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Kinetics of Anaerobic Digestion of Water Hyacinth, Poultry Litter, Cow Manure and Primary Sludge: A Comparative Study

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Abstract. Global depletion of energy supply due to the continuing over-utilization is a major problem of the present and future world community. It is estimated that the fossil fuels will be exhausted in the next few decades. In today's energy demanding life style, there is always a need for exploring and exploiting new sources of energy which are renewable as well as eco-friendly. Anaerobic digestion is a technology that utilizes various organic wastes (animal manure, energy crops and industrial wastes) to produce biofuel methane, which holds promise for the future while simultaneously addressing ecological and agrochemical issues. In the present study, kinetics of anaerobic digestion of dry water hyacinth, poultry litter, cow manure and primary sludge were undertaken in 250 ml biodigesters with 7% total solids and 60 days retention time and modified Gompertz equation was tested for its fitness. The kinetic parameters viz., biogas yield potential (P), the maximum biogas production rate (R_m) and the duration of lag phase (λ) were estimated for each case. The digester fed with poultry litter produced maximum biogas (0.39 $l(g\ VS)^{-1}$) and kinetic parameters P, R_m and λ were 0.3904 $l(g\ VS)^{-1}$; 0.0165 $l(g\ VS)^{-1}d^{-1}$ and 8.7498 days respectively.

Keywords: Anaerobic digestion, Biogas, Modified Gompertz equation, Kinetic parameters, Mesophilic range

1. Introduction

In recent times when fossil fuels are gradually depleting in addition to rising costs and instability in the major producer countries, renewable energy has become one of the best alternatives for sustainable energy development [1]. Renewable energy plays an important role in reducing the greenhouse gases; particularly energy from biomass could contribute significantly as it is a ''carbon neutral" fuel [2]. Anaerobic digestion is an environmental friendly biological process in which microorganisms work synergistically to convert organic wastes into biogas and a stable product (soil conditioner) for agricultural practices without any detrimental effects on the environment. The mankind has explored anaerobic digestion of organic materials greatly to generate biogas which comprises of methane (50 to 70%), carbon dioxide (30 to 40%) and traces of other gases which include CO, H_2S, NH_3, H_2, O_2 and water vapor etc. [3]. This process involves four major steps: hydrolysis, acidogenesis, acetogenesis and methanogenesis [4, 5]. Hydrolysis is the first step in anaerobic digestion, which involves the enzyme-mediated transformation of lipids, polysaccharides, proteins, fats, nucleic acids into soluble organic materials such as Monosaccharides, amino acids and other simple organic compounds that are sources of energy and cell carbon [6]. This step is carried out by strict anaerobes such as Bactericides, Clostridia and facultative bacteria such as Streptococci etc. Acedogenesis is the second step in which the soluble organic molecules from hydrolysis are utilized by fermentative bacteria or anaerobic oxidizers to produce volatile fatty acids (acetic acid, propionic acid and butyric acid), alcohols, aldehydes and gases like CO_2, H_2 and NH_3. In the third step, acetogenesis, the products of the acidification are converted into acetic acid, hydrogen, and carbon dioxide by acetogenic bacteria. The terminal stage of anaerobic digestion is the biological process of methanogenesis. In this step, acetic acid, hydrogen and carbon dioxide are converted into a mixture of methane and carbon dioxide by the methanogenic bacteria (acetate utilizers like Methanosarcina spp.and Methanothrix spp.and hydrogen and formate utilizing species like Methanobacterium, Methanococcus, etc.). A simplified generic chemical equation for the overall processes is represented as [7]

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$$

Biogas can be produced from variety of wastes, such as animal manure, energy crops, industrial wastes etc. Biogas production is a sustainable solution to treat the waste and the cost of the treatment is low [8]. In the present study anaerobic digestion of various organic wastes like water hyacinth (DWH) [9], poultry litter (PL), cow manure (CM) and primary sludge (PS) were studied in a series of laboratory experiments in 250 ml biodigesters with 7% total solids and 60 days retention time. The data obtained from these experiments were further used to check the fitness of modified Gompertz equation that describes kinetics of anaerobic digestion process. Kinetic parameters viz., biogas yield potential (P), the maximum biogas production rate (R_m) and the duration of lag phase (λ) were estimated different slurries and compared.

