Kinetic Study of Anaerobic Digestion of Goat Manure with Poultry Dropping and Plantain Peels for Biogas Production

Christian C. Opurum, Christian O. Nweke, Christopher E. Nwanyanwu, Ikenna N. Nwachukwu

Abstract— **In this study, the kinetics of anaerobic digestion (AD) of goat manure (GM) with poultry dropping (PD) and plantain peels (PP) for biogas production was evaluated. The digestion was carried out for a period of 47 days at pH range of 6.80-7.80 under an ambient temperature of 25-36OC. Seven (7) bio-digesters of ten (10L) capacity labeled A-G were used. Reactors A - C contained 520g final weight of GM and PD blended in the percentage combinations (GM/PD): 50/50, 75/25 and 85/15. Similarly, reactors D - F contained GM/PP while G contained only GM. Cow rumen liquor served as the inoculum source and daily biogas production was monitored by the water displacement method. The biogas production was described with Modified Gompertz model (MGM). Post Hoc Duncan test (ANOVA) was used to compare means of cumulative gas yield in the different treatments. The biogas produced was flammable in all the bio-digesters and burnt with a deep blue flame. The maximum cumulative biogas yield from the different treatments in decreasing order is: 23.36, 20.73, 18.41, 11.20, 6.53, 4.84 and 1.63 dm3 for digester G (GM only), A (GM/PD 50:50), B (GM/PD 75:25), C (GM/PD 85/15), D (GM/PP 50:50), E (GM/PP 75:25) and F (GM/PP 85:15) with yield/gVS of 0.720, 0.573, 0527,0.326, 0.182, 0.139 and 0.048, respectively. Duncan test showed a significant difference ($P \leq 0.05$) in cumulative biogas yield in all the treatments. The highest cumulative yield (23.36dm3) was recorded in bio-digester G (GM). The treatments exhibited antagonistic effects and significantly inhibited biogas production. The antagonistic effects occurred consistently in the various percentage combinations. The MGM predicted biogas production potential (Ym) is 20.961 ± 0.385, 19.125 ± 0.457, 12.407 ± 0.551, 6.848 ± 0.320, 5.514 ± 0.549, 1.654 ± 0.054 and 23.631 ± 0.656 for digester A- G, respectively. The MGM suitably fitted the experimental results, with R2 values greater than 0.97. The individual digester feeds used in this study exhibited very reasonable compositional characteristics, indicating a high potential for biogas production. It could be concluded that mono-digestion of goat manure can suitably be adopted in biogas production.**

Index Terms— **Biogas production; Kinetic Model; Goat manure; Poultry dropping; Plantain peel**

I. INTRODUCTION

Attempts to cushion world food crises have led to an advanced and aggressive approach to agricultural practices with a concomitant increase in productivity of agricultural produce and consequently increased waste generation. Animal husbandry produces a large quantity of manure that poses serious pressure on the environment [1]. The poultry industries are rapidly growing along with human consumption, which results in large quantities of animal wastes to be treated. Inadequate management of the generated manures may cause numerous undesirable consequences such as odor problem, attraction of rodents, insects and other pests, release of animal pathogens, groundwater contamination, surface water runoff, deterioration of biological structure of the soil, etc. Ammonia (NH_3) and greenhouse gases, CH_4 and CO_2, emitted from the waste storage units and dump sites cause air pollution problems [2].

In about 120 countries of the world, banana and plantains are grown, and India leads the world in banana production where it is cultivated in approximately 51 hectares with an annual production of 169 million tonnes, contributing to 27% of world's banana production [3]. Processing of plantain and banana results in the generation of a huge amount of waste: leaves, stems and peels and to some extent the degraded bananas itself. Indiscriminate disposal of these wastes when decomposed produces noxious gases such as hydrogen sulfide and ammonia, which pose serious environmental hazards. It is very important, therefore, to find an effective treatment approach to animal manure. Presently, anaerobic digestion (AD) has been considered and proven to be a reliable waste-to-energy technology for the treatment of organic wastes from agricultural and industrial activities, and offering numerous advantages, such as production of biogas, reduced pollution and emissions of greenhouse gases etc.[4], [5].

