately described biogas production with a respective goodness of fit (R^2) of 0.9988892, 0.885759 and 0.984124 and 0.960554.

4.0 CONCLUSION

Biogas production from cow dung and Chicken droppings was established to be feasible at average ambient temperatures of 20.45±4.41 °C and 37.00±2.93 °C. A total of 0.035444 m^3 and 0.210984 m^3 of biogas were produced from Cow dung and Chicken droppings respectively for the first temperature range while those for the second temperature range were 0.183471 m^3 and 0.321066 m^3 respectively for cow dung and chicken droppings. This study demonstrated that there is a clear variation in the volume of biogas produced at lower and higher temperatures within the mesophilic range. The application of modified Gompertz equation in studying the biogas production was able to predict biogas production with retention time. The goodness of fit (R^2) for Cow dung (at T_1 and T_2) and Chicken droppings (at T_1 and T_2) were respectively 0.9988892, 0.885759 and 0.984124 and 0.960554. Finally, the total biogas yield for Cow dung and Chicken droppings based on the Modified Gompertz equation were respectively 0.0374 m^3 and 0.217 m^3 for the first temperature range and 0.181 m^3 and 0.322 m^3 for the second temperature range.

TABLE 3: BIOGAS YIELD FROM COW DUNG AND CHICKEN DROPPINGS

	Total Volume of Biogas (m^3)		Average biogas yield per day (m^3/day)		Average yield per kg of slurry (m^3/kg)		Average daily yield per kg of slurry (m^3/kg/day)		Methane Content (%)	
	T_1	T_2	T_1	T_2	T_1	T_2	T_1	T_2	T_1	T_2
C. Dung	0.03544	0.18347	0.0011815	0.006116	0.0059073	0.030579	0.0001969	0.001019	44.9	64.89
C. droppings	0.21098	0.32107	0.007033	0.010702	0.03516	0.05351	0.0011721	0.001784	43.04	60.99

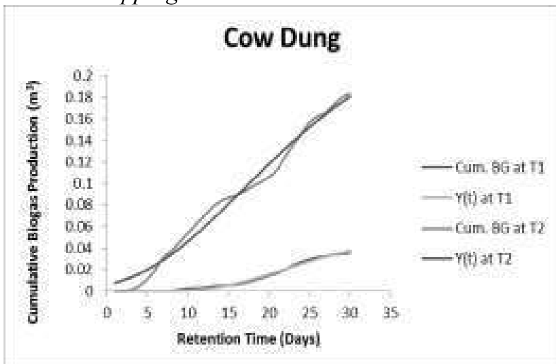

Fig. 8: Cumulative Biogas Production from Cow Dung

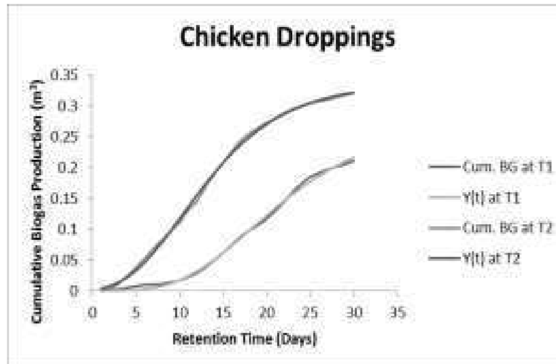

Fig. 9: Cumulative Biogas Production from

TABLE 4: RESULTS OF MODEL STUDY WITH MODIFIED GOMPERTZ EQUATION

	Total Biogas Volume (m^3)	A (m^3)	μ (m^3/day)	λ (days)	SSE	R^2
Cow Dung at T1	0.037384	0.053125	0.002439	13.60425	0.000409	0.998892
Cow Dung at T2	0.180722	0.256808	0.007491	4.198522	0.001664	0.885759
Chicken Droppings at T1	0.216594	0.274183	0.012397	10.10817	0.000408	0.984124
Chicken Droppings at T2	0.321842	0.336828	0.01949	3.99795	0.000461	0.960554

5.0 ACKNOWLEDGEMENT

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