2. Materials and Methods

2.1. Sample Collection

Water hyacinth used for the study was obtained from silver lake at HBR layout (Bangalore, Karnataka, India). Thickened primary sludge used was from primary clarifier in Vrishabhavathi sewage treatment plant at Vrishabhavathi valley, Nayandanahalli (Bangalore, Karnataka, India). Overnight, fresh poultry litter was collected from J M J Chicken Center (Bangalore, Karnataka). Fresh cow dung was obtained from Dodla dairy (Bangalore, Karnataka).

2.2. Biomethanation Unit

Biomethanation unit consists of a constant temperature bath with a provision to maintain desired temperature. A battery of digesters was kept in the temperature bath and the temperature was set at 35^0C. Each biodigester is connected to a graduated gas collector by means of a connecting tube. A stand holds all the gas collectors. Biogas evolved is collected by downward water displacement.

2.3. Preparation of Fermentation Slurries

Biomethanation of DWH, PL, CM and PS were studied in a series of laboratory experiments using 250 ml biodigesters with 7% total solids. Fresh water hyacinth leaves were chopped to small sizes of about 2 cm allowed to dry under the sun for a period of 7 days, after which they were dried in an oven at 60^0C for 6 hours. This oven-dried water hyacinth was then ground to fine powder [10]. Moisture free powder was used to prepare fermentation slurry DWH (7 g. water hyacinth and 93 g. water). Poultry litter, cow manure and primary sludge were homogenized previously before preparation of fermentation slurries PL (33 g. poultry litter and 67 g. water), CM (32.82 g. cow manure and 67.18 g. water) and PS (45.66 g. primary sludge and 54.34 g water). Biomethanation of these slurries were carried out in duplication for a retention time of 60 days in the mesophilic range. Cumulative biogas production, slurry temperatures were monitored throughout the study.

2.4. Analytical Methods

Solids analysis: Total solids and volatile solids were analyzed for water hyacinth and poultry litter according to standard methods [11].

pH analysis: pH was measured by pH meter which consists of potentiometer, a glass electrode, a reference electrode and a temperature compensating device. Electrodes were connected to the pH meter and were calibrated using buffer solutions before pH analysis

Biogas analysis: Gas chromatograph (Chemito 1000) equipped with a thermal conductivity detector was used to analyze the biogas sample. Hydrogen was used as carrier gas (25 ml/min) with Porapak Q column. Standard calibration gas mixture was used for calibration. Biogas samples were collected in rubber bladders;

the sample and standard were injected using a gas tight syringe in to the gas chromatograph. The parameters were set at oven temperature of 40^0C, detection temperature of 80^0C and the detector current of 180 mA.

2.5. Modified Gompertz Equation

The kinetic data obtained from digesters DWH, PL, CM and PS were checked for the fitness of modified Gompertz equation (MGE) [12]. The modified Gompertz equation is given by

$$M = P\times \exp\left\{-\exp\left[\frac{R_m\times e}{P}(\lambda - t)+1\right]\right\}$$

where

M Cumulative biogas production, l (g VS)$^{-1}$ at any time t

P Biogas yield potential, l (g VS)$^{-1}$

R_m Maximum biogas production rate, l (g VS)$^{-1}$d^{-1}

λ Duration of lag phase, d

t Time at which cumulative methane production M is calculated, d

The parameters P, R_m and λ were estimated for each of the digester using POLYMATH software. These parameters were determined for best fit.

3. Results and Discussion

3.1. Solids and pH Analysis

Total solids (TS) were determined gravimetrically after drying in oven overnight at 105^0C. Volatile solids (VS) content was determined by igniting dried sample at 550^0C for 2 hours and determining the ash free dry weight. Table 1 gives the solid analysis and pH data of water hyacinth, poultry litter, primary sludge and cow manure.