Annually, goat manure (GM) yield in China is approximately 3.216108t followed by dairy manure, swine manure and chicken manure. The total nitrogen (TN) contents of fresh GM (1.01%) and chicken manure (1.03%) are significantly higher than those of dairy manure (0.35%) and swine manure (0.24%). High TN content is beneficial in co-digestion with crop residues because it decreases the carbon-to-nitrogen (C/N) ratios of single Crop residues. GM is also insensitive to acidification during anaerobic digestion (AD). Hence, GM is an excellent raw material for AD and biofuel production [6].

Energy crises and climatic changes are currently global concerns. The rise in atmospheric temperature is now a global environmental challenge. The fourth assessment report of The Intergovernmental Panel on Climate Change (IPCC) indicates that the global surface temperature has increased by $0.74^{O}C$ over the last 100 years (1906–2005 AD) which is more than that reported in the third assessment, that is $0.6^{O}C$ for the period 1901-2001AD [7]. The global atmospheric concentration of CO_2 has increased from 280 ppm to 379 ppm in 2005. The emission of greenhouse gases (GHGs), particularly; CO_2, CH_4 and N_2O by various anthropogenic activities are the major drivers of rising atmospheric temperature.

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It has been predicted that crude oil reserves will probably run out by 2050 while the global deposits of gas and coal are expected to deplete rapidly [8]. Consequent upon this, attention is currently directed to alternative and renewable sources of energy. Biogas technology provides an exciting approach to address the issue of mitigation of global warming by harnessing the greenhouse gases (GHGs) emitted from uncontrolled decomposition of organic wastes and substituting unsustainable fossil fuel consumption practice for renewable energy.

Blending of goat manure and plantain peels with other organic wastes has continued to attract research interests in bioenergy production [9] - [11]. A myriad of organic materials, such as agricultural wastes, animal manures, sewage sludge, industrial and food wastes have been demonstrated to be suitable for co-digestion [12] – [16], but the ideal mixing ratios of these multi-component substrates with goat manure are largely unknown [6]. This study, therefore, investigates the kinetics of anaerobic digestion of goat manure with Poultry dropping and plantain peels for biogas production.

II. Materials and Methods.

Collection of Digester feeds and Preparation.

The digester feeds used in this study were goat manure (GM), poultry dropping (PD) and plantain peels (PP). The goat manure and poultry dropping were obtained locally from farmers who are into animal husbandry. The plantain peel was collected from restaurant operators in the Federal University of Technology, Owerri. The substrates were sun-dried for fifteen (15) days until sufficiently dried, sorted to remove unwanted materials and sand particles were sieved off. The goat manure, poultry dropping and plantain peels which had been shredded were ground with a grinding machine to reduce the particle size, manually sieved with a sieve mesh of 0.2mm diameter to pick the desired particle size and thereafter stored in airtight polyethylene bags.

Inoculum Preparation.

The inoculum (source of methanogens) was rumen liquor of a freshly slaughtered cow. The rumen waste was carefully collected in a sterile container, processed by filtration using cheesecloth and stored air-tight in order to ensure anaerobiosis required by the microbes (methanogens) for production of methane [17].

Proximate Composition of the Feeds

The proximate composition of the digester feeds was determined by adopting standard methods described by AOAC, [18]. The moisture content (MC), Volatile solid (VS), Total solids (TS), C/N ratio etc. were determined.

Experimental Design.