Table1: Solid Analysis and pH Data

Material	% TS	% VS	pH
Water hyacinth	16.89	82.85	6.4
Poultry litter	21.21	83.47	7.1
Primary sludge	15.33	51.84	6.8
Cow manure	21.33	72.47	6.3

3.2. Kinetics of Biogas Production

The cumulative biogas production data with time for all the digesters are presented in Table 2.

Table 2: Cumulative Biogas Production Data

	Cumulative biogas production (l (g VS)$^{-1}$)			
Digester → Time ↓(d)	DWH	PL	CM	PS
0	0	0	0	0
5	0.006	0.010	0.005	0.01
10	0.011	0.025	0.010	0.02
15	0.016	0.110	0.040	0.05
20	0.022	0.190	0.070	0.08
25	0.035	0.250	0.100	0.12
30	0.051	0.310	0.140	0.17
35	0.096	0.340	0.170	0.21
40	0.170	0.360	0.190	0.24
45	0.220	0.370	0.210	0.26
50	0.230	0.380	0.220	0.27
55	0.235	0.390	0.230	0.28
60	0.240	0.390	0.230	0.28

With an assumption that biogas produced is a function of bacterial growth in batch digesters, MGE relates cumulative biogas production and the time of digestion through biogas yield potential (*P*), the maximum biogas production rate (R_m) and the duration of lag phase (λ). To analytically quantify parameters of batch growth curve, MGE was fitted to the cumulative biogas production data. Values of parameters obtained are listed in Table 3. The best fit to MGE is compared with experimental data in Figure 1.

Table 3: Summary of Performance of Anaerobic Digesters

Digester	**Biogas yield**[a] $l(g\ VS)^{-1}$	**Modified Gompertz parameters (model)**			**R^2**	**Rmsd**
		P, $l(g\ VS)^{-1}$	R_m, $l\ (g\ VS)^{-1}d^{-1}$	λ, d		
DWH	0.240	0.2577	0.0116	25.1902	0.9836	0.0034
PL	0.390	0.3904	0.0165	8.7498	0.9989	0.0014
CM	0.230	0.2451	0.0074	10.7379	0.9991	0.0007
PS	0.280	0.3012	0.0091	10.7812	0.9981	0.0013

[a] Experimental final cumulative biogas yield

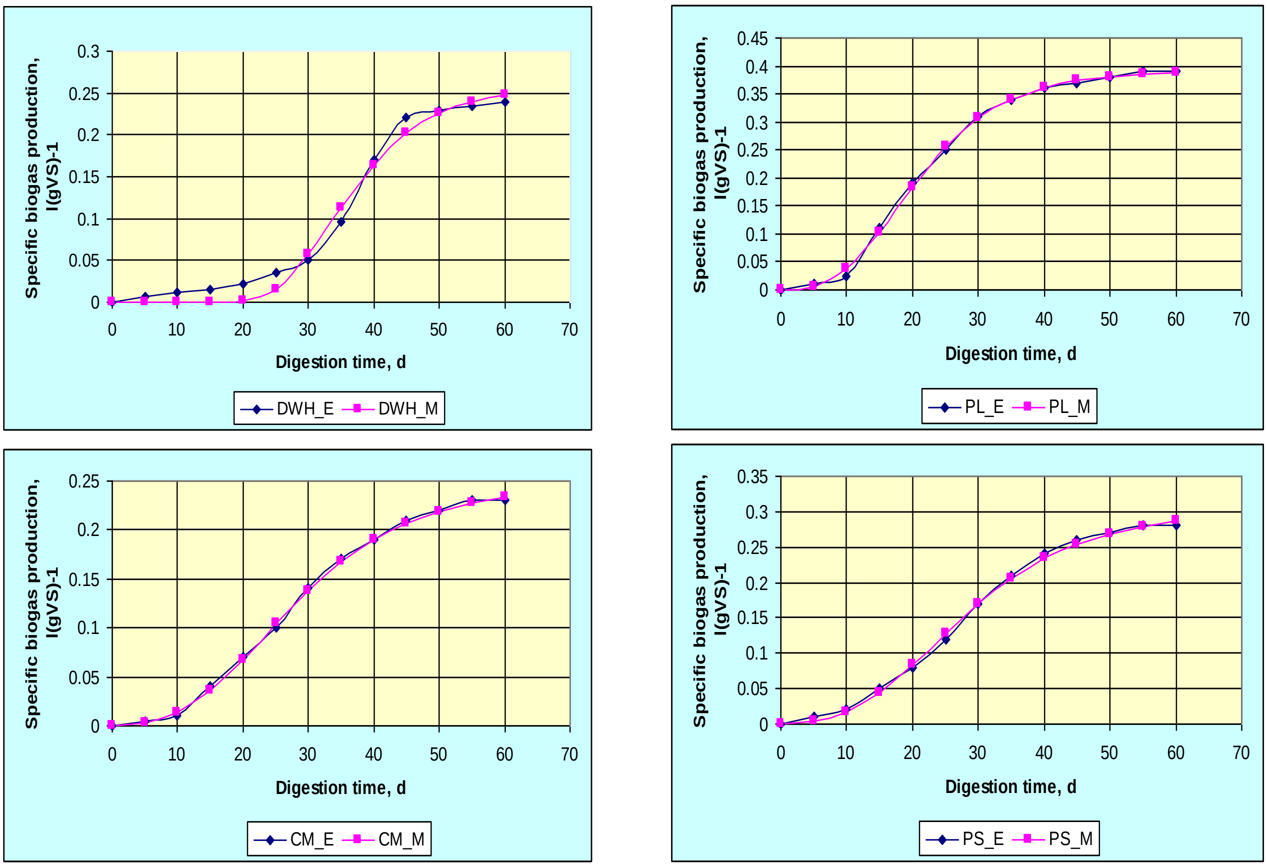

Fig.1: Comparison between experimental data and calculation using modified Gompertz equation

Observation can be made from Table 3 that digesters PL, CM and PS had the shorter lag period of 8.7498 days, 10.7379 days and 10.7812 days respectively while DWH had a longer lag period of 25.1902 days. This clearly indicates that digester DWH does not have essential microbes for early evolution of biogas and necessitates enriched seeding (inoculum) to enhance anaerobic digestion [13]. The digester PL exhibits higher biogas production rate ($0.0165\ l\ (g\ VS)^{-1}d^{-1}$) than DWH ($0.0116\ l(g\ VS)^{-1}d^{-1}$), PS ($0.0091\ l(g\ VS)^{-1}d^{-1}$) and CM ($0.0074\ l(g\ VS)^{-1}d^{-1}$). Therefore the amount of gas produced at the end of digestion period was highest for digester PL ($0.39\ l(gVS)^{-1}$). This could be because poultry litter is rich in nutrients and contains adequate amount of carbon, oxygen, hydrogen, nitrogen, phosphorous, potassium, calcium, magnesium and a number of trace elements which are very essential for the growth of anaerobic bacterium [14]. This could have optimized syntrophic interaction between acetogens and methanogens which is the most critical step in the biomethanation process [15]. However digesters PS, DWH and CM produced $0.28\ l(gVS)^{-1}$), $0.24l(gVS)^{-}$

^{1}) and 0.23l(gVS)$^{-1}$) of biogas respectively. From figure 1 it is clear that modified Gompertz equation fits best to the experimental kinetic data. However for DWH during lag phase there is negative deviation observed between best fit and experimental data which is indicated in the lower value of regression coefficient R^2 and slightly higher value of root mean square deviation (Rmsd).