The experimental design of Opurum *et al.*, [19] was adopted. Seven (7) bio-digesters of 10L capacity labeled A to G were used. The effective volume was eight (8L) liters, with 2L headspace. Reactors A - C contained 520g final weight of goat manure and poultry dropping (GM/PD) blended in the following percentage combinations: 50/50, 75/25 and 85/15. Similarly, reactors D - F contained GM/PP in different percentage combinations as earlier described, while G which served as the control contained only goat manure (520g). The total solids (TS) and volatile solids (VS) contents (g) of reactors A - G are as follows: A, 46.88 and 36.19; B, 47.03 and 34.95; C, 47.11 and 34.33; D, 47.17 and 36.13; E, 47.23 and 34.91; F, 47.26 and 34.30; G (control), 47.34 and 32.46, respectively.

A slurry of each combination of the digester feeds was first prepared in a clean calibrated container. The volume was adjusted to 6.4L with water and subsequently fed into the bio-digesters. The freshly prepared inoculum (20% of the effective reactor volume) was introduced into each of the charged reactors and mixed properly by agitation. The pH of the slurry was adjusted to 7.80 with NaOH and HCl, depending on the initial pH. The bio-digesters were tightly sealed and the outlet gas hose connected to the gas collecting system that previously filled with saline water (10% NaCl (w/v). Anaerobic digestion (AD) was carried out under ambient temperature condition, which varied between 25-36^{O}C. The pH of the digesting slurry was monitored at alternate days with digital pH meter and maintained at 7.80 throughout the hydraulic retention time (HRT).

The anaerobic bio-digesters were manually agitated 2-3 times daily to avoid stratification and enhance contact between the microorganisms and seeded sludge. The biogas produced in each bio-digester was collected by downward water displacement method. The produced gas inside the bio-digester build-up pressure which acts as a driving force for displacement of the brine solution [20]. The gas passes through brine solution which helps reduce its solubility. The collected biogas is measured every 24hr and tested for flammability. The hydraulic retention time (HRT) for the anaerobic digestion was 47 days. The performance of each anaerobic reactor was evaluated in respect of cumulative volume of biogas yield.

III. Data analysis.

Post-Hoc Duncan test implemented in IBM SPSS version 20.0 Statistics software was used to compare means of maximum cumulative biogas yield in the different treatments.

Cumulative Biogas production Kinetics.

Kinetics of biogas production in the batch bio-digesters was modeled with the modified Gompertz model. Should the kinetics of biogas production in batch mode have direct relationship with specific growth rate of methanogens in anaerobic bio-digester, the predicted biogas production rate, therefore, will obey modified Gompertz model equation [21] - [24]. The experimental data obtained from digesters A-G were simulated for the fitness of the modified Gompertz model equation.

The modified Gompertz model equation is given as follows:

$$Y_t = Y_m . \exp\left\{ - \exp\left[\frac{U.e}{Y_m} (\lambda - t) + 1 \right] \right\} \qquad (1)$$

Where:

Yt = The cumulative biogas production (dm^3)

Ym = the biogas production potential (dm3)

U = the maximum biogas production rate (dm3/day)

λ = Lag phase period (days)

t = cumulative time for production of biogas (days)

e = mathematical constant (2.718)

Kinetic constant (ym, λ and U) was determined using non-linear regression with help of Sigma plot graphic software, version 10.0.

IV. Results and Discussion.

Table 1 presents the determined proximate composition of the different bio-digester feeds. The percentage TS, VS and C/N ratio of the GM was 91.04, 62.43 and 14.70%, PD contained 89.26, 76.76 and 14.24% while PP had 90.37, 76.53 and 15.89%, respectively. The substrates are characterized by appreciably high percentage content of TS and VS, and fairly good C/N ratio.

Figure 1 depicts anaerobic digestion profiles and biogas production from GM/PD blended at different w/w percentages (50/50; 75/25, 85:15 and GM only). In bio-digester A, biogas production started very low on day1 to the 10th day (8-40ml). The peak of production was recorded on the 19th and 20th day, with 2.22litres of biogas. It decreased to 5ml on the 40th day and finally zero on the 47th day, with a cumulative biogas yield of 20.73dm^3 (Table 2). The gas was flammable by the 22nd day.

Similarly, there was low gas production in digester B from day 1(10ml) to 16th day and fluctuation in gas yield started subsequently, the peak was observed on the 20th day (2.13L) and gas production stopped on the 42nd day with 18.41 dm^3 as the cumulative yield. Combustibility check showed that the gas became combustible on the 20th day.

There was a lag period of 18 days in bio-digester C. The peak of gas production was on the 19th day (2.15L); followed by a sharp decrease in biogas yield to zero on the 42nd day, 11.20 dm^3 was recorded as the cumulative yield.

The anaerobic digestion pattern in bio-digester D - F is shown in Fig.2. In digester D, gas production started in day 1 (7ml) and increased in a stepwise pattern. The daily maximum production was 420 ml on the 38day, after which no appreciable gas production occurred. The cumulative biogas yield was 6.53dm^3.

In the first six (6) days of anaerobic digestion in bio-digester E, biogas production was similarly very low. On the 7th day, 235ml of gas was obtained followed by another period of low productivity which lasted from the 8th - 23rd day. The daily maximum biogas production was noted on the 32nd day (1000ml) and another peak on the 37th day (420ml). Cumulative biogas produced was 4.84dm^3. Biogas produced from this treatment became flammable on the 3rd day.

In bio-digester F, lag phase lasted for 23 days, two (2) peaked of biogas production were observed: 240 ml and 310 ml on the 24th and 29th day, respectively. Biogas production gradually decreased and by the 38th day, no appreciable production was recorded. The biogas became flammable on the 24th day. The lowest cumulative gas yield was noted in this treatment (1.654 dm^3).

The maximum cumulative gas yield in bio-digester G (control) was 23.36 dm^3. Biogas production started in very low volumes from 1 to the 10th day and gradually increased, reaching its peak on day 17-19 (2L), it decreased gradually and stopped on day 41. The test for flammability indicated flammable gas on the 16 day, burning with a deep blue flame which lasted for 5min 26sec.

Presented in Table 2 are the maximum cumulative biogas yield (dm^3) and yield/gVS in all the treatments. In decreasing order is: 23.36, 20.73, 18.41, 11.20, 6.53, 4.84 and 1.63 dm^3 for digester G (GM Control), A (GM/PD 50:50), B (GM/PD 75:25), C (GM/PD 85/15), D (GM/PP 50:50), E (GM/PP 75:25) and F (GM/PP 85:15), respectively. Digester G (GM) appeared to have produced the highest volume of biogas.

Post-Hoc Duncan test (ANOVA) used to compare means of maximum cumulative biogas yield indicated a significant ($P \leq 0.05$) inhibition in biogas production in all the treatments. There was also significant inhibition in GM/PP compared to GM/PD combinations.

The biogas yield parameters obtained by applying the Modified Gompertz Model equation is shown in Table 3. Digester G (GM) had the highest biogas production potential (Ym) of 23.631 ± 0.656 dm^3, maximum production rate (U) of 1.261dm^3/day and lag phase (λ) of 11.788 days with a correlation coefficient (R^2) 0.9928. This is followed by Digester A (GM/PD 50:50), with 20.961 ± 0.385 dm^3, 1.309dm^3/day, 14.499 days and 0.9966 as the Ym, U, λ and R^2, respectively.

Figures 3 and 4 show plots of simulation of the modified Gompertz model predicted biogas yield and the experimental data. In predicting biogas yield, the fitness of the model or correlation coefficient (R^2) was observed to be 0.9966, 0.9959, 0.9929, 0.9817, 0.9747, 0.9846 and 0.9928 for A (GM/PD 50:50), B (GM/PD 75:25), C (GM/PD 85:15), D (GM/PP 50:50), E (GM/PP 75:25), F (GM/PP 85:15) and G (GM 100%), respectively.