4. Conclusions

The following conclusions can be drawn from the study presented in this paper:

- Kinetics of biogas production was studied for DWH, PL, CM and PS. The most important finding from this study is that among all the substrates poultry litter (PL) produced the highest biogas with better production rate as it contains more nutrients and nitrogen compared to cow manure, primary sludge and water hyacinth [16].
- DWH is a very good biogas producer but requires enrichment with inoculum to enhance the biogas yield. The use of enriched and pretreated water hyacinth for biogas generation therefore, will be a good energy source. Thus for those residing in the coastal areas which face the menace of clogging of waterways by water hyacinth, this has a promise to be an alternative source of energy.
- The modified Gompertz equation best describes cumulative gas produced as a function of retention time.

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6. References

[1] Ofoefule A U, Uzodinma E O, and Onukwuli O D. Comparative study of the effect of different pretreatment methods on biogas yield from water Hyacinth. *Int. J. of Phy. Sci.* 2009, **4** (**8**): 535-539.

[2] Francesco Fantozzi, and Cinzia Buratti. Biogas production from different substrates in an experimental continuously stirred tank reactor anaerobic digester. *Bioresource Tech.* 2009, **100**: 5783-5789.

[3] Energy Commission of Nigeria-ECN. Rural renewable energy needs and five supply technologies. 40-42, 1998.

[4] Nwuche C O, and Ugoji E O. Effects of heavy metal pollution on the soil microbial activity. *Int. J. Environ. Sci. Tech.* 2008, **5** (**3**): 409-414.

[5] Nwuche C O, and Ugoji E O. Effect of co-existing plant species on soil microbial activity under heavy metal stress, *Int. J. Environ. Sci. Tech*. 2010, **7** (4), 697-704.

[6] Jagadish H Patil, MALourdu AntonyRaj, Gavimath C C, and B M Mali. A Study on effect of volatile fatty acid on biomethanation of water hyacinth. *Int. J. of Adv. Biotech. and Research.* 2011a, **2** (**2**): 257-262.

[7] Yadvika, Santosh, Sreekrishnan T R, Sangeeta Kohli, Vineet, and Rana. Enhancement of biogas production from solid substrates using different techniques—a review. *Bioresource Tech,* 2004, **95:** 1-10.

[8] Verstraete W, Morgan Sagastume F, Aiyuk S, Waweru M, Rabaey K, and Lissens G. Anaerobic digestion as a core technology in sustainable management of organic matter. *Water Sci. and Tech.* 2005, **52** (1-2): 59-66.

[9] Jagadish H Patil, MALourdu AntonyRaj, and Gavimath C C. Impact of dilution on biomethanation of fresh water hyacinth. *Int. J. of Chemical Sci. and Applications.* 2011b, **2** (**1**): 86-90.

[10] Jagadish H Patil, MALourdu AntonyRaj, and C C Gavimath. Study on effect of pretreatment methods on biomethanation of water hyacinth. *International Journal of Adv. Biotech. and Research.* 2011a, **2 (1):** 143-147.

[11] APHA, AWWA and WPCF, *Standard methods for the examination of water and waste water*, Washington D C 1995**.**

[12] Lay J J, Li Y Y, and Noike T. Mathematical Model for methane production from landfill bioreactor. *J. Environ. Engg.* 1998,**124** (8): 730-736.

[13] Patil J H, Molayan Lourdu AntonyRaj, Bhargav S, and Sowmya S R. Anaerobic co-digestion of water hyacinth with primary sludge. *Res.J.Chem.Sci.* 2011, **1(3):** 72-77.

[14] Kanwar S S, and Kalia A K. Anaerobic fermentation of sheep droppings for biogas production. *World j. of Microbiology and Biotech.* 1992, **9:**174-175.

[15] Schink B A and Stams J M., Syntrophism among prokaryotes. In: Dworkin M. (Ed.), The prokaryotes: an evolving

electronic resource for the microbiological community, 3rd Ed. Springer, New York, 2005.

[16] Ojolo S J, Oke SA, Animasahun K, and B K Adesuyi. Utilization of Poultry, Cow and Kitchen Wastes For Biogas Production: A Comparative Analysis. *Iran. J. Environ. Health. Sci. Eng*. 2007, **4** (4): 223-228.