V. Discussion.

This study was conducted under ambient temperature conditions of 25-36^{O}C for 47 days hydraulic retention time (HRT). It could be noticed from Figures 1and 2 (the daily biogas production patterns) that in all the bio-digesters, there was a remarkably low gas yield at the early stage of the digestion. This observation could be explained by the biochemical steps anaerobic digestions undergo. The process principally involves a four-stage process (hydrolysis, acidogenesis, acetogenesis and methanogenesis) that engages four different bacterial groups: hydrolytic, acidogenic, acetogenic and methanogenic bacteria [25] - [27]. Each of these bacteria has different nutritional and physiological requirements. The initial stages, hydrolysis and acidogenesis result in the release of monomers and volatile fatty acids with reduced pH which adversely affects the methanogens [28] that are directly involved in biogas production. If all four groups of bacteria are working under the same conditions, there will be an imbalance between the formations of acid and methane [29].

The second plausible explanation for this observation could be a result of acclimatization of the bacterial consortium (in the inoculum) to the multi-component substrates used as feedstock. It has been suggested that biogas production could be delayed in the initial anaerobic digestion period because the particle disintegration and hydrolysis steps are rate-determinants in the anaerobic digestion process [24].

The maximum cumulative biogas yield from the different treatments in decreasing order is: 23.36, 20.73, 18.41, 11.20, 6.53, 4.84 and 1.63 dm^3 for digester G (GM Control), A (GM/PD 50:50), B (GM/PD 75:25), C (GM/PD 85/15), D (GM/PP 50:50), E (GM/PP 75:25) and F (GM/PP 85:15), respectively. The biogas produced was flammable in all the bio-digesters and burnt with a deep blue flame, indicative of the level of methane content. For biogas to be useful in cooking, lighting etc. it must be flammable. Flammability of biogas indicates that the methane content is 45% and above, but if not flammable, it implies that the methane content is less than 45% and majorly contains CO_2 and other gases [26], [30].

Post-Hoc Duncan test (ANOVA) used to compare means of maximum cumulative biogas yield in the different treatments showed significant inhibition in all the treatments. Reports abound on the enhancement of biogas production by the co-digestion process [31] - [35]. It is suggested that co-digestion exacts synergistic effect, balances nutrients, supplying the lacking nutrients by co-substrates, increases buffering capacity and decreases the effect of toxic compounds [36].

Contrary to these reports, however, our result showed that Goat manure (GM) alone produced the highest volume of biogas, indicative of an antagonistic effect of the treatments on biogas production. This observation could be due to excessive production of volatile fatty acids (VFAs) by the microorganisms which adversely affected the release of the biogas. The high-fat content of PP (7.93%) and PD (6.98%) may have caused the inhibition in the different treatments. GM alone which produced the highest cumulative biogas had a fat content of 2.0%. In anaerobic digestion, as the hydrolysis of fats and oils to glycerol and long chain fatty acids (LCFAs) progress, LCFAs accumulate, often hindering the anaerobic digestion of fatty materials because of their inhibitory effects [24]. High levels of VFAs in the bio-digester may cause a decrease in pH of the process, particularly when the alkalinity level is low, resulting in a process failure. Short chain fatty acids of carbon atoms greater than two are usually monitored during the digestion process since alongside with pH, they indicate the presence of imbalance in the process [37]. Additionally, the treatments may have created a process imbalance which triggered the antagonistic effect.

Olugbemide *et al.,* [38] reported that co-digestion of maize leaves (ML) with Elephant grass has both synergistic and antagonistic effects on biogas production depending on the proportion. Co-digestion of food waste with rumen fluid showed an antagonistic effect as the added quantity of rumen fluid increased; implying that mono-digestion of food waste could yield a significant amount of biogas with impressive production rate [39].

It can be observed from the result of the proximate composition of the individual feedstock that there is no remarkable variation in a number of vital parameters except in the fat and ash content. The composition of their different mixed ratios did not therefore, differ appreciably. It could be inferred that the individual digester feeds used in this study exhibited very reasonable compositional characteristics and demonstrated high potential for biogas production. Adequate physiochemical properties inherent in the waste are suggested to favour the efficiency biogas production [30].

To ensure good conversion efficiencies and process stability, it is necessary to accurately characterize the feedstock, especially physicochemical properties such as Total Solid (TS), Volatile Solid (VS), carbon, nitrogen, ash etc. Based on such parameters, a decision can be made on whether to use a single feedstock or as co-substrate in the anaerobic digestion process [40]. It has been reported that high levels of moisture and ash content result in low organic matter content and consequently low yield in biogas, conversely, low moisture and ash content result in high organic matter content and hence high biogas yield [41].

The digester feeds had C/N ratios of 15:1, 14:1 and 16:1, for goat manure (GM), poultry dropping (PD) and plantain peel (PP), respectively. The C/N ratios of goat manure (12:1) and poultry dropping (8:1) used by Hanafiah *et al.,* [1] in biogas production were lower than the one used in this study. In their study on a comparative study of the biogas potential of plantain and yam Peels, Makinde and Odokuma, [42] reported a C/N ratio of 40.9:1 content in plantain peels. However, The C: N ratios in their treatments that produced high volume of biogas falls in the range of 15:1 and 28:1. The goat manure used in co-digestion with three crop residues for biogas production contained VS and C/N ratio of 82.21and 17.97, respectively, [6] which is closely related to that in our observation (62.43 and 16:1). Co-digestion of vegetable, horse manure and sludge evaluated by Van *et al.,* [43] showed that the biogas potential was in the range of 183-648 ml/g-VS with the best C/N ratio of 16.

C/N ratio indicates the relationship between the amount of carbon and nitrogen present inorganic substrate, a very important factor that controls biological treatment systems. The C/N ratio optimum for anaerobic digestion is 20-30 and excess N may lead to ammonia inhibition of digestion [44]. A high C/N ratio indicates rapid nitrogen consumption by methanogens which leads to lower gas production. Conversely, a low C/N ratio results in ammonia accumulation and an increase in pH values, which is toxic to methanogenic bacteria [6].

The maximum cumulative yields in biogas were modeled by applying the modified Gompertz model equation and their correlation coefficients (R^2) of greater than 0.97 showed that the model reflected the methanogenic process adequately. Modified Gompertz model has proven to be suitable in determining biogas production potential in many biogas production experiments. A number of researchers in biogas production have adopted the model to adequately describe biogas production process. The nonlinear regression was used by Zhu *et al.* [45] to correlate the cumulative biogas yield and digestion time in their work and it demonstrated that the Gompertz growth equation fitted the experimental results well. Yusuf *et al.* [46] used the model equation to assess biogas production from co-digestion of horse and cow dung. Predicting rate of biogas production from abattoir waste using empirical Models, Adamu *et al.* [47] reported that Gompertz model gave better goodness of fit than the Modified Logistic model with correlation coefficients of 0.998 and 0.996 for Gompertz and Modified Logistic models respectively. In their recent studies, Mehryar *et al.* [48] used neutral network algorithms and mathematical equations to evaluate and model anaerobic co-digestion of oil refinery wastewater with bagasse. Their results were computed by applying three mathematical models and modified Gompertz model provided the best fit.

VI. CONCLUSION.

One of the major findings in this study is that all the treatments investigated exhibited antagonistic effect and consequently produced significantly less biogas relative to the control. Although anaerobic co-digestion of substrates exerts a synergistic effect and improves biogas yield, this study has shown that in some cases, an antagonistic effect may be experienced, resulting in decreased biogas yield.

The individual digester feeds showed very reasonable compositional characteristics, indicative of their high potential for biogas production. Accurate determination of the physicochemical characteristics biogas feedstocks, especially properties such as Total Solid (TS), Volatile Solid (VS), carbon, nitrogen, ash etc.is very important in the choice on whether a single or co-substrate should be used in anaerobic digestion and biogas production process.

It can be concluded that mono-digestion of goat manure and some other agricultural wastes of suitable physicochemical properties could be adopted in the production of biogas (a carbon-neutral energy source) and management of the waste while maintaining a clean and green environment. The high ash content suggests it would be a good soil conditioner to enhance soil fertility. In predicting biogas production rate (U), biogas production potential (Ym) and the lag phase period (λ), modified Gompertz model equation suitably fitted the experimental results, with correlation coefficients greater than 0.97.

Table.1 Proximate Composition of the feedstocks.

Parameters (%)	Goat Manure (GM)	Poultry Dropping (PD)	Plantain Peel (PP)
Moisture content (MC)	8.96	10.74	9.63
Ash content	28.61	12.50	13.84
Fibre content	12.65	10.40	11.87
Nitrogen	1.70	1.55	1.78
Fat content	2.00	6.98	7.93
Crude protein	10.60	9.68	11.12
Organic Carbon	24.94	22.05	28.26
Total solid (TS)	91.04	89.26	90.37
Volatile solid (VS)	62.43	76.76	76.53
C/N ratio	15:1	14:1	16:1
CHO	37.18	49.70	45.61

Table 2. Cumulative Biogas Yield (dm3) from the Different Percentage
Combinations.

Treatments	Cumulative Yield	Yield (dm3/gVS)
A (GM/PD 50:50)	20.73	0.573
B (GM/PD 75:25)	18.41	0.527
C (GM/PD 85/15)	11.20	0.326
D (GM/PP 50:50)	6.53	0.182
E (GM/PP 75:25)	4.84	0.139
F (GM/PP 85:15)	1.63	0.048
G (GM Control)	23.36	0.720

Table 3. Biogas Yield Parameters from the Modified Gompertz Model.

Treatments.	Ym (dm3)	U (dm3)	λ(days)	R^2
A (GM/PD 50:50)	20.961 ± 0.385	1.309	14.499	0.9966
B (GM/PD 75:25)	19.125 ± 0.457	0.982	13.534	0.9959
C (GM/PD 85:15)	12.407 ± 0.551	0.606	17.665	0.9929
D (GM/PP 50:50)	6.848 ± 0.320	0.222	3.355	0.9817
E (GM/PP 75:25)	5.514 ± 0.549	0.297	24.526	0.9747
F (GM/PP 85:15)	1.654 ± 0.054	0.204	24.901	0.9846
G (GM 100%)	23.631 ± 0.656	1.261	11.788	0.9928

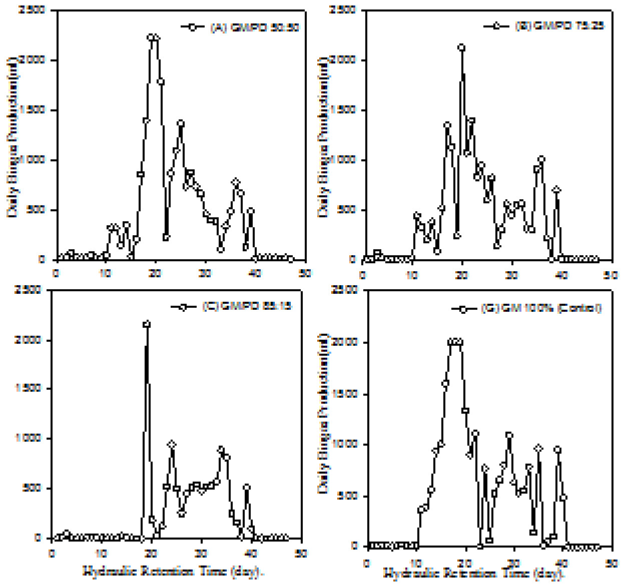

Fig. 1. Anaerobic Digestion Pattern and daily Biogas Yield from GM/PD at Different Ratios.

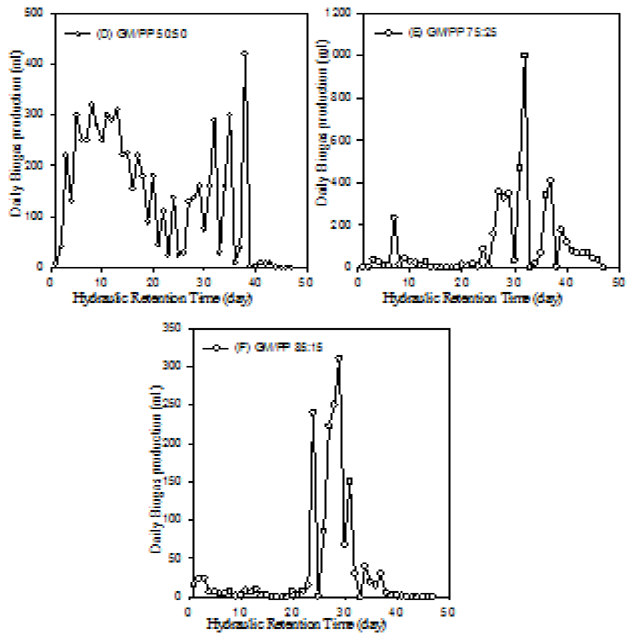

Fig. 2. Anaerobic Digestion Pattern and daily Biogas Yield from GM/PPat Different Ratios.

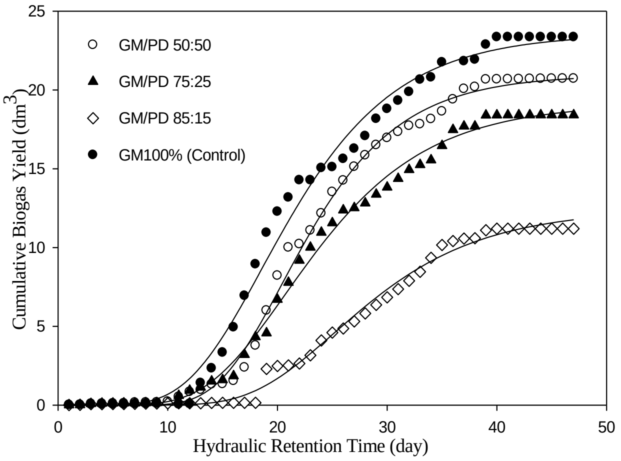

Fig.3. Comparison of Experimental Data and Modified Gompertz-model Predicted Biogas Yield.

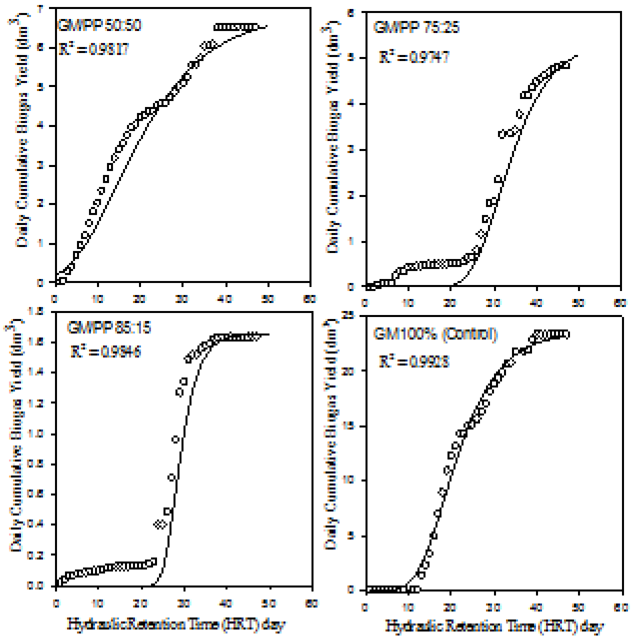

Fig.4. Comparison of Experimental Data and Modified Gompertz- model Predicted Biogas Yield.

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